THE IMPACT OF LONG-TERM SOCCER-SPECIFIC TRAINING ON THE PHYSICAL DEVELOPMENT OF ELITE JUNIOR SOCCER PLAYERS

Russell Wrigley

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ABSTRACT

The goal of any soccer talent development programme is to guide players towards professional characteristics. In order to maximise this process it is essential to gain an insight into their individual characteristics. Within this specific population there are many factors from maturation, hormonal, anatomical and musculoskeletal changes that accompany paediatric development and consequently have a direct impact upon their development. The aim of this thesis was to determine the relative influence of changes in maturation and long-term systematic training on the physical development of elite junior soccer players.

The aim of the first study (Chapter 4) was to assess the reliability of a range of anthropometric and performance measures in aged matched academy and non-academy soccer players (U14-18). The results demonstrated that all anthropometric (%CV values of 0.1 – 1.3%) and performance measures (%CV values of 1.8-6.2%) were highly reproducible in both the academy and non-academy soccer players. These assessments would be subsequently used to determine the impact of long-term training on changes in physical development of junior soccer players.

The aim of study two (Chapter 5) was to determine the validity of a non-invasive approach (maturity offset) for predicting end height stature in academy soccer players (U14-18). Overall, agreement between estimates of end height stature in elite youth soccer players' using skeletal x-ray and the maturity-offset method were poor with a SEM and 95 % LOA of 4 cm and $\pm$11cm being observed respectively. These findings indicate that care must be taken when predicating end height stature in academy soccer players when using maturity offset method.

The aim of the third study (Chapter 6) was to examine the typical weekly training load experienced by academy and non-academy soccer players (U12-U16) during the in-season competitive period. Physiological loading associated with training sessions and match-play were monitored using heart rate (HR) and ratings of perceived exertion (RPE). Training and match loads were calculated by multiplying global session RPE and duration (RPE-TL). Weekly training load in the academy players (U12, 737±51; U14, 646±106; U16, 750±81) was higher than the non-academy players (U12, 157±28; U14, 161±19; U16, 193±26) across the three age groups. Similarly, match load and % time spent >90%HRmax was higher in the academy players compared to the non-academy players. The present findings indicate that the overall load and intensity of training is greater in academy players compared to aged match non-academy players.

The aim of the fourth study (Chapter 7) was to determine the relative influence of changes in maturation and long-term systematic training on changes in physical performance in age matched academy and non-academy junior soccer player. The three-year change in the physical performance of twenty-seven academy and eighteen non-academy soccer players (U12-U16) were monitored. When corrected for differences in both baseline performance and change in maturity status (maturity offset), greater changes in countermovement jump (7.3 + 2.6 cm, 5.4 + 2.5 cm), 10 m (-0.15 + 0.05 s, -0.10 + 0.04 s) and 20 m sprint (-0.30 + 0.16 s, -0.15 + 0.13 s), agility (-0.19 + 0.01 s, -0.08 + 0.08 s), repeated sprint (-0.60 + 0.26 s, -0.41 + 2.1 s) and intermittent endurance capacity (1128 + 406 m, 315 + 370 m) were observed in the Academy players compared with non-academy players ($p<0.05$; Effect Sizes >0.7). These findings indicate that long-term player development programs accelerate the rate physical development of academy soccer players relative to age and maturity matched non-academy players.

In summary, the present thesis highlights that academy soccer players experience greater rates of improvement in physical performance indicators compared to non-academy players, independently from the initial performance level of the child and change in maturation over the same time period. These difference are likely to reflect the increased volume and intensity of soccer-specific training experienced by the young soccer players as part of the academy's approach to long-term athlete development. Future research is warranted in order to determine training loads in elite youth soccer players at different stages of biological maturity which serve to enhance performance whilst minimising the risk of injury.

