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ASSESSMENTS OF TRAINING LOAD IN ELITE YOUTH SOCCER

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Abstract

One of the most popular sports globally, soccer has seen a rise in the demands of the game over recent years. An increase in intensity and playing demands, coupled with growing social and economic pressures on soccer players means that optimal preparation is of paramount importance. Recent research has found the modern game, depending on positional role, to consist of approximately 60% more sprint distance in the English Premier League, which was also found to be the case for frequency and success of discrete technical actions (Bush et al., 2015). As a result, the focus on soccer training and player preparedness is becoming more prevalent in scientific research. By designing the appropriate training load, and thus periodization strategies, the aim is to achieve peak fitness in the most efficient way, whilst minimising the risk of injury and illness. Traditionally, training intensity has been based on heart rate responses, however, the emergence of tracking microtechnology such as global positioning system (GPS) and inertial sensors are now able to further quantify biomechanical load as well as physiological stress. Detailed pictures of internal and external loading indices such as these then combine to produce a more holistic view of training load experience by the player during typical drills and phases of training in soccer.

The premise of this research is to gain greater understanding of the physical demands of common training methodologies in elite soccer to support optimal match performance. The coaching process may then benefit from being able to prescribe the most effective training to support these.

The first experimental chapter in this thesis began by quantify gross training loads of the pre-season and in-season phases in soccer. A broader picture of the training loads inherent in these distinct phases brought more detail as to the type and extent of external loading experienced by soccer players at these times, and how the inclusion of match play influences weekly training rhythms. Training volume (total distance) was found to be high at the start compared to the end of pre-season (37 kilometres and 28 kilometres), where high cardiovascular loads were attained as part of the conditioning focus. This progressed transiently, however, to involve higher-speed, acceleration and change-of-direction stimuli at the end of pre-season compared to the start and to that in-season (1.18 kilometres, 0.70 kilometres and 0.42 kilometres high-intensity running; with 37, 25 and 23 accelerations >3m/s^2 respectively) . The decrease in volume and increase in maximal anaerobic activity was evident in the training focus as friendly matches were introduced before the competitive season. The influence of match-play as being a large physical dose in the training week may then determine the change in weekly periodisation and how resulting training loads applied and tapered, if necessary. The focus of research was then directed more specifically to the most common mode of training in soccer, that also featured regularly in the pre-season period in the present study, small-sided games (SSG).

The subsequent studies examined numerous manipulations of this specific form of soccer conditioning, such as player numbers as well as absolute and relative playing space available. In contrast to some previous literature, changing the number of players did not seem to influence training responses significantly, although playing format in the possession style brought about larger effects for heart rate (89.9%HR$_{max}$) and average velocity (7.6km/h^{-1}).

However, the following studies (Chapters 5, 6 and 7) revealed a greater influence of relative playing space available to players in SSG. The larger area at their disposal brought about greater aerobic responses (~90%HR_{max}), by allowing higher average and peak velocities (>25km/h^{-1}), as well as greater distance acceleration behaviour at greater thresholds (>2.8m/s^2). Furthermore, the data points towards space as being a large determinant in strategy of the player in small-sided games (SSG), subsequently shaping their movement behaviour and resulting physical responses. For example, higher average velocities in a possession format (8km/h^{-1}) reflects higher work rate and heart rate load but makes achieving significant neuromuscular accelerations at a high level difficult given higher starting velocities prior to the most intense accelerations (4.2km/h^{-1}).

By altering space available and even through intentional numerical imbalances in team numbers, it may be easier for coaches to achieve the desired stimulus for the session or individual player, whether that is for aerobic and neuromuscular conditioning. Large effects were found for heart rate being higher in the underloaded team (85-90%HR_{max}) compared to the team with more players (80-85%HR_{max}) as well as for RPE (5AU versus 7AU). This was also apparent for meterage and therefore average velocity. It would also seem neuromuscular load through high acceleration and deceleration efforts were more pronounced with less numbers (given the need to press and close down opponents, and in a larger area relative to the number of players on the underloaded team. The peak accelerations and deceleration achieved was also higher when playing with less players (3-6.2m/s^2 and 3-6.1m/s^2)

Having detailed ways in which to reach desired physical loading responses in common small training formats, Chapter 8 compared SSG to larger 9v9 formats with full-size 11v11 friendly matches. This enabled absolute and relative comparisons to be made and to understand the extent to which smaller training formats are able to replicate the required movements to be successful in competition. In relative terms, it was revealed that relative acceleration distance and Player Load were higher in smaller 4v4 games than match-play (1.1m.min^{-1} and 0.3m.min^{-1} >3m/s^2; 16.9AU versus 12AU). Although the smallest format did not replicate the high-velocity demands of matches, the results confirmed their efficacy in providing significant neuromuscular load during the training week, which may then be supplemented by high-intensity interval running in order to gain exposure to more maximal speed work.

In summary, the data presented provide valuable information from GPS and inertial sensor microtechnology which may then be used to understand training better to manipulate types of load according to physical conditioning objectives. For example, a library of resources to direct planning of drills of varying cardiovascular, neuromuscular and perceptual load can be created to give more confidence in session outcomes. Combining external and internal load data of common soccer training drills, and their application across different phases and training objectives may give coaches a powerful tool to plan and periodize training.

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This thesis is dedicated to my Grandmother, Mary Nowell.

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List of Abbreviations

ADP	adenosine diphosphate
ATP	Adenosine triphosphate
AU	Arbitrary unit
bpm^{-1}	Beats per minute
Q	Cardiac output
CV	Coefficient of variation
CMJ	Countermovement jump
CK	Creatine Kinase
°	Degrees
ES	Effect size
HR	Heart rate
Hz	Hertz
HIIT	High intensity interval training
h	Hour
IgA	Immunoglobulin-A
km.h^{-1}	Kilometres per hour
MAS	Maximal aerobic speed
MSS	Maximal sprint speed
HR$_{max}$	Maximum heart rate
$\dot{V}O_{2max}$	Maximum oxygen consumption
m	Metres
m.min^{-1}	Metres per minute
m/s^{2}	Metres per second
m^{2}	Metres squared
mg/L	Miligrams per litre
mmol/L^{-1}	Millimoles per litre
ng/ml^{-1}	Nanograms per millilitre
NdGPS	Non-differential global positioning system
1RM	One repetition maximum
OTS	Overtraining syndrome
Vpeak	Peak velocity
%	Percent
PC	Phosphocreatine
PL	Player Load
RPE	Rating of Perceived Exertion
RPA	Relative playing area
C$_{R}$	Running economy
SWC	Smallest worthwhile change
SEM	Standard error of measurement
T:C	Testosterone:Cortisol ratio
TRIMP	Training impulse
TEE	Typical error of the estimate
U/L^{-1}	Units per litre
VT	Ventilatory threshold

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CHAPTER 1.

General Introduction

Soccer is a high-intensity intermittent team sport that carries significant physical requirements. To perform at the elite level, soccer players must demonstrate high levels of a myriad of physical components such as endurance, strength speed and agility (Stolen et al., 2005).

The physical demands of soccer are characterised by fluctuating periods of high and low-intensity activity interspersed by recovery (Bangsbo, 1994). During the course of a 90-min match, players may cover distances of 8-14 km (Reilly, 1996). High-intensity running may be defined as the point at which an individual's exercise intensity progresses to a level which dictates that exercise may not be sustained for prolonged periods, due to innate physiological capacities (Wasserman, 1984; Davis, 1985). High-intensity running accounts for approximately 10% of the total distance, while sprinting accounts 2% with efforts of up to 30m and between 2-4 seconds in duration (Reilly and Thomas, 1976; Bangsbo, Norregaard and Thorsoe, 1991). The spontaneous movement pattern of match-play may consist of 1400 changes in activity. Such activities include unorthodox anaerobic efforts such as accelerations, decelerations, jumping, cutting and ball skills, for example, that are superimposed on the predominantly aerobic metabolic profile (Bangsbo, Norregaard and Thorsoe, 1991; Mohr, Krustrup and Bangsbo, 2003, Akenhead et al., 2013). It is these movements that contribute significantly to mechanical loading of the musculo-skeletal system as well as energy expenditure when compared to moderate intensity continuous exercise (Reilly, 1997; Greig, McNaughton and Lovell, 2006; Dellal et al., 2010).

Exercise intensity of soccer match-play equates to approximately 85%HR_{max}, with energy expenditure of 75% maximal oxygen consumption ($\dot{V}O_{2max}$), indicating significant metabolic demands (Bangsbo, Mohr and Krustrup, 2006). The need for a high aerobic capacity for physical performance in soccer has been highlighted in studies suggesting relationships between team success, positional role and an enhanced training status (Apor et al., 1988; Di Salvo et al., 2006; Hoff et al., 2004). Lower ranked teams have been found to have lower $\dot{V}O_{2max}$ than those of higher ranking in the Hungarian league (Apor et al., 1988), while the championship winning team had higher $\dot{V}O_{2max}$ values than the bottom team in Norway (Wisloff, Hoff and Helgerud, 1998). The development of superior $\dot{V}O_{2max}$ through appropriate training has been shown to increase total distance covered and that at high-intensity running with an improved ability to recover between intense efforts (Helgerud et al., 2001). This allows sustained physical performance throughout a match, when such distances have been observed to decline by 5% (Mohr, Krustrup and Bangsbo, 2003) in the second half as a consequence of longer periods of recovery, possibly as a result of accumulated fatigue. However, more recent research has suggested that changes in soccer running outputs may be influence buy contextual factors such as team tactics, activity of opposition or self-pacing by the individual to spare energy stores (Bradley and Noakes, 2013). Consequently, there is a clear need for appropriately prescribed training stimuli across the soccer season to facilitate a high level of conditioning for subsequent competitive success (Strudwick and Reilly, 2001). The many facets of soccer conditioning including strength, speed, power and endurance need to be optimised efficiently to withstand high physical demands and protect against injury (Stolen et al., 2005). Furthermore, recent evidence suggesting increased intensity of match-play coupled with external factors that add to the pressures on contemporary elite soccer players warrant optimised training and recovery modalities to prevent fatigue and injury (Meister et al., 2011). These elements all combine to suggest appropriate training practices are needed more than ever for the contemporary soccer player. Furthermore, the notion of training load and methods to monitor this are of paramount importance to ensure fitness and protection injury.

If it is feasible, the monitoring of physical loads that players are exposed to in both acute and chronic periods of training as well as matches, where possible, is advocated. An understanding of how both the team and the individual player are responding to the prescribed training is important for coaching and medical staff to ensure the stimulus provided is appropriate (i.e. enough to promote adaption and development but to avoid overtraining and injury). In-line with the coaches aims for technical-tactical preparation of the team, monitoring loads enables a picture of the types of load (such as high-speed running, accelerations and decelerations) training incorporates. Any stimuli specific to match-play that are absent may then be provided by additional conditioning work to make sure players have been subjected to these conditions they will face in a match. Combining physical physiological and subjective data in monitoring training load for an individual enables greater detail in evaluating how a player can cope with training demands in relation to their training status (fitness level) and ability to tolerate and subsequently recovery effectively. As a result, profiles of each player in different positional roles and of different physical make-up can be generated to understand where modifications in load may be required to ensure they can perform optimally on match-day and with the risk of injury minimised.

Overall Summary and Aims

The overall aims and objectives of this thesis are to characterise the typical training of elite youth soccer players through the use of daily monitoring techniques. More specifically, in relation to quantifying training load in this population, there is application directed towards optimising physical (and technical) performance, minimizing the risk of injury. This will be achieved through:

- The exploration of seasonal changes in training load across the phases of a periodized soccer season. By deliberate manipulation of loads players are exposed to between seasonal phases and the subsequent effect this may have on physical testing performance throughout the training year.

- Understanding what contributes to making up the overall training load of soccer players. Highlight the types of stimuli they experience in match play and the extent to which these are replicated in the training environment.

- Demonstrate how small-sided games can be modified as part of the coaching process to plan and execute a varied training prescription. Emphasise the impact certain variables have on internal and external load responses with regards to physical and technical conditioning for soccer in these formats. Finally, compare the extent that small and larger format drills replicate demands of match play and can the most appropriate conditions be deduced for inclusion in specific training sessions and players to prepare for competition.

It was hypothesised that seasonal performance testing parameters would improve over the course of the season. As training load is manipulated across pre- and in-season phases with a shift from aerobic to anaerobic and speed stimuli would influence improvements in soccer-specific endurance as well as speed and power capabilities in the subject population. This may also reflect the introduction and rationale of monitoring match loads as part of the weekly physical dose, despite a reduction in training volume.

Furthermore, an in-depth analysis of small-sided games would see an increase in internal load with less player numbers and greater biomechanical load than with larger player numbers on the same relative playing area. However, an increase in relative playing area would see increased internal loading demands as well as high-intensity running and highlight heightened acceleration requirements. When proposing uneven teams in a small-sided format, we would hypothesise significant differences in physical demands on the team at a numerical disadvantage, with a lower physical intensity and higher technical load associated with the team of more players. Finally, by comparing and contrasting small and large-sided training formats with match-play, we might identify more biomechanical and acceleration loading in more confined drills. Space would be hypothesised to be a key factor in determining average speed and therefore a player's capability to achieve high-speed running distances, more maximal velocities and ability to generate high-level accelerations over longer distances. As a result, a continuum of the magnitude of contribution of specific stimuli needed for soccer match-play by each format may be constructed in order to inform training prescription to be able to optimally prepare players physically through correct load assignment.

CHAPTER 2.

Literature Review

Training in Soccer

The increased intensity of elite match-play over the last ten years reported by Barnes, et al., (2014) is compounded by a concomitant rise in competitive schedules with fixture congestion meaning two or three matches may be played in a week. Furthermore, domestic travel, international fixtures, as well as media, social and financial forces contrive to increase pressure on coaches and players to succeed (Meister et al., 2011).

As a result, training in soccer is paramount, with training loads (TL's) prescribed becoming more demanding to maximise time available and ensure players cope with heightened physical demands across different phases of the training year (Iaia et al., 2009). This has previously been shown in rugby, whereby pre-season training loads have been increased in intensity whilst lowered in total duration (Gabbett, 2004). The premise behind such a strategy is to expose players to a variety of intense stimuli even above that experienced in match play in order to make them more resilient and decrease their propensity for injury (Gabbett, 2016).

The training year in soccer is comprised of discrete phases (off-season, pre-season and competitive season) with training implemented in each varying according to the stage of the season and indeed the aims of the coach. Primarily, the goal is to provide a training stimulus that optimises positive adaptations for performance and minimizes the risk of negative consequences (injury, illness and overtraining). Banister et al., (1975) likened this training-performance relationship to dose-response observations observed in pharmacological studies. Therefore, the training responses of an athlete occur due to differences in negative and positive functions. Soccer training may then be moderated in terms of volume and intensity to elicit beneficial adaptations for individual players by balancing the minimum TL for maintained performance and the maximum load feasibly tolerated for performance gains (Gabbett and Domrow, 2007). By accompanying the correct TL with periods of regeneration and super-compensation, adaptations are promoted as the body adjusts to an increased stimulus, whilst lowering the likelihood of overtraining symptoms that may predispose players to over-use, lower-limb injuries (Barnet, 2006; Gabbett and Domrow, 2007). The correct periodisation of the training week or phase can reflect this, with Gabbett and Ullah (2012) and Gabbett (2004) finding increased risk of injury with higher intensity, duration and loading of training following the pre-season period in rugby league. However, there is an overriding need to understanding the types of stimuli soccer players are exposed to in physical, technical and tactical training scenarios and indeed what constitutes high or low intensities and in relation to match.

In this instance, there have been several studies into injury prevalence in elite level soccer match-play. Rahnama et al., (2002) found injury risk to be higher in the first and last 15 minute periods of a soccer match, particularly in crucial attacking and defensive areas of the pitch. In congested fixture periods, Carling (2011) found injury rate per 1000h to be similar when comparing an intensive fixture period with a non-congested period (50.3 vs. 49.8 per 1000h exposure). In a similar study, Dellal et al., (2015) found a similar overall injury rate but did find a significant difference in match-related injuries in a normal schedule compared to a period of six games in eighteen days. A significant different was reported between the two (43.3 vs. 18.6 injuries per 1000h, <0.001).

As previously noted soccer is a complex sport that requires various prerequisites at the elite level. The training stimulus utilised must therefore address as many factors as possible to achieve performance benefits. In this light, the following sections will detail the use of common training modalities in elite soccer and their use in eliciting stimuli, specifically small-sided games.

Small-Sided Game Training in Soccer

The aim of small-sided games (SSG) in soccer is to implement a sport-specific training stimulus that will provide a more functional approach to preparing players for competitive match demands. The existing literature has reported numerous benefits to SSG use in soccer training, particularly at the elite level (Table 2.1). SSG have been suggested to be beneficial in providing an environment for both technical and physical development at physiological and locomotor intensities similar to that experienced in a match. Furthermore, skill and decision-making abilities are also taxed when operating under fatigue in these formats that take place on reduced playing areas. The concurrent development of the aforementioned abilities with the use of a ball has therefore been noted to increase motivation and compliance of players and are therefore attractive to coaching staff when prescribing training.

There are a myriad of variables that may be implemented in SSG in order to modify the intensity and magnitude of the contribution of certain physical and technical stimuli. Depending on the aims of the session, these may be manipulated in order to achieve the desired intensity for the team or individual player. These variables will be discussed in more detail in the following sections.

Pitch Size

Manipulating both the absolute and relative playing areas is a common variable to consider when prescribing exercise intensity in small-sided games (SSG). The effect of available playing space does seem to have some influence on loading variables in soccer SSG. The spatio-temporal demands have been suggested by Fradua et al., (2013) to dictate player’s constant adaptation to relative playing areas at their disposal. Success of SSG aims depends on design where constraints affect strategies, physical responses and learning opportunities (Vilar et al., 2014). Understanding how to create the right environment and how inter-personal distances change can affect physical, technical and cognitive stimuli which can all help to enhance the training process. The size of the pitch, location of goals and indeed the ball will shape a player's strategy and context of the game, labelled 'system destabilization' by Vilar et al., (2014). The location of the ball will affect space, particularly confined in central areas, encouraging players to seek space out wide (Fradua et al., 2013). The area covered will be determined by space in either elongated or flattened shapes with the separateness of the team increasing with greater pitch sizes (Silva et al., 2014), yet this had been found to be on areas of only 78-93m^2 in match play (considerably smaller than areas used in studies of SSG).

However, existing research regarding the extent to which intensity is influenced by the space available. Numerous studies have reported higher intensities through heart rate, perceptual effort and average speed in SSG played on larger areas. Rampinini et al., (2007) increased absolute pitch size by 20% in games of 3v3 to 6v6 in amateur soccer players. Main effects were reported for pitch size, with greater heart rate (89% vs. 87% HR$_{max}$) and blood lactate (5.1 and 4.6mmol.L^{-1}) and subjective responses on larger pitch sizes compared to small. This may be due to the greater absolute pitch size that dictates greater average speed and high-intensity activity in order to cover this larger space available, closing down opponents and making supporting runs, for example. Lower coefficients of variation (CV) and high intensities reported in smaller pitch games were suggested to be more reproducible than lower intensity games found on larger pitch sizes, however. Better reproducibility may therefore have practical applications for coaching staff who can be more confident in prescribing smaller areas to induce the necessary conditioning outcomes of the session.

Increasing relative playing area by 100m^2 in 5v5 amateur youth players, Casamichana and Castellano (2010) also found physiological and subjective responses to be elevated in large and medium-sized pitches versus small. Significantly greater overall meterage was found with large pitches (125 vs. 87m.min^{-1}) as was high-intensity running (74 vs. 5m) and peak velocity (23 vs. 18.05km/h^{-1}). On the other hand, motor behaviours were more numerous on smaller pitches involving more stoppages and therefore less effective playing time due to specific conditions implemented, therefore promoting lower intensity activity and lower subsequent heart rate and rating of perceived exertion (RPE).

Despite no difference in heart rate intensity (~87%HR_{max}), higher external demands have been reported for 4v4 on larger pitches by Hodgson, Akenhead and Thomas (2014) in a study on university soccer players, finding passing, turning and tackling technical demands to be emphasised in SSG on smaller areas. This study also showed the presence of significantly higher acceleration demands, particularly with a medium size pitch (40x30m) enabling the attainment of more high-intensity activity and greater peak velocities compared to smaller pitch, while still enabling frequent technical actions. Total acceleration (327 and 230m) and deceleration distance (298 vs 198m), for example, were much greater in the larger pitch sizes ($p<0.05$). High relative acceleration demands in SSG on large and medium-size pitches in particular adds more detail to the intensity and movement demands on different playing environments, although number of efforts were not quantified in this study. Gaudino, Alberti and Iaia (2014) also found that even though total metres covered and high-intensity distance are lower with less space per player, moderate (2-3m/s^2) and high-level (>3m/s^2) accelerations may be more pronounced in 5v5 and 7v7 SSG and possession-style games compared to the larger 10v10 field size (30x30m and 45,35m vs. 66x45m). This highlights significant actions that require metabolic and neuromuscular outlay, efforts that have often been ignored in previous research with regards to their contribution to energy cost in team sports such as soccer. Only the work of di Prampero et al., (2005) and Osgnach et al., (2009) has attempted to quantify acceleration and energy cost, although this was performed on a treadmill in a closed laboratory environment that did not account for multidirectional and skill-related efforts.

In a more comprehensive study, Owen et al., (2014) examined games of 4v4 to 11v11 that were classified as either small, medium or large games. Although relative playing area (RPA) was not systematically controlled (94-336m^2), physical parameters of total distance covered (TDC), high-intensity activity (HIA) and peak velocity were all greater in the 'large' games, with technical skills such as passing, dribbling and shooting greater in the 'small' games. Furthermore, the study also demonstrated a good level of test-retest reliability of these measures in different SSG for physical and technical values (both $r=0.99$).

In another study of SSG modifications, manipulating player numbers and subsequent RPA available with the use of a floater to create temporary or fixed numerical overload situations (i.e. 5v3) also influenced physical and subjective outputs. Hill-Haas et al., (2010) reported higher RPE, high-intensity activity and number of sprints performed by floaters and underloaded teams. Heart rate, blood lactate and total distance were in fact not different compared to the team with a numerical advantage, however, despite disproportionate RPA required of each team to cover in 4v3 and 5v6 SSG. Moreover, the floater role has no 'fixed' RPA at the disposal of both teams and so did entail a greater mean speed than the team of 4 players ($p<0.05$) that may provide additional conditioning benefits. This suggests that RPA specifically may not influence physiological responses in SSG and may instead be determined more by the role asked of them in terms of being a constant outlet of play for whichever team is in possession of the ball. It is difficult to confirm this as some formats in this study either used goalkeepers or small size goals which may have influenced the area outfield players operated within as well as the overall strategy of the game and subsequent movement behaviour. Furthermore, the aim may be dictate modifications in the stimulus produced by the drill. For example, designating specific work-rest periods for certain players or positions may induce different physical development responses, for aerobic or anaerobic purposes.

In contrast, Kelly and Drust (2010) reported that increasing RPA (60, 140 and $200m^2$) saw similar heart rate responses to three 5v5 SSG on different pitch sizes (91, 90 and $89\%HR_{max}$), with technical actions more apparent with larger available areas. The authors concluded that changing the playing area had little effect on heart rate response, but smaller areas may produce a greater frequency of tackling and shooting actions compared to larger pitches. Furthermore, when manipulated in conjunction with a change in player numbers, playing area may have more of an influence on physiological responses and intensity in SSG.

Varying the space at a player's disposal in SSG modifies environmental constraints, learning opportunities and physical and technical expressions. Effects on inter-personal distances and team relationships in different environments will be related to individual strategies, where context has a large bearing on how they functionally adapt to improve chances of scoring success (Seifert, Button and Davids, 2013).

Player Numbers

Equally common is the variation in the number of players in SSG has been suggested to regulate exercise intensity. Generally, the existing literature in soccer has indicated an increase in intensity with lower player numbers (Rampinini et al., 2007; Owen et al., 2011).

In a study entailing SSG from 2v2 to 5v5, using the same RPA (150m^2), Aguiar et al., (2013) saw greater heart rate responses (%HR$_{max}$ and time >90%HR$_{max}$) in SSG with less youth players (90 vs. 84%HR$_{max}$, $p<0.05$). Average speed (685m) and high-speed running distance above 18km/h^{-1} more pronounced in 3v3 compared to 2v2 ($p<0.05$), 4v4 and 5v5.

On the same RPA, Hill-Haas et al., (2009) also found SSG of less players to induce greater heart rates as well as RPE and blood lactate responses. Games of smaller player numbers were also found to bring a greater technical load and frequency of ball involvements compared to those with more players per team. This was suggested to result from more interactions and subsequent turnover of possession (previously postulated by Balsom et al., 1999) than in larger SSG that might simulate movement in match play more easily. For example, there is more movement off the ball that reaches more maximal velocities. Despite the requirement of higher speeds with more players, no differences were found between player numbers for the total distance covered and indeed the distance covered at sub-maximal speed zones.

Comparing 3v3 to 6v6 in youth players, Rampinini et al., (2007) again reported less player numbers to increase physiological and perceptual markers in SSG (heart rate, blood lactate and RPE). Moreover, the intense games with less numbers demonstrated less variability (lower coefficient of variation) then the lower intensity SSG involving more players per team. Interestingly, blood lactate concentrations were found to have a greater degree of variation in SSG of different player numbers compared to both heart rate and RPE. Anaerobic provision was suggested to be more apparent in SSG of low player numbers and short duration, where repeated anaerobic involvements increased lactate production, then relying on the glycolytic system to aid recovery between intense bouts. These may be more frequent with less players due to greater involvement which concurrently ensures an increased technical load (Rampinini et al., 2006). Larger numbers may have required greater aerobic energy sources that could have implications for the periodization of different formats SSG's in training (Owen et al., 2012).

Comparing 5v5, 7v7 and 10v10, Gaudino, Alberti and Iaia (2014) analysed time-motion analysis collected by GPS whilst normalising for differences in duration. Larger player numbers saw significantly greater total distance covered and high-speed running compared to 5v5. Moderate and high-level accelerations however, were more frequency in 5v5 versus 7v7 and 10v10 formats. This may be due to a reduction in absolute space in smaller number SSG in this study, preventing high velocities and thus requiring more fluctuation in speed to change direction. Furthermore, the greater higher intensity activity and maximal accelerations achieved with greater numbers may also reflect greater energy cost as well as high metabolic power in the larger formats that is enabled with greater playing space (though these markers are unclear in the literature in their quantification of energy cost).

Many studies have examined SSG number variations with teams of even numbers. Hill-Haas et al., (2010) used both even and uneven teams and the use of a floater to prescribe both permanent and temporary overload situations. No significant differences were found in heart rate or blood lactate concentrations, though RPE was reported to be higher in the underloaded team of less players (4v3 and 6v5). Motion-analysis also revealed no differences between players of uneven or that of even teams with a floater, with only total distance and sprint frequency found to be greater in the player designated as the floater in 5v5 and 6v6.

Several other studies have examined the effects of number of players on responses to SSG. Medium and Large teams were found to have superior meterage, high-intensity distance and peak speeds, with technical actions of passing, shooting and dribbling instead emphasised in games with lower player numbers (Owen et al., 2014). Furthermore, in repeating each drill (4v4 to 11v11), test-retest reliability of 5Hz GPS running data and recorded technical actions found both to have a reliability of 0.99. Higher intensities through blood lactate and RPE were also reported by Koklu et al., (2011) and Dellal, Drust and Lago-Penas (2012) in SSG with less players. Koklu et al., (2011) showed heart rate to be higher in 3v3 and 4v4 with blood lactate greater in 1v1 and 2v2, implying different preferences in aerobic and anaerobic energy provision. With little opportunity for recovery, high levels of lactate produced in the muscles in 1v1 and 2v2 activities exceed clearance rates and are also compounded by depletion of short-term creatine phosphate stores (Glaister, 2005) which may have implications for training prescription in soccer players. Dellal et al., (2012) described heart rate to be higher in SSG compared to match-play, with matches seeing greater levels of lactate in the blood perhaps due to more involvement in SSG but more gross movements possible in a ninety-minute match. However, on a note of caution, lactate concentrations are highly dependent on activity just prior to sampling and therefore may not be a true representation of metabolic demands of the whole match (Bangsbo, 1994). Although RPE was not different, implementing rules of one and two-touch elevated heart rate and RPE in 4v4 games compared to those with unlimited touches of the ball despite less absolute space. Curiously, high-intensity running was higher in SSG than match play in this study, though this may be due to a discrepancy between velocity zones and sampling rates used in GPS and semi-automated analysis systems. Duels and subsequent interactions were more frequent in 4v4 versus 11v11, and although no acceleration data was presented, this may indicate greater anaerobic ATP-PC requirement for short, intense efforts with larger format match-play necessitating anaerobic glycolysis energy provision. Finally, Dellal, Drust and Lago-Penas (2012) detailed variation in 2v2, 3v3 and 4v4 SSG on the same 75m^2 RPA. Higher heart rate and blood lactates in 2v2 were attributed to short durations and recovery periods as well as possibly an increased requirement to cover the 75m^2 per player compared to teams of larger numbers. Although previously suggested by Hill-Haas et al., (2010) to control player activity, the constant RPA still saw significantly higher high-intensity distances in 3v3 and 4v4 compared to the 2v2 SSG.

In summary, research into player number effects in soccer SSG suggests physiological and perceptual intensity to be elevated with less players per team. However, physical running loads may be increased with more players where high-velocity activity is more feasible with higher absolute space. Future directions may therefore look towards interaction of concurrent player and space manipulation on intensity of SSG with regards to team numbers and the absolute and relative playing area available.

Game Format

The stimulus of SSG has also been altered through the format or regimen implemented. For example, studies have employed drills with (SSG) or without (possession) goalkeepers and modified the size of the goals used.

In 3v3 SSG using elite youth soccer players, Mallo and Navarro (2006) utilised traditional small-sided and possession games with and without goalkeepers. Results showed considerably greater total distance and time spent cruising and sprinting (>12.9 and 18km/h^{-1}) in possession games than those with goalkeepers ($p<0.001$). Heart rate was also higher in possession-based formats ($p<0.05$). The elevated physical intensity of the possession was speculated to result from improved defensive organisation with the presence of goalkeepers. Furthermore, possession games have no directional element of play (no goals), therefore reinforcing a more continuous movement pattern involving switches of play whereas the use of goalkeepers brings a more sporadic, intermittent nature to the game.

Castellano, Casamichana and Dellal (2013) compared three formats of SSG with large or small goals or with or without goalkeepers and the effect on heart rate and locomotor outputs. On areas of 210m^2 per player, %heart rate mean was greater in the possession game than with large or small goals. Peak velocities were higher in games using small goals compared to possession, with total distance and Player Load lower in SSG including goalkeepers. Again, these may be a result of goalkeepers bring more formational structure to these semi-professional players, with possession games being a more continuous mode of exercise that increase TDC and Player Load. The possession games higher distance covered and mean velocity would therefore limit attaining high-velocity and acceleration behaviour due to a higher starting velocity employed as part of the player's strategy to help maintain work-rate and possession of the ball for the team in question. Therefore, the different conditions (goalkeepers, goal posts) may dictate either predominantly aerobic (higher meterage) or neuromuscular (acceleration behaviour) tendencies in the particular small-sided format.

In a similar study, Gaudino, Alberti and Iaia (2014) observed greater meterage in possession games, with high-speed activity and peak velocities also higher in SSG using goalkeepers. No differences were found between the two formats for moderate and high accelerations, but maximum accelerations and decelerations were greater in SSG with goalkeepers. SSG may therefore promote high-level accelerations and absolute speeds due to a lower initial starting velocity of running efforts compared to possession-based games. A lower average exercise velocity could then allow more significant changes in speed to be made for decisive actions in the game, having implications for training prescription.

Other Variables

The effect of other variables has also been described in the literature. Using both amateur and elite male players Fanchini et al., (2011) examined the effect of bout duration on SSG intensity. Performing 3v3 in three bouts of 2, 4 or 6 minutes, heart rate was found to increase non-significantly from 2 to 4 minute bouts, with a decline for 6 minutes possibly due to fatigue in this bout duration. As previously alluded to by Hoff et al., (2002) this small increase may take into account time taken to attain cardio-respiratory kinetics at the start of exercise following an initial oxygen deficit. Similarly, heart rate increased from bouts one to two and again decreasing by the final bout. When the first minute was excluded from analysis, however, average heart rate from the two minute bouts exceeded that of the 6-minute bout. RPE increased with subsequent bouts but was unaffected by the total duration of each of the three interventions. Duration was also found to have no effect on technical actions although a reduction in total and successful passes in the final bout was observed.

In 2v2, 3v3 and 4v4, Dellal et al., (2012) used four bouts of durations of 2, 3, and 4 minutes in a group of international soccer players. Higher percentage of heart rate mean was seen in latter bouts as was RPE and blood lactate concentration, with a coinciding drop in high-intensity and very-high intensity running of ~15%. On the same RPA (75m^2), technical behaviour in the number of duels and successful passes decreased, while the number of balls lost increased from bouts one to four. These data suggest that duration may also play a role in mediating appropriate exercise intensity in these soccer training formats.

The use of coach encouragement during games has also been investigated in soccer training (Hoff et al., 2002). Rampinini et al., (2007) found it was possible to increase exercise intensity in SSG with versus without coach encouragement. Significantly higher heart rate, blood lactate and RPE were found when coaches were allowed to encourage the players, with comparisons of effect sizes showing this to be a larger determining factor of exercise intensity than playing areas (ES η^2=0.668, 0.764 and 0.976, >0.15 was considered as a large effect) through the provision of external coach motivation.

As well as overall and individual bout duration, SSG regimen may be altered. Casamichana, Castellano and Dellal (2013) employed three formats of 5v5 using semi-professional players of 1x16 minutes, 2x8 minutes and 4x4 minutes on areas of 210m^2 per player. Average heart rate (>85%HR$_{max}$) was not different between each regimen, with a decline in heart rate observed in the final 4-minute bout, though this was still significantly higher than that in the second bout of 4 to 8 minutes. Interestingly, total distance covered was greater in both the intermittent regimens, with accelerometer-derived Player Load highest in 2 x 8 minutes. This may be attributed to the period of intervening recovery enabling reloading of oxygen and energy stores perhaps. The effects of total and bout duration are highlighted as well as the importance of recovery duration in influencing cardiovascular response and the effect of fatigue on subsequent running performance.

Hill-Haas et al., (2009b) also used an intermittent and continuous design over a total duration of 24 minutes (or 4 x 6 minutes for intermittent). It was found that average heart rate and RPE were higher in the continuous format, with no differences in absolute distance and distance covered at sub-maximal intensities. Possible explanations for this might include more frequent re-setting of the muscular-venous pump, responsible for blood and muscle reoxygenation during lower intensity periods of intermittent exercise, compared to continuous exercise modes (Hoff et al., 2002). Furthermore, there may also be differences in the HR and VO$_2$ relationship where the motion profile of soccer and the larger muscular involvement can cause disproportionate changes in these physiological responses (Buchheit et al., 2009; Mendez-Villanueva et al., 2013). However, high-speed running and sprint efforts were more numerous in the intermittent SSG, more indicative or match-play although still substantially less than in competition. Despite observing lower heart rates than that of Casamichana, Castellano and Dellal (2013), intermittent formats were advocated by the authors for player compliance as well as improving fitness and 'repeated-sprint' ability requirements as well as accommodating coaching points in recovery periods. However, it may be more prevalent to explore ‘repeated-effort’ demands, given the short, explosive nature of efforts in soccer. In this instance, acceleration behaviour was not examined which may provide more detail in to position-specific demands to aid in training prescription.

Table 2.1: Summary of Small-Sided Game research in soccer

Study	**Population**	**Design**	**Results**
Rampinini et al., (2007)	20 amateur Italian soccer players	-Increasing RPA 20% in Small, Medium and Large pitches (12x20m-36x48m). 3 x 4 mins (3 mins recovery). -Teams of 3-,4-,5- and 6v6 on each pitch size.	-Larger field sizes saw ↑ heart rate (~89%HR_{max}) and blood lactate (5.1mmol.L^{-1}). -Less players produced ↑ heart rate (~90%HR_{max}), blood lactate (6mmol.L^{-1}) and RPE (8AU).
Gaudino, Alberti and Iaia (2014)	26 elite male English Premier League soccer players	Different formats of SSG and Possession games in 5v5, 7v7 and 10v10.	↑ total distance, HSR and top-speed with larger number and absolute space. ↑ moderate-high acceleration efforts in smaller 5v5 formats.
Kelly and Drust (2010)	8 English elite youth male soccer players	Different size pitches for 4v4 SSG. (30x20m, 40x30m, 50x40m)	Heart rate similar between pitch sizes. ↑ frequent technical actions (tackling and shooting) on larger pitch
Fanchini et al., (2011)	19 Male amateur and elite soccer players	3v3 SSG of 3 x 2, 4 and 6 minute bouts (4 min recovery) on 191m^2 per player. (30-30m – 52x52m)	Heart rate ↑ from 2 to 4 minute bout durations, ↓ in 6 minutes. RPE ↑ after each bout but was unaffected by bout duration
Casamichana, Castellano and Dellal (2013)	10 elite male Spanish soccer players	5v5 (1x16, 2x8 and 4x4 minute intervals) on same size area (55x38m, 210m^2 per player).	No difference in heart rate between regimens. Heart rate in minutes 12-16 > 4-8 minute intervals. Total distance and Player Load ↑ in intermittent training regimes
Castellano, Casamichana and Della (2013)	14 Semi-Professional soccer players	3v3, 5v5 and 7v7 with small goals, large goals goalkeepers and possession formats). Field sizes for different player numbers 40x30m, 55x38m and 64x46m (6 minutes per game format, 5 minute recovery).	Greater HR response to possession formats in each different player numbers ↓total distance, Player Load and top-speed with GK's included

Fatigue in Small-Sided Games

Given the associated high intensity of exercise associated with SSG, the literature reviewed above often refers to elements of fatigue curtailing work-rate and responses to the given training stimulus. As with competitive match-play, there are numerous factors that could all play a part in a playing experiencing 'fatigue' during SSG. During SSG of different designs, some of these factors may be more apparent. For, example, in games on small playing areas where frequent changes in direction, acceleration and deceleration are required, the musculature is required to absorb and produce force perhaps more frequently, disturbing muscle ion balance and subsequent contractile function within the muscle cell. The increase in potassium levels in cellular space, for example, may inhibit contraction coupling and action potential to produce a given level of force when required (McKenna et al., 1996). In addition, depleted levels of phosphocreatine which help produce energy for explosive efforts in intense periods could affect sprinting and other outputs that require rapid execution (Krustrup et al., 2003). Similar other metabolic changes such as the accumulation of lactate in the muscles ensures an increase in acidosis thereby lowering pH, particularly in intense periods, that inhibit muscle function. This can be exasperated by the depletion of other energy substrates such as glycogen used in the production of adenosine-triphosphate (ATP) to fuel the contraction of individual muscle fibres. These muscle fibres may be partially or nearly completely used in the latter stages of exercise, meaning muscle function and the ability to produce forceful contractions when required is limited (Saltin, 1973).

Environmental conditions, in the heat for example, may also see faster rises in core temperature and dehydration in an attempt to cool the body. The result is heightened cardiovascular and thermal strain, or hyperthermia, in excessive cases causing a reduction in physical output or termination of exercise (Gonzalez-Alonso et al., 1997).

Pacing has also been suggested to be a potential element to consider when fluctuations in work-rate occur (Bradley and Noakes, 2014). When intense periods of activity are evident, running outputs, particularly at high-intensity may be temporarily reduced due to increases in lactate, acidosis and depletion of energy stores, such as phosphocreatine. This temporary form of fatigue may subside following sufficient recovery of these mechanisms, often through low intensity activity. On the other hand, when work-rate maybe reduced towards the end of the SSG or match, the decrement may be more permanent and due to factors mentioned above (substrate depletion, muscle acidosis or dehydration). Other cognitive and social factors to consider may also provide explanations for movement profiles, fatigue-related or not. Players may employ pacing strategies to preserve energy stores for later in the activity, depending on the status and scoreline. Furthermore, the individual's tactical role dictated by the coach may also have an effect on why there is variation in levels of activity, that also may reflect the activity of their opponent(s).

Small-sided game limitations

Despite their popularity, previous research on SSG in soccer do hold some limitations. Although there is a large volume of literature, comparing exercise intensities and individual responses between studies is difficult. For example, there are contrasting study designs that entail the use of varying populations of different ages, nationalities and training status, all of which have been suggested to effect responses to soccer-specific exercise and match-play (Harley et al., 2010; Di Salvo et al., 2012; Krustrup et al., 2005). Furthermore, study duration and the number of subjects employed also varies. Impellizzeri et al., (2006) utilised forty junior Italian players in an intervention study lasting twelve weeks in pre-season whereas Owen et al., (2014) had fifteen elite adults in a four-week in-season intervention. Additionally, the use of different equipment in methodologies also suggests caution should be taken when comparing results of such studies into SSG outputs. This is in particular reference to time-motion analysis that has evolved over the last twenty years, with early work involving manual and video-based recordings that is now in the form of global positioning systems (GPS) and semi-automated tracking systems. With GPS, comparisons are often hindered by the use of different manufacturers with different models that operate at different sampling rates, producing results where reliability may be questioned (Cummins et al., (2013). Further, the technology's ability to accurately portray high-velocity activity is compromised, specifically when detecting high-speed movement over short distances, and also with distance covered when incorporating frequent changes in speed, typical of confined SSG (Varley, Fairweather and Aughey, 2013).

Also, there is a lack of consistency in the classification of activity levels of each intensity, what constitutes 'high-intensity activity', maximal accelerations and which method of heart rate should be reported (%HR_{max}, %HR_{res}, %HR_{mean}). The limitations associated with time-motion analysis and GPS technology will be discussed in more detail later in this thesis.

In addition to these methodological concerns, disadvantages with SSG may also include their efficacy to produce desired responses in players possessing higher levels of aerobic fitness. Although it may be said that they could still be programmed as technical-based sessions to benefit these players. The intermittent nature of these games has been suggested to negate continuous exercise and the attainment of significant cardiovascular strain required for achieving adaptations and improvements in $\dot{V}O_{2max}$. By this, it is meant that the intermittent pattern forces the continued re-setting of the muscular-venous pump that limits stroke volume and cardiac output (Hoff and Helgerud, 2004). As a result, SSG have been suggested to involve a 'ceiling effect' for fitter players, indicating the need for alternative modes of conditioning. Finally, despite claims SSG are effective training to simulate match-play, this has recently been questioned (Gabbett, Jenkins and Abernethy, 2009; Casamichana, Castellano and Castagna, 2012). Key aspects common in match-play include high-speed sprint efforts and maximal accelerations of distances of over 20m are not feasible. Environmental restraints and condition contrive to inhibit these types of activity, therefore questioning the specificity of SSG to simulate the movement profile associated with competition, and indeed of the right magnitude. As alluded to previously, a more continuous exercise pattern (mean velocity), coupled with a lack of relative space available in SSG prevents reaching high speeds with player interactions and pitch boundaries forcing more low level accelerations and decelerations to change direction from a relatively high average velocity.

Having described the benefits and limitations inherent with SSG, it is appropriate to note the significance of high-intensity training and the mechanisms behind its use in soccer training, whether as SSG or more controlled and repeatable ‘generic’ interval training for conditioning.

High-Intensity Interval Training (HIIT) for Performance

Soccer is a sport that requires high levels of aerobic fitness, approximately 55-60ml.kg.min^{-1} (Bangsbo, 1994). Possessing greater aerobic capabilities has previously been correlated with improved work rate, recovery from high-intensity intermittent exercise and greater total distance and number of sprint efforts (Helgerud et al., 2001; Laursen and Jenkins, 2003). In order to improve aerobic fitness, low-moderate sub-maximal endurance training of increased duration have historically been employed that bring about central (cardiac) and peripheral (muscular) adaptations that describe muscles transport and use of oxygen respectively (Laursen and Jenkins, 2003).

However, the use of higher-intensity exercise in the form of interval training has become more common. HIIT has been defined by Laursen and Jenkins (2002) to involve “*repeated bouts of short to moderate duration at an intensity above the anaerobic threshold...separated by brief periods of low-intensity activity that allow partial but often not full recovery*”. High-intensity exercise has been suggested to induce similar adaptations to traditional endurance training in a more controlled and time-efficient manner (Helgerud et al., 2007). This type of training may then be used as an effective way to tax physiological systems contributing to endurance performance (Daniels and Scardina, 1984). Moreover, cardiac and pulmonary adaptations enhancing ones' ability to transport and utilise oxygen and an alteration in substrate metabolism, increasing fat oxidation while sparing glycogen stores (Gibala and McGee, 2008) are perhaps the most prudent adaptations resulting from more training. Specifically, these include cardiac hypertrophy of the heart myocardium to then increase force and amount of blood that is ejected with each beat. Also, the increased capiliarisation and surface area of alveoli in the lungs serve to make processes of gaseous exchange more efficient to sustain exercise intensity through provision of oxygen (McCardle, Katch and Katch, 2006). The format of HIIT can be manipulated according to training aims, demands of the sport and the specific training phase (Daniels and Scardina, 1984). Variables that may differentiate between protocols and responses gained include; intensity, duration, frequency and the intensity and duration of recovery periods. For example, Helgerud et al., (2007) showed HIIT to be more effective in increasing aerobic fitness by 5-7% compared to no change with moderate intensity training (at 70 or 85%HR_{max}). The idea here is to alter the metabolic demands of systems above that required for the sport. HIIT is often constructed around fixed ratios that dictate bouts of work and recovery (1:1, 1:2, 2:1) and may be short (5-6 seconds) or longer (2-10 minutes) duration that will influence subsequent aerobic and anaerobic metabolism (Billal et al., 1991).

There have been many studies detailing different HIIT interventions and the proposed benefits to sporting performance compared to those of moderate intensity, steady-state exercise (Table 2.2). These have entailed both trained and untrained populations, with those of higher training status found to obtain smaller increases in adaptations compared to untrained individuals as a result of already having superior physiological development. Furthermore, whereas any increases in $\dot{V}O_{2max}$ in training may influence an increase in endurance performance, elite athletes may instead require increases in training intensity rather than volume to create a stimulus conducive to higher performance for them (Helgerud et al., 2007).

Research by Pate and Kriska (1984) suggested that variations between individual differences in endurance performance may be influence by $\dot{V}O_{2max}$, lactate threshold and running economy. It has also been said that these variables may be mediated by both central and peripheral factors. Central adaptations to HIIT benefit performance by enhancing transport and delivery of oxygen to the working muscle cells (Helgerud et al., 2007). For maximal exercise, maximum oxygen consumption ($\dot{V}O_{2max}$) may be limited by the supply of oxygen. However, this may be improved through HIIT by increasing stroke volume of the heart deriving from cardiac hypertrophy of the left ventricle enabling greater cardiac filling and contractile force, thus increasing pressure for a higher cardiac output. There is then further cardiovascular stability through an increased blood volume that prevents a decline in arterial-venous pressure (Sawka et al., 2000) and ensuring more efficient oxygen transport and pulmonary kinetics for energy supply (Krustrup, Hellsten and Bangsbo, 2004).

+Peripheral adaptations from HIIT concern the ability of skeletal muscle to use oxygen in the production and utilisation of ATP to sustain performance (Green et al., 1992). Such adaptations are largely characterised by changes to substrate metabolism and the upregulation of enzymes to specific energy systems and are a result of increased energy demands at the cellular level (Coyle, 2000). Therefore, muscle energy state is enhanced by being able to preserve high-energy phosphates and use fatty acids as an immediate energy source (Green, 2000; Billat, 2001a). Improved muscle buffering capacities may also aid ATP production through the buffering of H+ ions. This in turn maintains function of anaerobic enzyme phosphofructokinase (PFK) in facilitating anaerobic ATP production (Spriet, 1995) in supramaximal repeated-sprint performance (McKenna et al., 1996). Finally, the up regulation of Na^+-K^+-ATPase and $Ca2^+$-ATPase (maintain concentration gradients for muscle membrane potential and cross-bridge formation of actin and myosin) in the sarcoplasmic reticulum, muscle capillarisation, adrenaline release and enhanced myoglobin stores may also help delay muscle fatigue and improve performance as a result of HIIT training (Green, 1998; Billat, 2001a).

In a study of fourty moderately trained males, Helgerud et al., (2007) compared training interventions of different protocols. Training intensity was different between the four modes, though all were matched for energy consumption. Training three times per week for eight weeks, subjects were assigned to HIIT (either 4x4 minutes or forty-seven repetitions of 15:15 seconds both at 90-95%HR_{max}), long slow distance (LSD, forty-five minutes at 70%HR_{max}) or lactate threshold (LT, twenty-four minutes at 85%HR_{max}). The HIIT groups $\dot{V}O_{2max}$ improved more than LSD and LT, with all groups significantly increasing running economy and velocity at lactate threshold. HIIT protocols both saw significant increase in stoke volume post training which was linked to superior increases in $\dot{V}O_{2max}$. The authors suggested $\dot{V}O_{2max}$ is limited by oxygen supply during intense exercise that derives from stroke volume and cardiac output efficiency. Although all groups improved running economy, possibly due to running efficiency and lower metabolic cost through peripheral adaptations, HIIT would seem to be more effective than moderate intensity exercise, with exercise above 90%HR_{max} governing greater cardiovascular adaptations. Helgerud et al., (2001) also demonstrated this mode of exercise to improve soccer match performance in elite Norwegian youth players. An 11% increase in $\dot{V}O_{2max}$ in eight weeks was found for elite players in the HIIT group, whereas the control group had no difference. This then translated to an increased match total distance, sprint frequency and ball involvements by 20%, 100% and 24% respectively compared to pre-intervention. The large increase in sprint efforts is not quantified by pre- and post-intervention data to support this finding in youth players, however. It may be appropriate to examine similar interventions with elite adult players to compare the extent of adaptations and match performance between the two populations. Although these data may reflect training adaptations and capacity to execute these actions more frequently, this does not necessarily translate to better or more successfully performance. The outputs of a player may be self-paced of influenced by opponent activity depending on the context of the game. Therefore, high physical outputs are not necessarily a successful outcome.

Other studies have employed shorter interval training (IT) to examine central and peripheral adaptations. For example, Gibala et al., (2006) assigned sixteen active males to either an endurance training (END, 90-120 minutes cycling at 65%VO_{2peak}) or sprint interval training groups (SIT, 6x30 seconds all-out efforts with four minutes recovery). Both groups completed six sessions over a two-week period, with SIT found to have slightly greater improvements in time-trial performance and mean power output compared to END. Muscle buffering capacity increased 7 and 6% and 28 and 17% in resting glycogen content respectively for SIT and END. Although SIT was only 10% of training volume in END, this type of training was able to induce similar physiological adaptations. This type of IT may therefore be more efficient in increasing maximal activity of mitochondrial (oxidative) enzymes and altering substrate utilisation to spare glycogen stores and improve muscle buffer capacity for performance in soccer, for example.

In another study of five male university students, Rodas et al., (2000) used fourteen sessions to examine muscle adaptations to all-out sprint interval training over a short two-week period. Subjects performed repetitions of 15 seconds with 45 seconds rest and 30 seconds all-out with 12 minutes recovery between. Training started with two repetitions of each interval type, increasing by one every second session. The authors found this combination of SIT training brought about large increases in energy substrates as well as changes in aerobic and anaerobic metabolic enzymes. Resting phosphocreatine (PCr) and glycogen were increased by 31 and 32% accompanied by lower increases in lactate concentration, pyruvate and pH levels post-intervention. Furthermore, after the 30s all-out test activity of creatine kinase (CK), lactate dehydrogenase (LDH) and PFK anaerobic enzymes were increased by 44, 45 and 100% in addition to aerobic enzyme citrate synthase (CS) activity 38%. The intensity of these protocols may therefore have stressed both aerobic and anaerobic pathways to a large extent and in a time efficient manner that improved substrate provision and enzyme activity for energy yield. This also accompanied increases in $\dot{V}O_{2max}$ and power output of 11 and 10% each, improving cycling performance and recovery, delaying onset of fatigue. This type of short interval training could therefore be applicable in soccer scenarios of rehabilitation and inactivity to improve conditioning in a short time.

Although using cycling as the mode of exercise, Tabata (1997) also so employed SIT. Different work-to-rest periods were used for supramaximal cycling intervals in nine university students to examine aerobic and anaerobic stress. The first protocol (IE1) involved 6-7 repetitions on 20 seconds at 170% $\dot{V}O_{2max}$ with 10 seconds passive recovery, with the second (IE2) consisting of 4-5 repetitions of 30 seconds at 200% $\dot{V}O_{2max}$ with 2 minutes passive recovery, both to exhaustion. Work output increased after the second protocol, with accumulated oxygen deficit greater in the first. Peak oxygen consumption in the last stages of IE1 was close to $\dot{V}O_{2max}$ with IE2 considerably lower. IE1 may therefore have been better for aerobic energy release as well as improving anaerobic capacity given the short recovery duration that may benefit performance as lactate levels rise and there is not enough time for PCr resynthesis that may take 1-2 minutes (Mendez-Villanueva et al., 2012). Longer recovery allowed in IE2 may therefore have enabled greater recovery of PCr stores, lower lactate levels and greater myoglobin reloading during this time.

