# AN EXAMINATION OF THE TRAINING LOADS WITHIN ELITE PROFESSIONAL FOOTBALL

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# ABSTRACT

The popularity of soccer throughout the world has led to the demand for a scientific approach to the preparation of players for competitive matches. Although previous researchers have attempted to understand the training demands undertaken by soccer players, limited information is known regarding the structure of training in soccer. At present research has focused on the frequency and duration of soccer training without using both objective and subjective measures of training load to systematically evaluate training practices in elite teams. Little is also known regarding the periodisation strategies employed by elite soccer teams across a competitive season and whether they follow traditional models of periodisation. With this in mind, the primary aim of this thesis is to therefore characterise the current training periodisation practices that exist in elite soccer using applied methods of training load assessment.

The aim of the first study (Chapter 3) was to evaluate the use of Global Positioning Devices (GPS) for the measurement of soccer-specific activities to provide objective data for training load assessment. Findings from this study were applied to study 3 (Chapter 5) of the thesis. Firstly, a soccer-specific movement course was designed based on the movements exhibited by an elite soccer player during a competitive match using a multi-camera tracking system (ProZone®). Two moderately trained males performed 10 bouts of the soccer-specific track following familiarisation and a 10 minute standardised warm up. Both subjects wore two 10Hz GPS units inside a custom-made vest during all bouts of the track to determine both reliability and inter-unit reliability of the GPS devices. Data analysis revealed the reliability of the GPS devices was good for distance covered at lower velocities (0 – 4 m/s; CV% = 0.6 – 3.6%). However when the velocity of movement increased (> 4 m/s), the reliability of the units decreased (mean change from 13.8 to 33.6 CV%). Both total distance (mean CV% = 1.1%) and max speed (mean CV% = 2.7%) were both found to be highly reliable variables. However the devices demonstrated high levels of inter-unit reliability error due to an increase in systematic error with random distribution of data points between both devices for all variables measured. The data suggested that 10Hz GPS devices are reliable for the measurement of lower velocity (0 – 4 m/s) running. However, care must be taken when analysing data in higher velocity bands (> 4 m/s) due to the high

error rates observed. The high inter-unit reliability error also suggests that 10Hz GPS devices cannot be used interchangeably between players in order to minimise the associated error.

The aim of the second study (Chapter 4) was to quantify the reliability and validity of a portable vertical jump assessment tool (Optojump®) for use in the applied setting. Vertical jump assessment was utilised as a measurement tool to analyse the effect of training load on the neuromuscular system that was evaluated in study 4 (Chapter 6) of the thesis. Eleven healthy male subjects were familiarised to perform four separate common types of vertical jump test: countermovement with arm swing (CMJ-W), countermovement without arm swing (CMJ-WO), squat jump (SJ) and drop jump (DJ). Contact time, flight time and jump height were selected as variables for the study. For reliability assessment, all subjects performed 3 efforts of each jump type across 5 identical testing sessions (separated by minimum of 2 days). For validity assessment, subjects were asked to perform the same jump modalities as the previous investigation on one occasion while data was simultaneously collected from both a force plate (criterion instrument) and the Optojump photocells. The data revealed the Optojump device was highly reliable for the assessment of jump flight and height for CMJ-W, CMJ-WO, SJ and DJ (all CV% = 3.2 and 5.6%). However reliability of the device was reduced for the measurement of contact time with the DJ (CV% = 13.9%). Validity data revealed that all jump types and variables were highly valid in comparison to the force plate criterion measure (SEE% = < 1%, Pearsons correlation = r > 0.99). This study revealed that the Optojump device is highly reliable and valid for all jump types and variables, with the exception of contact time for DJ. Therefore the Optojump system may be used with confidence to detect within-group changes in applied assessments of vertical jump performance. Due to the high cost and lack of portability of laboratory-based force plates, the Optojump system is a viable alternative for accurate jump measurement and neuromuscular assessment. The CMJ-WO jump assessment was chosen for study 4 for comparison with previous research.

The aim of the third study (Chapter 5) was to quantify the periodisation strategies employed by an elite professional soccer team throughout a competitive season. Training load data was collected from 37 elite outfield soccer players at one professional English soccer team over a 45 week period during the 2011-2012 domestic season. All players wore global positioning system (GPS) devices, heart rate (HR) belts and were asked to provide a rating of perceived exertion (RPE) for each training session to generate training load data. Players were assigned to one of 5 positional groups: central defender (CD), wide defender (WD), central midfielder (CM), wide midfielder (WM) and attacker (AT). The data was separated into the pre-season (6 weeks duration) and in-season (39 weeks duration) phases in order to investigate specific training periods recognised within the annual plan. The pre-season phase was further separated into weekly blocks for analysis of the structure employed in each specific microcycle. The in-season phase was divided into 6 x 6 week blocks for analysis of mesocycle structure. Within the in-season data, three separate microcycles (weeks 7, 24 and 39) were selected consisting of the same weekly training schedules to determine whether differences in microcycle training load pattern existed. In addition, the training data within a given microcycle was analysed to investigate the loading patterns in relation to number of days away from the competitive match fixture. Linear mixed modelling analysis revealed significant differences for total distance and average HR ($P < 0.05$) between period 1 with periods 3 and 6 during training mesocycles. However no differences were found for the remaining training variables during both pre-season and in-season microcycles ($P > 0.05$). Training load variables were significantly reduced on match day (MD) -1 ($P < 0.05$) but remained similar across MD-2, MD-3 and MD-5 ($P > 0.05$) during in-season microcycles. CM players generally covered the most total distance compared to other positions. Defenders reported higher internal load values (average HR and RPE) compared to attackers during in-season training phases but such differences were not evident during pre-season. This study revealed that training load doesn't appear to be systematically periodised across a competitive season in an elite soccer team. This may have practical implications for training planning, as monotonous training load prescription may lead to maladaptation in soccer players during a competitive season. This was the first study to systematically evaluate periodisation strategies in an elite soccer team, but further work is required to determine such practices at different soccer teams.

The aim of the fourth study (Chapter 6) was to determine the neuromuscular response to a microcycle of soccer training in elite soccer players using vertical jump assessment via the Optojump device. Nine elite level youth soccer players from an U18 soccer academy team were recruited for the study. The players underwent four separate on-field soccer training sessions following familiarisation of all testing procedures. Players were assessed for CMJ (flight time and jump height) both pre and post each training session in order to determine any differences in neuromuscular status across a training microcycle. Training load data was analysed using GPS, HR and RPE and the relationship with the absolute change in CMJ performance was assessed. Data analysis revealed no significant difference in CMJ performance across the four separate training sessions leading into a competitive match ($P > 0.05$). Training load data was significantly reduced on MD-1 for all training load variables (with the exception of high speed distance). There was no relationship found between the absolute change in CMJ performance and training load variables ($P > 0.05$). This study suggested that neuromuscular status remains unaffected in soccer players during a typical microcycle of training. This may be due to the emphasis of fitness maintenance during the in-season phase in order to maximise recovery between matches resulting in the players becoming accustomed to repeated maintenance loading.

In summary, the work undertaken from the studies in this thesis provides novel information in relation to the training loads within elite professional soccer in relation to periodisation strategies. Specifically, this is the first work to systematically examine the training load across a competitive soccer season using both objective and subjective measures. Methodological work in this thesis also highlighted the importance of quantifying and interpreting errors associated with measurement tools when using applied methods to quantify training load in soccer players. It was also found that neuromuscular status remained unchanged throughout a planned microcycle in preparation for a competitive match. These findings suggest that the way in which training periodisation is applied is of utmost importance as opposed to trying to use traditional models and methods. Due to the limitations of traditional periodisation and training load management in elite soccer, future work should focus on developing periodisation models unique to the competition demands of soccer.

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# CONTENTS

# LIST OF ABBREVIATIONS

ANOVA, Analysis of variance

AT, Attacker

AU, Arbitrary unit

BLa, Blood lactate

BPM, Beats per minute

CD, Central defender

CM, Central midfielder

CMJ, Countermovement jump

CMJ-W, Countermovement jump with arm swing

CMJ-WO, Countermovement jump without arm swing

CV, Coefficient of variation

DJ, Drop jump

EMG, Electromyographic

GAS, General adaptation syndrome

GPS, Global positioning systems

HR, Heart rate

$HR_{max}$, Maximal heart rate

ICC, Intraclass correlation coefficient

LoA, Limits of agreement

MVC, Maximal voluntary contraction

$\dot{V}O_2max$, Maximal oxygen uptake

OBLA, Onset of blood lactate accumulation

RPE, Rating of perceived exertion

SJ, Squat jump

SSC, Stretch-shortening cycle

SSE, Standard error of the estimate

SSG, Small sided games

TEE, Typical error of the estimate

TRIMP, Training impulse

WD, Wide defender

WM, Wide midfielder

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**CHAPTER 6**

# CHAPTER 1

# GENERAL INTRODUCTION

## 1.1. BACKGROUND

Soccer is a complex intermittent-type sport in which the activity pattern contains periods of high-intensity and low-intensity efforts. This type of activity patterns leads to a high level of anaerobic and aerobic energy turnover during a soccer match (Bangsbo 1994). The ability to recover between bouts of high-intensity exercise and produce high levels of sprint distance is one of the major differences between elite-level soccer players and those of a lower standard (Mohr et al. 2003). The physiological stress associated with match-play is further complicated by a number of interdependent factors, such as psychological, tactical and technical elements closely linked to soccer performance. Development of specific match activities such as dribbling, kicking and tackling are also required for successful soccer performance at all levels. Due to these numerous factors, soccer players are required to be competent in various areas of physical fitness and technical abilities (Krustrup et al. 2005).

The annual competitive season within soccer is split into three distinct phases: pre-season, in-season and off-season phases (Reilly 2007). During the in-season phase, elite level soccer teams typically play upwards of 40 competitive matches throughout this period. Due to fixture congestion and scheduling dictated by external factors (e.g. television subscription rights), elite teams will often play two matches per week. Although the physical output of soccer players may not be affected by playing two matches per week, previous work suggests injury rate is significantly increased with such fixture scheduling (Dupont et al. 2010). Clubs that have significant financial resources and can afford high level replacement players are able to rotate between players in order to minimise injury occurrence. However, smaller clubs are unable to afford high quality squad players and are forced to play the same players repeatedly. Taking this into consideration and the requirement for adequate recovery between soccer matches, the training time available for physical and technical enhancement is severely limited. When only one soccer match is played per week, for example with teams who do not compete in European competition, the opportunity for structured soccer training for performance development is significantly enhanced. However, it is important that soccer teams utilise this available training time in order to maximise physiological adaptations and technical/tactical development.

The use of training periodisation strategies in sport are well established, particularly in individual sports such as swimming and athletics (Bondarchuk 1986; Stewart & Hopkins 2000). Training periodisation refers to the division of an entire seasonal annual plan into smaller periods and training units (Matveyev 1981). The overall aim of training periodisation is to optimise training adaptation whilst preventing overtraining through the management of fatigue (Plisk & Stone 2003). Periodisation allows training sessions to be programmed within a specific training unit with the aim of meeting the requirements of individual athletes (Bompa 2009). Despite the obvious benefits of employing training periodisation in soccer, the application of current periodisation models and methodology is limited due to external factors (e.g. fixture scheduling). Compared to individual sports in which coaches may have several months to prepare an athlete for a competition phase, soccer players may only have 1-2 training sessions in between competitive matches of which the emphasis is on recovery. Limited research is currently available relating to the application of training periodisation strategies in elite soccer. Of the current research available (Mallo 2011; Mallo 2012), no study has systematically evaluated the periodisation strategies employed in elite level soccer teams throughout a competitive season. Previous studies have quantified the frequency and duration of soccer training sessions within a competitive phase. However, systematic evaluation using both objective and subjective training load data has not been conducted.

Impellizeri et al. (2005) have previously described the training process involved in soccer, dividing the overall training load into two separate sub-sections termed external and internal training load. The external training load refers to the training prescribed by the coaches, with the internal load referring to the physiological response to the external training stimulus. The training load response may also be subdivided into acute and chronic responses to a given training stimulus. The acute response refers to a single training session comprising of individual training drills. Previous research has attempted to quantify the acute response to soccer training through the physiological response to soccer drills (Bangsbo et al. 2006) and training sessions (Impellizeri et al. 2005). The chronic response refers to the accumulation of individual training sessions, ranging from a single week to several months throughout an annual cycle (Bompa 2009). Several authors have described the chronic response of soccer training during both the pre-season (Jeong et al. 2011) and in-season (Gaudino et al. In Press; Impellizeri et al. 2006; Jeong et al. 2011) phases. Several methods exist in order to monitor soccer training, including global positioning systems (GPS), heart rate (HR) monitoring and post-training rating of perceived exertion (RPE).

It may also be possible to monitor accumulated fatigue of the neuromuscular system in both the acute and chronic setting in response to soccer training. Any fatigue-induced impairment in neuromuscular function could have subsequent implications for soccer performance (Oliver et al 2008). It is currently unknown whether neuromuscular function is altered during periods of soccer training during the in-season phase. Despite previous attempts to quantify training load in soccer players, no study has systematically quantified both the acute and chronic response to soccer training with reference to training periodisation.

## 1.2. AIMS AND OBJECTIVES OF THE THESIS

The overall purpose of the present thesis is to characterise the current training periodisation practices that exist in elite soccer using applied methods of training load assessment. This will be investigated through the fulfilment of the following aims:

1. To evaluate the use of GPS devices for the measurement of soccer-specific activities.

2. To evaluate applied methods of neuromuscular status assessment.

3. To quantify the training periodisation practices used by elite soccer players throughout a competitive season.

4. To determine the neuromuscular response during a weekly microcycle of soccer training in elite soccer players.

The successful completion of the above aims will enable a deeper understanding of the periodisation strategies employed by elite soccer teams. This will be accomplished by the following objectives:

1. The reliability of 10-Hz GPS devices for the measurement of soccer-specific activities will be evaluated through the development of a soccer-specific movement track. This will be achieved through completion of Study 1 (Chapter 2).

2. The reliability and criterion validity of a portable photoelectric cell system (Optojump) will be evaluated for the assessment of neuromuscular status using various vertical jump types and parameters. This will be achieved through completion of Study 2 (Chapter 3). Results from completion of this objective will form the basis for vertical jump type selection for Study 4.

3. Quantification of training periodisation practices employed by an elite soccer team will be determined through analysis of internal and external training load data using applied methods of data collection throughout a competitive season. This will be achieved through completion of Study 3 (Chapter 4).

4. The neuromuscular response to a weekly microcycle of soccer training will be evaluated through the use of vertical jump assessment in elite soccer players. The vertical jump type used for assessment will be determined from the findings of Study 2. This objective will be achieved through the completion of Study 4 (Chapter 5).

# CHAPTER 2

# LITERATURE REVIEW

## 2.1. OVERVIEW OF SOCCER

Team sports, such as soccer, involve changes in the exercise pattern that are irregular in nature (Bangsbo 1994). These intermittent bouts of activity result in complex physiological responses compared to sports exhibiting a more continuous exercise profile (Drust et al. 2000). The typical total distance covered by a top-class outfield player during a soccer match is around 10 – 13 km (Dellal et al. 2011; Di Salvo et al. 2007). Several studies illustrate positional differences in these values with central midfielders covering the highest distance during a match and central defenders covering the least (excluding goalkeepers) (Bradley et al. 2009; Carling 2011; Di Salvo et al. 2007). Wide midfielders have been reported to cover a greater distance in high intensity running (> 14.4 km.h$^{-1}$) compared to other outfield positions (Bradley et al. 2009). Each player performs around 1000 – 1400 mainly short activities changing every 4 – 6 seconds during a match (Mohr et al. 2003). These include around 30 – 40 sprints (Bangsbo et al. 2006), more than 700 turns (Bloomfield et al. 2007) and 30 – 40 tackles and jumps (Bangsbo et al. 2006). Other soccer-specific actions include accelerations/decelerations, kicking, dribbling and tackling (Bangsbo 1994). Soccer is therefore a complex sport in terms of its demands that places high requirements on different physiological energy systems to meet the physical demands placed on players.

A soccer match consists of large periods of moderate to low intensity activity (Di Salvo et al. 2007). The prevalence of these activities suggests that soccer players are mainly dependent upon aerobic metabolism during match-play (Stolen et al. 2005). Bangsbo (1994) reported that aerobic energy production accounts for more than 90% of the total energy consumption during a match. This concept is also supported by research reporting mean and peak heart rates of around 85 and 98% of maximal values, respectively (Krustrup et al. 2005; Mohr et al. 2004). These heart rate values correspond to an average exercise intensity of approximately 75% of maximal oxygen uptake ($\dot{V}O_2max$) (Astrand et al. 2003). The $\dot{V}O_2max$ for male outfield professional soccer players has been reported to vary between 55 – 75 mL/kg$^{-1}$/min$^{-1}$ (Stolen et al. 2005). These high values further indicate that the aerobic energy system is frequently stressed during a soccer match.

Other physiological components also contribute to an elite soccer player's physical performance. Due to the unpredictability of soccer match-play, players are often required to perform high-intensity actions (Dupont et al. 2004). It has been suggested that these decisive actions are often crucial for the outcome of matches and are supported by anaerobic metabolism (Cometti et al. 2001; Faude et al. 2012). Evidence of an anaerobic contribution to soccer comes from the analysis of blood and muscle metabolites. Previous research has reported mean blood lactate values of up to 10 $mmol.l^{-1}$ during soccer matches (Bangsbo 1994; Krustrup et al. 2006). Creatine phosphate concentrations have also been reported to decline below 30% of resting values when recovery periods are short following intense exercise periods (Krustrup et al. 2006). This evidence, when taken together, would suggest a significant contribution from anaerobic metabolism during match-play.

## 2.2. TRAINING PRINCIPLES AND PERIODISATION

Improvements in athletic performance are largely dependent on a systematic training programme. Training is a process by which an athlete is prepared for the highest level of performance (Stone et al. 2007). The process of training targets the development of specific attributes with the aim of enabling the proficient execution of various sports specific tasks (Stone et al. 2007). These attributes include physical development, technical skills, tactical abilities, psychological characteristics and injury resistance (Bompa 2009). The successful acquisition of these attributes is based upon the application of a training methodology that is both specific to the sport and the individual athlete. The advancement in sports science research over the last few decades has led to the evaluation and progression of traditional training methodologies (Issurin 2010). This section will aim to evaluate the principles of training and physiological adaptation to a training stimulus. In addition, the current models of periodisation will be explored and evaluated in terms of their application to soccer training.

### 2.2.1. PRINCIPLES OF TRAINING ADAPTATION

Training is an organised process whereby athletes are constantly exposed to stressors of varied volume (quantity) and intensity (Bompa 2009). The ability of an athlete to adapt and adjust to workloads imposed by training and competition is crucial for the achievement of optimal levels of performance. Seyle (1956) developed a model to explain the response to a physiological stimulus termed the general adaptation syndrome (GAS). This model proposes that all stressors result in similar responses. Figure 2.1 depicts some of the key aspects of the GAS model as relevant for training adaptation. The figure refers to the process of homeostasis in which the human biological system adapts to imbalances in homeostatic status due to external stressors. The process is based on a negative feedback principle in which physiological sensors regulate adaptive processes in order to maintain homeostasis within the body.

Bompa (2009) has described how the GAS model can be directly applied to exercise training. The model of Bompa directly relates to the changes associated with Seyle's ideas, i.e. a temporary higher state of physiological functioning following an exercise stimulus termed 'supercompensation'. The author described the supercompensation cycle as having four separate distinct phases following a physiological stimulus. The first phase occurs 1-2 hours after the end of exercise and results in exercise-induced fatigue. This fatigue can occur in both central and peripheral mechanisms, i.e. the central nervous system and musculoskeletal system (Davies 1995). The second phase of supercompensation occurs 24-48 hours post exercise. This phase results in the restoration of various physiological systems to previous baseline levels. For example, muscle glycogen may be restored within this time period (Coyle et al. 1991) depending on the level of muscle damage that has occurred (Costill et al. 1990). In addition muscle function, as reflected in electromyographic (EMG) activity and maximal voluntary contraction (MVC), can also be fully restored back to baseline levels (Zainuddin et al. 2006). The third phase occurring 36-72 hours post exercise is marked by a supercompensation of the physiological systems. For example, a secondary rebound in MVC occurs during this phase that leads to a higher state of performance than previously shown (Nicol et al. 2006). The fourth phase of the model occurring 3-7 days post exercise relates to the period in which the athlete is required to apply another stimulus in order to maintain or increase the newly attained physiological level. If the athlete does not apply another training stimulus during this period then a process termed 'involution' occurs in which a decrease in the physiological benefits obtained during the supercompensation phase happens. However, if the athlete is exposed to high training stimuli too frequently without sufficient time for recovery, the ability to adapt to the training stimuli will be significantly compromised and overtraining may occur (Fry et al. 2006). Therefore it is crucial that the time-course of the physiological response to a physiological stimulus is understood in order to effectively plan for optimum training adaptations.

When specific training is repeated over time, several neuromuscular adaptations may occur within skeletal muscle. The most prominent result of training relates to the hypertrophy of skeletal muscle (Booth & Thompson 1991). In soccer players, this growth is particularly important in relation to fast twitch glycolytic and oxidative-glycolytic fibres that result in an increased cross-sectional area (Costill et al. 1979). Such improvements in muscle fibre content enhances the potential of explosive type movements for soccer players that may impact on performance (Thorlund et al. 2009). A decrease in volume or ineffective training can lead to a decrease in the volume fraction of myofibrils following a period of specific training (Rosler et al. 1985). Soccer training may also lead to increased activity of oxidative enzymes and thus oxidative phosphorylation evidenced by an increased number of mitochondria and ATP in skeletal muscle (Hoppeler et al. 1985). Such adaptations have significant effects on the neuromuscular function of players, therefore it is important the neuromuscular status is either maintained or enhanced throughout a competitive season.

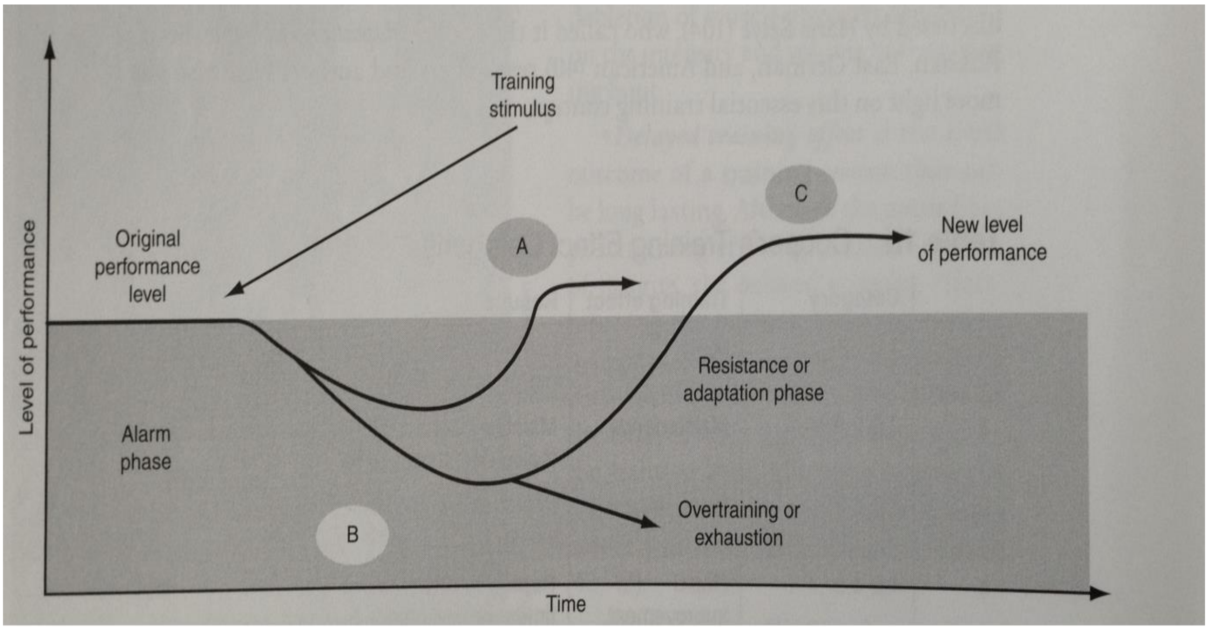



**Figure 2.1.** The general adaptation syndrome (GAS) model developed by Selye (1956) (adapted from Bompa 2009). The GAS model has three distinct phases in which training adaptations occur. The 'alarm phase' relates to a reduction in the physiological state following a stimulus. This is followed by the 'resistance phase' in which an

individual/organism returns to homeostasis often with a higher state of physiological functioning. Finally the ‘exhaustion phase’ may occur when the imposed stress is greater than the rate of adaptation. This may ultimately lead to injury if this situation is maintained across a longitudinal period

### 2.2.2. PRINCIPLES OF TRAINING PERIODISATION

In order to achieve optimal physiological adaptation, training sessions need to be programmed and adjusted to meet the requirements of individual athletes (Bompa 2009). As the competition demands of both individual and team sport athletes typically cover yearly cycles, coaches are required to plan in order for the athlete to give optimal physical performances during competition. This planning is typically organised as the ‘annual plan’ (Bompa 2009). Training periodisation refers to the division of an entire annual plan into smaller periods and training units (Matveyev 1981).

In most sports, the annual training plan is divided into three main phases: preparatory, competitive and transition. In soccer, these phases are more commonly referred to as pre-season, in-season and off-season (Reilly 2007). The aim of the pre-season phase is to establish the physical, technical and psychological base from which tactical development can occur (Bompa 2009). The adaptations produced during this phase, as a result of increased volume of training, will enhance the athlete’s tolerance to the increase in training intensity that occurs in the competitive phase. During the in-season phase the main tasks are the perfection of training factors that enable an athlete to compete successfully in competitions. These factors include dissipating fatigue and elevating preparedness, maintaining sport-specific fitness and the continued development of technical and tactical knowledge (Bompa 2009). Finally the off-season phase allows for both physiological and psychological recovery following long periods of preparation and competition. During this period athletes typically cease all forms of training before beginning a general physical preparation period during the remainder of the phase. This approach aims to limit the effects of detraining (Reilly 2007). In professional European soccer, the pre-season phase typically lasts for 6 weeks, followed by an in-season phase lasting approximately 40 weeks. This allows a 6 week period for the off-season phase.

Within each phase of the annual training plan, training phases can be further subdivided into various smaller blocks of training termed microcycles (Bompa 2009). In soccer, microcycles are typically 3-7 days in duration (Reilly 2007). The microcycle is structured according to the training objectives, volume, intensity and methods that are the focus of the overall training phase (Bompa 2009). Microcycles are considered the most important functional planning tool in the overall training process (Stone et al. 2007). Each microcycle must be flexible in terms of individual session content according to the athlete's working capacity, requirements for recovery and the competition plan (Stone et al. 2007). When a microcycle is modified the subsequent training sessions must be modified in order to maintain the focus of the particular microcycle to ensure the training objectives are met (Verkhoshansky 1985). Within professional soccer a weekly microcycle may consist of a competitive match every 3 – 4 days. During this time the training load must be adjusted to ensure players are able to perform optimally during games (Impellizeri et al. 2005). Previous research has demonstrated that training volume and intensity is significantly reduced in the days following and before a soccer match in elite soccer players (Bangsbo et al. 2006; Impellizeri et al. 2005). Therefore in top club soccer teams who compete in both domestic and multi-national competitions in which two games per week is common place, the number of days available for high volume/intensity sessions is limited. When several microcycles are combined within the macrocycle phase, these phases are referred to as mesocycles (Matveyev 1981). Mesocycles may typically vary in length from 2 weeks to several months during an annual cycle (Bompa 2009). An example of a mesocycle period in soccer is during the pre-season phase. During this period, several microcycles are combined to form a periodised training programme over a 6 – 8 week period (Castagna et al. *In Press*) with the aim of fitness improvement.

Despite the logical reasoning for employing periodisation strategies in elite sport, the majority of theories and practice are based upon traditional views formulated over 50 years ago. In terms of the scientific underpinning supporting the use of periodisation, previous research suggests that periodised programmes are superior to non-periodised counterparts. Stone et al. (1999) reported in a review of 15 studies of varying mesocycle length (7-24 weeks) that 13 of those studies concluded that periodised training provided statistically superior performance improvements when compared with constant-repetition programs. Despite the scientific evidence, periodisation philosophy relies on the presumption that biological adaptation to future training is largely predictable and follows a determinable pattern (Kiely 2012). Individualisation of training responses is often overlooked in current periodisation models. For example, Skinner et al. (2001) found that training-induced changes in $\dot{V}O_2max$ varied extensively in a large population multi-centre trial. The average increase in $\dot{V}O_2max$ was 19%, however 5% of participants had little or no change in $\dot{V}O_2max$ despite being subjected to a similar training stimulus. By extension, identical sessions performed by an individual will elicit a unique training response depending on the transient functional states of component sub-systems. Thus, it would appear that traditional views of periodisation are out-dated and require new information based on individual responses to formulate updated models.