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LIST OF ABBREVIATIONS

PT	Physical Training
WU	Warm Up
MAT	Match
TT	Technical/Tactical
PT/TT	Physical and Technical/Tactical Training
CD	Cool Down
PAQ-c	Physical Activity Questionnaire
%HRmax	Percentage of Maximum Heart Rate
HR	Heart Rate (beats.min^{-1})
LOA	Limit of Agreement
SEM	Standard error of measurement
GLM	General linear model
CD	Compact disc
s	Seconds
min	Minutes
cm	Centimetres
m	Metres
kg	kilograms

CV	Coefficent of variation
CMJ	Countermovement jump
SD	Standard deviation
GPS	Global positioning systems
mSv	millisievert
TRIMP	Training impulse
RPE	Rating of perceived exertion
RPE-TL	Rating of perceived exertion training load
$\dot{V}O_{2max}$	Maximal oxygen uptake ($L.min^{-1}$)
AU	Arbitrary units
PAQ-C	Physical activity questionnaire
MO	Maturity offset
PHV	Peak height velocity
YY1R2	Yo-Yo intermittent recovery test level 2

CHAPTER 1

INTRODUCTION

1.1. BACKGROUND

Development and professional guidance of its players is a priority for any professional soccer club in order to maintain their competitive and financial status. Many clubs therefore selectively enrol promising players at a relatively early age and provide specialist training with the goal of developing elite players. Paramount to coaches and practioners is the application of direct techniques to advance paediatric sporting development (Ford et al., 2011). Exercise adaptations to strength, anaerobic and aerobic training have been extensively researched in adults, however, young people respond differently to such exercise stimuli compared to adults (Matos and Winsley 2007). Children are not simply ‘mini adults’ indicating that our understanding of the exercise physiology of an adult cannot just be scaled down and applied to children (Armstrong and Welsman 2002; Lloyd and Oliver, 2012).

Physiological profiling has frequently shown that elite junior soccer players have an advantage over their sub elite counterparts in terms of both body composition and physical performance (e.g. speed, agility, endurance and muscular power) (Janssens et al., 1998; Reilly et al., 2000; Malina et al., 2007) and these differences may remain consistent over an extended period of time (Vaeyens et al., 2006). This suggests that such physiological measures may serve as a useful tool in predicting later success in soccer (Jankovic et al., 1997). Despite such observations, the degree to which these differences are attributed to normal growth and maturation (Vaeyens et al., 2006) relative to the effects of systematic training (Williams and Reilly, 2000) has yet to be fully evaluated. The need to control for differences in biological maturation represents an important element since the adolescent growth spurts varies in timing and tempo and is closely associated with improvements in physical performance that mimic the effects of training (Naughton et al., 2000; Philippaerts et al., 2007). Future work comparing elite and sub elite junior soccer players considering both chronological age and biological maturity is therefore needed in order to provide a more accurate comparison of physical performance characteristics.

Along with the effects of normal growth and maturation research has shown that junior level athletes' physical performance (i.e. strength, anaerobic and aerobic power) increases in response to systematic training (Matos and Winsley, 2007; Pittoli et al., 2010; Sokolowski and Chrzanowska, 2012). Indeed part of the continued physiological superiority of elite junior soccer players maybe due to the long-term systematic approach to training rather than a player's genetic physiological ability or differences in maturity status (Williams and Reilly, 2000, Malina et al., 2005, Figuriredo et al., 2011). However, to date little attempt has been made to quantify the relative contribution of long-term systematic training on the observed differences in physical performance between elite and sub-elite junior soccer players. Future work which compares long-term changes in physical performance in these groups when accounting for training history, chronological age and biological maturation will provide an important insight into the potential impact of long-term training on the changes in physical development of elite junior players (Sproviero et al.,2002; Ford et al., 2011).

In a sport where vast amounts of time and resources are being utilised in the long term aim of maximising a soccer players potential an evaluation of the combined effect of growth and maturation and long-term training on the changes in physical development of elite junior soccer players will not only provide coaches and practitioners with an accurate evaluation of the effects of systematic training but also its effectiveness.

1.2 INTRODUCTION TO RESEARCH STUDIES

Determination of the impact of growth and maturation and long-term specific training on the changes in physical development of elite junior soccer players will be achieved through a series of studies. When selecting any performance measure, test validity or the degree to which a test relates to performance must be an essential consideration (Svensson and Drust, 2005). Another important factor in the test selection, which can be of considered primary importance, is the test reliability. In the initial investigation the reliability of all anthropometric and performance measures will be assessed. These protocols will be used subsequently to determine the impact of long-term training on changes in physical development of junior soccer players.