Table 2.2: Physiological and performance outcomes of different HIIT protocols (modified from Iaia, Rampinini and Bangsbo, 2009).

	Population	**Subjects**	**Protocol**	**Stage of Season**	**Physiological responses**	**Performance Improvements**
Helgerud et al., (2001)	Norwegian elite junior	19	4 x 4mins @ 90-95%HR_{max} (3 mins @ 50-60%HR_{max})	Pre-Season (8 weeks)	↑11% VO_{2max} ↑6.7% C_R ↑Lactate Threshold	20% ↑ total distance 100% ↑sprint efforts 24%↑ ball involvements
McMillan et al., (2005)	Scottish elite junior	11	Dribbling track 4 x 4mins @90-95%HR_{max} (3 mins @ 70%HR_{max})	Pre-Season (10 weeks)	↑9% VO_{2max} No change C_R	↑CMJ 2.7% ↑SJ 6.9%
Dupont et al., (2004)	Elite adult	22	12-15 15:15s @120%MAS and 12-15 maximal 40m with 30s rest	Mid-Season (10 weeks)		↑8.1%MAS ↑3.5% 40m sprint
Ferrari-Bravo et al., (2008)	Junior elite and adult amateur	13	6x40m maximal 180° shuttle sprints (20s rest, 3sets)	In-Season (8 weeks)	↑5% VO_{2max}	↑2.1% RSA

MAS - Maximal aerobic speed, CMJ - Countermovement jump, RSA – Repeated-sprint ability, C_R – Running economy, VO_{2max} – Maximal oxygen consumption

In light of the repeated-effort demands in soccer, Ferrari-Bravo et al., (2008) compared the effects of HIIT or repeated sprint training on indices of soccer performance in junior soccer players. Players took part in 12 weeks testing and training completing two sessions per week of either 4x4 minutes running at 90-95%HR_{max} with 3 minutes active recovery at 60-70%HR_{max} (ITG) or 3x6 maximal shuttle sprints with 180° turns every 20 or 40m with 20 seconds recovery (STG). Both groups saw small increases in $\dot{V}O_{2max}$, although STG had a further 15% increase in YoYoIR1 performance compared to ITG. Repeated-sprint test performance was increased by 2.1% in STG but no change was seen in ITG.

No changes were evident in linear sprint and jump performance for either group. The improved performance in soccer-specific tests (YoYo test and repeated-sprint) by STG may be due to concurrent taxing of both aerobic and anaerobic energy pathways in these tests that are used heavily in soccer match-play. Also, the neuromuscular training with turns of ST may have had a bearing on YoYo test performance. However, it was stated that further evidence is required as to whether either form of training is more beneficial to match performance and the effect of varied change-of-direction training protocols.

In the first of a series of studies evaluating time spent at $\dot{V}O_{2max}$ at different supramaximal velocities (15 seconds exercise with 15 seconds passive recovery to exhaustion), Dupont et al., (2002) used intensities of 100, 110, 120, 130 and 140% maximal aerobic speed (MAS) in 9 male students. Significantly more time (58%) was spent at $\dot{V}O_{2max}$ in exercise at 120%MAS, with time at 90-100% $\dot{V}O_{2max}$ (93%) greatest at 110 and 120%MAS compared to continuous running at 100%MAS. It has been suggested that most of the increases in cardio respiratory fitness may result from the attainment of high levels of oxygen consumption (VO_2) and the subsequent time spent at that level by running above critical velocity, 104%MAS in this case (Billat, 1999; Billat, 2000a: 2000b). However, attaining $\dot{V}O_{2max}$ using repeated intermittent bouts at different supramaximal intensities with short recovery may be effectively achieved with high VO_2 kinetics to increase aerobic power. In light of this, an intensity of 120%MAS appeared appropriate to maximise time at $\dot{V}O_{2max}$ for adaptation, where oxygen, myoglobin and PCr stores are reloaded in the short recovery period. This was further elucidated by Dupont, Akakpo and Bethoin (2004) who implemented 12-15 repetitions of 15:15s running at 120%MAS in combination with 12-15 repetitions of all out 40m sprints in soccer players. An 8% increase in MAS and 4% reduction in sprint times were found in these elite senior players, concluding that HIIT can induce physical performance increases during a 10-week intervention during the competitive season. With reference to recovery mode, Dupont and Berthoin (2004) compared time spent at $\dot{V}O_{2max}$ and above 90% $\dot{V}O_{2max}$ in 15:15s at 120%MAS running with either active (AR, 50%MAS) or passive (PR) recovery in twelve male students. The time to exhaustion was found to be lower in AR ($p<0.001$), suggested to be due to better myoglobin and PCr resynthesis to maintain exercise. There were no differences between AR and PR for absolute time at $\dot{V}O_{2max}$ and above 90% $\dot{V}O_{2max}$, although when expressed as a percentage of time to exhaustion, the time of both was longer with AR ($p<0.05$ and $p<0.001$). Given that exhaustion was brought about quicker with AR, it was advocated that more repetitions should be performed in PR to attain a similar proportion of time at high levels of $\dot{V}O_{2max}$ as AR.

Summary

The use of different forms of HIIT may provide significant physiological and performance improvements. Appropriate IT in a controlled environment has been shown to be a potent, time-efficient stimulus for adaptation. The design of intensity, duration, repetitions and recovery mode may all contribute to the magnitude of the training responses. Longer IT at critical velocity may induce higher VO_2, closer to $\dot{V}O_{2max}$ where central elements such as stroke volume and cardiac output dictate greater oxygen delivery to the muscles (Helgerud et al., 2007; Laursen and Jenkins, 2002). Furthermore, shorter IT, SIT and RST may also improve fitness predominantly through peripheral adaptations. Both aerobic and anaerobic energy metabolic pathways may be enhanced through upregulation of oxidative and glycolytic enzyme activity, benefiting muscle energy state and preserving glycogen and phosphate stores. Improved muscle cell diffusion capabilities through an enhanced capillary density with the metabolic changes noted will also contribute to an improved muscle buffer capacity and muscle environment preserving cell integrity for force production and resistance to fatigue (Tomlin and Wenger, 2001). Finally, this may also be supplemented by morphological adaptations that see a conversion of type IIx to type IIa muscle fibers, with an increase in cross-sectional area of both type I and type II fibres, depending on the nature of exercise (steady-state or intense-intermittent) shown by the protocols employed in Table 2.1. Also, with sarcoplasmic reticulum development giving increased calcium uptake for cross-bridge formation between contractions (Ross and Leveritt, 2001).

Comparison of Small-Sided Games versus Traditional Interval Training in Soccer

As alluded to earlier, SSG are often implemented as sport-specific forms of traditional interval training (IT), where the intensity may be mediated and there is a positive skill transfer to the competitive environment. In addition to these benefits, there have been several training studies that have compared the physiological responses of 'generic' and 'specific' interval training in soccer players, most notably in 4x4 minutes exercise >90%HR_{max} by Helgerud et al., (2001) and Hoff et al., (2002) with further studies more recently (Impellizzeri et al., 2006, Reilly and white, 2003, Hill-Haas et al., 2009).

The first study to compare the benefit of SSG to generic interval training was that of Reilly and White (2003). Eighteen elite English youth players were randomly assigned to either 5v5 SSG or Aerobic Interval Training Group at 85-90%HR_{max} (both 6x4 minutes) twice per week for 6 weeks. Both groups were found to have small improvements in $\dot{V}O_{2max}$, though there were no changes in lactate peak. When related to physical performance tests, no differences between groups were observed in power, agility, speed and endurance performance. The authors therefore concluded SSG training to be an acceptable substitute for traditional interval training in soccer players conditioning despite the argument that there was little benefit to physical conditioning in either in this study.

Allocating players to either a soccer training group (STG) or generic training group (GTG), Impellizzeri et al., (2006) used a twelve-week study on young Italian soccer players to evaluate effects on aerobic fitness parameters and match performance. STG performed SSG of 3v3 to 5v5 for 4x4 minutes, with

GTG 4x4 minutes continuous running around a pitch at an exercise intensity of 90-95%HR_{max}. No differences in heart rate response were found (91.3% and 90.7%HR_{max}), although STG spent 29s more exercise above 90%HR_{max}. At the end of the study period, there were no between group differences for $\dot{V}O_{2max}$ (7 and 8%), lactate threshold (11 and 13%), running economy (3 and 3%) or soccer-specific endurance (13%). Match performance saw small improvements in both groups for total distance, high-intensity running and a declining in walking distance. Therefore, both regimes are equally effective in conditioning soccer players and improving match performance. The authors suggested priority should be based on practicality of each training mode.

Hill-Haas et al., (2009) detailed seven weeks of SSG training (STG) of games from 2v2 to 7v7 with bout durations of 1-13 minutes or generic training (GTG) that involved a mix of 'aerobic power', repeated-sprint training, high-intensity intervals, change of direction and speed drills. The authors found similar results for $\dot{V}O_{2max}$ in both groups of elite Australian youth players when scaled appropriately and also for the Multistage Fitness Test. Instead, increases were found in YoYoIR1 performance for both groups, although no change in repeated-sprint or straight-line speed were found in either group. GTG reported a higher perceptual load (RPE) which may have been due to the unaccustomed nature of this type of training. STG showed greater time spent at 80-89 and >90%HR_{max}. However, smaller increases in $\dot{V}O_{2max}$ compared to previous studies may be a result of the lower average exercise intensity of each group that did not elicit enough time at high-intensities needed for cardiovascular adaptations. Some of the activities in GTG may have contributed to this given their short nature that may not have been long enough to obtain sufficient heart rate kinetics to contribute to $\dot{V}O_{2max}$ development (Buchheit and Laursen, 2013). Moreover, this study was carried out later in pre-season compared to Impellizerri et al., (2006) and so the training status of the players may have been higher at the start of this study producing smaller increases. Despite this, the study showed that SSG training may be evaluated by YoYoIR1 that is sensitive enough to show changes in soccer-specific fitness in trained youth players.

In contrast to the previous interventions, Dellal et al., (2008) compared physiological responses of generic high-intensity interval training (GTG) and SSG in the same group of elite male French soccer players. Interval training consisted of durations from 5-30s with 10-30s either active or passive recovery at intensities of 100-120% $\dot{V}O_{2max}$. Depending on the duration and intensity of each repetition, 1-2 sets of 7-10 minutes were carried out in a single session. SSG consisted of 1v1 to 10v10 games (some including goalkeepers) with duration lasting 4x1 minute to 3x20 minutes. The highest heart rate was found in 30-30 seconds at 100% $\dot{V}O_{2max}$ with active recovery compared to 1, 4, 8 and 10v10 SSG formats. 10-10 seconds at 110% $\dot{V}O_{2max}$ with passive recovery saw a greater heart rate response than 1, 8 and 10v10 SSG, although 2v2 and 8v8 with goalkeepers were not different to the intermittent running drills. It had been said by Balsom (1999) that continuous exercise with a ball in 3v3 and 10-10s at 110% $\dot{V}O_{2max}$ provides sufficient stimulus to stress the cardiovascular system to improve fitness in soccer players. The inclusion of ball work may increase energy cost (Reilly and Ball, 1984) but Dellal et al., (2008) observed greater coefficient of variation in SSG versus intermittent running (CV= 12 and 8%). This may be due to the unpredictable, spontaneous environment of SSG where the presence of goals and opponents may increase heart rate due to a motivation to score or prevent opponents from opportunities. Intermittent running may instead be a more controlled, environment where there is a lower risk of contact injury. Additionally, the reproducibility may be better with GTG where there is less variation in responses compared to SSG (CV 4-8% versus 8-16%, Dellal et al., 2008). Combined with findings from Dupont and Berthoin (2003), this study highlights the necessity of exercise intensities above 100% $\dot{V}O_{2max}$ in GTG in order to elicit heart rate responses required to improve $\dot{V}O_{2max}$. Varying exercise duration may also benefit fitness improvements with development of aerobic or anaerobic energy pathways. The time spent at $\dot{V}O_{2max}$ will also be aided by recovery interval intensity with Dupont and Berthoin (2003) advocating passive recovery to be beneficial for improving $\dot{V}O_{2max}$ by allowing muscle reoxygenation of haemoglobin and myoglobin.

Some of the limitations of SSG have already been presented, though there are additional benefits of employing more generic HIIT. One of the primary reasons one might use this type of conditioning is for safety and reduced risk of contact injury. Furthermore, staff will have greater control over the exercise stimulus through the appropriate prescription of work-rest intervals, speeds and distances and can therefore be confident it is within capabilities. Indeed, pre-planning volume and intensities makes generic conditioning more reproducible with the absence of opposing players removing the element of unpredictability. As a result, there are times in elite soccer that these types of conditioning may be preferred to more functional SSG. A final important point to consider is the efficacy of training all players in the same way when positional requirements in match-play may differ greatly. For example, the total distance, sprint frequency and peak velocities typically associated with a wide midfielder contrast to those of a central defender. As a result, programming the training prescription (whether generic or specific), should account for this to ensure the appropriate stimulus is given to a player of a certain position to prepare for competition, implementing specific conditions and rules if necessary, or employ more controlled, generic interval training methods.

The previous sections have detailed the most common forms of training format applied within elite soccer to provide physical and often technical conditioning. Although these may bring the desired adaptations over time to ensure optimal preparation for competition, it is now well recognized that the load players are exposed to in training and matches must be monitored in order to control the volume and intensity across days and weeks to prevent injuries and maintain freshness. The next section is focused on the rationale and different methods of monitoring physical load in soccer.

Application of Monitoring Training Load in Soccer

The high physical demands of soccer are often accompanied by the implementation of a high training load (TL) by coaching staff who require a fit and injury-free squad to select from. Accumulating over 1750AU in week (Rogalski et al., 2013), unique training demands are joined by other stressors such as economic and media pressures that are inherent in contemporary soccer (Bengtsson, Ekstrand and Hagglund, 2013; Carling, Le Gall and Dupont, 2012; Morgans et al., 2014). Similarly, an increasing competitive schedule in soccer of over sixty matches in a season, often in congested periods, increases residual fatigue as a result of frequent travel, climactic changes and disruption of sleep patterns (Fullagar et al., 2015). Periods of intense training schedules and high match exposure (Meister et al., 2011) can therefore have implications for susceptibility to illness or injury depending on tolerances for training and competition. This warrants monitoring tools to indicate periods of stress and reduced performance capabilities to pro-actively identify those potentially at risk.

Training load consists of the relationship between volume and intensity, which, when manipulated correctly can improve physical performance. As such, the training-performance relationship is said to be 'dose-related' (Gabbett and Domrow, 2007) and entails the optimum amount (and intensity) of training to produce successful performance. This performance response is then the difference between positive and negative functions (illness and injury). The training provided should then maximise performance with minimal negative effects, and has been advised as the minimum TL with which to improve fitness and the maximum load tolerable before illness or injury. This may differ between individuals depending on their level of fitness with players of higher $\dot{V}O_{2max}$ perhaps experiencing a ceiling effect in training responses, requiring additional stimuli to challenge their physiological systems (Hoff et al., 2002). A superior $\dot{V}O_{2max}$ may then enable the duration of a largely aerobic sport, sustaining high-intensity efforts with efficient recovery between (Helgerud et al., 2001).

In the ergonomics model, competition has been said to be the main affecting variable (Reilly, 2005) with TL prescribed around match-play. Training may vary day to day in volume and intensity depending on the fixture schedule or even previous results, with poor performance causing reactive increases in TL by coaching staff that may place players at risk of injury (Kentta and Hassmen, 1998). TL in a team sport such as soccer, however, is difficult to plan due to its many physical requirements. Depending on the weekly training period (micro-cycle) or coaches aims, training must provide a suitable stimulus to be physically and technically provoking (within capabilities) whilst also providing adequate recovery to minimise monotony, fatigue and injury prior to competition (Foster, 1998). High volume training has been shown before to reduce performance levels compared to more intense training prescription that entails greater variation in stimuli (Lehmann et al., 1992). Therefore, the alternate approach of hard and easy or recovery training days with progressive changes in intensity may also help to control any negative training outcomes (Bruin et al., 1994). In this regard, and given its multi-peak nature with frequent matches to prepare for, soccer does not lend itself to conventional periodization models across the season, however. Periodization of training will be discussed later in this thesis.

As a result, the monitoring of TL is of paramount importance to be able to confidently quantify training periodization and its ultimate effect on performance. Successfully mastering the art of providing optimal TL has been said by Coutts (2001) to achieve maximum performance gains by "prescribing the optimum amount of physical training with appropriate recovery periods to allow for greatest adaptation", or supercompensation (Halson and Jeukendrup, 2004).

The challenge in soccer is to promote requested adaptations effectively through the appropriate dose for each player that acts as a stimulus for internal training load and physiological stress (Viru and Viru, 2000). Measured TL then serves to evaluate the extent of compliance between the desired and actual responses to training (Casamichana et al., 2013). However, due to individual variation in training-status, the TL on a given day may not be sufficient to challenge an individual's physical capabilities, thus not inducing the desired responses (Barreson and Lambert, 2009). This has been suggested by Shepherd (2003) to be apparent in some forms of SSG in soccer (Gomez-Piriz, Jiminez-Reyes and Ruiz-Ruiz, 2011) where positional variations in players of higher aerobic fitness reported lower scores of RPE and body load. As stated by Shepherd (2003), the response of an individual is related to their level of fitness and magnitude of the training load prescribed. Furthermore, the demand of training may also vary with other factors such as bodyweight, injury history, age and playing experience. Demands on younger players for example have also been reflected in higher RPE scores which may be due to a lower training-status and musculo-skeletal maturity that should be considered in youth player's transitions to higher level training. In such cases, the principles of training must be adhered to with Rogalski et al., (2013) proposing a modification strategy of TL for young players to aid coping with a gradual increase in TL, controlling their exposure in order to minimise the risk of overuse and injury. This may also be the case for players undergoing rehabilitation from injury who are subject to return-to-play protocols (Rogalski et al., (2013).

Influence of Phase of Training on Load in Soccer

Measures of TL are advocated over training cycles to gauge daily and weekly tolerance (Coutts, 2001) culminating in performance testing that can help evaluate the extent of necessary adaptations to the TL provided in that period. Studies have been carried out over specific training phases with regards to TL patterns. Several have reported increased TL in pre-season compared to the competitive in-season (Gabbett, 2004) where pre-season entails higher volume and intensity training and less recovery with the aim of improving physical conditioning, while the in-season TL may be tapered with greater emphasis on recovery and technical-tactical development due to the inclusion of competitive matches that now produce a large proportion of an individual's weekly TL. The subcomponents of training have therefore been described to differ between pre- and in-season phases, with physical and technical training bringing about more time above 90%HR_{max} and higher RPE. Such responses have been suggested to be a direct function of subtle changes in subcomponents (Jeong et al., 2011). TL distribution differs as a result across phases of soccer training where the inclusion of competitions dictate micro- and meso-cycles of varied TL.

Using subjective measures of in-season field and gym TL (session rating of perceived exertion, sRPE), Wrigley et al., (2012) found more time spent on physical and technical-tactical combination training (30%) compared to technical-tactical and strength training sessions in academy soccer players of different age groups. Higher load and duration of training in older U18 players were identified (2464AU versus 1892AU and 1643AU), although lower than that of Impelizzeri et al., (2004). The greater number of training sessions and training principles in relation to maximising performance with regards to more advanced maturity status may account for this difference. In this instance, older age groups experience high TL earlier in the week before tapering in the days before competitions, as previously described by Bosquet et al., (2007). On the other hand, younger age groups maintained relatively high loads throughout the week which may have been to maximise limited contact time with coaches as well as the philosophy of prioritising development over match-play (Wrigley et al., 2013).

In a similar way, Jeong et al., (2011) described how subtle changes in sub-components can directly affect training responses. In professional Korean players, 34 sub-components were noted in pre-season (including double sessions) compared to 18 in-season. A larger proportion of time spent above 90%HR_{max} was found to be due to heart rate responses of technical-tactical drills performed in pre-season, subsequently giving higher ratings of perceived exertion. The importance of monitoring to aid prescription and understand the contribution of technical or physical-based activities is reinforced where different exposures are not subject to any misconceptions.

Elucidating the TL in soccer helps gauge training-status and conditioning in preparation for match-play, as well as gauging limits to load tolerability and when loading can become excessive beyond that which an individual can withstand. The increased TL (in pre-season for example) has been associated with a 2.6 times more injuries compared to in-season in a study by Gabbett (2001). In another study, Gabbett (2004) employed gradual changes in TL of ~15% by reducing pre-season volume and intensity of rugby training over three seasons. A significant decrease was found in overuse and severe injuries, whilst still increasing fitness levels by 15%. A progressive decrease in load (duration and intensity) during three successive pre-seasons was therefore seen to protect against injury occurrence as well as maintain fitness levels before tapering in the competitive period by the third season. The lack of insufficient recovery in pre-season periods, coupled with a high training intensity ensures a greater propensity for injury occurrence. However, this can also occur more transiently as a result of accumulated fatigue over previous weeks, with a delayed effect on injury (Orchard et al., 2009). A coach-increased TL can therefore cause alterations in muscle activity with fatigue that causes injuries when recovery is insufficient between exposure, with a correlation of injuries and TL per week (r=0.675) found in a study in female basketball players (Anderson et al., 2003). Furthermore, large increase in TL, perhaps as a result of poor performance in a previous match may also have an effect on injury rates, with Anderson et al., (2003) suggesting muscle fatigue leads to alterations in muscle activity, such as decreased integrity of muscle membrane and inhibition of cross-bridge function (Green, 1998) that is conducive to injury. The author found a significant relationship between TL and injury (r=0.675) with a gradual increase in TL suggested to be one way to avoid injuries. Roglaski et al., (2013) made similar reference to the importance of monitoring week-to-week increases in TL. sRPE TL over a whole season greater than 1750AU and 4000AU accumulated over one and two weeks, or a weekly increase of 1250AU was found to be associated with a 2.58 higher risk of sustaining injury. Furthermore, the possibility of a delay effect from the previous two weeks training load has also been shown to increase injury risk by 1.77 in international cricketers (Orchard et al., 2009).

Other markers such as the number of physically-demanding accelerations of all intensities may be factors for no-time loss injuries as well as very high-intensity activity measured by GPS, with risk of soft-tissue injury said to be reduced with more low-intensity activity and greater acceleration distance at different intensities offering a protective effect (Gabbett and Ullah, 2012). Also, intensive periods of training may also have immunosuppressive effects by increasing susceptibility for illness and infection. Measuring immune markers such as immunoglobulin sIgA over time has shown sustained high TL's to produce a preceding spike in sIgA in 84% of subjects prior to becoming ill (Foster, 1998). Prolonged intense training periods promote monotony, staleness, and muscle damage which may also indicate symptoms of overreaching or overtraining. It is these and the 'pathophysiologic' abnormalities common in soccer player’s professional commitments that can lead to fatigue, poor performance and potentially a state of over-training (OT).

The management of daily TL is therefore important to examine the effect of subtle changes to training prescription and its subcomponents which may affect different types of loading (Jeong et al., 2011; Wrigley et al., 2012). The content of technical-tactical and physical training may induce varied stimuli training responses depending on the aims of the session with regards to intensity. Undulating TL with the use of 'hard' and 'easy' training days during the week has been suggested by Foster (1998) to help sustain performance, limiting monotony by varying training stimuli that may then minimise negative consequences that could hinder participation or performance (Bruin et al., 1994). Specific methods and markers of training load that are used in practice and their applications to overtraining will be discussed in the following section.

Methods of Monitoring Training Load in Soccer

In order to achieve the correct TL, methods of monitoring utilised must evaluate holistic TL as well as accounting for individual differences. The demands of team sports comprise of a 'complex interaction of physiological capacities' that make quantification of TL difficult (Coutts, 2001). Internal and external loading should be quantified to elucidate both metabolic and mechanical loading experienced that will differ between sessions and drills of different goals in seasonal training phases and thus the adaptive responses gained. As alluded to previously, TL in soccer varies greatly and its complexity makes it difficult to quantify with great precision. Several training studies have described soccer training through various methods of physiological, mechanical and subjective loads (Scott et al., 2012; Casamichana et al., 2013; Wrigley et al., 2012; Rogalski et al., 2013).

Other methods of monitoring previously employed in soccer such as blood lactate (Coutts et al., 2009) and the validity of sRPE (Impellizzeri et al., 2004) which has been linked to injury incidence with successive high scores of perceptual TL (Cormack, 2001). Furthermore, other measures of mechanical (such as creatine kinase, Ascencao et al., 2008) and metabolic (testosterone, cortisol, uric acid, Meister et al., 2011) stress have also been assessed to measure different types of loading resulting from soccer performance. By tracking such markers over short and long-term periods, it may then be possible to build individual profiles of responses to certain training and match exposure. This could then aid injury prevention strategies as the link between effective training load and injury may be better understood.

Training Load and Injury Relationship

One of the greatest rationale for the monitoring of training and load in soccer players is to reduce fatigue and injury incidence and promote freshness. Tracking individual outputs and responses to training and competition stimuli can help illustrate how they are coping with the physical demands and schedule over short periods from a day to a week (acute, indicating fatigue) or even long a month to a year's cycle (chronic, indicating fitness). Monitoring over these different time periods is epitomised when using the acute-chronic workload ratio, an index of 'athlete preparedness' (Gabbett, 2016). The individual ratio of how an athlete is responding to a given stimulus, over time, can build a specific profile that can illustrate when a player is above or below their 'normal' range. This may occur when an athlete is carrying an injury or due to the inclusion of unaccustomed loading. There are two example scenarios that Gabbett (2016) has suggested to be responsible for increasing odds of injury and changes in the acute-chronic workload ratio. Firstly, large week-to-week increases in training load may influence injury incidence with changes of greater than 10% were found to increase probability of injury by 15% in rugby league players (Gabbett, 2004) with Piggott et al., (2009) and Rogalski et al., (2013) finding similar results in AFL. Secondly, the chronic training load completed by a player (over 3-6 weeks) can influence propensity for injury. For example, a low chronic load may produce low levels of fitness and thereby resilience when exposed to sudden 'spike' in higher load (such as match-play). The athlete preparedness is therefore not optimal for competition. Conversely, higher chronic workloads have been show to improve protection from injury to a point in elite rugby league players (Hulin et al., 2015). However, excessively high chronic loads may actually produce higher risk of injury. As a result, a 'sweet spot' for the acute-chronic workload ratio of 0.8-1.3 has been suggested to provide sufficient training stimulus and protection from injury, with a ratio >1.5 representing greater risk of sustaining injury.

As a result, both low and excessively high workloads can heighten odds of injury and the use of daily monitoring and over longer training cycles can help to identify individual profiles to identify those at risk and modify their activity accordingly (Gabbett, 2016).

Heart Rate

There are numerous methods employed to describe exercise intensity in different sports, with heart rate (HR) often the preferred indicator of physiological stress. Heart rate monitors were first used in the 1960's with the development of electrocardiogram (ECG) measuring electrical activity of the heart in sport with the help of radio telemetry (Dellal et al., 2012). By the 1980's, wireless technology enabled cardiac monitoring through belts worn around the chest that were able to store heart rate data, later analysed through dedicated software (Dellal et al., 2012). Monitors today also enable instantaneous feedback, tracking exercise intensity in real-time with watches, tablets and laptop computers ensuring the correct or intended load and intensity is adhered to.

The validity and reliability of HR measures have been addressed by comparing seven heart rate monitors with ECG measures (Polar Sport Tester). MacFarlane et al., (1989) found variation of <1 beats per minute (bpm^{-1}) in HR monitors using chest electrodes compared to longer ranges of variability in other monitors. Furthermore, Seaward et al., (1990) demonstrated HR monitor accuracy during activities of low-moderate intensities as well as intense, maximal work (walking, running, dancing and cross-country skiing). It was reported that there were no differences between portable HR telemetry and direct ECG measurement values ($p>0.05$) with correlation coefficients of $r=0.998$-0.999.

HR is seen as the traditional measure of work intensity. Furthermore, it has been used in predicting energy expenditure in sport and physical activity. This derives from the linear HR-VO_2 relationship that exists at sub-maximal aerobic intensities, where HR values can estimate oxygen consumption (Astrand and Rodahl, 1986). The maximal heart rate and energy expenditure at certain intensities may be determined by incremental treadmill testing in a laboratory, however, which do not account for sport-specific anaerobic actions that may not be reflected in heart rate in a sensitive manner. As a result, the measurement of exercise intensity may subsequently be misrepresented in field settings. The HR-VO_2, as well as speeds at specified blood lactate values (2 and 4mmol.L^{-1}) have also been used to delineate different intensity zones based on the individual physiological profile (Conconi, 1982; Helgerud et al., 2001; Impelizzerri, Rampinini and Marcora, 2005).

It has been speculated that HR values in sport may be affected by numerous factors that should be accounted for when evaluating exercise intensity and monitoring training load of athletes. Training status, for example has been shown by Helgerud et al., (2001) and Helgerud et al., (2007) to influence heart rate responses in soccer players. Performing 4 x 4 minutes at 90-95% maximal heart rate (HR_{max}) was shown to be beneficial in increasing stoke volume and lowering exercise heart rate due to an increased cardiac output (Q), whilst also enhancing $\dot{V}O_{2max}$ and running economy (C_R) compared to long slow distance running (Helgerud et al., 2007). Similar conclusions were made when elite junior soccer players performed the same protocol of four 4-minute bouts at the same equivalent HR intensity, seeing large improvements in match running performance. The TDC number of sprint efforts were seen to increase 20% and 100% respectively which were not observed in the control group. A more efficient cardiovascular system and recovery from intense bouts might also be reflected in the strong relationship found between the extent of parasympathetic activity earlier in recovery periods (Kannankeril et al., 2004). This may then also help in providing feedback on fatigue and signs of overreaching.

Training and matches in soccer may often take place in warmer climates when international camps and tournaments are organised, in the pre-season and winter breaks for example. Gonzalez-Alonso et al., (1997) and Gonzalez-Alonso et al., (1999) reported a reduction in stroke volume when exercising in a hot environment (40°C). Heat stress may result from elevated core, muscle and skin temperatures which can see a reduction in blood volume, cardiac output and stroke volume, affecting oxygen delivery (Gonzalez-Alonso, Crandall and Johnson, 2008). When exercising in environments such as this, heart rate and skin blood flow may be increased in order to dissipate heat from the body (shunting blood flow from central areas to the periphery) which may be exacerbated by dehydration causing an increased demand on the heart potentially leading to fatigue (Gonzalez-Alonso, Crandall and Johnson, 2008).

Moreover, dehydration, particularly in hot environments may affect heart rate responses. Heat stress from a loss of fluid and 1-4% of bodyweight has been said to have implications for cardiovascular, metabolic and thermoregulatory strain (Gonzalez-Alonso, Crandall and Johnson, 2008). It is the reduction in muscle and skin blood flow, compounded by glycogen utilisation that can accelerate hyperthermia and cessation of exercise. Gonzalez-Alonso et al., (1997) saw a 9% increase in heart rate with trained cyclists in a state of dehydration and hyperthermia. Further, stroke volume and cardiac output were reduced 1% and 13% respectively, with a lower mean arterial pressure and increased vascular resistance likely causes. On the other hand, cold environments see reduced blood flow to the skin where blood is restricted to central areas by vasoconstriction and mechanisms of venous return (Achten and Jeukendrup, 2003). Negligible changes in HR have been reported though when VO_2 has increased at low temperature due to higher stroke volume and cardiac output rather than any HR affects to increase central blood volume (McCardle et al., 1976).

Similarly, soccer may occasionally be played at high altitudes, which players can be unaccustomed to. Performing at altitude has also been said to affect heart rate and cardiac output, increasing 15% and 22% at sub-maximal intensities (Vogel, Jansen and Harris, 1967). The reduction in partial pressure of oxygen (PO_2) at high-levels (~4000m) is compensated for by an increase in oxygen delivery (heart rate and therefore cardiac output) by shunting blood to the working muscles (Achten and Jeukendrup, 2003). Heart rate at rest was also shown by Buchheit et al., (2013) to increase initially at the start of a ten-day training camp at altitude, before returning to baseline by day ten. Exercise HR saw a more sustained increased over the camp, which was suggested by the authors to be useful in high-intensity monitoring at altitude, with a large relationship found with YoYoIR1 performance. Maximal exercise may see lower HR responses at altitude however, with coinciding decrease in VO_2 at the same HR_{max} with respect to the linear HR-VO_2 relationship seen at sea-level (Stenberg, Ekblom and Messin, 1966).

Heart rate in soccer training

In soccer, Esposito et al., (2004) carried out a validation study for the use of HR as a measure of exercise intensity in soccer training and match-play. Laboratory incremental treadmill testing and soccer-specific field test (modified Ekblom test) were carried out by seven amateur soccer players, whilst measured for HR and expired respiratory gas composition by portable metabolic cart ($K4b^2$, Cosmed, Italy) to compare values in HR-VO_2 relationship. Results showed the regression slope of HR-VO_2 did not differ between laboratory and field protocols with correlation coefficients of HR-VO_2 of r=0.954 and r=0.991 in each setting respectively. The results showed it may therefore be possible to deduce oxygen consumption deriving from a laboratory test of soccer-specific activity through the use of heart rate monitoring.

Rampinini, Sassi and Impellizzeri (2004) determined the reliability of HR in exercise both with and without the soccer in young soccer players. The same training session was repeated twice consisting of small-sided games (4v4, 4v2, 10v10) and two change-of-direction circuits. HR was recorded at 5Hz samples using Vantage NV, Polar Electro (OY, Kempele, Finland). Exercise intensity ranges from 75-89% of individual maximum heart rate (HR_{max}). Intra-class correlation coefficients in training drills ranged from r= 0.381 (warm-up) to r=0.624 (4v4). Correlations were found to be higher in the soccer-specific movement circuits (r=0.888) when the two trials were compared. It was concluded that although HR monitors may not be necessary in running bouts, they may be necessary to control exercise intensity in soccer-specific training drills that involve the ball adding to energy cost (Reilly and Ball, 1984).

In addition to traditional HR reporting (%HR_{max} and %HR_{res}), aerobic training load may also be represented by the training impulse (TRIMP) of an exercise session. First presented by Banister (1975), TRIMP can take into account average session HR intensity, maximum and resting HR multiplied by the duration (volume) of the session and a scaling factor. This was further developed by Edward's who employed a weighting value of 1-5 for the duration of time spent in each HR zone, then summed to create a TRIMP score in arbitrary units (AU). The efficacy of such models have been used in studies of soccer training and match-play, such as that of Scott et al., (2013). An average HR response of 67.3%HR_{max} was found among elite Australian soccer players over 97 individual sessions. TRIMP models of Banister and Edward's, that use mean exercise and resting HR or weighted HR zones respectively. Each produced average values of 77.5AU and 169AU per session, both of which were subsequently found to correlate well (r=0.40-0.80) with all measures of external training load collected by GPS ($p<0.01$). Similar findings were also found by Casamichana et al., (2013) who monitored training sessions of semi-professional Spanish soccer players. Edwards method was found to produce very-large and large correlations with accelerometer Player Load (r=0.72) and session rating of perceived exertion (sRPE, r=0.57). The method by Lucia also differs slightly to other existing methods. The time spent in three zones (below ventilatory threshold (VT), below VT and above the respiratory compensation point) is multiplied by a coefficient (k) for each zone before summing each score. The primary difference to Edwards' and Banisters' method is that Lucia's TRIMP utilises individual physiological parameters determined by laboratory testing. In a study of sRPE use in soccer training load, Impellizzeri et al., (2004) found Lucia's TRIMP to produce higher correlation coefficients (r=0.61-0.85) compared to that of Banister and Edwards when each TRIMP was related to internal sRPE training load of Foster et al., (2001).

Examining the effect of different training regimens on HR intensity and subsequent changes in fitness parameters, Helgerud et al., (2007) employed four different training regimens of different intensities matched for similar total oxygen consumption over a period of eight weeks. The groups performing higher intensity, shorter exercise bouts (15:15 seconds and 4 x 4 minutes at 90-95%HR_{max}) experienced greater improvements in $\dot{V}O_{2max}$ and stroke volume (~7% and 10%) compared to of groups of long slow distance or lactate threshold running at 70%HR_{max}. The time spent at higher HR intensities was suggested to contribute to greater cardiovascular strain that enabled adaptations in stroke volume and cardiac output to improve physical fitness parameters. Furthermore, Hoff et al., (2002) employed a soccer-specific dribbling track in 6 male Norwegian soccer players. Using the same duration and intensities (4 x 4 minutes at 90-95%HR_{max}, it was found that the dribbling track induced improvements in $\dot{V}O_{2max}$, finding the average oxygen consumption to be superior to that found in the same subjects when playing a 5v5 SSG (91.7% vs. 84.5% $\dot{V}O_{2max}$). It was also found that the HR-VO_2 of both the dribbling track and SSG did not differ from that found in the relationship at different sub-maximal intensities in a laboratory incremental treadmill test in the same group (r=0.844, p<0.01).

Away from the focus on conditioning exercises in soccer training, Eniseler (2005) used HR to inform exercise intensity of various game-specific technical and tactical drills in elite players in Turkey. A ninety-minute friendly match brought about the highest mean HR (157bpm^{-1}), whereas a modified game played on half a pitch saw a response of 135bpm^{-1}. Technical and tactical drills consisting of skill and passing activities then patterns of play build-up ending with crossing and finishing also on half a pitch saw average heart rates of 118bpm^{-1} and 126bpm^{-1}. HR responses were presented as proportion of time spent either below, between or above equivalent individual HR's at 2-4$mmol.L^{-1}$

blood lactate from incremental 20m shuttle field test. All types of training drills were found to be different ($p<0.01$). Match-play entailed the most time spent at heart rates equivalent to that above the 'high intensity' point of 4mmol.L^{-1} (49.6%), compared to that of the technical training drill that did not meet this reference HR. In technical and tactical drills, the majority of time was spent at heart rates below that corresponding to the 2mmol.L^{-1} reference point (63.4% and 77.0%). As a result, the author was able to deduce the contributions of aerobic and anaerobic work for different types of drills typical in soccer training. The ratio of aerobic-to-anaerobic work was suggested to be 50:50% in a pre-season friendly match play, 75:25% in modified game; 100:0% in technical drills and 96:4% for tactical training. The results to this study emphasised the need to evaluate training on an individual level based on physiological profiles. As well as this, the importance of quantifying all forms of training soccer players are exposed to is suggested and how intensity and energy system contribution may vary between sessions.

As alluded to previously, one of the most heavily recorded uses of HR in soccer training has been its application to SSG intensity with regards to moderating desired exercise intensity through drill design.

In an in-depth study on amateur soccer players, Rampinini et al., (2007) investigated the effect of changing both pitch size and player numbers on SSG HR intensity. It was found that lower player numbers would elicit greater HR's (~89.5%HR_{max} in 3v3) as would SSG on larger pitches (90.9%HR_{max}). Similar patterns have been found in other studies in SSG for player numbers (Hill-Haas et al., 2009; Aguiar et al., 2013) and pitch size (Casamichana and Castellano, 2010), although others have found no differences (Kelly and Drust, 2010; Akenhead et al., 2014).

Changing the bout duration in SSG was found by Fanchini et al., (2011) to increase HR exercise intensity in bouts from 2-6 minutes in 3v3. However, when the first minute of the bout was removed from analysis, the 6 minute bout average HR was lower than that of 4 minute ($p<0.01$) and 2 minute bout durations (87.7% vs. 89.5 and 88.5%HR_{max}). Four minute bouts were therefore concluded to be the most appropriate duration to ensure HR necessary for physical conditioning adaptations, as previously stated by Helgerud et al., 2007). Depending on the aims of the session, coaches should be aware of the HR ramp at the start of exercise in which HR kinetics are still accelerating and may take at least the first minute to stabilise according to the nature of the exercise (Hoff et al., 2002). Addressing HR in SSG or possession games either with or without goalkeepers, Castellano, Casamichana and Castagna (2013) found possession games to produce greater HR responses in 7v7 versus 5v5 and 3v3 (94.9 vs. 94.6 and 94.6%HR_{max}) in semi-professional players. On the other hand, SSG's player with goalkeepers saw higher HR's in 3v3 (94.5 vs. 92.1 and 93.2%HR_{max}). Overall pooled data showed that possession formats can give greater physiological strain than traditional SSG with goalkeepers (94.7% and 93.2%HR_{max}, $p<0.05$). This may be because of the greater positional organisation and team structure goalkeepers and goals bring to formats, particularly with larger numbers, where the movement patterns are more constricted.

Dellal et al., (2008) compared modes of interval training, SSG (1v1 to 10v10) and intermittent running (5-30s work duration with active or passive recovery), for magnitude of HR responses. HR was significantly higher in 30:30s with active recovery (85.7%HR_{max}) versus 1v1, 4v4, 8v8 and 10v10 SSG ($p<0.05$), although the same protocol with passive recovery did not differ to SSG. The 10:10s with passive recovery intervals did however give higher HR than 1v1, 8v8 (no goalkeepers) and 10v10 soccer games, though 2v2 and 8v8 with goalkeepers were not different to any intermittent running formats ($p>0.05$). Interestingly, although SSG formats appeared to be as effective as short-duration intermittent running for soccer-specific endurance training, they did demonstrate an increased variability between players compared to interval running (11.8% vs. 5.9% CV). This demonstrated the greater control coaches may have in obtaining the desired exercise intensity for soccer conditioning and time above 90%HR_{max} and close to $\dot{V}O_{2max}$ (Dupont and Berthoin, 2004). Moreover, the soccer-specific movements (cutting accelerations and directional changes) may alter heart rate in a disproportionate manner (Tumilty, 1993) that makes controlling a defined exercise intensity and safe environment more difficult.

Heart rate in soccer match-play

Although HR monitoring is not permitted in competitive matches (Drust, Atkinson and Reilly, 2007), there is data available from friendly matches in different levels of play.

One of the first studies to describe soccer match HR was on twenty-seven semi-professional, university and recreational players of defensive, midfield and attacking positions (Ali and Farrally, 1991). Using a Sport Tester PE 3000 chest strap transmitter (5Hz), average match heart rates were for semi-professional, university and recreational players were 171, 165 and 168bpm^{-1}. Similar decrements in HR were found for each group between halves, with midfielders and defenders producing the highest and lowest HR on average.

Later, Bangsbo (1994) reported HR in elite adult Danish players to average 170bpm^{-1}, equating to 85%HR$_{max}$. Stroyer et al., (2004) used elite and non-elite youth players, including players at the beginning and end of puberty to examine the effect of maturity status. HR was higher in elite players at the end of puberty (173bpm^{1}) compared to elite and non-elite at the beginning of puberty (169 and 159bpm^{-1}), with all three groups seeing second half decrements. Oxygen consumption (relative to body mass) was also found to follow the same pattern, with the more mature elite players having the highest $\dot{V}O_{2max}$. In early maturing players in particular, VO$_2$ was found to be similar to adult players and that youth soccer may carry a significant aerobic load.

In comparison to soccer match-play values, heart rates from matches in other sports have also been reported. In AFL, some of the only data from the 1970's where Pyke and Smith (1975) found average

HR's of 160-178bpm^{-1} and some over 180bpm^{-1} in the most intense periods of play (94%HR_{max}), particularly in midfield players. Waldron et al., (2011) reported heart rates of 81-84%HR_{max} across positions in elite rugby league players, with Coutts, Reaburn and Abt (2003) reporting 44% of time to be spent above 85%HR_{max} in semi-professional players. In rugby union, Cuniffe (2009) reported higher intensities typical of soccer of 172bpm^{-1} (88%HR_{max}) with forwards having more time in the highest heart rate zones which may reflect the type of work required of the two positional groups (15% at 95-100%HR_{max}). Similarly, in junior rugby union players, Deutsche (1998) found no difference between positions on maximal intensity work >95%HR_{max}, although percentage of time at high-intensity between 85-95%HR_{max} was also higher in forward positions than backs (57 vs. 37%).

Despite its widespread use in sport, there are several limitations associated with heart rate monitoring in sports such as soccer.

Firstly, the determination of maximum heart rate through traditional laboratory treadmill tests may be questioned in intermittent field sports. Such sports incorporate multi-directional movement patterns that entail periods of significant anaerobic energy provision that are not accounted for in the laboratory, underestimating energy cost and the applicability of the resultant HR_{max} to soccer sessions (Dellal et al., 2012). It has been suggested by Dellal et al., (2012) that specific intermittent field tests (such as the 30:15 Intermittent Fitness Test, Buchheit, 2008) and YoYoIR1 and 2 (Krustrup, et al., 2003) may be more valid in relation to the nature and energy requirements of the sport. Moreover, the use of heart rate reserve has also been suggested to be more appropriate for illustrating individual differences in physiological capacities by accounting for one's resting, exercise and maximal HR (Dellal et al., 2008; Dellal et al., 2010).

Moreover, the linear nature of the HR-VO_2 relationship may not be appropriate in intermittent sports (Tumilty, 1993) with non-steady state, intermittent activity seeing slower responses of heart rate compared to the changes observed in VO_2 (Achten and Jeukendrup, 2003) leading to misinterpretation of true energy cost. Also, at intensities greater than vVO_{2max} such as those used in high-intensity interval training, (Billal 2001a; Billal, 2001b; Dupont et al., 2002) heart rate may be compromised (>90%HR_{max}) with the shorter duration bouts unable to achieve high-level heart rates, depending on series repetitions. This could be due to a 'lag' in HR response compared to VO_2 at the start of exercise as kinetics are slower to adapt and need time (30s seconds-2 minutes, Achten and Jeukendrup, 2003) to achieve steady-state. This may take up to four minutes to establish the HR-VO_2 relationship (Astrand and Rodahl, 1976) as adjustments in the cardio-respiratory system occur, increasing stroke volume and cardiac output. High-intensity efforts and sprints of short duration but considerable effort also underestimate energy cost in soccer, increasing HR in a disproportionate manner (Dellal et al., 2008), with Buchheit and Laursen (2013) suggesting the temporal dissociation of HR, VO_2, and blood lactate at high-intensity means that HR may not be entirely reliable in these instances.

Rating of Perceived Exertion (RPE)

Despite, the existence of methods and technology to measure both internal and external training load (heart rate and GPS), these may not always be possible in some settings. Coaching staff have a need to prescribe and evaluate both the volume and intensity of training and match-play in order to ensure appropriate training loads are adhered to across the training year. Over recent year’s subjective measures of training load, such as rate of perceived exertion (RPE) have become more popular in tracking changes in training load in different cycles. RPE is a psycho-physical measure of effort and is traditionally collected by 6-20 or CR-10 scales (Borg, Hassmen and Langerstrom, 1985) where the athlete is asked 'How was your workout?' within thirty minutes of the end of the session (Foster et al., 2001). The CR-10 scale has since been modified (CR-100 scale) in order to prevent limitations of sensitivity with its predecessor. However, whether this scale is effective in this purpose has been questioned in a study in AFL players, where similar correlations to internal and external load and degrees of variability (32 and 39%) were found for CR-10 and CR-100 scales (Scott et al., (2013).

The session rating of perceived exertion (sRPE, Foster, 1998) validated by Foster et al., (2001) is a simple and inexpensive tool that may be implemented as a measure of training load that accounts for both volume (duration) and intensity of the exercise session. Session RPE is thought to incorporate the athlete's perception of difficulty regardless of the exercise mode and varying types of stimuli and exercises they are exposed to that may target different physical conditioning capacities. RPE may represent both internal (oxygen consumption, respiratory rate, blood lactate, heart rate) and external loads (total distance and Player Load) that support the use of sRPE as a global measure of exercise intensity (Coutts et al., 2009; Impellizzeri et al., 2004, Scott et al., 2012; Casamichana, et al., 2013). The score derived by multiplying session duration and the athlete's subjective RPE value produces a training load figure in arbitrary units (Coutts, 2001).

Foster (1998) also demonstrated the efficacy of sRPE in moderating training load through 'hard' and 'easy' training days here intensity is varied to prevent overtraining and training monotony.

The sRPE method of evaluating training load has several advantages including its easy administration and understanding required by athletes as well as being non-invasive as other methods such as blood and muscle samples are (Coutts, 2001). The magnitude of training monotony and training strain may also be calculated with the use of sRPE values. Thus, not only training intensity but variation and risk of overtraining are also accounted for (Coutts, 2001). As well as its use in soccer, sRPE has been compared to heart rate and blood lactate in a variety of settings to quantify training load, including; swimming (Wallace, Slattery and Coutts 2008), cycling (Green et al., 2006) and resistance training (Day et al., 2004). Conclusions drawn from these works include the sensitivity of RPE measurement to training induced changes and its use in tracking planned loads as part of a periodised plan, where 'standard' training drills reveal variation in reporting that may indicate acute fatigue (Wallace, Slattery and Coutts 2008; Green et al., 2006). Impellizzeri et al., (2004) examined the use of RPE measures to detail internal training load compared to HR-based methods over seven weeks in young soccer players. The internal training load has said to be indicative of stimuli for physiological adaptations that may result from prescribed external training load (Viru and Viru, 2000) with individuals will giving different responses. Furthermore, the restriction of HR belts to be worn in match-play warrants another means of obtaining match load data as it forms a large component of the weekly training load (Impellizzeri et al., 2004). Over the study period the average weekly training load was 2000AU, 625AU for match-play. When compared to three well-known TRIMP methods (Banister, Lucia and Edwards), RPE was found to significantly correlate with each method ($r=0.77$, $r=0.85$, $r=0.78$, $p<0.01$). The authors suggested the correlations to be lower than that of previous research due to the presence of anaerobic energy provision as part of the intermittent nature of soccer, causing increased RPE and internal training load. This has been elucidated in other studies showing that subjective loading scores may be higher in intermittent versus continuous exercise protocols, despite a similar VO_2 (Drust, Reilly and Cable, 2000).

Interestingly, the efficacy of sRPE TL monitoring has also been demonstrated by Casamichana, Castellano and Castagna (2013) to hold large to very-large correlations with external load markers of total distance and player load ($r=0.74$ and 0.76) and Edwards HR method ($r=0.57$). Similar findings were found in Australian soccer players by Scott et al., (2012), with Rogalski et al., (2013) reporting two and three-week sRPE training load and a log increase of 150AU per week may be related to odds of injury risk.

Despite the existing evidence on validity, reliability and relationships with TL markers, some important considerations when using RPE have been stated by several authors. Barroso et al., (2014) that there is a risk of under reporting with younger athletes, leading to coaches prescribing moderate training loads that may induce monotony and possible overreaching. Furthermore, the incompatibility of RPE between coach and youth athlete may be exacerbated with lower ages, also leading to maladaptations placing athletes at risk of injury. It is therefore important to consider age and training history when using perceptual measures of exercise intensity. Training experiences and individual cognitive development has been said to greatly impact on one's ability to differentiate between intensities and grade the level of difficulty. Therefore, Eston (2009) suggested that the more training athletes are exposed to consisting of varied stimuli (cardio-respiratory, metabolic, thermal and situational), a better appreciated of intensity ranges (including 'maximal' exercise) are obtained which may aid reliability of results (Eston et al., 2000; Parfitt, Shepherd and Eston, 2007).

Creatine Kinase

The intensity and variation in specific movements inherent in numerous team sports have been well documented, and are relevant to the physical demands of training and match play, periodized training and recovery strategies. (Gregson et al., 2010; Varley and Aughey, 2013). The mechanical effect of these movements on the body and subsequent physiological effects has led researchers and practitioners to investigate blood markers of muscle damage in the hope of understanding training load and recovery patterns. Perhaps the most prominent of these markers is the protein Creatine Kinase (CK). CK is a globular protein (40-45kDa molecular weight) that buffers cellular ATP and ADP by catalysing the reversible exchange of high-energy phosphates (phosphocreatine and Adenosine Diphosphate, ADP) produced during contraction (Brancaccio, Lippi and Maffulli, 2010). It therefore has a role in controlling the energy status within muscle cells and managing immediate substrate for intense exercise. Typical athlete values of 82-1083U/L^{-1} in males and 47-513U/L^{-1} in females have been reported by Mougious (2007). Levels of blood CK may rise particularly after high-intensity, weight-bearing exercises involving large eccentric contractions. The increase in CK mirroring preceding activity results from damage to the sarcomere and contractile myofibrils and disruption to calcium homeostasis in the sarcoplasmic reticulum after eccentric contraction (Urhausen and Kindermann, 2009). The extent of CK levels in the blood may depend on both exercise and individual characteristics. For example, changes in CK will differ between exercise of differing intensities, durations and mode (Brancaccio, Lippi and Maffulli, 2010). Activities such as ultra-endurance and downhill events may see higher CK responses due to the repetitive muscular contractions and large eccentric components involved. Furthermore, age, gender, muscle mass and training status of the individual will also influence CK levels (Silva et al., 2013). It has been shown that males may have twice the levels of females, with athletes having higher CK at rest as a residual effect of accumulated training (Mougious, 2007). Indeed, elite athletes may instead see a blunted rise in CK after exercise as a result of muscle becoming accustomed to eccentric exercise (Silva et al., 2013; Proske and Morgan, 2001). This has been suggested to occur in rugby and American soccer players who become more resistant to muscle trauma due to the 'repeated-bout effect' with the muscle becoming more sensitised with greater training status that pre-conditions and protects the muscles from bouts of eccentric exercise (Newham et al., 1987; McHugh, 2003). More frequent exposure to large eccentric movements may later provide a protective mechanism against muscle damage, with optimised integrity and permeability of the cell, the loss of cellular contents is reduced, also preventing influx of extra cellular ions that helps maintain force transmission during intense efforts (Brancccio, Lippi and Maffulli, 2010).