### 2.2.3. MODELS OF TRAINING PERIODISATION

Following the original published work on training periodisation by Matveyev (1965), various models of periodisation now exist across a range of both individual and team sports. Matveyev (1965) postulated a gradual progressive increase in intensity as time progresses during the annual plan. This is now more commonly referred to as a 'linear' periodisation model (Bradley-Popovich 2001). In contrast, 'non-linear' models have been developed that include variations of intensity within the weekly and daily programme (Bradley-Popovich 2001). As opposed to the linear model, this model proposes that training is in fact non-linear and that training prescription must be altered in order to adapt to the demands of the athlete. Another common form of periodisation in individual sports is 'concentrated unidirectional training' proposed by Verkhoshansky (1985). The methodology is based on mesocycles containing highly concentrated training followed by a restitution mesocycle to allow sufficient recovery for accelerated adaptation. Original work by Bondarchuk (1986), proposed the use of specialized mesocycle blocks termed 'block periodisation'. The system consisted of various blocks with a specific training aim during each block. For example, a 'development block' aims to gradually increase workload levels up to maximal loads. Several individual sports also typically employ a phase in which the amount of training that athletes undertake is significantly reduced in the days leading into a major competition. This method is commonly referred to as a training 'taper' (Mujika 2010). The aim of the taper is to diminish fatigue induced by prior intense training in order to maximise physiological adaptations (Bosquet et al. 2007). Traditional models of periodisation originate from Olympic sports involving individual athletes. The application of these models can be problematic for team sports such as soccer.

Numerous previous studies have described the number of training sessions and type of training sessions during both the pre-season and in-season periods in soccer (Bangsbo et al. 2006; Castagna et al. *In Press*; Impellizeri et al. 2005; Jeong et al. 2011; Reilly 2007). However the description of training frequency doesn't allow for detailed analysis of training periodisation strategies currently employed in elite soccer. Studies investigating periodisation are difficult to control in the applied setting due to confounding factors that may affect the training outcome as opposed to a specific periodisation model. An example of this is the control of training drills by the soccer coach, in which volume and intensity may be intuitively adjusted compared to pre-planned targets. This can occur, for example, through a coach wanting to achieve their coaching goals (e.g. stoppages in play to emphasis a coaching point). However by quantifying the current periodisation strategies in elite level soccer, scientists and applied practitioners will gain invaluable insight into training methodologies. Two attempts have currently been made to investigate periodisation in elite soccer (Mallo 2011; Mallo 2012). Both of these studies investigated the use of a block periodisation approach on physical fitness parameters. However the studies only considered the physical component of training (e.g. speed) which doesn't provide a measure of the overall training load. Thus there is a lack of evidence-based research examining training periodisation involving overall training loading (i.e. physical, technical and tactical training) in elite soccer.

In soccer, the application of periodisation strategies is dependent on external factors that are not in control of the coaches/sports scientists, such as fixture scheduling. When multiple matches are played during a typical weekly microcycle period, soccer players may only participate in 2 – 3 training sessions during the cycle, with emphasis on recovery (Bangsbo et al. 2006). In situations when one match per week is played, soccer coaches have greater opportunity to periodise training in order to maintain or improve physiological adaptations. Previous studies (Impellizeri et al. 2005; Jeong et al. 2011) have shown RPE load (RPE x training duration) to be highest 4 days prior to a match, with significant reductions in the subsequent days leading into a match. Reducing the training load in this way may not necessarily be deemed a 'true' taper. In individual sports, typical tapering phases last between 7 – 28 days prior to competition in order to maximise physiological adaptations (Mujika et al. 2004). Although the use of periodisation models during the in-season period is limited, the pre-season phase offers the potential to employ a periodised approach to training. This phase, typically lasting 6 – 8 weeks, allows time for coaches to progressively enhance both physical and soccer-specific performance prior to the beginning of the competitive season (Reilly 2007). Due to the limitations in employing traditional models of training periodisation, it may be that soccer requires a sport-specific periodisation methodology supported by objective external and internal physiological data. At present, no study has examined this approach to periodisation in elite soccer.

### 2.3.4. TRAINING LOAD IN SOCCER

The combination of factors that can be manipulated for training periodisation, i.e. intensity, duration and frequency, is commonly referred to in soccer as 'training load' (Impellizeri et al. 2005). There is a complex interaction between the athlete's fitness, the training load, and the athlete's ability to tolerate training (Smith 2003). Impellizeri et al. (2005) divided the overall training load into two separate sub-sections termed external and internal training load. The relationship between external and internal load is detailed in Figure 2.2. The external load refers to the specific training prescribed by coaches and practioners, such as the numbers of sets/bouts of a particular drill. The internal training load refers to the physiological stress that this actually imposed on the player. It is this stress that stimulates the training-induced adaptations produced from the exercise (Booth & Thompson 1991). The internal response to a given external stimulus can be influenced by factors such as genetic background and previous training experience (Bouchard & Rankinen 2001). As the majority of soccer training drills are performed as a team, it is crucial that an individualised approach is taken in order to maximise training adaptations. This notion applies both within the individual training session and longitudinally across both microcycles and mesocycles. Quantifying the external and internal loads both objectively and subjectively provides practioners with crucial information on the individual response to each soccer training session. This approach then allows subsequent training loads to be adapted.

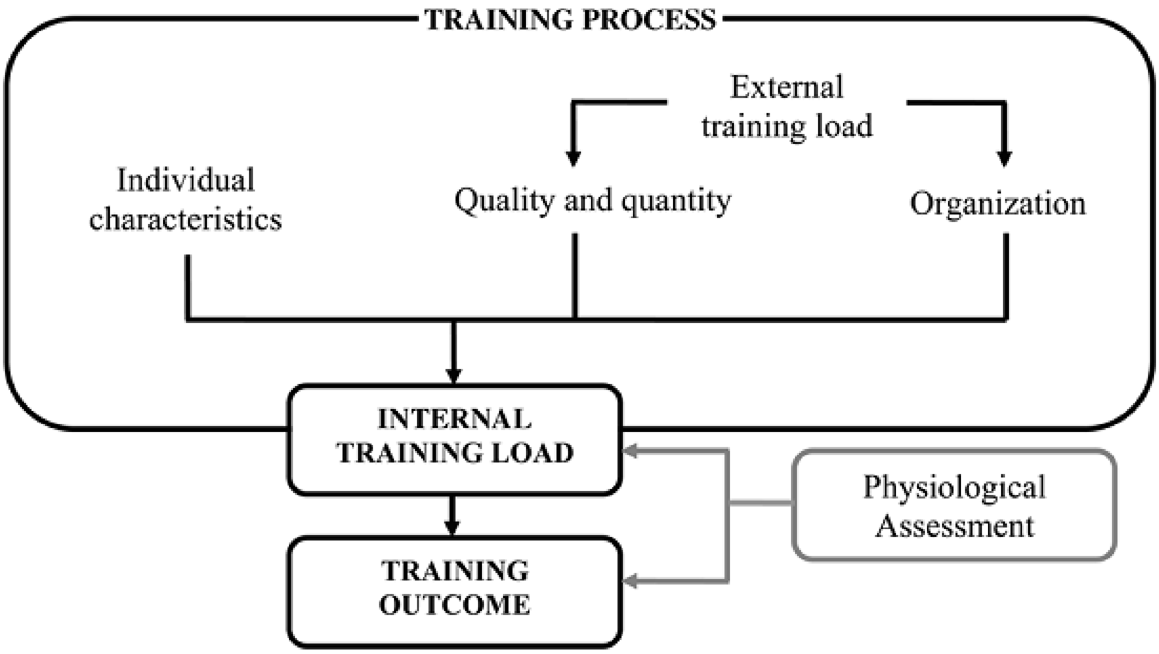



**Figure 2.2.** The training load process of internal and external loading (adapted from Impellizeri et al. (2005). The process relates to the relationship between external and internal training load. Several individual characteristics, such as genetics, can influence the internal response to a given external exercise stimulus. The external load may also be controlled by the practitioner in terms of quantity (e.g. sets and repetitions) and organisation (e.g. order of training drills)

## 2.3. MONITORING OF SOCCER TRAINING

In order to optimise the physical performance of soccer players throughout a competitive season, the global training load prescribed must be individualised to suit the needs of each player (Alexiou & Coutts 2008). The unstructured movement patterns associated with soccer training reduces the likelihood that players will receive training loads that are associated with their individual requirements and also can result in inappropriate training loads (Impellizzeri et al. 2005). Such indicators of inappropriate training load include increase in injury rates (Dupont et al. 2010), increased risk of banal illness (Foster 1998) and subjective recovery measures (Brink et al. 2012). This point emphasises the requirement for applied objective and subjective data in order to monitor the adaptation response for each player. The most commonly used applied technologies to monitor soccer training are GPS and HR devices (Casamichana et al. 2013). Subjective information is also commonly collected both post training (RPE) and prior to training using measures such as sleep quality and muscle soreness. Sports scientists may also collect blood and salivary samples from players following matches and intense periods of training in order to monitor markers of muscle damage (e.g. creatine kinase) and hormonal balance (e.g. testosterone-cortisol ratio) (Brancaccio et al. 2007; Filaire et al. 2001). This section will focus on monitoring techniques used to quantify soccer training load, specifically GPS, HR and RPE.

Irrespective of the methodology used to monitor training, subsequent data produced should be both reliable and valid. The reliability of a measurement tool refers to the repeatability of a measure or variable across multiple assessments (Hopkins 2000). Reliability can be calculated through a variety of statistical approaches, aimed at quantifying the within-subject variation, change in the mean and test-retest correlation (Hopkins et al. 1999). Validity refers to the ability of a measurement tool to accurately determine what it is designed to measure (Atkinson & Nevill 1998). This can be quantified by comparing the measurement tool in question (practical measure) with a criterion measurement tool often seen as the 'gold standard' for that particular measurement (Hopkins 2004). Therefore the importance of quantifying both the reliability and validity of commonly used methods of training load monitoring is clear for soccer practitioners, particularly within their own specific cohort of players. An example of such error has been highlighted in GPS devices by Varley et al. (2012) who reported poor validity in GPS devices when measuring high velocity decelerations (> 5 $m/s^2$). By quantifying the amount of error surrounding measurement using the specific players, this allows direct application of estimation calculations to be applied.

### 2.3.1. GLOBAL POSITIONING SYSTEMS (GPS)

Recent developments in GPS technology have provided a platform for the production of commercially available devices that can be used for player motion analysis (Aughey 2011). GPS systems rely on space-based navigation that provides the location and movement of individuals through radio signal based calculations between the satellites and a GPS receiver on Earth. Only when the GPS receiver is connected to four separate satellites can an accurate location be triangulated and velocity-based calculations derived (Larsson 2003). Modern GPS receivers also include triaxial accelerometers that measure the frequency and magnitude of movement in three dimensions (anterior-posterior, mediolateral and longitudinal) (Krasnoff et al. 2008). Accelerometers typically have sampling frequencies of 100Hz and therefore offer a higher sampling rate compared to devices without (Boyd et al. 2011). Accelerometers can also be used indoors as well as outdoor and have the potential to measure gross fatiguing movements such as accelerations and decelerations (Boyd et al. 2011). GPS devices incorporated with accelerometers are also portable and relatively cheap and as a consequence are now commonly used by elite soccer clubs. The regulations of international governing bodies do however prevent players from wearing such external devices during match play in the highest level competitive games. As a consequence GPS systems are predominantly employed for the monitoring of training.

GPS systems can provide an indication of external training loads for individual players during training sessions (Casamichana et al. 2013). A range of variables related to the velocity of player movement can be recorded such as the total distances covered in various velocity thresholds (Harley et al. 2011). By differentiating the velocity thresholds, this allows for the quantification of low, moderate and high speed running. Such thresholds typically include velocity bands that incorporate high-intensity running and sprinting (Harley et al. 2010). High-intensity running distance is typically classified as distance above 5.5 m/s (19.8 km.h$^{-1}$) when using the ProZone semi-automatic camera system. Velocities below this threshold are often termed as low-intensity activities and include movements such as jogging and walking. Dellal et al. (2012) measured the distances covered in different velocity thresholds during 4 vs. 4 small sided games (SSG) in training practices in elite adult players. The training drill consisted of 4 x 4 minute games with 3 minutes of passive recovery within a 30m x 20m area, with free-play rules applied in possession of the ball. The authors revealed that distance covered in high-intensity running (> 14.4 km.h$^{-1}$) and sprinting (> 25.1 km.h$^{-1}$) accounted on average for 483m and 382m, respectively. The total distance covered during the training drill on average totalled 2664m. The data reveals that the technical training drill produced both high volume and intensity values for total distance and high intensity running. In comparison to matches, Bradley et al. (2009) reported average high-intensity running values ranging from 1834 – 3138m across all positions. This emphasises the requirement for banding of velocity zones in order to determine the contribution of training drills to overall training session volume and intensity.

The inclusion of triaxial accelerometers in GPS devices has led to the quantification of other metabolically demanding activities that are not taken into account by analysis of movement velocity distances alone (Casamichana et al. 2013). Accelerometers are highly sensitive due to their high sampling rate and ability to calculate the accelerations and decelerations produced in three planes of body movement (Boyd et al. 2011). Combining the data from all planes of movement has led to the production of an alternative method of monitoring external training load termed 'body load' or 'player load'. Both calculations are based on the root mean square of the squared instantaneous rate of change in acceleration in each of the three vectors (X, Y and Z axis) and divided by 100. Each individual calculation is manufacturer based and is specific to the type of accelerometer used (Boyd et al. 2011; Gomez-Piriz et al. 2011). Accelerometers have demonstrated acceptable levels of reliability both within and between devices using laboratory and field based testing (Boyd et al. 2011). Further work is however required to evaluate the effectiveness of accelerometers for monitoring training load in soccer due to the novel nature of the metrics produced.

Despite advantages in the use of GPS systems to analyse external training load, interpretation of GPS data should be viewed in relation to the limitations associated with the technology currently available (such as sampling frequency and quality of satellite coverage). Previous studies investigating the reliability and validity of GPS devices for the measurement of team sport movement have used devices with sampling frequencies of between 1Hz – 10Hz (see Table 2.1). Portas et al. (2010) reported a larger range of error in 1Hz GPS units compared to 5Hz units for multidirectional courses. The 1Hz devices had a standard error of the estimate (SEE) ranging between 1.8 – 6.8%, compared to 2.2 – 4.4% reported for 5Hz devices. Johnson et al. (2012) reported an increase in the typical error of measurement using 5Hz GPS units from 3.3% to 123.2% when comparing walking (0 – 6 $km.h^{-1}$) and sprinting (> 25 $km.h^{-1}$) distances. Recent research by Varley et al. (2012) using 10Hz GPS units revealed these units were up to six-fold more reliable for measuring constant velocity compared to 5Hz units. The 10Hz GPS units demonstrated lower coefficient of variation (CV) % values of 2.0 – 5.3% during different starting velocities (1 – 8 $m.s^{-1}$) compared to 5Hz units (CV% 6.3 – 12.4%). These data suggest that the magnitude of measurement error is increased when the sampling frequency of the GPS units is reduced. In addition, increases in velocity and multidirectional motion also lead to a decreased accuracy of measurement. Portas et al. (2010) reported an increase in SEE% values across various multi-directional courses ranging from 45 – 180 degrees turning actions (2.4 – 6.8 SEE%) compared to straight line running (2.6 SEE%). This is important when quantifying soccer-specific movement as soccer players undergo a high number of changes in direction (i.e. turning) during match play (Bloomfield et al. 2007). Despite the limitations within the GPS technology at present to quantify soccer play, the devices still provide objective data regarding training load that extends what would be possible using subjective interpretations alone. It is however vital for sports scientists using GPS is to quantify the degree of error present in the specific GPS system in use and incorporate these measurements into any decision-making process that is implemented. It is also important that practitioners follow precise instructions from each GPS manufacturer in order to limit the degree of error. Such examples include leaving the devices on 30 minutes prior to activity in order to maximise satellite lock on. Also conducting activity in an open space as opposed to covered areas will allow an increased number of and enhanced signals to the surrounding satellites.

Due to the restrictions placed within competition by UEFA and FIFA, teams are not permitted to wear GPS devices within competitive matches. Thus, teams will typically employ semi-automatic camera systems to quantify match demands. However, a limitation exists between comparing match data quantified by such systems and training data quantified by GPS devices. Randers et al. (2010) revealed GPS systems (both 5-Hz and 1-HZ devices) significantly under-reported high-intensity running, low intensity running and total running distance in comparison to the Amisco© multiple-camera system. In support of these findings, Harley et al. (2011) reported both sprint distance and high-intensity running distance were underestimated in 5-Hz GPS devices compared to the ProZone© multiple-camera system. Therefore, it appears that GPS and multiple-camera systems, such as Amisco© and ProZone©, cannot be used interchangeably when comparing match and training data.

**Table 2.1.** Reliability and validity studies of GPS devices relevant in current research literature. HI = high intensity, PS = peak speed, TD = total distance.

| Study | Subjects | GPS Device | Study Protocol | Reliability Findings | Validity Measure | Validity Findings |
|---|---|---|---|---|---|---|
| Barbero-Alvarez et al. (2010) | 21 Physical Education Students | GPSports SPI Elite 1Hz | 7 x 30m Repeated Sprint Test | Max Speed = 1.7 CV%<br>Fatigue Index = 36.2 CV% | Timing Gates | Fastest Time = r = -0.93 ($P$ < 0.001)<br>Fatigue Index = r = 0.11 ( $P$ > 0.05) |
| Castellano et al. (2011) | 9 Trained Male Athletes | Catapult Minimax v4.0 10Hz | 15m and 30m Sprints | TD 15m Sprint = 1.3 CV%<br>TD 30m Sprint = 0.7 CV% | Timing Gates | PS 15m Sprint = 10.9 SEM%<br>PS 30m Sprint = 5.1 SEM% |
| Coutts & Duffield (2010) | 2 Moderately Trained Males | GPSports SPI Elite and WiSPI 1HZ | Team Sport Running Circuit | TD Circuit = 6.4 CV%<br>HI Running Circuit = 32.4 CV% | Timing Gates | PS 20m Sprint Time = -0.40 to -0.53 ($P$ < 0.001) |
| Gray et al. (2010) | 1 Male Triathlete | GPSports SPI Elite 1Hz | 200m Non-Linear Course | PS Jogging = 2.3 CV%<br>PS Sprint = 3.4 CV% | Measuring Tape | TD Course Sprint Movements = 6.0 SEM% |
| Jennings et al. (2010a) | 20 Male AFL Players | Catapult Minimax v2.5 5Hz | COD and Team Sport Circuit | TD Circuit = 3.6 CV%<br>Sprint Distance = 77.2 CV% | Timing Gates | 10m Sprint Distance = 30.9 SEM %<br>40m Sprint Distance = 11.9 SEM% |
| Johnson et al. (2012) | 9 Trained Males | Catapult Minimax v2.5 5Hz | Team Sport Circuit | TD Circuit = < 5 CV%<br>Sprint Distance = > 10 CV% | Timing Gates | PS Sprint = 5-10 TEM% |
| Portas et al. (201) | 1 Male Recreational Athlete | Catapult Minimax v2.5 5Hz | Soccer-Specific Track | TD Track = 3-8 CV% | Measuring Tape | TD Track = 1.5-2.2 SEM% |
| Varley et al. (2012) | 3 Sub-Elite Team Sports Athletes | Catapult Minimax v4.0 10Hz | Straight Line Running | Constant Velocity 1-3 m/s = 5.3 CV%<br>Constant Velocity 5-8 m/s = 2.0 CV% | VICON Laser | Constant Velocity 1-3 m/s = 8.3 CV%<br>Constant Velocity 5-8 m/s = 3.1 CV% |

### 2.3.2. HEART RATE MONITORING

The use of HR monitors for quantification of internal training load has been commonplace amongst many elite soccer clubs for 5 to 10 years. Similar to GPS devices, HR monitors are not allowed to be worn during competitive soccer matches and are therefore limited to use in training and non-competitive matches (e.g. pre-season matches). The development of radio telemetry technology has allowed for the creation of ‘team systems’ which are commercially available to soccer teams. The systems allow the recording of heart rate data for all members of the playing squad at one time and can be monitored in ‘real-time’ during training sessions. This development has led to many elite clubs using real time team systems as they can potentially intervene during the training session rather than reacting to data post training. HR monitors are used to quantify the cardiovascular strain placed on an individual in response to a given external training load (Drust et al. 2007). HR responses have therefore been used to discriminate between different training drills based on pitch dimensions (Kelly & Drust 2009) and technical/tactical conditions (Sassi et al. 2005) implemented in training. Thus team HR systems are predominantly employed to monitor both the total cardiovascular exertion in the session and responses to individual drills during a given training bout.

Early research using HR response during soccer matches typically reported data as average HR for a given duration. Ogushi et al. (1993) reported average HR values of 161 beats per minute (bpm) for a 90 minute friendly soccer match. Similar values were reported during competitive soccer matches by Bangsbo (1994). Recent analysis of training sessions in professional Korean soccer players has shown average HR responses of 124 bpm during pre-season sessions and 112 bpm during the in-season training phase (Jeong et al. 2011). Researchers have also often expressed HR measurement as a percentage of an individual’s maximal HR ($HR_{max}$) score in order to quantify the average work intensity (Helgerud et al. 2001). Hoff et al. (2002) reported average HR values of 91.3% $HR_{max}$ during a soccer-specific endurance training drill consisting of a dribbling track. Dellal et al. (2012) measured the HR response during 4 vs. 4 SSG of 4 minutes duration, revealing average HR values of 87.6% $HR_{max}$. The data suggests that soccer players work at a high relative intensity during training activities of both a physical and technical nature.

Although different methods exist to calculate summary statistics, such as training impulse (TRIMP), the majority of previous researchers have reported the time spent in different HR zones during training in soccer players. Hill-Haas et al. (2009) measured HR response during SSG in youth soccer players consisting of 2 vs. 2, 4 vs. 4 and 6 vs. 6 games of 24 mins duration. The 2 vs. 2 games resulted in the highest mean and $HR_{max}$, with players on average spending 7.2 mins above 90% $HR_{max}$, 4.8 mins between 80-89% $HR_{max}$, 1.6 mins between 75-84% $HR_{max}$ and 0.5 mins below 75% $HR_{max}$. Jeong et al. (2011) quantified the physiological response during one week of pre-season compared to in-season training phases in elite Korean soccer players. The authors reported players spent on average 4 minutes within 90-100% $HR_{max}$ during pre-season, compared to 0.3 minutes during the in-season phase. Compared with lower heart rate zones of > 50% $HR_{max}$, players spent on average 17 and 26 minutes within this zone during pre-season and in-season phases, respectively. Use of such methods allows coaches and sports science practioners to regulate training intensity depending on the session objective, i.e. for improving cardiovascular fitness (Impellizeri et al. 2005) or maintaining light intensity for recovery days following matches (Reilly & Ekblom 2005).

Despite the value in the use of % $HR_{max}$ to determine training intensity, the training volume must also be quantified during sessions. The concept of combining HR as an intensity marker with the amount of training volume (i.e. duration) was first suggested by Banister et al. (1975). As the original calculation by Banister and colleagues was based on mean exercise HR, the calculation fails to reflect the physiological demands of intermittent exercise in which fluctuations in HR can influence the overall HR profile (Akubat & Abt 2011). As a consequence alternative calculations have since been developed in order to adequately quantify TRIMP for team sport activity. Edwards (1993) initially developed this concept by separating individuals HR response into five separate HR zone categories determined according to % $HR_{max}$. Each of the five zones were given a weighting depending on the intensity level of each zone, with time spent in each HR zone multiplied by the zone weighting factor to give an overall training score. Stagno et al. (2007) further developed the modified TRIMP score for use with hockey players. Their approach separated the HR response into five separate HR zones which were created around blood lactate (BLa) thresholds on a HR-BLa curve. Each zone was given a weighting factor based on the regression equation of the curve, which included two breakpoints of a typical blood lactate response curve (the lactate threshold and onset of blood lactate accumulation (OBLA)). Although this method is limited due to the continuous exercise protocol used in the study (Akubat & Abt 2011), the use of an individualised weighting factor is important when analysing the heart rate response in soccer players. Each individual player will show a different response to a given stimulus and therefore any calculations should be based on individual calculations. If this is not possible due to lack of testing data available, then methods utilising $HR_{max}$ data can be used. It is also important to take the positional role of each player into account to ensure specificity of the training programme (Reilly 2005). These factors are incorporated into the overall training process to ensure both external and internal loads are optimal for each player.

The use of HR monitoring in soccer provides a wealth of information regarding the training status and cardiovascular response of soccer players to training. When interpreting such information it is important to contextualise the data in relation to the external training load stimulus. For example, a low heart rate response to a given external training stimulus during soccer training may be interpreted as either a lack of effort or a state of superior aerobic conditioning compared to other players within the team (Burgess & Drust 2012). In addition external factors such as dehydration (Gonzalez-Alonso et al. 1997), ambient temperature (Gonzalez-Alonso et al. 2000) and day-to-day HR variation (Brooke et al. 1970) may affect HR data. Despite the different factors that may influence HR during exercise, the monitoring of HR is still a useful tool in order to quantify the internal response of individual soccer players in response to an external stimulus.

### 2.3.3. RATING OF PERCEIVED EXERTION (RPE)

Another popular method of determining internal training load following soccer training is the use of a subjective rating based on a simple ratio scale. Since the early development of the original Borg scale (Borg 1970) a number of different adaptations have been developed to allow an individual to grade exercise intensity. For example, the 10 point scale developed by Foster (Foster 2001) and the adapted Borg CR10-scale (Borg 1982). Despite the differences in the number of points and wording within the scales, they are used in the same way to determine an individual’s internal response to an external stimulus. The use of RPE for quantifying internal training load is easy to collect, doesn’t require specialist technical expertise and is cost-effective. RPE has also been suggested to be a more appropriate measure of internal training load as it includes the player's psychological state (Morgan 1973), a variable which is not considered when looking at objective physiological data. In order for RPE to be effective in determining internal training load, players must follow correct collection procedures. Soccer players are required to be familiar with the RPE scale used to collect regular data, as lack of familiarisation may result in under/over represented values given. The data also needs to be collected individually to prevent peer pressure from other players influencing the rating given (Burgess & Drust 2012).

Similar approaches to the TRIMP methodology developed by Bannister (1991) have also been applied for subjective scales in order to quantify both training volume and intensity. Foster's (2001) 10 point scale can be multiplied by the session duration (volume) to provide an overall global score of training session load. When multiple training sessions are performed on a single day, the training load scores are summated to create a daily training load. The training load during each week can then be summated to create a weekly training load. This method is significantly correlated with a number of methods that are based on HR monitoring (Impellizzeri et al. 2004; hill 1998). Foster (1998) has also developed calculations based on daily RPE load to calculate training monotony and weekly strain. Training monotony is a measure of daily training variability (weekly mean RPE load/weekly standard deviation of RPE load) while training strain is a product of training load and training monotony (weekly training load x training monotony). These calculations have been related to the over-training syndrome and have displayed relationships with the incidence of illness during a training period when values for training load were above acceptable thresholds (Foster 1998). Therefore RPE can not only be used as an indicator of internal training load response for an individual session, but can also be used for calculation of training adaptation across a longitudinal period to prevent over-reaching and over-training.

Although the measurement of RPE post-exercise is a cost-effective method of quantifying internal training load, several limitations exist. As RPE requires a significant psychological input (Morgan 1994), the mood of the player may influence the score given post-exercise. For example, a player may have had an altercation during the training session which has left them in a negative mood which results in change of their true RPE score for the given session. As RPE collection is a subjective measure, sports science practitioners are left to rely on each individual player to give an accurate score. As discussed previously, lack of familiarisation and peer pressure from other players may influence RPE rating given. Such limitations may suggest that these subjective measures are most informative when used alongside more objective data collection systems as RPE cannot provide enough objectivity as a single measure. By analysing both objective and subjective data collectively, sports scientists may then be able to make more informative decisions to feedback to players and coaches.

## 2.4. SUMMARY

In summary, this section describes the importance of the use of monitoring tools in order to accurately quantify both external and internal training load. Several technologies and methodologies have been discussed, specifically focusing on GPS, HR monitoring and RPE. These three methods of training load monitoring will therefore be employed in the current thesis in order to quantify the seasonal periodisation of training load within an elite soccer team. The importance of quantifying reliability and validity of measurement tools will be investigated to ensure accurate data analysis.

# CHAPTER 3

# RELIABILITY OF GLOBAL POSITIONING SYSTEMS (GPS) FOR THE MEASUREMENT OF SOCCER-SPECIFIC ACTIVITIES

## 3.1. INTRODUCTION

The recent development of complex semi-automated video analysis systems (e.g. ProZone® and Amisco Pro®) has enabled detailed motion analysis of elite soccer players during match-play (Bradley et al. 2009; Carling et al. 2012; Di Salvo et al. 2010). However, this type of technology is generally only available at match stadia for game day analysis. Thus many elite level soccer clubs have had to use alternative technologies for motion analysis during the organised soccer training used in preparation for competitive fixtures. The use of GPS is now commonplace amongst many teams due to the system's portable nature and the capacity for data collection on multiple athletes. A number of different GPS devices are currently available on the market, with modern units using different sampling frequencies of between 5 – 10 Hz. Due to the differences in both the sampling frequency and method of data collection, the accuracy of measurement from GPS units has become an area of interest for sport scientists looking to quantify the reliability and validity of such systems (Aughey 2011). To date, numerous researchers have attempted to quantify these measures of GPS technology with limited success.