In conjunction with long-term training, growth and maturation underpin any structured developmental program of elite youth sports people. Since individual differences in the timing and tempo of biological maturation are considerable, particularly during and pre adolescence, an understanding and knowledge of an individual's level of maturity is essential (Mirwald et al. 2002; Malina 2011). While invasive measures of maturity such as skeletal age represent the gold standard (Le Gall et al., 2006; Malina et al., 2007), such approaches are invasive, costly and difficult to implement within the field therefore more practical, non-invasive measures would be of significant benefit for those practitioner working in the field. However, to date, limited attempt has been made to examine the validity of potential field based estimates of maturity in junior soccer players. Therefore the second aim of the thesis will be to examine the agreement between classifications based on non-invasive methods and skeletal maturity.

Training to improve athletic performance is an adaptational process that involves the progressive manipulation of a physical load (Manzi et al. 2010). The third aim of the thesis will be to examine the typical weekly training load experienced by academy and non-academy soccer players during the in-season competitive period and to what extent potential differences in load and intensity exist between the two groups.

The final aim of the thesis will be to use the battery of field tests developed in Study 1 to compare the magnitude of change in physical performance of academy and non-academy junior soccer players over a 3-year period taking into account any differences in baseline performance and change in maturation status. By adopting this research design we will be able to determine whether systematic training alone enhances the rate of physical performance development of academy players compared to non-academy players.

1.3 AIMS AND OBJECTIVES

Aims

To investigate the impact of growth and maturation and long-term soccer-specific training on the physical development of elite junior soccer players

Objectives

1. To determine the reliability of a range of anthropometric and performance measures in academy and non-academy soccer players

2. To determine the validity of maturity offset as a non-invasive estimate of biological maturity in academy soccer players
3. Quantification of a typical weekly in season training load in academy and non-academy soccer players
4. To determine the relative influence of long-term soccer-specific training and normal growth and maturation on the changes in the physical development of academy soccer players

CHAPTER 2

REVIEW OF LITERATURE

The aim of this review of literature is to provide the reader with information regarding the impact of soccer-specific training on the physiological development of elite junior soccer players. The initial section of the review looks at the physical and physiological demands of elite junior soccer. This is followed by a review of the literature regarding the influence of both growth and maturation and training on the physiological development of elite junior soccer players is provided.

2.0. INTRODUCTION

The goal of any soccer talent development programmes is to guide players towards professional status in adulthood (Elferink-Gemser et al., 2012). Attempts to accelerate and therefore maximise the performance of elite junior athletes' represents a key element of long-term athlete development programmes in professional clubs (Ford et al., 2011). In elite soccer, coaches are constantly seeking the most effective formula for developing talented young players (Stratton et al., 2005). To be successful in professional soccer, extensive technical, tactical and physical training are necessary to improve and maximise performance (Brink et al., 2010). In this respect, the role of elite soccer academy's and the effectiveness of programs they administer are vital in this process. It is imperative that programs are not only structured and tailored to the requirements of the game but also to the individual (Reilly et al., 2005; Ford et al., 2011).

2.1. PHYSICAL & PHYSIOLOGICAL DEMANDS OF ELITE JUNIOR SOCCER PLAYERS

Training is an essential part of preparing for sports competition and if training for soccer is to be effective it must be related to the demands of the game (Reilly et al., 2005). Elite youth soccer players (U16-U12) have been reported to cover up to 6-8 km dependent on age, with older age groups U16 covering significantly higher total distances than U12 (Harley et al., 2010). It is also important to note that the majority of the activity performed in a soccer match is completed in low-intensity activities such as walking and jogging (Rienzi et al., 2000). However these values are maybe affected by not only pitch size but also duration of games which can vary dependent on age group. Sprint type activities in senior players account for approximately 12% of the total distance covered with such efforts being short both in terms of distance and time (Mohr et al., 2003). A sprint bout occurs approximately every 90 seconds, each lasting an average of 2-4 seconds (Stolen et al., 2005). Elite youth soccer players between U12 and U16 have reported sprint distances covering between 302 – 174 m with U16 sprint distance being higher than at U12 level (Harley et al., 2010).