The extent of such changes will be influenced by the factors mentioned previously, with reports of large between-athlete variability in CK levels after exercise and competition. The notion of 'high' and 'low' responders and their blood kinetics will then partly explain the range of values found in studies of CK responses in team sports (Brancaccio, Lippi and Maffulli, 2010). These have examined the different phases of training as well as the time-course following competition. For example, Hoffman et al., (2005) found CK levels to be five-times higher in the pre-season (~500U/L^{-1}) period following the off-season when training load is increased, compared to that in-season. The competitive period was suggested to be a time when players have become sensitized to muscle trauma and contacts following the more intense pre-season training camp. In another contact sport of rugby union, CK levels were found by Cuniffe et al., (2010) to rise from 333-519U/L^{-1} immediately after a match, peaking at 1182U/L^{-1} after 14 hours and 750U/L^{-1} at 38 hours, both significantly higher than pre-match ($p<0.05$). McLellan, Lovell and Gass (2010), moreover, found CK to still be significantly elevated above pre-match values at 120 hours ($p<0.05$) of a competitive rugby league match. The contact nature of these sports and the use of upper body musculature also revealed correlations of CK levels with both the number of tackles ($r=0.86$) and contact situations ($r=0.78$) 38 hours post-match (Cuniffe et al., 2010). The results of these studies indicate the extent of mechanical damage can vary between position, exercise modes and game actions that will combine to impact recovery and weekly training periodization.

In soccer, Heisterberg et al., (2013) conducted an extensive study monitoring soccer player's blood samples across different points of the season. CK was 329U/L^{-1} on average for the season whole season and was found to be twice as high in the pre-season compared to other periods (544U/L^{-1}), with 54% of players remaining above the range of 50-270U/L^{-1} (Mougious, 2007). Following soccer matches, peak CK has been reported at both 24 (844-1277U/L^{-1}, Silva et al., 2013) and 48 hours (950U/L^{-1}, Ispirlidis, et al., 2008), up to 800% above pre-match values (Magalhaes et al., 2010). The baseline value in the latter study (300U/L^{-1}) was suggested to be residual CK resulting from soccer players training and match daily schedules. Similar to the studies of CK in contact sports, Thorpe et al., (2012) found correlations between CK levels and the high-intensity ($r=0.92$) and sprint distance ($r=0.78$) and sprint efforts ($r=0.80$) performed during a soccer match. This may aid planning of training schedules and match exposure for individual players during the season to control ensuing muscle damage. The prolonged time-course of CK responses and recovery following intense soccer schedules and competition has been scrutinised in such studies which have also found this to have performance implications. When CK levels rise above baseline, changes in performance can include loss of force production, range of movements, neuromuscular activation (sprinting and jumping ability) as well as increased delayed-onset muscle soreness (DOMS) (Takashi et al., 2005; Nybo et al., 2013).

For example, Ascencao et al., (2008) found CK to be elevated for 72 hours after a soccer match, accompanied by reductions in repeated-sprint ability and hamstring and quadriceps muscle strength (peak torque) between 24 and 72 hours as well as an increase in delayed-onset muscle soreness (DOMS) at 48 hours. Ispirlidis et al., (2008) found similar increase in CK that were mirrored by reductions in 1RM squat and 20m speed for 72 hours post-match, although vertical jump was only lowered for 24 hours. It was suggested that more intense anaerobic exercises may be compromised in the subsequent 72-120 hours recovery from an elite soccer match. The reliability of some of these measures in relation to performance changes may still be questioned, however, with Silva et al. (2013) reporting no effect on tests of speed and agility after a soccer match.

Testosterone

Testosterone is a steroid hormone secreted at the hypothalamic-pituitary axis that is responsible for anabolic actions within the body. The presence of testosterone aids muscle protein synthesis and reduce protein degradation enabling improved muscular performance as well as indirectly stimulating the release of growth hormone (GH, Papacosta and Nassis, 2011). As a result, depending on the phase of the season, knowledge of hormone levels may be valuable in implementing specific training stimuli for adaptations and physical development during the soccer season. Typical values in blood plasma are from 2.9-13ng/ml^{-1} (Silva et al., 2013) with a circadian rhythm seeing testosterone levels peak at 0800h and reduce to lowest levels in the evening at 2000h (Papacosta and Nassis, 2011). A member of the androgen group that responsible for male characteristics, testosterone production and use is significantly higher in males than females. Research has found testosterone to increase with high-intensity exercise and strength training, leading to greater strength gains (Crewther et al., 2006).

Cortisol

Cortisol is a glucocorticoid also secreted by the pituitary gland. This hormone has higher levels in the morning increases in the body as a result of experiencing stressful situations or increasingly intense exercise (>60% $\dot{V}O_{2max}$), peaking twenty minutes thereafter (Viru, 1996). Cortisol levels have therefore been said to be useful as chronic indicator of training stress and has been correlated with increases in blood lactate (Port, 1991). The monitoring of cortisol levels may therefore have applications in tracking player wellness and physical readiness to perform across a season, particularly in winter periods when incidence of illness may increase, coinciding with congested competition schedules. Typical values of cortisol have been reported to be between 30-150ng/ml^{-1} (Silva et al., 2013). There is no difference between cortisol levels in males and females (MacKinnon et al., 1997).

Studies into these hormones in sporting contexts have found cortisol to be higher in soccer players who play matches more regularly compared to non-starting players as a result of greater competition exposure (Haneishi et al., 2007). Filaire et al., (2001) noted a slight increase in cortisol following a period of high-intensity training in elite soccer players, although no statistical change was found over the sixteen-week study period. Following a soccer match, cortisol levels have been found by Silva et al., (2013) to rise at 24h and 48h ($p<0.05$) and testosterone not to change, with similar findings reported by Ispirlidis et al., (2008). This was concluded to demonstrate a catabolic state following a soccer match due to a lack of testosterone increase to balance the hormonal profile, inhibiting protein synthesis and muscle function. Significant increases in cortisol (40%) and decreases in testosterone (43%) compared to pre-match values have also been found in other studies on rugby

(Cuniffe et al., 2010) with McLellan, Lovell and Gass (2010) reporting elevations at 24h and 120h for cortisol and testosterone respectively following a match in rugby league. Despite similar findings for cortisol responses after a soccer match, Ispirlidis et al., (2008) on the other hand found consistently lower testosterone levels to decline up to 144h post-match compared to those of the control group. Cortisol was highest 48h after a match in the study of Silva et al., (2013), returning to baseline at 72h, whereas no changes were found in testosterone across the post-match recovery period. The study also found no change in performance in sprint, change of direction and isokinetic leg strength, though jump performance was impaired at 24h ($p<0.05$).

Some of the markers reviewed above will now be reflected upon in the context of overtraining and overreaching in soccer.

Overtraining and Sports Performance

Overtraining Syndrome (OTS) in sport has been an area of great interest in the scientific literature in recent years. Generally, OTS is associated with decreases in athletic performance accompanied by physiological and psychological changes can persist for months or even years. There is however a continuum that has been speculated to exist detailing the progressive changes in markers that may eventually lead to OTS (Fry, Morton and Keast, 1991). It is possible that over time, elite athletes, such as soccer players may experience periods of fatigue across training cycles and playing seasons. The performance and individual responses of athletes may fluctuate as a result of training and competition exposure that influence the training stress balance and weekly load. However, when greater loads are accumulated there is potential for fatigue manifesting transiently that can lead to a 'temporary disruption in homeostasis' and subsequent fatigue. Additionally, the greater training load and multiple stressors experienced over time, coupled with inadequate recovery (i.e. intensified training periods) may lead to functional overreaching whereby the intentionally high loading is prescribed in order to bring about desired adaptations as part of a supercompensation response compared to baseline levels (Meeusen et al., 2006). Continued excessive loading, however, may potentially lead to more apparent overtraining whereby performance is compromised for significantly longer periods of several months. Therefore, the difference between overreaching and overtraining is largely discriminated by the time required for performance restoration (Meeusen et al., 2006). Despite the large amount of research into biochemical markers such as hormones, some researchers have suggested that changes to these may '*simply reflect stress of training rather than breakdown of adaptive process'* rather than overtraining *per se* (Wilmore and Costill, 1994). Indeed, others have also suggested blood and endocrine measures to exhibit a large degree of variability which is compounded by no universally agreed thresholds of high and low values (Hartmann and Mester, 1998; Meeusen et al., 2006). This is important to note with soccer players who may not experience ‘overtraining’ as such but rather overreaching at times across the season as mentioned previously. This may be deliberately induced as part of the training programme (functional overreaching), but may also occur due to high loading exposure, with symptoms here requiring considerably less time to recovery than a truly overtraining individual athlete, for example.

The continuum can therefore represent the fine balance of prescribing elite soccer players with correct training loads depending on various factors to ensure appropriate conditioning and readiness to train or participate in competition. Such factors influencing the control of appropriate training loads will entail the coach to take into account age, training status, training history, previous injury, and the 'delay effect' of preceding training load (Orchard et al., 2009). Contributing to the onset of overreaching and overtraining symptoms, external factors such as travel, sleep, economic pressures and congested fixture schedules may also increase physical and cognitive pressure on athletes at the elite level and should be accounted for (Meister et al., 2011).

Testosterone, Cortisol and Testosterone-Cortisol ratio in Overtraining

OTS has been linked to disorder of the hypothalamic-pituitary axis which may explain key changes in hormonal status and immune function (Table 2.2) with regards to training adaptation (Gleeson, 2002). Studies have found catecholamine secretion to be significantly lowered in overtrained athletes with a negative correlation with ratings of fatigue (Lehmann et al., 1998), although Urhausen, Gabriel and Kindermann (1998) instead found no difference in both sub-maximal and maximal catecholamine excretion in a similar population. Testosterone and Cortisol hormones have also been described in relation to instances of intensified training periods and overtraining. Cortisol is seen as a makers of individual training stress, however maximal levels may be blunted to lower-than-normal responses as a result of chronic training loads associated with overreaching rather than overtraining (Snyder et al., 1995). Studies in to levels of serum testosterone have also found decreases or no change with intensive training in overreached endurance athletes with some studies finding the same pattern in performance tests (Vervoorn et al., 1991). Furthermore, a decline in T:C of over 30% has been suggested to indicate possible overtraining as hormone levels react to intense exercise where there is a disruption in the adaptive response as a result of incomplete recovery (Aldercreutz et al., 1986). Also, a lower sensitivity of hormone receptors and binding affinity and neurotransmitter release may occur due to desensitization of the hypothalamic centre in the brain that controls endocrine responses to a particular stressor, thereby hindering restoration of homeostasis from an overtrained state (Lehmann et al., 1993).3

Table 2.3: Immune markers in different periods of training (Modified from Gleeson, 2002).

	Normal Training	**Heavy Training**
Neutrophil:Lymphocyte	1.4	1.5
Saliva IgA (mg/l)	115	104
Plasma Cortisol (µM)	431	471
Plasma Glutamine (µM)	686	646
Plasma CK (U/L)	137	564

The testosterone-cortisol ratio (T:C) has been purported to a marker of anabolic-catabolic status in athletes suspected to be overreached or overtrained. Changes in this ratio may occur in athletes due to reductions in testosterone and less cortisol, a higher increase in testosterone compared to that of cortisol and a greater lowering of cortisol than testosterone (Urhausen, Gabriel and Kinderman (1995). Such changes may result dependent on both the intensity, duration and mode of exercise as well as the stage of season, training phase and simply diurnal variation between individuals, which may all promote varying hormonal responses (Banfi et al., 1993). Indeed, with these factors in mind, T:C may be able to help indicate an athlete's ability to recovery from intense exercise and synthesis protein to maintain an anabolic environment required for muscular adaptations (Garstecki, Latin and Cuppett, 2004). However, more recent research has indicated this ratio may only describe physiological strain rather than explaining overtraining syndrome (Meeusen, 1999).

Studies into the testosterone-cortisol ratio in soccer have shown conflicting results as to changes occurring in this marker. Following a soccer match, T:C has been found to be significantly lowered between 24-48h post-match following no change in testosterone and a large increase in cortisol ($p<0.05$, Silva et al., 2013). Conversely, following two games played consecutively within twenty hours, Malm, Ekblom and Ekblom, (2004) saw no significant change in T:C at 72h after the last match ($p>0.05$). Long-term studies such as that by Filaire and colleagues (2001) have also found there to be no changes, with T:C remaining constant throughout a season in elite French soccer players. Measurements of salivary hormones were taken at the start of the training year, start and end of the pre-season training period, and mid-competition with sample taken when waking, before breakfast and mid-afternoon. Only slight increases were seen during the course of the daytime with no correlation found between T:C and mood state. Handziski et al., (2006), on the other hand, found T:C to rise significantly from the start to the end of pre-season training in elite soccer players, then decreasing following the competitive season (both $p< 0.05$). Similar findings were also reported by Hoffman et al., (2005) in American Soccer, where the rise in T:C following a pre-season training camp was said to be indicative of a rise in testosterone and lower cortisol that produced a more anabolic environment. The changes were reported to be a result of high training loads altering hormonal levels in pre-season with a greater than 30% reduction in the competitive phase possibly a result of accumulated fatigue across the soccer season. Kraemer (2004) studied the changes in T:C in starting and non-starting collegiate soccer players over an eleven-week season finding no significant changes in the regular starting-line up. However, non-starter ratios were found to increase significantly from the start to the end of the season ($p<0.05$) with the starters T:C correlated with a significantly lower jump performance in week nine compared to baseline ($r=0.65$). The influence of comparably higher training loads has also been evident in reductions in salivary Immunoglobulin A (sIgA) (Table 2.2). IgA is an antimicrobial protein that is present on mucosal surfaces in the boy, preventing pathogens from entering the body. Research has shown though, that as with other markers, sIgA is also reduced following high volume or intensity bouts of exercise of prolonged exposure to heavy training and travel schedules (Fahlman et al., 2001; Nieman et al., 2002; Libicz et al., 2006).

The importance of hormones and the endocrine system in maintaining homeostasis within the body and regulating physiological adaption is well known (Papacosta and Nassis, 2011), therefore, profiling hormonal responses for an individual in training and match-play may help guide training loads and recovery strategies implemented in order to ensure optimal readiness to compete.

Creatine Kinase and Overtraining

Creatine kinase has also been investigated as a blood marker of overtraining syndrome (OTS). There has also been said to be large variation in serum CK measures between individuals. For example, different athletes may be classified as either low (<65U/L^{-1}) or high (>150U/L^{-1}) responders, suggested to have higher degrees of variability in the latter group. Moreover, more excessive levels of up to 1150U/L^{-1} and 3000U/L^{-1} have been reported in female and male athletes respectively (Hartmann and Mester, 2000). This may be due to thresholds specific to each individual regarding muscle properties and the level of enzyme release into the blood (Brancaccio et al., 2010). As mentioned previously, other factors such as preceding training load (including volume, intensity and mode), training status and experience of eccentric muscular contractions may contribute to different measurements between athletes and non-athletes after exercise and at rest (Brancaccio et al., 2010; Mougious, 2007).

However, despite increases in this enzyme perhaps mirroring mechanical strain on the muscles with a view to injury prevention, it may not be appropriate for use in diagnosis of OTS (Urhausen and Kindermann, 2002). Research has found that despite finding high levels of CK activity following heavy exercise, any further eccentric exercise was found to not exacerbate CK levels any further or compromise strength performance (Clarkson and Tremblay, 1988). Furthermore, CK levels have actually been found to be within the normal range in athletes showing other more pronounced symptoms of OTS (Budgett et al., 1989).

In addition to these observations, changes in heart rate have also been associated with states of overtraining. A higher resting heart rate may indicate fatigue (Jeukendrup et al., 1992) while a lower maximal heart rate may occur as a result of lower sympathetic nervous activation and action with catecholamine presence or lower ability to produce maximal effort. Lower sub-maximal heart rate and blood lactate may also be evident in conjunction with depleted glycogen and glutamine stores that may contribute to lowered energy provision and reduced immunoglobulins leading to immunosupression and increased risk of upper respiratory tract infection (URTI) in overtrained athletes. This may also be compounded by a concomitant reduction in number and function of leukocyte white blood cells, sensitive to training load, that are responsible for cell immunity and function (Reinke et al., 2009). Also, Niemen (1994) demonstrated a correlation between increasing exercise load and immunity particularly with higher intensity training. Therefore, over time accumulated training load contribute to the 'open window' for infection as a result of lowered cell-mediated immunity, energy status and an increasingly oxidative environment.

The increasingly congested schedule and number of matches in the soccer season may induce elements of overreaching phenomena described. Periods of intensive training in pre-season that dramatically increase training loads following a short off-season break may potentially lead to disruption of physiological and psychological homeostasis (Reinke et al., 2009). Undertaking the competition phase, fatigue is then accumulated further over time when there is little opportunity for recovery between successive matches due to the necessity to train (Lago-Penas et al., 2011). As a result, hormonal, substrate, neural and immune changes may occur that can leave a player susceptible to both infection and potential injury. The stressors and potential implications for elite soccer players and their teams therefore suggest effective monitoring and prescription of training load to prevent any negative consequences and consistently optimise performance (Hooper and MacKinnon, 1995). There is also a need to identify the time-course of various measures following training and competition in order to identify individual baselines that will aid training plan periodization and adaptation response (Urhausen and Kindermann, 2002).

Periodization of Training in Sport

Soccer is a complex sport that requires proficiency in a myriad of physical and technical parameters for optimal performance. As well as technical skill, there is a necessity for players at the elite level to possess high levels of endurance, strength, power and agility. The challenge is therefore devoting time to developing these aspects in a time-efficient way within the annual training cycle.

" The outcomes of training are anatomical, physiological, biochemical and functional changes specific to the sport discipline…the training process is characterized by the systematic repetition of physical exercises "(Viru and Viru, 2000).

The concept of periodization offers a framework that enables the division of the seasonal macrocycle into smaller periods, or cycle that may last months (mesocycles) or one week (microcycles). Within these cycles, coaches can plan training to systematically develop selected abilities to improve performance. This is often achieved through the manipulation of training volume and intensity in preparation for the competition phase (Bompa, 1999). Early periodization began in research by Russian scientist Leo Matveyev in the 1960s who proposed the traditional method of periodization entailing ‘purposeful sequencing of different training units’. This then consisted of alternating days of high and low training loads within microcycles in order to obtain desired training adaptations, whilst minimizing monotony and fatigue.

The General Adaptation Syndrome (GAS) is the theory of training design conceived by Seyle (1956). The GAS describes three phases experienced by the athlete when undertaking a training programme. The first phase is the 'alarm' phase when exercise is unaccustomed and the body's systems are disrupted leading to feelings of soreness and tiredness. The 'resistance' phase sees the body undergo positive adaptions to be able to cope with the new stressor experienced through supercompensation. The final phase, 'exhaustion', occurs when the training load experienced becomes to great or too frequent that there is insufficient time to recover the body's systems enough to continue to support the training demands. This may lead to symptoms of OTS.

The limitations of trying to training mixed abilities for a sport concurrently may result in conflicting physical responses (energy pathways for example) and thereby reducing the effect of the training stimulus. Some other methods different to the traditional idea have been put forward to periodize training in sport. Linear periodization involves progressive increases intensity over time, whereas the non-linear or undulating approach (Fleck and Kraemer, 1987) sees fluctuation in training intensity between days over the course of a microcycle for example (Fleck and Kraemer, 1997; Bradley-Popovich, 2009). A variation in low, moderate and high intensity exposure may therefore benefit sports that involve multiple peaks to competitions where optimal performance is attained, such as that in a soccer macrocycle. The idea here may be to utilize load-recovery cycles where acute fatigue is induced by training load followed by sufficient recovery to improve training capacities and obtain adaptations through means of supercompensation (Issurin, 2008). This has also been proposed by Gilliam (1981) who saw greater strength gains with high training frequency whilst mixing hard and easy days, avoiding overtraining, neural fatigue and maintaining rate of force development.

On the other hand, there are proponents of the block periodization model whereby training is organized in to highly concentrated blocks that specialize in the development of specific training components (Issurin, 2008). As a result, this may be a more time-efficient way to improve performance in certain areas without conflict of training responses and adaptations. Furthermore, Bondarchuk introduced his own block system for Olympic athletes in 1980's and 1990's that comprised of three mesocycles. Developmental blocks were aimed at progressively increasing training loads, the competitive block where emphasis was on event performance with the restoration block allowing the athlete to recover for the next developmental aims.

In a method also following a block structure, Issurin (1985) described an accumulation block for specific motor abilities (strength, power endurance); transformation block sport-specific running capacities and realization where maximum competition intensity was targeted with low volume. Mallo (2011; 2012) recently used this approach to observe fitness and performance in elite soccer players by peaking prior to competition at the end of the three blocks. In this instance accumulation, transmutation and realization blocks were repeated three times in order and were aimed at high-intensity aerobic conditioning, repeated sprint ability and speed-endurance and then speed and maximal exercise. At the end of each training stage comprised of the three blocks, jump, sprint and YoYoIR1 scores were all improved (Mallo, 2012). Team success was enhanced further in the realization block where low volume maximal intensity work was interspersed with larger recovery periods serving as a taper prior to match-play (Mallo, 2011), allowing adaptation to training effects from the previous training blocks (Mujika and Padilla, 2003). The employment of sub-maximal workloads was suggested to benefit subsequent performance by undulating physical work as a result of the multi-peak soccer schedule. Furthermore, organizing training this way enable development of discrete facets key in soccer. As a result, periodization strategies should take into account the requirements and annual schedule of the sport to effectively enhance performance and minimize negative consequences (illness, injury).

Periodization in soccer

The challenge of effective training in soccer during different phases is represented by numerous factors. For example, a large increase in domestic and international competitions means up to seventy games may be played in one season. Furthermore, major summer tournaments after the domestic season reduce the off-season break before pre-season training commences. As a result, recovery and regeneration from fatigue of the previous season may not be dissipated as high-intensity training and match-play are reintroduced. The financial pressures accompanying these competitions are also increasing, with coaches requiring their strongest team to be fielded for as many games as possible in order to achieve success (Meister, 2011).

The soccer training year is divided into off-season, pre-season and competition phases, where the training objectives vary. For example, the pre-season period will typically focus on optimizing the physical conditioning of the players following the off-season break with high volume and intensity exercise. Early pre-season may focus on general and specific conditioning that involves more time spent at high heart rate zones and closer to $\dot{V}O_{2max}$ as well as gym-based strength and injury prevention work. As players become more accustomed to soccer activity, the emphasis may change progressively during pre-season to incorporate higher-speed, anaerobic work also interspersed with technical and tactical skill refinement. Strength work may focus more on force development and power execution to transfer to high-velocity movements in soccer. A reduction in the training volume at this time may be compensated for by the inclusion of friendly matches to allow controlled exposure to the match environment. Despite these matches being reported to be of a lower intensity than 'true' match-play (Drust, Atkinson and Reilly, 2007; Rogalski et al., 2013) coaches are able to build on playing time over several games prior to the start of the competitive season with specific positional demands and requirements. Challenges of the pre-season period for those responsible for the programming include the very short time in which to prepare players. The coaches may have players returning from short off-seasons, depending if they have played international tournaments that reduces time available to recover from the previous season. As a result, although fitness levels may still be high, there may also be an element of residual fatigue accrued over time that holds potential for injury in the pre-season where training loads are high (Gabbett, 2004).

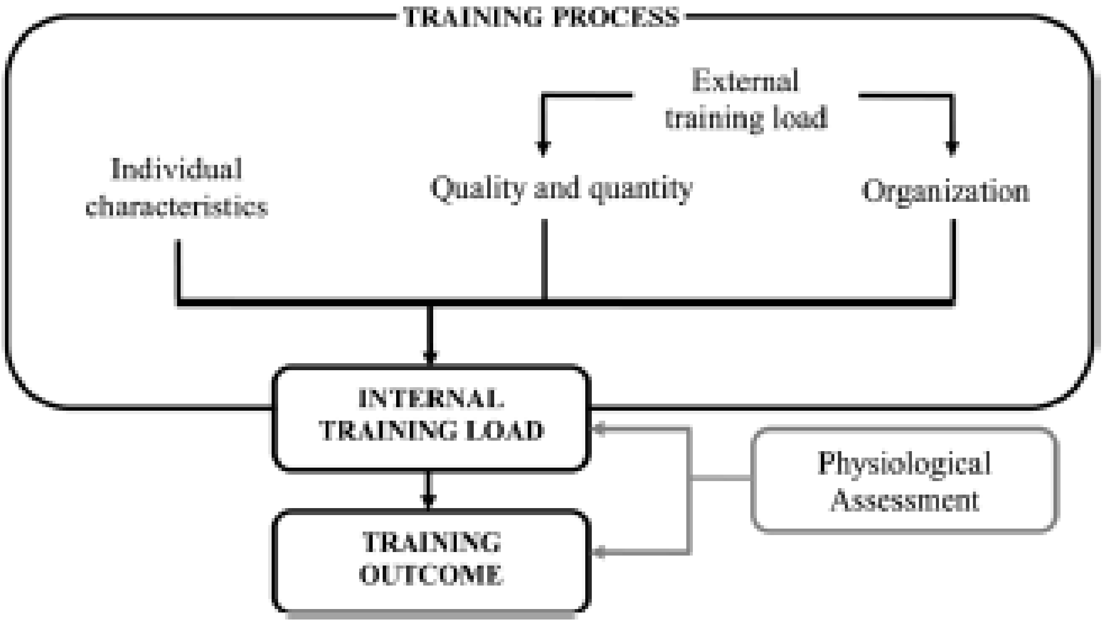


Figure 2.1: Training process outcome results from internal responses and external prescription (from Impellizzeri, Rampinini and Marcora, 2005).

During the competitive season, regular match-play sees many microcycles tailored to more techno-tactical training for one, two or even three-game weeks. As a result, periodising training for multi-peak sports like soccer is an art that enables recovery for regular starting players whilst maintaining fitness and sharpness of substitutes (perhaps in reserve matches also) who may be required when there is illness or injury. Therefore, sub-groups requiring maintenance or developmental work may be subjected to differing microcycles throughout the soccer season. It is therefore hard to programme sufficient training to balance physical dose for those players who are not getting consistent aerobic and neuromuscular stimulus of match-play. Displayed in Figure 2.1, the training context and subsequent physiological adaptations are obtained by exposure to these by the external load prescribed (Viru and Viru, 2000).

Having detailed the most common content, how to monitor and ways to organise training in soccer, the measurement of external load and methods associated with that will now be presented as a pre-cursor to the techniques applied in the experimental chapters in this thesis.

Time-Motion Analysis in Soccer

For over thirty years, time-motion analysis (TMA) has been employed to qualify physical demands in training and match-play. Common areas of analysis have been directed towards distances covered and time spent exercising at various sub-maximal intensities as well as the frequency of those behaviours (Bradley et al., 2009). Existing studies of TMA have covered numerous different sports such as cricket, rugby union, rugby league, Australian Rules Soccer (AFL) and hockey (Petersen et al., 2009; McLellan et al., 2010; Waldron et al., 2011; Aughey, 2010; White and MacFarlane, 2015). However, perhaps the largest proportion of research has been focused on soccer, with the earliest match observations from the classical study of Reilly and Thomas (1976).

Soccer Match Analysis

Analysis into the activity profile of elite soccer players during competition is increasingly common and can provide valuables data to coaches, medical and fitness staff. The data compiled can detail the volume and frequency of activity at varying intensities detailing absolute and relative physical outputs and work rate in different positions as well as any fluctuations due to pacing strategies or potentially fatigue over the course of a match (Carling, Le Gall and Dupont, 2012). As a result, there have been numerous studies describing activity profiles at the elite level. Reported total distance covered (TDC) has been 10881 metres and 11019 metres in elite English and Italian players (Barnes et al., 2014; Rampinini et al., 2007) with values of nearly fourteen kilometres reported in top Spanish midfielders (Di Salvo et al., 2006). It has generally been accepted that soccer players cover eight to twelve kilometres during a match (Reilly and Doran, 2003), less than the average TDC reported in other sport such as AFL (13 kilometres, Coutts et al., 2010) and cricket fast bowler (13.4 kilometres, Petersen et al., 2009) although more than that reported in rugby union backs (5.6 kilometres, Deutsch et al., 1998) and elite field hockey (7.7 kilometres, White and MacFarlane, 2015). However, given the contrasting durations of competition in these sports, Aughey (2011) suggested a preference for comparing match analysis data in relative terms between sports. Therefore, meterage for soccer, cricket, rugby union and field hockey would be 110, 60, 80 and 115m.min^{-1} (Aughey, 2011). Accounting for 1-10% of total distance (Mohr, Krustrup and Bangsbo, 2003), high-intensity running distance (HIR) has been suggested to be a more sensitive measure of physical performance in soccer (Bangsbo, 1994). Its inherent variability between matches of around 30% has been demonstrated by Gregson et al., (2010) and may be influenced by factors such as, positional role, training-status, age, playing standard, stage of season and arguable most of all, team formation and tactical system (Di Salvo et al., 2006; Krustrup et al., 2005; Harley et al., 2010; Mohr, Krustrup and Bangsbo, 2003; Rampinini et al., 2007; Bradley et al.,2011). High-intensity distance (HID) and its classification has varied in the literature, with Barnes et al., (2014) reporting an average of 1151 metres in the 2012-2013 English Premier League (>19.8km/h^{-1}). However, Mohr, Krustrup and Bangsbo (2003) found top standard Italian players to cover closer to 3000m (>15km/h^{-1}). More maximal sprint behaviour has seen distances of around 200m on average (Di Salvo et al., 2010) in European competition and Norwegian first division players (Ingebrigsten et al., 2014). In addition to more activity of higher velocities, a couple of studies have investigated acceleration behaviour of lower velocities with Bradley et al., (2010) and Ingebrigsten et al., (2014) finding players to perform 90 acceleration efforts >2m/s^2 over a match, generally from lower starting velocities with the necessity to overcome inertia. Inclusion of these activities has been suggested to be more pertinent in time-motion analysis in sport (Varley and Aughey, 2013), adding to information on intense activity despite the lower absolute velocity that are below normal high intensity and sprint thresholds. Such efforts have been said to be greatly taxing on the metabolic system and require large forces to execute efficiently in decisive situations (Osgnach et al., 2010; di Prampero et al., 2015; Varley and Aughey, 2012). By examining these movements in closer detail the number of efforts 'sprint' efforts have increased by six to eight-fold when including the top 5% of accelerations with sprint efforts of the traditional definition above 6.1m/s^2 or 21.96km/h^{-1} (Dwyer and Gabbett, 2012; Varley and Aughey, 2013) although literature from competitive match-play is scarce.

The outputs described above are, however, subject to different degrees of variation between matches. There are numerous situational, environmental and individual factors that can all contrive to contrasting physical outputs across the season. To provide more context to the data collected regarding the methodologies employed and activity profiles in training and match-play, the following sections will propose some important considerations.

Methods of Motion Analysis

The popularity of TMA in sport has grown rapidly in recent years as practitioners have seen value in training and match information gathered along with the evolution of methods and technologies employed to generate data (Table 2.4). The comprehensive pools of data subsequently collected therefore provide technical and conditioning staff with information regarding exercise intensity and work-rate, technical proficiency, fatigue profile and even propensity for injury or overtraining. As a result, training prescription and periodization of annual cycles are facilitated by monitoring group and individual movement and loading patterns to ensure appropriate exposure and ultimately high performance levels in the competitive environment depending on specific schedules.

Table 2.4: Methods of motion analysis

Authors	**Method**	**Sport**	**Cases (*n*)**
Reilly and Thomas (1976)	Manual Notation	Soccer	51
Bangsbo, Norregaard and Thorsoe (1991)	Video camera recording	Soccer	34
Edgecomb and Norton (2006)	Computer-based tracking	Soccer	3
Bradley et al., (2009)	Multiple-Camera System	Soccer	28
Brewer et al., (2010)	1Hz GPS (GPSports SPI-10)	AFL	16
McLellan, Lovell and Gass (2010)	5Hz GPS (GPSports SPI-Pro)	Rugby League	1
Petersen et al., (2009)	1Hz and 5Hz GPS (GPSports SP1-10 & SPI-Pro; Catapult MinimaxX)	Cricket	26
Casamichana, Castellano and Castagna (2012)	10Hz GPS (Catapult MinimaxX)	Soccer	7

The strengths and limitations of each type of motion analysis employed in scientific research are discussed further in the following section.

Manual Tracking

The first study of TMA was carried out using manual tracking techniques in real-time was done so from one observation of a single player's match activity, by one observer (Reilly and Thomas, 1976). Diagrams of the pitch were used with markings and cues used to estimate distances travelled. Paint marks on the pitch were extended at regular intervals, with the colour of the grass cut also aiding recording on to a grid superimposed on the pitch map. In addition, coded commentary was made via cassette recorder during 51 games analysed in the old Division 1. Average distance covered was calculated to be 8680m of which 11% was at high-intensity and 2% covered whilst in possession of the ball. A soccer match was also found to entail around 1400 changes in activity encompassing transitions to different locomotor intensities as well as specific skill-related movements of the sport dribbling, tacking, shooting, for example). This method was tested for validity, objectivity and reliability by the authors and is still considered to be an acceptable method of tracking a soccer player's movements (Reilly, 2003), although this method is somewhat subjective still and is related to human error and interpretation of events.

Video-Based Analysis

TMA methods were further developed with the use of video cameras in tracking player movements (Withers et al., 1982; Mayhew and Wenger, 1985; Bangsbo, Norregaard and Thorsoe, 1991, Mohr, Krustrup and Bangsbo, 2003). The benefits of this approach included the ability to track either an individual or multiple players at the same time by using more than one camera. Furthermore, recording of matches also allowed more detailed analysis of physical and technical parameters after the match. Bangsbo, Norregaard and Thorsoe (1991), for example, used several elevated cameras to film nine semi-professional Danish soccer players in thirty-four matches. Average velocities for discrete activities were derived by analysing match footage in conjunction with recordings of players moving along the shorter side of the penalty box at different intensities (walking to sprinting). Duration, total time and the frequency for each intensity were recorded, with the distance covered found by multiplying the mean velocity by time taken.

Mohr, Krustrup and Bangsbo (2003) also used video camera analysis of moderate and international standard players. Each player was filmed individually in a minimum of seven matches from cameras positioned at the halfway line, at a height of fifteen meters. Recordings were later coded by computer to analyse locomotor patterns. Variables analysed in this study included the distance covered, number of efforts and duration of each activity of different classifications. These were also divided into time periods of 5, 15, and 45 minute periods to identify fluctuations in work-rate patterns over the course of a ninety-minute match. Speeds were calculated from video recordings using the time taken to cover a known distance with the help of markers on the pitch. Subsequent total distance covered at each intensity (defined by Bangsbo, Norregaard and Thorsoe, 1991) were calculated by multiplying the total time and average speed for each magnitude of forward and backward motion.

Spencer et al., (2004) on the other hand used only two cameras in TMA of elite male hockey players. The two cameras covered wither the near 60% of the pitch to the grandstand or the furthest 40-50%, covering the whole pitch between them whilst overlapping coverage to ensure players movements across the pitch were in view at all times. Analysis of motion was classified by an experience operator with two further operatives calling and entering changes in activity to a computer whose software linked any change in activity to the time recorded on the video. Reliability of data measurements for intra-tester reliability was assessed through typical error of measurement (TEM) and checked for levels of agreement between the mean of test and retest (Hopkins, 2000). Percentage TEM was found to be greater in standing, striding and sprinting (~10%) for frequency of efforts, whereas TEM for average time spent in each exercise category was highest for that spent walking.

Deutsch et al., (1998) also used three cameras positioned at halfway to track six positions in four competitive rugby union matches. Six movement categories (according to Reilly and Thomas, 1976) were recorded by a computer as well as instances of static work such as mauls and rucks. The total and relative time as well as frequency and average duration of discrete activities were recorded, subsequently deducing distance covered from these. Reliability for each movement category was achieved by the average of three trials per player at each intensity with the use of electronic timing gates. A match simulation was then employed to validate the method of predicting distances with the use of distance markers for each speed zone. Validity ranged from r=0.738-0.939 in utility and jogging movements with reliability of 1.88-4.86% in walking and sprinting for the estimation of average distance.

Video analysis has been said to be valid in changes in soccer running variables (Randers et al., 2010), with Krustrup and Bangsbo (2001) reporting coefficient of variation of 1% for total distance and up to 5% in high-intensity running distance. However, as well as the fact that the studies reviewed are sometimes of non-competitive matches, there are several other limitations. For example, video recording is restricted to filming a single player at one time with real-time analysis not possible. Video-based methods also have poor spatio-temporal resolution that also makes identifying changes in gait patterns difficult, particularly with unorthodox movements of team sports. Finally, this method does rely heavily on the experience and quality of observation of the observer. Discrepancies between certain testers may provide conflicting results thereby compromising reliability of results and the conclusions drawn in to the activity profile of a team or individual.

Computer-based methods

Computer-based tracking (CBT) was introduced in an attempt to improve the analysis process in tracking player moments more efficiently. CBT enables researchers to track players live during matches as first performed by Edgecomb and Norton (2006). Players were tracked by one researcher and computer each for distance covered and average speed with the use of a scaled-down version of the pitch. Special software was used to tell the computer the player's current location in *x-y* pixel coordinates on screen at a specific time point. The subsequent linear distance moved on screen since the last rerecorded time point with a calibration factor used to convert pixels to metres which took into account both the field dimensions and the size of the screen resolution used. Movement of each player was recorded to a tablet or using a mouse pen with the small-scale field calibrated to account for pitch reference points to ensure movements of the pen showed distance travelled.

Validity of CBT was found to be r=0.999 over a marked course with intra-tester reliability examined over three matches of 4.7% TEM for match video analysis and 6.1% TEM in matches tracked live. When compared to trundle wheel measurements, CBT did produce an error of 7.3% on the marked course which was found to decrease with increasing distance.

Burgess, Naughton and Norton (2006) using video analysis and specialist computer software, estimated movement demands from 45 cases of male Australian soccer players. Trained researchers were then able to use scaled down versions of the pitch on a tablet connected to a computer, tracking player's movements using a drawing pen. Soccer-specific actions were recorded with the use of pre-defined key sequences on the computer. Each individual dataset was analysed by a single researcher. TEM was subsequently found to be 4.6% when analysing movements from five halves of matches on two different occasions. Inter-observer reliability was assessed by comparing the observers reports to those of other observers on the same match. The game was analysed three times producing a Pearson's correlation of r=0.98 for distance travelled. The Trak Performance software used has also previously been reported to have acceptable error of around 5% for distance covered whilst also demonstrated its validity in findings compared to those from video analysis (Norton, Craig and Olds, 1999).

However, it should be noted that limitations of this method mean that these studies are subject to inter- and intra-rater reliability and human error. This also will conflict with the interpretations of observers of other studies employing the same methodologies regarding the classification of movement behaviour. Furthermore, the efficacy of using these softwares for quantifying rapid changes in speed and direction remains questionable.

Optical Tracking Systems

More recent advancement in match-play tracking technology in sport has come in the form of optical tracking systems such as Prozone® and Amisco®. Such systems entail a series of eight colour cameras placed strategically up in the stands of sporting stadia. Furthermore, each player on the pitch is the vision of at least two cameras at any one time to improve the accuracy of tracking. Data from the cameras is analysed by trained operators using specific match analysis software that was recorded at a sampling rate of 10-25Hz (depending on the system). Stored data will produce distances covered, time and frequencies spent exercising at certain intensities

The development of multiple camera systems to monitor and analyse match play in sport such as soccer has enabled concurrent tracking of multiple players for physical and technical and tactical outputs in competitive environments. Di Salvo and colleagues (2006) produced a validation study of Prozone® system (PZ) in its application to monitoring soccer-specific behaviour of six male subjects, performed in an elite stadium setting. Protocol involved the subjects performing a course of various activities at different speeds including sixty metre linear, fifty metre angles, fifteen to thirty metre jog-sprint-dribble sequences and a twenty-meter change of direction. These movements were performed at different intensities similar to early TMA of Bangsbo, Norregaard and Thorsoe (1991) (7, 11, 14, 19 and 23km/$^{-1}$) controlled by an audio signal. Changes in speed were assessed further by a fifteen-meter maximal effort as well as a twenty metre run with a 90° turn left or right. Each type of activity was compared to timing gate data. The MCS installed in the stadium had eight cameras each calibrated for orientation and field of vision to capture every part of the playing field and each player on at least two cameras. Data from the cameras was fed back to a central server where Prozone Stadium Manager software collated the recordings. Player coordinates and trajectories or paths were then tracked and translated on to pitch coordinates, finally verified by trained operators for quality, control and accuracy.

Speed results showed an R^2 value of 1.00 for Prozone versus timing gates in linear trials over sixty metres, this was 0.9998 over 50m curved running, 0.9501 in the fifteen metre sprint and 0.9216 through twenty metres with a change in direction. Typical errors (TE) of coefficient of variation (%CV) were 0.2, 0.3, 0.2 and 1.3% respectively for the same modes of activity. As a result, it was concluded that this MCS had acceptable validity and reliability in tracking soccer-specific movements in elite stadium environments.

One of the first of several studies to utilise PZ in soccer match play research was that of Bradley et al., (2009) in the first in a series of English Premier League studies. Twenty-eight games involving 370 players of all positions were analysed with speed zones classified into default thresholds. Inter- and intra-observer reliability through coefficients of variation (CV) ranged from 0.9-3.5% in distance covered by activities from walking to sprinting. Detailed activity profiles revealed 5.6% of time spent standing, with low-intensity activity (LIA, walking and jogging) accounting for over 85%, high-intensity (HI) activity >14.4km/h^{-1}, 9%. Average total distance covered (TDC) across positions was 10714m with 2492m at high intensity. TDC was significantly greater in central midfield players whereas as wide midfielders totalled greater high-, very-high intensity and sprint distances and peak velocities, ahead of attackers and full-backs ($p<0.05$). Central and wide midfielders were also found to have the shortest recovery between high intensity bouts ($p<0.05$), with central defenders significantly lower than all other positions in these physical outputs ($p<0.05$). Work-rate patterns fluctuated across the match that may have suggested the presence of fatigue. TDC and high-intensity distance then recovery durations decreased and increased respectively in the second half as well as in the last 15 minutes of the first and second halves compared to the first 15 minute period of the match ($p<0.01$). Recovery duration was 15% greater in the second versus the first half and 28% longer in the final 15 minutes of the match (both $p<0.05$). Detailed 5-minute analysis revealed temporary decrements in performance in HI running where the peak 5 minutes of HIR was followed in the next 5 minutes by high-intensity distance 6% less than the average for the entire match

($p<0.05$). Clear physical demands were shown for each position in this study in EPL matches, through temporary and perhaps more permanent effects on performance are evident suggesting a transient accumulation of fatigue. As a result, this data may direct towards appropriate conditioning strategies to specific positions, particularly in relation to high-intensity bouts and subsequent recovery requirement.

This study was consolidated by Bradley et al., (2010) where fourteen elite domestic and one international soccer match were analysed in 100 players using PZ to examine any differences in levels of play. No differences were found between playing levels for TDC, frequency and time spent at each locomotor intensity. Similar decrements were also found between 15 minute periods and between halves and the most intense 5 minute period of high-intensity running. Recovery duration increased again in the second half which was more pronounced in domestic matches, though this was not as large in international matches. Maximal running speeds also showed no different between playing levels. This study also sought to include acceleration data (2.5-4.0m/s^2 and >4.0m/s^2). Accelerations were most common when commencing from LIA, with elite domestic players completing 106 moderate and 13 high-intensity accelerations, with no significant decrease found across the match. It was therefore suggested that high-intensity and recovery demands are similar between the two playing levels although positional differences were still evident, particularly later in the match and in attackers HIA and recovery duration in central defenders. As mentioned in the previous study, conditioning for repeated high-intensity efforts (RHIE) may be an important training consideration to combat effects of fatigue on intense actions across a whole soccer match in domestic and international playing standards.

A final study carried out by Bradley et al., (2011) analysed how the tactical formation of a team may influence physical and technical outputs. Twenty EPL matches using the same PZ multiple-camera system recorded team formations of 4-4-2, 4-5-1 and 4-3-3. No differences were found in TDC, although more walking was reported with 4-5-1 and jogging in 4-4-2 and 4-3-3 formations. Very high-intensity work (VHID) when off the ball was higher in 4-5-1 ($p<0.05$) with HID similar for all formations, though 4-4-2 enabled considerably more passes to be made and received compared to the other formations. Positional differences saw as much as 30% higher HID in attackers in 4-3-3 ($p<0.05$), with 4-4-2 the formation that saw greatest TDC and high-intensity distance in central defenders. More HID was achieved in all positions in 4-4-2 and 4-3-3 versus 4-5-1 when in possession of the ball, though attackers VHID was more apparent in 4-5-1 without ball possession. Technical actions of passes and success rate were better in 4-4-2 and 4-3-3 though total ball possession was not different. Overall, physical outputs were not greatly affected by formation, though VHID and ball possession would seem to be influencing factors for certain positions in terms of the physical demands required of them. This may have specific implications for formations employed by coaches as well as the rotation of players and use of substitutes for certain positions and how players are prepared in the build up to matches.

Di Salvo et al., (2010) observed sprint behaviour in sixty-seven European matches over four seasons and several nations. Total sprint efforts >25.2km/h^{-1} were greatest in wide midfield positions compared to central midfield and defence with the larger proportion made up of leading sprints from a moving start (77%) than explosive sprints starting from static positions (23%) in wide midfielders and defenders and attacking positions. The average total sprint distance of 205 metres was slightly lower than that in EPL player in Bradley et al., (2009), even though the same sprint definition was used. Sprints in this study of European players were found to be of short nature around 10 metres, with longer sprint efforts executed by wide playing positions who are able to exploit space ahead of them. In light of this and the difference between sprint behaviour of different positions, devising specific training programmes based on intense, short duration efforts may be warranted to improve player’s capacity to deal with this in top-level elite matches.

As alluded to previously, HIR is a sensitive measure of physical performance. In a study detailing the composition of high-intensity activity, Gregson et al., (2010) used PZ data to highlight variability in high-intensity running (HIR) between matches in 485 players over three EPL season (over 7000 observations). 'High-speed' activity (HSA) was the term used in this study in order to avoid misinterpretation of physical capacities of individuals with regards to their outputs at different speeds. This was necessary as velocities constituting high-intensity may different between individuals, positions and training status (Abt and Lovell, 2009). Total high-speed running (THSR, >19.8km/h^{-1}) varied greatly between positions from 604 metres to 1162 m in central defenders and wide midfielders, also the case in sub-classifications of HSR (19.8-25.2km/h^{-1}), sprint distance (SPD) and efforts (>25.2km/h^{-1}), and HSR in possession. Wide defenders and central midfield players performed more HSR without the ball ($p<0.05$). Positional variation between matches for THSR, sprint distance and HSR in possession was greatest in central defenders (20.8, 36.4 and 44.5%), with attackers exhibiting more variation without possession of the ball (CV, 29.2%). Regardless of position, THSR, SPD, HSR in possession and without possession showed coefficients of variation of 17.7, 30.8, 30.6 and 23.5%. This variation was found to be exacerbated further in periods of fixture congestion closer to 40% between matches. Each sub-classification of HSA increased across three seasons whether in possession of the ball or not. This increase in HSR volume and variability of around 30% in this large-scale study emphasises the sensitivity of this marker to performance and external game factors. However, the umbrella classification of 'HSA' should be assessed in discrete components in order to pinpoint where most variability in HSA activity is encountered in relation to the age, capacity of the individual and positional role.

A large-scale study by Barnes et al., (2014) over seven seasons and 15,000 observations, described changes in physical and technical outputs of the EPL. TDC increased slightly from 2006-2013 (ES: 0.22) with HID also increasing from 890-1151 metres (ES: 0.82) and 118-176 high intensity efforts (ES: 1.41) in the same period. HID also increased both with and without possession after 2008-2009 season (ES: 0.93). Sprint activity saw a greater proportion of explosive sprints over time ($p<0.001$), although average distance actually decreased slightly to 5.9 metres per effort. The maximal running speed attained significantly increased on average from 9.12-9.55m/s^{2} (32.8-34.38km/h^{-1}). Technical analysis showed a 40% increase in the number of passes attempted, with successful pass completion rising in 2011-2012 and 2012-2013 compared to 2006-2007 seasons. Longer passes, shot and tackle frequency were more variable over the study period, although passing success rate (those <70% success rate) decreased from 26 to 9% by 2012-2013. This study on how performance parameters have evolved over a long time-period may have been helped by describing changes whilst taking into account differences in seasonal context, tactics and playing style in a domestic league. Large increase in HI and sprint activity compared to TDC alone has suggested a more explosive elite competition as well as harbouring greater technical skill execution and success. However, the increased demands may come at a cost in terms of physical exertion which may then lead to injury. Appropriate conditioning and recovery strategies may therefore be as important as ever in elite domestic soccer.

The Amisco® optical tracking system has also been used in numerous studies of match analysis in soccer. Dellal et al., (2011) used this system with a sampling rate of 25Hz to examine cultural differences in physical and technical outputs of domestic leagues (La Liga and EPL). The study sought to address how different leagues might require different demands in the two areas and would reinforce issues of comparisons between certain studies of soccer match analysis. Here, 600 matches (5938 individual cases) were collected by MCS that operates in a similar way to that previously described for PZ, though with different speed zones (HIR, 21-24km/h^{-1} and Sprinting >24.1km/h^{-1}). No differences were found between positions for TDC except for attacking central midfielders which were higher in EPL competition ($p<0.01$), with central defensive midfield and central defenders the highest and lowest respectively in both leagues. HID was higher in EPL, except for full back and wide midfield positions ($p<0.001$). HID when in possession was greatest in La Liga attacking central midfielders versus EPL, though the opposite was the case for all positions when out of possession except for players in wide defence and midfield ($p<0.05$). Sprint distance was greater in all positions in EPL, with wide positions again covering the most distance >24km/h^{-1} when in possession ($p<0.05$). Technically, the number of successful passes were similar across leagues with full back and attacking central midfielders having more ball possessions, particularly in La Liga, as was the case for time in possession in defensive central and wide midfielders ($p< 0.001$). Total number of ground duels were more frequent in EPL across all positions ($p<0.001$), although there were no differences in the success in these between leagues. These results highlighted the differences between requirements in European nations and may also suggest the necessity for a different training load prescription to cope with contrasting demands in specific facets.

Examining the influence of game context on physical motion-profiles, Castellano, Blanco-Villasenor and Alvarez (2011) also used La Liga matches in Spain (n=434). The study reflected on variables of match-location, level of opponent, match-status or scoreline and effective playing time (EPT). It was found that high-intensity and sprint distance was increased when playing against higher quality opponents, with HID (17.1-21km/h^{-1}) and VHID (21.1-24km/h^{-1}) slightly greater playing at away venues compared to home field matches, where sprint distance was greater. When the reference team were losing the game, an increase in average total distance of all intensity zones was observed compared to when the team were drawing or winning the match. One limitation of this study is the lack of positional data which may have accounted for changes with each contextual variable to different extents. For example, playing away from home might mean employing a different formation or tactical role of a certain position than when playing at home. Furthermore, the notion of 'context' is key to interpreting TMA in soccer as well as effective playing time in this study that would benefit from relative analysis rather than absolute values, where stoppages and substitutions may prevent appropriate comparisons between research. Indeed, EPT in the first and second halves were 26 minutes and 19 seconds and 26 minutes and 4 seconds respectively. The ball was therefore in play for 55% of total playing time, giving a new perspective on the demands of soccer match-play.

Harley et al., (2010) used a single friendly match observation of six EPL players, comparing match activity from PZ to that of 5Hz GPS. The GPS system was found to report a TDC greater than that by PZ ($p<0.05$), HID and VHID (14.4-19.8 and >25km.h^{-1}) were no different between the two systems with sprint distance measured higher with PZ. A difference of 7.6% in TDC was speculated to be a result of error inherent in both systems to ether under- or over-estimate distance travelled in team sports. However, HIA (14.4-19.8km/h^{-1}) may be more comparable between GPS and optical tracking systems in their use in soccer, but not in more maximal efforts above 25km/h^{-1} according to the authors, with a 68% deficit in measurement.

The use of optical tracking systems has produced numerous studies that have tied to quantify the effect of different variables and contextual factors that might influence physical and technical performance to different extents. Some studies have produced vast datasets with many observations that provide statistically strong results that previous TMA methods were not capable of doing. There are numerous limitations to these findings, however, that warrant caution when comparing and contrasting research findings.

Primarily, the availability of such systems is restricted to more wealthy institutions due to the large cost of installing and subscribing to optical tracking systems. This means many teams and sports may be unable to fully quantify performance and loading parameters in competition to compare to training data and its effectiveness in optimising match play. Also, the reliance on trained observers and analysts still has some potential for human error in coding activities from the computer software, despite the ability to capture data in a much-more time efficient manner.