The majority of previous studies relating to the reliability and validity of GPS have used versions of the technology with sampling frequencies of 1Hz (Barbero-Alvarez et al. 2010; Coutts & Duffield 2010; Edgecomb & Norton 2006; Gray et al. 2010) and 5Hz (Jennings et al. 2010; Johnston et al. 2012; Portas et al. 2010; Waldron et al. 2011). These studies concluded that both sampling frequencies were reliable and valid for the assessment of total distance covered and the peak speeds measured during high intensity running. The majority of the previous studies, however, reported that the error increased when high velocity and multidirectional motion was introduced. This may be due to the actual distance measured being accurately detected (i.e. going from point a to b) but the variation in velocity in between may not be accurately measured. For example, Johnson et al. (2012) reported an increase in the typical error of measurement from 3.3% to 123.2% when comparing the reliability of 5Hz GPS units when walking (0 – 6 $km.h^{-1}$) and sprinting (> 25 $km.h^{-1}$). Jennings et al. (2010) also revealed a significant increase in the percent bias of all locomotion speeds when multi-directional movements were analysed using 1Hz and 5Hz GPS units. These data would suggest that GPS devices of 1Hz and 5Hz sampling frequencies are limited in their ability to assess player motion during intermittent exercise that is characterised by high-intensity activities as well as frequent changes in velocity and direction such as soccer.

Research has revealed an increased accuracy when sampling frequency is increased (Jennings et al. 2010; Portas et al. 2010). The development of 10Hz GPS devices from a number of major manufacturers (e.g. GPSports® and Catapult Sports®) has provided opportunity to potentially detect both high-intensity movements and frequent changes in direction. To the author's knowledge, only two studies have been conducted on the accuracy and repeatability of such devices (Castellano et al. 2011; Varley et al. 2012). Both studies did however use only straight line protocols and did not attempt to quantify the error associated with changes of direction. Both issues would seem important for team sports movements. Therefore the aim of the present study was to determine the accuracy of 10Hz GPS units for the measurement of movement during a soccer-specific track.

## 3.2. METHODS

### 3.2.1. SUBJECTS

Two moderately trained males (age: 26 ± 1 yr; height: 1.8 ± 1.4m; mass: 77.8 ± 3.4kg) volunteered and provided written consent to participate in the study. Subjects were regularly engaged in physical activity (minimum 2 sessions per week) and had a history of participating in intermittent type sports (i.e. soccer, rugby). Subjects were required to refrain from drinking alcohol and strenuous exercise 24 hours before each trial. Written informed consent was given by each subject, with the study being approved by the University Ethics Committee of Liverpool John Moores University.

### 3.2.2. EXPERIMENTAL DESIGN

During all trials, each subject wore two 10Hz GPS units (SPI Pro X, GPSports®, Canberra, Australia) worn inside a custom-made vest. All devices were calibrated prior to data collection according to the manufacturer's guidelines. The units were positioned across the upper back between the right and left scapula, with 5 cm distance between units. In order to quantify whether the distance between GPS unit placement on the subjects influenced raw GPS data, pilot testing was carried out prior to commencement of the study. Two moderately trained males (age: 33 ± 9 yr) performed a series of 40m straight line running bouts with units placed either 5cm (near) or 15cm (far) apart. Subjects completed bouts of walking, jogging and sprinting for both GPS unit placements. Dependent t-test analysis revealed no significant difference ($P > 0.05$) in terms of bias for either condition for different parameters (e.g. total distance, max speed). A distance of 5 cm between GPS units was therefore selected for the main data collection due to ease of GPS placement on subjects. The average satellite coverage during all experimental trials was 10. All units were turned on 30 minutes prior to commencement of testing as per manufacturer's instructions.

### 3.2.3. DEVELOPMENT AND PROCEDURES OF THE SOCCER-SPECIFIC MOVEMENT TRACK

In order to determine an appropriate soccer-specific movement course, the typical movement characteristics of an elite soccer player was analysed. One English Premier League soccer match was recorded using a multiple-camera tracking system (ProZone Version 3.0, ProZone Sports Ltd. ®, Leeds, UK) and examined using the respective software (ProZone Desktop V 10.1). One player in a central midfield position was selected for analysis. This position requires both attacking and defensive tactical duties. The tactical duties associated with this role therefore produces varied movement demands across all areas of the pitch (Mohr et al. 2003). From the data collected, the most intense 2 minute period during the game was selected. This was defined as the highest amount of distance covered in a 2 minute time frame (i.e. meters per minute) during the full match. This segment was broken down for angle and frequency of turn, velocity of movement as well as change in velocity. Movement maps were subsequently extracted from the software and recreated in the field. The running movements were 'simplified' in order to ensure that participants were able to accurately follow the distinguished track. This was achieved through a change in curved movements to straighter movement paths. Figure 3.1 represents the individual distances and movement requirements. The soccer-specific movement course consisted of 9 walking, 6 jogging, 2 cruising and 4 sprinting bouts. Table 3.1 details the breakdown of distances covered across the four separate movement velocities in the soccer-specific track.

A calibrated trundle wheel (Perform Better, Warwickshire, UK) was used to determine the distance for the different movement categories and directions. All trials were carried out on a grass training pitch that replicated the dimensions of the stadia used for the activity profile on which the soccer-specific track was determined. Participants were instructed to move at the following speeds during each bout: walking (2.0 m/s), jogging (4.0 m/s), cruising (5.5. m/s) and sprinting (7.0 m/s). These velocities were selected as they replicated the velocities used in the ProZone® match analysis system. Each of these changes in velocity were highlighted on the soccer-specific track by the use of colour coded cones for each speed (walking = blue, jogging = yellow, cruising = orange, sprinting = red). Each subject was also given verbal instructions and feedback during each bout to ensure appropriate patterns of velocity change. The track consisted of clear start and end points, identified using larger cones on the track.

Prior to commencement of the experiment trial, each participant was familiarised with the soccer-specific track. Each participant engaged in a 10 minute standardized warm up consisting of sub-maximal running, dynamic stretching of the lower and upper body, and 6 short sprints of 30m before each trial. Each participant completed 5 laps of the track two days prior to the experimental protocol at the same time of day (15:00 hours) on the same grass pitch. The aim of the 5 laps was to familiarise the subject with the track layout and the activity changes. A timed rest period of 5 minutes was employed between each trial. For the experimental trial, participants completed 10 bouts of the soccer-specific track.

Following all trials, GPS data was downloaded using the respective software package on a personal computer (GPSports® Team AMS software V R1 2011.16 P10) and exported for analysis. The software-derived smoothed data was used for analysis, as opposed to the raw data, because the smoothed data was used for the longitudinal data collection in Chapter 5. A custom-built GPS receiver (GPSports®, Canberra, Australia) and software application (GPSports SPI Realtime V R1 2011.16) were used to time-code the trials. At the beginning of each trial (i.e. participant on the start line) the investigator manually clicked a button in the software to 'stamp' the GPS data streaming. This was repeated again when each participant crossed the finish line for every lap of each trial. The time provided in GPS data is very accurate (Misra & Enge, 2006) and was synchronized between all GPS units. Following data collection, these 'stamped' times were used to identify start and end times of each bout of all trials. Velocity and distance covered data were analysed in five separate velocity zones that consisted of the following: Zone 1 = 0 – 2 m/s; Zone 2 = 2 – 4 m/s; Zone

3 = 4 – 5.5 m/s; Zone 4 = 5.5 – 7 m/s; Zone 5 = > 7 m/s. These velocity zones were based on the recommendations of the ProZone system to define low intensity and high intensity movements. In addition, total distance, maximal speed and high speed distance (distance covered > 5.5 m/s) were also analysed.

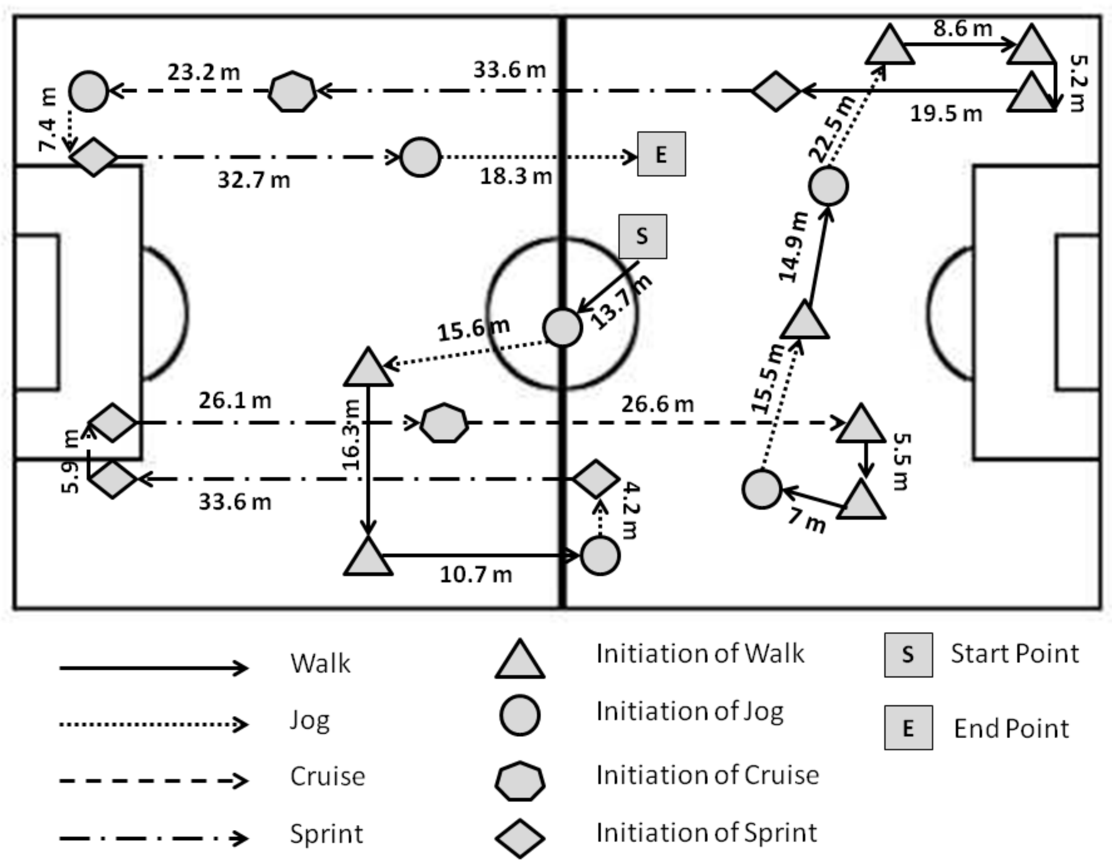



**Figure 3.1.** Schematic representation of soccer-specific movement track. Distances between each change in movement reported. Note start point began with initiation of walk. Differences in velocity categories are indicted by respective arrow type. Change in speed during the course is indicated by the respective symbol.

**Table 3.1.** Representative distances measured for the soccer-specific movement track across all velocity zones.

| **Velocity Band** | Walk Distance (2.0 m/s) | Jog Distance (4.0 m/s) | Cruise Distance (5.5 m/s) | Sprint Distance (7.0 m/s) | Track Total Distance |
|---|---|---|---|---|---|
| **Total Distance (m)** | 81.9 | 83.5 | 49.8 | 131.9 | 347.1 |

### 3.2.4. STATISTICAL ANALYSIS

In order to assess the level of reliability of one 10Hz GPS unit for assessment of movement parameters performed on a soccer-specific track, the typical error was calculated and expressed as a CV%. The CV% was calculated by dividing the SD of the data by the mean and multiplying by 100 (Atkinson & Nevill 1998). Analysis was performed individually for each subject in order to quantify the degree of random variability of a single individual's values on repeated testing (Hopkins 2000). Values were interpreted according to previous research (Duthie et al. 2003) and classified as follows: good (< 5%), moderate (5-10%) and poor (> 10%). The inter-unit reliability of the 10Hz GPS units was determined using the Bland-Altman method (Bland & Altman 1986). Bias (mean error) and limits of agreement (LoA) are presented for each movement parameter for both subjects. LoA was calculated as the standard deviation of the mean differences between GPS unit 1 and 2 for both subjects, multiplied by 1.96. Graphical interpretation was conducted according to the recommendations of Bland and Altman (1986).

## 3.3. RESULTS

### 3.3.1. RELIABILITY OF GPS FOR SOCCER-SPECIFIC TRACK MOVEMENTS

For both subjects the reliability of the GPS units declined as the velocity of movement increased (Table 3.2). The distance covered in zone 1 and zone 2 showed low typical error reported using the CV% calculation. Values ranged from 1.7 to 3.6 CV% for both subjects in these two velocity zones. However the degree of error increased in velocity zones 3 – 5 with CV% values ranging from 7.6 – 33.6%. High speed distance reported moderate CV% values for the two subjects (3.7 – 7.5 CV%), despite the large error reported for velocity zones 4 and 5. Maximal speed reported small error values (2.6 and 2.7 CV%).

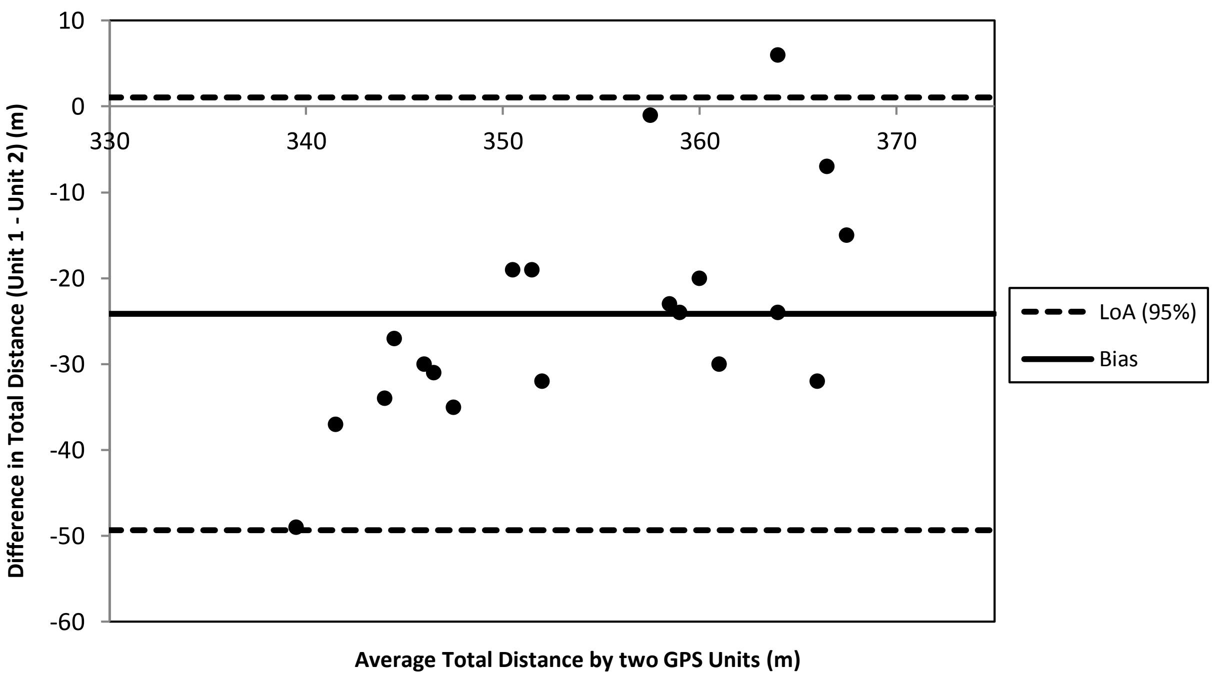
**Table 3.2.** Reliability data recorded by two subjects for the soccer-specific movement track. Mean ± SD represents values for each subject across 10 bouts of the track.

| GPS Variable | Reliability Data | Subject 1 | Subject 2 |
|---|---|---|---|
| **Total Distance** | **Mean ± SD** | 372 ± 6 | 361 ± 2 |
| | **CV %** | 1.5 | 0.6 |
| **Zone 1 Distance** | **Mean ± SD** | 97 ± 2 | 97 ± 3 |
| **(0 – 2.0 m/s)** | **CV %** | 1.7 | 3.4 |
| **Zone 2 Distance** | **Mean ± SD** | 90 ± 3 | 87 ± 3 |
| **(2 – 4 m/s)** | **CV %** | 3.5 | 3.6 |
| **Zone 3 Distance** | **Mean ± SD** | 48 ± 6 | 34 ± 5 |
| **(4 – 5.5 m/s)** | **CV %** | 12.7 | 14.8 |
| **Zone 4 Distance** | **Mean ± SD** | 110 ± 8 | 70 ± 13 |
| **(5.5 – 7 m/s)** | **CV %** | 7.6 | 18.7 |
| **Zone 5 Distance** | **Mean ± SD** | 25 ± 8 | 71 ± 12 |
| **(> 7 m/s)** | **CV %** | 33.6 | 16.8 |
| **Max Speed** | **Mean ± SD** | 7.4 ± 0.2 | 8.0 ± 0.2 |
| | **CV %** | 2.7 | 2.6 |
| **High Speed Distance** | **Mean ± SD** | 135 ± 10 | 141 ± 5 |
| **( > 5.5 m/s)** | **CV %** | 7.5 | 3.7 |

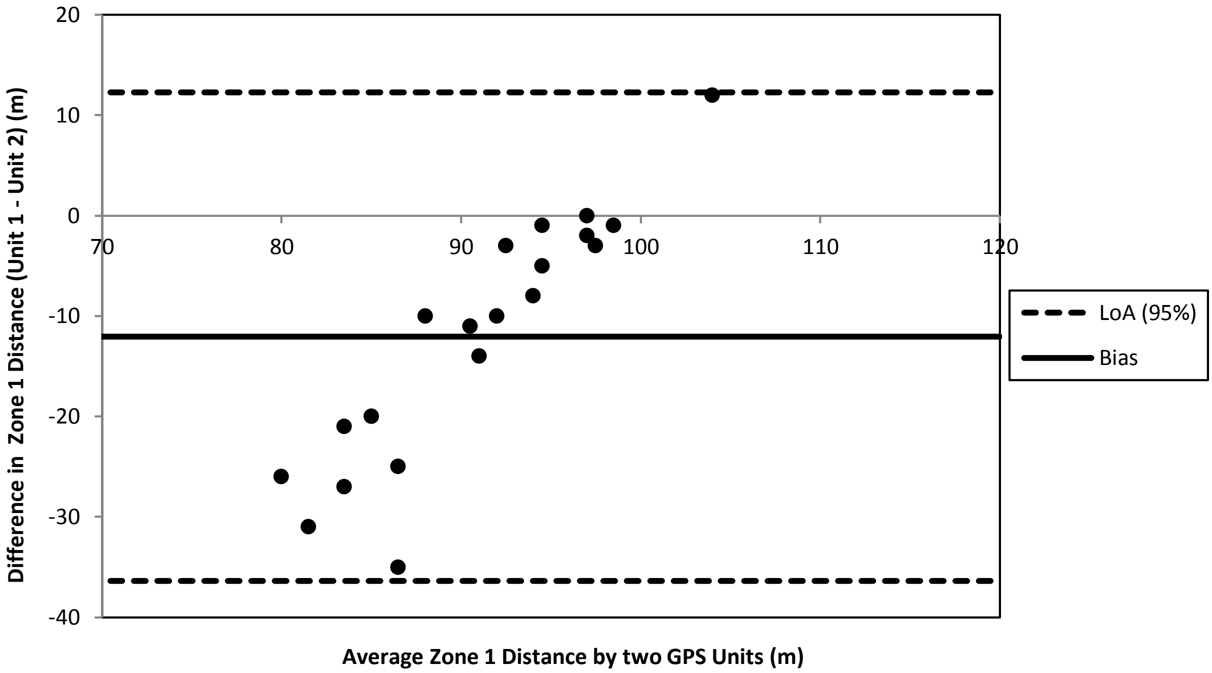
### 3.3.2. INTER-UNIT RELIABILITY OF GPS FOR SOCCER-SPECIFIC TRACK MOVEMENTS

Figures 3.2a–h show Bland-Altman plots determining the differences in different variables between two GPS units worn during the soccer-specific track testing. There was a small bias for total distance; however the difference between units reported large LoA values (1 to -49 m). The values on the graph are scattered mainly below the x-axis, indicating a difference in measurement for GPS unit 2. Velocity zone 1 distance reported a small bias value but with relatively large LoA values (12 to -36m). The difference values displayed a positive linear relationship toward GPS unit 2, indicating a decrease in systematic error as the average zone 1 distance between unit's increases. This pattern was also evident for velocity zone 2 distance. Velocity zones 3, 4 and 5 distances all displayed low bias values on the x-axis, with random distribution of data points around the mean of the two GPS units. However the LoA values recorded were large enough to have a significant impact on the results from the soccer-specific track testing. High speed distance also displayed a similar graphical pattern to that shown for zones 4 and 5 distance. Max speed was negatively distributed across the x-axis toward GPS unit 2, suggesting an increase in systematic error as the mean values between GPS units 1 and 2 increased. The data points were evenly distributed around the x-axis, with no upward or downward trend evident.

**a)**

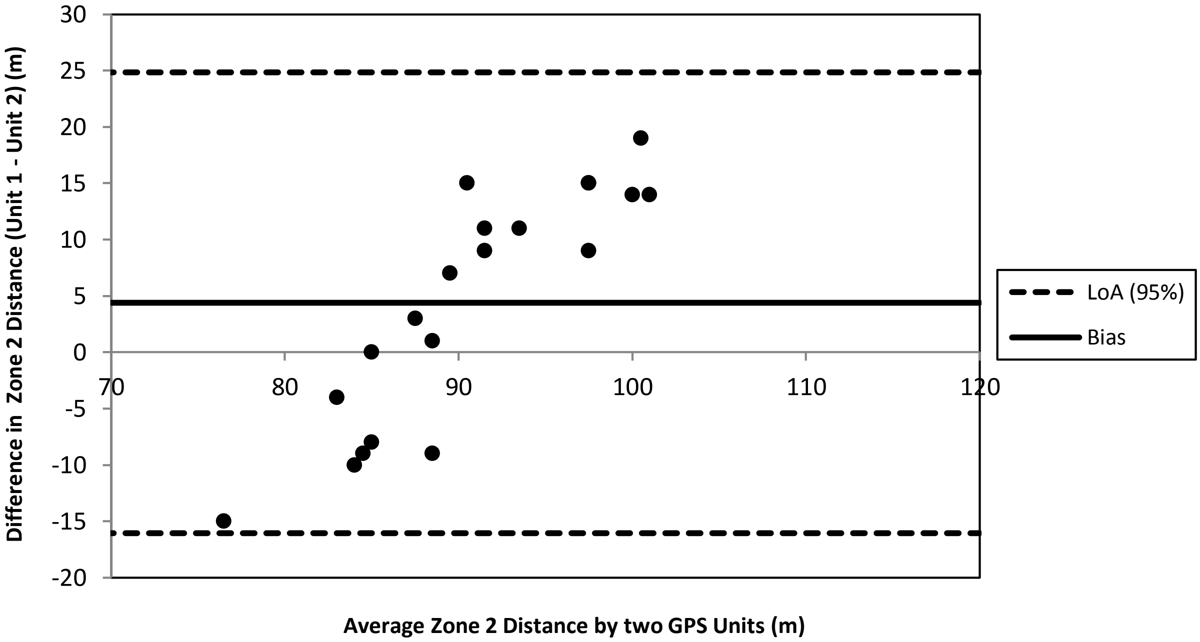


**b)**



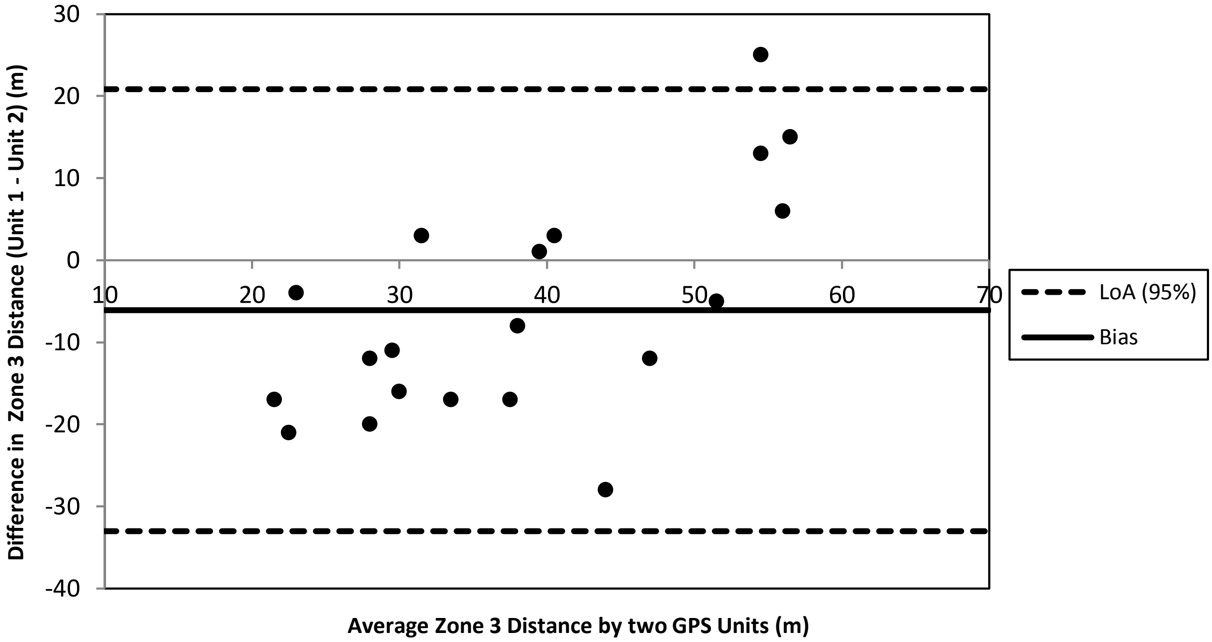
20
10
0
-10
-20
-30
-40
70
80
90
100
110
120
Difference in Zone 1 Distance (Unit 1 - Unit 2) (m)
Average Zone 1 Distance by two GPS Units (m)
LoA (95%)
Bias


**c)**

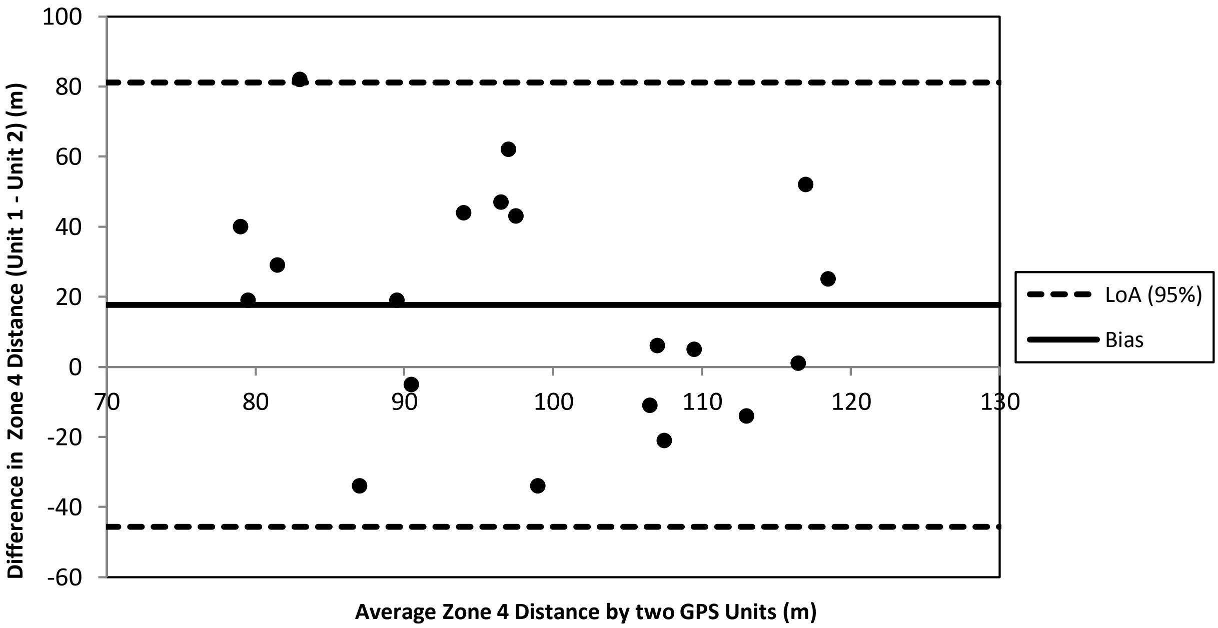


30
25
20
15
10
5
0
-5
-10
-15
-20
70
80
90
100
110
120
Difference in Zone 2 Distance (Unit 1 - Unit 2) (m)
Average Zone 2 Distance by two GPS Units (m)
LoA (95%)
Bias