The prevalence of the sub maximal nature of walking and jogging activity in soccer matches predominately stresses the aerobic energy system (Bangsbo, 1994). However, anaerobic provision is also needed in order to support the high-intensity bouts of exercise included in a game (Krustrup et al., 2006). The average exercise intensity, measured as a percentage of maximal heart rate (HRmax), during a 90 minute soccer match is close to the anaerobic threshold, normally between 80-90% of HRmax (Stolen et al., 2006). In comparison of elite and non-elite youth players Stoyer et al., (2004) reported that HRs during soccer matches were higher in young elite soccer players than in non-elite counterparts of the same age (12 years). Relative to maturity the average HR during games has been reported to be similar in young elite players in early puberty and end of puberty. But interestingly early maturing elite players have been reported to have higher $\dot{V}O_{2max}$ related to body mass and elite players at the end of puberty have also been shown to have higher absolute $\dot{V}$O2max values during match play.

2.2. PHYSICAL CAPACITIES OF ELITE JUNIOR SOCCER PLAYERS

To cope with the physiological demands of soccer, players must be competent across several fitness components (Turner et al. 2011). Physiological and anthropometric tests can provide useful information on not only the physical capacities of players but also on their training status (Viru and Viru, 2001) with physiological tests having also been used as a means to physiologically profile junior soccer players (Reilly et al., 2000).

2.2.1 Anthropometry

Studies of adolescent (13-15 years) and adult players have showed that defenders and goalkeepers tended to be the tallest (178.1-183 ± 4.1cm) and heaviest (78-78.7 ± 7.4kg), while midfielders and forwards tended to be the shortest (173.7-175.1± 6.1cm) and lightest (71.6-71.7 ±7kg) (Malina et al., 2007; Rebelo et al., 2013). Elite junior soccer players (13-15 years old) also tend to be taller and heavier than non-elite players (Malina et al., 2007). For example, Rebelo et al., (2013) reported that U19 elite soccer players were taller (Elite, 183.3 – 174.7 ± 5.7cm; Non-elite 178.1 – 171.2 ± 6.6) and heavier than non-elite (Elite, 78.7- 69.3 ± 7.3; Non-elite, 73.1 – 66.6 ± 8.2kg) particularly goalkeepers and central defenders. Indicating that anthropometrically elite players have an advantage over non-elite youth players.

2.2.2. Physiological profile

2.2.2.1. Aerobic

The $\dot{V}O_{2max}$ in outfield players varies from about 50-70 mL/kg/min with goalkeepers ranging from 50-55 mL/kg/min. While the intensity corresponding to the anaerobic threshold has been reported to range from ~76-90 % HRmax (Stoyer et al., 2005). Interestingly, Helegrerud et al., (2001) found junior soccer players to have a reported $\dot{V}O_{2max}$ of 64.3 ml/kg/min and elite junior U18 players to have an average value of 73.9 mL/kg/min. Stoyer et al. (2005) observed higher values for junior soccer players at the end of puberty (14 years of age) than younger players. When comparing elite soccer players to non-elite soccer players, similar $\dot{V}O_{2max}$ response have been observed (Stoyer at al., 2005). In contrast, when applying tests which replicate the intermittent nature of soccer such as the Yo-Yo intermittent recovery test (level 2) elite players have frequently been reported to perform better. For example, Ingebrigtsen et al., (2012) reported that elite players performed approximately 40 % better compared to non-elite soccer players, similarly Bangsbo et al., (2008) documented values of 2030m in elite players compared to 1810 m in non-elite players. It is therefore indicated that mature junior soccer players have a greater aerobic capacity than less mature and elite players a superior aerobic performance than non-elite.

2.2.2.2. Anaerobic

Speed, agility and repeat sprint ability have also been reported to be distinguishing physiological factors between elite and non–elite players (Rebelo et al., 2012). In U17 youth players, isometric leg extension (elite, 976.5±132.6; sub-elite, 743.5±126.6N), vertical jump height (elite, 23.6±3.5; sub-elite, 21.4±4.5) and 10m sprint time (elite, 1.95±0.34s; sub-elite 2.14±0.41s) were all superior in elite junior soccer players compared to sub-elite (Gissis et al. 2006). This superiority has also been reported by Vaeyans et al., (2006) who highlighted superior performances of skills requiring increased anaerobic power (sprint performance, vertical jump and standing broad jump) in elite youth soccer players when compared with sub-elite and non-elite youth soccer players (U13–U14). Of necessity, the literature highlights that soccer players of all ages must adapt to the physical demands of the game, and moderate to high levels of speed, agility, and aerobic endurance have been described as important physiological qualities for elite soccer (Rebelo et al., 2013). Also performances of elite relative to non-elite players also suggests a need for greater ability to sustain high work rates during a match and recover quickly from all out efforts (Reilly et al., 2000). This is particularly significant since performance on intermittent high intensity tests and distances covered at high-intensity during a match are significantly related (Bangsbo et al., 2006).