Aside from these practical disadvantages it is the methodological contradictions that may necessitate more caution. Despite evidence of large datasets collected over multiple seasons, some studies are based on samples of just 20-30 games (Bradley et al., 2009). In this instance, Gregson et al., (2010) demonstrated the extent of specific physical parameter's variability between matches, thus advocating 'multiple longitudinal' observations to gain more meaningful an comprehensive evaluation of metrics whilst accounting for variation.

As a result, these data may be subject to a degree of variation due to the influence of various uncontrollable factors in relation to motion profiles and physical work-rate. For example, these OTS studies may not specifically take in to account factors such as individual pacing strategies, the effect of travel, changes in tactical system and the set-up and activity of the opposing team too. These contextual elements contrive to give match-to-match variability in physical parameters, and so must be viewed with more observations over a longer time period. Finally, key information on neuromuscular load with regards to acceleration behaviour are also absent from these studies utilising this technology. The distance covered and frequency of efforts performed at different changes in speed may often represent defining events in competition and will therefore form essential components to a soccer players training regimen. It could be said that this technology, whilst it can portray gross physical demands in terms of distance and speed, a more complete picture of stimuli experienced by players in matches is warranted.

In addition to this, match play variation may be impacted upon by numerous external factors that may contribute to contradictions in existing research. For example, research has found factors such as population, age, training-status and playing standard to all help produce varying match outputs (Harley et al., 2010; Krustrup et al., 2005; Dellal et al., 2011, Mohr, Krustrup and Bangsbo, 2003). By recruiting participants with varying characteristics, it is therefore hard to make confident conclusions as to whether match analyses are indeed applicable to all soccer players or are typical of that specific population.

Table 2.5: Movement intensity classifications of MCS studies

Castellano, Blanco-Villasenor and Alvarez (2011)	AMISCO®	Standing, Walking, Jogging (0-11km/h^{-1})	Low-Intensity (11.1-14km/h^{-1})	Moderate-Intensity (14.1-17km/h^{-1})	High-Intensity (17.1-21km/h^{-1})	Very-High Intensity (21.1-24km/h^{-1})	Sprinting (>24km/h^{-1})
Bradley et al., (2009)	Prozone®	Standing (0-0.6km/h^{-1})	Walking (0.7-7.1km/h^{-1})	Jogging (7.2-14.3km/h^{-1})	Running (14.4-19.7km/h^{-1})	High-Speed (19.8-25.1km/h^{-1})	Sprinting (>25.1km/h^{-1})
Dellal et al., (2013)	AMISCO®	Walking and Light-Intensity (0-12km/h^{-1})	Moderate-Intensity (12.1-18km/h^{-1})	High-Intensity (>21km/$^{-1}$)			
Carling, Le Gall and Dupont, (2012)	AMISCO®	Light-Intensity (0-11km/h^{-1})	Low-Intensity (11.1-14km/h^{-1})	Moderate-Intensity (14.1-19km/h^{-1})	High-Intensity (>19.1km/h^{-1})		

As we have seen from MCS studies reviewed in this section, MCS and match analysis research in general may employ dissimilar velocity and acceleration thresholds (Table 2.5). Again, this makes between-study comparisons hard given that speeds regarded as high-intensity may fluctuate and also not be appropriate for certain populations. For example, the physical capabilities or adult and youth players or central defenders and wide midfielders may be quite different and generating speeds of over ~19km/h^{-1} will be easier for some than others. The notion of match analysis thresholds and individualisation methods will be discussed in the following section.

Definition of speed zones and Individualisation

The development of optical tracking systems and the use of GPS in monitoring physical outputs of players in terms of distances covered and speed intensities is common in elite sport. The aim is to quantify match outputs as well as further describe the weekly exposure or physical dose. However, one area of contention in match analysis concerns whether the thresholds utilised are appropriate and how could they be improved. Many studies, such as those in Table 2.6, will use similar speeds (i.e. in arbitrary 'default' zones in those employing optical tracking systems, >19.8km/h^{-1}) while other may be based on very early match analysis research from 1970's-1990's (Reilly and Thomas, 1976; Bangsbo, Norregaard and Thorsoe, 1991). Given that high-intensity running is accepted as a valid measure of match performance in producing high-speed efforts and recovering to execute repeatedly, its value is given high regard in a large proportion of soccer research. However, the potential for large variation in high-intensity running components between matches shown by Gregson et al., (2010) must also take into account factors contributing to these fluctuations. HIR, for example, has been shown to differ between standards of play (Mohr, Krustrup and Bangsbo, 2003), positional role (Di Salvo et al., 2009), training status (Helgerud et al., 2001), chronological age (Harley et al., 2010) and cultures (Dellal et al., 2011). This implies that physical capacities may be inherently different in these populations subsequently over- or underestimating performance in players of different $\dot{V}O_{2max}$ and body mass. As a result, velocity thresholds could be better informed to accurately reflect them in a more appropriate way.

In order to discriminate between default and individualised speed thresholds, Abt and Lovell (2009) evaluated HID in elite soccer matches using the second ventilatory threshold (VT_2). VT_2 has been purported to represent the transition from moderate to intense exercise (Beaver, Wasserman and Whipp, 1986) and has been used to describe training intensity in cyclists and endurance runners (Esteve-Lanao et al., 2005; Lucia et al., 2000) and therefore suggested to be more representative of individual ability to maintain exercise over a specified intensity. VT_2 was established by an incremental treadmill test in the laboratory, with mean speed at VT_2 found to be 15.3km/h^{-1} in 10 elite English soccer players. Three full matches for each player were also obtained via data from Prozone®. The default HIR zone for match play was 19.8km/h^{-1} (5.5m/s^{2}), with the analysis also adjusting match data to include the speed at VT_2. Results showed HIR distance using the default threshold to cover an average of 845 metres compared to 2258 metres when using VT_2, a difference of 167% (ES: 4.8, very large). The massive discrepancy between the two methods for classifying HIR is therefore likely to present massive underestimations when using default zones, misinterpreting physical performance and its contribution to a player’s weekly load. VT_2 may be more appropriate in its sensitivity taking in to account changes in fitness which arbitrary thresholds do not account for. Despite this, the testing protocols of laboratory use may be expensive in order to gain detailed physiological profiles.

Then including positional differences, Lovell and Abt (2013) used eight outfield EPL players to compare individual and default (PZ) speeds in match-play based on the first (VT_1) and second (VT_2) ventilatory thresholds. Difference in HSR between players was 5% when using the default threshold (>14.4km/h^{-1}) which increased up to 40% in one instance when comparing the high-intensity activity of two different central midfielders when using distance above the speed corresponding to their individual VT_2. In conclusion, results of this study demonstrated there may be a need to individualise training and match outputs to obtain more reliable data specific to each player that may enable more confident comparison between individuals. However, the sample size in the study was relatively small and further investigation with a larger population of different characteristics may help to quantify these claims.

Table 2.6: Speed zone classifications and intensity definitions in soccer research

	Population	**Zone 1**	**Zone 2**	**Zone 3**	**Zone 4**	**Zone 5**	**Zone 6**	
Bradley et al., (2009)	Elite male	Standing (0-0.6km/h^{-1})	Walking (0.7-7.1km/h^{-1})	Jogging (7.2-14.3km/h^{-1})	Running (14.4-19.7km/h^{-1})	High-Speed Running (19.8-25.1km/h^{-1})	Sprinting (>25.1km/h^{-1})	‘High-Intensity’ (>14.4km/h^{-1}) ‘Very-High Intensity (>19.8km/h^{-1})
Mohr et al., (2003)	Elite and moderate male	Standing (0-5.9km/h^{-1})	Walking (6-7.9km/h^{-1})	Jogging (8-11.9km/h^{-1})	Low-Speed Running (12-14.9km/h^{-1})	Mod-Speed Running (15-17.9km/h^{-1})	High-Speed Running (18-29.9km/h^{-1})	Sprinting (>30km/h^{-1})
Hill-Haas et al., (2010)	Sub elite youth male	Standing & Walking (0-6.9km/h^{-1})	Jogging & Cruising (7-13km/h^{-1})	High-Intensity Running (>13km/h^{-1})				
Andersson et al., (2010)	Elite female	Standing (0-6km/h^{-1})	Walking (6-8km/h^{-1})	Jogging (8.1-12km/h^{-1})	Low-Speed Running (12.1-15km/h^{-1})	Moderate-Speed Running (15.1-18km/h^{-1})	High-Speed Running (18.1-25km/h^{-1})	Sprinting (>25km/h^{-1})

Jastrzebski and Radziminski (2015) attempted to individualise 10Hz GPS time-motion data in SSG in thirteen elite soccer players compared to generic bands of both Di Salvo et al., (2006) and Rampinini et al., (2007) with Amisco® and Prozone® respectively. Velocity at lactate threshold (LT) was deduced by an incremental field test to exhaustion that also determined corresponding heart rates at LT and maximum heart rate. However, this test may not be appropriate for the determination of LT and maximum heart rate for soccer players. Players performed 4v4 and 5v5 SSG (4x4mins with 2 minutes active recovery as in McMillan et al., (2005). As suggested by Mendez-Villanueva et al., (2012) individual speed zones were calculated by maximum sprint velocity (S_{max}) over 40m with a sprint classified as greater than 80%S_{max} and HIR between the velocity at LT and 80% of S_{max}. Average velocity at LT was 12.96km/h^{-1} (3.8m/s^{2}) and S_{max} 29.7km/h^{-1} (8.26m/s^{2}). TDC in each zone was found to be quite different compared to default thresholds. In relation to the SSG, percentage distance at high-intensity was 24 and 17% for 4v4 and 5v5 which were 2.1 and 2.8% with the default ($p<0.05$). No differences were observed in sprint data with the individual and generic sprint definitions. Furthermore, distance at low-intensity (LID) accounted for 30% TDC when individualised compared to ~16% LID with Di Salvo et al., (2006). This may provide pertinent information on activity profiles in SSG where low-velocity activity is common and still provides significant mechanical loading where changes in direction occur in smaller SSG. This study highlights the possibility of accounting for individual physical capacities in forming discrete thresholds for high intensity exercise. This may help prescribe and evaluate individual training load more appropriately to ensure the right physical dose is applied that is tolerable. However, it should be noted that comparing these new thresholds to defaults previously should be done with caution as previous research has implemented these in full match play whereas SSG are not able to replicate high-speed, intense efforts of match play due to space restrictions.

In their study of maturing soccer players in five age groups, Harley et al., (2010) used 5Hz GPS to compare physical outputs in match-play. The positive relationship between sprint performance and chronological age to determine velocity ranges that are more appropriate in younger populations. Normalized zones were found by 10 metre flying sprint time over a total of 20 metres (Barnes, 2006) with peak velocity (V_{peak}) contributing to forming age-group specific V_{peak}. This was calculated the V_{peak} of adult soccer players to form zone thresholds from standing-sprinting for each age group. Each activity zone was calculated by dividing senior velocities by the average velocity of each age group then multiplied by the default threshold used in senior match analysis (Bradley et al., 2009). HIA in this study was classified as velocities ranging from 19.1km/h^{-1} (U12) to 23.1km/h^{-1} (U16). Therefore, when relative speed characteristics are employed, although greater absolute values are observed with increasing age, activity profiles are similar between age groups when represented relative to match exposure, higher than some data of adult HID. Field-based methods may therefore provide a basis for individualisation that accounts for physical capabilities versus default bands. However, this study was based on average group data and so did not take into consideration any effects of maturational age on sprint performance.

Using a different approach, Dwyer and Gabbett (2012) described the velocity distribution curves of five field sports before developing a new threshold for defining sprint behaviour and maximal efforts that could either be low or high velocity in nature. Data from five games from five players of soccer, hockey and AFL were collected by 1Hz GPS although lower sampling rates have been suggested to be less reliable in tracking high-speed actions (Rampinini et al., 2015). The average velocity distribution were similar for each, as were the ranges of velocities in each category (i.e. standing, walking, jogging etc). The variance in each frequency distribution for each player and each velocity zone was calculated to obtain the top 5% of accelerations and where those thresholds occurred. These thresholds were then used to determine when a sprint effort occurred in each of the discrete velocity zones. When applied to the match-play data, using the top 5% of accelerations, 125 sprint efforts were recorded, of which only 6 occurred over greater than one second duration and over 4.2 metres (maximum of 7.9 metres). When the traditional sprint definition threshold was used (5.6m/s^2

or 20.16km/h^{-1}) only 19 sprint efforts were found, with sprint distance 273 and 174 metres for the new and old definitions. The discrepancy between the two shows the need for standardizing values in match analyses. It also warrants the inclusion of accelerations inherent in SSG and matches that might take place at low absolute velocities but still require significant effort to generate forces from low initial velocity and are therefore taxing. As well as the small sample size, another limitation of this study is that GPS sampled at only 1Hz which has been shown to have lower accuracy in measuring high-speed, multidirectional efforts associated with team sports (Randers et al., 2010; Rampinini et al., 2014).

In light of numerous methods employed to detail TMA, Hunter et al., (2015) carried out a method comparison on twelve elite youth soccer players. Given that transition between thresholds is fixed in previous analyses, these may differ relative to individual performance capabilities. Further, using maximum speed alone may also incite errors in that maximal values are acknowledged not to be achieved in matches (Mendez-Villanueva et al., 2011). A lower peak velocity, for example, would then give a higher intensity distribution at the same absolute workload compared to faster players who would have higher thresholds for HIA and sprinting and therefore likely produce less HID in matches even through aerobic competence was the same. Activity profiles and distributions were determined in the laboratory to find maximal aerobic speed (MAS), maximal sprint speed (MSS) and respiratory compensation threshold (RCT) by ramp and 40 metre sprint tests. Twenty-two matches were monitored by 5Hz GPS. It was reported that MAS and MSS may not suitably account for individual differences like RCT. RCT may be useful in incorporating aerobic and anaerobic abilities to represent the change to HIA whilst also reflecting changes in fitness over time. As has been described by Buchheit and Laursen, (2013) it was suggested that individual anaerobic speed reserve (ASR) and $vVO2_{max}$ and MSS may best demonstrate exercise tolerance and the transition between various exercises intensities in soccer match analysis.

Despite the different approaches to individualization in motion analysis in sport, we did not chose to individualize motion profiles in this research. This was decided as the testing battery carried out assessed speed only over a 20m distance and ethically this was part of the agreed testing battery in place within the club at the time. As a result, a true maximal sprint speed may not be reached with which to base speed zones from. Furthermore, the main aim of this research was to examine SSG in soccer in further detail with regards to the stimuli and loading patterns they provide. Given the confined nature of playing areas in these activities, players are unlikely to reach maximal speeds as a result of pitch boundaries and interactions with opposing players. Moreover, the data collected was analysed with respect to the average of the team participating in each SSG, not individuals *per se*, to give a representation for each format utilised.

Factors influencing variations in activity profiles

Fatigue

These measures of activity in competition are however subject to fluctuations as a result of individual pacing strategies (Bradley and Noakes, 2013) and elements of temporary and permanent fatigue accumulating transiently over the course of a match (Mohr, Krustrup and Bangsbo, 2003). Several studies have examined within-game variations on total distance and that at different intensities in an attempt to identify significant periods of performance decrements. This then has implications for physical conditioning strategies, squad rotations and the use of substitutes.

The total distance covered has been shown to decrease around 5% between halves in soccer (Mohr, Krustrup and Bangsbo, 2003). Further decreases have also been observed in distance in the last 15 minutes of the first half, first 15 minutes of the second half and final period of the match in studies of match fatigue and injury risk (Rahnama, Reilly, Lees and Graham-Smith (2002). Indeed, several studies have observed significant decrements in high-intensity activity between halves of over 10% (Mohr, Krustrup and Bangsbo, 2003; Di Salvo et al., 2009; Rampinini et al., 2007) depending on the extent of this type of activity in the first half (Bradley and Noakes, 2013). The presence of fatigue has been quantified even further in 5-min detail in match-play. Time-motion analysis revealed that high-intensity running immediately after the most intense 5-minute period consisted of distance 6-12% lower than that of the 5-minute average high-intensity running for the entire match, postulated as the occurrence of temporary fatigue (Bradley et al., 2009; Mohr, Krustrup and Bangsbo, 2003). This was accompanied by finding that recovery time increased 15% between bouts of high-intensity work in the second half, and by 28% in the last fifteen minutes of the match. The use of substitutes may therefore again be warranted at specific times. Substitutes could run 15% more distance at high-intensity (Bradley and Noakes, 2013) and as much as 25% more in the final fifteen minutes (Mohr, Krustrup and Bangsbo, 2003), particularly in relative meterage and HID of later replacements compared to team changes made earlier and players starting the match. The initial 10 minutes following half-time had been found to have less high intensity running in a ‘high activity group’ (Bradley and Noakes, 2013), postulating that players may be consciously pacing themselves for later in the game when an end ‘spurt’ may be required (Aughey, 2010).

On the other hand, changes in outputs during matches may also purely be due to the intensity of the game, inducing lower physical work rate and activity at maximal levels (for sprinting and accelerating and decelerating example) as a result of muscle fatigue, substrate depletion and dehydration, for example (Reilly, Drust and Clarke, 2008; Saltin, 1973; Gonzalez-Alonso et al., 1997).

Positional Role

The influence of positional role has been heavily examined in the literature (Di Salvo et al., 2006; Mohr, Krustrup and Bangsbo, 2003; Bradley et al., 2009; Dellal et al., 2011). The premise behind this focus is to understand what the typical requirements and subsequent outputs are for specific roles within the team. This may then form the basis of any physical conditioning programme.

Di Salvo et al., (2006) reported Spanish central and external midfield players to cover the most total distance in-excess of 12 kilometres, significantly more than that of central defenders and attacking players ($p<0.001$). Bradley et al., (2009) found a similar trend in English Premier League players, although full-backs (~11 kilometres) were not different in Norwegian and Spanish and English players in studies by Mohr, Krustrup and Bangsbo (2003) and Dellal et al., (2011). The consistently high-volume of running in the midfield positions, is likely due to the role of linking patterns of play in central areas facilitating defensive-offensive transition or the availability of space in wider positions on the pitch (Di Salvo, et al., 2006). High-intensity running analysis in several studies has shown wide midfielders to cover substantially more distance than all other positions (1049-2430m, $p<0.05$) with central defenders the least distance (681m, Mohr, Krustrup and Bangsbo, 2003; Di Salvo et al., 2009). Sprint performance has also been said to change with position, Di Salvo and colleagues (2009) finding sprint activity to be more apparent in forward positions with attackers producing significantly higher maximal velocity distances of approximately 900m ($p<0.05$). On the other hand, wide or 'external' midfielders have also been found to sprint further in match-play, perhaps due to greater availability of pitch space to exploit at more maximal velocities of over $30km/h^{-1}$ (Di Salvo et al., 2006; Bradley et al., 2009). Although there is a great deal of literature regarding positional differences, care must be taken in making comparisons. Primarily, this is due to methodological differences such as the use of alternative data collection technologies as well as velocity classifications for each intensity (see section on Defining speed zones and Individualisation). Furthermore, there are many other contextual factors such as opposition activity, formation and tactical system employed which may influence physical outputs required. For example, a coach may employ two central midfielders with contrasting roles (either a defensive or attacking emphasis). The tactical role therefore dictates the role of a player in a match, perhaps limiting them to certain areas of the pitch and therefore negating the attainment of high velocities and sprint efforts. These instructions may therefore have consequences for training prescription to enable the individual to carry out their role effectively from a physical point of view. Central midfielders, linking play constantly have a higher average speed to maintain (therefore total distance covered) compared to a central defender, producing differences in physical capacities between positional roles. The myriad of other factors which may shape match context will be addressed in the following section.

Age

The majority of match analyses in soccer have employed adult populations to portray match outputs. However, with respect to talent identification, injury prevention and maturation status, the capacities of youth players must also be quantified. Younger players may have lower maximal aerobic capacity and muscle mass and strength compared to adults (Baechle and Earle, 2008). As a result, considering growth-related conditions is important in managing subsequent training loads.

Harley et al., (2010) used age-group specific velocity thresholds in U12-16 elite soccer players instead of arbitrary delimitations often used in senior player analysis. These age groups also involve reduced pitch sizes and durations of 3 x 25 minutes (U12) to 2 x 40 minutes (U16) which may also dictate ability to accumulate distance as well as high-speed work. Total distance covered in absolute terms was greatest in U16 compared to U12 and U14 (7672m vs. 5813m and 5715m). Relative distance, however, was higher in U15 (118.7m.min^{-1}) compared to both U16 and U13 (115.2m.min^{-1} and 98.8m.min^{-1}, $p<0.01$). Distance at high-intensity (15.1-18km/h^{-1}) was also highest in U16 than all other age categories (2481m, $p<0.05$), although no relative differences were observed. Proportion of total distance spent at high-intensity was 30% which interestingly is slightly higher than that in adult match-play (Bradley et al., 2009). This indicates intense activities may be more apparent in youth soccer having implications for mechanical loading with regards to maturity status and development.

In a similar study from Qatar, Buchheit and colleagues (2010) used ninety-nine U13-18 trained soccer players to assess running performance in relation to individual physical capacity. Older age groups (U18 and U16) were also found to produce higher overall distance as well as that at high-intensity. As in the study of Harley, match exposure and pitch size were increased with age which may partly account for a concomitant rise in absolute distance at each intensity. High-intensity running (13.1-16km.h^{-1}) increased significantly from U13-18 (671m-976m) as did sprint distance (186m-666m) and peak speed (22.3km/h^{-1}-28.3km/h^{-1}) which all reflect increasing physical outputs with older age groups. When adjusted for age and playing time, however, no differences were found and only pronounced between total distance of oldest and youngest age groups. Furthermore, differences between positions in physical capacities did not necessarily reflect positional differences in match-play running match running performance showing lower magnitudes of effect. This highlights that although physical capacities are important in identifying and training talented players, age and maturity may not necessarily determine match running performance and could also be impacted upon by uncontrollable contextual factors.

Playing Standard

One of the main topics of concern when interpreting TMA data between studies is the use of populations of different standards. Different standards, participating in different level leagues may also involve different training and match-play exposure, varying the training status between teams. Subject teams may play anything from 20-70 matches within a season, with some playing mainly through winter and others in summer domestic competitions. Several studies have attempted to elucidate the extent to which training status affects subsequent match outputs. The activity profile of amateur players has previously been highlighted by Van Gool et al., (1988) and O'Donoghue et al., (2001). Mohr, Krustrup and Bangsbo (2003), however, aimed to illustrate changes in match-play intensity by comparing two discrete populations of different standards. One team of international players from Italy's Serie A was compared over two seasons to an elite team from Denmark. Time spent standing and walking were found not to be different, though total distance was 5% higher and high-intensity and sprint contributions were 28% and 58% higher in the higher standard players ($p<0.05$). Peak 5-minute high-intensity running, number of efforts and sprint efforts were all significantly greater in the top team ($p<0.05$). High-intensity activity was found to relate to YoYoIR1 performance in both teams, though a relationship with YoYo test and positional role was found only in the higher-standard team.

Drawing on these findings, Bradley et al., (2010) tried to distinguish between different performance levels given that high-intensity activity is related to training status (Krustrup et al., 2005; Krustrup et al., 2003). 110 players in fourteen elite domestic and one friendly international match were analysed using Prozone® semi-automated tracking of all positions. Results showed no differences between activity for velocity and accelerations for total distance, number of efforts and time. The decrease in TDC between halves in domestic players was not observed in international players. This was also the case for HID in the final fifteen minutes of each half compared to the first fifteen minutes of the match whereas the international players managed to maintain this ($p>0.001$). Interestingly, both standards covered similar total distance at high-intensity (2520m and 2745m) and in the peak 5-minute period (243m and 222m), higher than that reported in Italian and Danish players by Mohr, Krustrup and Bangsbo (2003). Intense running was maintained more in the last 5 minutes of domestic games. Limitations that should be accounted for include the fact that only one international match was used in the study and may not be representative of match-play at that level in general. Furthermore, the game was a friendly and being a non-competitive fixture may have lowered motivation and physical work-rate compared to those that are more competitive (Rodrigues et al., 2007).

Di Salvo et al., (2013) compared players from different level league of the same country (English Premier League and Championship) including over 2500 players over two seasons. Results showed lower level Championship players to cover more distance at selected intensities (except walking), total distance 11102m vs. 10746m; high-speed running 750m vs. 693m; sprinting 273m v 258m. However, the small effect sizes were suggested to indicate negligible differences between leagues (ES: -0.38, -0.22, -0.12). A similar pattern was found between positions with central defenders and attackers having the largest and smallest effect sizes for TDC (-0.71 and -0.36). In terms of high-speed running, wide midfielders had the greatest distance compared to other positions (955m in Championship and 898m in EPL, ES: -0.29) with central defenders the lowest (540m and 482m, ES: -0.47). Accompanying the small effect sizes, although distances were similar, the contributions of different exercise intensities to the TDC was found to differ. In this light, Championship players performed more fatiguing changes in speed than those of the EPL. This may reflect a more refined decision-making process in the EPL, where errors are not as common and patterns of play may flow more efficiently. Despite finding small differences between levels of play, the authors put forward this to be of minimal effect, but rather due to the large sample size employed that would help limit effect of contextual variations on smaller match sample sizes.

Gender

Krustrup et al., (2005) investigated movement demands on an elite Danish female soccer population in order to reveal any potential contrasts to their male counterparts and the relationship to training status. TDC ranged from 9700-11300m, with high-intensity running (>15km/h^{-1}) 1300m, and sprinting 160m when >25km/h^{-1} less than that later reported by Andersson et al., (2010) in international versus domestic female players. High-intensity distance fell 30% between first and second halves which was considerably less than reported in moderate and top-level male soccer players (10%, Mohr, Krustrup and Bangsbo, 2003). All activity >15km/h^{-1} consisted of distances considerably less than studies of men's soccer matches. When assessing relationships between match-play performance and training-status, no link was identified between TDC and $\dot{V}O_{2max}$ or incremental treadmill test performance, although a correlation was found between TDC and YoYoIR1 performance (r=0.56) and velocity at 2mmol.L^{-1} (r=0.64). Total HID was significantly correlated with $\dot{V}O_{2max}$ (r=0.81), treadmill time to exhaustion (r=0.82), velocity at 2mmol.L^{-1} (r=0.83) and YoYoIR1 (r=0.76). HIR in the final fifteen minutes of each half was also found to correlate with all four training status measures. However, despite covering a similar HID, the $\dot{V}O_{2max}$ of some players varied suggested that some may not have taxed their capabilities to the same extent as others which may also reflect different positional stipulations. The extent of high-intensity activity may be more evident in female soccer compared to males where a relationship between $\dot{V}O_{2max}$ and high-intensity activity was not found (Krustrup et al., 2003).

Stage of Season

The factors accounting for variation in match-play outputs may also be inherent in the stage of the season. Physical performance may fluctuate between pre-, mid- and late-season, with some leagues made up of larger schedules than other, some even utilising mid-season breaks. Rampinini et al., (2007) found TDC to be significantly higher in mid-late season compared to the beginning. This was also the case for high- and very-high-intensity running, with end season associated with greater distance than mid-season ($p<0.05$). The results of this study suggest that players may need to adapt to high-intensity running exposure over time in the competitive schedule. As training status improves following pre-season friendly matches and early league matches, a greater tolerance is built for high-intensity intermittent exercise that is typified by improvements in aerobic capacity, fatigue buffering and recovery.

Conversely, Ingebrigsten et al., (2014) found top Norwegian players to walk more and jog less in the final third of the season compared to the first game of the season, with accelerations >2m/s^2 following the same trend ($p<0.05$). Contrary to the work of Rampinini and Mohr, Krustrup and Bangsbo (2003), performance, especially in wide positions showed greater variation at the end of the season with sprinting and accelerations markedly reduced ($p<0.05$). These decrements could be due to factors such as an accumulation of fatigue on explosive actions over the course of the competitive season with fixture congestion as well as coach instructions on style of play.

Fixture Congestion

Playing fifty to sixty games in a season is becoming more common with the number of domestic and international competitions that are organised (Carling, 2015). Players are exposed to more congested schedules where schedules may see matches every 2-3 days. As a result of such periods, there is risk of accumulated fatigue as well as illness and injury, reducing physical outputs. The minimal time between fixtures has been suggested to be sub-optimal for recovery and therefore making recovery strategies even more vital. However, despite several existing studies into intense fixture periods in soccer, there is some evidence questioning whether or not players do exhibit any decline in physical performance across consecutive matches Dupont et al. (2010), though injury rates may increase with more games in a discrete period of time.

In smaller-scale studies of only one team, such as that of Morgans et al., (2014), total distance, high-intensity and sprint distance were not affected in a cycle of seven games in thirty-one days in the EPL. The authors also sought to see any effects on the mucosal immunity marker Immunoglobulin-A (IgA), finding salivary IgA to decrease over the study period, particularly after games three and five compared to the first game (p<0.01), returning to baseline two days after the seventh and final game with the schedule returning to one game a week. Despite the absence of any significant reduction in physical performance, careful monitoring of training load and well-being was advocated for both starting and substitute players during intensive match schedules.

Lago-Penas et al., (2011) also observed no difference in distances covered at various intensities in top Spanish players who were exposed to either one (n=41) or two games (n=131) per week. It was found that playing in one game consisted of more moderate and maximal intensity running, with a non-significant increase in walking and jogging employed when playing in two matches per week. The similar physical outputs may suggest little effect of match exposure in this study, however subtle differences in exercise at different intensities may instead be affected by contextual factors such as match location, quality of opposition and score line.

Similar to Dupont et al., (2010), Rey et al., (2010) focused on two games in three days, also seeing no significant difference in absolute distance and that covered at high-intensity. However, a decline in average exercise velocity and increase in subsequent recovery between bouts of intense efforts was noted in the second half of the second match (p<0.01). Peak velocity was also reduced in the second half of both games, though not significant (p>0.05).

As with other studies, Folgado et al., (2015) reported no change in running performance in two groups of congested and non-congested fixture periods where recovery between matches was either three or six days. However, an interesting observation was the suggested increased movement synchronisation of the reference team in their lateral and longitudinal displacements during the less congested time (p<0.05). Therefore, though sustaining physical outputs, synchronisation may be compromised, particularly in periods of 'low risk', when players are experiencing accumulated mental fatigue that is heightened in condensed schedules.

Carling and Dupont (2011), observing one team in French Ligue 1 analysed 35 games that occurred in the pattern of three games-a-week in midfield players. As reported previously, physical parameters did not differ over the study period. Technical performance was also unaffected by fatigue with improvements in shots on target, ball retention and success in duels in the last game of each three-game cycle. It was therefore suggested that monitoring both the physical and technical side is required to evaluate performance capabilities in periods of high exposure with less opportunity for recovery.

As well as the physical and technical parameters alluded to, a few studies have also examined the effect of a congested fixture calendar on injury rates. Dellal et al., (2013), Carling, Le Gall and Dupont (2012) and Dupont et al., (2010) have all scrutinized tight fixture periods from 2 games within a week to six-to-eight games in eighteen to twenty-six days. Alternatively, Bengtsson et al., (2013) compared match injury rates in relation to the number of recovery days separating each match (either three, four or six days). All of the aforementioned studies have found no difference between each match for total distance and that at high-intensity and sprinting thresholds. The exception was that Carling, Le Gall and Dupont (2012) found more low-intensity activity to increase total distance covered in games four and seven of eight games played in twenty-six days ($p<0.001$). In this study a total of seven injuries with a layoff of at least two days were sustained with the rate of injury 50.3 per 100 hours. This rate was no different to that observed outside of the designated study period. Furthermore, Dellal et al., (2013) did find an increased injury rate in match-play during a congested compared to that of a non-congested period ($p<0.001$), although time lost to injury and occurrence of training injuries were lower in the non-congested periods. This was postulated to be a result of lower intensity training employed by the coaches during periods of high exposure, with a squad rotation policy regulating the amount of competitive minutes player’s played that also benefitted subsequent recovery before the next match. This may also have benefitted physical and technical performance that were unaffected in the congested period.

Generally, these studies showing little relationship with loss of running performance or higher injury rates during heightened match exposure. However, the study of Verheijen (2012) demonstrated that a period of less than three days recovery between successive European and domestic matches may result in reduced team success. Indeed, less than four days recovery may also see greater subsequent injury occurrence compared to six days separating matches. More specifically, an increase in muscle injuries were identified with high match loads coupled with minimal intervening recovery.

Taking a different approach, Ekstrand (2004) was supplied data from eleven of Europe's top soccer teams. Between leagues, players played a range of 40-76 matches per season, varying more because of those participating at the 2002 FIFA World Cup (n=65) who totalled an average of 46 matches during the season compared to 33 by those who were not representing their countries. The study found that 60% of players whose season continued at the World Cup (and played more than one game per week prior) sustained an injury or were adjudged to have 'underperformed'. Although more variation was found between leagues, the average number of games per player was similar (36). Players at the World Cup had no further risk of injury in match-play, and as in Dellal et al., (2013), and were also found to have lower risk of training injury (3.2 versus 5.5 injuries per 1000 hours, p<0.01). This could again be a result of intentionally lowered training intensities by national team coaches or even a greater coping mechanism in these players who had higher match exposure throughout the season for their domestic teams.

Despite considerable evidence of players maintaining physical outputs and technical performance during periods of fixture congestion, it seems there is still potential for residual fatigue and insufficient recovery to increase the propensity for injury or underperformance (Dupont et al., 2010). Therefore, the use of a squad-rotation policy to protect players at risk of injury may be warranted, also requiring the maintenance of non-starting players physical conditioning. Also, the onset of injury risk may occur over previous weeks training and justifies the use of longitudinal load monitoring. On a note of caution, some of the studies reviewed above have actually entailed only a small proportion of players who start and complete all matches in a congested period (Carling, Le Gall and Dupont, 2012; Dellal et al., 2013), raising doubt over concerns of risks to players at these times. Therefore, coaches may intentionally rotate starting line-ups depending on the importance of the match and the competition for example where other players (reserves and youth players) are given senior match exposure. Additionally, the natural variation in high-speed activities between matches may be up to 30% (Gregson et al., 2010) and simply reflect match context rather than performance decrements *per se*. In this light, Carling et al., (2015) recommended larger-scale studies across teams to account for this variability and allow more confident inferences with regard to impact of soccer schedules. Indeed, metabolic (Gaudino et al., 2013) and acceleration (Akenhead et al., 2013) metrics may provide more sensitive information on performance-fatigue effects in intense periods.

In essence, a more complete approach that notes travel, biochemical, sleep and wellness elements as well as the traditional physical and technical data may be beneficial. This is particularly pertinent given that running performance may not be greatly affected with less recovery, with Buchheit et al., (2011) finding a beneficial effect of a specific recovery protocol on running performance between youth soccer games.

The main methods of match analysis in soccer have been presented and the most prominent influencing factors on match physical outputs discussed. However, in line with the aims and methodologies used in this research, it is important to detail the applications of training and match load monitoring with the use of GPS and inertial sensor technology as well.

Global Positioning System (GPS) Application in Elite Sport

The physiological demands of various sports have been heavily examined in previous research, with numerous methods of time-motion analysis (TMA) employed to detail movement patterns (see previous section). However, these methods have shown numerous limitations with regards to validity and reliability as well as practicality. Furthermore, the distance covered at various speeds, also incorporating unorthodox locomotion in intermittent team sports such as soccer. are inherently difficult to quantify accurately. The emergence of Global Positioning Systems (GPS) in the 1990's derived from use in military settings, using satellites orbiting the Earth which emit radio signals decoded by GPS receivers on the surface (Townshend, Worringham and Stuart, 2008). Clocks set in each satellite and receiver are synchronised with the time taken for signals to travel between the two calculated. Using trigonometry, the distance travelled can then be deduced by the product of travel time and the speed of light (Larsson, 2003) or speed of displacement using changes to radio frequency signals called the Doppler shift (Shutz and Herren, 2002). GPS exists as either differential or non-differential systems with the former using fixed ground receivers at known locations that are compared to satellite positions with connective signals then sent to the GPS receivers. This method also removes the possibility of the old 'selective availability' noise employed by US Military to disrupt GPS signals (Shutz and Herren, 2002). Differential GPS are able to reduce error from atmospheric obstructions from the receiver, improving accuracy (Larsson, 2003; Shutz and Herren, 2002). Non-differential GPS (NdGPS) has been suggested to hold advantages of being a smaller, practical and more cost-effective alternative (Townsend, Worringham and Stuart, 2008). The discontinuation of 'selective availability' has also benefitted accuracy and speed quantification in NdGPS (Witte and Wilson, 2004) where no fixed receiver is necessary with measurement from GPS receivers is enhanced.

Commercially available GPS have become widely used in the sporting environment (Aughey, 2011), particularly in team sports such as soccer (Harley et al., 2010; Casamichana, Castellano and

Castagna, 2012; Scott et al., 2013). It has been suggested by Randers et al., (2010) that there is currently no 'gold standard' of player tracking in soccer due to its unpredictable nature. However, the use of GPS systems in these settings has many benefits for coaches and medical staff. The ability to track multiple players concurrently to evaluate work rate, exercise intensity and fluctuations in performance outputs through distances and speeds can provide valuable data. This information can be utilised to identify normative values for individual outputs and capacities as well as training load and fatigue accumulated, increasing propensity for overtraining and/or injury. Additionally, these technologies can aid understanding of physical demands of training and match-play scenarios in intermittent sports where traditional heart rate and subjective measures of training load may not be appropriate for describing holistic demands (metabolic and biomechanical). For example, the numerous key actions associated with team sports such as collisions, impacts, changes in direction and velocity are unorthodox events that are hard to quantify in terms of energy cost, magnitude and frequency. Previously underestimated, a more informed view of energetic and biomechanical implications can be obtained with GPS to help with training prescription and periodization.

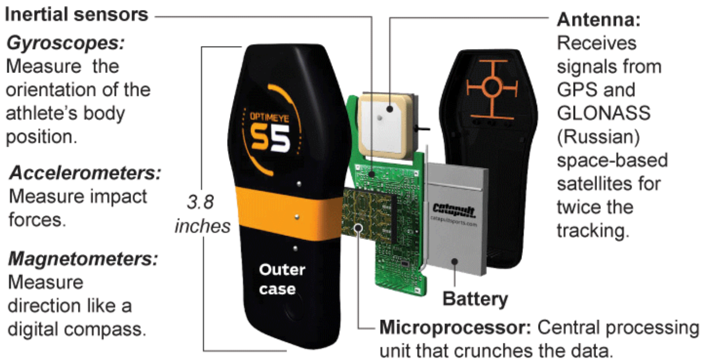


Figure 2.2: Key features of the latest commercial GPS unit (Catapult Innovations, Australia)

The rapid growth of GPS in elite sports monitoring has seen the expansion of several companies offering similar models that are continually evolving. Perhaps the most well-known manufacturers are Catapult Innovations (Figure 2.2) and GPSports, both based in Australia. Both these have advanced early products in terms of sampling rates, processing speeds and memory capacity and on-board accelerometry. They have also been used extensively in validation studies (Coutts and Duffield, 2008; MacLeod et al., 2008; Portas et al., 2010; Jennings et al., 2010) as well as describing training (Scott et al., 2013; Aguiar et al., 2013) and match-play (Randers et al., 2010) settings. The following section will provide detail on the validity and reliability of GPS and its application in sport.

1Hz GPS

Validity

There have been several studies seeking to validate 1Hz GPS in sport. Comparing computer-based tracking (CBT) with GPSports SP 110 model, Edgecomb and Norton (2006) used 59 trials of a marked circuit of known distance to assess validity and reliability of GPS in Australian Soccer. Distance covered by GPS was compared to that of a trundle wheel and found to differ significantly with GPS overestimating by 4.8% for the oval-shaped circuit ($p<0.05$).

Townshend, Worringham and Stuart (2008) validated distance and velocity measures over linear and circular courses using GPS (BT55, Wonde Proud Technology Co., Ltd.). Measurement of distance over 100m walking was found to be within two metres of the known distance. Compared to timing gates over splits of 60m distance when walking and running, GPS was found to correlate largely with true speed of the gold standard ($r=0.9994$) with a mean error of $0.01m/s^{-1}$. Participants also walked and ran the perimeter of a circle 10m radius with velocities ranging from $1.23\text{-}5.81m/s^{-1}$. Speed by GPS Doppler shift was found to correlate with actual speed from timing gates ($r=0.9985$) with a mean error of $0.6m/s^{-1}$. The curved path at different intensities was found to include 71% of values within $0.1m/s^{-1}$ of timing gates with 86% within $0.2m/s^{-1}$. The change in position was also used to calculate GPS speed and compared to criterion measures with correlation coefficients of $r=0.997$ and a mean error of $0.07m/s^{-1}$.

Coutts and Duffield (2010) had two male subjects complete eight bouts of six laps of a 128.5m circuit that simulated team sport movement patterns including changes in direction and velocity (Bishop et al., 2001). Three models of 1Hz GPSports units were used by each subject in the same custom garment (SPI-10, SPI Elite, WiSPI). Compared to the actual total distance, WiSPI showed the closest agreement (0.7%) compared to SPI-10 and SPI Elite (4% and 2%). The peak speed was significantly lower in SPI-10 versus both other devices ($p<0.05$). All three devices showed significant negative correlation with 20m sprint time in the circuit ($r=-0.40$ to -0.53, $p<0.01$) which may have demonstrated validity in the measurement of these actions. However, limitations in longer sprint distance measurements and brief actions taking place in very short durations were conceded by the authors.

Based on TMA from match-play (MacLeod et al., 2007), MacLeod et al., (2008) devised a hockey specific circuit of multidirectional movements, shuttles and sprints on which 9 male and female hockey players performed fourteen laps wearing GPSports SPI Elite 1Hz units. Pearson's correlations of $r=0.99$ were revealed for mean speed between GPS and timing gates with a mean difference in shuttles speed of $0.0 \pm 0.9\text{km/h}^{-1}$. T-tests also showed no difference in mean speed over linear and zig-zag components of the course, although a difference between shuttles at sprint speeds was identified ($p<0.05$). Total distance of the GPS was found to be slightly overestimated although not significant ($p>0.05$). T-shaped shuttle was overestimated by 0.1m, as was straight line shuttle and shuttle sprint distance (0.2m and 0.1m, all $p<0.05$). Zig-zag distances were underestimated 0.1m by GPS ($p<0.05$). It was concluded that this GPS device may be valid in its measurement of speed and distance in relation to hockey-specific movements.

Given the movement demands of team sports, the validity of GPS (SPI Elite) was assessed by Barbero-Alvarez et al., (2010) in measurement of repeated-sprints compared to timing gates. Twenty-one students were asked to perform 7x30m sprints from a standing start with gates placed at 0, 15 and 30m. Strong correlations were reported for peak speeds ($r=0.93$) and total sprint time (r=0.96) measured in the repeated-sprint ability test and those determined by timing gates. Assessment of split speed measurements at 15m and 30m also saw a significant correlation of r=0.87 and r=0.94 respectively (p<0.001). The summed maximum speed was found to have a low coefficient of variation (1.7%) and peak speed attained (1.2%). However, greater variation was found when the magnitude of performance decrement was calculated between trials.

Reliability

In trials on an oval circuit repeated three times, Edgecomb and Norton (2006) concluded reliability of the GPSports SPI-10 to be satisfactory. A typical error of measurement for intra-tester reliability of 5.5% was found for distance covered around the course and repeat trials produced correlations r=0.989 for total distance.

Coutts and Duffield (2010) examined intra-model reliability of two devices from each of three different models of GPS (GPSports SPI-10, SPI Elite and WiSPI). Assessment of reliability was made through typical error and coefficient of variation. Reliability of distance covered ranged from 3-8%CV of each lap of a team-sport circuit in all three models. Low-intensity activity (<14.4km/h^{-1}) CV was lowest in SPI Elite (4%), with coefficient of variation increasing in all models with increasing intensity (high (>14.4km/h^{-1}) and very-high intensity running (>20km/h^{-1}) up to 30% in SPI-1O devices. Peak speed measurement also had the least variation in SPI Elite (2%), with the top velocity band >20km/h^{-1} having greatest variation in SPI-1O compared to SPI Elite and WiSPI (30.4% vs. 15.4% and 11.5%). The SPI-10 was therefore said to not be as reliable as newer devices from this manufacturer, although caution should be used with all devices at sprint speeds due to low sampling rate.

Gray et al., (2010) observed both inter and intra-receiver reliability in GPSports WI SPI Elite NdGPS. Coefficients of variation were lower at each of the four intensities employed in the linear course compared to the non-linear when using the same units. Greater variation was found on the non-linear course except for jogging which was actually higher in a straight line (2.54% vs. 1.98%). Reliability between receivers was also improved on linear courses with the exception of jogging also, 2.33% vs. 1.63%). The reliability of these GPS was concluded to be acceptable in linear paths at lower intensity, but may be compromised when incorporating changes in direction at higher velocities typical of intermittent team sports.

1Hz and 5Hz comparison

There have also been some studies investigating validity and reliability of GPS units of different sampling rates.

Portas et al., (2010) used 1Hz and 5Hz devices (MinimaxX v.2.5) NdGPS in three trials. Linear trials were conducted along one half of a soccer pitch including acceleration, steady state and deceleration phases. Multidirectional courses were carried out on six courses using pitch marking entailing short and long distances with left and right turns of 45, 90 and 180°. These two trials were both carried out at speeds of $1.79m/s^2$ and $3.58m/s^2$ controlled by audio beeps through individual headsets. Sport-specific course was designed from Prozone® data of English Premier League matches of defenders, midfielders and attackers with the most representative one-minute period of match-play used for the study, with a one minute period of high-intensity activity also included. Validity of distance covered on all courses saw correlations with trundle wheel of r=0.99 in both 1 and 5Hz with standard error of the estimate (SEE) was similar for 1 and 5Hz systems for walking and running (SEE 2.6-2.7% and 2.9-3.1%). In a multidirectional setting 5Hz showed smaller SEE for validity compared to 1Hz (SEE 2.2-4.4% vs. 1.8-6.8%). This was emphasised more in trials that increased in complexity with more severe changes in direction. The soccer-specific trials were similar for GPS of either sampling rate (SEE 1.3-3% and 1.5-2.2%). Both GPS overestimated linear walking distance by 1% with

1Hz underestimating high-intensity motion by 2%. With different turns, 1Hz underestimated distance more than 5Hz (up to 11% and 2% respectively, with large and small effect sizes). The soccer-specific trials saw under- and overestimation by 1Hz and 5Hz systems by 1% in both.

Reliability was found to be similar in both sampling rates for movement in a straight line. Typical error (TE) is the random variation between a subjects tests and was 4.5% and 5.3% for 1Hz and 5Hz systems. With changes in direction, the 5Hz system had slightly lower TE (3.4-6.1% vs. 3.1-7.7%) that was increased with more complex turns for both sampling rates. Typical error in the sport-specific trials were similar between sampling rates (2.0-4.9% for 1Hz and 2.2-4.5% 5Hz). Although valid and reliable in measuring linear motion, more complex and intense tasks may be hinder this with low sampling rates. Moreover, results from both systems revealed typical errors higher than the smallest worthwhile change (SWC) of 0.6% for 1Hz and 0.2% for 5Hz and so may therefore not be able to discriminate significant changes in performance.

Using the same Catapult MinimaxX v.2.5 (1Hz and 5Hz), Jennings et al., (2010) evaluated different GPS in team-sport scenarios in a similar fashion to Portas et al., (2010). Twenty Australian soccer players did two repetitions of a linear course over 40m and four progressively intense changes of direction (COD) also over 40m with short and long 90° turns. A 140m circuit (Bishop et al., 2002) was carried out by 10 players for five repetitions of various intensities, turns and accelerations with one minute allowed for completion of each lap.

Validity of both devices was found to be reduced with increasing speed over greater distances. Larger errors (SEE) were found in a straight line over a 10m distance in both 1Hz and 5Hz for jogging (25.7% and 23.2%), striding (31.1% and 27.4%) and sprinting (32.4% and 30.9%). Moreover, the degree of error was reduced over greater distances (>10m) at all movement intensities in both sampling rates. In the two COD trials, validity was better in 5Hz although SEE increased with higher speeds in both trials in each sampling rate, with walking being the exception on the course with tighter turns in 1Hz. Linear distance was underestimated with 1 Hz and 5Hz over shorter 10m when striding (30.8% and 15.0%) and sprinting (37.1% and 26.0%), improving with increasing distance. This was also the case for distance in the tight COD where the 5Hz system showed slightly less error in striding (12.4% and 7.8%) and sprinting (17.4% and 12.9%). Both GPS overestimated total distance at high-speed, but this was also improved with increasing distance. Team-sport circuit was found to be underestimated by both 1Hz (5.7%) and 5Hz (3.7%). Reliability of both devices was found to improve with higher sampling rate and greater linear distance compared to higher coefficients of variation in COD trials. Typical error in both COD was reduced with higher speed, however TE was greater than SWC in at all intensities for 1Hz and 5Hz in tight and gradual COD trials. In the team sport circuit, CV showed good reliability of 3.6%, although the TE of distance covered was greater than SWC in 1Hz (4.6m) and 5Hz (4.7m). In conclusion it was said that validity was better in 5Hz GPS, with reliability improving following the acceleration phase of running in 5Hz, although 1Hz may not be reliable in measurement of short, high-speed efforts and instantaneous changes in speed.

Petersen et al., (2009) compared 5Hz GPS (Catapult MinimaxX and GPSports SPI-Pro) using two units of each model with SPI-10 1Hz (GPSports) with one male in cricket. Estimated distance at different velocities (walking-striding) of fast bowlers in match-play were used to be measured against criterion distance covered in a 400m running track using specific speed zones and the total distance covered at that intensity in matches. Each unit repeated this trial twenty times with verbal feedback on pacing given regularly. Sprint trials, also repeated twenty times, used only 5Hz GPS models over 20, 30 and 40m as well as a cricket-specific 'three run' test (3 x 17.68m) with 180° turns to test COD.

Total distance of GPS compared to criterion track distances saw a Pearson correlation of r=0.99. SEE validity of SPI-10 was between 0.6% and 2.1% for walking to striding, with MinimaxX 1.7% and 3.8% and SPI-Pro 0.4%-2.4%. Validity of MinimaxX (14.4-23.8%) and SPI-Pro (2.9-10.5%) units improved with greater distance when sprinting 20-40m. The SPI-Pro showed better validity than MinimaxX on average for units A and B in the three-run test (SEE 2.6 and 6.7% vs. 12.7 and 5.3%). Both SPI-10 and SPI-Pro underestimated distance up to 4% when walking to striding with sprinting as much as 20%

bias in SPI-Pro. MinimaxX on the other hand overestimated distance walking-striding by 3% and underestimated sprints by 20-40%, particularly over a shorter 20m distance.

Reliability was also improved with greater distance. SPI-10 showed TE of less than 2% up to striding intensities with SPI-Pro and MinimaxX under 4% TE. When sprinting, SPI-Pro had better reliability for longer distance sprints and three run test and was also found in MinimaxX although sprint distance was more variable (CV 4-43%) compared to SPI-Pro (CV 2-13%).Differences were still found between 5Hz GPS when wearing two of the same model for distance covered. Furthermore, both 5Hz systems underestimated short-duration, high-speed efforts which was suggested to potentially mean under- and overestimation of high and low intensity activity. Therefore, the GPS model used should be noted when comparing data due to the variation of each in describing activity of different intensities due to issues relating to custom-algorithms and satellite availability.

In a more recent study, Varley, Fairweather and Aughey (2011) assessed validity and reliability of instantaneous changes in velocity for 5Hz GPS (MinimaxX v.2.0) with 10Hz GPS (MinimaxX v.4.0). Three sub-elite male athletes completed eighty trials on a straight-line course involving three different intensities for constant velocity running and acceleration (1-3, 3-5,5-8m/s^2) and deceleration (5-8m/s^2) phases. Velocity feedback was given by handheld radio devices giving audio cues of starting velocity. Lasers sampling at 50Hz were criterion measure for speed placed at the start behind the athlete to be aligned with the running path. In each trial subjects wore either two 5Hz or 10Hz units.

In constant-velocity running, 5Hz GPS underestimated speed by 0.5%, with 10Hz underestimating at 3-5m/s^2 and 5-8m/s^2 (both 0.2%). Both sampling rates overestimated constant velocity running at 1-3m/s^2 by 2.4 and 0.6% respectively. During the acceleration phase, both GPS underestimated criterion velocity, but this was improved with higher starting velocities and higher sampling rate. During deceleration, velocity was overestimated by 5Hz (19.3%) and 10Hz (8.9% bias). Pearson correlations showed strong correlations with 10Hz GPS compared to criterion at all starting velocities in all three phases (r=0.92-0.98). Correlations were weaker with 5Hz and higher constant and starting velocities. Reliability of these devices was higher with higher starting velocities regardless of sampling rate. In fact, accuracy was found improve 67% in these instances. The 10Hz GPS showed less variation in constant velocity, acceleration and deceleration phases compared to 5Hz (2.0-5.3% vs. 6.3-12.4%; 1.9-4.3% vs. 9.5-16.2%; 6.0% vs. 31.8%). The coefficients of variation were greater than SWC in all phases for 5Hz, with the opposite true for 10Hz in constant velocity and acceleration phases at 3-5m/s^2 and 5-8m/s^2. A higher sampling rate was found to be 2-3 times more accurate and 6-times more reliable than older models of lower sampling rates when assessing different phases of straight-line running. However, the authors acknowledge the significant limitation of not including sport specific movements that include changes in direction that should also be quantified.