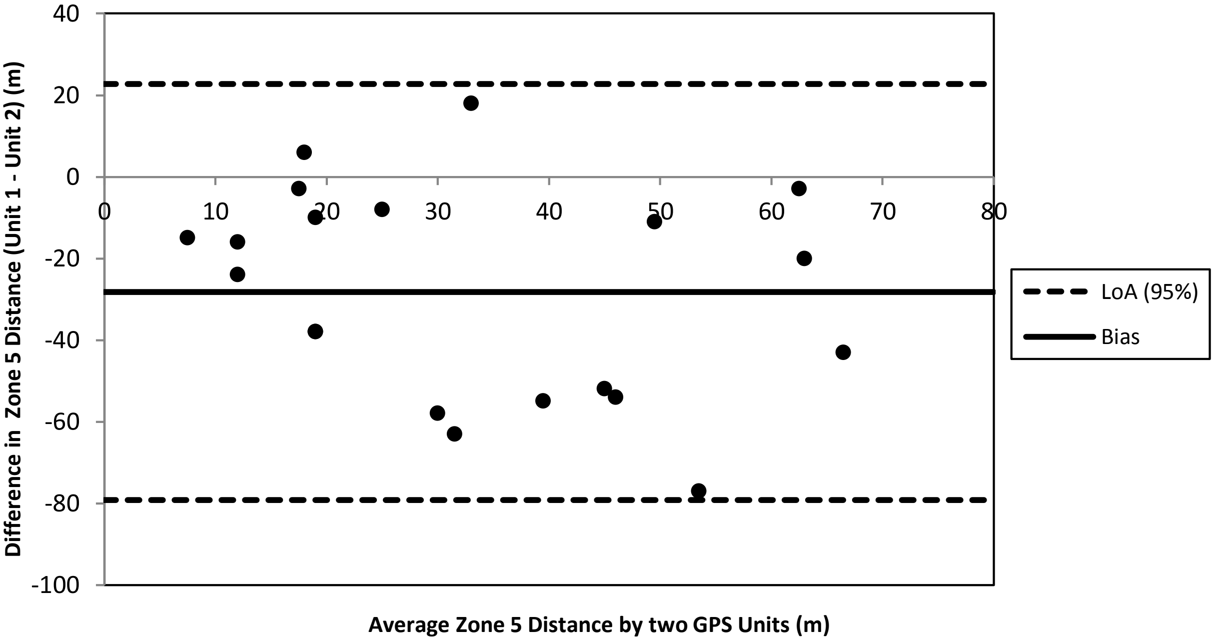
**d)**


30
20
10
0
-10
-20
-30
-40
10
20
30
40
50
60
70
Difference in Zone 3 Distance (Unit 1 - Unit 2) (m)
Average Zone 3 Distance by two GPS Units (m)
LoA (95%)
Bias

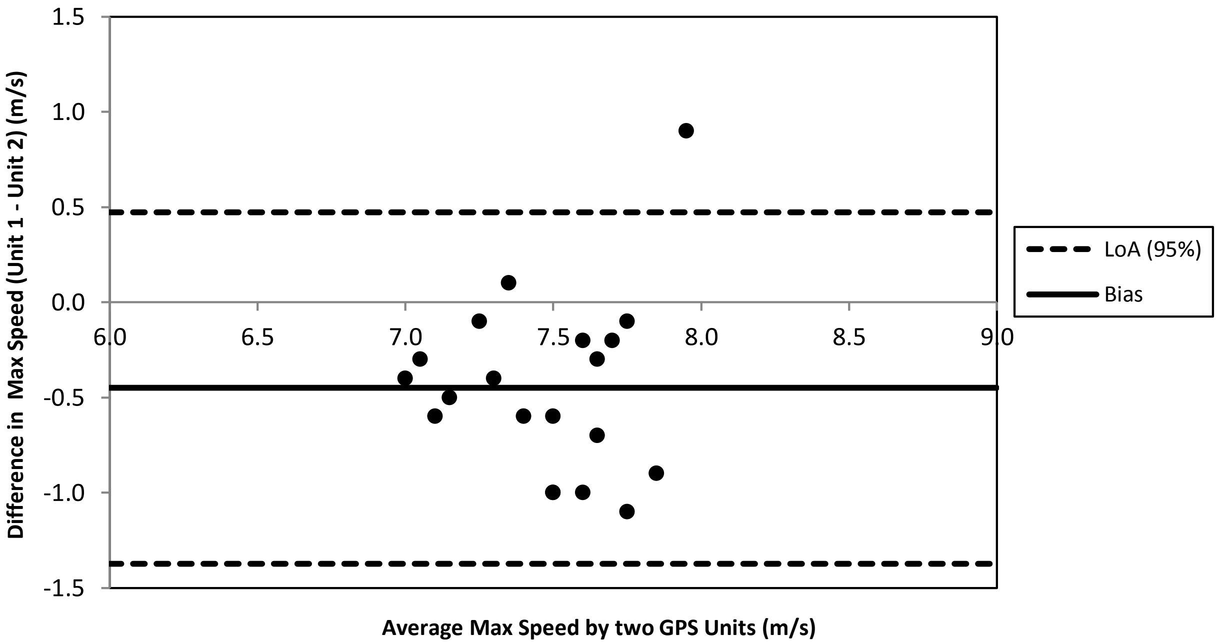
**e)**


100
80
60
40
20
0
-20
-40
-60
70
80
90
100
110
120
130
Difference in Zone 4 Distance (Unit 1 - Unit 2) (m)
Average Zone 4 Distance by two GPS Units (m)
LoA (95%)
Bias

**f)**


40
20
0
-20
-40
-60
-80
-100
0
10
20
30
40
50
60
70
80
Difference in Zone 5 Distance (Unit 1 - Unit 2) (m)
Average Zone 5 Distance by two GPS Units (m)
LoA (95%)
Bias

**g)**


1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
Difference in Max Speed (Unit 1 - Unit 2) (m/s)
Average Max Speed by two GPS Units (m/s)
LoA (95%)
Bias

h)

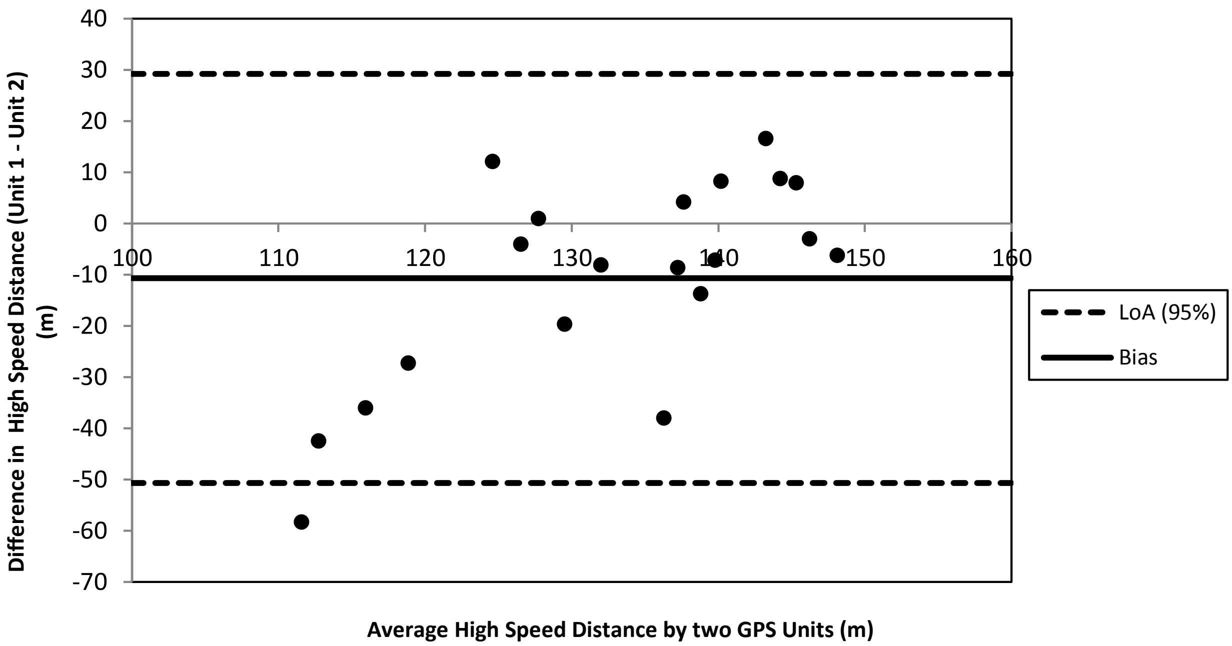



**Figure 3.2.** Bland-Altman plots determining the differences between two GPS units used for soccer-specific track testing. Variables measured are as follows: a) total distance; b) zone 1 distance; c) zone 2 distance; d) zone 3 distance; e) zone 4 distance; f) zone 5 distance; g) max speed; h) high speed distance

## 3.4. DISCUSSION

This study aimed to investigate the accuracy of a 10-Hz GPS system for the measurement of variables associated with movement velocity during a soccer-specific movement track that incorporated changes in direction. In addition, the study also determined the inter-unit reliability between GPS devices. The present findings demonstrate that 10-Hz GPS devices have an inability to accurately measure the movement velocities performed in higher velocity running (> 4 m/s). An increase in the amount of error was evident with an increase in movement velocity. The GPS devices also displayed a high level of inter-unit error, which is in agreement with earlier studies using earlier GPS devices (Duffield et al.

2010; Jennings et al. 2010b). This finding would suggest that 10-Hz GPS devices cannot be used interchangeably between soccer players.

In theory, the higher sampling frequency, improved satellite signal and advances in microchip sets in 10-Hz GPS devices should allow for improved detection of locomotion compared to previous devices of lower sampling frequency (i.e. 5-Hz and 1-Hz). The present study observed low coefficient of variation values ranging from 0.6 – 1.5% for the measurement of total distance. Only one previous study has employed a soccer-specific protocol to evaluate the reliability of GPS devices (Portas et al. 2010). The authors revealed low CV% values (< 5%) for total distance measured in agreement with the present study. Previous research has reported high CV values (> 10%) for the measurement of total distance using a combination of straight line and change of direction circuits for both 1-Hz (Jennings et al. 2010a) and 5-Hz GPS devices (Duffield et al. 2010). Therefore it appears that the increased sampling frequency in 10-Hz GPS devices improves the accuracy to measure total distance covered during sport-specific movements.

Similar observations were also evident for the max speed recorded during the soccer-specific track. The CV% ranged from 2.6 – 2.7% for both subjects, indicating a high level of reliability of 10-Hz GPS devices. Waldron et al. (2011) reported similar findings using 5-Hz GPS devices with a CV% of 0.78%. No other study has attempted to quantify reliability of max speed using 10-Hz GPS devices, with neither Castellano et al. (2011) or Varley et al. (2012) reporting reliability statistics for max speed. Other studies using both 1-Hz and 5-Hz devices have found higher (> 5%) CV values for max speed (Coutts & Duffield 2010; Duffield et al. 2010; Johnson et al. 2012). Thus it appears that 10-Hz GPS devices display good reliability for the measurement of total distance and max speed during soccer-specific movements.

In the present study, it was found that as the velocity of movement increased the accuracy of the 10-Hz GPS devices declined. Distance covered between 0 – 4 m/s reported CV% ranging from 1.7 – 3.6%. However the CV% increased when the movement velocity increased between 4.0 – 5.5 m/s (12.7 – 14.8 CV%), 5.5 – 7.0 m/s (7.6 – 18.7 CV% and above 7.0 m/s (16.8 – 33.6 CV%). Similar findings have been observed in both 1-Hz and 5-Hz GPS devices for distances covered at higher velocities with CV% ranging from 10.4 – 112%

(Coutts & Duffield 2010; Jennings et al. 2010a; Johnson et al. 2012). Lower CV% values have been reported using 10-Hz devices (2.0 – 10.9%; Castellano et al. 2011; Varley et al. 2012); however these studies have only used straight line protocols without sport-specific changes of direction and multiple changes in velocity during a relatively short period of time. The present findings suggest that 10-Hz GPS devices are unable to accurately measure distances covered during higher movement velocities. It is unclear as to the exact cause of the high error percentages reported in the present study. It may be that the initial acceleration of the subject could have contributed to the associated error as the speed of change in movement would have increased during higher velocity movements (i.e. sprints). As the CV% values reported in the present study are lower than those observed in previous studies using 5-Hz and 1-Hz GPS devices, it would appear that increased sampling frequency plays a major role in the accuracy of GPS systems to detect higher movement velocities. This would suggest that at present the measurement of distances across higher movement velocities is limited by the technology available to sports science practitioners in the applied setting.

The present study revealed a high level of inter-unit reliability error across all variables measured indicated by high values for both bias and the limits of agreement. This finding is in agreement with previous studies (Coutts & Duffield 2010; Duffield et al. 2010; Jennings et al. 2010b). The degree of error for the assessment of distance at different velocities in 1-Hz devices has previously been reported from 9.5 – 32.4 CV% (Coutts & Duffield 2010; Duffield et al. 2010). In both studies the degree of error increased between units with an increase in movement velocity. Similar findings were also evident for 5-Hz GPS devices during change of direction and team-sport courses, with percentage differences between units of above 10% (Jennings et al. 2010b). Recently the inter-unit reliability error has been quantified in 10-Hz GPS devices (Castellano et al. 2011; Varley et al. 2012). The studies revealed that the 10-Hz devices demonstrated good inter-unit reliability when measuring straight-line distance of 15 – 30m (0.7 – 1.3 CV%) and measurement of constant velocity at various velocities up to 8 $m/s^{-1}$ (2.0 – 5.3 CV%). This data is conflicting with the results of the present study. One possible reason for the difference between findings is the type of GPS manufacturer used during the study. Each GPS manufacturer has their own unique algorithms that they use to determine GPS variables (MacLeod et al. 2009). This makes it likely that the results from this investigation relate solely to the manufacturer used.

Another possible explanation for the present findings is due to the type of protocol used to investigate the inter-unit reliability (soccer-specific vs. straight line protocols). Therefore the present study would suggest that 10-Hz GPS devices of the manufacturer cannot be used interchangeably between subjects. Practically, this would suggest that soccer player should wear the same device for each training session to prevent inter-unit error occurring. It should also be noted that some degree of variability may exist between trials due to human error associated with the track. However, despite this limitation, there is no current study design that is available to replicate soccer-specific movements involving change of directions, as previous work has only utilised straight line designs.

In summary, the 10-Hz GPS devices used for the present study demonstrated an acceptable level of reliability for the measurement of total distance and max speed for soccer-specific movement patterns. However it was found that the degree of error increased above acceptable levels during higher velocity running (> 4 m/s). This has important implications when interpreting training data relating to high velocity movements (i.e. high speed distance covered). The associated error must be taken into context when generalising any findings based from these data. It should also be noted that some of the associated error may have resulted from human error associated with the soccer-specific track. However, there is currently no 'gold-standard' approach for assessment of sport-specific movements without the inclusion of such human factors. The 10-Hz GPS devices also demonstrated poor levels of inter-unit reliability for the type of manufacturer used in this study. It would therefore be suggested that GPS units for this manufacturer are not used interchangeably between athletes to assess sport-specific activity.

# CHAPTER 4

# RELIABILITY AND VALIDITY OF OPTOJUMP PHTOELECTRIC CELLS FOR MEASUREMENT OF VERTICAL JUMP PARAMETERS

## 4.1. INTRODUCTION

The stretch-shortening cycle (SSC) is particularly important during critical bouts of exercise such as sprinting and jumping in soccer (Oliver et al. 2008). When these actions are repeated frequently over certain time periods without adequate recovery, SSC force production is reduced due to neuromuscular fatigue (Komi 2000). Any fatigue-induced impairment in SSC function could have implications for soccer performance as these actions have been associated with goal scoring opportunities (Faude et al. 2012). By assessing neuromuscular function following games and/or training, practitioners may be able to quantify the degree of accumulated fatigue associated with a given exercise stimulus. This will enable effective planning of post exercise recovery strategies which will provide a platform for preparation for subsequent soccer performance.

Different methods have been used to monitor the mechanisms of neuromuscular fatigue, such as surface EMG and the assessment of MVC. Regular monitoring in the field demands a simple and easy to perform test that would enable frequent, fast, and unobtrusive assessments. The type of test must also have immediate feedback that can be given to practioners so that the subsequent practice can be affected if necessary. One such method is the assessment of an athlete's vertical jump performance as jump performance is a functional test specific to the actions of soccer that can be easily applied in the field without the need for laboratory testing. Changes in neuromuscular function can be monitored using a variety of vertical jump modalities (Oliver et al. 2008). Several researchers have employed this approach to examine neuromuscular fatigue in soccer using various jump types including a countermovement jump (CMJ) (Andersson et al. 2008; Hoffman et al. 2003; Mohr et al. 2010; Oliver et al. 2008), squat jump (SJ) (Hoffman et al. 2003; Oliver et al. 2008) and a drop jump (DJ) (Oliver et al. 2008). Significant reductions in jump performance have been observed following soccer-specific exercise for CMJ by 4.4 to 8.2% (Andersson et al. 2008; Hoffman et al. 2003; Mohr et al. 2010), SJ by 15.5% (Hoffman et al. 2003) and DJ by 2.3 cm jump height (Oliver et al. 2008). Due to the inconsistent methods used and subject populations tested, no conclusive data exists amongst these studies to monitor neuromuscular fatigue in soccer using vertical jump performance as a monitoring tool.

Various measurement tools are commonly used for field based vertical jump assessment, such as linear position transducers (Cronin et al. 2004), yardsticks (Leard et al. 2007) and contact mats (Garcia-Lopez et al. 2005). However these measurement tools have limitations that affect jump performance outcome, such as intra-body displacement and lack of contact with natural surface (Glatthorn et al. 2011). Biomechanical force plates that measure data at high frequencies are generally considered as the 'gold standard' for the assessment of vertical jump performance (Cronin et al. 2004). However due to their high cost and lack of portability in the field, their use outside the laboratory is impractical. The Optojump photoelectric system (Microgate, Bolzano, Italy) is a portable device capable of measuring vertical jump performance on any sports surfaces (except for sand), making the device highly portable. The reliability and validity of the Optojump system has recently been quantified (Glatthorn et al. 2011), demonstrating strong concurrent validity and test-retest reliability for the assessment of vertical jump height. However this study used only a limited number of jump modalities and only analysed a small proportion of the potential data available from the systems. Thus a more detailed investigation of the Optojump device is required to determine both the most appropriate jump type to assess neuromuscular fatigue and the reliability/validity of the equipment.

Therefore the aim of the present study was to quantify the reliability and criterion validity of the Optojump photoelectric system. Jump performance was evaluated for three common types of vertical jump test (squat, CMJ and drop jump) across various measurement derived variables (contact time, flight time and jump height). The criterion validity of the Optojump system was evaluated using concurrent force plate measurements. The outcome from the study aimed to determine the suitability of the Optojump system for field-based assessment of vertical jump performance.

## 4.2. METHODS

### 4.2.1. SUBJECTS

Eleven active healthy male subjects were recruited to participate in the study (age 26 ± 3 years; mass 77.2 ± 7.4 kg; height 1.8 ± 0.3 m). Subjects were regularly engaged in physical activity (minimum 2 sessions per week) and had no current injuries that hindered their participation. All subjects completed the reliability part of the study, however only 9 subjects completed the validity part. Subjects were required to refrain from drinking alcohol and strenuous exercise 24 hours before each trial. Written informed consent was given by each subject, with the study being approved by the University Ethics Committee of Liverpool John Moores University.

### 4.2.2. EXPERIMENTAL DESIGN

The purpose of the present study was to determine the reliability and criterion validity of the Optojump photoelectric cell system. The study was separated into two components with the same subjects used in both parts. In the first investigation, subjects were asked to perform CMJ with arm swing (CMJ-W), CMJ without arm swing (CMJ-WO), SJ and DJ assessments on 5 identical testing sessions (separated by minimum of 2 days). As the Optojump system was the focus of the present study, multiple trials of jump testing with a small sample size was chosen to form this pilot study. Contact time, flight time and jump height was compared across trials to examine the reliability of the Optojump system. In the second part of the investigation, subjects were asked to perform the same jump modalities as the previous investigation on one occasion while data was simultaneously collected from both a force plate (criterion instrument) and the Optojump photocells. This data collection was carried out to assess the criterion validity of the Optojump. Testing for both investigations was carried out in the laboratories located at Liverpool John Moores University.

### 4.2.3. EXPERIMENTAL PROTOCOL

The protocols for jump performance for the different jump modalities were identical for the 2 investigations. Prior to commencement of the main study data collection, all subjects completed familiarisation sessions for all jump types until a plateau in jump height was observed. After a full explanation of experimental procedures, subjects completed a standardized warm-up consisting of sub-maximal vertical jumps (5 minutes) and dynamic stretching of the upper and lower extremities. The following jump modalities were performed: CMJ-W, CMJ-WO, SJ and DJ. Each jump was repeated 3 times. Each type of vertical jump represents a different component of neuromuscular function. The CMJ involves use of the SSC engaging in a sequence of eccentric stretch, isometric coupling and concentric shortening of muscle (Komi 1984). However the SJ only involves the concentric phase of the SSC, and has demonstrated reduced jump height compared to a CMJ (Bobbert et al. 1996; Komi & Bosco 1978). The DJ involves rebounding vertically after a drop from a specific height and also utilizes the stretch-shortening cycle (Byrne & Eston 2002). It has been suggested that following fatiguing exercise both braking and propulsive contact times increase (Avela & Komi 1998; Nicol et al. 1991), reflecting a reduced ability to tolerate the impact loads due to a reduced tendomuscular system function (Paavolainen et al. 1999).

For CMJ-W subjects were instructed to start in an upright standing position with their arms free to move. They were then instructed to flex their knees to approximately 90 degrees as quick as possible and then jump as high as they could using their arms to propel the body upwards whilst ensuring their knees were not in a flexed position at the end of the jump phase. The same jump protocol was used for CMJ-WO. The only difference being the jump was performed with their hands on their hips (i.e. without arm swing). For SJ, subjects started from an upright standing position with their hands on their hips. They were then instructed to flex their knees to approximately 90 degrees and hold this position for 3 seconds. The subject was then instructed to jump as high as possible without performing any countermovement before the execution of the jump. For DJ, subjects were instructed to step off a wooden box from a height of 0.40m without lifting their centre of gravity and land in between the two Optojump photocells placed adjacent to the wooden box on the floor. The subjects were instructed to jump for maximal height whilst attempting minimal contact with the floor. A rest interval of 30 seconds was interspersed between jump repetitions, with 2 minutes rest allocated between jump modalities. The jump with the highest jump height was selected from the 3 repetitions for each trial for analysis. This was determined by the Optojump device in the reliability part of the study and by the force plate in the validity part.

The force plate (Kistler, Winterhur, Switzerland) used for the criterion validity assessment was embedded firmly into the ground. This enabled an accurate measurement of vertical reaction forces. Data was collected for a period of 6 seconds. This included approximately 2 seconds of quiet standing before each jump commenced as well as the jump performance including the landing phase. This applied for all jump modalities apart from DJ, in which the subjects started in a position off the force plate (i.e. on the wooden box adjacent). The force plate was connected to a personal computer with all parameters collected using the loaded software (QJ software, version 1.0.9.2). The force data was collected at 960 Hz. The Optojump photoelectric cells, which consist of two parallel bars (one receiver unit and one transmitter unit) were placed approximately 1 m apart and parallel to each other. The transmitter unit contains 32 light emitting diodes, which are positioned 0.3 cm from ground level. For the criterion validity investigation, the Optojump bars were placed parallel across the force plate to ensure data could be collected simultaneously from both systems. Optojump bars were connected to a personal computer with the proprietary software (Optojump software, version 1.5.1.0) allowing calculation of jump variables. The Optojump system measured the flight time of vertical jumps with an accuracy of 1/1000 seconds (1 kHz).

### 4.2.4. STATISTICAL ANALYSIS

In order to assess the degree of reliability of the Optojump system for the assessment of vertical jump performance, the typical error (i.e. the within-subject variability from trial-to-trial) was calculated and expressed as a CV%. In order to obtain this measure, the data was log-transformed and analysed using a within-subjects analysis of variance (ANOVA). The data were log-transformed in order to reduce the influence of outliers and also reduce skewness when analysing within-subject variability (Field 2009). The typical error was then calculated as the square root of the mean squares for error and then back-transformed to produce the CV% value. Values were interpreted according to previous research (Duthie et al. 2003) and classified as follows: good (< 5%), moderate (5-10%) and poor (> 10%). Intraclass correlation coefficient (ICC) was calculated using a two-way reliability ANOVA analysis for single measures according to the methods of Hopkins (2000). As no current consensus exists for the interpretation of ICC analysis (Weir 2005), values were interpreted according to previous research (Barbero-Álvarez et al. 2010; Johnson et al. 2012). All statistical analyses were performed using SPSS 17.0 (SPSS, Chicago, IL). Validity of jump assessment between the Optojump and force plate was determined using the validity spreadsheet of Hopkins (Hopkins 2009). The typical error of the estimate (TEE) was assessed and classified according to previous recommendations (Hopkins 2009). Pearson's correlation coefficient was analysed and classified as follows to signal the strength of the relationship (Hopkins 2009): trivial (0.0), small (0.1), moderate (0.3), large (0.7), nearly perfect (0.9) and perfect (1.0).

## 4.3. RESULTS

### 4.3.1. RELIABILITY

The reliability of the Optojump system for assessment of vertical jump parameters is presented in Table 4.1. The results demonstrate that the degree of variability ranged from good to moderate for all jump parameters, with the exception of contact time during the drop jump test which recorded high variability. The reliability of flight time for all jump types was deemed to present a good level of variability (< 5 CV%) and a very large ICC scores (range 0.85 – 0.90). For jump height, the results from the reliability testing revealed a moderate level of error for all jump types (< 5.6 CV%) and very large ICC scores (range 0.85 – 0.90). Contact time during the drop jump test demonstrated a poor level of variability (13.9 CV%) but with a very large ICC score (0.87).

### 4.3.2. VALIDITY

The validity results between the Optojump system and force plate are presented in Table 4.2. The results for flight time for all jump types revealed both excellent levels of error (< 1% TEE) and almost perfect Pearson's r values (range 0.997 – 0.999). Similar findings were also evident for jump height values, with TEE% ranging from 0.5 – 0.8% and with Pearson's r value correlations ranging from 0.997 – 0.999. The contact time measure from the drop jump test also revealed a good level of error (0.5 TEE%) and perfect agreement of Pearson's r value correlation (1.000).

**Table 4.1.** Reliability measures of the Optojump photoelectric system across five trials using a series of vertical jump types

| Jump Type | Jump Variable | Optojump Data (Mean ± SD) | CV% | ICC |
|---|---|---|---|---|
| CMJ-W | Flight (secs) | 0.54 ± 0.04 | 3.2 | 0.88 |
| | Height (cm) | 36.0 ± 5.3 | 5.6 | 0.88 |
| CMJ-WO | Flight (secs) | 0.50 ± 0.03 | 3.2 | 0.87 |
| | Height (cm) | 31.0 ± 4.2 | 5.6 | 0.87 |
| SJ | Flight (secs) | 0.50 ± 0.03 | 3.2 | 0.85 |
| | Height (cm) | 31.2 ± 3.9 | 5.6 | 0.85 |
| DJ | Flight (secs) | 0.57 ± 0.04 | 3.2 | 0.90 |
| | Height (cm) | 40.2 ± 6.2 | 5.6 | 0.90 |
| | Contact (secs) | 0.47 ± 0.15 | 13.9 | 0.87 |

CMJ-W: countermovement jump with arm swing; CMJ-WO: countermovement jump without arm swing; SJ: squat jump; DJ: drop jump.

**Table 4.2.** Validity measures of the Optojump photoelectric system compared with force plate assessment using a series of jump types

| Jump Type | Jump Variable | Optojump Data (Mean ± SD) | Force Plate Data (Mean ± SD) | TEE% | Pearson's Correlation (r) |
|---|---|---|---|---|---|
| CMJ-W | Flight (secs) | 0.57 ± 0.04 | 0.58 ± 0.04 | 0.3 | 0.999 |
| | Height (cm) | 40.0 ± 5.0 | 41.1 ± 5.0 | 0.7 | 0.999 |
| CMJ-WO | Flight (secs) | 0.53 ± 0.03 | 0.54 ± 0.03 | 0.5 | 0.997 |
| | Height (cm) | 34.5 ± 4.0 | 35.6 ± 4.0 | 0.8 | 0.997 |
| SJ | Flight (secs) | 0.51 ± 0.03 | 0.52 ± 0.03 | 0.2 | 0.999 |
| | Height (cm) | 32.3 ± 3.5 | 33.4 ± 3.6 | 0.5 | 0.999 |
| DJ | Flight (secs) | 0.57 ± 0.03 | 0.57 ± 0.03 | 0.3 | 0.998 |
| | Height (cm) | 39.3 ± 4.1 | 40.4 ± 4.1 | 0.7 | 0.998 |
| | Contact (secs) | 0.40 ± 0.15 | 0.39 ± 0.15 | 0.5 | 1.000 |

CMJ-W: countermovement jump with arm swing; CMJ-WO: countermovement jump without arm swing; SJ: squat jump; DJ: drop jump; TEE%: typical error of the estimate %.

## 4.4. DISCUSSION

The main aim of the present study was to quantify the reliability and criterion validity of the Optojump photoelectric system for the assessment of vertical jump parameters. Subsequently, the most appropriate jump type could then be selected for the experimental study later in the present thesis. The current findings revealed the Optojump system demonstrated excellent reliability and criterion validity. This data is in agreement with previous work (Glatthorn et al. 2011). Analysis of different vertical jumps revealed similar accuracy across all jump types, with the exception of contact time for DJ testing. This would suggest that DJ testing may not be suitable for the assessment of vertical jump performance using the Optojump system.