2.3. FACTORS INFLUENCING THE PHYSICAL DEVELOPMENT OF ELITE JUNIOR SOCCER PLAYERS.

Along with the effects of normal growth and maturation, the physical performance of junior athletes (i.e. strength, anaerobic and aerobic power) has also be shown to increase in response to systematic training (Matos and Winsley, 2007). Indeed Williams and Reilly, (2000) argue that part of the continued physiological superiority of elite junior soccer players relative to sub-elite players maybe due to the long-term systematic approach to training rather than a player's genetic physiological ability or differences in maturity status. However, within this specific population there are many factors from maturation, hormonal, anatomical and musculoskeletal changes that accompany paediatric development and consequently have a direct impact upon the development of specific fitness components and any training program that aims to enhance them (Ford et al., 2011). Therefore in order to achieve optimal development of elite junior soccer players, not only is a structured individualised long-term athlete development programme required but also a thorough insight into the longitudinal physiological and maturational characteristics of those players (Williams and Reilly, 2000; Elferink-Gemser et al., 2004).). A significant amount of evidence shows that these physiological and biological changes are non-linear and dynamic resulting in a variance in the development of fitness components between individuals, with potentially resulting windows of opportunity when development of these components can be maximised. As soccer is a team sport, players from the same team can differ considerably in physique and physiological development due to their individual rate of growth and maturity. These biological changes will impact upon any developmental training program and therefore adaptation for theses variations must be incorporated within the planning of physical training to make it as effective and safe as possible (Bailey et al., 2010; Ford et al., 2011; Malina et al., 2004). However, to date limited appreciation of these factors and its impact on adolescent physiological development is evident in many elite training environments (Balyi and Hamilton, 2004). This is something which has hindered our understanding of the impact current physiological developmental programs are having on elite junior soccer players. Therefore in order for any conclusions to be made it is important that the research evidence regarding the development process is examined, including an examination of the influence of maturity, physical training and reference to potential windows of opportunity in maximising development of youth soccer players.

2.3.1. Biological vs. chronological age

With advanced biological maturity and chronological age physiological performance increases (Matos and Winsley, 2007). Lower baseline anthropometric and physical performance measures have generally been observed in youth soccer players who either dropped out (Figueiredo et al., 2009) or who were not selected to play at the next level (Gil et al., 2007) compared to those progressing to a higher playing standard. Similar findings have been observed in elite academy players who on eventual graduation were not offered a professional contract compared to those awarded a contract (Le Gall et al., 2010). It can be argued that potential reasons for these lower anthropometric measures maybe due to maturational differences. Indicating that biological maturity and physical performance have a significant impact on future success in elite soccer. Within the same age group boys who are advance in maturity from their chronological age are taller, heavier, stronger than less mature (Malina et al., 2004). A further complicating factor is that the process of biological maturation does not occur at the same chronological age in all people and the 90% percentile range of peak growth age is approximately 4.5years, creating significant discrepancies within groups of individuals (Gil et al., 2007). Significantly within soccer, elite youth players are frequently advanced in biological maturity status compared to chronologically matched non-elite players (Malina, 2003, 2011).