Randers et al., (2010) carried out a comparison study of four different match analysis systems in quantifying movement patterns and fatigue in soccer match-play. Twenty elite youth Spanish players took part in one non-competitive match (2 x 47.5 minutes) that was monitored by video camera, Amisco® 25Hz multiple-camera system (MCS) and GPS sampling at 5Hz (GPS-1, MinimaxX v.2.0) and 1Hz (GPS-2, GPSports SPI Elite). MCS gave the highest total distance, 12% higher than video-based analysis and GPS-2 ($p<0.001$), though there was no difference to GPS-1. High-intensity distance (>15km/h^{-1}) was also highest with MCS, 39, 37 and 24% more than video-based analysis, GPS-1 and GPS-2 ($p<0.001$). The 5Hz GPS (GPS-1) also recorded 17% more high-intensity running distance than 1Hz GPS-2, this was also the case in sprinting where there was a 39% difference in distance covered ($p<0.05$). Distance covered at low-intensity (7-13km/h^{-1}) was similar between MCS and video-based recording but MCS saw 15% and 20% greater distance in this zone than GPS-1 and GPS-2 ($p<0.001$). Differences in high-speed activity distance were attributed to different sampling rates of MCS and GPS systems with 1Hz not able to detect higher velocities and efforts as effectively. The authors therefore concluded that although all four systems could identify movements patterns and fatigue-related changes in match running performance. However, large discrepancies in absolute distances covered at varying intensities should warrant caution when comparing match analysis data from studies using different technology.

Inertial Sensor Application in Elite Sport

Modern GPS units are often integrated with inertial sensor (IS) technology such as gyroscopes and magnetometers informing orientation and direction as well as more traditional accelerometers.

Accelerometers have been widely used in health and physical activity interventions to assess energy expenditure and have shown correlations with VO_2 in clinical populations (Rowlands, Eston and Ingledew, 1998). However, the ability of accelerometers to inform frequency and magnitude of accelerations and biomechanical movements (Chen and Bassett, 2005) has seen their application in sport increase. Early accelerometers entailed data measurement in a single plane of motion (uni-axial), with tri-axial models (antero-posterior, medio-lateral, vertical planes) more popular in multi-directional activities. When acceleration occurs, this causes transmission of the force through a spring that accelerates a mass suspended inside the unit (Figure 2.3). It is the displacement of these structures inside that generates an electrical signal proportional to the acceleration (van Hees, van Lummel and Westerterp, 2009). In this instance, accelerometers convert kinetic energy into electrical energy that is then translated into data to describe acceleration.

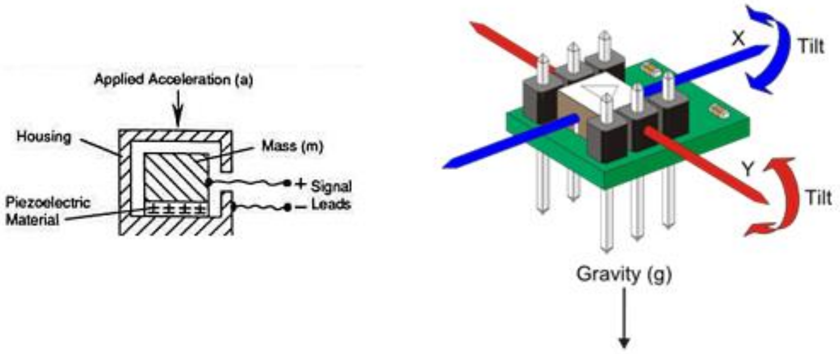


Figure 2.3: Schematic diagram of a triaxial accelerometer

Vanhelst et al., (2010) carried out a reliability study on the 2-10Hz RT3 accelerometer (StayHealthy Inc., CA) in 60 subjects. Heart rate, VO_2 and two accelerometers in the sagittal plane at the hip recorded each individuals trial of fifteen minute periods for activities ranging to from sedentary, walking, kick a soccer ball and treadmill running selected to reflect normal daily activities of increasing intensities. Results showed greater variability in vector magnitude (square root of sum squared in *x*, *y* and *z* vectors) with low-intensity and sedentary activity compared to more vigorous movement, particularly in vertical accelerations of the *y* axis. All three measures increased with intensity of activity although lower intensity activity was seen to have greater intra-unit variability, compromising the reliability of these actions in RT3. Validations of the RT3 have uses walking as the primary mode to compare acceleration counts with changes in velocity and measures oxygen consumption and energy expenditure (Levine et al., 2001; Rowlands et al., 2004). Greater velocities were found to increase the relationship between accelerations counts and walking and running at progressive velocities (r=0.80) (Rowlands et al., 2004).

Fudge et al., (2007) compared two uni-axial (CSA 7164, MTI Inc., FL. and Actigraph GT1M, MTI Inc., FL) and two tri-axial (3dNX, BioTel Ltd, UK; ActiHeart, Cambridge Neurotechnology Ltd, UK). Each were of different sampling frequencies and filtering ranges 10-100Hz. Subjects performed two tests; one continuous incremental treadmill test to exhaustion and one discontinuous incremental treadmill test of walking and running at selected speeds to exhaustion. Increased sampling frequency saw stronger relationships with running speed and accelerometer count and also with VO_2 and heart rate. This was especially true in tri-axial models with the uni-axial units seeing a plateau in accelerometer count at higher speeds attributed to vertical accelerations in running mechanics levelling off. Only tri-axial accelerometer 3dNX showed a linear relationship with VO_2 prediction during running up to 18km/h^{-1} (r=0.873). This model was said to be the best predictor for VO_2 when used in conjunction with heart rate which was associated with lower SEE (2.06ml/kg/min^{-1}). This then warranted the use of tri-axial accelerometers in future studies given their ability to record motion in three planes. Furthermore, quantifying these movements may help in evaluating an individual's running economy in relation to their $\dot{V}O_{2max}$. Depending on running biomechanics, greater vertical oscillation or lateral movement at given speeds may increase metabolic cost unnecessarily (Heise and Martin, 2001) suggesting the practical value of IS in sport for improved athletic performance and injury prevention.

One of the first studies to attempt validation and reliability of accelerometers in sport was by Boyd, Ball and Aughey (2011). MinimaxX 2.0 (Catapult, Australia) includes a 100Hz tri-axial piezoelectric linear accelerometer. Piezoelectric accelerometers detect movement when the seismic mass inside causes displacement of the piezoelectric element that then builds up an electrical charge proportional to the magnitude of acceleration (Chen and Bassett, 2005). The positioning of the mass in relation to beams causing deformation of the element can then detect accelerations in different directions other than that of the vertical axis (Chen and Bassett, 2005). Using the devised vector magnitude, Player Load, trials were carried out in a laboratory for static (6 x 30s) and dynamic (10 x 10s) reliability using a cradle mounted on a trundle wheel and a hydraulic shaker respectively. 180 high-intensity field training sessions and nine matches were then monitored in semi-professional Australian soccer players. Static reliability within and between-device were CV 1.0% each, dynamic reliability within-device was CV 0.91-1.05% and CV 1.02-1.04% between-devices at 0.5*g* and 3.0 *g*. Coefficient of variation in team training increased to 1.94%. In matches, between-device reliability was 1.9% CV, with all units below CV 2.80%. Data from the two attached devices on each player in matches revealed relationships of r=0.996-0.999. CV of all three testing scenarios were found to be less than the smallest worthwhile difference (SWD) of 5.88%, said to be of practical significance (Jennings et al., 2010). Overall, the MinimaxX accelerometers were suggested to be reliable in monitoring of team sports, showing higher reliability than those used in studies of physical activity and health.

Accelerometery in team sport training and match play

As a result of validation studies and purported benefits of accelerometer use in sports, numerous studies have utilised the technology in soccer training and match-play (Gomez-Piriz, Jiminez-Reyes and Ruiz-Ruiz, 2011; Gabbett and Ullah, 2012; Scott et al., 2012; Casamichana et al., 2013; Colby et al., 2015).

In a study of Spanish soccer players over 44 training sessions, Casamichana et al., (2013) sought to compare different indicators of load in quantifying soccer training, including 100Hz accelerometer (MinimaxX, v.4.0, Catapult Innovations). Sessions taken mid-season involved variations of technical-tactical training, SSG and running drills. Accelerometer-derived Player Load® (Figure 2.4) was on average 789AU per session. This vector magnitude represents the instantaneous rate of change of acceleration (Catapult Innovations Technical Note) and includes both running and non-running activity as a measure of effort. Player Load® was found to have large to very large correlations with total distance covered (r=0.70) due to the large contribution of vertical acceleration from the heel strike in running, Edward's HR TRIMP (R=0.72) and subjective sRPE scores (r=0.76). The authors suggested relationships between Player Load and internal load measures could signify importance of monitoring acceleration behaviours in helping to monitor training intensity where HR and high-speed activity are not emphasised. However, the study only analysed a small number of sessions and in a lower standard population. As such, there may be significant differences between results if an elite population was used of differing physiological characteristics and training loads.

$$\text{Player load} = \sqrt{\left((aca_{t=i+1} - aca_{t=1})^2 + (act_{t=i+1} - act_{t=1})^2 + (acv_{t=i+1} - acv_{t=1})^2\right)} \Big/ 100 \,,$$

Figure 2.4: Equation for Player Load vector magnitude used in MinimaxX devices triaxial accelerometer (Catapult Innovations, Australia).

In a similar study of even less observations (n=13) in elite Spanish players, Gomez-Piriz et al., (2011) used Body Load measures (GPSports SPI Elite) to assess training relationships with subjective RPE measures. Acceleration forces ('*g*') in three planes are used in by the tri-axial accelerometer in calculating Body Load in order to describe volume and intensity of accelerations. The data collected recorded accelerations and impacts of different magnitudes ranging from 5*g* (light player collision/ ground contact) to over 10*g* (severe tackle/impact). Contrasting with Casamichana et al., (2013), total accelerometer Body Load was found to have a weak correlation (r=0.23) with sRPE compared to that previously observed with HR and sRPE. Furthermore, sRPE was said to account for only 5% of the variance in Body Load which was thought to result from exclusion of specific skill-related actions of metabolic cost in soccer that may be accounted for better when using other methods to evaluate internal training load (RPE). Body Load was therefore concluded to be limited in its application to quantifying training load in soccer.

Comparing Player Load (MinimaxX v.2.0, Catapult Innovations) with sRPE and Banister and Edward's heart rate TRIMPS, Scott et al., (2013) monitored twenty-nine field training sessions with elite Australian soccer players. Average Player Load in a session was 558AU (range 278-1053AU), lower than that of Casamichana et al., (2013) but closer to values reported in match-play in team-sports (Boyd, Ball and Aughey, 2011). Player Load was found to have strong correlations with measures of external load from GPS such as total distance (r=0.93), a result of accumulated vertical plane acceleration forces from the repetitive heel strike during pro longed running that also involve a large braking force (Catapult, 2008). Although not found in IS Body Load (GPSports) by Gomez-Piriz et al., (2011), moderate relationships were also found between accelerometer Player Load and sRPE (R=0.84), Banister (R=0.73) and Edward's TRIMPS (r=0.80) also suggesting accelerometers may enhance quantification of external training load and can be related to internal measures. A more holistic representation of training may then be more attainable.

Using soccer-specific training drills (SSG) accelerometry is beginning to become more apparent in the literature. Casamichana, Castellano and Dellal (2013) found Player Load to be higher (~250AU) during SSG of larger numbers and in more continuous (2x8 and 1x16 minutes) regimen exercise bouts compared to interval-based games (4x4 minutes). Castellano, Casamichana and Castagna (2012) used the same device (MinimaxX v.4.0, Catapult Innovations) to compare any differences in Player Load metrics from SSG and friendly match-play. Player work-load was found to be increased when normalised for time in SSG compared to match-play (15.8 versus 13.5AU/min). This may again be reflected by the necessity for higher-intensity work and meterage (relative distance covered, 118 versus 113m/min^{-1}) in smaller format games of shorter duration than matches in order to attain a conditioning response. However, a higher distance and Player Load in SSG was not necessarily found by Casamichana, Castellano and Dellal (2013) and may be due to more unorthodox acceleration movements that don't contribute significantly to locomotor distance. Contrasting findings have also been reported in basketball. Comparing training drills, 5v5 scrimmages and matches, Montgomery, Pyne and Minahan (2010) saw Player Load to be significantly higher in a match (30AU/min) than offensive/defensive and scrimmage drills ($p<0.05$). Possible explanations for this were thought to be due to greater whole-court coverage in matches, but the discrimination between individual axis motion from Player Load and the inclusion of other IS such as gyroscope and magnetometer data may be appropriate in multi-directional movements that supplement mechanical load further.

Walker et al., (2016) used MinimaxX v.4.0 (Catapult Innovations) and SenseWear™ (Bodymedia, Pittsburgh, PA) tri-axial accelerometers in AFL training and matches to deduce methods of measuring energy expenditure. MinimaxX and SenseWear™ devices were used to determine absolute energy expenditure and thermogenesis from non-physical activity while Player Load was also plotted against estimated energy expenditure at certain VO_2 each minute of an incremental treadmill test to create individual regression equations. Mean Player Load in matches was 1235AU equating to 5745kJ. In training, Player Load of 565AU (2719kJ) was similar to that found in soccer by Scott et al., (2013). This study demonstrated that accelerometers may be useful tools in helping to determine energy expenditure in contact and team sports. However, caution was highlighted in interpreting energy cost between locomotion on a treadmill and in training where surface changes may see different gait patterns (stride length, contact time, vertical/horizontal displacement) and utility actions that will alter energy cost (di Prampero et al., 1986).

Colby et al., (2014) used inertial sensor technology to assess injury risk in all trainings and matches across a season in elite AFL players with the 5Hz SPI Pro X and 100Hz accelerometer (GPSports, Canberra, Australia). Variables were selected on the basis of low coefficients of variation previously found and their relation to injury risk in sporting settings. Analysis included distance above anaerobic threshold (>2m.mol/L^{-1}), velocity load (continuous running power at high speed), relative velocity change (algorithm of accelerations and decelerations in change in direction, summed), force load (foot strikes and collisions). Accelerometer-derived metrics (force and velocity loads and relative velocity change) were all higher in pre-season versus in-season period ($p<0.001$) and were also found to decrease in more experienced players with over seven years in AFL ($p<0.05$) who also had an insignificant increase in injury in-season. In pre-season, velocity load between 6737-8046AU over three weeks was suggested to see lower injury risk compared to lower values which was a weekly change in relative velocity change of 0.1-9.4AU. In-season, three-week force loads above 5397AU were associated with higher probability of injury, as was a four-week relative velocity change load >102AU. Metrics from inertial sensors and GPS may therefore help provide information on injury risk in team sport athletes across training phases. External load is important to measure biomechanical stress to minimise overtraining and subsequent injury in players of different ages and training experience (Rogalski et al., 2013; Colby et al., 2014). This study also highlights a minimum requirement of accumulated velocity load and total distance in certain groups (over a minimum three-week period) in order to provide a protective effect against soft tissue injuries injury and also to withstand rigours of match-play. It must be noted that the metrics used in this study are not validated and as such require further scrutiny and data collection with regards to their application in the team sport setting.

Having previously validated accelerometer use in team sports, Boyd, Ball and Aughey (2013) quantified external loading of AFL match-play using tri-axial accelerometry with Player Load and Player Load Slow (activity $<2m/s^2$). This is of particular importance in intermittent team sports such as soccer where low-velocity activity often consists of energetically taxing utility movements or ball-skills (Varley and Aughey, 2013). Using MinimaxX v.2.0, matches (n=24) and training sessions (n=32) were analysed in forty top-level AFL players. Results showed Player Load and Player Load Slow per minute to be higher in SSG compared to open and closed skill drills, similar to the findings of Montgomery, Pyne and Minahan (2010) in basketball. Furthermore, match-practice had a higher relative Player Load then skill drills (16AU/min in midfielders), though tactical training saw greater relative Player Load Slow than match practice (3.5 versus 3.3AU/min). SSG had greater relative values for both Player Load metrics compared to match practice which also agrees with research in soccer using a similar MinimaxX accelerometer (Casamichana, Castellano and Castagna, 2012). Relative accelerometer Player Load variants may therefore be more appropriate tools in monitoring low-velocity running loads as opposed to traditional time-motion analysis and further discriminate between training drills on different playing areas and high-velocity capabilities. This can then elucidate relative loading on the musculo-skeletal system whilst avoiding the underestimation of energy cost in training and match scenarios. Finally, identifying differences between positions in exposure to low-velocity activity may help plan training and better prepare these groups for competition when HR methods are limited in confined spaces and short duration activity. Further the use of metrics relative to time in these instances are also necessary to be able to compare intensity between training and matches, for example (Aughey, 2011).

Furthermore, Gabbett and Ullah (2012) monitored 117 training session of elite rugby league players with 5Hz GPS and accelerometry (MinimaxX v.2.0, Catapult Innovations) to examine how low and high-velocity activity in training may affect soft tissue injury risk. Distance of accelerometer-derived accelerations of mild, moderate and maximum intensities were found to be predictors of injury rates in no and time-loss injuries in pre- and in-season periods. Up to 60% lower risk of time-loss injuries were reported with low-intensity running >542m and distance in moderate and maximum accelerations above 217m and 143m respectively. These types of low-velocity activity are therefore important to monitor with the help of accelerometers in order to quantify volume over time that may provide protection against potential injury.

Application of GPS and Inertial Sensors in Training and Match-Play

Training studies

As alluded to previously, GPS microtechnology is widely used in sport to help plan, quantify and moderate training and loads to lower injury risk and improve performance as well as describing work-rate/fatigue patterns in competition.

In soccer, Casamichana et al., (2013) using 10Hz MinimaxX v.4.0 GPS, found players to cover an average total distance of 6385m of which 191m was at high-speed (>18km/h^{-1}) and 62m sprinting (21km/h^{-1}) over 44 training sessions. The authors concluded GPS monitoring to provide valuable data on external load experienced during normal soccer training, with markers of volume (total distance) found to correlate with subjective indices and training load (TL). This may then provide a more holistic retrospective account TL accounting for different types of stress players are exposed to during sessions of different aims and intensities. It is well known, however, that prescription and intensity of training will differ between various staff concerned which can be a contributing factor to injury (Ekstrand et al., Unpublished, 2015).

Monitoring 29 sessions in, Scott et al., (2013) conducted a similar study of different TL markers, this time with 5Hz MinimaxX v.2.0. Average distance of 4467m (61m.min^{-1}) was less than that of

Casamichana et al., (2013), 70m.min^{-1}, and although different thresholds were employed, high-speed running (HSR, >14.4km/h^{-1}) and very high-speed running (VHSR, >19.8km/h^{-1}) were greater in the study by Scott (544m and 132m). Correlation coefficients revealed moderate to large relationships (r=0.41-0.80) of TDC, LID, HSR and VHSR with methods of internal load (sRPE, Banister and Edward's TRIMPS). Fluctuation in external load markers was also able to demonstrate planned periodization of the reference team in terms of volume and intensity markers (TDC, HSR). However, the study did not account for high-intensity acceleration efforts which have been suggested to be key in describing intense actions inherent in soccer (Dwyer and Gabbett, 2012; Varley and Aughey, 2013) and may provide improved detail with regards to the load of a training session.

In a study of over 3000 individual observations, Colby et al., (2014) used interpolated 15Hz GPS of 5Hz true sampling rate (SPI Pro X, GPSports, Canberra, Australia) to assess the use of GPS and accelerometers in linking player workload and injury over one AFL season. The pre-season period was found to have significantly higher TL of GPS metric such as TDC, distance >velocity at 2mmol.L^{-1}, HIR and sprinting. Accelerometry date also increased ($p<0.001$) in the preparatory period for velocity load (continuous and high-speed running power), force load (collisions and foot heel strikes, similar to the Player Load of Catapult GPS system) and relative velocity change incorporating the sum of accelerations, decelerations and changes in direction. Further, match-play running variables were elevated in-season compared to pre-season practice matches ($p<0.001$), with more experienced players (>7 years) producing reduced running outputs in the in-season training ($p<0.05$) than younger players of a lower training history. Similar to the study by Rogalski et al., (2013), preceding three and four-week TL accumulation was calculated to predict subsequent injury occurrence in pre-season with TDC of 70-86 kilometres associated with 5.5-times more risk of injury. However, a velocity load between 6737-8046AU was linked to a decreased risk of injury, as was sprint distance 864-1453m in such periods. A two-week total distance between 39618-45257m in-season on the other hand may reduce injury risk as did a force load of <4561AU over three weeks in-season, though relative velocity change greater than 102AU over four weeks may heighten injury risk in-season. This study demonstrated a greater variety of running modes in pre-season for development of physical fitness, though injury risk was elevated with the introduction of competitive match-play in-season, highlighting the need for correct training prescription and match monitoring in this period. Monitoring TL markers over three and four-week periods can detail accumulation of TL elements, minimising large increase in TL that may cause injury. As previously stated by Gabbett and Ullah (2012), however, higher TL's may be able to provide a protective effect against injury in some sports, but a balance of biomechanical loading will depend on the sport and nature of training in certain phases. Furthermore, GPS and accelerometers may provide pertinent information such as this in relation to sub-populations within a team depending on age and training history.

Match-play studies

GPS has been widely used in several sports for analysis of match-play activity such as both rugby codes, hockey, cricket, AFL and soccer (McLellan, Lovell and Gass, 2010; White and MacFarlane, 2013; Petersen et al., 2009; Akenhead et al., 2013). This is to provide key initial data with regards to the activity profiles of these sports (Aughey, 2011). The data from match-play analysis is also very different between sports with absolute comparisons ill-advised with expressions in relation to time more appropriate given varying durations and rotational policies (Aughey, 2011). To understand player outputs and periods of fatigue in the competitive environment which may then be translated into training practices, several key metrics are often utilised. These include total distance covered (TDC), high-intensity running (HIR), sprint distance (SPD) and accelerations and decelerations. All these may be influenced by contextual factors from match-to-match such as team formation (Bradley et al., 2011), match importance (Aughey, 2011), early dismissal (Carling and Bloomfield, 2010), fixture congestion (Della et al., 2013) and standard and rank of opponent (Mohr, Krustrup and Bangsbo, 2003; Rampinini et al., 2007). These should therefore be accounted for in post-match analysis of physical running performance for specific positional roles.

In AFL, Aughey (2010) used 5Hz GPS (MinimaxX v.2.0) in 29 elite matches to quantify player work-rate. Played over approximately 100 minutes of four quarters, TDC in AFL can often exceed 14 kilometres (140m.min^{-1}) of which the majority is under 15km/h^{-1} with one third HIR (>15km/h^{-1}). Specific changes in velocity were also described to incorporate physically demanding acceleration behaviour. Based on evidence of elite 100m sprinters accelerating at a maximal rate of 6m/s^2 in the first two seconds of a race followed by increases of 2m/s^2 thereafter combined with unpublished data of team sport athletes maximally accelerating between 2-3m/s^2, with 2.78m/s^2 decided upon to represent AFL athletes in this study. Findings showed that players maintained TDC and LIA over four quarters (except in the second), with HIR and maximal accelerations decreasing slightly from quarters two, three and four. These reductions indicated that fatigue may have had an influence on these key match variables. However, the author noted the importance of discriminating the time-course and context of these phenomena that may determine changes in physical outputs over a match. Relative analysis is also important in AFL and field hockey due to the large amount of rotations employed that see different absolute match exposures and distances covered.

In a similar study (Aughey, 2011) compared the physical outputs of regular and domestic AFL finals matches using 5Hz GPS (MinimaxX v.2.0). Although no differences were found in sRPE training load, TDC was substantially increased in some quarters and rotations and by 11% overall in finals matches. Furthermore, a 9% increase in HIR, particularly in the fourth quarter was found with maximal accelerations per minute nearly twice that (96.6%) of domestic matches showing large to very-large effect sizes (ES 0.46-2.22). An increase of 8-46% in starting velocity of accelerations of different bands was also observed in finals matches, with a reduced recovery period between maximal efforts. A larger number of accelerations were found to occur at higher starting velocities in finals, often starting at the lower end of the HIR running band culminating in more high-speed running that also saw the start of efforts of further acceleration (that may also culminate in higher magnitude decelerations, although not reported). The distance of high-level accelerations was estimated to be around 450m, calculated to incur an extra energy cost of 410kJ during these matches. These data reinforce the importance of monitoring physical loads during matches of different competitions and importance. The implications will benefit future conditioning strategies and use of substitute and rotations to maintain the physical outputs of the team over the course of the match.

The importance of high-velocity activity and maximal accelerations highlighted by Aughey (2010;2011) was taken further by Varley and Aughey (2013) in elite Australian soccer players during 34 matches with 5Hz GPS (SPI PRO, GPSports). An average of 126 high velocity efforts were recorded, being most frequent in wide defenders (156) and sprint efforts greatest in forwards (14). Maximal accelerations (>2.78m/s^2) occurred an average of 73 times, significantly higher in wide than central defenders ($p<0.05$). Further accelerations analysis revealed 48% of the highest efforts commenced <1m/s^2, 30% between 1-2m/s^2, 14% 2-3m/s^2, 6% 3-4m/s^2 and 2% above 4m/s^2 starting velocity. No differences were found between positions for either start or end velocity in top accelerations. Less than 1% of maximal accelerations efforts reached the sprint velocity thresholds, however this was suggested not to be a necessity in soccer to achieve top-speed, with 34% of sprints following a maximal acceleration. This study found maximal acceleration efforts to occur eight-times more than traditional sprint efforts (65 vs. 8), which was more than that of Bradley et al., (2009) using Prozone®. In soccer therefore, maximal sprint capacities may not be fully utilised in match-play (Carling et al., 2008). However, high-speed activity may still be attained through smaller accelerations following maximal accelerations which should question definitions of high-intensity activity in the literature. It would seem apparent that the ability to generate force and change speed effectively is key in soccer and that this should form part of optimal conditioning and monitoring strategies.

In rugby union, McLellan, Lovell and Gass (2010) average TDC from 5Hz (SPI-Pro) GPS was lower than other codes, 4774m and 5747m for forwards and back positions, with distance above 20.17km/h^{-1} in backs double that of forward ($p<0.05$) as was peak velocity (24.4 vs. 27km/h^{-1}), considerably less than that reported for AFL (300 vs. 3334m, Aughey, 2011) although different velocity bands for high-intensity work were employed. In twelve rugby league matches, movement patterns were found by Waldron et al., (2011) to be different to other team sports in seventeen elite players using 5Hz GPS (SPI-Pro, GPSports). Backs covered greater TDC than adjustables and forwards (6917 vs. 6093 and 4181m), sprinting 35 times for 316m, less than that reported in both AFL (Aughey, 2011) and soccer (Mohr, Krustrup and Bangsbo, 2003).

It is also important to note the use of GPS in the inclusion of impact events in collision sports such as rugby as a measure of physical load and trauma. Gabbett, Jenkins and Abernethy (2011) measured frequency of mild, moderate and heavy collisions to be from 14-26 in training depending on positions and around 30 collisions during one trial match as detected by 5Hz GPS and 100Hz accelerometer using the MinimaxX system (Catapult Innovations). Despite lower absolute running distances than other team sports, GPS and IS technology can still quantify a significant loading component in contact sports from frequent collisions, tackles and impacts that will subsequently require a different training emphasis. More data is still needed to elucidate these metrics, however.

With regards to soccer, there are few studies of competitive matches with GPS at the elite level due to restrictions on wearable technology. In 112 elite youth players from five age groups (U12-16), Harley et al., (2010) used 5Hz nDGPS (MinimaxX v.2.0) to assess activity profiles of youth players at different stages of maturation. Twenty-metre sprint times were used to deduce age-specific peak velocities (between 10 and 20m) and subsequent ratios when compared to sprint times of adult players (adult sprint time divided by age group mean). Six age-group speed zones were calculated with high-intensity running ranging from 15-18km/h^{-1} and sprint distance 19-23km/h^{-1} between age groups. Under 15 and 16 teams produced faster 10m peak velocities compared to under 12, 13 and 14 age groups. Absolute TDC was greater in U16 ages (7627m) as was high-, very-high intensity and sprint distances compared to all other age groups ($p<0.05$). All age groups covered approximately 30% TDC at high-intensity, 11% very-high intensity and 3.6% sprinting. When the data was analysed according to relative exposure, U15 covered highest TD compared to U12 and 13 age groups (118 versus 103 and 98m/min^{-1}). Using GPS to deduce age-specific velocity categories and accounting for match exposure, the match outputs of the five age groups in this study did not differ. However, using group means is a limitation as this may not account for individual capacities for maximal sprint speed (MSS) and aerobic capacity ($\dot{V}O_{2max}$) that may under or overestimate physical load (Hoff et al., 2002; Buchheit and Laursen, 2013).

There is an obvious need to monitor soccer match-play in competitions at the elite level in order to quantify outputs, fatigue and contribution to the weekly load for different populations. This can inform training and recovery practices, periodization and individual or positional attention. However, this is hindered as GPS devices are currently not permitted in official competitions.

GPS, Training Load and Injury

The interest in monitoring of training loads in relation to the incidence of injury is prevalent in elite sport. This is particularly important with the subsequent prescription of training. The emergence of wearable technologies and their application in monitoring athlete training loads, however, has helped describe external movement demands in training and match-play and can be utilised in explaining risk of injury and illness. More informed training prescription and potential for injury modelling and prediction are also made more realistic. As a result, there have been several studies across sports investigating the use of this technology in monitoring and injury prevention strategies. In semi-professional rugby league, Gabbett (2004a) found differences between pre- and in-season training intensity, duration and load in different standards of play. Furthermore, these variables were all found to be significantly related to injury incidence in both training and matches across the season ($p<0.05$). A gradual reduction in training intensity and duration by 10-15% over three seasons was also been shown to help reduce pre-season injury rates, where load is traditionally higher (39.8-50%), whilst still maintaining aerobic fitness (Gabbett, 2004b). These studies highlight the necessity for appropriate training periodization across phases to ensure preparedness for match-play whilst minimising injury risk. Gabbett and Domrow (2007) found differences in phases of training, their training loads, fitness levels and injury in two seasons of rugby league. The odds of injury were higher in pre-season with log increase of each load unit (155-590AU) compared to in-season where match-play ensured a reduction in training load whilst maintaining fitness.

In rugby league, Gabbett and Ullah (2012) used 5Hz GPS to examine how training running loads at different intensities affected soft-tissue injury rates in thirty-four elite players. Higher total distances were found in pre-season compared to the competition phase, with time-loss injuries three times more frequent than injuries that resulted in missing a match (42.1 versus 13.1 per 1000 hours). No time-loss injuries were found to be more common in wide-running forward positions (81.2 per 1000 hours), whereas time-loss and missed match injuries were more frequent in outside back positions (71.8 and 33.1 per 1000 hours). Using the Cox regression model, the distance covered at mild, moderate and high-intensity were significantly related to both time-loss and no time-loss injuries ($p<0.01$). Very-high intensity distances over 9 metres in a training session were also found to be related to more no time-loss injury risk, although interestingly this risk was lowered with greater distances covered at low-intensity and maximum acceleration bands. It was concluded that greater volumes of low and moderate intensity running and distance at different accelerations may protect against injury incidence. As a result, intense running and sprinting were advocated to be limited in training. However, this may be seen to underprepare players for high-intensity, intermittent sports where distances at near maximal velocities (~30km/h^{-1}) may exceed 300 metres and therefore players need exposure to these activities, serving as an injury prevention strategy for the hamstrings, for example.

Colby et al., (2014) used a different model of interpolated 15Hz GPS of 5Hz true sampling rate (SPI Pro X) in a study on workload and injury incidence in AFL training and match-play. Building on the work of Rogalski et al., (2013), different weekly loads and week-to-week changes in loads were calculated using GPS and accelerometer-derived metrics. GPS total distance, distance >individual aerobic threshold ($2mmol.L^{-1}$) and sprint distance as well as accelerometer force load, velocity load and relative velocity change (acceleration load) were all greater in pre-season training compared to that in-season ($p<0.001$). Conversely, match-play outputs were higher for in-season matches than pre-season non-competitive games ($p<0.001$). Injury incidence was higher in-season (110 versus 78 per 100 hours), consisting mainly of strains and contusions of thigh, ankle and foot. With respect to weekly loads, the strongest association with injury risk was with summed three-weekly loads. Pre-season injuries were more common with three-week total distances of 73-86 kilometres than those under this. However, velocity loads of 6737-8046AU and sprint distance 864-1453 were found to be associated with reduced injury risk. In-season injury risk was increased with force loads above 5397AU versus those less than 4561AU, with four-week relative velocity change above 102AU seeing greater risk compared with that less than 84AU. Week-to-week changes in RVC of 0.1-9.4AU in pre-season and in total distance of -549-6955m in-season were related to a reduced risk of injury. The proposal of ranges of loading metrics may help to guide volume and intensity of training sessions, with Rogalski et al., (2013) using sRPE finding previous to current week changes of >1250AU to increase odds of injury compared to a low-load group by 2.58 times, with Gabbett and Domrow (2007) reporting similar findings with a log increase in training load of 150AU. Although this comprehensive study provides data on the use of GPS and inertial sensors to link loading patterns and injury, several specialised metrics from accelerometer are not currently validated for team sport movements, with 9% of reported data also predicted due to issues with GPS coverage.

In a study of Australian soccer players (n=19), Ehrmann et al., (2015) compared GPS variables (5Hz, GPSports, SPI-Pro) from training and pre-season matches with soft-tissue injuries over one season. For each injury GPS loads were calculated for Injury (one and four weeks prior to injury), Pre-Injury

(1 and four weeks before Injury block). The only significant changes in metrics were in Injury block preceding an injury were found in metres per minute (9% increase compared to the season average) and New Body Load (7% reduction compared to the season average, both p<0.01). No differences were found in TDC, HID and VHID prior to injury in either one or four-week periods. It was suggested that an increase in session intensity with regards to relative distance and Body Load may have contributed to injury incidence, with in-season training consisting of shorter durations sessions, but having lower recovery periods between drills, therefore increasing training density. The reduced Body Load may have been a result of player pacing strategies or a warning of potential injury and could also signify an element of underpreparedness for match demands. This metric was suggested by the authors to be a more sensitive measure of other GPS variables for identifying injury risk, although this is a new measure that has yet to be validated in its reporting of physical demands in sport. Furthermore, the inclusion of match-play data to weekly loads is compromised by the fact that this was estimated from just eight pre-season matches which may not truly reflect demands of A-League competition in-season. This study was also based on a small population that encountered few injuries during the season (n=16) making it difficult to make confident conclusions with regards to the validity of these two metrics in relation to injury risk in soccer.

The use of these technologies in soccer settings has grown and enables a much-needed picture of external load. This included the context and strategy of the activity that will then influence outcome responses. Despite this, there is a need for continuity in scientific methodologies with regards to population, speed thresholds, and model. Indeed, more data is also required in the use of IS in soccer where quantification of sport-specific movements will benefit from further observations to improve statistical power and confidence.

Summary

The previous section discussed additional forms of monitoring commonly used in elite soccer environments. Combined with other physiological measures described earlier (blood and saliva enzymes and hormones) and GPS and inertial sensor biomechanical indices, these may all help to provide information on training load. Collecting relevant information detailing different types of load experienced by an individual can help in adjusting periodised training plans as well as gauge readiness to train and compete in a more holistic and individual way. As a result, performance and recovery are optimised in the lead up to competition, whilst also minimising risk of injury and /or illness in elite soccer.

Chapter 3.

COMPARISON OF GPS AND INERTIAL SENSOR TRAINING DATA WITH FIELD PERFORMANCE TESTS

Abstract

The aim of this study was to investigate the efficacy of using global positioning system (GPS) technology to monitor training load and subsequently inform performance testing outcomes in elite soccer players. Training sessions over 6 weeks in both pre-season (PS, n=26) and in-season (IS, n=24) and friendly matches (n=10) of 20 elite youth soccer players were monitored with kinematic loading data provided by 5Hz GPS. Training prescription was intentionally different in each pre- and in-season training phase in accordance with the principles of training. Training load was related to testing batteries for soccer-specific endurance (YoYoIR2), speed (20m straight-line) and power (squat jump) conducted in early pre-season (EPS), late pre-season (LPS) and at the end of a 6 week in-season competition period (C). The average durations of training sessions in pre-season and in-season phases were 98.1 ± 16.0 and 88.9 ± 15.9 minutes. Total distance covered was highest in EPS (37.9 ± 3.0km, $p < 0.05$) compared to LPS and C (27.8 ± 3.0km and 24.8 ± 3.3km). Average distance covered above 21km/h^{-1} was highest in LPS (1.18 ± 0.5km) compared to EPS and C (0.70 ± 0.1km and 0.42 ± 0.1km, $P < 0.05$). The frequency (number) of decelerations >3m/s^2 accumulated was 36.8 ± 2.8, 19.8 ± 1.4 and 7.0 ± 3.3 for EPS, LPS and C although these were not significantly different ($p > 0.05$). YoYoIR2 performance increased through the phases (1082 ± 184m in EPS, 1383 ± 217m in LPS and 1400 ± 277m in C). Sprint performance over 20m was reduced at LPS from EPS (3.11 ± 0.07s versus 3.04 ± 0.11s, improving by C (3.08 ± 0.06s). Power performance in squat jump was not different between each of the three testing sessions. When related to performance testing scores, markers of training load from GPS saw weak negative relationships with performance testing outcomes. Soccer-specific endurance performance was higher volume of training (total distance), with speed and power performance also improving over time. These should be recognised within the context that increased training status following an off-season break will also contribute to this as more training is accumulated and match-play is introduced through the pre-season and competition periods. In conclusion, although monitoring training by GPS may be beneficial in quantifying training load exposure, it may not be able to inform physical performance testing. The addition of friendly and competitive match-play data and

its effect on weekly training load may be warranted. Practical implications of this research reinforce monitoring practices of load to align with performance testing carried out periodically throughout the soccer season.

3.1 Introduction

Classical periodization of preseason training in soccer would target endurance and strength gains in the early preseason period before tapering the training load towards competitive match play. However, despite this reduction in training load there is, albeit largely anecdotal, evidence that physical performance progressively improves during the early period of the competitive season (an observation that is frequently referred to as ‘match fitness’). The lack of objective data to support the influence of match play on physical preparation is surprising because precise monitoring of training load is widespread. There are limited data available on manipulating training load in soccer but previous studies have only examined training load during a single phase (Wrigley et al., 2012; Scott et al., 2013) or compared discrete observations at different points across the season (Jeong et al., 2011). Furthermore, previous research has ignored the inclusion of match-play data to the weekly training load.

The aim of this study was, therefore, to determine how training prescription in the early preseason, late preseason and early playing season is influenced by match play. A further, novel rationale was to highlight the use of load monitoring techniques to describe and explain performance in relation to seasonal changes in physical capacities in a periodic testing battery. It was hypothesised that high aerobic loads of greater volume and intensity would improve soccer-specific endurance in pre-season, with the introduction of high-velocity work and match-play maintaining speed and power performance into the competitive in-season.

3.2 Methods

Twenty elite youth male soccer players (Age 18.3±1.2 yrs; Height 182.2±7.4 cm; Weight 76.1±7.6 kg) were recruited to take part in the study. All players participated in the Scottish Premier Soccer League U20 competition and UEFA Youth League at the time of data collection in the 2013-14 season. Data was collected during the first 6 weeks of the season (Pre-Season training sessions, PS, n=26) and also in the first 6 weeks from the start of competition (In-season training sessions, IS, n=24). Data from 10 friendly matches of the same playing squad played during the pre-season period were also included but the use of GPS was not permitted during official in-season competition. Match-play data from competitive matches in-season was collected through Amisco® semi-automated tracking system at a sampling rate of 25Hz (Randers et al., 2010). It should be noted that caution should be taken in comparing sprint behaviour (>24km/h^{-1}) in GPS and optical tracking systems due to variation in data reported (Harley et al., 2011). However, for the purposes of this study this was the only method of collecting match data. Training prescription in each phase was intentionally different with PS training led by coaching and conditioning staff with emphasis on optimising physical fitness in preparation for competition. PS began with combinations of large aerobic training games, intensive small-sided games (SSG) and continuous running drills. Over time, training progressed to smaller formats of SSG and possession games with shorter, aerobic intermittent linear and multidirectional running drills, reflecting a more anaerobic stimulus. IS training was dictated by the introduction of competitive match-play with a concurrent reduction in training volume and duration with more technical-tactical emphases, and a short taper leading up to a match. PS training typically consisted of five training days, with one recovery session and one day off. IS training schedule involved 3-4 training sessions, one match, one recovery day and one day off.

All players had been in full-time training for at least two years and were accustomed to the different formats of high-intensity interval training used in this study. All procedures were explained fully, with informed consent and medical approval obtained. The study was approved by the University of Glasgow ethics committee.

Procedures

Three testing sessions at the start (EPS) and the end (LPS) of preseason and after a six week in season period were carried out as part of normal periodic physical performance testing (Figure 3.1). The testing battery consisted of soccer-specific endurance which also determined individual’s maximum heart rate (YoYoIR2 test, validated by Bangsbo et al., 2008), a speed test over 5, 10 and 20m (previously used by Strudwick, Reilly and Doran, 2002) and lower body power with a squat jump (validated by Markovic et al., 2004).

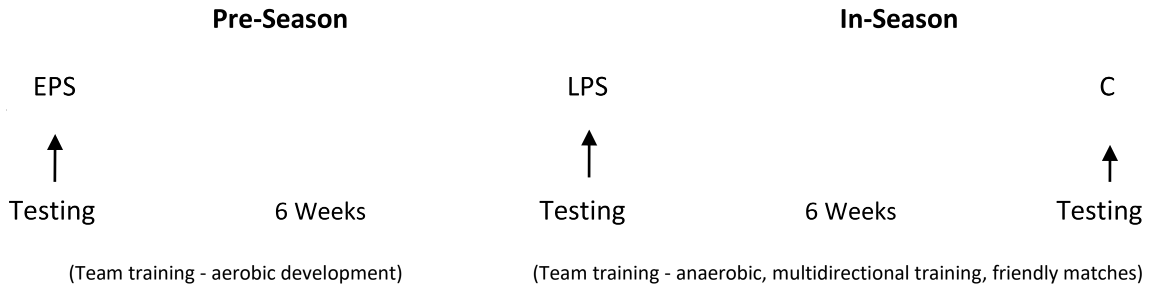


Figure 3.1: Schematic of study design

During each training session over the twelve-week study period, internal physiological loading was measured by heart rate telemetry (Polar Team2, Kempele, Finland) using monitors worn across the chest measuring at 5Hz. Polar Team2 software was used to analyse data immediately after each training session. Analysis calculated the average heart rate load of the session ($\%HR_{max}$ and beats per minute) as well as training impulse (TRIMP) for the session by multiplying mean heart rate by the session duration in minutes. The proportion of time spent exercising in discrete HR zones was also recorded (51-60, 61-70, 71-80, 81-90, $>90\%HR_{max}$, Dellal et al., 2012).

External, biomechanical loading was monitored using a 5Hz global positioning system (GPS, MinimaxX, Catapult Innovations, Scoresby, Australia) previously validated Portas et al., (2010) for use in monitoring soccer-specific movements. GPS units were positioned between the shoulder blades in a specially designed vest and switched on at least fifteen minutes prior to training. Velocity recorded was categorised into discrete thresholds and were similar to those used in previous studies of soccer time-motion analysis (Castellano, Blanco-Villasenor and Alvarez, 2011); 0-11km/h^{-1}, 11-14km/h^{-1}, 14-17km/h^{-1}, 17-21km/h^{-1}, >21km/h^{-1} (High-Intensity), >24km/h^{-1} (Sprinting). Total distance covered, frequency of efforts and percentage of time spent exercising at each of these intensities were recorded. GPS also provided frequency, and distance covered for accelerations and decelerations of different intensities; Low 1-2, Moderate 2-3, and High >3m/s^2 (Hodgson, Akenhead and Thomas, 2014). It was not feasible to individualise speed thresholds as it was felt the defined testing battery would not provide a true maximal sprint speed with which to base relative speed zones from.

To provide a subjective measure of training load, players were asked to give a rating of perceived exertion (RPE) a minimum of thirty minutes after training in accordance with Foster et al. (2001). Each player was asked ‘how hard was your session?’ to then provide their RPE using the modified Borg CR-10 scale (Borg, Hassmen and Langerstrom, 1985). This rating was then multiplied by the session duration in minutes to give a score in arbitrary units (session RPE). This measure of training load has previously been validated for use in monitoring soccer training, drawing correlations between sRPE and three heart-rate derived measures of internal training impulse (Impellizzeri et al., 2005).

All players were familiar with all methods of monitoring and had been using GPS and heart rate technology for the previous two seasons.

Statistical Analysis

Results are presented as mean±standard deviation. T-tests were carried out to determine differences between performance tests across each phase (EPS, LPS and C). Regression analysis was carried out to examine relationships between the mean weekly training load immediately prior to each testing session and subsequent performance testing scores. One-way analysis of variance (ANOVA) was used to identify differences between markers of training load in each phase. Correlations of match-play exposure (minutes played) were performed using Pearson's correlation coefficient. Significance was set at $p \le 0.05$. Analysis was carried out using IBM SPSS Statistics version 21 (Chicago, Illinois).

3.3 Results

Training duration in EPS was 95 ± 14 minutes on average, while LPS training was 92 ± 17 minutes and C (86 ± 7 minutes). EPS duration was greater than that in C ($p < 0.05$).

Table 3.1 shows data for selected markers of training load and intensity across EPS, LPS and C. Not including match-play, the average total distance covered (TDC) per week in EPS was 37.9 ± 3.0km compared to 27.8 ± 3.0km in LPS ($p < 0.05$). Relative distance per unit of time was 70.1 ± 3.5m.min^{-1} and 65.0 ± 4.1m.min^{-1} for EPS and LPS respectively ($p < 0.05$). TDC was also lower in C compared to LPS (24.8 ± 3.3km, $p < 0.05$). The average distance covered at high-intensity (>21km/h^{1}) per week during training was highest in LPS versus EPS (1.18 ± 0.5km and 0.70 ± 0.1km, $p < 0.05$) and also lower in C compared to EPS (0.42 ± 0.1km 0.70 ± 0.1km, $p < 0.05$). Peak velocity attained was greatest in LPS (26.6 ± 2.2km/h^{-1}) compared to 25.1 ± 1.2km/h^{-1} and 25.6 ± 1.9km/h^{-1} ($p < 0.05$) in EPS and C. The number of high magnitude accelerations were most frequent in LPS (37.0 ± 10.3) compared to EPS and C (24.7 ± 5.5 and 22.5 ± 5.0, $p < 0.001$ for both). Distance covered accelerating at this intensity was also highest in LPS (641 ± 115m), with average distance greater in C than EPS (518 ± 83m vs. 463.4 ± 76m). Decelerations >3m/s^2 accumulated each week in training progressively lowered through each testing phase. EPS (33 ± 8 decelerations) was significantly greater than LPS and C (23 ± 5 and 11 ± 3, $p < 0.05$ for both). However, the average distance covered of these decelerations were highest in LPS and EPS (383± 79 and 344 ± 63.2) versus C (260 ± 50, $p < 0.001$). Peak acceleration values were greatest in LPS (5.1 ± 0.2) compared to C ($p < 0.05$) and EPS (4.8 ± 0.1 and 5.0 ± 0.4). Peak decelerations were found in LPS (5.1 ± 0.1) which was higher than that in EPS and C (4.7 ± 0.4 and 4.5 ± 0.1, $p < 0.001$).

Comparing training (GPS) and match data (Amisco®), significant differences were found in the distance covered and number of efforts performed for both high intensity accelerations and decelerations when using their respective thresholds (>3m/s^2 and >6m/s^2 for accelerations; >-3m/s^2 and >-5m/s^2 respectively, $p < 0.001$).

Table 1 shows the average time-motion data from both friendly and competitive matches across the study period using either GPS or Amisco systems. All physical parameters except for total distance covered and meterage were higher in matches performed in-season compared to pre-season ($p < 0.001$).

Table 3.1: Time-motion analysis of match-play in pre-season and in-season periods

	Total Distance (m)	**m.min**	**High-Intensity Distance (m)**	**High-Intensity Efforts (#)**	**Sprint Distance (m)**	**Sprint Efforts (#)**	**Acceleration (# >3m/s^2 or >6m/s^2)**	**Deceleration (# >3m/s^2 or >5m/s^2)**
Pre-Season (GPS)	10427 (1036)	116 (12)	440 (170)	26 (9)	175 (100)	11 (5)	10 (8)	13 (5)
In-Season (Amisco)	10856 (928)	121 (10)	638 (191) ^{b**}	40 (11) ^{b**}	304 (136) ^{b**}	15 (6) ^{b**}	34 (10) ^{b**}	5 (3) ^{b**}

^{a}-PS>IS; ^{b}-IS>PS ($p < 0.05$; *$p < 0.01$; **$p < 0.001$).

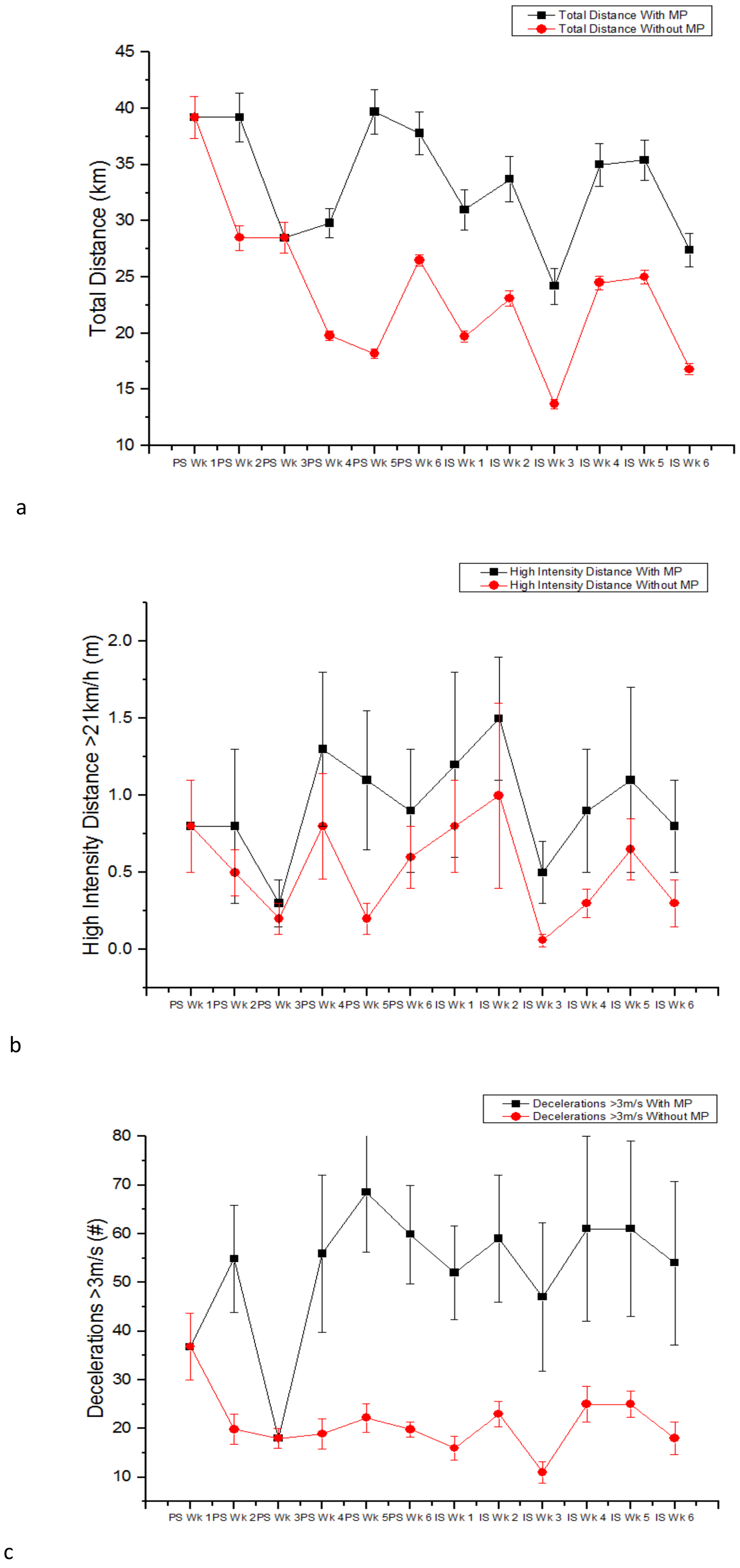


Figure 3.2: Pre-season and in-season performance parameters with and without match-play data. a – Total Distance Covered, b – High-Intensity Distance and c – Deceleration frequency

Table 3.2: Average player exposure in Friendly and Competitive matches in pre-season and in-season

	Matches (n)	**Total Minutes**	**Average minutes**	**90 min matches completed**
Pre-Season	3.6 (1.8)	251.2 (145.8)*	68.54 (21.6)	1.9 (1.5)
In-Season	23.9 (13.2)	1830.1 (1117.1)*	76.3 (14.3)	13.1 (8.5)

*Correlation between match minutes in pre-season and in-season r=0.987

Performance testing score changes across the pre- and in-season training phases are shown in Table 3.2. YoYoIR2 performance increased from EPS to LPS ($p < 0.05$) and again in C. 20m speed was worse at LPS compared to EPS ($p < 0.05$) but not different at C compared to EPS ($p > 0.05$). Squat jump performance did not change significantly through each phase and testing session. Jump power was found to increase non-significantly from EPS, LPS and C (45 ± 6, 47 ± 6, 49 ± 8W.kg^{-1}, $p > 0.05$). Squat jump increased from EPS to LPS and again at C. Body mass during the study period increased non-significantly from 63.2 ± 6.1kg in EPS to 63.4 ± 6.7kg and 65.01 ± 6.5kg in LPS and C respectively.