The present study revealed low CV% (ranging from 3.2 – 5.6%) for the assessment of jump height and flight time across all jump types measured. In addition the intraclass correlation coefficients for reliability were very high (range: 0.85 – 0.90) for the same jump parameters and types. There appears to be a consistent bias between jump flight time and jump height. This is most likely due to jump height being derived from flight time once the subject moves from the photocells. The current data is in agreement with previous studies investigating the reliability of the Optojump system (Casartelli et al. 2010; Glatthorn et al. 2011). The CV% values obtained in the present study using the Optojump system are also in the lower range of those reported by Hopkins et al. (2001). The authors reported CV% values ranging from 3.1 – 8.6% for jump height measured using yardsticks, contact mats and commercially portable force plates. The present data would suggest that the Optojump system is more reliable in terms of jump height assessment in comparison to other types of portable testing equipment. The difference in findings may be due to the jump technique required to perform the vertical jump assessment. When using yardsticks, it is possible that jump height may be influenced by the degree of shoulder and elbow flexibility of the athlete (Glatthorn et al. 2011). In addition, the use of portable contact mats doesn't allow the athlete's feet to be in direct contact with the ground which may alter the surface interaction during takeoff. As the Optojump system allows the athlete to jump in a normal controlled fashion with direct contact with the sport-specific surface, this may explain the superior reliability of the Optojump system compared to other field-based methods. Another major factor may relate to the sampling frequency of the Optojump system being similar to that of the force plate (i.e. 1 kHz). By taking more measurements per second, the Optojump holds the advantage over other devices in which the sampling frequency is reduced.

Criterion validity was assessed using a force plate which is referred to as the 'gold standard' for assessment of vertical jump performance (Cronin et al. 2004). Data from the present study revealed a nearly perfect correlation for all variables across each jump modality (range: $r$ = 0.997 – 1.000) between the Optojump system and force plate derived data. Analysis also revealed low levels of error (< 1% TEE) between the two jump measurement methods. These findings are in line with those reported in previous studies investigating the criterion validity of the Optojump system in comparison to a force plate (Castagna et al. 2013; Glatthorn et al. 2011). These authors reported near perfect correlations between the two devices ranging from 0.997 – 0.998 for assessment of jump height and flight time for SJ, CMJ-W and CMJ-WO. Previous research has investigated the validity of alternative methods of vertical jump assessment. Both contact mats and yardsticks have been found to have a high correlation (0.906 – 0.967) with a 3-camera motion criterion reference for vertical jump height (Leard et al. 2007). However the criterion measure used in this study is not deemed the gold standard criterion measure. Linear position transducers have been suggested to be valid methods of measuring jump performance in comparison to force plate measurement (Cronin et al. 2004; Hansen et al. 2011). However both studies investigated force-based measurements of jump performance (peak and mean) and the use of an external load (Hansen et al. 2011) which makes the present results incomparable. Linear position transducers may also be limited for certain jump modalities because of the upward intrabody displacement of the centre of mass with arm elevation (Glatthorn et al. 2011). The present study therefore suggests the Optojump system is a valid method for the assessment of vertical jump performance.

It is important to ensure that measurements of vertical jump performance for the assessment of neuromuscular function have both adequate reliability and validity in order to detect a true change in performance (Atkinson & Nevill 1998). Evaluation of the reliability and validity data from the present study revealed similar values for both jump height and flight for CMJ-W, CMJ-WO and SJ. However reliability analysis revealed poor reliability of contact time for DJ assessment (CV% = 13.9%). Thus it would appear that the use of DJ for assessment of jump performance using the Optojump system would not be recommended. This apparent increase in error associated with contact time with the DJ may be due to the rebound nature of the jump and the higher complexity of the technique, resulting in higher variation in landing position and/or task performance for each jump repetition. The reliability and validity data was similar for CMJ-W, CMJ-WO and SJ, and therefore the most appropriate and applicable test can be determined from these jumps to assess neuromuscular function. The SJ only involves the concentric phase of the SSC, whereas CMJ involves use of the full SSC engaging in an eccentric stretch, isometric coupling and concentric shortening of muscle (Komi 1984). The majority of key actions during soccer involve full use of the SSC function, such as high speed sprinting, which includes both eccentric and concentric actions (Oliver et al. 2008). In addition, soccer players are required to perform multiple jumping actions in which a player has to rapidly move from a concentric to eccentric phase, such as heading the ball when under pressure from the opposition (Bangsbo et al. 1994). Therefore due to the sport-specific nature of the CMJ test and use of the full SSC, it would make practical sense to select the CMJ for neuromuscular evaluation. The present study has employed two variations in CMJ for vertical jump assessment. The most common type of CMJ in the literature involves placing the hands on the hips during jump assessment (Andersson et al. 2008; Hoffman et al. 2003; Mohr et al. 2010; Oliver et al. 2008). Therefore the CMJ-WO test is recommended as it satisfies the test objectives and permits comparison with previous literature.

Certain limitations exist when interpreting the data from the current methodologies. Such limitations may influence the generalisations that can be made from the data regarding the applications of the jump protocols to future experimental investigations in this thesis. It would be preferable if the reliability/validity of the jumps was determined using the same population of subjects across all studies in the present thesis. It could be suggested that a selection bias may exist in the present study due to the lack of availability of elite level athletes for this methodological study. Thus it could be argued that the difference in subject group limits the generalisation of the data. The counter-argument to this point would be that data should be comparable for the Optojump system regardless of jump performance (i.e. higher values for elite athletes). Another limitation of the present findings relates to the timings in which the reliability measures were obtained. Hopkins (2001) argues that the time between trials should be similar to the time between the pre and post tests that will be used in the experimental study. In the present study we measured reliability across 5 trials on separate days with a minimum of 2 days between trials. Despite not assessing reliability twice on the same day, we measured jump performance on different days which represents the design used in the present thesis. The small sample sized used in this study (n = 11) may also hinder the generalisation of the study findings. It may also be evident that the ICC analysis may not be sensitive enough to detect within-subject differences. It was found for the DJ that despite a high CV% (13.9 CV%), the ICC score still remained high (0.87), which indicates high reliability. These differences in interpretation may be due to the lack of clear consensus when interpreting ICC scores (Weir 2005).

To summarise, the present study systematically evaluated the reliability and validity of the Optojump photocell system for different variables across various jump modalities. The Optojump system demonstrated a high level of reliability and validity for the assessment of jump height and flight for CMJ-W, CMJ-WO and SJ. However, there was a poor level of reliability shown for contact time for the DJ test. Therefore the Optojump system may be used with confidence to detect within-group changes in applied assessments of vertical jump performance. Due to the high cost and lack of portability of laboratory-based force plates, the Optojump system is a viable alternative for accurate jump measurement. Due to the sport-specific relevance of the CMJ for soccer activity, it would be suggested that the CMJ can be used in subsequent experimental studies in the present thesis. Due to the small sample size and limited statistical power, it would be suggested that the present findings cannot be generalised across different test populations.

# CHAPTER 5

# QUANTIFICATION OF TRAINING PERIODISATION STRATEGIES EMPLOYED BY AN ELITE PROFESSIONAL SOCCER TEAM

## 5.1. INTRODUCTION

The evolving professional nature of soccer has led to the requirement for a scientific background to training planning and structure. Training periodisation refers to the division of an entire annual plan into smaller periods and training units (Matveyev 1981). The aim of periodisation is to maximise training adaptations through dissipation of fatigue and improvement of sport-specific fitness (Bompa & Haff 2009). Traditional periodisation models have been developed in individual sports, such as track and field. In such models athletes may have several months to prepare for a competition (Bondarchuk 1986; Matveyev 1981; Verkhoshansky 1985). The application and knowledge of training periodisation in team sports, such as soccer, is currently limited. This is probably a consequence of the complex scheduling of competition that is a reality for most elite teams (Issurin 2010).

The data that is currently available regarding training organisation and soccer would suggest that in a typical week with one match to play, the players within a professional team may undergo up to five on-field training sessions (Bangsbo et al. 2006). The frequency of training sessions may then be reduced to three when two competitive matches are played per week (Bangsbo et al. 2006). The number of training sessions during a week may also be dependent on the training phase during a competitive season as soccer players undergo almost twice as many training sessions during the pre-season compared to the in-season phase (Castagna et al. *In Press*; Impellizeri et al. 2005; Jeong et al. 2011). The focus of the available data on descriptions of training frequency doesn't allow for a detailed analysis of the training periodisation strategies that may be employed in elite soccer. A comprehensive understanding of the application of models of training within the sport will only be provided when additional information on other important parameters, such as the intensity and volume of the exercise stimulus, is obtained in conjunction with data on the training frequency. At present no published study has systematically quantified the periodisation practices of elite soccer teams using a variety of measures of training load over a prolonged period of time.

The purpose of this study was to quantify the training loads employed by an elite professional soccer team across a competitive season. Such information would provide detail of the training periodisation strategies currently used in elite level soccer. Such knowledge would allow soccer coaches and sports scientists to help optimise the training programmes used for the preparation of players. It was hypothesized that the variation in training load would be limited due to the time restraints of elite level soccer competition.

## 5.2. METHODS

### 5.2.1. SUBJECTS AND TRAINING OBSERVATIONS

Training load data was collected from 37 elite outfield soccer players competing in the English Premier League over a 45 week period during the 2011-2012 domestic season. The physical characteristics of the players (mean ± SD) at the end of the pre-season phase were as follows: age = 25 ± 5 years; height = 183 ± 7 cm; body mass = 80.5 ± 7.4 kg. A total of 3513 individual training observations were collected during the pre-season and in-season competition phases with a median of 111 training sessions per player (range = 6 – 189). Players were assigned to one of 5 positional groups: central defender (CD) (training observations = 731), wide defender (WD) (training observations = 868), central midfielder (CM) (training observations = 905), wide midfielder (WM) (training observations = 668) and attacker (AT) (training observations = 341). Goalkeepers were excluded from data analysis. In order to standardise the data analysis across the season, only training sessions in which the players who previously played in matches was included for analysis. Only data derived from team-based field training sessions was analysed, with no individual rehabilitation or additional fitness sessions included for analysis. The full duration of each training session was used for analysis, including the team warm up and all training drills. Data collection for this study was carried out at the soccer club's outdoor training pitches. All players were made aware of the purpose of the study and provided written consent. The study was approved by the University Ethics Committee of Liverpool John Moores University.

### 5.2.2. EXPERIMENTAL DESIGN

Data collection for the study was carried out on a daily basis throughout the 2011/2012 soccer season. All players wore global positioning system (GPS) devices, heart rate (HR) belts and were asked to provide a rating of perceived exertion (RPE) based on the ratio scale of Foster et al. (2001) for each training session. The players were familiarised with all procedures preceding the beginning of the study data collection. The content of each training session was determined by the team's soccer coaches and fitness coach in line with the physical, tactical and technical objectives for each given session. It was beyond the scope of this study to compare the intended training load against the outcome due to a lack of information from the soccer coaches. In order to investigate the periodisation strategies employed throughout the competitive season, the training load data was separated into five categories for analysis (Figure 5.1). The data was separated into the pre-season (6 weeks duration) and in-season (39 weeks duration) phases in order to investigate specific training periods recognised within the annual plan. The pre-season phase was further separated into weekly blocks for analysis of the structure employed in each specific microcycle. The in-season phase was divided into 6 x 6 week blocks. This division allowed the investigation of loading patterns incorporated within this training unit (frequently defined as a mesocycle) (Bompa & Haff 2009).

Within the in-season data, three separate microcycles (weeks 7, 24 and 39) were selected in order to analyse the training loads at the start, middle and end of the in-season phase. Each of these microcycles consisted of the same weekly training schedules. This design was selected in order to determine if any differences in microcycle training load pattern existed during the in-season phase. In addition, the training data within a given microcycle was analysed to investigate the loading patterns in relation to number of days away from the competitive match fixture.

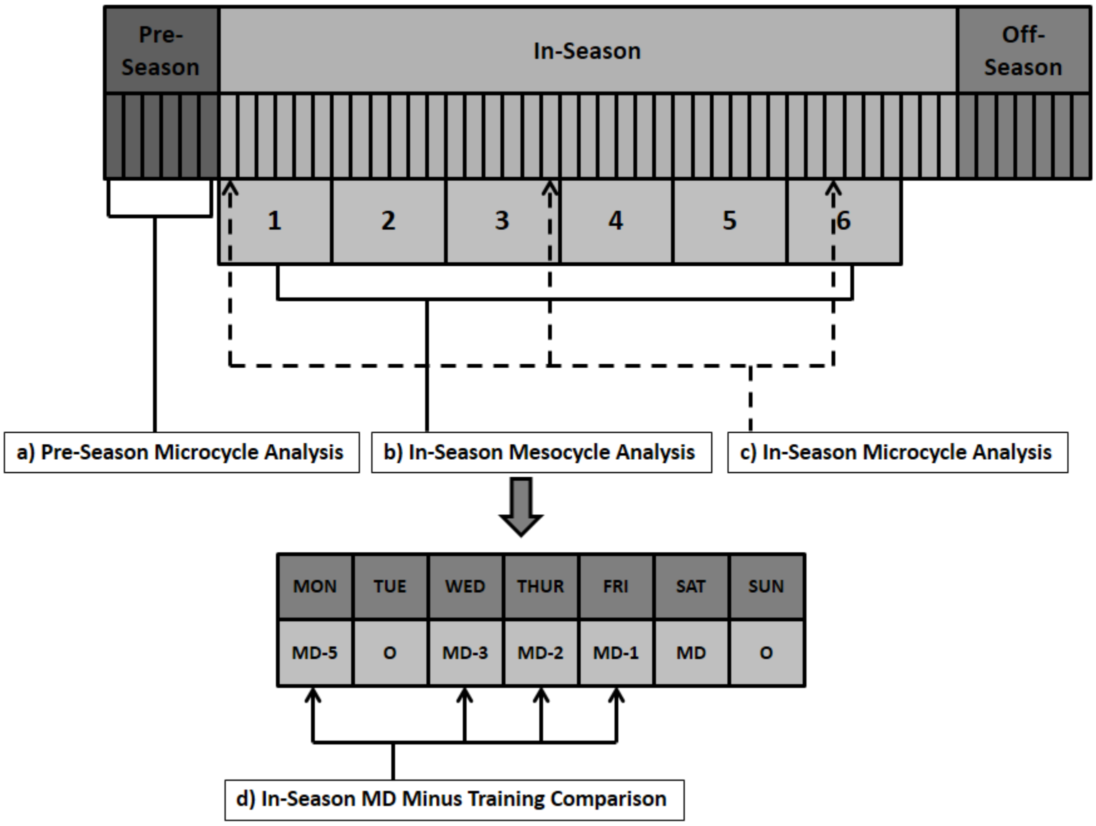



**Figure 5.1.** Outline of the experimental design. Each small block represents an individual weekly period across the annual cycle. Large blocks represent 6 week mesocycle periods across the in-season phase. Minus symbol represents training session in respect to number of days prior to a competitive match. MD = match day; O = day off.

### 5.2.3. TRAINING DATA COLLECTION

The player's physical activity during each training session was monitored using portable GPS technology (GPSports© SPI Pro X, Canberra, Australia). The device provides position, velocity and distance data at 10Hz (i.e. 10 samples per second). Each player wore the device inside a custom made vest supplied by the manufacturer. The device was positioned across the upper back between the left and right scapula. This position on the player allows the GPS antenna to be exposed for a clear satellite reception. All devices were activated 30-minutes before data collection to allow acquisition of satellite signals as per manufacturer's instructions. Following each training session, GPS data was downloaded using the respective software package on a personal computer (GPSports© Team AMS software V R1

2011.16 P10) and exported for analysis. A custom-built GPS receiver (GPSports©, Canberra, Australia) and software application (GPSports SPI Realtime V R1 2011.16) were used to time-code the start and end periods for each training session. Prior work conducted in Study 1 of the present thesis showed the devices to have high inter-unit variability. Therefore each player wore the same GPS device for each training session in order to avoid this variability. Data from Study 1 also reported good reliability (CV < 5%) for the following variables: total distance covered and average speed (distance covered divided by training duration). Both of these variables were selected for analysis in addition to high speed distance (distance covered above 5.5 m/s) covered and training duration. High speed distance covered was selected despite Study 1 revealing poor levels of reliability (CV > 10%). However it was unknown whether the variability associated with high speed distance covered was above the observed differences found in training data. Therefore high speed distance was included for analysis, with the view of interpretation based on the high variability findings from Study 1.

During each training session, all players wore a portable team-based HR receiver system (Acentas GmBH©, Freising, Germany). The beat-to-beat HR data was transmitted to a receiver connected to a portable laptop and analysed using the software package (Firstbeat Sports©, Jyväskylä, Finland). This software was used to determine the average HR for each individual player during training sessions. Immediately following the end of each training session, players were asked to provide an RPE rating. The players were previously familiarised with the scale. Players were prompted for the RPE rating individually using a custom-designed application on a portable computer tablet (iPad©, Apple Inc., California, USA). The player selected their RPE rating by touching the respective score on the tablet, which was then automatically saved under the player's profile. This method helps minimise factors that may influence a player's RPE rating, such as peer pressure and replicating other player's ratings (Burgess & Drust 2012).

Training data was collected for each training session completed and related to number of days away from the subsequent competitive fixture. In a week with only one match, the team typically trained on the second day after the previous match (match day (MD) minus 5; MD-5), followed by a day off and then three consecutive training sessions (MD-3, MD-2 and MD-1, respectively) leading into the next match.

### 5.2.4. STATISTICAL ANALYSIS

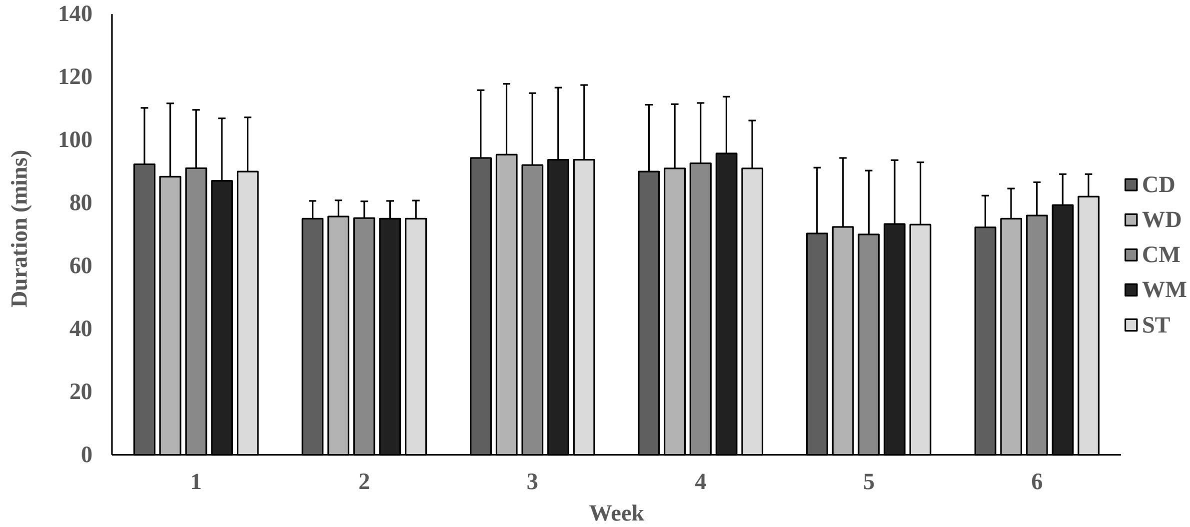
Data was analysed using linear mixed modelling using the statistical software package R (Version 3.0.1). Mixed linear modelling can be applied to repeated measures data from unbalanced designs, which was the case in the present study since players differed in terms of the number of training sessions they participated in (Di Salvo et al. 2009). Mixed linear modelling can also cope with the mixture of both fixed and random effects as well as missing data from players (Cnaan et al. 1997). In the present study, time period (mesocycles, microcycles and days in relation to the match (i.e. MD minus) and player's position (CD, WD, CM, WM and AT) were treated as categorical fixed effects. Random effects were associated with the individual players in relation to the specific training sessions and time period. A step-up procedure was used to select the model of best fit for each analysed data set and compared using likelihood ratio tests. Initially an intercept-only model was applied, with more complex models built by adding the fixed and random effects (including interactions) until no significant difference ($P > 0.05$) was found between the selected model and the complex models. When one or more fixed effects were statistically significant in the selected model ($P < 0.05$), Tukey post-hoc pairwise comparisons were performed to examine contrasts between pairs of categories of the significant predictor(s). Data is represented and analysed as mean ± SD.

## 5.3. RESULTS

### 5.3.1. PRE-SEASON MICROCYCLE ANALYSIS

The training load data across 6 x 1 week microcycles during the pre-season phase for different positions is represented in Figure 5.2. There was a significant random effect found between individual players and training sessions across the separate microcycle weeks for duration, total distance and average HR ($P < 0.05$). No differences were evident between the six microcycle weeks for all variables ($P > 0.05$). CM players reported higher total distance and average speed values during pre-season compared to CD and ST ($P = 0.01$ for both variables). WD players were also found to cover higher total distance and average speed compared to ST ($P = 0.03$ and $P = 0.04$, respectively). WM players covered more total distance compared to CD players during pre-season ($P = 0.01$).

a)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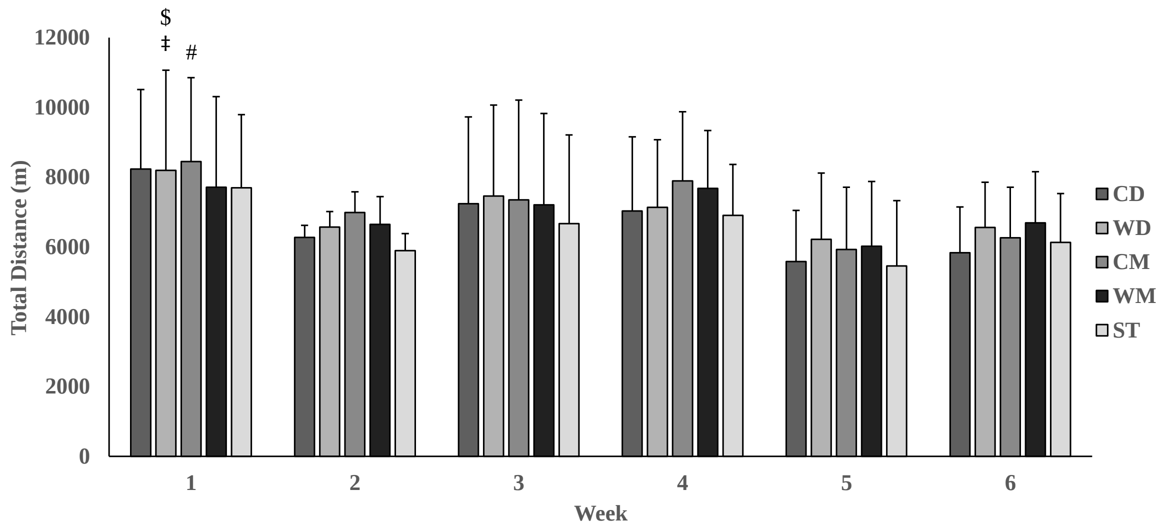
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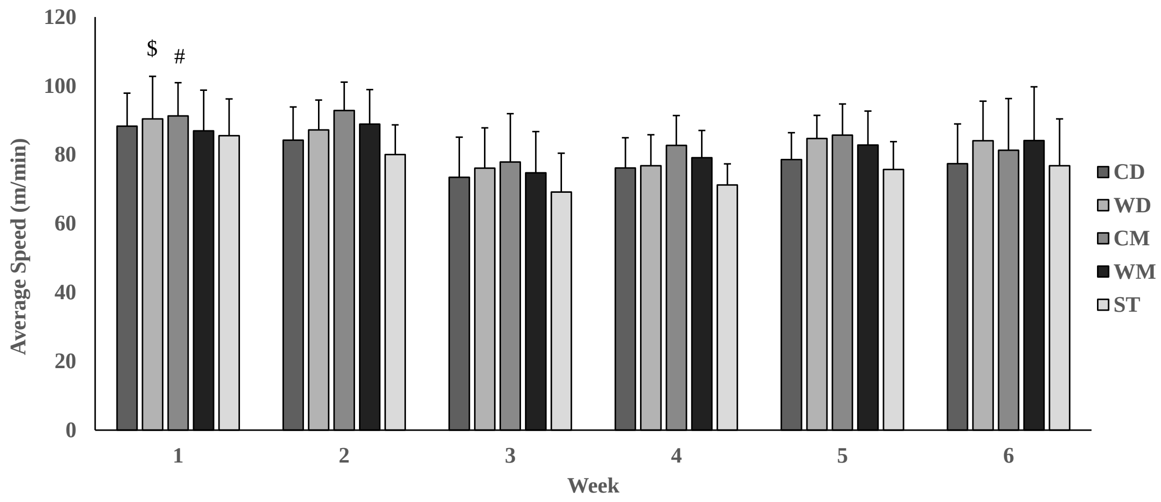
c)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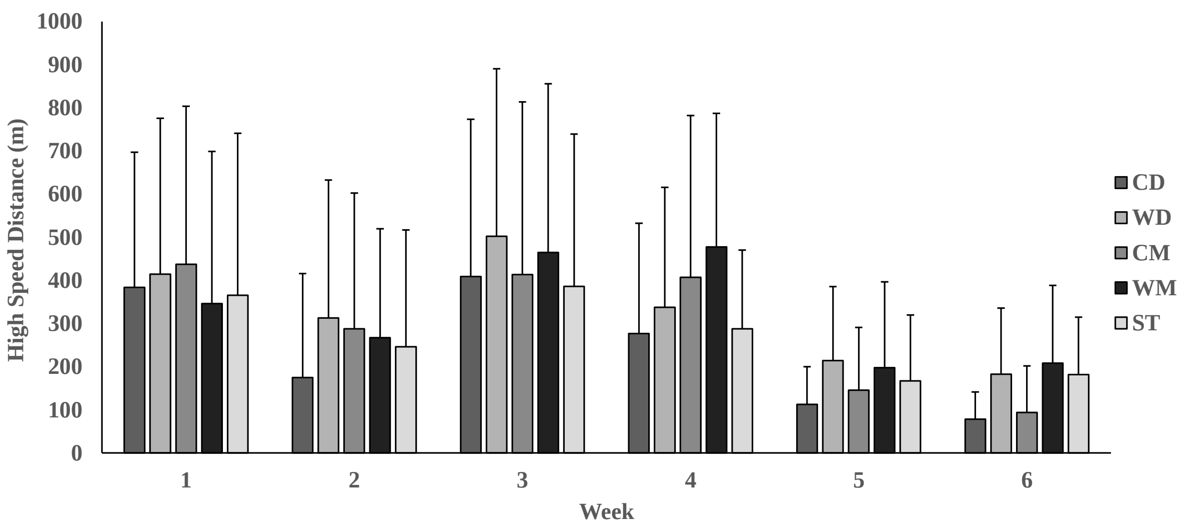
High Speed Distance (m)
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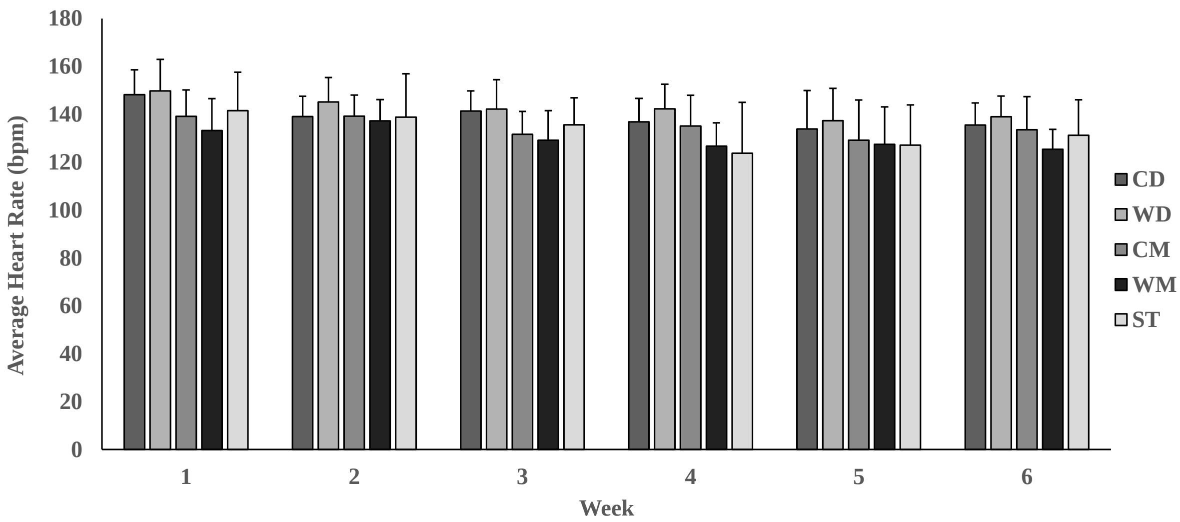
e)




f)

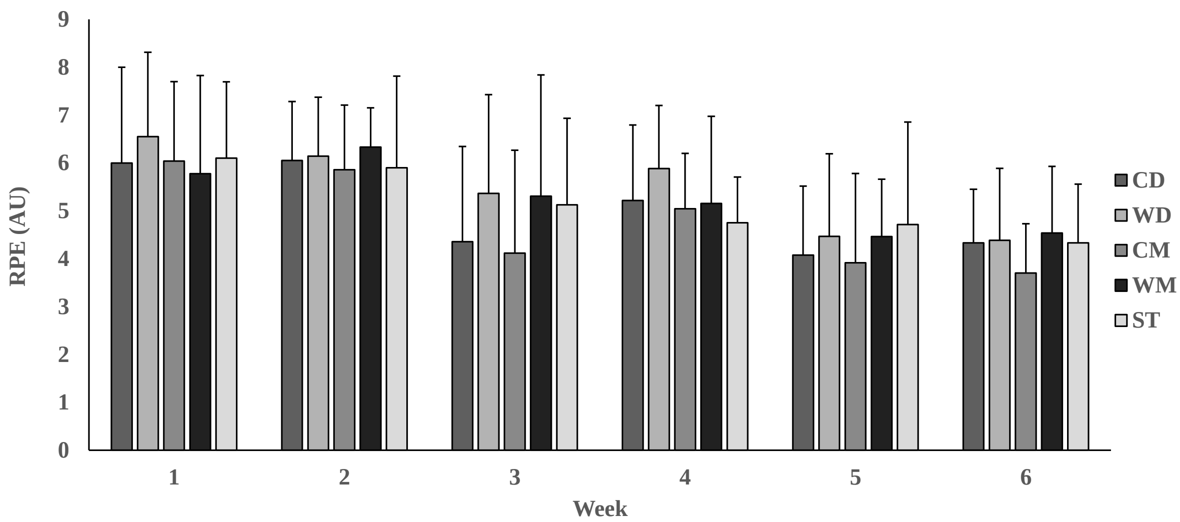
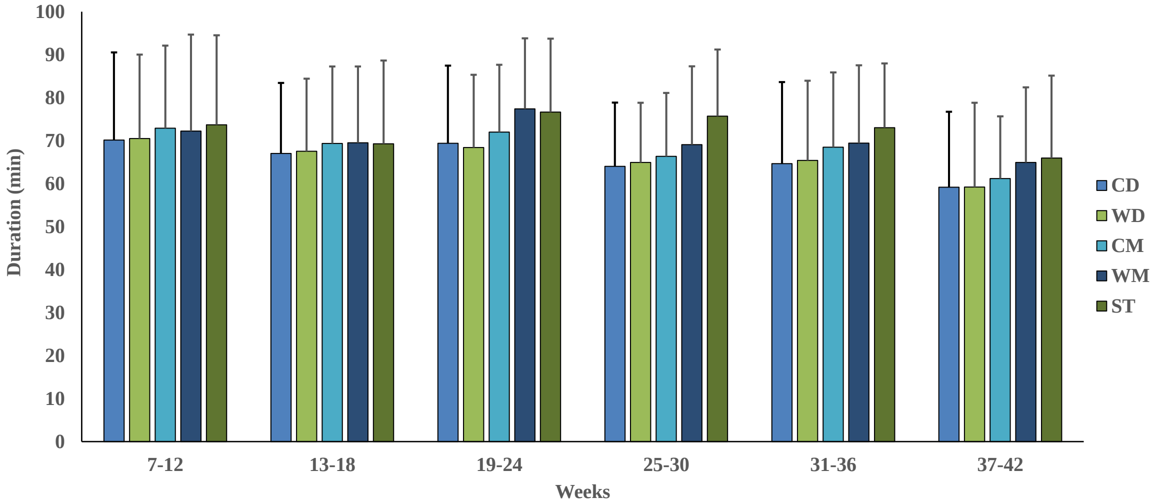



**Figure 5.2.** Training load data represented across 6 x 1 week microcycles during the pre-season phase between positions. a) duration; b) total distance; c) average speed; d) high speed distance; e) average heart rate; f) RPE. **#** denotes CM sig. difference vs. CD and ST; **$** denotes WD sig. difference vs. ST and CD; CD = Central defenders; WD = Wide defenders; CM = Central midfielders; WM = Wide midfielders; ST = Strikers.