Physical performance tests are usually based on the measurement of muscle strength and functional movement performance under standardized testing conditions (Jaric et al., 2005). It is reported that a number of well-known factors may affect the outcome of the physical performance tests, such as body composition, age, gender, level of physical activity, or skill (Abernethy et al. 1995; Keating and Matyas, 1996), causing differences among individual subjects and comparative populations particular when matched by chronological age. However, an often neglected factor that plays a role in the outcome of performance tests is maturity status (Ford et al. 2011; Philippaerts et al. 2006). The relationship is pronounced when boys of contrasting maturity status (i.e. early vs late maturers) are compared. Boys who are advanced in biological maturity are generally better performers than their later maturing peers (Malina et al. 2004; Pillippaerts et al., 2006; Vandendriessche et al., 2012). Research argues that performance differences among maturity groups are apparent by 13 years of age and tend to be greatest at 14 to 15 years (Lefevre et al., 1988, 1990; Malina et al., 2004). This is supported by Figueirdo et al., (2009; 2011) who reported vertical jump scores that were significantly superior for early compared to late maturing 13-14 year old Portuguese soccer players but not among 11-12 year olds. Boys who are advanced in maturity tend to perform better in tasks requiring strength, power, and speed compared with average and late maturing boys of the same age (Malina et al., 2005). In a sample of Portuguese soccer players aged 13.2-15.1 years, maturity (measured via stage of pubic hair) in combination with body mass, height or experience accounted for 49%, 39% and 18% of the variance in a 30m sprint, countermovement jump and yo-yo test respectively (Malina et al., 2004). Research has also indicated that future successful young male athletes in several sports as well as soccer (e.g. swimming, baseball and ice hockey) tend to be on average advanced in biological maturity status during adolescence (Malina et al., 2005). It is important to note that the available research regarding maturity associated variation in the physical and functional capacities of youth soccer players is, largely limited to cross-sectional studies. The difficulty with such studies is that they are a reference of a particular point in time and therefore not only neglect to consider longitudinal changes but also fail to legislate for inter-individual differences in biological maturation (Valente-dos-Santos et al., 2012).

Biological maturity is also a confounding factor in youth soccer talent identification (Vandendriessche et al., 2012; Malina et al., 2004). Many youth soccer coaches when trying to identify future talent base their judgement on current physical ability and mistake early physical maturation for physical talent leading to a selection bias of early maturing soccer players' (Vandendriessche et al., 2012). This is despite the fact that major maturity-related differences exists in height, weight, strength, speed and endurance of youth soccer players at identical chronological age (Reilly et al., 2000; Vaeyens et al., 2006; Malina et al., 2007). In youth sport, chronological age is the usual method of dividing children into age related training and competitive groups, but between individuals in the same age group maturity, can differ by as much as four years via skeletal maturity (Malina et al., 2000). From the age of about 14 years of age, boys advanced in maturity status (sexual and skeletal maturation) are better represented on junior soccer teams (Malina, 2003; Malina et al., 2000; Pena Reyes et al., 1994). This is consistent with the hypothesis that late maturing boys are excluded from soccer either voluntary, dropping out or systematically and early maturing boys are preferentially selected as age and sport specialization increases (Malina, 2003). This corollary will result in early maturing boys who are selected for elite soccer teams being exposed to greater training stimuli than non -elite players since these teams will have a greater concern in developing the physical aspects of the players (Pittoli et al., 2010). As a consequence any differences in performance measures, in elite junior soccer players maybe a result of systematic training stimuli rather than genetic disposition.

To date, maturity status has rarely been a factor used in participant classification into youth sports. With chronological age being the predominantly method used resulting in a maturity bias in selection processes due to the physiological advantages early maturing players exhibit. Therefore it has been argued that chronological age is of limited utility in the assessment of growth and maturation (Malina, 2000). As a consequence it is argued that matching adolescents according to their maturity status will not only enhance their chance for success and reduce the potential for injury but also provide developmental assessment and guidance to young athletes which is an essential objective that any practitioner should adhere to (Mirwald et al., 2002; Johnson et al., 2009; Malina et al., 2006). Therefore it seems that the need to assess maturity status, the timing and tempo of the progress towards maturity, is imperative in the study of junior sports development (Mirwald et al., 2002).

2.3.2. Maximising Development – *Windows of Opportunity*

Adolescence is a stage of development characterized by unprecedented physiological changes in the musculoskeletal, cardio respiratory and reproductive systems of the body (Naughton et al., 2000). Evidence drawn from longitudinal studies of youth soccer players suggests that maximal gains in running speed, agility, aerobic endurance and lower limb explosive strength occur, on average, close to the time of peak velocity (Philipparets et al., 2006). Within the literature this concept has been described as 'windows of opportunity', where accelerated adaptation can be achieved via the right training stimulus (Bayli and Hamilton, 2004; Stratton et al., 2004). As a consequence, the changes which occur during adolescence may have significant impact upon the long-term development of soccer players and are of significant interest to any practioner aiming to maximise an elite soccer players potential.