Table 3.3: Soccer-specific endurance, speed and power performance testing scores

	Early Pre Season	**Late Pre Season**	**Competition**
YoYo IR2 (m)	1082 (184)	1383 (217)	1400 (277)
20m Speed (s)	3.05 (0.11)	3.12 (0.07)	3.09 (0.06)
Squat Jump (cm)	60.5 (5.9)	61.0 (4.6)	63.8 (6.2)

Average weekly training load data and performance test scores were compared to examine any relationships between load exposure and training outputs with any changes in physical performance as a result of aerobic speed and strength training. Regression analysis revealed no relationships between training output and change in testing performance. TDC and YoYoIR2, distance covered above 21km/h^{-1} and 20m speed, and, decelerations >3m/s^2 and squat jump performance respectively were all found to have weak negative correlations in relation to the influence of training loads on changes in physical performance tests (Figure 3.3).

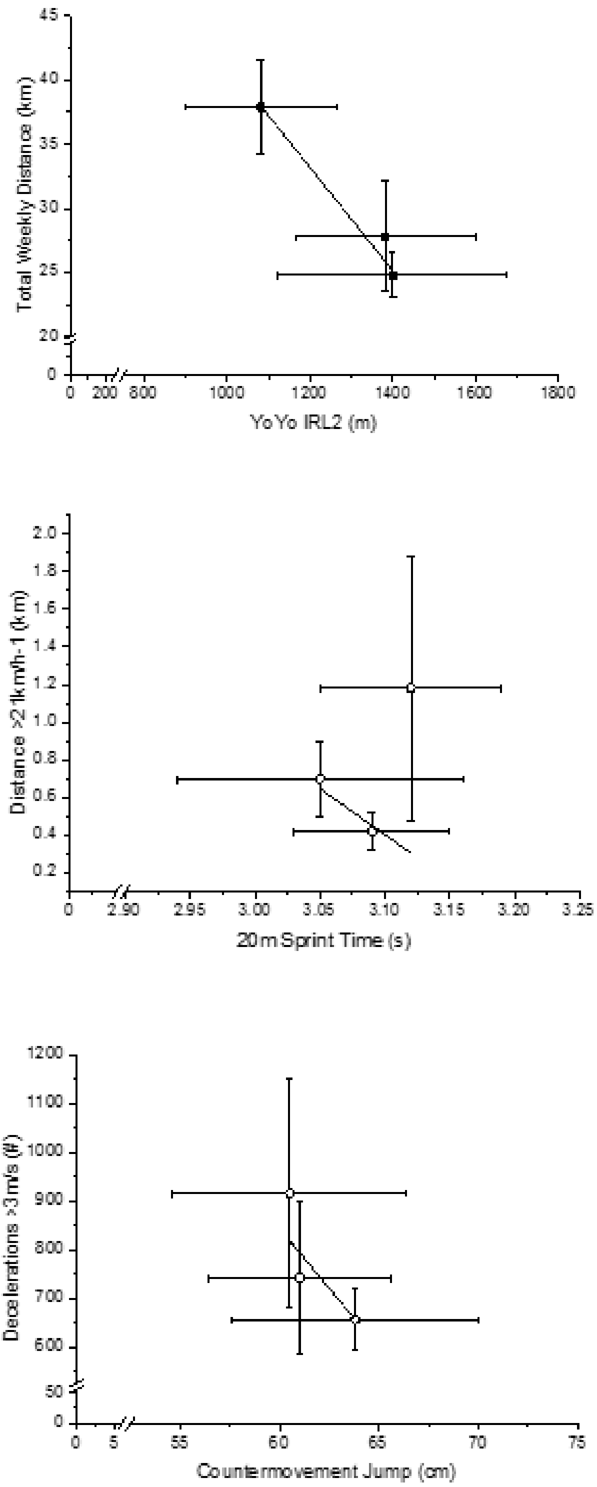


Figure 3.3: Regression analysis of training load measures and performance testing scores

3.4 Discussion

The aim of this study was to use GPS and inertial sensor technology to describe soccer training from an elite youth squad across two specific training phases. The secondary aim was to examine the relationship between the provision of different training loads and physical performance testing in each training phase and the additional effect of match-play on weekly training volume and intensity.

In a periodised training programme, EPS began with aerobic training of high volume and intensity progressively modified to anaerobic and finally more technical-tactical stimuli in LPS and C respectively as friendly and competitive match-play were introduced. Moreover, the aim was to promote stimuli to increase physical conditioning in PS to then maintain in C with a reduction in volume and intensity to IS training prescription.

The importance of monitoring training load and testing physical capacities specific to the sport has previously been reviewed (Casamichana et al., 2013; Svensson and Drust, 2005). Results showed significantly greater total distance covered in EPS approaching 40 kilometres per week subsequently reduced in LPS and C ($p < 0.05$). During this time soccer-specific endurance capacity increased at each testing point, meaning an inverse relationship was found between training distance covered and endurance testing performance, with mean YoYoIR2 distance increasing as training volume was reduced. Possible reasons for this increase in YoYoIR2 performance include a higher proportion of time spent exercising above 90%HR_{max} during the pre-season period (also found by Jeong et al., 2011) which was suggested by Helgerud et al., (2001) to be of benefit to aerobic fitness development, enabling more time to be spent exercising through aerobic sources before exhaustion. Furthermore, despite the lower training volume players were exposed to in training the introduction of friendly and competitive match-play in LPS and C may have provided a significant contribution to the aerobic load. The study of Rogalski et al., (2014) suggested similar effects of the gradual introduction to match-play in the pre-season period prior to competition. Similar to Gabbett (2004), they found that although training loads were reduced as the in-season period began, weekly loads were in fact increased as a result of match loads once or twice per week. Previous studies of competitive soccer matches have shown players to covered distances in excess of 12 kilometres (Bradley et al., 2009), equating to approximately 130m.min^{-1}, and at an average intensity of 85% maximal heart rate (Bangsbo, 1994). Moreover, match-play comprises of numerous high-intensity efforts that make up the intermittent profile that taxes both aerobic and anaerobic energy pathways (Carling, Le Gall and Dupont, 2012). As a result, this type of stimulus is also likely to have had an effect on improving $\dot{V}O_{2max}$ and subsequent YoYo test performance. The YoYoIR2 has previously been validated in its application to soccer players, with test performance showing a correlation of r=0.56 with $\dot{V}O_{2max}$ on an incremental treadmill test. Shown in Figure 3.2a, performing one match per week is therefore likely to provide a large contribution to an individual's weekly aerobic dose during the training week through total distance covered and high-intensity distance.

As in the present study, small-sided games in soccer training are frequently employed as a way of developing sport-specific fitness benefits. However, SSG do not fully replicate the repeated high-intensity demands associated with match-play as previously suggested (Sampaio, Abrantes and Leite, 2009) with research advocating larger games to replicate match-specific demands in youth soccer players (Hill-Haas et al., 2009). In the current study, training was supplemented in LPS with high-velocity, intermittent interval running that enabled controlled high-intensity conditioning that promote higher velocities and accelerations and decelerations over longer distances. These are indicative of match-play, but are not possible in confined small-sided games (Gabbett, Jenkins and Abernethy, 2009; Casamichana, Castellano and Catsagna, 2012). The exposure to maximal sprinting activity was hypothesised to also aid linear speed performance over 20m. However, our results showed a reduction in speed performance from EPS to LPS. It could be suggested that this decrement is a result of elements of fatigue accumulated by players over the 6-week pre-season period that affected sprint performance more than jump and soccer-specific endurance tests. This may be so due to the increase in training load in the pre-season period for soccer players following the off-season break, which Rogalski et al., (2013) suggested may be apparent in elite AFL players.

Evidence of deceleration behaviours in soccer are scare in current literature. The present study showed the frequency of high-intensity decelerations executed in training declining from the start of pre-season to the competitive period, there were no differences found between squat jump performance at each testing phase ($p < 0.05$). The maintenance of power performance measured by squat jump could be attributed to the inclusion of high-velocity running drills in LPS that are less common in EPS where aerobic conditioning was of longer duration to provoke a higher cardiovascular training response. High-velocity running may help to act as muscular conditioning for large muscle groups such as the hamstrings which play a large role in eccentric force production and absorption in sprint mechanics and decelerations typical of match-play (Small et al., 2009). The movement pattern and neuromuscular involvement in a squat jump may then be refined as a result with the hamstrings role as powerful extensors of the hip. Although generic strength training programmes may have contributed to squat jump performance, it should also be considered that the finding of increases in player's bodyweight at each testing period throughout the study, with simultaneous maintenance of jump performance, could indicate an improvement in force capabilities. Thus, greater power is required to elevate larger mass and avoid reductions in performance. Furthermore, the inclusion of match-play to the training week in this study may have supplemented this significantly increasing volume of decelerations, with a larger playing area permitting longer and faster running efforts developing speed and acceleration proficiency (Hill-Haas et al., 2009), as well as other actions such as jumping that require high rates of muscular force development and eccentric production that may not be as easily simulated in training.

Although it may be suggested that improvements in physical performance testing may have occurred as a result of increasing match-play exposure throughout the twelve-week period, it should be noted that this is presented as a squad average. As friendly matches are introduced through the pre-season period, players may typically be given similar playing time of 45-60 minutes to gradually expose them to match environments, providing a similar volume of work representing the squads training load. However, matches have been purported to be of a lower intensity compared to ‘true’ competitive matches performed in-season, underestimating central nervous system and endocrine responses (Drust, Atkinson and Reilly, 2007; Rodrigues et al., 2007). As a result, there is a need to understand the context of individual matches (friendly or competitive) that can influence variability in movement activity, particularly at high-speed, where match-to-match changes can be as much as 30% (Gregson et al., 2010). For example, formation employed, opposition, home field advantage, match scoreline as well as the effect of an early dismissal may all effect physical outputs of the reference team (Gregson et al., 2010; Carling and Bloomfield, 2010). During the in-season, the introduction of official matches may then divide the playing squad into groups of distinctly different weekly training loads, starters and non-starters. It is common that the regular starting outfield players will gain weekly match exposure of close of ninety minutes at a higher intensity than friendly matches of pre-season. The source of training volume will differ in non-starters who may only play a small part in matches from the substitute’s bench (Table 3.2). To address this deficit, it is necessary for such players to be subject to additional conditioning that taxes both the cardiovascular and musculo-skeletal system through high-speed running and agility activities. This additional training may then effectively simulate key repeated high-intensity demands of match-play that are not easily attained in SSG (Casamichana, Castellano and Castgana, 2012).

Despite principles of training dictating a reduction in training load (taper) prior to competitive match-play, we have shown the inclusion of friendly matches in pre-season to maintain or even increase overall training load (Figure 3.2). In late pre-season and competition, total distance covered, high-intensity distance and deceleration volume in the training week are supplemented by matches which may contribute an increased weekly load that is often unaccounted for in training load analyses. However, there should be caution when comparing training and match data using different methods that employ contrasting sampling rates.

Practical Applications

The results of the present study show the value of implementing GPS technology to monitor elite soccer training. Although analysis revealed no statistical relationship with performance testing, the data provided can highlight the efficacy of training loads prescribed as well as identifying key metrics which can be related to physical performance proficiencies. Furthermore, it highlights the importance of taking into account other factors that may contribute to fluctuations in physical performance (such as accumulated fatigue, strength training sessions and the introduction of match-play). Nevertheless, the results may be useful in generating normative data to compare with planned training loads in different phases of the season and identifying appropriate game-play formats that offer different stimuli in order to prevent excessive loading that are beyond the physical capabilities of the group or certain individuals, subsequently leading to fatigue and potential injury. This will be explored in the subsequent experimental chapters. However, despite the use of friendly matches in the present study, which is a limitation, the results also suggest the inclusion of accurate match-play loads are warranted in-season when training is intentionally tapered prior to competition. Including information of physical demands of match-play would the enhance understanding of holistic training load across cycles of training which may help in minimising injury risk and overtraining.

Chapter 4.

Player numbers and game format in small-sided games

Abstract

The aim was to examine the effect of different player numbers on game strategy and subsequent loading responses in SSG (4v4, 5v5, 6v6) and how this compared to responses of possession format games without goals or goalkeepers (5v5). Twelve elite youth soccer players were monitored with heart rate and 5Hz global positioning system, with rate of perceived exertion providing perceptual load. The results show that changing player numbers and game format influenced indices of training load. Decreasing player numbers when goalkeepers were present produced higher internal heart rate load (89.0±2.9%HR_{max}, ES=0.8), whereas meterage, high-intensity activity and high-level acceleration distance were elevated in 6v6 compared to smaller organisation (141±9m.min^{-1}, ES=0.9, 47+30m, ES=0.8 and 27±16, ES=0.8). The possession game produced highest aerobic loads through percent maximal heart rate (89.8±3.1HR_{max}), meterage 144±9m.min^{-1} and mean velocity 7.6±0.5km/h^{-1}). The data would seem to suggest an influence of mean exercise velocity the attainment of cardiovascular and particularly mechanical loads. Starting velocity may determine the ability to change speed and execute high-level accelerations in confined playing areas of different small-sided game formats. These data show that the number of players may not alter training responses, but physiological and mechanical intensity may be influenced further by the format and subsequent context of the SSG which are not necessarily position specific. Instead, the relative playing area available may be a more pertinent variable for mediating training load of SSG's in soccer.

4.1 Introduction

The use of small-sided games (SSG) in soccer training is very common, often prescribed by coaches as specific forms of high-intensity interval training. The benefits of employing training drills in these formats are that they can replicate and even exceed the metabolic and musculo-skeletal loads of match-play (Mallo and Navarro, 2007) in a more controlled, reproducible environment (Fradua et al., 2013). SSG's are an attractive tool due to their versatility and potential to influence training intensity. Numerous studies have examined the effect of manipulating variables such as pitch size (Kelly and Drust, 2009); player numbers (Hill-Haas et al., 2010) and bout duration (Fanchini et al., 2011) that can alter the subsequent training load (TL). Many of these studies have focused on examining intensity through internal heart rate load and found this to be higher with lower player numbers (Rampinini et al., 2007; Hill-Haas et al., 2009). However, there is little evidence on possession formats and running and acceleration demands with results contrasting and the effect on loading of different player numbers in relation to relative playing area remains controversial.

Manipulating this variable has been said to influence exercise demands by inducing a high heart rate response, yet the reliability of heart rate to describe intensity of an intermittent activity such as soccer has been questioned (Achten and Jeukendrup, 2003; Buchheit and Laursen, 2013).

The use of global positioning systems (GPS) may be a way of discriminating between SSG intensity. A better understanding of Player Loading in SSG may be achieved through a combination of GPS and heart rate measures (Drust, Atkinson and Reilly 2010). This may then provide a more accurate representation of the demands of different SSG by including previously unaccounted mechanical outputs, such as maximal accelerations, that could have further implications for muscular fatigue and energy cost compared to traditional sprints of longer distance and more linear in nature (Dwyer and Gabbett, 2012).

The aim of this study was to examine the influence of player's strategic adjustment to different SSG formats on common GPS derived indices of training load. This study will also include further detail with the inclusion of acceleration behaviour and a comparison of SSG and a possession-based formats without the use of goalkeepers.

4.2 Methods

The data in this study was collected during the 2013-2014 soccer season. All players were familiar with heart rate and GPS equipment having worn them regularly in training prior to the study. Before data collection took place, all players completed the team sport specific YoYo Intermittent Recovery Test Level 2 (Bangsbo et al., 2008) in order to determine their maximum heart rate (HR_{max}). It had previously been found to produce heart rates of 100±1.0 and 99±1.0 % for YoYo IR levels 1and 2 compared to heart rate values obtained in a laboratory treadmill test Krustrup et al., 2003; Krustrup et al., 2006).

Subjects

Twelve elite youth male soccer players from the same squad were used for data collected for all small-sided games (Mean ± Standard Deviation; 18.0 ± 1.2 yrs, 182.1 ± 7.9cm, 74.7 ± 6.3kg, 194.3 ± 6bpm; YoYoIR2 1338 ± 249m). All players played at a club participating in the Scottish Youth Premier League and UEFA Youth League. Players also had a minimum of two year's experience of full-time training in this study. The typical training week consisted of 3-4 field training sessions, 3 gym-based strength sessions, one competitive match and one recovery session. Approval for the research study was given by the University of Glasgow ethics committee.

Procedures

Each SSG were performed in a random order following a standardised 20 minute warm up and carried out at least twice, separated by a minimum of seven days. Players were fully accustomed to sport-specific high-intensity interval training in the form of different SSG modes. The independent variables were the number of players used and playing area, relative to player numbers, of each SSG. In SSG of different numbers (4-, 5-, and 6-a-side), absolute pitch size was altered to ensure relative pitch size was kept constant at ~150m^2 (Aguiar et al., 2013). These player numbers were chosen as they are common in the applied soccer training environment. To compare different SSG formats, a possession game (without goals) of 5 v 5 was employed with a relative playing area was 152m^2 per player. All SSG formats were performed as 4 x 4 minute high-intensity aerobic intervals (2 minutes active recovery). It was not possible to record the time the ball was in play. The design of each SSG is outlined in Table 4.1.

Table 4.1: Design and format of small-sided games

	4v4 (SSG4)	**5v5 (SSG5)**	**6v6 (SSG6)**	**Possession (5v5)**
Duration (mins)	4 x 4	4 x 4	4 x 4	4 x 4
Recovery (mins)	2	2	2	2
Pitch size (m)	40 x 30	45 x 34	49 x 37	39 x 39
Total area (m^2)	1200	1530	1813	1200
Area per player (m^2)	150	153	151	152
Goalkeepers	Yes	Yes	Yes	No
Conditions	2nd game 2T, 3rd game 3T	2nd game 2T, 3rd game 3T	2nd game 2T, 3rd game 3T	2nd game 2T, 3rd game 3T

2T= Two touch; 3T= Three touch

The following methodological procedures regarding monitoring equipment used for measuring heart rate internal load, locomotor external load and self-reported subjective load will be common to the each of the subsequent experimental chapters in this thesis. Similarly, the statistical analysis in the results sections will include magnitude-based inferences (Effect Sizes) for each chapter.

Heart rate responses

Internal physiological load was measured using heart rate telemetry (Polar Team2, Kempele, Finland) with monitors worn across the chest measuring five times per second. Intensity of exercise was classified according to four heart rate zones; 60-70%, 71-80%, 81-90%, >90%HR_{max}. The mean heart rate (bpm), percentage of maximum heart rate and time spent in each zone were analysed using Polar2 Team Software. Training Impulse (TRIMP) was also calculated according to Banister et al., (1975) by multiplying mean heart rate (bpm) by the duration of the SSG (minutes) to give a score in arbitrary units (AU).

Activity Profile

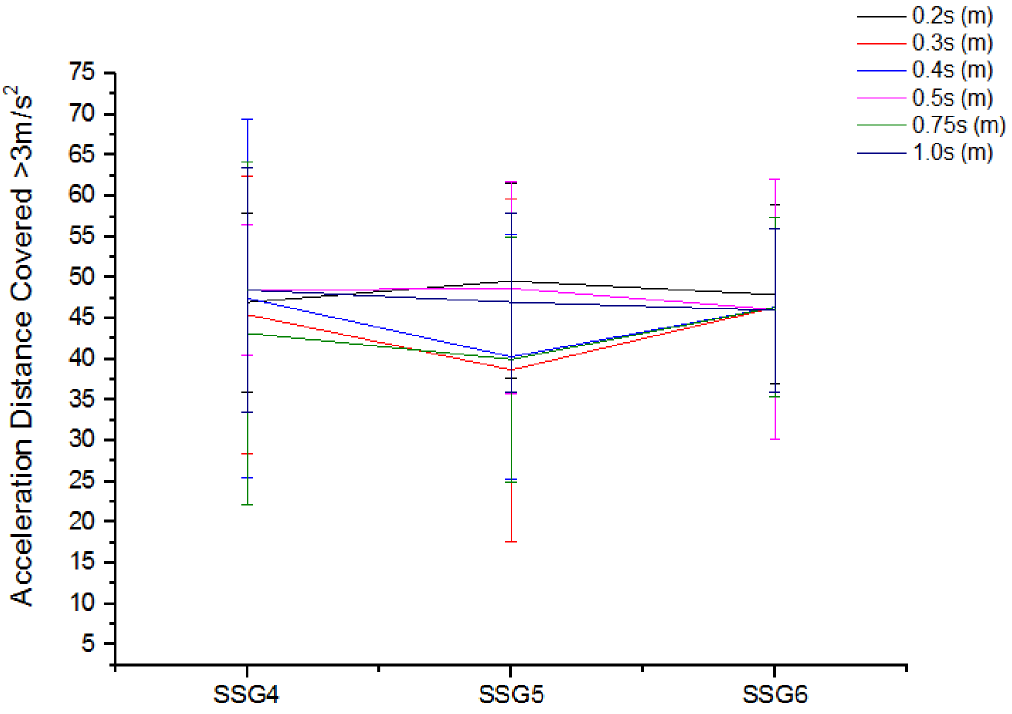
Analysis of locomotor activity was collected by GPS technology at a sampling rate of 5Hz (MinimaxX, Catapult Innovations, Scoresby, Australia) validated by Varley, Fairweather and Aughey, (2011). Velocity was categorised into discrete thresholds and were similar to those used in a previous study of time-motion analysis in soccer (Castellano, Blanco-Villasenor and Alvarez, 2011); 0-11km/h^{-1}, 11-14km/h^{-1}, 14-17km/h^{-1}, 17-21km/h^{-1}, >21km/h^{-1} (High-Intensity), >24km/h^{-1} (Sprinting). The distance covered, frequency of efforts and time spent exercising at each of these intensities were recorded. Furthermore, the distance covered ≥11km/h^{-1} and that ≤10.9km/h^{-1} were used to describe periods of work and rest respectively to deduce the work-recovery ratio.

Tri-axial accelerometer (100Hz) provided frequency and magnitude of non-locomotor, low velocity movements. Accelerations and decelerations were each divided into three levels; Low 1-2m/s^2, Moderate 2-3m/s^2, High >3m/s^2. A filter rate of 0.5s was applied to acceleration data in order to distinguish the most appropriate duration with which to record reliable frequency and distance of true acceleration efforts. A value of Player Load was utilised to obtain acceleration data in three planes of motion to provide an arbitrary value of mechanical loading (Boyd, Ball and Aughey, 2011). It has previously found to be correlated with distance covered, heart rate TRIMP and session rate of perceived exertion (Casamichana et al., 2013). Player Load is calculated using the following formula;

$$\text{Player load} = \sqrt{\left((aca_{t=i+1} - aca_{t=1})^2 + (act_{t=i+1} - act_{t=1})^2 + (acv_{t=i+1} - acv_{t=1})^2\right)} \Big/ 100\,,$$

GPS provided accelerations and decelerations that were divided into bands; 1-2m/s^2, 2-3m/s^2, >2.78m/s^2 and >3m/s^2. Analysis of filtering rates applied to qualifying accelerations of higher intensity (>3m/s^2) was also performed. Filter rates of 0.2, 0.3, 0.4, 0.5, 0.75 and 1.0s were applied for each SSG with goalkeepers of different player numbers used in the study to distinguish the most appropriate duration with which to record reliable frequency and distance of acceleration efforts. Initial analysis at 0.2s filtering was considered too low and produced very high frequency of efforts. The author therefore felt it necessary to be able to adequately discriminate between intentional accelerations with actual locomotion and simply a change in upper body orientation of the GPS unit. This would then deduce an appropriate filter for recording acceleration behaviour. Figure 4.1 illustrates different filter applied to SSG data, with 0.5s found to be the median rate discriminating high-level acceleration efforts.

GPS units were turned on a minimum of fifteen minutes prior to the session commencing to allow for sufficient satellite signal to be received. Data from GPS and accelerometer were analysed using Catapult Sprint software version 5.0.9.2.



a)

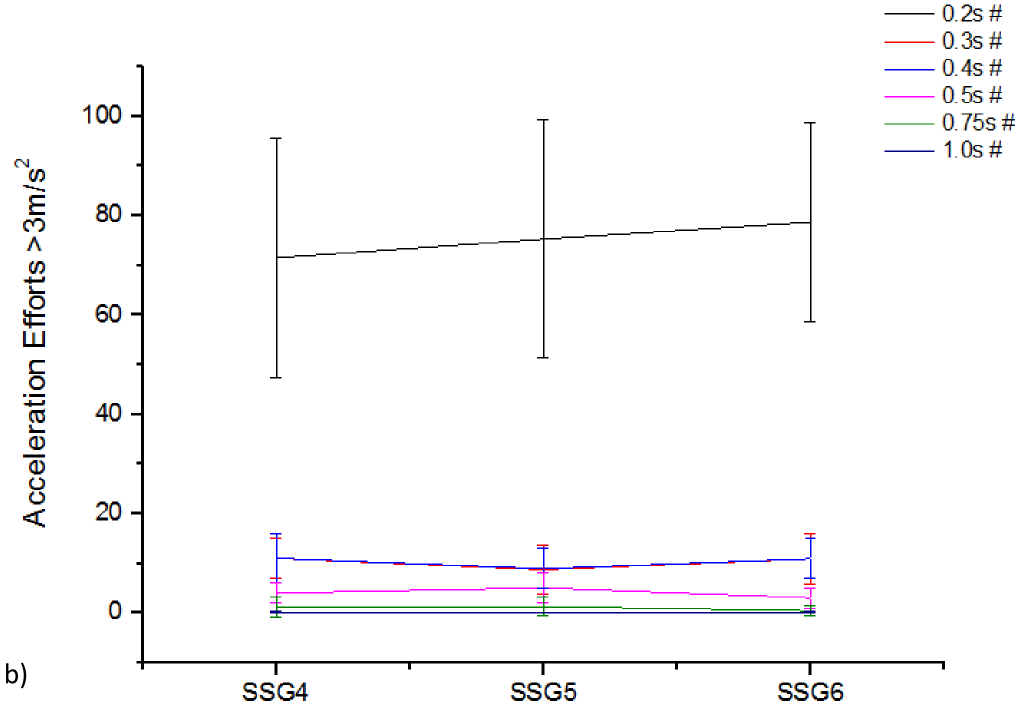


Figure 4.1: Effect of different GPS sampling rates on a) distance covered and b) number of efforts reported for accelerations >3m/s^2 in small-sided games of different player numbers

Subjective Loading

A subjective score of perceptual training load was provided by each player after each SSG. This was done a minimum of thirty minutes after cessation of each training drill in accordance with Foster et al., (2001). The score given was taken from the Borg CR-10 scale (Borg, Hassmen and Langerstrom, 1985) which was then multiplied by the total duration of the SSG in minutes to calculate a session rating of perceived exertion (sRPE). The validity of sRPE has been confirmed by Impellizzeri et al., (2004) with (Casamichana et al., 2013) drawing correlations between sRPE and the Edward's method of heart rate TL.

Statistical Analysis

Results are presented as mean ± standard deviation. Differences between dependent variables (distances, speeds, heart rate and subjective measures) were determined using one-way analysis of variance (ANOVA). Any differences between different game formats (SSG and possession) were determined using paired *t*-tests. Bonferroni post hoc tests were used to identify significant differences between parameters in each SSG format. Pearson's correlations were performed between dependent variables of each SSG format. Significance was set at $p \leq 0.05$. Analysis was carried out using IBM SPSS Inc. 19 for Windows. (Chicago, IL, USA). Magnitude-based effects were also determined according to Cohen's *d*. Effect sizes were classified as small (0.2), moderate (0.5) and large (0.8) (Cohen, 1988).

4.3 Results

Internal Training Load

Physiological load was represented by heart rate analysis of 4 x 4 minute bouts for each SSG format and is presented in Table 4.2. Data given is as a percentage of individual maximum heart rate values. No differences were found between SSG of increasing player numbers ($p > 0.05$). The possession format produced a significantly higher average heart rate than that of SSG6 ($89.8 \pm 3.1\%HR_{max}$ vs. $87.1 \pm 3.6\%HR_{max}$, $p < 0.05$, ES=0.8). Time spent in the highest HR zone was greater in SSG4 (46±12%) compared to SSG5 (34.8±14%, $p < 0.05$, ES=0.8). No differences were found between 5 v 5 SSG and 5 v 5 possession formats ($p > 0.05$).

Subjective Training Load

RPE was not different with SSG of increasing player numbers ($p>0.05$). Subjective loading was higher in Possession compared to SSG5 ($p<0.001$, ES=1.7), SSG6 ($p<0.01$, ES=1.2) and SSG4 ($p<0.05$, ES=1.3).

Table 4.2: Physiological and subjective responses to SSG of different player numbers and game formats

	SSG4	**SSG5**	**SSG6**	**Possession**
Relative Playing Area (m^2)	150	153	151	152
%HR$_{max}$	89.0 (2.7)	88.4 (3.5)	87.1 (3.6)	89.8 (3.1) ^{c}
TRIMP (AU)	2803 (115)	2769 (163)	2769 (122)	2860 (117)
RPE (AU)	7.0 (1.2)	6.1 (1.1)	6.8 (0.9)	7.9 (0.9) ^{a,b**,c*}

^{a}- POSS > SSG4; ^{b}- POSS > SSG5; ^{c}- POSS > SSG6 ($p<0.05$, *$p<0.01$, **$p<0.001$).

SSG4 = 4v4; SSG5 = 5v5; SSG6 = 6v6; POSS = Possession. %HR$_{max}$ = Percentage of maximum heart rate; AU = Arbitrary Units; TRIMP = Training Impulse; RPE = Rate of Perceived Exertion

External Training Load

As shown in Table 4.3, GPS and inertial motion analysis revealed meterage to be significantly higher in the Possession and SSG6 games than SSG4 ($p<0.05$, ES=1.4 and ES=1.3). Distance covered at high-intensity and mean and peak velocities were not different between games of different player numbers ($p>0.05$). High-intensity distance was higher in Possession than SSG4 and SSG5 ($p<0.001$, ES=1.4 and ES=1.3). Furthermore, the average exercise velocity was higher in Possession games compared to all other SSG formats when player numbers were varied ($p<0.001$, ES=2.6, ES=2.7 and ES=2.2). Work-recovery ratio consisting of the distance covered both under and over 11km/h^{-1} was greatest highest in Possession compared to all other SSG formats ($p<0.001$).

When comparing 5 v 5 formats, high-intensity distance was higher in the possession format ($p<0.01$) as was mean velocity and work-to-recovery ratio ($p<0.001$), although the peak velocities achieved were in SSG ($p<0.05$).

Table 4.3: Time-motion outputs for SSG of different player numbers and game formats

	SSG4	**SSG5**	**SSG6**	**Possession**
m.min^{-1}	130 (14)	137 (12)	141 (9) ^{a*}	144 (9) ^{d**}
High-Intensity Distance >21km/h^{-1} (m)	26 (19)	28 (25)	47 (30)	67 (35) ^{d**,e**}
High-Intensity Distance m.min^{-1}	1.6 (1.2)	1.8 (1.5)	2.9 (1.8)	4.2 (2.2)
Mean Velocity (km/h^{-1})	6.1 (0.7)	6.5 (0.6)	6.5 (0.5)	7.6 (0.5) ^{d**,e**,f**}
Peak Velocity (km/h^{-1})	24.3 (2.0)	24.3 (2.0)	25.1 (1.9) ^{c*}	23.0 (1.2)
Work-Recovery ratio (<11 km/h^{-1})	0.4 (0.1)	0.4 (0.1)	0.5 (0.1) ^{a,b}	1.0 (0.3) ^{d**,e**,f**}

^{a}- SSG6 > SSG4; ^{b}- SSG6 > SSG5; ^{c}- SSG6 > POSS; ^{d}- POSS > SSG4; ^{e}- POSS > SSG5; ^{f}- POSS > SSG6 ($p<0.05$, *$p<0.01$, **$p<0.001$).

SSG4 = 4v4; SSG5 = 5v5; SSG6 = 6v6; POSS = Possession. m.min^{-1} = Distance covered per minute; km/h^{-1} = velocity in kilometres per hour; m = distance in metres

Differences in acceleration profiles between SSG of different player numbers are illustrated in Table 4.4. Analysis showed acceleration distance above 2.78m/s^2 was highest in SSG6 compared to the Possession and SSG4 ($p<0.001$, ES=1.4 and ES=0.9). The number of efforts at this intensity was greater in SSG5 versus the Possession format ($p<0.01$, ES=0.8). Distance covered accelerating above 3m/s^2 was higher in SSG6, SSG5 and SSG4 compared to Possession ($p<0.05$, ES=1.6, ES=1.2 and ES=1.3). This was also the case for the number of efforts executed ($p<0.001$). Deceleration distance above 2.78m/s^2 was greatest in SSG6 compared to 4v4, 5v5 and Possession formats ($p<0.001$, ES=1.6, ES=1.3 and ES=1.4), though no difference was found in the number of efforts ($p>0.05$). Above 3m/s^2, the distance decelerating was higher in SSG6 than 4 v 4 and 5 v 5 ($p<0.001$, ES=0.9 and

ES=0.9) and Possession (p< 0.05, ES=1.2). SSG6 was also found to have statistically more efforts of this magnitude than Possession (p<0.01, ES=0.8).

SSG5 was found to have greater acceleration distance and number of efforts >2.78m/^{2} and >3m/s^2 compared to the possession format of the same numbers (both p<0.001). Deceleration distance of the same magnitudes, however, were higher in possession (both p<0.01), though efforts decelerating >3m/s^2 were higher in SSG5 (p<0.05).

Peak acceleration values were higher in SSG4 (p<0.001, ES=2) and SSG6 (p<0.01, ES=1.6) compared to the possession game. Peak accelerations were found to be positively correlated with high-intensity distance (r=0.430), mean (r=0.346) and peak velocity (r=0.350, all p<0.001). Conversely, the highest decelerations achieved on average were found to be in the possession game although this was not significant (p>0.05).

Table 4.4: Acceleration and deceleration data of SSG of different player numbers and game formats

	SSG4	**SSG5**	**SSG6**	**Possession**
Accelerations >2.78 (m)	**23 (12)**	**27 (16)** ^{b}	**36 (16)** ^{c*,e**}	**16 (10)**
Accelerations >2.78 (#)	**6 (3)**	**7 (4)** ^{b*}	**6 (3)**	**4 (3)**
Accelerations >3 (m)	**17 (8)** ^{a}	**20 (13)** ^{b*}	**27 (16)** ^{e**,f*}	**8 (5)**
Accelerations >3 (#)	**4 (2)** ^{a**}	**5 (3)** ^{b**}	**3 (2)** ^{e**}	**0 (0)**
Peak acceleration (m/s^2)	**4.9 (0.6)** ^{a**}	**4.4 (0.8)**	**4.8 (0.8)** ^{e*}	**3.8 (0.4)**
Decelerations >2.78 (m)	**3 (3)**	**5 (4)**	**17 (12)** ^{c**,d**,e**}	**5 (3)**
Decelerations >2.78 (#)	**4 (3)**	**4 (3)**	**5 (2)**	**4 (3)**
Decelerations >3 (m)	**2 (2)**	**2 (2)**	**13 (15)** ^{c**,d**,e}	**6 (4)**
Decelerations >3 (#)	**2 (2)**	**2 (2)**	**3 (2)** ^{e*}	**1 (2)**
Peak deceleration (m/s^2)	**4.0 (0.4)**	**3.9 (0.7)**	**4.3 (0.5)**	**4.5 (0.6)**

^{a}-SSG4 > POSS; ^{b}- SSG5 > POSS; ^{c}- SSG6 > SSG4; ^{d}- SSG6 > SSG5; ^{e}- SSG6 > POSS; ^{f}- POSS > SSG4. (p<0.05, *p<0.01, **p<0.001).

SSG4 = 4v4; SSG5 = 5v5; SSG6 = 6v6; POSS = Possession. m = distance in metres; # = number of efforts

When altering player numbers, no differences were found between SSG for distance covered accelerating >3m/s^2 ($p>0.05$) except between 0.2s and 0.5s in SSG4 and between 0.2s and 0.5, 0.75 and 1 second filters in SSG5 ($p<0.05$). In terms of efforts recorded, each format had significantly different frequencies at each filter rate applied ($p<0.001$), except for efforts at 0.3 and 0.4s. A filter rate of 0.5s was applied to acceleration data analysis in this study.

4.4 Discussion

The aim of this study was to compare physical loading indices of small-sided games entailing different player numbers and game format whilst maintaining relative playing area. Although this has been addressed in previous research, player numbers were manipulated whilst maintaining a constant playing area, something that has been inconsistent in the literature. It was hoped that changing the number of players with the same space available to them and comparing two distinctly different game formats would then clarify the effectiveness of monitoring intensity in soccer training drills through heart rate and GPS.

Despite considerable research into loading of SSG, the effect of altering the number of players on physical responses remains controversial. Existing research has tended to focus on a change in player numbers whilst also increasing pitch size (Rampinini et al., 2007). However, it would seem that this methodology does not address which specific variables are most responsible for influencing subsequent physical outputs. Moreover, is it an increase in the number of players utilised or a reduction in available space? Additionally, traditional heart rate-based methods may not be entirely appropriate for grading SSG intensity in soccer. There may be a lack of sensitivity to quantify the intermittent profile of soccer training that incorporate significant anaerobic energy contributions. Furthermore, short bout durations may not allow the attainment of steady-state heart rate responses and given the lag in heart rate kinetics at the onset of exercise, it may instead be more appropriate to analyse responses in time periods towards the end of the exercise bout rather than the total average. The use of GPS may then help in elucidating mechanical demands of these formats in elite soccer that heart rate may not be able to reflect.

When controlling for both player numbers and the relative pitch area, the main findings of this study was that traditional small-group play of different player numbers had no difference in physiological and perceptual responses in elite youth soccer players. However, altering game format when using the same player numbers appeared to influence locomotor and neuromuscular loading indices to a much greater extent than traditional SSG's in this study. In this case, the possession format (without goals) may have had a larger effect on markers of aerobic load in terms of average velocity and heart rate response, whereas SSG5 (with goalkeepers) may entail a greater mechanical load. Similar findings for possession formats were found by Castellano, Casamichana and Dellal (2013), who also found SSG including goalkeepers to produce even higher heart rate responses. This then highlights the influence of the game context to then dictate a player's strategy and ensuing behaviour and responses (Aughey, 2011).

As reported by Rampinini et al., (2007) and Hill-Haas et al., (2009), SSG of smaller player numbers increased physiological and perceptual load. However, heart rate measures and RPE between traditional SSG were not different, suggesting that there is little effect of player numbers on heart rate and RPE when playing area is also controlled, which these present studies results concur with. In the past, the number of ball involvements and player interactions in smaller SSG have been suggested to contribute to metabolic and perceptual load compared to those of larger numbers (Balsom, 1999; Owen et al., 2011). However, given the pronounced meterage employed, it could be suggested that it is the strategy of the player to move away from opponents in order to find space that is of more importance in determining movement behaviour and loading responses. This may be a more appropriate way to evaluate the load and intensity experienced in these scenarios given the limitations of heart rate application in intermittent settings, where bout duration, field size and player numbers may alter heart rate kinetics disproportionately (Dellal et al., 2012).

Different player numbers had some impact on time-motion outputs. Average speed, quantified by metres per minute was not different between SSG's with restricted space in each meaning aims were directed at creating more distance between themselves and opponents. Furthermore, the threshold set as 'recovery' was still above that of the average speed which could have affected the ability to produce higher-speed efforts in such a confined environment. Our results are comparable to that of Gaudino, Alberti and Iaia (2014) suggesting a more continuous aerobic exercise pattern, particularly in the non-directional possession format, in which finding space to receive the ball is the main priority and allow more time for decision-making. On the other hand, the contribution of high-level accelerations to loading of the neuromuscular system appeared to be greater in SSG6 compared to SSG4. The number of acceleration efforts were not dissimilar between SSG4, SSG5 and possession game, yet with greater player numbers, efforts were executed over longer distances in SSG6 ($p<0.05$). This may result from desire to create large interpersonal distances between opposing players by producing larger accelerative forces towards space with the greater absolute area available (Vilar et al., 2014). High magnitude decelerations were not different in frequency with player numbers, with distance greater in SSG6 compared to SSG4 and SSG5. A similar mean but higher peak velocity achieved in SSG6 may explain this finding with larger player numbers. There may be a greater necessity to slow down or stop from higher starting speeds attained (due to opposition movements or pitch constraints) that culminates in greater eccentric load. The need to reduce speed in this instance accompanies the more activity at high intensity (>21km/h^{-1}) compared to 4- and 5-a-side games that is curtailed as a result of confined playing areas.

In contrast to traditional 5 v 5 SSG on the same playing area, adapting the format and rules of the game design appeared to mediate acute physiological, time-motion and subjective loading outputs to a larger extent. The inclusion of a possession game without goals, with the aim to maintain ball possession to score was intended to compare with SSG responses with the same player number as a result of different conditions imposed.

The possession format produced higher mean heart rate than SSG6 ($p<0.05$). A cause of this may also be due to a more continuous movement pattern then SSG, increasing mean velocity where players are constantly moving to find space to achieve the desired number of passes, as well as the fact there is no directional element to play without goals. Similar findings were reported for a possession game by Castellano, Casamichana and Dellal (2013), reflecting the requirement for increased work rate (distance covered, meterage and work-recovery ratio) compared to SSG's, suggesting a larger aerobic load demand in possession formats. The continuous profile may not only influence a higher perceptual load but also acceleration demands. These were hypothesised to be higher due to players attempting to track opponents and close off passing options (characterised by increasing acceleration efforts). However, higher accelerations and decelerations ($>2.78m/s^2$ and $>3m/s^2$) previously suggested by Aughey (2010) to be appropriate for team sports are not as apparent in possession compared to the intermittent nature of 5 v 5 SSG in this study with lower mean velocities. Previous research into similar formats implemented default acceleration thresholds that may not be as appropriate for soccer, however (Castellano, Casamichana and Dellal, 2013). Greater distance and frequency of high-level accelerations and decelerations performed may be more common in SSG due to a lower mean (and therefore starting) velocity compared to possession which requires forceful initiation of efforts to overcome inertia, change speed and subsequently stop again efficiently from higher peak speeds of SSG. Although higher magnitude initiation and termination of effort would suggest greater mechanical load in terms of concentric-eccentric force production and absorption, associated with muscle damage, it may be that the training formats in this study are not appropriate for reproducing key high-intensity aspects of match-play (Casamichana, Castellano and Castagna, 2012). The higher relative playing area available in matches ensures more walking and standing as players are already in enough space. Therefore, when accelerations are required, the starting velocity is lower. Osgnach et al., (2009) argued that a similar power to high-speed running can be achieved in maximal acceleration starting at low velocities, and it is this change in speed that is more taxing. On the other hand, it may be that different thresholds for ‘higher-intensity accelerations’ are required to form appropriate magnitudes for those in SSG compared to match-play.

It would therefore seem that modifying game format with the same player numbers and pitch size influences loading indices to different degrees.

Practical Applications

Coaches may mediate training intensity to achieve loading patterns more easily when changing format of traditional SSG’s rather than player numbers in soccer. The playing area may better discriminate between intensity of soccer training drills.

With the same player numbers, SSG and possession games may differ in terms of the strategy players adopt to be successful. Possession formats without the use of goals may stimulate more continuous exercise behaviour inducing greater cardiovascular and perceptual demands. With the use of GPS for biomechanical indices, the data may better describe SSG’s where heart rate may not adequately discriminate between games. As a result, another important finding of this study is the inclusion of mean and starting velocities with reference to acceleration behaviour employed and associated mechanical load. Dictated by the strategy of the format, player’s velocity may differ by desiring to move away from opponents or towards the goal to provide time and space to make decisions and manipulate the ball. Instantaneous velocity then determines how much force is required to change speed and overcome inertia, attaining higher speed and slow down when space is restricted. However, the distance and frequency of key acceleration actions may not be fully replicate match demands and high-speed activity due to environmental constraints. Interestingly, it could be the playing area available that has a more direct influence of markers of training intensity then varying player numbers. Later research in this thesis will look at the effect of this variable in more detail. It may therefore be said that both SSG formats used in this study may be more appropriate for aerobic conditioning, with additional conditioning activities needed to simulate anaerobic demands of matches. It may be of further use to include technical data in future studies, which was a limitation of this study. Coaches may therefore prescribe training more effectively for different stimuli according to conditioning purposes, player numbers and availability of goalkeepers.

Chapter 5.

Relative playing area in small-sided game formats

Abstract

The aim of this study was to examine how physiological, mechanical (acceleration) and perceptual loading varied in small-sided games (SSG's) on different relative playing areas with the same number of players and when uneven teams were employed. Twelve elite youth male soccer players were monitored for heart rate and time-motion analysis through global positioning system (GPS) in each SSG format. The results showed that cardiovascular, physical, perceptual demands were higher when relative pitch area was increased. These were most evident on the medium size pitch where heart rate was 88.7%HR_{max} and high-level acceleration efforts of 8, compared to 86.7%HR_{max} and 2 accelerations over 3m/s^2 in the small pitch format. The larger relative area available had particular influence on high-intensity distance (47±30m, ES=1.1 and ES=1.3) and peak velocity (25.2±1.6km/h^{-1}, ES=0.8 and ES=0.76) compared to the small pitch, as well as the length and occurrence of the most intense (>3m/s^2)accelerations and decelerations (35±9 and 8±3; 13±15 and 5±3 efforts) compared to the small pitch (all $p<0.01$). Deliberately uneven teams saw significantly greater markers of aerobic load in the underloaded team (84.4±4.9%HR_{max} vs. 80.4±4.8%HR_{max}), concluding that these possession formats with deliberate imbalance of team numbers may target conditioning stimuli for certain players. Furthermore, this study demonstrates how training load and intensity of SSG's may be mediated through contextual design that subsequently alters game strategy.

5.1 Introduction

Small-sided games (SSG) are a common form of training used in soccer to elicit stimuli for technical and physical conditioning purposes. Their versatility makes them attractive to coaches through a myriad of variations with which to manipulate game format and subsequent intensity. Some of the most common variables employed have altered the number of players (Hill-Haas et al., 2009; Hill-Haas et al., 2010), use of goalkeepers (Castellano, Casamichana and Dellal, 2013), bout duration (Fanchini, 2011) and both absolute and relative playing area (Aguiar et al., 2013; Rampinini et al., 2007). Previous research has examined physiological (heart rate and blood lactate) and subjective responses to traditional SSG with goalkeepers, with some reporting higher physiological cost and rate of perceived exertion (RPE) found to be higher with smaller player numbers (Rampinini et al., 2007) and larger playing areas (Casamichana and Castellano, 2010), although Kelly and Drust (2009) reported the opposite effect on heart rate with pitch size. Heart rate, however, has been questioned with regards to applicability to soccer training and match-play given the inherently intermittent movement pattern that comprises of a significant anaerobic energy contribution (Achten and

Jeukendrup, 2003; Buchheit and Laursen, 2013). To avoid any underestimation of physical intensity, work-rate may be further quantified with the use of global positioning systems (GPS), an area missing from earlier research (Rampinini et al., 2007). The use of GPS can help detail the frequency and magnitude of sport-specific actions that have not been included before. Initial research using this technology has emphasised the need for exercise over rest in SSG of greater relative playing area (RPA) with a higher total distance covered (TDC) and at higher speeds (Casamichana and Castellano, 2010).

Although a large body of literature has suggested significant cardiovascular strain in SSG with greater playing areas, it is unknown whether this is the case for mechanical loading indices. The physiological load of SSG has previously been described, but it may be proposed that these drills do not adequately simulate the movement demands of match-play in training, with specific reference to high-intensity efforts and higher magnitude accelerations and decelerations (Gabbett, Jenkins and Abernethy, 2009; Casamichana, Castellano and Castagna, 2012). To be able to repeatedly execute such actions are key physical requirements in soccer and form decisive changes in speed that are energetically taxing (Osgnach et al., 2009). As a result, the mechanical load on the musculo-skeletal system may not significantly challenged as in match-play. The addition of acceleration data absent from similar studies (Aguiar et al., 2013) may as provide vital information to this.

Other research comparing SSG with and without goalkeepers (possession) have found games without goalkeepers to be more physiologically and kinematically demanding in semi-professional players (Castellano, Casamichana and Dellal, 2013). Higher heart rate responses were found with less player numbers, with running demands greater with more players in possession formats on the same relative playing area. It could therefore be said that there is potential to mix the training design of small group play, with modifications to the design enabling mediated physical stress, ensuring greater control over the training process. Hill-Haas et al., (2010) had also studied the effect of using a floater and uneven teams with different player numbers on the same relative pitch size, hoping to quantify the effect of imposed imbalances had on training outputs. No physiological differences were found but perceptual responses were significantly higher in the underloaded team.

There is little research, however, surrounding the loading responses with these different formats, particularly in relation to acceleration behaviours (Aguiar et al., 2013). The different aims and underlying movement strategies employed by the players may tax physiological systems and/or the musculoskeletal system more significantly than others.

It is therefore the aim of this study to assess the loading and intensity of two different formats of SSG using the same player numbers. Building on previous research, the effect of relative playing area per player will be examined in traditional SSG conditions as well as an overload format of uneven teams, which may provide further information on how these types of activity can be manipulated to achieve greater physical or technical emphases. We hypothesise that higher physiological load will be associated with traditional SSG with goalkeepers, while possession and overload drills will require a greater kinematic workload, specifically with underloaded teams who may also elicit a greater internal response.

5.2 Methods

Data was collected during the 2013-2014 soccer season. All players were familiar with heart rate and GPS equipment having worn them regularly in training prior to the study. Before data collection took place, all players completed the YoYo Intermittent Recovery Test Level 2 (YoYoIR2, Bangsbo et al., 2008) in order to determine their maximum heart rate (HR_{max}).

Subjects

Twelve elite youth male soccer players from the same squad were used for data collected for each small-sided game format (Mean ± Standard Deviation; 18.0 ± 1.2 yrs, 182.1 ± 7.9cm, 74.7 ± 6.3kg, 194.3 ± 6bpm; YoYoIR2 1338 ± 249m). All players played at a club participating in the Scottish Youth Premier League and UEFA Youth League. Players also had a minimum of two year's experience of full-time training and were accustomed to high-intensity interval training formats used in this study. The typical training week consisted of 3-4 field training sessions, 3 gym-based strength sessions, one competitive match and one recovery session. Approval for the research study was given by the University of Glasgow ethics committee.

Procedures

Each of the SSG were performed in a random order following a standardised 20 min warm up and carried out at least twice, separated by a minimum of seven days. The independent variables were the, game format, number of players per team and playing area, relative to player numbers, of each game format employed. In SSG of 6-a-side the key variable was that relative pitch size was increased by 25m^2 each time for small, medium and large pitches, similar to that in the study by Rampinini et al., (2007). To compare different SSG formats and a subsequent change in available playing area per player, an 'overload' game of uneven teams of 6 v 4 was employed with a relative playing area was 84m^2 and 126m^2 per player in the team of 6 and team of 4 respectively. Each drill was performed as high intensity aerobic interval training, with the overload format entailing shorter work and recovery durations given the uneven nature of the teams, total work time was still the same, however. It was not possible to record the time the ball was in play in each drill. The design of each SSG is outlined in Table 5.1.

Table 5.1: Design and format of small-sided games

	Small Pitch (SSGS)	**Medium Pitch (SSGM)**	**Large Pitch (SSGL)**	**Overload (6 v 4)**
Duration (mins)	4 x 4	4 x 4	4 x 4	8 x 2
Recovery (mins)	2	2	2	1.5
Pitch size (m)	40 x 30	45 x 34	49 x 37	23 x 23
Total area (m²)	1200	1530	1813	506
Area per player (m²)	100	125	150	88/132
Goalkeepers	Yes	Yes	Yes	No
Rules	2nd game 2T, 3rd game 3T	2nd game 2T, 3rd game 3T	2nd game 2T, 3rd game 3T	2nd game 2T, 3rd game 3T

2T= Two touch; 3T= Three touch

5.3 Results

Internal Training Load

The heart rate response was highest in SSG played on the medium (125m^2) and large (150m^2) pitch sizes for 6 v 6 compared to the total average in the overload game ($p < 0.05$, ES=1.1 and ES=0.7). No difference was found between SSG on different pitch sizes as well as the overload game for time spent in the highest heart rate zone ($p > 0.05$).

In the overload format, playing as the underloaded team of 4 produced the higher mean heart rate compared to the team of 6 ($p < 0.001$, ES=0.8) as well as the amount of time spent above 90%HR$_{max}$ ($p < 0.01$, ES=0.81).