### 5.3.2. IN-SEASON MESOCYCLE ANALYSIS

The training load data represented across 6 separate six week mesocycle periods is represented in Figure 5.3. There was a significant random effect (i.e. estimate of variances) found between individual players and training sessions across the separate periods for all variables with the exception of high speed distance ($P < 0.05$). Total distance values were significantly higher at the start of the competitive season compared to the end ($P = 0.04$). Average HR values were significantly higher in weeks 19-24 compared to weeks 7-12 ($P = 0.04$). CM players covered significantly more total distance and had a higher average speed compared to all other positions except for WD ($P < 0.05$). WD players reported significantly higher total distance values compared to CD ($P = 0.02$) and ST ($P = 0.01$). Differences were also found between WD and ST for average speed ($P = 0.01$). CD players covered significantly lower high speed distance compared with all other positions ($P < 0.05$). CD and WD players reported higher average HR values compared to ST ($P = 0.01$ and $P = 0.02$, respectively). CD and WD players also reported higher RPE values compared to CM and WM players ($P < 0.05$).

a)



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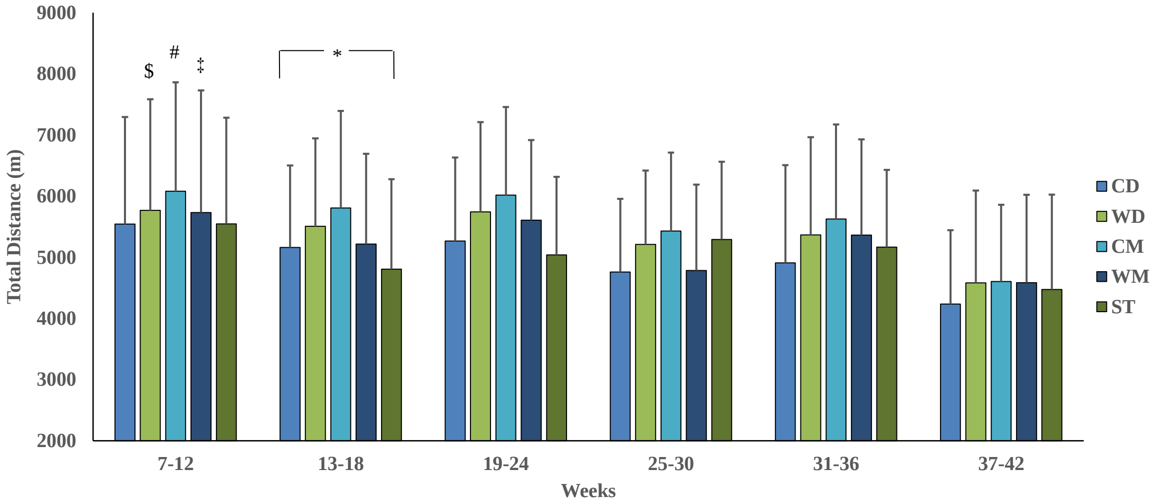
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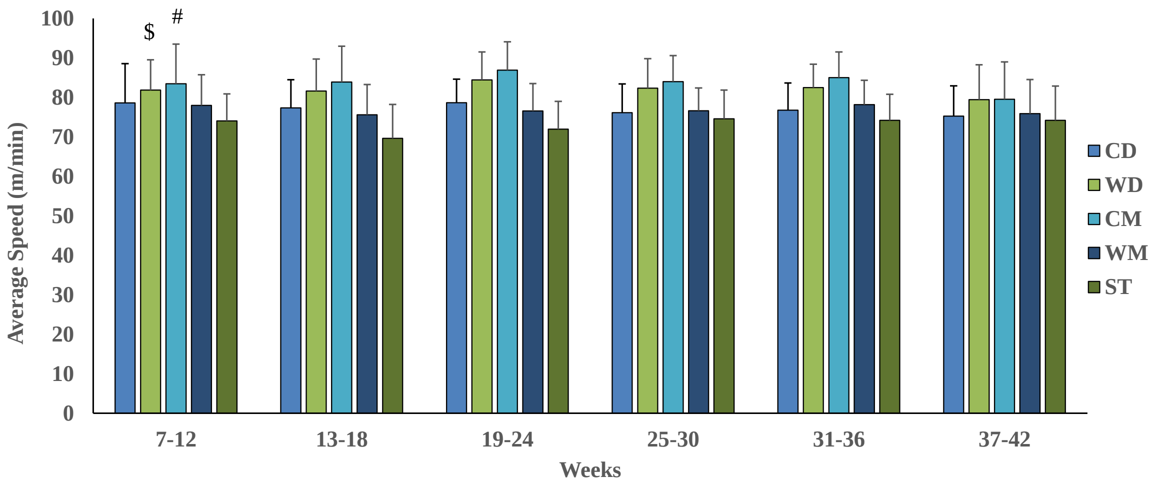
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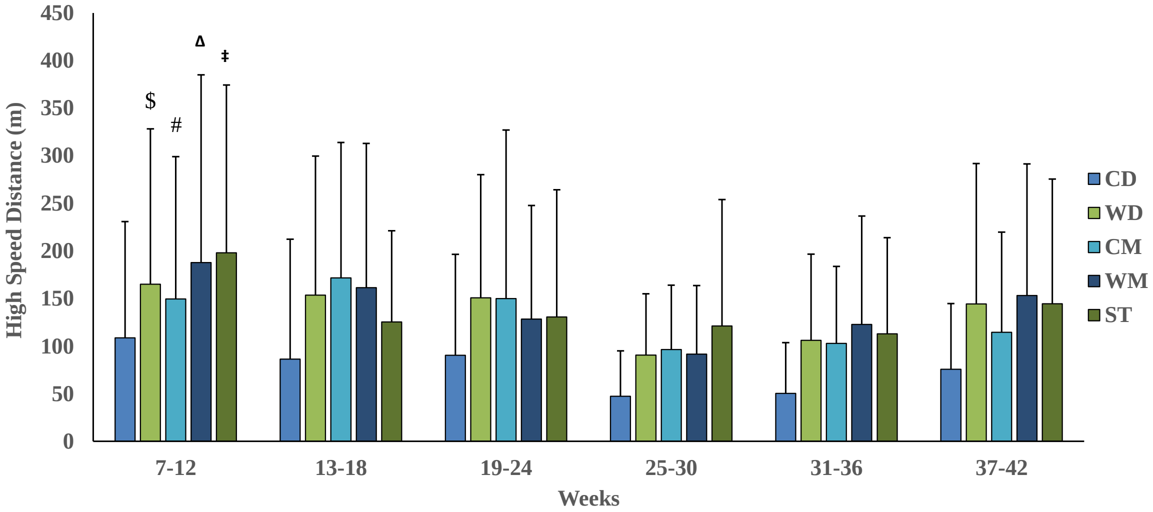

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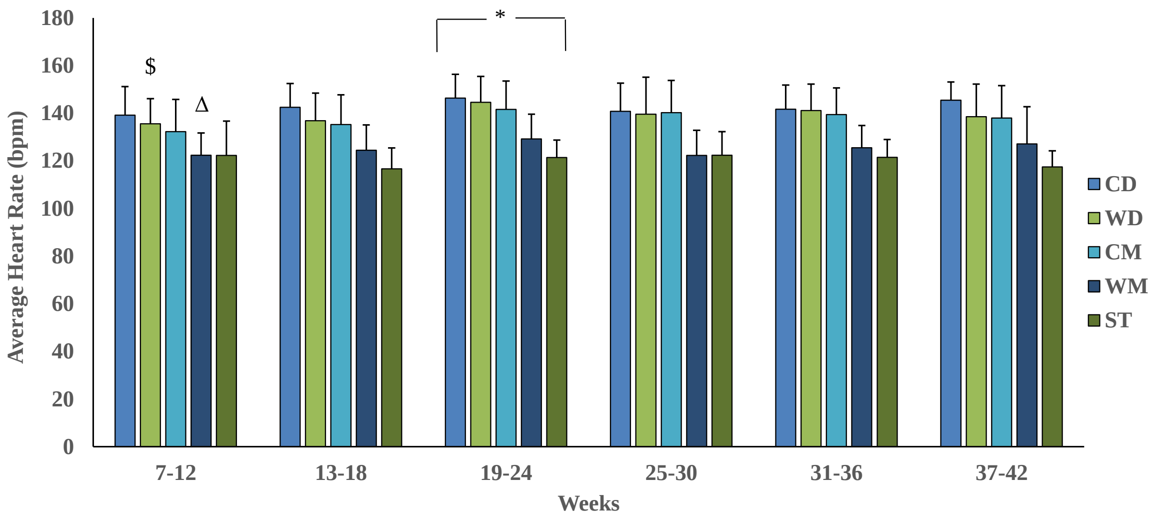

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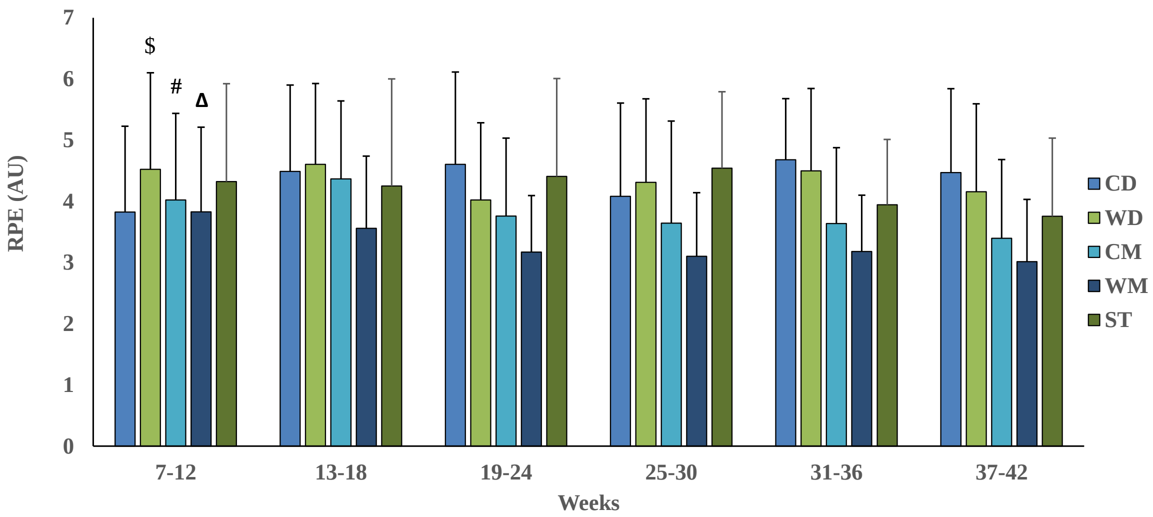



**Figure 5.3.** Training load data represented across 6 separate six week mesocycle periods during the in-season phase between positions. a) duration; b) total distance; c) average speed; d) high speed distance; e) average heart rate; f) RPE. ***** denotes sig. difference with weeks 7-12; **#** CM sig. difference vs. all other positions; **$** WD sig. difference vs. CD, WM, ST; **‡** ST sig. difference vs. CD, WM; **Δ** WM sig. difference vs. CD; CD = Central defenders; WD = Wide defenders; CM = Central midfielders; WM = Wide midfielders; ST = Strikers.

### 5.3.3. IN-SEASON MICROCYCLE ANALYSIS

The training load data represented across 3 separate one week microcycles during the in-season phase between positions is presented in Table 5.1. There was a significant random effect found between individual players and training sessions across the three different in-season microcycles for duration, total distance RPE ($P < 0.05$). Average HR was significantly lower in week 7 compared to both week 24 ($P = 0.01$) and week 39 ($P = 0.01$). CM players covered higher total distance compared to CD ($P = 0.01$) and ST ($P = 0.02$), with higher average speed compared to ST also ($P = 0.04$) for all analysis. WM players covered a higher amount of high speed distance across the different microcycles compared to CD ($P = 0.01$). CD players recorded a higher average HR response compared to WM players ($P = 0.01$).

**Table 5.1.** Training load data represented across 3 separate one week microcycles during the in-season phase between positions. a) duration; b) total distance; c) average speed; d) high speed distance; e) average heart rate; f) RPE. ***** denotes week 7 sig. lower values vs. week 24 and week 39. **#** denotes CM sig. difference vs. CD and ST; **Δ** denotes WM sig. difference vs. CD; CD = Central defenders; WD = Wide defenders; CM = Central midfielders; WM = Wide midfielders; ST = Strikers.

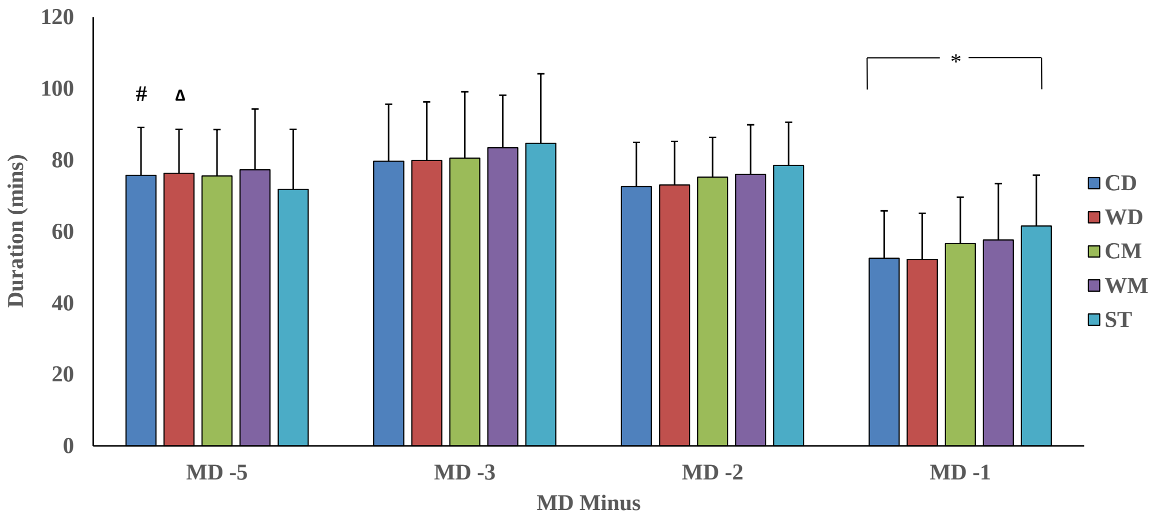
| Period/ Position | Duration (mins) | Total Distance (m) | Average Speed (m/min) | High Speed Distance (m) | Average HR (bpm) | RPE (AU) |
|---|---|---|---|---|---|---|
| **Week 7** | | | | | | |
| CD | 74 ± 28 | 6066 ± 1885 | 78 ± 10 | 190 ± 202 | 138 ± 10 * Δ | 4 ± 2 |
| WD | 71 ± 27 | 6024 ± 1990 | 84 ± 8 | 224 ± 223 | 133 ± 9 * | 5 ± 2 |
| CM | 76 ± 25 | 6426 ± 1804 # | 85 ± 10 | 234 ± 225 | 128 ± 12 * | 4 ± 1 |
| WM | 77 ± 26 | 6265 ± 1936 | 80 ± 6 | 293 ± 262 Δ | 121 ± 7 * | 4 ± 1 |
| ST | 78 ± 28 | 5780 ± 1823 | 74 ± 5 | 303 ± 258 | 126 ± 15 * | 5 ± 1 |
| **Overall** | **76 ± 24** | **6182 ± 1841** | **81 ± 9** | **243 ± 229** | **129 ± 12 *** | **4 ± 1** |
| **Week 24** | | | | | | |
| CD | 70 ± 15 | 5719 ± 1066 | 82 ± 5 | 169 ± 186 | 151 ± 8 | 6 ± 2 |
| WD | 72 ± 15 | 6274 ± 1201 | 88 ± 4 | 237 ± 195 | 149 ± 8 | 4 ± 1 |
| CM | 73 ± 13 | 6515 ± 1065 | 89 ± 6 | 271 ± 283 | 146 ± 12 | 5 ± 2 |
| WM | 74 ± 13 | 6148 ± 1105 | 83 ± 4 | 217 ± 169 | 136 ± 4 | 4 ± 1 |
| ST | 73 ± 14 | 5602 ± 1111 | 80 ± 5 | 244 ± 224 | 127 ± 7 | 6 ± 2 |
| **Overall** | **76 ± 13** | **6105 ± 1121** | **85 ± 6** | **225 ± 213** | **144 ± 12** | **5 ± 2** |
| **Week 39** | | | | | | |
| CD | 58 ± 21 | 4203 ± 1514 | 75 ± 5 | 75 ± 80 | 148 ± 8 | 4 ± 1 |
| WD | 60 ± 16 | 4815 ± 1403 | 81 ± 7 | 137 ± 92 | 140 ± 10 | 5 ± 1 |
| CM | 62 ± 22 | 4911 ± 1669 | 82 ± 5 | 161 ± 121 | 146 ± 11 | 4 ± 1 |
| WM | 62 ± 23 | 4616 ± 1634 | 77 ± 5 | 179 ± 103 | 131 ± 10 | 3 ± 1 |
| ST | 67 ± 26 | 4866 ± 2102 | 76 ± 9 | 184 ± 105 | 120 ± 5 | 4 ± 1 |
| **Overall** | **60 ± 20** | **4714 ± 1581** | **79 ± 7** | **146 ± 104** | **138 ± 13** | **4 ± 1** |

### 5.3.4. IN-SEASON MATCH DAY MINUS TRAINING COMPARISON

The training load data completed on a training day in respect to the number of days prior to a competitive match during the in-season phase between positions is represented in

Figure 5.4. There was a significant random effect found between individual players and training sessions across each of the MD minus training days for all variables with the exception of high speed distance ($P < 0.05$). MD-1 displayed significantly lower values compared with MD-2 for all variables with the exception of high speed distance ($P < 0.05$). MD-1 also displayed significantly lower values compared to MD-3 for all variables ($P < 0.01$). MD-5 displayed higher values compared to MD-1 for duration, total distance, high speed distance and RPE ($P < 0.01$). WM and ST players displayed higher values for duration compared to CD ($P = 0.02$ and $P > 0.01$, respectively) and WD ($P = 0.04$ and $P = 0.01$, respectively) across all four training day types. CM players covered higher total distance compared to CD ($P < 0.01$). Defenders generally reported higher RPE values, with higher values evident for WD compared to CM ($P = 0.02$) and WM ($P < 0.01$) and for CD compared to WM ($P < 0.01$).

a)



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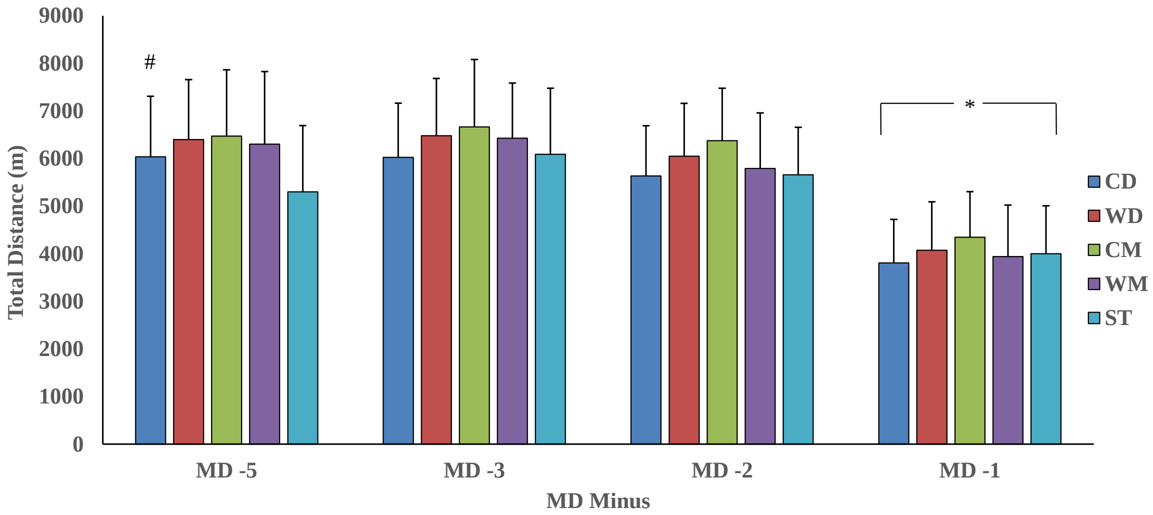

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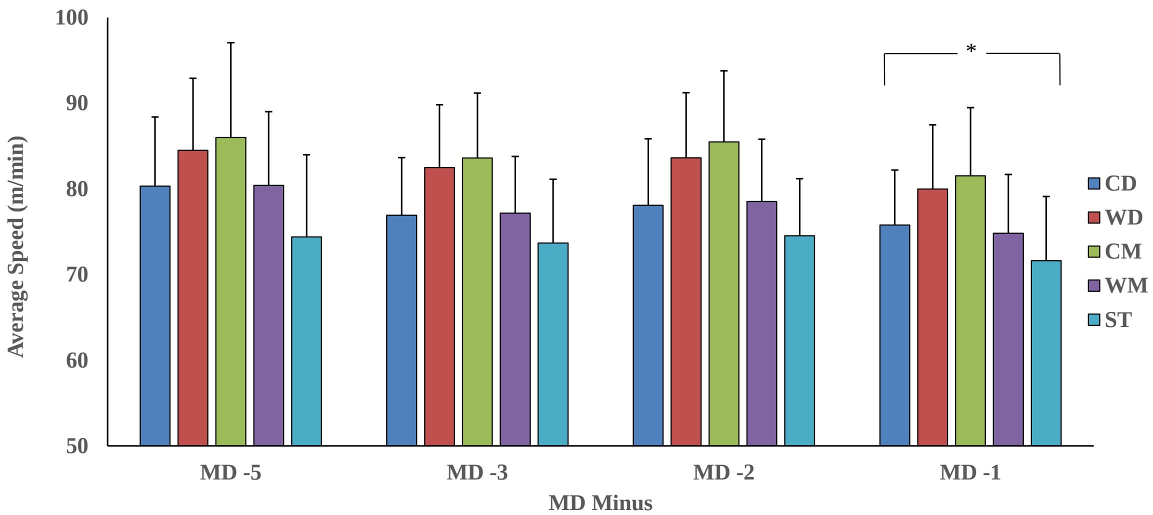

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MD Minus

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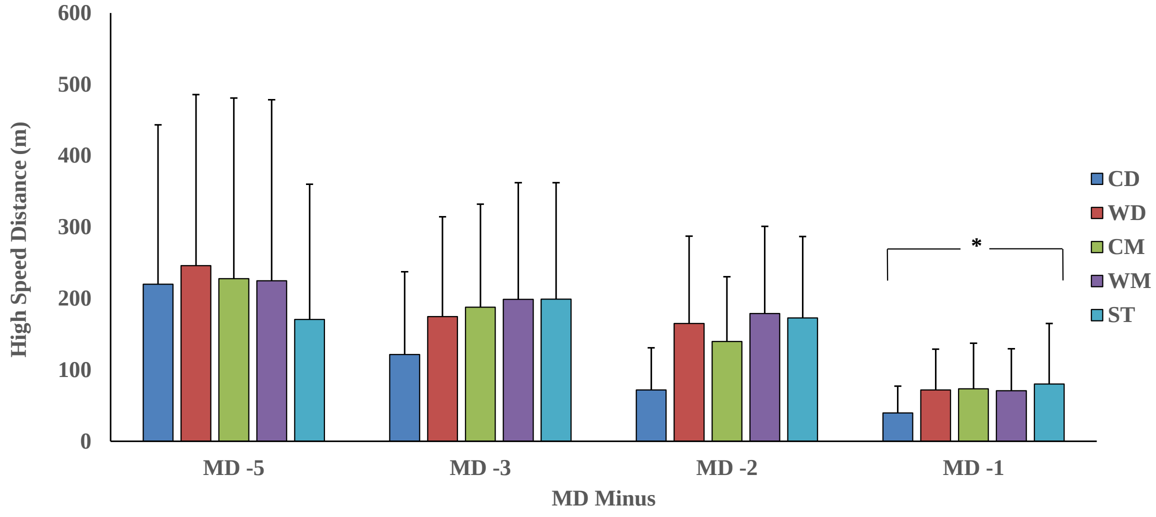
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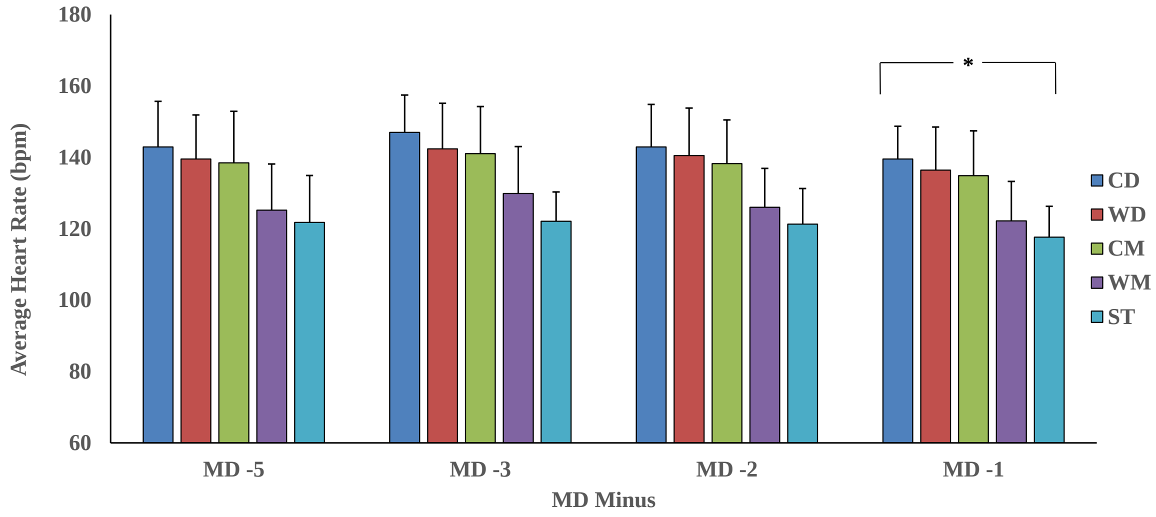
MD Minus

e)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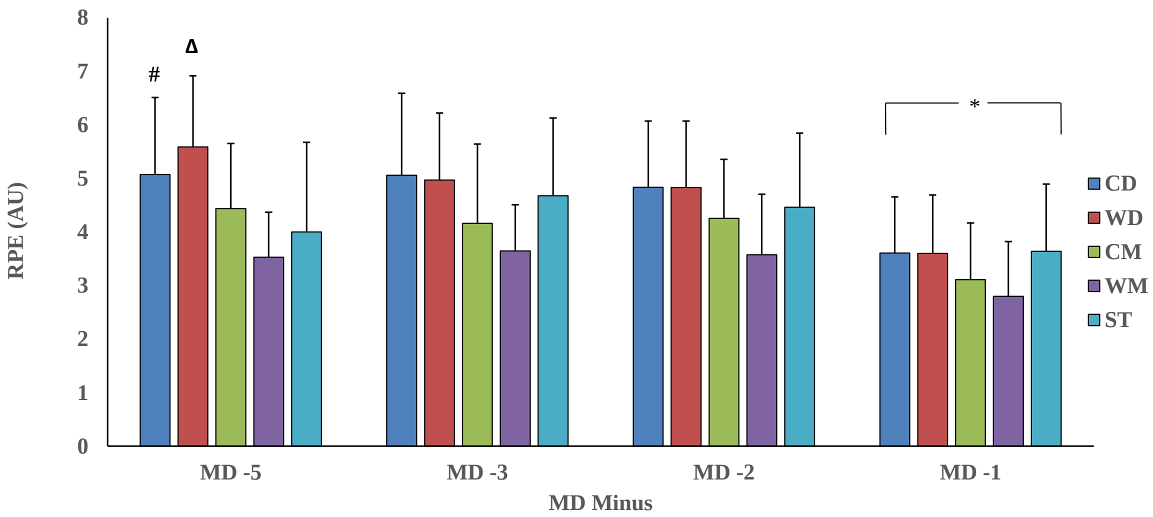



**Figure 5.4.** Training load data represented on training day in respect to days prior to a competitive match during the in-season phase between positions. a) duration; b) total distance; c) average speed; d) high speed distance; e) average heart rate; f) RPE. ***** MD-1 sig. difference vs. MD-5, MD-3 and MD-2; **#** CD sig. difference vs. CM, WM and ST; **Δ** WD sig. difference vs. CM, WM and ST. CD = Central defenders; WD = Wide defenders; CM = Central midfielders; WM = Wide midfielders; ST = Strikers.