The development of aerobic fitness and its impact on performance is influenced by growth related changes, biological development and the volume of training (Valente-dos-Santos et al., 2012; Rowland, 1985). It is important to note that the intra and inter individuality of these components varies throughout childhood and adolescence (Naughton et al., 2000). Peak oxygen uptake, acknowledged as the 'gold standard' criterion method of assessing an individual's aerobic fitness (Jones and Carter, 2000; Naughton et al., 2000), increases from infancy into adulthood and different methods of physical training have been shown to enhance it (Viru et al., 1999). Nevertheless it has been suggested that there are natural accelerated and decelerated periods of development during maturity (Baquet et al., 2003; Viru et al., 1999). These are highly individualised, which can be attributed in part to the fluctuating rates in anatomical, neurological, muscular, metabolic, and hormonal development (Naughton et al., 2000; Ford et al., 2011). The current body of research has failed in many cases to legislate for these inter individual disparities. Both Ford et al. (2011) and Naughton et al. (2000) conclude that findings are obscured further by genetic background and also training load which are rarely reported and that long-term studies that map changes in aerobic capacity during adolescence and measure the influence of training concurrently are required.

It has been argued that the development of anaerobic fitness and speed throughout childhood is entirely maturational and age related (Balyi and Hamilton, 2004). For example, the development of speed throughout childhood is likely to be influenced by changes in muscle cross-sectional area and length, biological and metabolic changes, morphological alterations to the muscle tendon, neural/motor development, as well as biomechanical and coordination factors (Ford et al., 2011). Philippaerts et al. (2006) reported that sprint speed and anaerobic capacity in 11-13 year old youth footballers showed the largest gains around the time of peak height velocity, suggesting a combined training and maturational affect. However, the longitudinal data presented by Philippaerts et al. (2006) reported a decline in sprint performance in the 12 months preceding peak height velocity, and it has been argued that any subsequent gains may simply have reflected a correction of previously impaired performance (Ford et al., 2011). In contrast Valente-dos-Santos et al., (2012) in 11-17year old youth soccer players found total sprint time to improve progressively with age and subsequent increases in maturity. Interestingly Phillippaerts et al. (2006) also reported that in contrast to sprint performance, the anaerobic capacity of soccer players improved following peak height velocity. This is consistent with general observations that anaerobic performance probably improves into late adolescence (Bar-Or, 1983; Malina et al., 2004). Valente-dos-Santos et al. (2012) also reported a curvelinear increase in anaerobic performance with age, however, further assessment of the players beyond 17 years of age did not occur and consequently conclusions regarding performance levels in late adolescence could not be derived. It is important to note however that the sample size was relatively small and the subjects were sub-elite emphasising the need for further research. Therefore the limited research available does appear to support the hypothesis that improvements in anaerobic performance and speed during adolescence are influenced by not just training status but also maturation. However further research is required that legislates for these intercessions if conclusion are to be made regarding anaerobic fitness and speed development in elite junior soccer players. As previously argued research that incorporates not just genetic background but also training load longitudinally, while mapping changes in anaerobic fitness and speed development during adolescence concurrently are required to truly measure the influence of training on anaerobic fitness and speed development in elite youth soccer and whether key windows of opportunity exist in which development of these areas can be maximised.

The development of muscular strength and power is a multi-faceted, performance related fitness component that is also underpinned by muscular, neural and mechanical factors (De Ste Croix, 2008). The complex interaction of these components makes the study of the changes in strength and power during adolescence challenging (Ford et al., 2011). Strength increases linearly in boys until the age of 14 when a spurt is evident (Malina et al., 2004). It is important to note that this is a simplistic model utilizing chronological age as a maker for development in strength and power and does not take into account the individual timing and tempo of growth and maturation and the resulting variance in performance this would exhibit. Few longitudinal controlled studies have concurrently examined the influence of known variables such as maturation, training exposure using appropriate statistical techniques (De Ste Croix et al, 2002; Round et al., 1999; Wood et al., 2004). Most studies that have determined maturation have shown that it does not exert an independent effect when other factors, such as body mass and stature are accounted for (De Ste Croix et al., 2002; Hansen et al., 1997). Consistently, stature appears to play a key role in strength development and this may be attributed to the strength spurt that has been linked to peak height velocity (Ford et al. 2011). Research data for strength development in youth soccer players indicated peak gains in bent arm hang and vertical jump performance coinciding with peak height velocity, however, estimated velocities for the measures remained positive after peak height velocity (Malina et al., 2004). The trends for muscular strength and power reflect continued growth and perhaps as a consequence of systematic training (Philippaerts et al., 2006). However as with previous physical parameters, without longitudinal data incorporating training exposure and a measure of maturity true conclusions are difficult.