Table 5.2: Physiological, time-motion and subjective responses to SSG formats on different relative playing areas.

	SSGS	**SSGM**	**SSGL**	**Overload (Total Drill)**	**Team 6**	**Team 4**
RPA (m^2)	**100**	**125**	**150**	**53**	**88**	**132**
%HR_{max}	**86.7 (3.7)**	**88.7 (3.1)** ^{d*}	**87.1 (3.6)**	**83.9 (4.9)**	**80.4 (4.8)**	**84.4 (4.9)** ^{i**}
m.min^{-1}	**119 (18)**	**135 (10)** $^{b**, d**}$	**141 (9)** $^{e**, f**}$	**115 (5)**	**102 (10)**	**134 (8)** ^{i*}
HID (m)	**18 (18)** ^{a}	**47 (24)** $^{b**, d**}$	**47 (30)** $^{e**, f**}$	**0 (0)**	**0 (0)**	**0 (0)**
Mean Velocity (km/h^{-1})	**6.1 (0.9)**	**6.8 (0.3)** ^{b}	**6.5 (0.5)**	**6.7 (0.4)** ^{h}	**5.7 (0.6)**	**7.9 (0.5)** ^{i**}
Peak Velocity (km/h^{-1})	**23.5 (2.3)** ^{a**}	**25.2 (1.6)** $^{b*, d**}$	**25.1 (1.9)** $^{e*, g**}$	**16.4 (0.7)**	**15.6 (1.0)**	**17.4 (0.8)** ^{i**}
W:R (<11(km/h^{-1})	**0.3 (0.1)**	**0.5 (0.2)** ^{b**,d}	**0.5 (0.1)** ^{e**}	**0.4 (0.1)**	**0.3 (0.1)**	**0.6 (0.2)** ^{i**}
Acc >2.78 (m)	**13 (5)**	**43 (9)** ^{b**,d**}	**36 (16)** $^{e**, g**}$	**7 (5)**	**3 (2)**	**4 (4)**
Acc >2.78 (#)	**3 (2)**	**10 (2)** ^{b**,d**}	**6 (3)** $^{e**, g**}$	**2 (2)**	**1 (1)**	**1 (2)**
Acc >3 (m)	**10 (4)**	**35 (9)** $^{b**, d**}$	**27 (16)** $^{e**, g**}$	**2 (3)**	**1 (1)**	**2 (3)**
Acc >3 (#)	**2 (1)**	**8 (3)** $^{b**, c**, d**}$	**3 (2)** ^{g*}	**1 (2)**	**1 (1)**	**1 (2)**
Peak Acceleration (m/s^2)	**4.0 (0.4)** ^{a}	**5.0 (0.3)** ^{b**,d**}	**4.8 (0.8)** $^{e*, g**}$	**3.4 (0.4)**	**2.8 (0.5)**	**3.0 (0.6)**
Dec >2.78 (m)	**3 (2)**	**7 (3)**	**17 (12)** $^{e, f, g*}$	**4 (4)**	**1 (1)**	**4 (3)** ^{i**}
Dec >2.78 (#)	**4 (2)**	**6 (3)** $^{b**,d**, c}$	**5 (2)**	**3 (3)**	**1 (1)**	**3 (3)** ^{i*}
Dec >3 (m)	**4 (2)**	**5 (3)**	**13 (15)** $^{e**, g**, f}$	**1 (1)**	**0 (0)**	**2 (2)** ^{i*}
Dec >3 (#)	**2 (1)**	**5 (3)** ^{d*,b*}	**3 (2)**	**2 (1)**	**0 (0)**	**2 (2)** ^{i}
Peak Deceleration (m/s^2)	**4.3 (0.9)**	**4.5 (0.6)** ^{d}	**4.4 (0.5)** ^{g}	**3.7 (0.5)**	**2.8 (0.7)**	**3.1 (0.5)** ^{i**}
RPE (AU)	**5.7 (1.4)**	**6.3 (0.7)**	**6.8 (0.9)** ^{e**}	**6.7 (0.7)** ^{h*}	**5.6 (0.5)**	**7.7 (0.8)** ^{i**}

^{a}- SSGS>Overload; ^{b}-SSGM>SSGS; ^{c}-SSGM>SSGL; ^{d}-SSGM>Overload; ^{e}-SSGL>SSGS; ^{f} -SSGL>SSGM; ^{g}-SSGL>Overload; ^{h}- Overload>SSGS; ^{i}-Team 4>Team 6 ($p < 0.05$, *$p < 0.01$, **$p < 0.001$).

External Training Load

Time-motion data for each SSG format is displayed in Table 5.2. Global work-rate in terms of meterage was significantly higher in SSGL (ES=1.5 and ES=1.1) and SSGM (ES=2 and ES=0.6) compared to both SSGS and overload ($p < 0.001$). This was also the case for total distance covered at high-intensity ($p < 0.001$, ES=1.1 and ES=1.4), with SSGS consisting of a greater distance than overload ($p < 0.05$). In terms of mean exercise velocity, this was highest in SSGM and overload games compared to SSGS ($p < 0.05$(ES=1.1 and ES=0.86). The peak velocity achieved was higher in SSGM (ES=0.8) and SSGL (ES=0.76) compared to SSGS ($p < 0.01$) as well as all 6-a-side SSG compared to the 6 v 4 overload game ($p < 0.001$). The work-to-rest ratio of activity under and above 11km/h^{-1} was greatest on the medium (ES=1.2) and large (ES=2) pitch versus the small pitch size ($p < 0.001$), with SSGM also significantly higher than overload ($p < 0.05$, ES=0.6).

When comparing the uneven teams used in the overload format, the team of 4 was found to have higher meterage, mean and peak velocities (ES=3.5, ES=3.9 and ES=1.98) as well as a higher work-to-rest ratio compared to the team of 6 ($p < 0.001$ in each case, ES=1.89).

Acceleration data showed distance covered and efforts >2.78m/s^2 and >3m/s^2 were higher in SSGM and SSGL compared to the small pitch and overload games ($p < 0.001$). Deceleration distance >2.78m/s^2 was greater in SSGL than overload ($p < 0.001$, ES=1.5), SSGM and SSGS ($p < 0.05$, ES=1.1 and ES=1.6). The number of efforts, however, were more frequent in SSGM compared to SSGS and overload ($p < 0.001$, ES=0.7 and ES=1) and SSGL ($p < 0.05$, ES=0.4). The highest decelerations >3m/s^2 had a greater distance on the largest pitch compared to both the small and overload games ($p < 0.001$, ES=0.8 and ES=1.1) and medium pitch ($p < 0.05$, ES=0.7). Again, efforts at this magnitude were more frequent on the medium size playing area versus overload ($p < 0.01$, ES=1.3) and small 6 v 6 SSG ($p < 0.05$, ES=1.3).

There were no differences between accelerations above 2.78m/s^2 or 3m/s^2 in either the team of 6 or team of 4 players ($p > 0.05$). However, significantly more distance was covered by the team of 4 decelerating >2.78m/s^2 ($p < 0.001$, ES=1.3) and more often ($p < 0.01$, ES=1.9). This was also the case at an intensity above 3m/s^2 for distance covered ($p < 0.01$) and efforts performed ($p < 0.05$) compared to the team of 6 players.

Peak accelerations were higher on medium and large playing areas compared to the small (ES=2.8 and ES=1.2) pitch and overload (ES=4.5 and ES=2.2) format ($p < 0.001$ for both). The highest decelerations were found to occur in the medium and large pitches also, greater than those achieved in the overload game ($p < 0.05$, ES=1.4 for both). Peak acceleration in the SSG in this study was negatively correlated with mean velocity (r=-0.52) but positively correlated with peak velocity recorded (r=0.362, $p < 0.001$). Decelerations were also positively correlated with peak velocity (r=0.240, $p < 0.01$).

Subjective training load

Perceptual load was greater in SSGL and total average in the overload format compared to SSGS ($p < 0.001$ and $p < 0.01$, ES=0.9 for both). In the overload format, RPE was significantly higher when in the team of 4 than that reported for the team of 6 ($p < 0.001$, ES=3.1).

The difference in sampling rates applied to high-intensity accelerations (>3m/s^2) when comparing SSG formats on pitch designs of increasing relative playing area is shown in Figure 5.1.

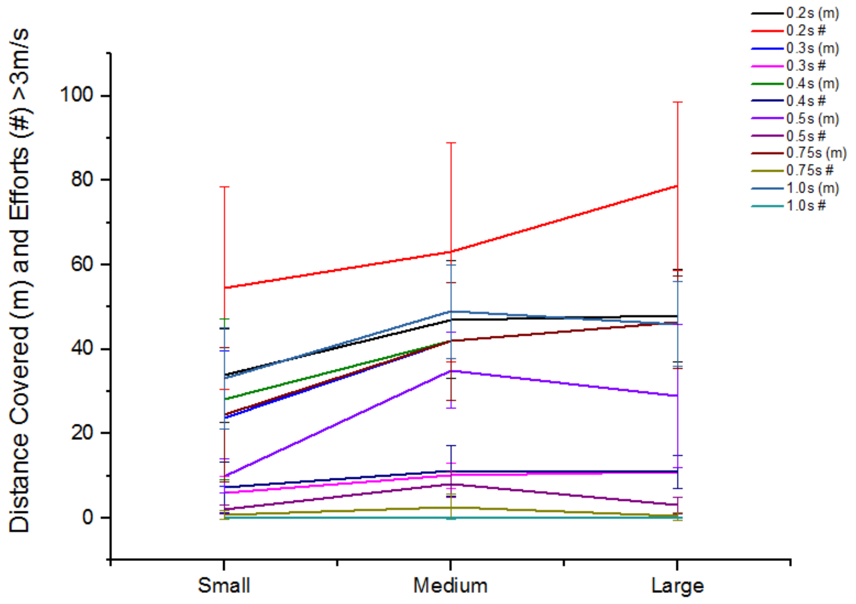


Figure 5.1: Effect of different sampling rates on distance covered and number of efforts of accelerations >3m/s^2 in small-sided games of different relative playing areas

Comparing the effect of filter rate on pitch size, no differences were found between distance covered >3m/s^2. However, the number of efforts performed were significantly different for each filter rate on each pith size ($p < 0.001$), except between 0.3 seconds and 0.4 seconds in all three pitch sizes. A filter rate of 0.5 seconds was applied to acceleration data analysis in this study.

5.4 Discussion

The aim of this study was to examine any differences between physical outputs during SSG of equal numbers on increasing relative playing areas and secondly to observe the effect of prescribing unequal or overloaded team formats that encountered differing relative playing areas as a result of the enforced imbalance in player numbers. Previous studies of SSG have utilised heart rate measures which may not accurately represent true intensity and loading of players over short durations and confined spaces. The extent as to whether or not SSG can effectively replicate key movements associated with match-play on varied playing areas in training may therefore be quantified through GPS devices.

The main findings of this study were that the physiological, time-motion and perceptual loading responses of SSG in soccer differ according to the relative playing area available. In contrast to previous research (Drust and Kelly, 2009; Rampinini et al., 2007), this study found increased physiological perceptual responses with larger areas. Furthermore, by progressively increasing the area per player, this study found a concomitant increase in accelerative load, particularly higher magnitude decelerations. This may have subsequent implications for mechanical loading with an environment more conducive to eccentric demands to promote adaptations to better withstand force. The use of numerical disadvantages between teams may also serve to inflict greater loading responses influenced by a requirement for strategies of higher work-rate to regain possession.

The results of this study are similar to other SSG studies in soccer (Hodgson, Akenhead and Thomas, 2014; Casamichana and Castellano, 2010; Rampinini et al., 2007), higher heart rates were attained with the use of larger playing areas relative to the number of players (% maximum heart rate and time spend >90% maximum), although SSGL was lower in this study in comparison (87.1%HR_{max}). This increase in heart rate with available space may partly be explained by the resultant increase in average velocity and subsequent meterage in SSGL and SSGM, augmenting the higher work-to-rest ratios observed in these formats. Therefore, SSG on larger areas may be beneficial for providing a stimulus for aerobic conditioning compared to those on smaller pitches, as heart rate intensity is close to that suggested to aid $\dot{V}O_{2max}$ improvements (Helgerud et al., 2001). It is these cardiovascular adaptations that aid in the transport and utilisation of oxygen to fuel what is a predominantly aerobic sport, also enabling faster recovery kinetics from intense efforts, therefore delaying effects of fatigue (such a muscular acidosis with lactate accumulation). These metabolic bi-products are then used in the Kreb's Cycle to be converted back in to energy substrates to continue exercise and preserve muscle function (Tomlin and Wenger, 2001). This effect on work-rate in larger games was also found by Casamichana and Castellano (2010) on increasing relative pitch area in 5v5. As in the present study, various measures of motor-behaviour (total distance, high-intensity distance, peak speed and work-to-rest ratio) and perceptual load were also greater on larger playing areas. This may be more useful information on physical intensity, given the existing limitations on heart rate application to monitoring exercise in intensity in intermittent sports9, such as soccer.

The time-motion data would suggest a significantly higher requirement for 'working' behaviour (>11km/h^{-1}) despite maintaining the relative area at each player's disposal. The inclusion of this data highlights the important role GPS monitoring may play in further discriminating between SSG's with different constraints imposed. This is such as traditional measures of heart rate may not adequately illustrate this with the intermittent movement pattern limiting high stroke volume (Hoff et al., 2002). Furthermore, although average heart rate and meterage achieved in the current study are in excess of those previously reported for match-play (Bangsbo, 1994; Bradley et al., 2009), our data suggests that small-sided soccer training drills may not effectively reproduce key high-intensity actions associated with competitive matches (Gabbett, Jenkins and Abernethy, 2009; Casamichana, Castellano and Castagna, 2012). For example the distance covered and frequency of efforts performed for high-level accelerations and decelerations are not as feasible in these environments. This is largely due to area constraints where interactions are more likely with players, particularly in central areas therefore increasing average velocity to move away from opponents and find space (Fradua et al., 2013). Also, players may initiate forceful accelerations in these games but are quickly hindered by pitch boundaries. It has been put forward by Seifert, Button and Davids (2013) that player's movements may be a result of continual functional adaptation that derive from the game design in order to maximise success. Indeed, the dynamic environment of SSG's channel relationships and subsequent behaviour of each team and individual players (Vilar et al.,2014). The observed higher work-rate and increased mean (and therefore starting) exercise velocity hinder any large changes in speed in SSG. This is especially true when space is quickly curtailed by pitch size, ensuring minimal high-intensity activity and lower peak speeds in comparison to match-play.

In addition to traditional SSG's of equal numbers, this study also compared responses of players performing as part of uneven teams in a possession format. One previous study has examined the effect of creating overload scenarios. Our results showed that the underloaded team of 4 experiences significantly higher physiological and perceptual strain compared to the team of 6, contrasting with Hill-Haas et al., (2010) who found no differences. Although not measured by the previous study, our time-motion analysis revealed meterage, mean velocity and work-to-rest ratio were also significantly higher in the underloaded team ($p < 0.001$). The higher exercise velocity and heart rate in the underloaded team is influenced by a different the conventional strategy in 6v6. Instead this team works to press and closing opponents down constantly for the 2 minute bout duration, working as a defensive unit to dictate their movements and limit passing options. Moreover, this team had to cover a relative area one-a-half times that of their opponents requiring continual work-rate. The team of 6 on the other hand, experienced lower cardiovascular strain, where workload is more technical with a necessity to cover less relative space. The greater mechanical load and acceleration profile of the underloaded team may also result from higher average and peak speeds achieved compared to the larger team, producing a degree of anaerobic as well as aerobic energy cost whilst trying to win possession back. The higher exercise velocity may also explain the lower peak acceleration values achieved in the underloaded team compared to those of the traditional 6v6 formats in this study. By changing the balance of teams in small-sided training games, the relative playing area required of the players to play in differ greatly, ultimately determining game strategy and different outputs of training load. This type of game may be appropriate for aerobically fitter players who have been suggested to benefit less from traditional SSG's due to a 'ceiling effect' from the intermittent nature preventing higher exercise intensities for fitness development (Hill-Haas et al., 2011; Hoff et al., 2004). The introduction of an artificial sprint in the study of Hill-Haas increased peak speeds and high-intensity distance that are more typical of match-play and are shown to be missing from this study. However, sampling at 1Hz the threshold in the earlier study was a lot lower than the present study which reflects that of match-play (13km/h^{-1} vs. 21km/h^{-1}). The overload game does not appear to be conducive to any high-speed activity which may also explain the absence of significant occurrences of high-end decelerations. These types of game may instead be associated with more frequent changes in direction at lower intensities that may not require as large a muscular force as match decelerations that occur cumulatively over distances of 900m (Akenhead et al., 2013). Acceleration profiles may still constitute 'high-intensity' activity as they are energetically taxing despite low absolute speed (Varley, Aughey and Pedrana 2011). The higher RPE as an underloaded team compared to all other formats in this study would suggest there is still a degree of intensity in this format, however.

Practical Applications

The main findings of this study indicate that increasing the relative area available to each player increases physiological, physical and perceptual responses. This may reflect the strategy of players to find space away from opponents to ensure more time for decision making and skill execution. In addition, manipulating SSG to give teams of uneven numbers in a possession-based game may produce significantly greater loading on the team with less players. As a result, this type of design may enable coaches to target players in need of further aerobic and muscular conditioning that accompany the context of the underloaded team’s defensive role to ss and close opponents down.

Our results highlight the versatility of small-sided training formats and we have demonstrated the ability to moderate intensity for specific individuals through changes in relative space available or uneven teams. This may result from inherently different strategies implemented by players to create space, maintain or regain ball possession.

Coaches and conditioning staff may use these variables to inform training prescription with greater confidence depending on group and individual requirements. The use of inherently different formats of SSG may be necessary at times within the elite soccer training environment, as a result, the following chapter will focus on how loading outputs may vary depending on these conditions implemented.

Chapter 6.

Loading responses to three different formats of small-sided games in soccer

Abstract

The primary aim of this study is to discriminate between loading responses of inherently different design of SSG, using the same player numbers. Ten elite youth male soccer players wore global positioning system (GPS) and heart rate monitors in each activity and were also asked to give a subjective rating of intensity (sRPE). The results showed higher physiological stress in the two formats with even teams compared to an overload (~90%HR_{max}, ES=1.9 and ES=1.5). This was also the case for absolute distance and high-intensity distance (28±25m and 67±35m above 21km/h^{-1}). Distance covered accelerating >3m/s^2 was significantly lower in the overload format compared to SSG (2±3 vs. 23±13m), although efforts at lower thresholds were not different. The extent of higher-intensity acceleration behaviour would seem to be influenced by the conditions implemented and relative playing space asked of each team. Less space gave lower average starting speeds prior to an acceleration enabling the attainment of higher acceleration efforts, 3.6±0.9km/h^{-1} in the case of SSG, whereas the absolute space and nature of the overload game was not conducive to high-level changes in speed. When using the same number of players, the conditions and strategy may be modified, therefore influencing the available space to cover. The space and average speed would then help determine the degree of physiological and locomotor responses attained in different 5v5 SSG formats. This may help in future planning of training that require varying contributions of conditioning stimuli.

6.1 Introduction

Small-sided games (SSG) are a common form of training used in soccer to elicit high-intensity training stimuli largely through high heart rate responses to promote cardiovascular adaptations. Their versatility makes them attractive to coaches through a myriad of variations with which to manipulate game format and subsequent intensity. Some of the most common variables employed have altered the number of players, absolute and relative pitch area, use of goalkeepers, bout duration and technical rules (Rampinini et al., 2007; Aguiar et al., 2013; Castellano, Casamichana and Dellal, 2013; Fanchini et al., 2011). However, SSG are often viewed as 'sport-specific' forms of interval training that can replicate or even exceed loading indices associated with competitive match-play. Previous research has examined physiological (heart rate and blood lactate) and subjective (RPE) responses to traditional SSG with goalkeepers, with higher physiological cost and rate of perceived found to be higher with smaller player numbers and larger playing areas (Rampinini et al., 2007; Casamichana and Castellano, 2010). However, heart rate has been questioned with regards to applicability to soccer training and match-play given its inherently intermittent movement pattern that comprises of a significant anaerobic energy contribution (Buchheit and Laursen, 2013). Furthermore, motion-analysis through global positioning systems (GPS) has revealed higher total distance covered (TDC) and at higher speeds with more players and more relative playing area (RPA) (Casamichana and Castellano, 2010).

Despite a large body of research on the physiological intensity of SSG, it has been proposed that these drills may not effectively simulate the movement demands of match-play in training, with specific reference to high-intensity efforts and accelerations and decelerations of greater magnitudes. To be able to repeatedly execute such actions are key physical requirements in soccer and to decisive moments in competition. As a result, the mechanical load on the musculo-skeletal system is not significantly challenged as in normal match-play.

In our previous research, we have found SSG with goalkeepers to provide an environment where TDC increases with more player numbers and playing space, explained by a higher average velocity of players trying to find space away from their opponents. A higher average velocity also makes it difficult to accelerate or decelerate to and from high speed given that movement velocity is already relatively high and the confined space in SSG does not allow high-speed activity. It may therefore be suggested that SSG appear to be greatly contextual in how their design affects individual physical and subjective output.

Other research comparing SSG with and without goalkeepers (possession) have found games without goalkeepers to be more physiologically and kinematically demanding in semi-professional players. Higher heart rate responses were found with less player numbers, with running demands greater with more players in possession formats on the same relative playing area (Castellano, Casamichana and Dellal, 2013). It could therefore be said that there is potential to mix the training design of small group play, with modifications to the design enabling mediated physical stress, ensuring greater control over the training process (Hill-Haas et al., 2010). The same author took this further by starting to explore SSG with uneven numbers, whereby numerical advantage or disadvantage produced over and under-load situations using a ‘floater’, with and without the use of goalkeepers. It was thought that such rules may heighten the demands on certain players and emphasise the desired style of play for different teams, whether to press or create space in attacking and defensive settings. Using the same relative playing area no differences in heart rate and lactate between over and underloaded teams, although RPE was higher when underloaded. No differences were found with TDC or high-intensity running (>13km/h^{-1}) between different player numbers. However, implementing rules that increased the chance of a team scoring was found to increase intensity in these SSG’s. Finally, the use of a floater that links play for either team to create temporary overload situations may help develop fitness through more work at sub-maximal velocities, but no difference was found for physiological and perceptual responses. The results of the above studies highlight the different methods of manipulating training intensity within SSG’s but all warrant caution with regards to changing technical rules or design as each may have independent effects on subsequent intensity (Hill-Haas et al., 2010).

The existing data available on small-sided games with goalkeepers, as possession or with uneven teams suggest that physical and subjective responses could be influenced by the contextual issues of each. Furthermore, the varied format ensures different aims and objective of players to be successful. The use of goalkeepers provides more tactical structure and organisation where players may move away from opponents to create space for themselves to receive the ball. In possession games, when their team is in possession of the ball players may also try to find space to receive a pass, whereas the team not in possession are trying to close off passing options with short accelerations and eventually intercept the ball. Finally, games with uneven team numbers will see the underloaded team trying to ‘press’ together and close down their opponents quickly, minimising time to make a decision and pass to a team-mate (Fradua et al., 2013).

There is little research, however, surrounding the loading responses vary with these different formats of small group play. The different aims and underlying movement strategies employed by the players may tax physiological systems and/or the musculoskeletal system more significantly.

It is therefore the aim of this study to assess the loading and intensity of three different formats of SSG using the same number of players. In a novel approach, three contrasting formats of SSG will be used to show how physiological, running and acceleration outputs can differ despite the same total number of players. The overload drill in this study is similar to that in Chapter 5 but will now be compared to other specific formats and conditions implemented in small-group play. We hypothesise that higher physiological load will be associated with traditional SSG with goalkeepers, while possession and overload drills will require a greater kinematic workload, specifically with underloaded teams who may also elicit a greater heart rate response.

6.2 Methods

The data in this study was collected during the 2013-14 soccer season. All players were familiar with heart rate and GPS equipment having worn them regularly in training prior to the study. Prior to the training intervention, players completed the YoYo Intermittent Recovery Test Level 2 (Bangsbo et al., 2008) in order to determine their maximum heart rate (HR_{max}).

Subjects

Ten elite male soccer players from the same squad participate in the small-sided game study (Mean ± Standard Deviation; 18.0 ± 1.2 yrs, 182.1 ± 7.9cm, 74.7 ± 6.3kg, 194.3 ± 6bpm; YoYoIR2 1338 ± 249m). All players played at a club participating in the Scottish Youth Premier League and UEFA Youth League. Players also had a minimum of two years' experience of full-time training and were accustomed to high-intensity interval training formats used in this study. During the week, the squad completed 3-4 field training sessions, 3 gym-based strength sessions, one competitive match and one recovery session. All participants were fully informed about the procedures involved in the study and approval for the research study was given by the University of Glasgow ethics committee.

Procedures

Each SSG format was performed at least twice, and in no particular order, on a natural grass pitch, separated by a minimum of seven days. The study was designed around the commonly used 5 v 5 format played on three different formats; SSG with goalkeepers, Possession without goalkeepers and Overload possession of uneven teams (6 v 4). These three would then represent inherently different conditions and therefore aims of the players participating in order to be successful. Moreover, bout duration was different for the overload game given the imbalance in players on each team, though total time was matched for all formats. Each format would represent common formats in the soccer environment whereby, depending on the coaching staff aims, goalkeepers may not always be required, different player numbers are available and some individuals may require specific physical or technical-based training. Resources available did not allow for the measurement of the time the ball remained in play. The design used in each game format is shown in Table 6.1. In possession and overload formats, the objective was to complete eight consecutive passes in order to score a point.

Table 6.1: Design of different small-sided game modes

	SSG	Possession	Overload
Duration (mins)	4 x 4	4 x 4	8 x 2
Recovery (mins/secs)	2	2	60s
Pitch size (m)	45 x 34	39 x 39	23 x 23
Total area (m²)	1530	1521	529
Area per player (m²)	153	152	53
Goalkeepers	Yes	No	No
Rules	2nd game 2T, 3rd game 3T	2nd game 2T, 3rd game 3T	2nd game 2T, 3rd game 3T (Overload Team)

2T= Two touch; 3T= Three touch

6.3 Results

Table 6.2: Physiological and time-motion responses to different small-sided game formats

	Total Distance (m)	m.min	High-Intensity Distance (m)	High-Intensity Efforts (#)	Average Speed (km/h^{-1})	Peak Speed (km/h^{-1})	PLSlow (AU)	%HR$_{max}$	RPE (AU)
SSG	2178 (200)^{c**}	136 (12.5)^{c**}	28 (25)^{c**}	2.8 (2)^{c**}	6.5 (0.6)	24.3 (2.0)^{a*,c**}	111 (18)^{a**}	88.4 (3.5)^{c**}	6.1 (1.1)
Possession	2307 (163)^{d**}	133 (9)^{d**}	67 (35)^{b**,d**}	6 (3)^{b**,d**}	7.9 (0.5)^{b**,d**}	23.0 (1.2)^{d**}	54 (6)	89.9 (3.1)^{d**}	7.9 (0.9)^{b**}
Overload	1649 (249)	113 (9)	0 (0)	0 (0)	6.6 (0.6)	16.2 (0.7)	75 (6)^{e**}	81.9 (4.8)	6.5 (0.6)
6 Players	824 (76)	103 (10)	0 (0)	0 (0)	5.7 (0.7)	15.6 (1.0)	46 (7)^{g**}	80.3 (5.0)	5.6 (0.5)
4 Players	764 (52)	127 (8)^{h**}	0 (0)	0 (0)	7.7 (0.7)^{h**}	16.9 (0.6)^{h}	26 (3)	83.8 (5.0)^{h}	7.7 (0.8)^{h**}

^{a} SSG > Possession; ^{b} Possession > SSG; ^{c} SSG > Overload; ^{d} Possession > Overload; ^{e} Overload > Possession; ^{f} Overload > SSG; ^{g} 6 Players > 4 Players; ^{h} 4 Players > 6 Players (p<0.05, *p<0.01, **p<0.001)

Game Format

Table 6.2 shows the physiological, time-motion and perceptual responses to the different SSG's employed in a 5 v 5 format. Average heart rate was higher in possession and SSG formats (89.9 ± 3.1% and 88.4 ± 3.5%HR_{max}, ES=1.9 and ES=1.5) compared to the overload game (81.9 ± 4.8%HR_{max}, $p<0.001$). This was also the case when considering time spent exercising at the highest heart rate zone above 90%HR_{max} ($p<0.01$, ES=0.8 for both).

Time-motion analysis revealed both total distance travelled and meterage to be highest in possession and SSG drills, significantly higher than that of overload ($p<0.001$). Taking in to account effective playing time of each drill, accounting for proportion of total duration, the percentage of total distance covered at 0-11km/h^{-1} were greater in the overload and SSG (74.1 ± 6.4% and 72.9 ± 5.1%) compared to the possession, 51.5 ± 6.6% ($p<0.001$). At velocities 11-14km/h^{-1}, the possession and overload formats entailed a greater proportion of total distance compared to SSG (20.6 ± 1.9% and 17.5 ± 4.0% vs. 13.7 ± 2.4%, $p<0.001$ and $p<0.01$). At velocities between 14-17km/h^{-1} and 17-21km/h^{-1}, significantly more percentage of distance was found in the possession format (16.0 ± 3.4% and 9.0 ± 2.4% compared to 7.8 ± 1.7% and 4.3 ± 1.6% in SSG and 7.0 ± 2.4% and 1.5 ± 0.7% in the overload drill ($p<0.001$ for both). Overload games produced no high-intensity activity above 21k/m^{-1} with the most in possession and SSG 67 ± 35 and 28 ± 25m respectively ($p<0.001$, ES=1.2). The proportion of high-intensity and sprint distance covered were therefore higher in possession than both SSG and overload games ($p<0.001$). Possession games saw the most sprint distance and efforts (16.6 ± 9.8m and 1.6 ± 0.9) compared to SSG (5.6 ± 8.6m and 0.7 ± 0.8, $p<0.01$, ES=1.1 in both) and overload games (0 ± 0m and 0 ± 0, $p<0.001$). The average velocity of locomotion was significantly higher in possession formats compared to both SSG (ES=2.5) and overload ($p<0.001$, ES=2.4), but higher peak velocity attained was found in SSG (24.3 ±2.0km/h^{-1}) compared to both possession (ES=0.8) and overload games ($p<0.001$, ES=5.4). Accelerometer-derived Player Load Slow (PLSlow), quantifying movement below 2m/s^2 was highest in SSG (ES=4.2), followed by overload games

(ES=3.5) in comparison to the possession game ($p<0.001$). The RPE was significantly greater in possession compared to both overload and SSG ($p<0.001$, ES=1.7 and ES=1.6).

Number of players

The physiological, physical and perceptual responses to teams of different numbers employed in the overload training drill are also shown in Table 6.2. Average heart rate response of 83.8 ± 5.0%HR_{max} was higher in the underloaded team (4 players) compared to that of the overloaded team (6 players) which was 80.3 ± 5.0%HR_{max} ($p<0.05$, ES=0.7). Although there was no significant difference, the overloaded team completed a greater absolute total distance, but meterage considerably greater in the underloaded team of 127 ± 8m.min^{-1} vs. 103 ± 10m.min^{-1} ($p<0.001$, ES=2.6). Distance covered at 0-11km/h^{-1} was higher in the overloaded team (71.9 ± 9.1% vs. 66.1 ± 5.3%, $p<0.01$, ES=0.7) with the only other difference in percentage of total distance at 14-17km/h^{-1} (10.5 ± 2.6% in underloaded vs. 7.9 ± 3.7% in the overloaded team, $p<0.05$, ES=0.8). No high-intensity or sprint activity was found in either team. Average and peak velocity were greater in the underloaded team (7.7 ± 0.7 vs. 5.7± 0.7km/h^{-1}, $p<0.001$, ES=2.9, and 16.9 ± 0.6 vs. 15.6 ± 1.0, $p<0.05$, ES=1.6). Moreover, the arbitrary metric of PLSlow was 46 ± 7AU with 6 players compared to 26 ± 3AU in the team of 4 players ($p<0.001$, ES=3.7). This reflects the change in proportion of work that is carried out at higher average speeds between the two teams, with emphasis on work -rate evident in the underloaded team of 4. RPE for each team in the overload drill was reported to be significantly higher in the team with less players underloaded, ($p<0.001$, ES=3.1).

Table 6.3: Acceleration data of different small-sided game formats

		SSG	**Possession**	**Overload**	**6 Players**	**4 Players**
Accelerations	**1-2m/s^2**					
	Distance (m)	249 (29)	327 (46)b**,d**	231 (45)	114 (16)	110 (19)
	Efforts (#)	82 (9)	90 (20)	82 (13)	37 (6)	43 (5)
	2-3m/s^2					
	Distance	72 (21)c**	76 (16)d**	34 (16)	15 (6)	18 (10)
	Efforts	20 (6)c**	19 (5)d**	10 (6)	4 (2)	6 (3)
	≥3m/s^2					
	Distance	23 (13)a**,c**	8(5)	2 (3)	1 (2)	1 (1)
	Efforts	5 (3)c**	2 (2)	0 (0)	1 (1)	1 (1)
Decelerations	**$^{(-)}$1-2m/s^2**					
	Distance (m)	132 (20)c**	173 (22)b**,d**	107 (22)	53 (6)	50 (9)
	Efforts (#)	79 (14)c	76 (9)	70 (14)	30 (4)	37 (9)
	$^{(-)}$2-3m/s^2					
	Distance	22 (8)c	31 (10)b**,d**	15 (8)	10 (5)	5 (3)
	Efforts	16 (5)	16 (6)	13 (6)	8 (3)	5 (3)
	$^{(-)}$≥3m/s^2					
	Distance	2 (2)	6 (4)b**,d**	1 (1)	1 (1)	0.2 (0)
	Efforts	3 (3)c	4 (2)d**	2 (1)	1 (1)	1 (1)

[a] SSG > Possession; [b] Possession > SSG; [c] SSG > Overload; [d] Possession > Overload;

[e] Overload > Possession (p<0.05, *p<0.01, **p<0.001)

The acceleration profiles of the different formats of 5 v 5 are displayed in Table 6.3. Accelerations of the lowest magnitude were more frequent and of greater distance covered in possession (ES=2 and ES=0.8) compared to SSG and overload, ES=2.1 and ES=0.4, (p<0.001). This was also the case for accelerations of 2-3m/s but with no difference between possession and SSG. The most intense accelerations were greatest in SSG, with distance higher than both other formats (p<0.001, ES=2.6 and ES=1.6) and number of efforts higher than overload (p<0.001, ES=2.6 and ES=1.6). Lower intensity decelerations were of greater average distance in possession than SSG (ES=1.9) and overload (ES=3), (p<0.001) but more frequent in SSG compared to overload (p<0.05, ES=0.6). Although the number of decelerations 2-3m/s was the same for SSG and possession, the latter saw a higher average distance accumulated between those efforts (p<0.001, ES=0.9). Finally, the highest decelerations covered most distance in possession compared to SSG and overload (p<0.001, ES=1.2 and ES=1.7) with the number of efforts also higher than overload (p<0.001, ES=1.3).

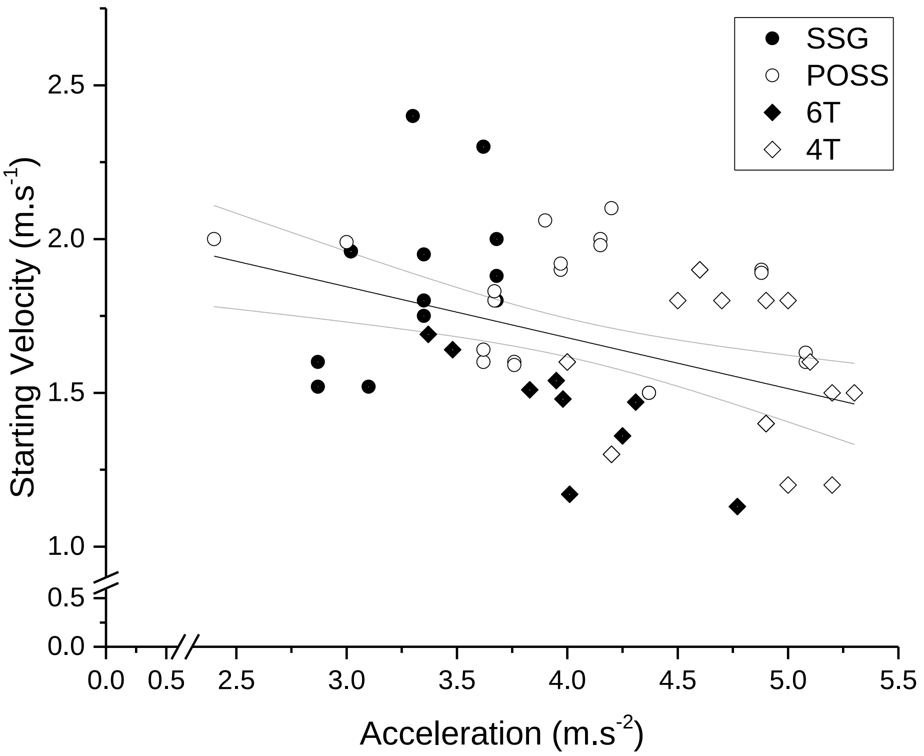


Figure 6.1 – Relationship of average acceleration and corresponding starting velocity in different SSG formats (95% Confidence Interval).

The contrasting characteristics of accelerations in each format are outline in Table 6.4. Average acceleration values for an effort were greatest in SSG 5v5. The underload team had significantly higher starting velocity upon beginning an acceleration compared to the team of 6 (ES=2), SSG (ES=3.9) and possession (ES=1.2), ($p<0.001$). Furthermore, the velocity at the end of an acceleration effort was greatest in possession versus SSG, and the team of 6 and team of 4 (ES=0.4, ES=4, and ES=2), which also saw greater peak velocities attained. Finally, with the exception of the overload team, ninety percent of acceleration efforts began below the average velocity of the drill, with the greatest proportion of accelerations ending above the high-intensity running threshold (21km/h^{-1}) in SSG (9%).

Table 6.4 Acceleration characteristics of different small-sided game formats

	Average Acceleration (m/s^2)	**Starting Velocity (km/h^{-1})**	**End Velocity (km/h^{-1})**	**Peak Velocity (km/h^{-1})**	**% Start < Ave. Velocity**	**% Ending > 21km/h^{-1}**
SSG	1.91 (0.27)	3.6 (0.9)	12.4 (0.9)	24.3 (2.0)	92 (6)	9.2 (4.9)
Possession	1.80 (0.19)	4.2 (1.0) [a]	12.8 (1.1)	23 (1.2)	99 (2)	2.5 (3.2)
6 Team (overload)	1.40 (0.18)	4.1 (0.1)	9.6 (0.2)	15.6 (1.0)	81 (4)	0 (0)
4 Team (underload)	1.65 (0.23)	5 (0.1) [b,c,d]	11.2 (0.2)	16.9(0.6)	91 (5)	0 (0)

[a] Possession>SSG, [b] 4 Team>Possession, [c] 4 Team>6 Team, [d] 4 Team>SSG ($p<0.001$)

6.4 Discussion

The aim of this study was to quantify the intensity of three different formats of SSG, using the same player numbers, on physiological, mechanical and perceptual load. This is one of the first studies to examine the effect of each of these training designs on training load. The results show higher aerobic load in possession and SSG formats in both physiological and physical responses. However, when expressed in relative terms according to playing time, the occurrence of low-intensity accelerations is more apparent in underloaded teams. The results may therefore show a difference in aerobic and mechanical energy costs as a result of manipulating game format of pitch size, player numbers and rule changes.

The aerobic load of small-group play was greater in possession and SSG formats where heart rate was similar to that reported by Castellano, Casamichana and Dellal (2013) (89.9 ± 3.1 and 88.4 ± 3.5%HR_{max} versus 94.6 ± 4.1 and 92.1 ± 4.0%HR_{max}), 88.8 ± 2.3%HR_{max} with goalkeepers (Rampinini et al., 2007) and 91%HR_{max} in possession games (Mallo and Navarro, 2007). The time spent exercising >90%$HR_{max}$was also greater in the possession format, although SSG was not different, which may provide a beneficial stimulus to develop cardiovascular conditioning in a sport-specific manner (Helgerud et al., 2007). The lower heart rate associated with the overload game is similar to that reported by Hill-Haas et al., (2010) in uneven teams of four and six players (83.5 ± 5.0% HR_{max} and 80.3 ± 5.0% HR_{max} versus 83.1 ±4.0%HR_{max} and 81.4 ± 5.1% HR_{max}). The difference between these teams was found to be different ($p < 0.05$) in the present study but not in that of Hill-Haas. This emphasises the physiological demands required of underloaded teams to work harder when not in possession of the ball and need to press as a defensive unit, elevating cardiovascular response in the two minute bout. The lower average heart rate achieved compared to the other formats may be a result of the lower bout duration employed which is the result of a 'lag' in kinetics to attain higher heart rates Buchheit and Laursen, 2013). The numerical advantage of size players may then have contributed to the lower heart rate due to the availability of passing options and necessity to cover less relative space in which to maintain possession. Caution must be taken when comparing heart rate for these formats given their inherently different designs for player numbers, reduced relative playing area and shorter bout duration which are also subject to limitations of heart rate kinetics in intermittent sports such as soccer.

In terms of external load, total distance covered and high-intensity activity were heightened in possession and SSG formats, with TDC (expressed as meters per minute) considerably higher in this study than that of Hill-Haas (2010) on the same relative playing area (104 versus 135 m.min^{-1}). Similarly, Mallo and Navarro (2007) had also demonstrated decreased TDC in soccer games using goalkeepers compared to possession-based games. The design of pitch and duration of bouts of each game in this study may have influenced significantly higher running loads in SSG and possession compared to the overload game. Higher relative playing area and bout duration saw increased TDC and high-intensity activity with more space allowing longer accelerations also more conducive to high mean and peak velocities (Figure 6.1). This may also reflect the underlying context of players to find space away from opponents to recover the ball meaning more continuous running and higher mean velocity. This is also reflected in the starting and end velocities of accelerations efforts, with greater magnitude accelerations and peak velocities attained in efforts starting from lower intensities (such as those in SSG and the overload team). The greater space available could also accommodate higher-intensity activity (>21km/h^{-1}) although, accumulated distance is comparatively low versus match-play, as is the peak velocity attained as a result of spatial constraints. Furthermore, this activity is not feasible in overload games due to even less space in which to generate high-speeds despite a similar mean velocity to SSG. The larger contribution of Player Load slow also suggests SSG and overload are higher intensity in nature compared to possession which entailed higher mean running velocity and a lower Player Load Slow.

Practical Applications

The environment provided, namely the relative area at each player's disposal would seem to be a large factor in mediating physical and subjective loading responses. The spatial-temporal demands are increased with less space where players have less time for decision making, needing to constantly adapt to the changing environment. As a result, in the overload game, for example, it may be possible to achieve greater technical and physical loads for the team of 6 and 4 respectively. The smaller absolute and relative space of an overload format may induce a greater biomechanical load through plentiful accelerations and changes in direction as the space is congested, and will be explored further in the next experimental chapter. On the other hand, SSG and possession games of even teams seem to produce greater aerobic loads and higher average velocities. This may provide valuable information in periodising the weekly training plan and to target individual conditioning.

Chapter 7.

Physiological, time-motion and perceptual responses to overload small-sided soccer games

Abstract

The aim of this study was to elucidate the effect of implementing different formats to SSG's in soccer and how training responses varied with uneven team numbers and relative playing area available. Twelve elite youth male soccer players were monitored with heart rate, time-motion and perceptual responses in three overload game formats. Results showed higher physiological, time-motion and perceptual loading in games involving less players and lower absolute pitch sizes. With regards to imbalance in team numbers, the underloaded teams displayed significantly higher markers of aerobic load through heart rates (85-90% HR_{max}, ES=0.8) and metres per minute in excess of match-play (~130m/min^{-1}). The higher average velocity in these teams and multidirectional pressing strategy saw a larger mechanical load through acceleration behaviour at high magnitudes relevant to team sport activity (>2.78m/s^2). GPS may therefore elucidate the contextual elements of different SSG formats that may be implemented by coaches. The strategy required of teams with a numerical disadvantage may dictate superior aerobic and muscular conditioning stimuli for certain players, whereas the overload team may be subjected to loading of a more technical nature.

7.1 Introduction

Small-sided games (SSG) are widely used in soccer due to their ability to concurrently create technical and physical conditioning stimuli. A significant amount of research exists that examines the effect of mediating training intensity through various manipulations to prescribed designs. These have included altering player numbers, absolute and relative pitch size, bout duration, rule changes and game format (Rampinini et al., 2007; Casamichana and Castellano, 2010; Fanchini et al., 2011; Castellano, Casamichana and Dellal, 2013). Popularly, SSG with less player numbers have been found to elicit greater physiological responses (heart rate and blood lactate) and perceptual demands, with more players producing increased physical running loads. Furthermore, changing the relative player area available to players, whilst maintaining player numbers, may give larger heart rates as well as total distance covered and that at high-intensity (Casamichana and Castellano, 2010).

Although research into game format is scarce, Castellano, Casamichana and Dellal, (2013) compared the intensity of SSG's with and without the use of goalkeepers in a possession game. It was found that the possession formats with smaller player numbers gave significantly greater physiological and physical outputs compared to traditional SSG's with goalkeepers, with pitch size maintained in each format of the same player numbers. There is little information on loadings responses to SSG's employing uneven teams however. Hill-Haas et al., (2010) investigated the use of uneven teams and the use of 'floater' players that ensured permanent or temporary situations of overload, often found in match-play. The team with less players reported significantly higher subjective load compared to those in the team of superior numbers, however no differences were found between physiological measures. It may still be suggested that it may be possible to contrast training intensity for different groups or individuals to target conditioning stimuli with the use of these formats.

As has been suggested previously, the lack of sensitivity and reliability of heart rate-based measures of intensity in soccer may reduce the ability to discriminate between different training formats such as those alluded to previously (Achten and Jeukendrup, 2003). The use of global positioning system (GPS) technology in monitoring soccer training and match-play has become more common (Scott et al., 2013; Casamichana, Castellano and Castagna, 2012; Randers et al., 2010). GPS can provide information pertinent to external loading on the musculo-skeletal system through distance, speeds and acceleration behaviour. This provides a more holistic view on exercise loading to quantify further the intensity of activities of different formats and conditions that may not necessarily induce significant cardiovascular responses, yet are still mechanically and metabolically taxing as a result of game-specific movements.

It is therefore the aim of this study to compare the training responses of three SSG's of uneven teams and the effect of different player numbers and relative playing area on physiological, movement and perceptual demands on each team. We will build on previous research by detailing acceleration behaviour and their contribution to neuromuscular load in variations of these specific formats.

7.2 Methods

Data was collected during the 2014-15 soccer season. All players were familiar with heart rate and GPS equipment having worn them regularly in training prior to the study. Before data collection took place, all players were asked to complete the YoYo Intermittent Recovery Test Level 2 (Bangsbo et al., 2008) in order to determine their maximum heart rate (HR_{max}).

Subjects

Twelve elite youth male soccer players were used for data collected for each small-sided game format (Mean ± Standard Deviation; 18.0 ± 1.2 yrs, 182.1 ± 7.9cm, 74.7 ± 6.3kg, 194.3 ± 6bpm; YoYoIR2 1338 ± 249m). All players played at a club participating in the Scottish Youth Premier League and UEFA Youth League. Players also had a minimum of two years' experience of full-time training and were accustomed to high-intensity interval training formats used in this study. The typical training week consisted of 3-4 field training sessions, 3 gym-based strength sessions, one competitive match and one recovery session. Approval for the research study was given by the University of Glasgow ethics committee.

Procedures

Each SSG format was performed in a random order following a standardised 20 minute warm up and carried out at least twice, separated by a minimum of seven days. The independent variables were the number of players on each team from eight, ten and twelve players respectively, absolute pitch size and pitch size relative to the number of players on each team. Similar the study by Hill-Haas et al., (2010), absolute pitch size for each of the three formats was constant although smaller at ~$50m^2$. Each format consisted of 8 x 2 minute bouts, with each player performing 4 bouts as both the under- and overloaded team. The study design is outlined in Table 7.1.

Table 7.1: Design and format of small-sided games

	8 v 4	**6 v 4**	**5 v 3**
Duration (mins)	8 x 2	8 x 2	8 x 2
Recovery (mins)	1	1	1
Pitch size (m)	25 x 25	23 x 23	20 x 20
Absolute area (m^2)	625	529	400
Area per player (m^2)	78/156	88/132	80/133
Goalkeepers	No	No	No
Rules	2nd game 2T, 3rd game 3T. OL-8 passes to score, UL- 3 passes to score	2nd game 2T, 3rd game 3T. OL-8 passes to score, UL- 3 passes to score	2nd game 2T, 3rd game 3T. OL-8 passes to score, UL- 3 passes to score

OL=Overload team, UL= Underload team. 2T= Two touch; 3T= Three touch for overloaded team

7.3 Results

Internal Training Load

Table 7.2 shows percentage of maximal heart rate to be significantly greater in the 5 v 3 on average compared to both other formats ($p < 0.001$, ES=0.7 and ES=1.1). This was also the case for the proportion of time spent exercising >90%HR_{max} ($p<0.001$) which ranged up to 60% of time in this zone.

When comparing player number within each SSG, the underloaded teams all produced higher heart rate responses than the overload team (4 > 6, $p<0.001$, ES=0.8; 4 > 8, $p<0.01$, ES=1; 3 > 5, $p<0.01$, ES=0.8) which ranged from 30% in 8v4 and 6v4 to 75% of time in the 5v3 game. Again, amount of time spent > 90%HR_{max} was considerably higher in the team with less players (3 > 5, $p<0.01$; 4 > 6, $p < 0.01$; 4 > 8, $p<0.05$).

Table 7.2: Physiological, time-motion and subjective responses to Overload SSG formats

	8 v 4	**6 v 4**	**5 v 3**
RPA (m^2)	52	53	50
%HR_{max}	82.9 (4.0)	83.9 (4.9)	87.5 (4.4) ^{e**,f**}
$m.min^{-1}$	104 (12)	115 (5) ^{c}	130 (11) $^{e*, f**}$
HID (m)	5 (13)	0 (0)	2 (4)
Mean Velocity (km/h^{-1})	5.5 (0.7)	6.7 (0.4) ^{c*}	7.4 (0.7) $^{e*, f**}$
Peak Velocity (km/h^{-1})	16.8 (1.3)	16.4 (0.7)	18.4 (0.8) ^{e**,f**}
W:R (<$11km/h^{-1}$)	0.3 (0.1)	0.4 (0.1) ^{c**}	0.7 (0.2) ^{e**,f**}
Acceleration >$2.78m/s^2$ (m)	16 (10) $^{a*, b}$	7 (5)	7 (10)
>2.78 (#)	4 (3) ^{a}	2 (2)	2 (0)
>3 (m)	10 (8) ^{a**,b**}	2 (3)	3 (1)
>3 (#)	3 (2) ^{a*}	1 (2)	2 (1)
Deceleration >$2.78m/s^2$ (m)	4 (4)	4 (4)	3 (1)
>2.78 (#)	4 (3)	3 (3)	3 (1)
>3 (m)	2 (1)	1 (1)	2 (0) ^{e}
>3 (#)	2 (2)	2 (1)	2 (0)
RPE (AU)	6.6 (0.9)	6.7 (0.7)	6.9 (0.6)

^{a}-8v4>6v4; ^{b}- 8v4 >5v3; ^{c}- 6v4>8v3 ^{d}- 6v4>5v3; ^{e}- 5v3>6v4; ^{f}- 5v3>8v4 ($p<0.05$; *$p<0.01$; **$p<0.001$)

External Training Load

Time-motion and acceleration data are presented in Table 7.3. Relative distance of metres per minute was highest in 5 v 3 versus both other formats (p<0.01, ES=1.7 and ES=2.4)) and 6 v 4 games compared to 8 v 4 (p<0.05). High-intensity distance recorded was only found in 8 v 4 and 5 v 3, although no difference between all three formats was found (p>0.05). Average velocity and work-to-rest ratio were both higher in 5 v 3 than 8 v 4 (p<0.01, ES=2.7 and ES=2.5) and 6 v 4 (p<0.01, ES=1.2 and ES=1.8) and 6 v 4 higher than 8 v 4 (p<0.001). The peak velocities were attained in the 5 v 3 also (p<0.001).

Acceleration analysis showed distance covered and efforts >$2.78m/s^2$ were highest in 8 v 4 compared to 6 v 4 (p<0.01, ES=1.1 and ES=0.7) and for distance only compared to 5 v 3 (p<0.05, ES=1.4). This was also the case >$3m/s^2$ for distance covered ($p<0.001$, ES=1.2), with efforts higher than those of 6 v 4 ($p<0.01$, ES=1). Decelerations were not different between SSG for distance and efforts >$2.78m/s^s$. The 5 v 3 SSG had significantly greater distance covered decelerating > $3m/s^2$ versus 6 v 4 ($p<0.05$).