## 5.4. DISCUSSION

The aim of this study was to quantify and evaluate the training loads employed by an elite professional soccer team across a competitive season. During the pre-season phase, CM and WD players covered significantly more total distance and reported a higher average speed compared to CD and ST players. During the in-season phase CM players also covered the highest total distance, with defenders (CD and WD) displayed a higher internal load response (average HR and RPE) during both mesocycle and microcycle periods. In addition, CD players covered significantly less high speed distance compared to all other positions across 6 week mesocycle periods. Despite finding significant differences between positions, there was no difference observed in training load variables across weekly microcycles during the pre-season phase. Analysis also revealed limited variation in training load variables across the majority of in-season mesocycles and microcycles. It is important to acknowledge that due to the vast amount of data collection points across the season, missing data occurred throughout the data collection period. However mixed linear modelling was used to analyse the dataset as it can cope with missing data from players and unbalanced designs (Cnaan et al. 1997). Overall, the findings of the present study were in agreement with the original hypothesis, with variation in training load limited during both the pre-season and in-season phases.

The emphasis during pre-season is on the rebuilding of fitness parameters following the detraining that occurs during the off-season (Reilly 2007). During this period, both the external and internal load prescribed by soccer coaches surpasses that observed during the in-season phase (Jeong et al. 2011). Such training patterns dramatically increase the training demands and physiological stress associated during this phase (Goto et al. 2007). When analysing the training loads across six weekly microcycles during the pre-season phase, no significant differences were observed across the 6 separate weeks. At present, limited information is available describing the variation in pre-season microcycles using objective data. The number of sessions observed during the pre-season phase in the present study was less than previously reported for professional Italian soccer players (Castagna et al. *In Press*). The differences between studies may be due to the number of friendly matches played during this phase. Castagna et al. (*in press*) reported the Italian team only played one match per week, whereas in the present study the team played two matches per week in 2 of the 6 weekly microcycles. This suggests that the number of friendly matches may influence the number of training sessions that a team may undertake during pre-season. This is evident during the different microcycles, with players undergoing more training sessions in the first week of pre-season compared to the final week (8 vs. 4 sessions) when no matches were played during the first week. There were also no double training sessions employed in week 6 compared to two days of double sessions in week 1. Despite the differences observed in terms of the number of training sessions employed, both the external and internal training load remain similar across the pre-season phase. This may be due to the type of training employed on days in which double training sessions occurred. The first session was often high in terms of training volume and intensity with a physical emphasis, whereas the second training session was designed for tactical development at a lower training threshold. Therefore this resulted in the overall training load being similar across each microcycle regardless of whether it contained double sessions. This highlights the importance of using objective data to analyse training periodisation as limited information is available to the coach when descriptive information is used only (i.e. number of training sessions).

During the in-season phase, the emphasis of training reverts to technical and tactical development and the maintenance of the physical capacities developed during pre-season (Reilly 2007). Previous research has shown that both the number of training sessions and the physiological response is reduced during the in-season phase compared to pre-season (Jeong et al. 2011). In the present study, we investigated the training load pattern across 6 week mesocycle blocks during the in-season phase of a competitive season. There were some marked differences observed across the different mesocycles during the season. It was observed that the players covered more total distance at the start compared to the final mesocycle of the season (5734 vs. 4495m). As mentioned previously, the structure of training periodisation during the mesocycles may be influenced by external factors, such as the number of matches played during a period. However it is important that soccer coaches periodise soccer training appropriately during the available time to elicit physical fitness maintenance or improvement longitudinally. The limited variation in training load variables across a season observed in the present study may have a negative influence on achieving such physical objectives. Previous research has suggested that a lack of variation in training over a longitudinal period may lead to training monotony and subsequently increase the risk of illness and overtraining (Foster 2001). This research highlights the importance of structured training periodisation in which the training load is varied to avoid training monotony and strain (Foster 1998). This is the first study, to the author's knowledge, that has analysed objective data for the evaluation of training mesocycles during a competitive season in elite soccer players. The findings would suggest that training load variation is limited at different points of the season.

In soccer, training planning and periodisation is typically structured around weekly microcycles during the in-season. Microcycles are considered the most important functional planning tool in the overall training process (Stone et al. 2007). The present study compared three separate microcycles at the start (week 7), midpoint (week 24) and end (week 39) of the in-season phase. This analysis was conducted in order to determine whether microcycle structure varied across different points of a season. Data analysis revealed a lack of variation in training load variables in weekly microcycles across all three time points of the season. The only training load variable that showed marked differences was average HR. It was found that average HR that was lower in players at the start (129 bpm) compared to mid (142 bpm) and end points (137 bpm) of the season. This suggests that the internal training load response increased from the mid to end points of the season for a similar amount of external training load. This may be due to a lack of adaptation occurring over time due to the monotonous external training loads employed or possibly an accumulation of fatigue across the season (Foster 1998). The findings are conflicting to those reported in previous studies in which internal load is reduced as the season progresses due to physiological adaptation (Miloski et al. 2012). Another possible explanation may be due to the way in which the training stimulus was presented across each specific microcycle. Although the overall external training load was similar across each time point, the specific training drills used to generate the loading may elicit different HR responses. Hill-Haas et al. (2009) reported an increased HR response when the number of players was reduced in SSG. Alternatively it could be suggested that the physical fitness of the players was reduced as the season progressed due to the monotonous training loads employed. Therefore, it appears that despite similar external loading (i.e. GPS variables) across all three individual microcycles, the increase in internal loading (i.e. HR) suggests a decrease in cardiovascular conditioning. This was evident despite the lack of change in RPE scores, suggesting that the particular drills selected in each individual microcycle resulted in an increased HR response but not in perceived effort from the players.

As highlighted previously, microcycle planning is a tool that is mainly utilised by soccer coaches in order to periodise soccer training. In elite teams, the structure and content of each training session can be expressed in terms of the number of days prior to the next competitive match (i.e. MD minus) (Impellizzeri et al. 2005). In the present study, in-season microcycles were analysed following such an approach in order to evaluate the influence of daily training loading on overall microcycle periodisation. It was observed that training load was significantly reduced on MD-1 (i.e. the day before a match) with no differences observed across the remaining training days (MD-2, MD-3 and MD-5). This finding conflicts with the data presented by Impellizzeri et al. (2005) in which there was a gradual increase followed by reduction in training load in the two days leading into a competitive match. However these author’s only used RPE load as a measure of overall training load and didn’t include objective training load data in the analysis. It would appear in the present study that the coaches employed similar training loads on the majority of training days, then attempted to unload on MD-1 in order to limit fatigue leading into the match. It is questionable whether reducing the load in this way will actually reduce the amount of fatigue and allow for maximal preparation leading into a match. The majority of research relating to unloading refers to individual sports, in which training load is reduced between 7 – 28 days prior to competition, which is not relevant to soccer (Mujika et al. 2004). At present no research has been conducted to determine whether unloading one day before a match, as observed in the present study, has a positive or negative effect on physiological performance. As described previously, the lack of variation in training load on MD-5 to MD-2 may lead to high levels of training monotony and performance staleness. Therefore it would appear that there is a lack of variation in training load across in-season microcycle with respect to days prior to a match.

Despite the limited variation in overall training load across both the pre-season and in-season phases, positional differences were found across all training phases. Attacking players (CM, WM and ST) generally displayed higher total and high speed distance covered, with defenders (CD and WD) having a higher average HR and RPE response. Both WD and CM players' recorded higher average total distance (7023 and 7145m) and average speed (83.2 and 85.3 m/min) values across pre-season microcycles. CM players also covered the highest total distance and average speed (5594m and 83.8 m/min), with CD players covering the lowest high speed distance (76m) across in-season mesocycles. Defenders (CD and WD) displayed a higher internal training load response (average HR and RPE) compared to attacking players (CM, WM and ST) across in-season mesocycles. Such findings are unsurprising as such differences between positions have also been observed in match situations (i.e. CM players covering highest total distance) (Bradley et al. 2009). Therefore it would appear that the training load employed may at least be specific for each position. However it is unclear whether such differences were intentionally planned through training structure or whether individual players may have surpassed the expected loading for specific training sessions.

This is the first study to systematically quantify training loads employed by an elite professional soccer team across a competitive season using objective data. The study revealed that both external and internal training load was similar across both mesocycles and microcycles during the pre-season and in-season phases. Such findings have practical implications for training planning and organisation. Firstly, if similar training loads are repeated longitudinally, negative adaptations may occur and physiological capacity may be affected in soccer players. Secondly, if such training patterns are utilised and physiological capacity is reduced across a competitive season then this may negatively affect soccer performance in matches. Another aspect to consider relates to the degree of error associated with higher velocity distance covered (i.e. high speed distance) reported in Chapter 3 of the present thesis. Despite no significant differences reported for both pre-season and in-season (with the exception of MD-1 for match day minus analysis), a high amount of variation was observed within each player position. This variation may be due to the high error rates reported (16.8 – 33.6 CV% for distance covered > 7 m/s). Therefore, it must be noted that the outcomes from the present chapter relating to high speed running should be interpreted with caution. Future work should aim to develop and analyse periodisation strategies specific to soccer as it appears current guidelines developed in traditional periodisation models cannot be applied directly to soccer.

# CHAPTER 6

# EFFECT OF A MICROCYCLE OF SOCCER TRAINING ON THE NEUROMUSCULAR RESPONSE TO EXERCISE IN ELITE YOUTH SOCCER PLAYERS

## 6.1. INTRODUCTION

The complex structure of fixture scheduling in elite level soccer places significant demand on soccer players throughout a competitive season (Dupont et al. 2010). Due to competitive matches being played up to three times per week, it is crucial that the physiological response to soccer training in preparation for matches is fully understood. In a typical week for a professional soccer team with one match to play, the players may have up to five training sessions in five days with the day after the match free (Bangsbo et al. 2006). If there is a second match in midweek the team may only train three times per week, with this training consisting of lower volume/intensity content (Bangsbo et al. 2006). The weekly training may, however, show marked variations depending on the training methodology employed by the soccer coach. Little information is currently available relating to such training regimens in preparation for a soccer match.

The microcycle phase is often crucial for training load management in soccer teams due to the requirement to prepare for multiple matches during this phase. Absence in training variation during the microcycle phase may lead to training monotony which has been associated with markers of the overtraining syndrome (Foster 1998). Conversely, if the training load employed was above the rate of recovery between matches then this would also increase the risk of fatigue and overtraining (Rietjens et al. 2005). The detrimental effects of maladaptive training may impact the neuromuscular system, resulting in impaired capacity to exert explosive-type soccer actions (Thorlund et al. 2009). Previous research has examined the neuromuscular response during between-match training microcycles in professional rugby league (McLean et al. 2010). However no study has examined the response in elite soccer in which the opportunity for microcycle management is limited due to the large volume of competitive matches.

Changes in neuromuscular function have previously been monitored in soccer match play using a CMJ test (Andersson et al. 2008; Hoffman et al. 2003; Mohr et al. 2010). The CMJ test is a proxy functional assessment of neuromuscular status that can be easily applied in the field without the requirement of laboratory testing. Previous work in Chapter 4 of the thesis revealed that CMJ assessment using a portable measurement tool (Optojump®) demonstrated excellent reliability and validity (CV < 5%). Therefore the use of such an applied assessment may be useful to monitor the neuromuscular response to a microcycle of soccer training.

At present, no study has examined the neuromuscular response to multiple training bouts in professional soccer players. Therefore the purpose of this study was to determine the effects of a microcycle of soccer training on the neuromuscular response to training load using CMJ testing in elite male soccer players.

## 6.2. METHODS

### 6.2.1. SUBJECTS

Nine elite level male youth soccer players were recruited to participate in the study. All players were part of an U18 soccer team within an elite soccer academy. Of these players, 7 players have represented their respective countries at international level. The physical characteristics of the players (mean ± SD) were as follows: age 16 ± 1 yr; height 178 ± 6 cm; body mass 71 ± 9 kg; Yo-Yo Intermittent Recovery Test Level 2 Score 29 ± 5 level; 10m sprint 1.77 ± 0.08 secs. Written informed consent was given by each player, with the study being approved by the University Ethics Committee of Liverpool John Moores University.

### 6.2.2. EXPERIMENTAL DESIGN

The study was carried out during the in-season competitive period. Data collection was carried out between March – April during the 2012-2013 season. The design of the study utilised one microcycle of soccer training. The players underwent four separate on-field soccer training sessions. An outline of the design and experimental testing is represented in Figure 6.1. Prior to the experimental period, all players were familiarised to perform a CMJ without arm swing. Familiarisation was complete when the player recorded a plateau (i.e. similar consecutive values) in jump variables values in consecutive trials following a minimum of 3 trials. The jump variables selected for analysis in the present study were jump height and flight time. The number of sessions required for jump familiarisation ranged between 3 ± 1 trials. During the microcycle of soccer training, players performed a CMJ both pre and post each soccer training session. This design was employed to measure any potential changes in jump performance as a subsequent of each training session and across the microcycle. The content of each training session was determined by the coach and fitness coach of the team in line with the physical, tactical and technical objectives for each given session. The session content was not controlled throughout the study. Training sessions included physical, technical, possession, tactical and SSG drills. Training load was quantified for each session using the same methods employed in the previous chapter of the present thesis. This included use of GPS, HR and RPE. All soccer training and testing was carried out at the soccer club's academy training facilities.

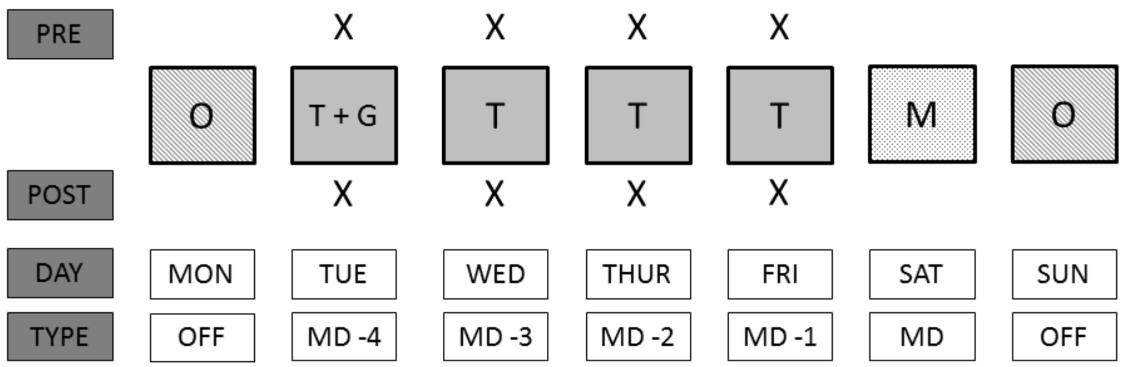



**Figure 6.1.** Outline of the experiment design. T = Training day; G = team gym session; M = competitive match; O = day off; MD = match day; X = CMJ assessment.

### 6.2.3. JUMP TESTING

When performing the CMJ, players were instructed to start in an upright standing position with hands placed on their hips. They were then asked to flex their knees to approximately 90 degrees as quick as possible and then jump as high as they could whilst ensuring their knees were not in a flexed position at the end of the jump phase. For each trial players completed 3 separate jumps with a rest interval of 30 seconds between repetitions. The highest jump was selected from the 3 repetitions for each trial for analysis. Any jumps that didn't follow the CMJ instructions (e.g. flexed knees at end of jump) or landed outside of the jump area were excluded from analysis and players were asked to perform an additional jump. The CMJ testing data was collected using Optojump photoelectric cells (Microgate, Bolzano, Italy). The cells were placed approximately 1m apart parallel at floor level. This equipment has been previously deemed reliable and valid from investigations in this thesis (see chapter 3) and other research (Glatthorn et al. 2011).

All players completed the CMJ pre and post training using the same procedures outlined above. All testing was performed in an indoor gym training facility. This provided a consistent stable flooring to minimise the influence of external factors (e.g. weather, foot-surface interaction). All players performed pre-testing approximately 45-60 minutes prior to the outdoor training session. The timing of pre-testing was not deemed a major factor to control as no exhaustive activity was performed prior to each training session for all players. Post-testing was then carried out immediately following the end of the training session. Post testing was completed around 5 minutes following completion of the session.

### 6.2.4. TRAINING LOAD QUANTIFICATION

Each player wore a 10Hz GPS device (Viper, Statsports®, Ireland) worn inside a custom made vest supplied by the manufacturer. Previous work in this thesis (chapter 2) has deemed 10Hz GPS devices to demonstrate good reliability (CV < 5%) for soccer-specific movements for selected variables (total distance, average speed, max speed). The weather (for satellite coverage) during the outdoor training sessions varied from clear skies to mild clouds. The number of satellites connected was 9.5 ± 0.5 during all outdoor training data collection. The same GPS data collection procedures were employed as those in chapter 2 of the thesis. The variables selected for analysis were determined from the previous reliability data from chapter 2 of the thesis on 10Hz GPS devices and were those employed in the previous chapter. High speed distance covered (distance covered above 5.5 m/s) was selected despite chapter 2 revealing poor levels of reliability (CV > 10%) as it was unknown whether the difference in the data were above the degree of variability associated with the variable. A technical fault with the GPS devices on one session resulted in the failure to collect data from 4 subjects during this training session. These subjects were excluded from the analysis of training load and jump performance in this session.

Players were also instructed to wear a portable HR belt (Polar T31, Polar Electro, Kempele, Finland). Average HR was calculated for all training sessions. Following each training session players were asked to report their RPE score using the modified Borg scale developed by

Foster et al. (2001). All players regularly used this scale to record subjective training load during sessions. Players were prompted individually using a laminated RPE scale sheet for guidance. This was in order to prevent external factors influencing the players score (Burgess & Drust 2012). The RPE score was collected within 15 minutes of the end of each training session for all players.

### 6.2.5. STATISTICAL ANALYSIS

In order to determine the differences for each training load variable (duration, total distance, average speed, high speed distance, average HR and RPE) across the microcycle, a one-way repeated measures ANOVA was employed. In the event of a significant F-ratio value being revealed, a Bonferroni *post hoc* test was used to determine the level of significance. To asses for differences in the absolute pre- to post-training session jump performance changes across the microcycle, a one-way repeated measures ANOVA was used for each jump performance variable (flight time and jump height) with training day (MD-4, MD-3, MD-2, MD-1) set as the independent variables. Pre-session jump performance was also compared across training days using a one-way repeated measures ANOVA. The relationships between the training load variables and the absolute changes in pre-to-post jump performance for jump flight time and height were analysed for all training sessions using Pearson product-moment correlation coefficients. All analyses were performed using SPSS for Windows version 18 (SPSS Inc., Chicago, IL, USA). Statistical significance was set at $P < 0.05$ for all tests used. Data is represented as mean ± SD.

## 6.3. RESULTS

### 6.3.1. TRAINING LOAD WEEKLY DATA

The training load during the microcycle leading into a competitive match is presented in Table 6.1. There were significantly higher values observed on MD-3 compared to MD-4 and MD-1 for average speed and RPE ($P < 0.05$). Significant differences were also found between MD-3 and MD-1 for total distance ($P = 0.008$) and average HR ($P = 0.027$). In addition, significantly higher values were observed for MD-4 compared to MD-2 and MD-1 for duration and between MD-4 and MD-1 for total distance ($P < 0.05$). There was no significant difference observed between training sessions for high speed distance ($P > 0.05$).

**Table 6.1.** Training load data for soccer training sessions observed during a week of periodised training in respect to days prior to a competitive match (mean ± SD).

| **Training Load Variable** | **MD -4** | **MD -3** | **MD -2** | **MD -1** |
|---|---|---|---|---|
| Duration (min) | 103 ± 5 | 81 ± 8 | 76 ± 7 * | 60 ± 0 * |
| Total Distance (m) | 5442 ± 619 | 5212 ± 590 | 4625 ± 688 | 3688 ± 225 * **$** |
| Average Speed (m/min) | 53.1 ± 4.1 | 65.5 ± 5.1* | 61.2 ± 8.2 | 53.6 ± 3.3 **$** |
| High Speed Distance (m) | 106 ± 15 | 71 ± 73 | 44 ± 29 | 36 ± 37 |
| Average HR (bpm) | 136 ± 4 | 145 ± 7 | 130 ± 6 | 131 ± 2 **$** |
| RPE (AU) | 3 ± 0 | 4 ± 1* | 3 ± 1 | 3 ± 1 **$** |

***** denotes sig. difference between MD -4 and MD -3, -2 and -1; **$** denotes sig. difference between MD -1 and MD -3; For all significance $P < 0.05$.

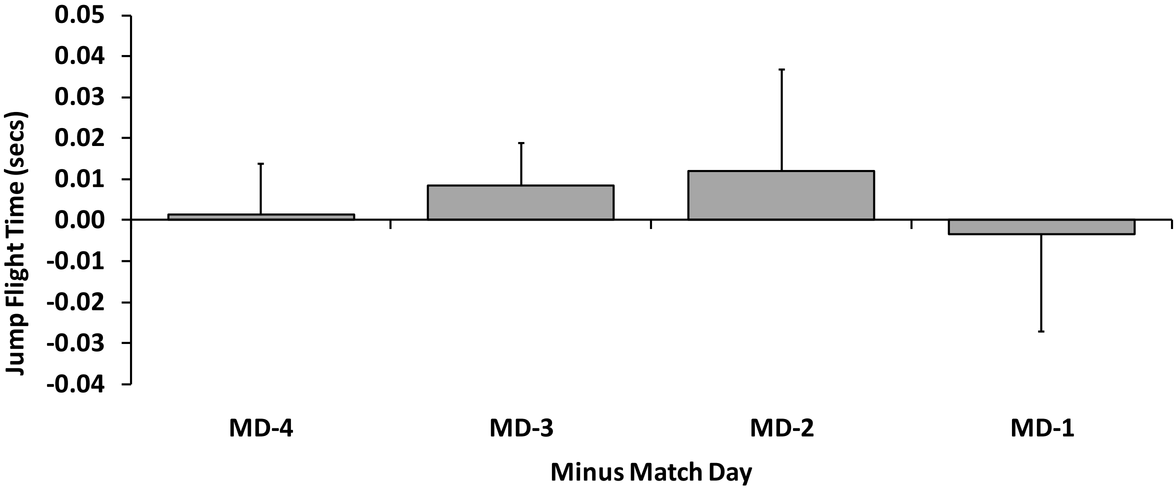
### 6.3.2. JUMP PERFORMANCE

The jump performance data measured both pre and post each individual session across the training microcycle is represented in Table 6.2. There was no significant difference for the absolute change in jump performance pre to post training for either flight time ($P = 0.224$) and jump height ($P = 0.234$) (Figures 6.2a and 6.2b, respectively) on MD-4 (0.001 ± 0.012 secs and 0.2 ± 1.5 cm), MD-3 (0.008 ± 0.010 secs and 1.0 ± 1.4 cm), MD-2 (0.012 ± 0.025 secs and 1.4 ± 2.9 cm) and MD-1 (-0.003 ± -0.024 secs and -0.5 ± -3.2 cm). There was also no significant difference in pre-session jump performance across the microcycle ($P > 0.05$).

**Table 6.2.** Jump variable data measured pre and post each individual training session across the microcycle (mean ± SD).

| Jump Variable | Time Point | MD -4 | MD -3 | MD -2 | MD -1 |
|---|---|---|---|---|---|
| **Flight Time (secs)** | **Pre** | 0.51 ± 0.03 | 0.51 ± 0.04 | 0.52 ± 0.06 | 0.54 ± 0.04 |
| | **Post** | 0.51 ± 0.04 | 0.52 ± 0.04 | 0.53 ± 0.04 | 0.54 ± 0.03 |
| **Height (cm)** | **Pre** | 31.5 ± 4.3 | 32.0 ± 5.0 | 33.2 ± 7.0 | 35.8 ± 5.6 |
| | **Post** | 31.7 ± 4.9 | 33.0 ± 4.5 | 34.6 ± 5.4 | 35.3 ± 4.6 |

a)



b)

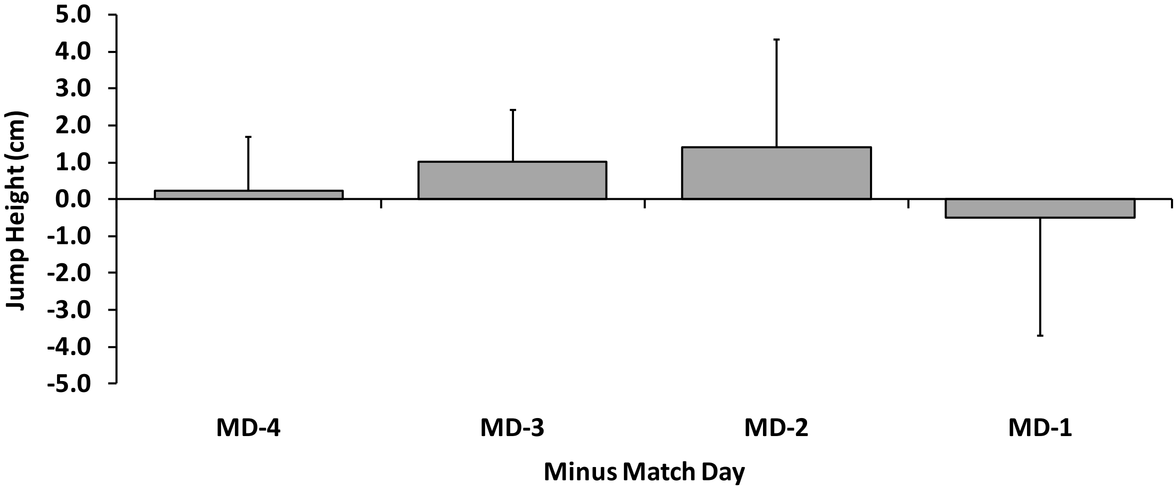



**Figure 6.2.** Absolute change in jump performance during a microcycle represented by training sessions days prior to a competitive match. a) jump flight time; b) jump height; MD = match day.

### 6.3.3. RELATIONSHIP BETWEEN TRAINING LOAD AND CHANGE IN JUMP PERFORMANCE

A summary of the correlations between training load variables and the absolute change in pre to post training values for jump flight time and jump height are presented in Table 6.3. There were no significant correlations found between flight time and all training load variables ($P > 0.05$). Correlations were also found to be non-significant ($P > 0.05$) between all training load variables and jump height.

**Table 6.3.** Relationship between training load variables and absolute change in pre to post values of jump parameters following a week of periodised soccer training.

| | Jump Flight Time | | Jump Height | |
|---|---|---|---|---|
| **Training Load Variable** | **Correlation (*r*)** | **Sig.** | **Correlation (*r*)** | **Sig.** |
| Duration (mins) | -0.091 | 0.632 | -0.069 | 0.717 |
| Total Distance (m) | -0.015 | 0.937 | -0.003 | 0.986 |
| Average Speed (m/min) | 0.135 | 0.478 | 0.122 | 0.520 |
| High Speed Distance (m) | 0.221 | 0.240 | -0.208 | 0.269 |
| Average HR (bpm) | -0.088 | 0.643 | -0.063 | 0.740 |
| RPE (au) | -0.165 | 0.383 | -0.153 | 0.419 |

## 6.4. DISCUSSION

This study aimed to investigate the neuromuscular response to multiple soccer training sessions across a typical microcycle planned in preparation for a competitive match. The present findings revealed no significant difference in jump performance across this time period. Analysis also revealed no relationship between absolute change in jump performance and training load as indicated by a number of variables. This was despite significant differences in training load across the different stages of the microcycle. These findings suggest that neuromuscular status is unaffected in soccer players during a typical microcycle of training.

An analysis of the representativeness of the training loads completed by the players in the present study is an important consideration. The participants in the study were elite youth academy players, and as such it is acknowledged that the training carried out may be specific to the population of players used. This limitation may influence the ability of the reader to generalise the findings from this research to other soccer playing populations. The overall training schedule and training session duration was however similar to those observed in Danish, Korean and English professional soccer teams during the in-season periods (Bangsbo et al. 2006; Gaudino et al. In Press; Jeong et al. 2011; Svensson et al. 2007). Measures of external training load (specifically total and high speed distance) using

GPS were also similar to those found in an elite senior English soccer team (Gaudino et al. In Press). The internal training load response, as indicated by average heart rate, was higher in the present study compared to elite senior international and domestic soccer teams (Bangsbo et al. 2006; Jeong et al. 2011). Such findings further suggests that the training loads observed in this study are similar, if not in excess of those reported for other elite soccer players within the literature. This would seem to suggest that the data generated in this investigation may have some generalisability to other populations.

Despite the significant variation in training load variables across the planned microcycle of training, there was no observed change in neuromuscular status measured by CMJ performance. It would appear feasible that one possible defining factor that may alter the neuromuscular status of soccer players is the prescription of soccer training. During the in-season period, the focus of training will predominantly relate to the maintenance of fitness levels as well as ensuring that players are fully recovered in between competitive matches (Reilly 2007). Thus soccer coaches typically employ maintenance training load (i.e. external training load that maximises recovery whilst maintains current physiological status; Viru & Viru 2001) as opposed to the inclusion of training stress designed to physiologically overload the players for fitness improvement. It could be argued, therefore, that the failure to find a reduction in CMJ was a consequence of the soccer players in this study were accustomed to such training loading. Previous studies have reported that CMJ performance significantly improves from the beginning to the end of the pre-season phase (Caldwell & Peters 2009) but remains unchanged from mid-to-end of in-season in professional soccer players (Casajus 2001; Clark et al. 2008). This data, in combination with the findings of the present study, would suggest that the external training load is not sufficient enough to result in an adaptation in neuromuscular physiology in soccer players during the in-season period.

Previous research has demonstrated that CMJ performance is significantly reduced following exhaustive soccer-play (Andersson et al. 2008; Magalhães et al. 2010; Mohr et al. 2010). The reductions observed in these studies may have been due to inhibition of several neural and cellular mechanisms. It has been suggested that following muscle damaging exercise, autogenic inhibition may occur in which the Golgi tendon organs restrict the amount of force produced from the muscle (Kenney et al. 2012). Increase in muscle inosine monophosphate and reduction in adenosine diphosphate concentrations has been found in fatigued muscles (Sahlin et al. 1990) and is implicated in reducing maximal shortening velocity (Cooke & Pate 1985). As there was no change in CMJ performance in the present study on each of the 4 individual training sessions, it would suggest that the soccer training was insufficient to cause alterations in the before mentioned neural and cellular mechanisms. The lack of CMJ change also suggests no adaptation of the neuromuscular system occurred during the microcycle. Bobbert and Van Soest (1994) reported that following training designed to enhance the neuromuscular system, the nervous system must learn to control and transfer the adaptation in neural function to increase SSC function. Hoffman et al. (1990) also found that low-frequency training resulted in minimal development of vertical jump performance. There it may be possible that the frequency and type of training employed in the microcycle of the present study was insufficient to cause an improvement in CMJ performance and adaptation of the neuromuscular system. However the exact mechanisms responsible may only be speculated as they weren't measured directly in the present study.

The lack of change in CMJ performance across the planned microcycle could be alternatively interpreted as been a consequence of an inability of the experimental methodology to detect a change in the neuromuscular status of the players following training. The CMJ was utilised for this study due to its ease of application in the field setting and relevance for neuromuscular status assessment according to previous research. Both the measurement tool and jump type used in the present study was found to be highly reliable and valid (CV < 5%) based on the findings in Chapter 2. Previous studies have found a significant decrease in CMJ performance from before and after a competitive soccer match (Andersson et al. 2008; Hoffman et al. 2003; Mohr et al. 2010). Data from these studies has reported average reductions in jump height ranging from -4.4 to -8.2% of pre values, with a -15.5% reduction in peak power during the CMJ. In the present study the average change in jump height before and after training was only reduced on MD-1 by -1.4%. This data would suggest that although the CMJ test is sensitive enough to detect significant alterations following a soccer match, the reduced load associated with soccer training may not elicit sufficient stimulus to cause a significant change in CMJ performance. Thus further work may be required to establish the sensitivity of the CMJ test to detect changes in neuromuscular status during soccer training.

In summary, this is the first study to quantify the neuromuscular response to multiple soccer training sessions across a typical planned microcycle in preparation for a competitive match. The study revealed no change in neuromuscular status across the microcycle, indicated by a lack of change in CMJ test performance. This finding may relate to a lack of training overload due to an emphasis on fitness maintenance during the in-season phase of a competitive season. This may in turn cause the soccer players to become accustomed to the maintenance loading pattern as a result of repeated exposure to similar loading throughout this phase. Another possible explanation for the findings may be due to the CMJ test not being sensitive enough to detect neuromuscular change in multiple soccer training sessions. It should be noted that the players used in the present study (U18 team) were different from those used in previous studies in this thesis (senior team). This suggests that the findings of the present study may not be generalised across all soccer populations. In addition, the GPS device used in the present study was different from the one used in Chapters 3 and 4 due to availability. It was deemed that such a difference in devices would not have a significant impact on the findings as both devices used the same sampling frequency (i.e. 10Hz). Future work should focus on quantifying the training response in microcycles at different points during the season (i.e. comparing pre-season to in-season phases) in relation to training load prescription. This would help to understand the neuromuscular response in soccer players when the loading pattern is designed to elicit physiological improvement (i.e. pre-season) compared with periods of training load maintenance (i.e. in-season). Prospective work should also look to further explore the sensitivity of vertical jump testing for assessment of neuromuscular status in soccer player.

# CHAPTER 7

# SYNTHESIS OF FINDINGS

# 7. SYNTHESIS OF FINDINGS

The purpose of the following chapter is to provide a conceptual and theoretical interpretation of the results obtained from the present thesis. An evaluation of the original aims and objectives will be conducted prior to reviewing the outcomes of the experimental studies.

## 7.1. EVALUATION OF AIMS AND OBJECTIVES

The overall purpose of the present thesis was to characterise the current training periodisation practices employed by an elite soccer team using applied methods of training load assessment. The individual studies conducted resulted in the fulfilment of the original aims stated in Chapter 1. These aims were met through the completion of four separate studies (Chapters 3, 4, 5 and 6).

The reliability of 10-Hz GPS devices was evaluated using the soccer-specific track (Objective 1). The GPS devices were found to demonstrate good reliability (< 5% CV) for low-intensity velocities (distance covered < 4 m/s) and overall total distance covered. As the velocity of movement increased (> 4 m/s), the GPS devices demonstrated an increase in the degree of error associated with soccer-specific movements. The GPS devices also displayed a high level of inter-unit error, suggesting that 10-Hz GPS devices cannot be used interchangeably between soccer players for longitudinal monitoring. Thus 10-Hz GPS are limited in their ability to analyse all aspects of movement in the measurement of soccer-specific activities (Aim 1).

The reliability and validity of a portable photoelectric cell system (Optojump) was also evaluated using various vertical jump types and measurement parameters for the fulfilment of Aim 2. The Optojump system was found to demonstrate good reliability (< 6% CV) for all vertical jump types and parameters with the exception of DJ contact time (> 10% CV). The device also demonstrated excellent validity across all jump types and measurements compared to a criterion measure. Thus the Optojump system was deemed reliable and valid for the assessment of both CMJ and SJ performance. The results of this study enabled the most appropriate jump type to be used in subsequent experimental chapters (Chapter 6).

In order to quantify the training periodisation practices used by elite soccer players (Aim 3), both external and internal training load data was analysed throughout a competitive season (Objective 3). No significant differences were observed for training load variables across training microcycles in both the pre-season and in-season phase. The majority of training variables also demonstrated no significant change across 6 week training mesocycles during the in-season phase. Positional differences were observed across both pre-season and in-season phases; with CM and WM players covering the most total and high speed distance compared to other positions and defenders demonstrating higher internal training load responses compared to attackers. This data suggests that training load does not follow a structured periodisation plan throughout a competitive season in an elite soccer team. This suggests that the periodisation requirements in soccer are unique to the sport and require careful planning in order to maximise physiological adaptation and minimise fatigue.

The neuromuscular status across a microcycle of soccer training was investigated to fulfil Aim 4. Significant differences were found between both internal and external training load variables on different training days prior to a competitive match. However there was no change in neuromuscular status (i.e. CMJ performance) evident across the week of training as indicated by the jump performance variables. This evidence suggests that the training the players completed during the microcycle did not impact the ability of the muscular system to generate force in subsequent training sessions. It would seem that players are able to tolerate the loading patterns completed during training sessions within this period of the competitive cycle.

The following section aims to discuss the general outcomes of the present thesis in relation to the theoretical and methodological frameworks associated with training. The first section will specifically analyse issues surrounding the methodological approaches to training monitoring and its practical application. The second section details the theoretical issues arising from the analysis of soccer training in the elite setting.

## 7.2. GENERAL DISCUSSION OF FINDINGS

When measuring training load in athletes, it is important to consider data from the wide array of physiological systems that are affected by exercise. Following soccer match-play and training multiple physiological systems are taxed including the nervous system, the musculo-skeletal, the endocrine system, immune function, respiration and the lymphatic and circulatory systems (Figure 7.1). The response to a given training stimulus may be specific to each of these physiological systems as well as being specific to each individual player. At present, sports science practitioners are able to consistently monitor the responses of the musculo-skeletal and circulatory system during soccer training as techniques such as GPS and HR are easy to apply and non-invasive. Other biochemical parameters can also be measured in the blood and saliva, although factors such as the high cost of analysis, the time to obtain results and the impracticalities of testing a full team of >20 players limit the application of such approaches. Other approaches to the analysis of the response to exercise are based around the assessment of performance. Such performance indicators are in reality proxy measures for the underlying physiological function. As a consequence such data is limited in its ability to provide a detailed mechanistic analysis of the body's response to training. It should therefore be recognised that the data in this thesis represents a small amount of the potentially useful information with which to analyse training load in athletes. Future investigations should look to explore the potential of novel technology that allows for the assessment of other physiological systems not currently measured during soccer training.

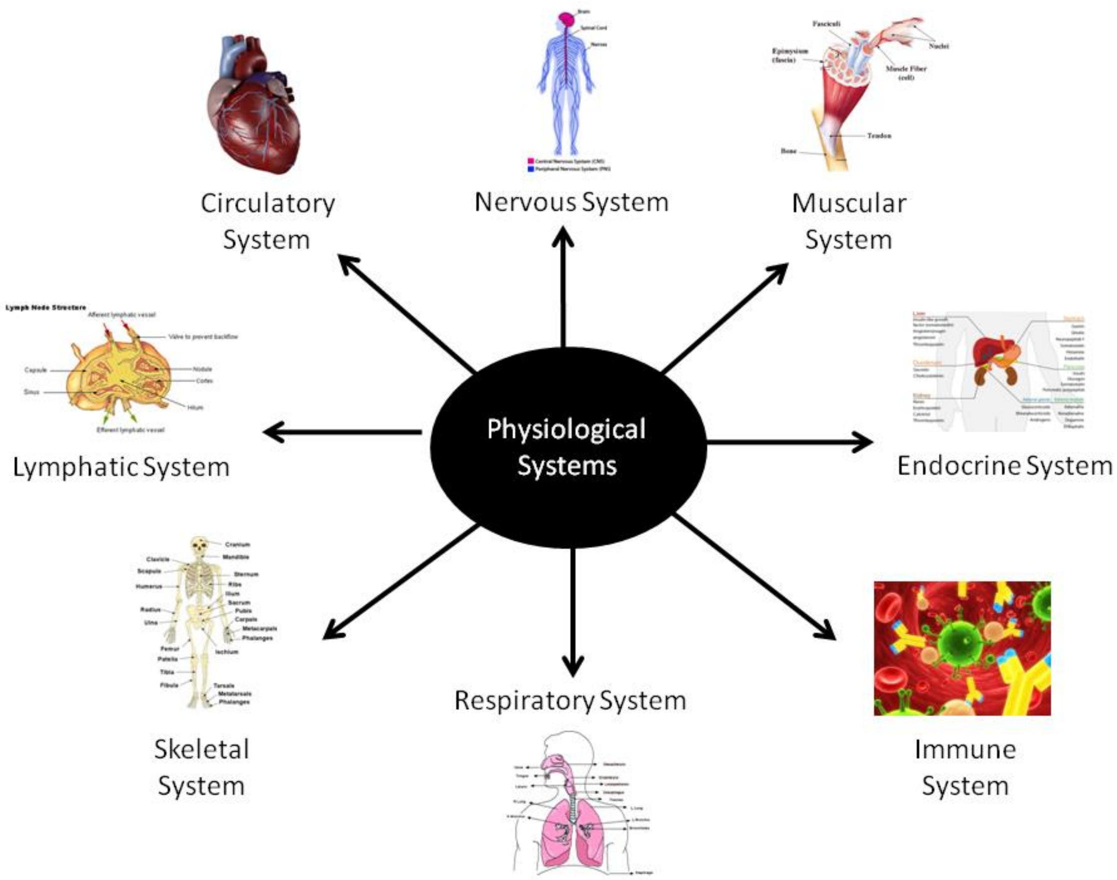



**Figure 7.1.** Representation of the physiological systems potentially affected by soccer match-play/training.

Any measurement systems that are utilised for training load monitoring should be both reliable and valid. Chapters 3 and 4 quantified these concepts in both 10-Hz GPS units and the Optojump device. The findings revealed that both techniques are associated with certain measurement issues that may impact their application in applied research and sport science support programmes. For example, Chapter 3 revealed a poor level of inter-unit reliability for the 10-Hz GPS units used in the study. This would have major implications for the application of this technology to the team setting. Primarily such data would indicate that units shouldn't be used interchangeably between players during longitudinal data collection periods. Such findings may not be an issue for elite teams who are able to provide individual GPS devices for each player. Other teams, with limited budgets, may only be able to afford a small number of devices and are therefore forced to use different units on multiple players on separate training days. These teams may have problems identifying small changes in training load that could lead to imbalances between adaptation and over-reaching/overtraining. Such situations would clearly render a monitoring strategy problematic. Such issues would seem to be a consequence of issues in either the manufacturing processes used for such equipment or be related to inherent limitations in the technology that is available. Even when a measurement system is deemed both reliable and valid, the sensitivity of the system to detect a meaningful change in performance needs to be established. In Chapter 4, although the accuracy of variables associated with vertical jump performance was established, it is unclear whether vertical jump performance is sensitive to changes in fatigue associated with soccer-specific actions. In order to progress the application of measurement systems for the assessment of physiological status, novel technologies must be developed to enhance the information available to sports scientists. For example, recent developments in GPS technology has led to the inclusion of accelerometers sampling at 100-Hz, with research suggesting improved accuracy compared to velocity-based measures (Boyd et al. 2011). Recent research has also attempted to use such data in order to evaluate the energy cost of soccer play (Gaudino et al. *Ahead of Print*; Osgnach et al. 2010). Such research may provide additional information relating to a players metabolic response to soccer training. However such novel technologies need to be validated against established methods and the reliability of measurement assessed before use in the applied setting longitudinally.

The purpose of soccer training is to prepare a player both physically and tactically for the subsequent demands of matches throughout the competitive cycle. From a physiological perspective, the response to a soccer training session will be specific to each individual player due to factors such as genetic background and previous training experience (Bouchard & Rankinen 2001). With this in mind, training sessions need to be programmed and adjusted to meet the requirements of individual athletes (Bompa 2009). Due to the high competition demands in soccer across an annual cycle, coaches are required to structure training in a way that allows for optimal training adaptation and recovery throughout this demanding period. The theory of training periodisation may allow for such training targets to be achieved. Periodisation refers to the division of an entire annual cycle into smaller periods and training units (Matveyev 1981). Within the periodisation framework, coaches are able to manipulate various factors, such as training volume and intensity, which will have a subsequent impact on the individual player's physiological response. These factors form the overall training load in which players are subjected to.

When an excessive training load is consistently applied without adequate recovery to allow for physiological supercompensation, soccer players may be exposed to over-reaching/overtraining that will have a negative impact on soccer performance. Conversely, when the training load employed is sub-optimal for training adaptation and/or maintenance of physiological status then a detraining effect may occur. Therefore it is crucial that the correct individual training load is applied in context to the requirements of the soccer competitive cycle. Training load has been previously classified by Viru and Viru (2001) into five different categories ranging from excessive load to useless load (Figure 7.2). The aim of Chapter 5 of this thesis was to quantify the periodisation strategies employed by an elite professional soccer team in relation to training load. Such information will enhance the current understanding of whether the periodisation strategies employed in soccer are able to balance the relationship between training adaptation and recovery across a competitive cycle.

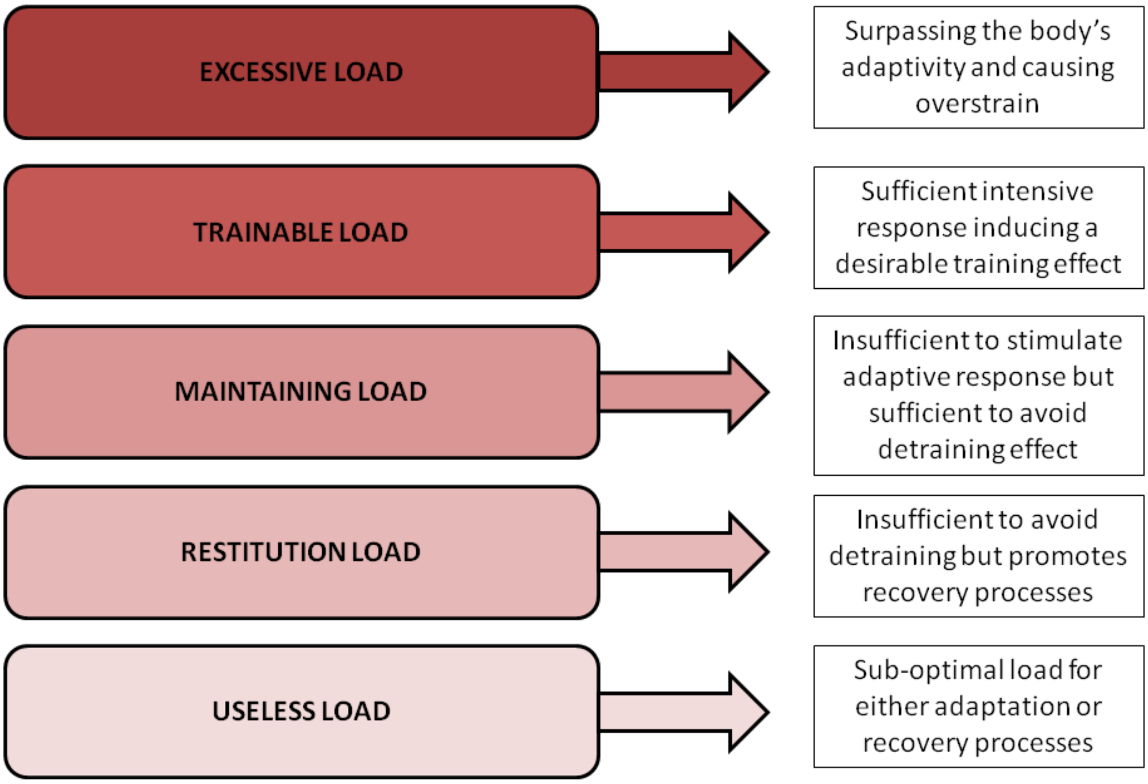



**Figure 7.2.** Classification of various levels of training load. Adapted from Viru and Viru (2001).

The findings of Chapter 5 revealed that training load remained similar across 6 week mesocycle blocks and weekly microcycles at different time points during the in-season and pre-season phases. The lack of variation in training load suggests that the soccer training was not periodised in order to vary the physiological stimulus given to the players. This notion was supported by the findings in Chapter 6, in which neuromuscular status remained unchanged throughout a weekly microcycle in professional soccer players. If the training load is inadequately periodised to elicit a supercompensation effect then the players will not enhance their physiological status. When such microcycles are repeated longitudinally, it may be that during the in-season period some players will become maladapted to the training load and possibly engage in a state of detraining. However Chapter 6 only investigated the neuromuscular response over one microcycle of soccer training that was 6 months into the in-season period. It would be of interest to repeat such an investigation at various time points in the season in order to determine if such a phenomenon is repeated throughout both the pre-season and in-season periods. The reason for the lack of physiological adaptation observed in Chapter 6 may be due to the emphasis on recovery in between matches and therefore the training load employed was aimed at restitution as opposed to inducing a training effect. Perhaps some coaches believe that employing excessive training load during the in-season period, combined with congested fixture scheduling, and may increase the risk of injury to key players. Therefore it may be evident that soccer cannot follow certain elements of traditional training periodisation modelling due to the external demands and must adapt its own methodology specific to the sport.

As previously highlighted, it appears that training periodisation is limited within professional soccer. This may be due to the external factors dictating the organisation of training that could make current periodisation strategies inadequate for soccer. It may also be possible that soccer coaches are unaware of how to fully implement training periodisation into their training planning and daily session content. When understanding the periodisation requirements of soccer, it is important to determine which elements of traditional periodisation strategies can still be employed within the sport. As demonstrated in Chapter 5, it is difficult to employ periodisation strategies within mesocycle blocks of training during the in-season period with specific aims of improving physical capacity. For example, it would be difficult to employ a concentrated unidirectional training block over a mesocycle as such excessive training loading, in combination with the competition demands, may lead to overreaching/overtraining and subsequent injury. It may be evident that the content and aims of each mesocycle block throughout the in-season is driven by the microcycle structure within each block. Microcycles have been previously considered the most important planning tool in the overall training process (Stone et al. 2007). This is due to the flexibility of microcycles in terms of individual session content according to the athlete's working capacity, requirements for recovery and the competition plan. For example, if the target training load for a specific training session is deemed too excessive then the training load can be reduced in the subsequent sessions in order to prevent the accumulation of fatigue within individual players. In Chapter 5 it was found that in scenarios in which only one match was played per weekly microcycle, the soccer team typically undertook 4 training sessions in preparation for a match. The pattern of training structure in this scenario was typically 3 consecutive training sessions leading into a match, with a day off on MD-4 and an additional training session on MD-5. It was found that the training load employed was similar on MD-5, MD-3 and MD-2 for the all internal and external training load variables, with the only significant reduction on MD-1. The aim of the reduction in training load on MD-1 is to apply a training taper in order to diminish fatigue prior to a soccer match (Mujika 2010). This microcycle structure also allows for training load to be modified on the other training days, with the potential opportunity to employ trainable loading earlier in the week to promote training adaptation. Therefore although training periodisation may not be possible at the mesocycle level in soccer, there is potential to periodise training throughout each microcycle in accordance to competition requirements.

The data generated from Chapters 5 and 6 of the thesis, that presents information on training load patterns across an annual cycle, is only representative of the professional soccer team that was investigated. As these training patterns are a consequence of the approach of the coach, it is highly likely that each individual soccer team will have a separate training approach that is designed to prepare players for the style of play in which they are attempting to play. With this in mind, it may be evident that the findings of Chapter 5 and 6 cannot be applied universally across soccer teams with different individual requirements. Some teams may employ different training structures in comparison to that observed in Chapter 5. For example, teams may train on four consecutive days leading into a match, compared to only three days observed in Chapter 5. The training content may also vary in terms of the type of training drills employed. Differences in training drills may have a profound effect on the physiological response and overall training loading (Little & Williams 2006). Therefore more information is required in order to quantify the variance in training periodisation practices across different soccer clubs before definitive conclusions can be determined.

## 7.3. CONCLUSIONS

The aims of this thesis were to characterise the current training periodisation practices employed in elite soccer using applied methods of training load assessment. These aims have been fulfilled through the completion of the objectives set out in Chapter 2. Discrepancies were found when quantifying the associated reliability and validity of applied methods of training load and vertical jump assessment. The use of GPS devices is now common amongst elite soccer teams. The thesis revealed an increase in the error associated with an increase in the velocity of movement during a soccer-specific movement track. High levels of error were also found for drop jump assessment when using a portable jump assessment device (Optojump). Therefore this highlights the importance of quantifying and interpreting such errors when using applied methods to quantify training load in soccer players. The training periodisation strategies were found to remain similar throughout both the in-season and pre-season phases of a competitive season. It was also found that neuromuscular status unchanged throughout a planned microcycle in preparation for a competitive match. These findings suggest that the training periodisation may be more applicable to maintaining levels of conditioning than improving fitness during certain periods of the season. In conclusion, this thesis revealed that traditional training periodisation is limited in professional soccer and there is a requirement for novel approaches to periodisation in soccer.

## 7.4. RECOMMENDATIONS FOR FUTURE RESEARCH

The studies completed within this thesis have provided novel information relating to training periodisation practices employed in elite soccer. In achieving the aims of the thesis, several issues and subsequent findings have prompted the formulation of recommendations for future research. This section details those recommendations in relation to each specific chapter of the thesis.

*Suggestions arising from Chapter 3:*

1) New developments by sports technology companies have led to the inclusion of inertial analysis in the latest GPS devices. This involves the inclusion of an accelerometer, magnetometer and gyroscope that allows for directional analysis across anatomical planes. Inclusion of such technology allows the potential for novel metrics of player assessment to be generated, such as the metabolic cost of exercise. The increased sampling frequency of accelerometer measurements compared to satellite-based velocity measures (100Hz vs. 10Hz) also potentially offers an improvement in data accuracy. Future work should look to establish the reliability and validity of novel accelerometer derived metrics before they can be applied longitudinally for training monitoring in soccer players.

*Suggestions arising from Chapter 4:*

2) The data from study 2 revealed good levels of reliability and validity for CMJ and SJ assessment using the Optojump measurement device. Although these jump types were deemed to be acceptable in terms of their accuracy, it is unclear as to their sensitivity to fatiguing exercise using the device. Future work should look to establish the response in jump performance to varying degrees of soccer-specific fatiguing exercise. One example may be the use of a treadmill-based lab protocol, with jump performance measured directly pre and post. The time-response to such protocols should also be investigated, following up post exercise measures with 12h, 24h, 48h and 72h assessments. This would provide further information relating to the use of vertical jump testing for detecting changes in physiological status in the applied setting.

*Suggestions arising from Chapter 5:*

3) The work from this chapter provided novel information relating to the training periodisation strategies employed by an elite English soccer team. However the findings of the study may be limited to the population that was used for the investigation. Therefore

more information is required to quantify the training periodisation practices of soccer clubs from different nationality and competition level. It would be of particular interest to explore the practices of clubs in the major European leagues, such as Spain and Germany.

*Suggestions arising from Chapter 6:*

4) The microcycle selected for investigation in Study 4 occurred in the later stages of the season in which the players had previously completed approximately 6 months of structured training. This time point was used as it was the most applicable time in which the players were available for testing. It would be of interest to compare the response during different time points during the annual cycle. Specifically, it would be useful to compare a microcycle in pre-season with the start, middle and end points of the in-season phase in order to establish any differences associated with training phase.

## 7.5. PRACTICAL RECOMMENDATIONS FROM PRESENT THESIS

In order to impact and improve soccer practice, it is important that practitioners are able to derive useful information from the present thesis that can be used in the applied setting. The following is a summary of key practical recommendations/findings that have been identified through completion of the present thesis:

1. Caution should be made when interpreting data from 10 Hz GPS devices when measuring distance covered at higher movement velocities (> 5.5 m/s).
2. Due to high intra-device reliability error, players should wear the same GPS device for all training sessions.
3. The Optojump measurement device is a reliable and valid method for the measurement of CMJ and SJ performance.
4. Caution should be made when using the DJ test measured by the Optojump device due to high error associated with jump contact time.
5. Practitioners are encouraged to monitor training longitudinally in order to identify patterns in training load across both microcycles and mesocycles.

6. Lack of variation in training load observed in the present thesis suggests that the training practices of elite soccer teams may not be optimal and should be analysed on an individual basis.
7. Soccer teams may employ maintenance training loads during typical training microcycles due to fear of injury, but practitioners should be encouraged to identify the correct times to employ a higher training load.
8. Jump testing alone may not be the most sensitive indicator of neuromuscular status in elite youth soccer players.

# CHAPTER 8

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