When examining differences between teams of uneven numbers, underloaded teams all had higher physical outputs for total distance covered, metres per minute, mean and peak velocity and work-to-rest ratio ($p<0.001$). In 8 v 4 the team of 4 performed accelerations over longer distances >$2.78m/s^2$ ($p<0.05$, ES=0.7) as well as the number of efforts >$3m/s^2$ ($p<0.01$, ES=0.8). Distance covered accelerating >$2.78m/s^2$ and $3m/s^2$ were also higher ($p<0.01$, ES=0.6). In 5 v 3, distance covered and frequency of efforts accelerations and decelerations of both higher-intensity magnitudes were also greater ($p<0.001$) except for distance covered accelerating above $2.78m/s^2$. The 6 v 4 saw no differences between teams in acceleration behaviour, though decelerations >$2.78m/s^2$ were more numerous ($p<0.01$, ES=0.8) and over larger distances ($p<0.001$). Distance ($p<0.01$) and efforts ($p<0.05$) were also higher in the team of 4 players. Peak accelerations were not different between under- and over-loaded teams, but decelerations were different in each ($p<0.05$); 8v4 (ES=0.30, 6v6 (ES=0.2) and 5v3 (ES=1.2).

Table 7.3: Physiological, time-motion and subjective responses of teams of different player numbers

	Team 8	Team 4	Team 6	Team 4	Team 5	Team 3
RPA (m^2)	**78**	**156**	**84**	**126**	**80**	**153**
%HR$_{max}$	**80.1 (5.1)**	**85.0 (3.9)** ^{a*}	**80.4 (4.8)**	**84.4 (4.9)**^{b**}	**86.3 (5.1)**	**90.0 (3.7)** ^{c*}
m.min	**82 (18)**	**126 (12)** ^{a**}	**102 (10)**	**134 (8)** ^{b*}	**108 (10)**	**142 (12)** ^{c**}
HID (m)	**0 (0)**	**3 (13)**	**0 (0)**	**0 (0)**	**1.5 (3.8)**	**0 (0)**
Mean Velocity (km/h)	**4.4 (1.0)**	**6.6 (0.5)** ^{a**}	**5.7 (0.6)**	**7.9 (0.5)** ^{b**}	**6.2 (0.7)**	**8.7 (0.7)** ^{c**}
Peak Velocity (km/h)	**15.4 (0.9)**	**18.2 (1.6)** ^{a*}	**15.6 (1.0)**	**17.4 (0.8)** ^{b**}	**17.4 (1.5)**	**19.5(1.1)** ^{c*}
W:R (<11km/h)	**0.2 (0.1)**	**0.4 (0.1)** ^{a**}	**0.3 (0.1)**	**0.6 (0.2)** ^{b**}	**0.3 (0.1)**	**1.0 (0.3)** ^{c**}
Acc >2.78 (m)	**5.4 (5.9)**	**10.2 (7.4)** ^{a}	**3 (2)**	**4 (4)**	**3 (1)**	**3 (1)**
>2.78 (#)	**2 (2)**	**2 (2)**	**1 (1)**	**1 (2)**	**2 (0)**	**3 (0)** ^{c**}
>3 (m)	**3 (4)**	**7 (6)** ^{a*}	**1 (1)**	**2 (3)**	**3 (1)**	**2 (1)** ^{c}
>3 (#)	**1 (1)**	**2 (2)** ^{a*}	**1 (1)**	**1 (2)**	**2 (1)**	**2 (1)** ^{c}
Peak Acceleration (m/s^2)	**3.1 (0.7)**	**3.2 (0.6)**	**2.8 0 (0.6)**	**3.0 (0.7)**	**5.6 (1.7)**	**6.2 (1.0)**
>2.78 (m)	**1 (1)**	**3 (3)** ^{a*}	**1 (1)**	**4 (3)** ^{b**}	**2 (0)**	**3 (1)** ^{c**}
>2.78 (#)	**1 (1)**	**2 (2)** ^{a*}	**1 (1)**	**3 (3)** ^{b*}	**2 (0)**	**3 (1)** ^{c**}
>3 (m)	**0 (1)**	**1 (2)** ^{a}	**0 (0)**	**2 (2)** ^{b*}	**2 (0)**	**3 (0)** ^{c**}
>3 (#)	**1 (1)**	**1 (2)**	**0 (0)**	**2 (2)** ^{b}	**2 (0)**	**3 (1)** ^{c**}
Peak Deceleration (m/s^2)	**2.8 (0.7)**	**3.0 (0.7)** ^{a}	**3.0 (0.5)**	**3.08 (0.5)** ^{b}	**5.1 (1.0)**	**6.1 (0.7)** ^{c*}
RPE	**5.7 (0.9)**	**6.6 (0.9)** ^{a*}	**5.6 (0.5)**	**7.7 (0.8)** ^{b**}	**5.2 (0.9)**	**7.1 (0.5)** ^{c**}

^{a}- 4 > 8; ^{b}- 4 > 6; ^{c}- 3 > 5 ($p < 0.05$; *$p < 0.01$; **$p < 0.001$)

Subjective Training Load

Perceptual load was higher in the 5 v 3 SSG format compared to 8 v 4 (p<0.05, ES=0.4). All three team of less player numbers reported higher RPE following each format (p<0.01, p<0.001 in 5 v 3), 8v4 (ES=1, 6v6 (ES=3.1) and 5v3 (ES=2.6).

Correlations

In each of the overload formats, significant positive correlations were found between the changing relative playing area (RPA) per player and several loading variables. In 8v4, relationships were found between the area available and average heart rate (%HR$_{max}$, r=0.438) and RPE (r=0.439, p<0.01).

Running loads of meterage ($r=0.830$), mean velocity ($r=0.828$), peak velocity ($r=0.593$) and work-to-rest ratio ($r=0.717$) were all positively correlated to the RPA ($p<0.01$). Furthermore, distance covered and efforts above $2.78m/s^2$ and $3m/s^3$ were moderately correlated with playing area ($r=0.344-0.455$, $p<0.05$).

In 6v4, average heart rate and RPE showed moderate and large correlations respectively with playing area ($r=0.397$ and $r=0.841$, $p<0.05$ and $p<0.01$). Similarly, meterage ($r=0.875$), mean velocity ($r=0.892$), peak velocity ($r=0.719$) and work-to-rest ratio ($r=0.707$) all demonstrated relationships with the size of the pitch. Only deceleration distance and efforts were linked to RPA in this format for distance and efforts $>2.78m/s^2$ ($r=0.556$ and $r=0.449$, $p<0.01$) and $>3m/s^2$ ($r=0.422$ and $r=0.401$, $p<0.01$). The 5v3 game correlated with RPE ($r=0.801$) and meterage ($r=0.896$), mean velocity ($r=0.874$), peak velocity ($r=0.6533$) and work-to-rest ratio ($r=0.853$, all $p<0.01$) from the GPS. Only acceleration efforts $>2.78m/s^2$ had a significant positive correlation with RPA ($r=0.456$, $p<0.01$), whereas as all deceleration activity, distance and efforts, at high-intensity showed positive relationships with RPA in this overload format ($r=0.726-0.918$, $p<0.01$). High-intensity distance and high acceleration distance were negatively correlated with RPA in 5v3.

7.4 Discussion

The main aim of this study was to detail the loading responses to different small-sided games played in an overload format with uneven teams. Previous studies have found intensity to be higher with less players in conventional SSG's, possession formats and larger playing areas (Rampinini et al., 2007; Casamichana and Castellano, 2010). Our results suggest that physiological, perceptual and particularly physical running responses are influenced as a result of modifying the playing environment. The most important findings indicated that overload-style games demand more continuous as opposed to intermittent activity with the use of less player numbers when performed on the same total relative playing area as games with more players.

Concerning the overall loading of each of the three SSG formats employed, heart rate and perceptual load were higher in 5v3. Furthermore, physical data from GPS (meterage, average and peak velocities and work-to-rest ratio) were all significantly elevated compared to 8v4 and 6v4. On the other hand, indices of mechanical load were found to be more prominent with more players in 8v4. Acceleration and deceleration distance covered and frequency of efforts at higher magnitudes (>2.78m/s^2 and >3m/s^2) were significantly greater in 8v4 compared to those of smaller player numbers. This may be due to the larger absolute pitch space available to enable intense changes in speed over longer distances that are not possible in the more confined areas of 6v4 and 5v3 games. Indeed, the higher overall average velocity demonstrated in the latter two formats may contribute to an inability to execute high-end acceleration behaviour given the higher starting velocity. Therefore achieving an acceleration (and subsequent deceleration) in the zones is difficult due to the continuous work profile suggested by the higher work-to-rest ratio. The team of 8 in this case may therefore initiate changes in speed from a lower starting (mean) velocity where more force is required to overcome forces of inertia and subsequently registering high-intensity accelerations. Osgnach et al., (2009) stated that such a significant change in speed is more taxing then sustained steady state locomotion. Recently the importance of these movements in analysis of intensity has been put forward as part of high-intensity activity classifications due to the high metabolic and neuromuscular cost associated with these key actions in game play (Varley and Aughey, 2013; Gaudino, Alberti and Iaia, 2014; Hodgson, Akenhead and Thomas, 2014), but are often absent from match analysis. The result is a subsequent underestimation of energy expenditure in relation to high-intensity activity, regardless of the start and end absolute velocities (Dwyer and Gabbett, 2012; Varley, Aughey and Pedrana, 2011).

One of the key elements of this study was to evaluate the changes in loading patterns when teams are often outnumbered in various match-play scenarios. To our knowledge, this has only been attempted in one other study (Hill-Haas et al., 2010). It was found that the team with less players reported significantly higher perceptions of exercise intensity but were not different to the team with superior numbers in terms of heart rate and time-motion behaviour. Despite bouts durations of 2 minutes, our data shows significantly higher taxing of the cardiovascular system (range: 80.4-90.0% HR_{max}), particularly in teams with less player numbers. This is surprising given the lag in heart rate kinetics have been shown to respond slower in shorter bouts compared to oxygen consumption (Buchheit and Laursen, 2013). However, Fanchini et al., (2011) found bout durations of 2 and 4 minutes to be more beneficial to stress the cardiovascular system. Our results showed contrasting total and high-intensity distance covered to that of the previous study. This is likely due to the much larger playing area and exercise duration used by Hill-Haas however allowing time and space to achieve high speeds. In relative terms, each overload format instead produced higher relative distance (126-142m/min^{-1} in underloaded teams), in excess of that demonstrated in match-play (Bradley et al., 2009). The disparity in high-speed distance between the two studies could also be explained by playing area available to accelerate into higher zones, as well as the much lower thresholds used compared to our study (13km/h^{-1} vs. 21km/h^{-1}) which is indicative of match analysis studies (Castellano, Blanco-Villasenor and Alvarez, 2011). Although there is an absence of high-intensity running, this could also be explained by the higher mean exercise velocity (particularly of the underloaded team) where a more continuous work-rate is required that also incorporates intermittent behaviour of numerous changes in direction and therefore fluctuations in speed that prevent attainment of high-intensity values (illustrated by the relatively low peak velocities compared to traditional SSG's). Also, the design of the games was possession-based where no goalkeepers were used and so removing the directional element of play of traditional SSG's enabling a more spontaneous movement pattern. Various SSG's in soccer training have previously been suggested to lack the ability to adequately replicate matches as first though, largely through high-intensity speeds and accelerative demands (Casamichana, Castellano and Castagna, 2012; Gabbett Jenkins and Abernethy, 2009). Hill-Haas et al., (2010) sought to overcome this with the introduction of an 'artificial' sprint to increase exercise intensity. This may be useful in exposing players to higher speeds associated with match-play that are difficult to execute in SSG's where spatial elements curtail these efforts.

The heightened physiological, running and perceptual outputs of 'overload' formats, particularly in underloaded teams are striking. The discrepancies between each team in the three SSG's here may be contextual and partly be explained by the strategy employed by each team as a result of the imposed external training load demands. For example, the numerical disadvantage would seem to dictate a high-intensity pressing work-rate where the aim is to close-down opponents and cut off passing options. The idea here may be to try to dictate opponent's movements, characterised by adjusting their own body position to direct them away from space and hinder cognitive decision-making abilities (Vilar et al., 2014). The hope here is for the underloaded team to work as a defensive unit to force errors, make a tackle or intercept the ball to regain possession. There may also be added motivation to regain possession through the additional rule to score a goal with three passes. Despite this incentive, this is also made more difficult for the underloaded team with the fact that, with less players, there is a requirement to cover more relative space then the larger opposing team. These constraints imposed could then influence the relationships and behaviour of each team depending on their specific goals (Silva et al., 2014).

By employing uneven teams in training games, it is therefore plausible to say that there is a significant higher physical demand with less players. As a result, coaches may be able to use this for specific individuals where heart rates >90% HR_{max} (30-70% of time when underloaded), relative distance and mean velocity may constitute beneficial stimuli in strategies to develop aerobic conditioning (Helgerud et al., 2001). A new concept in this study is the contribution of mechanical loading indices. Despite there being no high-speed running, with more total players and for the underloaded team, there appears to be more of a muscular conditioning role, with our results showing significantly higher reliance on producing high-end acceleration and eccentric deceleration efforts. These efforts have been suggested to be more taxing then maximal sprint activity of competition due to the force and metabolic power required to generate the ability to change speed quickly (Osgnach et al., 2009; Varley and Aughey, 2013). As a result, the musculo-skeletal system is also taxed where large eccentric forces are required to be absorbed which have been shown to be damaging to skeletal muscle and contribute to neuromuscular fatigue (Armstrong, Oglivie and Schwane, 1983). The low absolute distances covered in these domains however, is considerably lower than match-play (Akenhead et al., 2013). As a result, further conditioning strategies may be necessary to ensure exposure to larger-scale mechanical loading. On the other hand, the lower intensity experienced by overload teams may present a different training stimulus. The emphasis here may instead be on improving technical quality through passing and ball retention, eliciting a lower overall training load.

Practical Applications

Our findings suggest that possession-based SSG's with modifications to player numbers and relative area available can mediate training intensity through physical, perceptual and time-motion outputs in particular.

By prescribing an external training design of uneven teams, coaches and conditioning staff may be able to emphasise a different conditioning focus for specific players or positions. For example, underloaded teams requirement to win back possession may stimulate greater aerobic and neuromuscular conditioning benefits not demonstrated in previous research, whereas the overload team may involve technical and team attacking qualities. However, although some intense acceleration actions are evident with smaller teams and their objectives, the absolute distance of these and higher velocity activity of competition is difficult to achieve in these SSG environments. Despite this, overload format SSG may still provide a stimulus for both physical and technical elements that may be experienced in matches, depending on the conditions implemented. The effect of relative playing area and player numbers will finally be compared on small- and large-sided games with a full-match environment to portray how the contribution of physical, physiological and subjective loading parameters may vary.

Chapter 8.

Comparison of physiological and physical outputs of small- and large-sided games with match-play in soccer

Abstract

The aim of this study was to compare how modifying both player numbers and relative pitch area influenced loading outputs associated with different formats of soccer training games. Using GPS and heart rate measures, players performed small- (SSG) and large-sided games (LSG) and full-sized friendly matches (MP). Absolute distance and number of efforts for high-speed and high-acceleration activity were all higher in MP ($p<0.001$). When expressed relative to time, meterage, accelerations and inertial sensor Player Load Slow were instead more demanding in SSG ($p<0.01$). It is likely that the different space available in each format governed player strategy to exploit space necessary to increase inter-personal distances between themselves and opponents. Similarly, the more confined formats may inhibit attainment of traditional high-intensity activity and velocities, instead promoting biomechanical load associated with lower-velocity, changes in direction. These results suggest that SSG indeed do not fully replicate match-specific movements and that training prescription should take into account relative playing area to attain a desired training impulse.

8.1 Introduction

The physical demands associated with soccer match-play rate have been shown to increase in recent seasons (Barnes et al., 2014). It has often been said that training must subsequently be able to replicate and even exceed certain physical outputs of matches to ensure optimal conditioning of players to cope with the rigours of competition (Meister et al., 2011).

The use of small-sided games (SSG) in soccer is common due to their ability to create both techno-tactical and physical stimuli concurrently (Hill-Haas et al., 2011). Furthermore, they are an attractive tool to those responsible for training prescription due to their versatility in mediating training intensity. Previous research on SSG’s have shown physiological, time-motion and subjective loading outputs to be elevated in games with lower player numbers and greater relative pitch area (Rampinini et al., 2007; Dellal et al., 2008; Hill-Haas et al., 2009). As a result, smaller game-play is employed as an efficient way to develop prerequisites for successful performance in a sport-specific manner. This method of training has also been found to provide an equally beneficial aerobic conditioning stimulus compared to more generic protocols of high-intensity aerobic interval training (Impellizzeri et al., 2006; Dellal et al., 2008; Hill-Haas et al., 2009).

Heart rate has traditionally been used to describe exercise intensity in soccer (Bangsbo, 1994). However, it may be said that this indicator is not sensitive enough to reflect the changes in intensity in an intermittent sport such as soccer due to the large anaerobic component involved in soccer-specific movements (Achten and Jeukendrup, 2003). This may in turn result in underestimation of cost to the metabolic and muscular systems. The emergence of global-positioning systems (GPS) in sport may instead help to further quantify movement behaviour and resultant musculo-skeletal loading soccer players are exposed to in training and match-play (Dellaserra, Gao and Ransdell, 2014). Moreover, despite documented cardiovascular and technical loads induced by SSG, it has recently been suggested that these formats may not fully replicate match-play as first thought (Gabbett, Jenkins and Abernethey, 2009; Casamichana, Castellano and Castagna, 2012). Indeed, key high-intensity aspects involving high speeds over large distances are seen to be valid measures of soccer performance (Mohr, Krustrup and Bangsbo, 2003). Although previous research has found significant distance at high-speed in SSG (Hill-Haas et al., 2009; Dellal et al., 2012), these studies have employed low speed thresholds (~13km/h^{-1})that are not indicative of high-intensity activity in match play on a much greater playing area (Bradley et al., 2009). The environmental constraints of SSG dictate that these types of efforts are negated with curtailed space preventing attainment of near maximal speeds. Despite this, Varley, Aughey and Pedrana (2011) suggested that the inability to provide for higher speed activity does not necessarily mean there is an absence of 'high-intensity activity'. Other subsets of 'high-intensity activity' in the intermittent motion-profile involve multiple changes of direction and concentric/eccentric force capabilities. The frequent fluctuations in speed and direction are therefore characterised by significant initiation (acceleration) and termination (deceleration) of efforts that are seen to be highly taxing to the mechanically and metabolically (Osgnach et al., 2009; Gaudino, Alberti and Iaia, 2013). The acceleration behaviour in SSG's is missing from the literature and GPS may help to bring further information as to different types of loading (biomechanical as well as physiological) that elicit the overall exercise intensity.

The influencing variables such as player numbers and available playing area may therefore play a role in determining the proportions and intensities of locomotor and acceleration outputs of different scale formats of soccer game play. The environmental conditions imposed may therefore dictate a player's strategy for each format which subsequently regulates movement behaviour. A greater understanding of different formats may then help to periodize the appropriate intensity (physiological or mechanical) in a training week more effectively (Owen et al., 2012), depending on the training stimuli produced or intended.

The aim of this study was therefore to compare the loading responses of different formats of soccer game-play using heart rate and GPS. The rationale was to quantify the extent of SSG and LSG being able to replicate specific stimuli associated with match-play in soccer. Secondly, acceleration profiles were investigated to add to indices of biomechanical loading in terms of concentric-eccentric loading demands. This information would subsequently have a large influence on training prescription during the training week to appropriately prepare players in specific positions for competition.

8.2 Methods

The data in this study was collected during the 2014-2015 soccer season. Players were familiar with heart rate and GPS equipment having worn them regularly in training prior to the study. Prior to commencement of the study, all players completed the YoYo Intermittent Recovery Test Level 2 (Bangsbo et al., 2008) in order to determine their maximum heart rate (HR_{max}).

Subjects

Twenty-four elite youth male soccer players from the same squad were used for data collected for training drills and friendly matches (Mean ± Standard Deviation; 20.6 ± 3.6 yrs, 184.1 ± 6.9cm, 77.9 ± 5.7kg, 195.2 ± 6bpm; YoYoIR2 1338 ± 249m). All players were signed to a club participating in the Scottish Youth Premier League and UEFA Youth League. Each player participating in the study had a minimum of two years' experience of full-time training. The typical training week consisted of 3-4 field training sessions, 3 gym-based strength sessions, one competitive match and one recovery session. Approval for the research study was given by the University of Glasgow ethics committee.

Procedures

Each 4 v 4 (SSG) and 9 v 9 (LSG) were performed on a natural grass pitch in a random order following a standardised 20 minute warm up on a natural grass pitch. The small- and large-sided formats were each carried out three times, separated by a minimum of seven days. Match-play (MP) data was obtained from friendly matches over the course of the pre-season period (n=10). Players were fully accustomed to sport-specific high-intensity interval training in the form of different soccer-specific training modes. The independent variables were the number of players used (4v4, 9v9, 11v11), and playing area, relative to player numbers, of each format. The design of SSG is outlined in Table 8.1.

Table 8.1: Design and format of small-sided games

	4 v 4	**9 v 9**	**Match**
Duration (mins)	4 x 4	2 x 8	2 x 45
Recovery (mins)	2	2	2
Pitch size (m)	40 x 30	65 x 55	100 x 64
Total area (m^2)	1200	3575	6400
Area per player (m^2)	150	200	320
Goalkeepers	Yes	Yes	Yes
Conditions	2nd game 2T, 3rd game 3T	2nd game 2T, 3rd game 3T	~

8.3 Results

Results for physiological responses and physical running outputs are illustrated in Tables 8.2, 8.3 and 8.4.

Internal Load

Table 8.2: Physiological responses to different game-play formats

	SSG	LSG	Match
%HR$_{max}$	89.0 (2.7) $^{a**, b**}$	83.7 (3.4)	86.5 (2.7) ^{c}
%Time >90%HR$_{max}$	45 (13) $^{a **, b**}$	23 (19)	30 (16) ^{c}

^{a}- SSG>LSG; ^{b}- SSG>MP; ^{c}- MP>LSG ($p < 0.05$; *$p < 0.01$; **$p < 0.001$). SSG=small-sided game; LSG=large-sided game; MP=match-play

Average heart rate (%HR$_{max}$) was found to be higher in SSG and MP compared to the 9 v 9 LSG ($p<0.001$). The proportion of time spent at exercise intensities above 90%HR$_{max}$ was also higher in SSG compared to both LSG ($p<0.001$) and MP ($p<0.05$).

External Load

Table 8.3: Time-motion responses to different game-play formats

	SSG	LSG	Match
Total Distance (m)	2072 (221)	1831 (282)	10800 (1036) $^{a**, b**}$
m.min^{-1}			
High-Intensity Distance >21km/h^{-1} (m)	26 (19)	69 (39)	440 (170) $^{a**, b**}$
Sprint Distance >24km/h^{-1} (m)	0 (0)	10 (5)	175 (100) $^{a**, b**}$
Mean Velocity (km/h^{-1})	6.1 (0.7)	6.5 (0.7)	6.5 (0.7) ^{a}
Peak Velocity (km/h^{-1})	24.3 (2.0)	26.2 (2.9)	30.2 (1.9) $^{a**, b**}$
Work:Recovery (AU)	0.6 (0.2)	0.5 (0.2)	0.6 (0.2)^{b}

^{a}- MP>SSG; ^{b}- MP>LSG ($p < 0.05$; *$p < 0.01$; **$p < 0.001$).

Absolute total distance covered was greater with MP compared to both other formats (p<0.001). However, relative distance per unit of time was higher with less players in SSG compared to MP (p<0.01). MP was also found to have superior absolute and relative distances covered at high-intensity as well as total number of efforts versus SSG and LSG (p<0.001). The percentage of total distance covered at high-intensity was significantly higher in MP and LSG than SSG (p<0.001 and p<0.05 respectively). This was also the case for the same parameters with regards to the sprint classification (p<0.001).

Table 8.4: Acceleration and accelerometer data for different game-play formats

	SSG	**LSG**	**Match**
Player Load (AU)	270 (46)	164 (25)	1081 (210) $^{e**, f**}$
Player Load Slow <2m/s^2 (AU)	105 (15) ^{a*}	56 (4)	341 (62) $^{e**, f**}$
Total Acceleration Distance (m)	316 (62)	248 (53)	1163 (175) $^{e**, f**}$
Acceleration Distance >3m/s^s (m)	17 (8) ^{a}	8 (6)	28 (16) $^{e**, f**}$
Accelerations >3m/s^s	4 (2)^{a*}	3 (2)	5 (4) $^{e**, f**}$
Peak Acceleration (m/s^2)	4.9 (0.6)	4.03 (0.66)	5.2 (0.9) $^{e**, f**}$
Total Deceleration Distance (m)	149 (35)	123 (32)	586 (105) $^{e**, f**}$
Deceleration Distance (m) >3m/s^s	2 (2)	4 (3)	31 (10) $^{e**, f**}$
Decelerations >3m/s^s	2 (2)	3 (2)	12 (5) $^{e**, f**}$
Peak Deceleration (m/s^2)	4.0 (0.4)	3.94 (0.56)	5.2 (0.6) $^{e**, f**}$

^{a}- SSG>LSG; ^{b}- SSG>MP; ^{c}- LSG>SSG; ^{d}- LSG>MP; ^{e}- MP>SSG; ^{f}- MP>LSG ($p < 0.05$; *$p < 0.01$; **$p < 0.001$).

The work-to-recovery ratio (exercise above and below 11km/h^{-1}) was bigger in MP than LSG ($p<0.05$), with mean exercise velocity significantly faster than SSG ($p<0.05$) and peak velocity achieved greater than both 4 v 4 and 9 v 9 ($p<0.001$).

Accelerometer-derived Player Load was, in relative terms, greater in SSG than both MP and LSG ($p<0.001$). The same was the case for Player Load Slow per minute, with SSG nearly twice that of LSG and MP ($p<0.001$).

Results for the acceleration profiles of each game format analysed showed both the absolute distance and frequency of efforts of accelerations above 2.78m/s^2 and 3m/s^2 were significantly higher with MP than both other formats ($p<0.001$). Furthermore, distance covered ($p<0.05$) and efforts ($p<0.05$) above 3m/s^2 were also greater in SSG than LSG. When expressed relatively, distance covered above 2.78m/s^2 was higher in SSG and LSG versus MP ($p<0.001$ and $p<0.05$). This was also the case for efforts performed per minute ($p<0.001$ and $p<0.01$). At intensities above 3m/s^2 relative distance and efforts were also higher in SSG compared to LSG and MP ($p<0.001$). For high-level decelerations the total distance covered and number of efforts executed were all significantly higher in MP than SSG and LSG for intensities above 2.78m/s^2 and 3m/s^2 ($p<0.001$ in each case). Table 8.5 shows that, relative to time, decelerations above 2.78m/s^2 and 3m/s^2 saw greater distance in LSG and MP versus SSG ($p<0.001$ and $p<0.01$). There were no differences in relative efforts in each of these cases ($p>0.05$). When comparing different high-intensity thresholds employed in acceleration profiles, significant differences were found for absolute and relative distance covered and frequency of efforts for both accelerations and decelerations of 2.78m/s^s and 3m/s^2.

Table 8.5: Relative data for responses to different game-play formats

	SSG	**LSG**	**Match**
Total Distance (m.min^{-1})	129 (14) ^{b*}	124 (17)	120 (12)
High-Intensity Distance >21km/h^{-1} (m.min^{-1})	1.6 (1.2)	3.3 (2.6) ^{c*}	4.9 (1.9) $^{e**, f**}$
Player Load (AU.min^{-1})	16.9 (2.9) $^{a**, b**}$	11.1 (1.6)	12.0 (2.3)
Player Load Slow <2m/s^{2} (AU.min^{-1})	6.7 (1.0)$^{a**, b**}$	3.8 (0.3)	3.8 (0.7)
Acceleration Distance >3m/s^{s} (m.min^{-1})	1.1 (0.5) $^{a**, b**}$	0.5 (0.4)	0.3 (0.2)
Accelerations >3m/s^{s} (#.min^{-1})	0.2 (0.1) $^{a**, b**}$	0.1 (0.1)	0.1 (0)
Deceleration Distance >3m/s^{s} (m.min^{-1})	0.1 (0.1)	0.2 (0.2) ^{c**}	0.2 (0.1) ^{e*}
Decelerations >3m/s^{s} (#.min^{-1})	0.1 (0.1)	0.2 (0.1)	0.1 (0.1)

^{a}- SSG>LSG; ^{b}- SSG>MP; ^{c}- LSG>SSG; ^{d}- LSG>MP; ^{e}- MP>SSG; ^{f}- MP>LSG ($p < 0.05$; *$p < 0.01$; **$p < 0.001$).

Overall total distance covered for accelerations at all intensities was greatest in MP (p<0.001). Relative distance, however, was found to be higher in SSG and LSG than MP (p<0.001). This was the same for all decelerations (p<0.001), with SSG also consisting of more distance covered than LSG (p<0.05). The peak values attained for both accelerations and decelerations were both found to occur in MP (p<0.001).

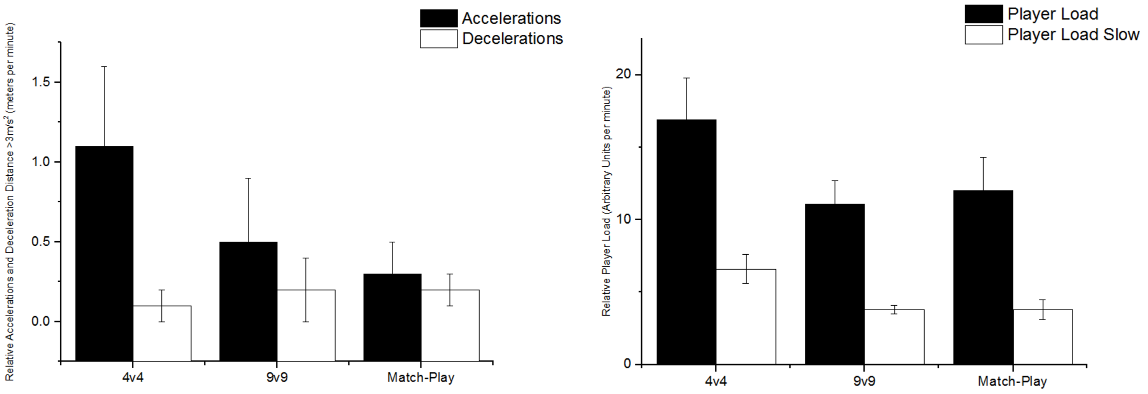


Figure 8.1: a – Relative distance of accelerations and decelerations >3m/s^{2}, b – Relative Player Load and Player Load Slow (<2m/s^{s}) in small- and large-sided games and match-play

8.4 Discussion

The aim of the present study was to evaluate and compare the differences in environmental stimuli players are exposed to in small and large-sided game play compared to match-play and how this influences associated physical work outputs. The secondary aim was to elucidate any differences in acceleration profiles between these formats and how they may have implications for training prescription across the training week. The intention was to validate existing literature regarding speeds and distances covered, but include more in-depth detail on the mechanical demands through the use of inertial sensor technology. As a result new observations in to discrete, intense actions of significant muscular cost, can help understand how changing training prescription (in terms of playing areas and player numbers) can condition players for competition.

The demands of modified training games in soccer have been extensively researched in the literature. For example, studies have found higher physiological and physical exercise intensities to be associated with less player numbers and larger playing areas (Dellal et al., 2008; Casamichana, Castellano and Castagna, 2012; Rampinini et al., 2007, Hill-Haas et al., 2009). The results of the current study concur with those of previous research, with higher heart rate intensities found in conditioned games of less players, with larger areas and match-play comprising higher physical running outputs in terms of distance covered and high-end velocities. Such studies have compared small and large-sided games with match-play (Owen et al., 2011; Owen et al., 2012; Dellal et al., 2012; Casamichana, Castellano and Castagna, 2012) with physical, technical and ball possession higher in 11 v 11 match-play. However, limitations within these include comparison between formats using either GPS or semi-automated systems that sample at different rates which have been shown to vary in measurement of high-intensity distances by 23-39% (Randers et al., 2010). Other studies on smaller formats have also employed considerably lower velocity thresholds required to constitute ‘high-speed activity’, which may be less appropriate to soccer and prevent continuity in comparison of research (Hill-Haas et al., 2009; Casamichana and Castellano, 2010; Aguiar et al., 2013). Furthermore there is a lack of data reported for frequency and magnitude of accelerations and inertial sensors data in soccer formats which may help to discriminate between loading of games and avoid underestimation of energy cost with also with regard to the effect of available space. Interestingly, this study's results suggest how, if the data is viewed in relative terms with regards to exercise duration, it may be that relative intensity of certain parameters may actually be greater in smaller training games than large-sided formats and friendly match-play.

The cardiovascular load in SSG is in excess of those traditional reported with match-play (Bangsbo, 1994) and those found in this study (89%HR_{max} versus 85% HR_{max}). This may result from conditions implemented in the 4 v 4 games such as the stipulation of limiting the number of touches, thereby requiring quicker cognitive decision-making and distribution of the ball with the incentive to score a goal. This has been suggested by to subsequently see a concomitant increase in energy cost with the number of ball involvements per player as well as increase turnover of possession, ensuring continual pressure of attacking and defending phases for either team (Owen et al., 2011; Reilly and Ball, 1984). However, the significant aerobic contribution to these games is further exacerbated by the short bout durations compared to those of larger games and match-play. A confined environment and lower exercise duration with short recovery periods ensures the requirement for higher work-rate to either close down opponents or conversely to create space to receive the ball. With a smaller relative playing areas, players try to find space, increasing average velocity and heart rate response. Therefore the desire for personal space reflects game strategy in different soccer formats, dictated by the RPA provided by coaches. This significantly higher meterage in SSG compared to larger games and friendly matches may also explain the superior relative Player Load. Higher total distances have been said to involve greater contribution of heel strikes and vertical acceleration forces in locomotion therefore increasing Player Load (Boyd, Ball and Aughey, 2011). SSG demands therefore see heart rate elevated and a greater proportion of time in spent in the highest intensity zones. Such a requirement may then contribute significantly to cardiovascular adaptations of increased cardiac filling and increased stroke volume (Helgerud et al., 2001).

Despite a lower average heart rate, there is still a significant aerobic load produced from ninety minutes of match-play. The necessity to perform for a long duration means that total distance covered can exceed 12 kilometres taxing all three energy systems to different extents compared to smaller formats. Much greater TDC, HID and SPD in matches are combined with a higher work-to-recovery ratio, mean and peak velocities. This may largely be due to the availability of greater space available per player, lowering frequency of ball involvements but making it easier for players to find and then exploit space. This allows the attainment of higher acceleration and running intensities and ensuing decelerations (Hill-Haas et al., 2009). As a result there is a greater reliance on anaerobic glycolysis provision to fuel more frequent high-velocity efforts over greater average distances. Conversely, in 4 v 4 the smaller available space, curtails the ability to achieve maximal velocities as in match-play. High-intensity efforts may therefore be shorter duration and lower absolute velocity and likely fuelled more by ATP-PC sources (Dellal et al., 2012). This reinforces the notion that SSG may not entirely reproduce match-specific high-intensity actions typical of match-play (Gabbett, Jenkins and Abernethey, 2009) and that space is a key determinant in permitting the extent of match-play simulation. Additionally, the conditions implemented create different scenarios that require players to functionally adapt to in order to produce successful outcomes (Seifert, Button and Davids, 2013). However, it is important to note some factors when comparing and contrasting the activities implemented in this study. Primarily, with the increasing size of drill design and match-play included within this study, the effect of positional role becomes much more apparent than outputs associated with SSG. With larger formats and matches, traditional positions are assumed which have been shown to dictate a players physical and technical outputs, also depending on the formation and role implemented by the coach (Di Salvo et al., 2006; Bradley et al., 2011). Additionally, the greater overall playing duration will bring periods of fatigue in to consideration. As has previously been described, there are periods of altered work-rate following intense periods, after the half-time interval and towards the end of a match. Reductions in high-intensity running in these periods during a 90-minute match have been suggested to be a result of physiological and neuromuscular fatigue as well as intentional pacing by players to preserve energy substrates and muscle force production capabilities (Bradley and Noakes, 2013).

A few studies have previously stated that acceleration demands should be incorporated to time-motion analysis in order to avoid underestimation of energy cost and effects of fatigue associated with an activity (Little and Williams, 2007). Recent studies have illustrated how the ability to change speed underpins key moments in matches, but are susceptible to neuromuscular fatigue and may decline over time (Osgnach et al., 2009; Castellano and Casamichana, 2013; Varley and Aughey, 2013). Moreover, Aughey (2010) suggested the use of thresholds for maximal accelerations that are more appropriate in team sports. He stated that maximal accelerations above 2.78m/s^2 may better reflect acceleration capacity of team sport athlete's and their motion profiles. This may be necessary as the mean exercise velocity (and starting velocity) will influence the subsequent ability to accelerate to a certain level before pitch area requires a deceleration or change in direction. The higher the starting velocity in this case, the harder it is to produce lager increases in velocity compared to those commencing from a lower intensity or static start. The significant difference in absolute volume of high-end accelerations and decelerations in match-play compared to smaller games is not unexpected. However, an interesting finding in this study is the apparent reverse in acceleration requirements when the data is examined in relative terms, Aughey (2011) stated this may be a more appropriate representation accounting for different exercise durations and may avoid underestimating activity demands. As well as the total acceleration and deceleration distance of all intensities, with specific reference to accelerations above 2.78m/s^2 and 3m/s^2, the distance and frequency of efforts per minute is greater in 4 v 4 and 9 v 9 games than match-play (Figure 8.1, $p<0.05$). Similar findings have been reported by Castellano and Casamichana (2013) intimating concentric and eccentric muscular demands of small training games are greater than MP. A possible explanation for this is the lower mean exercise velocity in 4 v 4, ensuring a lower starting velocity to overcome inertia and initiate greater changes in speed that may be decisive in a confined environment of more changes in direction searching for space. This may also be elucidated by the SSG values of Player Load Slow per minute being nearly twice that of LSG and MP (Figure 8.1b), promoting low-velocity movement with directional changes and curbing high-speed movement (Boyd, Ball and Aughey, 2013). Although high absolute velocities are not achieved in smaller relative playing areas of SSG and LSG, there is still significantly taxing of the muscular system to act concentrically and produce large forces efficiently. On the other hand, relative deceleration behaviour is still greater in match-play that may again result from a more expansive playing environment where it is easier to step away from an opposition marker and accelerate to more maximal speeds (~30km/h^{-1}) and then slow down, absorbing force eccentrically. Peak decelerations therefore may be higher in LSG and matches particularly in wide positions (Ingebrigsten et al., 2014), but there are still forceful reductions in speed in SSG, but the continuous exercise pattern and mean velocity dictates that fluctuations in absolute velocities are perhaps not as great as those observed in larger games. Furthermore, with previous findings that 98% maximal accelerations occur under and 85% do not exceed high velocity markers (Varley and Aughey, 2013), our results suggest that there may indeed be a zone in which typical exercise behaviour occurs in certain formats of soccer training drills. Specifically this will depend on the mean velocity and relative playing area that will determine the peak velocities as well as the magnitude of changes in speed (accelerations and decelerations) attainable.

It may therefore be feasible to say that despite a lack of traditional high-intensity activity with regards to absolute velocity, SSG may still consist of high-intensity actions in terms of load on the musculo-skeletal system but this is experienced through accumulation of superior relative volume and intensity of accelerations and decelerations that demand large initiation and acceptance of forces. These types of activity have been suggested by Varley, Aughey and Pedrana (2011) to be vital to high-intensity classifications and as a result may help to discriminate further between the loading of training drills and the associated energy cost of ‘high-intensity’ activity. Indeed it may signal a change in conditioning focus to be more repeated-effort rather than repeated-sprint based (Gabbett, 2012). A limitation with regards to this type of activity may be that the data from match-play was not analysed in discrete 5 minute periods in order to identify the most 'intense' periods of play, in terms of high intensity running or acceleration repeated efforts. These may then be compared to how frequent, and to what extent these periods are replicated in small and large-sided games in the training environment.

Practical Applications

In the present study we have demonstrated the use of GPS and inertial sensors for elucidating movement specificity and energy cost in relation to game context and an individual's movement strategy. We have shown how accumulated running and acceleration volume and efforts are more numerous over a ninety-minute match compared to small and large-sided training games. The acceleration profiles have also been examined with regards to how behaviour may be largely influenced by environmental constraints and subsequent strategy in the specific game format.

Although the absolute load from running activities is higher in matches, when the data is viewed in relation to exercise time, the relative biomechanical loading is greater in SSG. Coupled with a high cardiovascular response above that typical of match-play, SSG incorporate high-intensity activities that are energetically taxing but executed at low absolute velocities and involve fluctuations in speed to change direction as a result of a confined playing environment. Large-sided games more closely resemble match-play and are able to provide near maximal speeds over prolonged distances that are not reproduced in 4 v 4 training games.

It would therefore be feasible to say that SSG may elicit sufficient internal cardiovascular and external low-velocity-high-intensity loading, but higher-velocity and repeated-sprint demands are more easily attainable through LSG, 11 v 11 match-play or additional supplementary conditioning. This may enable a more complete training week for soccer players in preparation for competition, where a range of stimuli and loads are undertaken.

By understanding how soccer-specific training formats may bring about different loading conditions, coaches are better equipped to prescribe training more effectively in line with desired aims and objectives throughout the training week.

Chapter 9.

General Discussion and Conclusion

The purpose of this section is to evaluate the main findings from the experimental chapters presented in this thesis. These findings will be related to the original aims and objectives of the research and will be used to form conclusions and recommendations with regard to how they may be used in applied practice.

The aims of this research were first met by using GPS and inertial sensor technology to quantify the training load of elite youth soccer players. The typical training was described over a whole season detailing metrics of ‘external’ or locomotor load, combined with heart rate and rating of perceived exertion as markers of internal and subjective training loads. Significant differences were found in testing performance between early and late pre-season and competition phases for training volume and intensity. The improvement in soccer-specific endurance performance in YoYoIR2 across the three phases was significant and coincided with a simultaneous significant reduction in training volume (total distance covered). Changes in high-intensity distance covered and high-level decelerations were also evident between each phase, although no significant differences in speed and power performance were observed.

As a result, GPS monitoring over longer periods would appear useful in tracking changes in training load in soccer players. The efficacy of this technology in quantifying differences in physical outputs and accumulated loads may be helpful in justifying training prescribed to ensure optimal conditioning adaptations and minimizing the risk of injury. This is also important in phases were both friendly and competitive match-play are introduced which bring significant a physical dose and may therefore alter the rhythm of training prescribed around them as part of the weekly training load. Therefore, it is important to note that the inclusion of match-play’s contribution to loading is key in interpreting seasonal changes and subsequent training prescription.

Furthermore, the conditioning of soccer players in-season is a difficult task. Given that match-play brings a large aerobic volume to the microcycle, there may be more of a focus on speed and biomechanical loads for adaptation. It could be said that this biomechanical element is missing from previous research in small-sided games to provide more insight as opposed to traditional heart rate responses. GPS accelerations could give valuable information on neuromuscular load from more discrete changes in direction, rather than large overall and high-intensity distances that are curtailed by a lack of space and high starting velocities. On the other hand, the need of certain sub groups who are not regular starters in matches may still need supplementary cardiovascular development through generic high-intensity interval training.

In line with the premise of further quantifying soccer training load, the first experimental chapter sought to describe chronic training loads across a whole season. By showing how the overall load, and fluctuation in certain metrics occurs in discrete training phases this should aid evaluation of planned and actually training loads. The next aim, however, in the subsequent chapters was to highlight the most common forms of training within soccer, small-sided games. By doing this, it was hoped that intentional manipulation of various situational and contextual factors (number of players, pitch size and rules) would elicit contrasting physical responses from GPS and inertial sensors to provide more detail about whether or not specific facets of match-play are replicated effectively. Moreover, this analysis focused on common SSG and player numbers that are used in elite soccer training as ways of achieving specific stimuli for aerobic and muscular conditioning. As a result, it informs the coaches library of drills with more detail when prescribing session content. The comparison of formats with different player numbers is common in soccer research, though this was taken further by comparing games both with and without goalkeepers keeping constant the relative playing area. It should be noted that data collection of this type of training, in the elite soccer environment, may be influenced by small changes to planned work and rest periods, which were out of the control of our control. However, these would likely have little effect on our conclusions drawn The data agreed with previous findings showing SSG of smaller numbers to produce higher heart rate responses, with larger numbers increasing average speed and higher-speed activity as well as magnitude of acceleration. However, when goalkeepers were removed from 5v5, higher cardiovascular and relative distance (average speed) were increased further when compared to the

SSG with goalkeepers. The results, therefore, highlight a large effect of the conclusion of goals and goalkeepers which dictate a directional element to play. The possession format, may therefore me more unstructured, with less positional emphasis given the random pattern of play with no formal target to aim for. As a result, player's behaviour may be directed towards more steady state running (increasing total distance) in order to find space and support team mates in possession of the ball. The higher average speed in possession may also see less intense acceleration behaviour in this format compared to SSG as a higher starting velocity exists which makes attaining high accelerations over longer distances difficult when also confined by spatial constraints. The observation that external load variables were not different between SSG of different player numbers indicates that training responses may be governed by the relative playing area available.

To examine whether there was an effect of playing area on GPS variables of external load, the same 6v6 SSG was repeated on increasing relative areas whilst also compared to one format entailing a numerical overload scenario of 6v4, where relative playing area was unbalanced. In 6v6 SSG as pitch size increased, heart rate, average speed, high intensity distance and high-level acceleration behaviour increased significantly. This was also the case in the team of numerical disadvantage in the overload format, with perceptual load greatly different. This could be due to the vastly disproportionate relative space asked of this team to cover compared to the team of more numbers sharing more space between them. As a result of the smaller absolute area, the higher level accelerations observed in 6v6 SSG were negated in this activity. It may therefore be suggested that these data reinforce the notion that available playing area is more of an influential factor in game strategy and GPS metrics and intensity of training than player numbers. The contextual design regarding space can therefore be a more useful tool in targeting specific training stimuli, depending on the stage of the season, daily training and individual player conditioning aims.

Having examined components of player numbers and pitch area in their role in influencing training intensity and GPS external loading, the next chapter went on to look compare formats of the same player numbers but with different rules and design. Volume (total distance) and high-speed distance and peak speeds were greatest in the possession format with no goalkeepers compared to a traditional 5v5 SSG with goalkeepers and a 6v4 overload game. Heart rate responses were comparatively reduced in the overload game which entailed shorter work bouts, although all three formats were matched for total time. Acceleration and deceleration distance and efforts were similar between all three formats at lower intensities, however, overload games had significantly less than the possession format at higher acceleration thresholds. The results further showed how training intensity can be moderated by implementing specific environmental conditions to the SSG format. This can then achieve specific conditioning stimuli for the training session or selected individuals. This may be for aerobic fitness, or anaerobic speed and strength components that are not as easily reproduced in some training formats.

The efficacy of conditioning players with uneven numbers is a prevalent theme in elite soccer, given that squad numbers can change on a daily basis. As a result, small-group formats of uneven numbers are often utilised. However, the contribution of loading and exposure of either team, with a numerical advantage or not, to certain physical stimuli is not well understood. Using different player combinations, three overload formats of matched total duration and relative playing area were studied. When analysing markers of aerobic, biomechanical and perceptual training load, overload formats of less player numbers (eight) were found to have significantly elevated responses compared to those entailing ten or twelve players. Within each format, the underloaded team were found to have a much greater work rate and thus, aerobic and acceleration outputs when trying to press opponents and close passing lines by changing direction and through body orientation. In the case of this study, there appears to be a greater physical conditioning emphasis on players in teams of less numbers, compared to those of more number who may be subjected to more of a technical load when keeping possession of the ball in this training drill.

When examining the training context across the training year or soccer season, it is important to relate aims to performance in competition (as identified in the first study). Having scrutinised the training loads associated with various small-sided game modalities commonly used by soccer coaches today, it is also important to compare these responses to larger extensive formats as well as full-size matches. The final study then sought to validate existing time-motion analysis and compare each of these three environments that may be used in training and how they vary in relative demands. The variation in training stimuli during the week to optimally prepare players for match-play, by being exposed to stimuli indicative of matches. For example, high-speed running, maximal velocities and repeated acceleration and deceleration sequences through the addition of inertial sensor data. Consequently, this may benefit the adjustment of training for the team, positions and individuals with more confidence. Heart rate responses were highest of the three game types, although absolute values for external load were all highest in match-play given the longer duration compared to SSG and LSG formats. However, when the data is viewed in relative terms, the intensity in SSG of short total duration is actually greatest. Average speed or meterage and GPS and accelerometer-derived acceleration efforts are all enhanced in 4v4 activities which may provide the most beneficial stimulus for training these neuromuscular components that are critical in key match actions. However, as seen through studies 2 to 5, high-speed activity >21km/h^{-1} is greatly compromised in smaller game formats owing to the confined space that limits high level accelerations and peak velocities, also explaining a higher average speed here in order to find space. As a result of the large discrepancies between SSG, LSG and matches for volume and efforts of high-speed activity, additional work may be necessary to supplement the aerobic benefits achieved. Therefore, supplementary linear, speed work may be necessary as a way of prescribing a stimulus important in competition and for hamstring injury prevention where it is common to exceed 30km/h^{-1} when space is available, but are not replicated in traditional SSG.

Conclusions

Training in soccer is multifactorial and needs to address the numerous physical, technical and tactical requirements necessary for optimal competitive performance. The findings in this thesis build on existing data regarding training intensity in soccer, with special reference to small-sided games.

Table 9.1 – Drill recommendations with special reference to physical conditioning objectives

Aim	Drill	Conditions	Outputs
• **High intensity, aerobic conditioning, high cardiovascular and high-intensity running**	5 v 5 Possession No Goalkeepers	150m^2 per player 4 x 4 minutes (2 mins recovery) 2 and 3 Touch limits	133 m.min^{-1} 90%HR$_{max}$ 70m High-Intensity Distance Peak Velocity 23km/h^{-1} RPE 8
• **High mechanical, low high-intensity running**	Underload team 4 v 6 No GK Small goals optional	132m^2 per player 8 x 2 minutes (60 secs recovery) Score with 3 passes or goal	134m.min^{-1} 85%HR$_{max}$ 4 Decelerations >3m/s^2
• **High heart rate and high biomechanical**	6 v 6 Medium pitch Goalkeepers	45 x 34m 125m^2 per player 4 x 4 mins (2 mins recovery) 2 and 3 Touch limits	135m.min^{-1} 89%HR$_{max}$ 50m High-intensity running Peak Velocity 25km/h^{-1} 10 Accelerations >2.78m/s^2 8 Accelerations >3m/s^2 RPE 6
• **Low cardiovascular intensity, higher technical emphasis**	Overload team 8 v 4, 6 v 4, 5v3 No Goalkeepers Small goals optional	75-90m^2 per player 8 x 2 mins (60 secs recovery) 8 passes to score	80-100m.min^{-1} 80-85%HR$_{max}$ 0m High-intensity running Peak Velocity 15-17km/h^{-1} RPE 5
• **High cardiovascular, low high-intensity distance**	Underload team 4 v 8, 4 v 6, 3 v 5 No Goalkeepers Small goals optional	130-150m^2 per player 8 x 2 mins (60 secs recovery) 3 passes to score	120-140m.min^{-1} 85-90%HR$_{max}$ 0m High-intensity distance Peak Velocity 17-20km/h^{-1} RPE 8
• **High acceleration load**	6 v 6 Large field	49 x37m 4 x 4mins (2 mins recovery) 2 and 3 Touch limits	Peak Acceleration 5m/s^2 Peak Deceleration 4.5m/s^2 Acceleration >2.78m/s^2 – 17m and 5 efforts Acceleration >3m/s^2 – 36m and 6 efforts

From a broader, seasonal context, by systematically examining commonly used formats of specific-soccer training, it has been possible to quantify the efficacy of each of these drills in inducing desired stimuli when modifying contextual factors. Changing player numbers and particularly the relative playing area available, we have shown the ability to mediate physiological, biomechanical and perceptual training load in small soccer formats. Understanding the intensity that these drills and variations may bring to training may therefore add to a coach’s drill book, aiding training prescription according to aims in different phases of the season, proximity of match-play and individual conditioning goals (Table 9.1).

Monitoring through GPS and inertial sensor technology to inform planned and actual training loads may well be a powerful tool in identifying daily and weekly rhythms with an elite soccer setting to enable confidence in prescription in relation to the type of stimuli the players are exposed to. The biomechanical aspects brought by GPS can then add to existing understanding of heart rate in prescribing exercise intensity by providing a more holistic picture of training ‘intensity’, which may be further strengthened by the inclusion of technical data. Our data may also challenge previous literature regarding effect of player numbers and playing area with regards to the magnitude of effect on player’s responses. Combining these monitoring tools with variations in training design has been shown to be useful in highlighting the importance of the environment provided (space), how this regulates player strategy and behaviour and thus the resultant physical responses obtained. Moreover, the space may dictate average speed, high-intensity efforts and acceleration behaviour depending on the starting velocity.

Ultimately, it could be said that understanding soccer training and the load provided by using this microtechnology, it may aid periodisation strategies in reducing injuries, illness and fatigue within each setting that ensures optimal conditioning in preparation for optimal match performance.

Chapter 10. References

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