Although it is argued that there is a lack of empirical evidence to support the contentions of the long term athlete development model, the principles advocated are systemically embraced across many soccer developmental programs (Ford et al., 2011). The literature regarding long-term development of athletes highlights the concept of 'windows of opportunity', where accelerated adaptation can be achieved in response to the correct training regimes (Bayli and Hamilton, 2004; Stratton et al., 2004). However it is important to note that 30% of elite 9-16 year old soccer players in English Premier league clubs were reported to be either late or early developers (Johnson et al, 2009) with similar observations (37%) noted by Le Gall et al., (2007) in elite junior French players. This suggests that many players undergoing training in age defined groups might not benefit optimally from prescribed training regimes. With the large variability of skeletal age identified it would be very difficult for any coach or practioner to administer a program that would ultimately benefit all players and maximise their potential. In this context, to maximise the developmental programs administered it would be of significant benefit if players maturity level were evaluated longitudinally in conjunction with not just their performance outcomes but also training exposure to provide the coach all the necessary information to maximise a program that individually meets their requirements.

2.3.3. Physical Training

In elite soccer, coaches are constantly seeking the most effective formula for developing talented young players (Stratton et al., 2005) to ultimately succeed at senior level. Whilst the effects of acute and long-term systematic training on physical performance has been extensively studied in adults, research focused on adolescents is limited, this is despite the fact that young athletes respond differently to such exercise stimuli (Buchheit et al., 2012; Elferink-Gemser et al., 2012; Matos and Winsley, 2007; McNarry and Jones, 2012).

Previous research into junior soccer players has indicated that physical training has a positive impact on a variety of performance indices. For example, Jovanic et al., (2011) reported significant improvements in 5m and 10m sprint times ($p<0.05$) in elite U20 soccer players following 8 weeks of speed, agility and quickness training, compared to an aged matched control group. Using similar performance indices, Marques et al., (2013) reported that 6 weeks of supplementary plyometric and sprint training improved CMJ (7.7 % v -1.1%) and 30m sprint times (+1.7% v +0.9%) ($p<0.001$) in U14 non-elite soccer players compared to aged matched controls. With respect to aerobic performance, Helgerud et al., (2001) reported a 10.8% improvement in $\dot{V}O_{2max}$ in U18 elite soccer players compared to 4.5% in a control group after 8 weeks of an intervention strategy. However, it is important to note that while research does indicate that systematic training improves both elite and non-elite junior soccer players, levels of maturity have been omitted in these studies which makes it impossible to conclude whether improvements in physical performance can be attributed to physical training interventions or maturity.

While research is unable to conclude to what extent physiological improvements in performance in junior soccer players are as a consequence of intervention programs, or as a result of maturity, interest in the development of elite youth soccer players has increased. In recent years, particularly with the fruition of elite soccer academy's exposure and training stimulus has increased in elite youth soccer. Significantly research in U19 Portuguese soccer players has highlighted that elite players participate in a greater quantity of training than sub-elite players (d>1.2) (Rebelo et al., 2013). Interestingly Elferink-Gemser et al., (2012) reported that the intermittent endurance capacity of current players is up to 50% higher than that of players at the same competitive level 10 years ago across all age categories. A possible explanation hypothesised is an increase in training hours. However, this is an estimate and it maybe that the quality of training plays a more significant role (Ericsson, 2003). Williams and Reilly, (2000) argue that part of the continued physiological superiority of elite junior soccer players maybe due to the long-term systematic approach to training rather than a player's genetic physiological ability or difference in maturity status. However, our understanding of the relationship between training and performance improvements in youth athletes has historically been clouded by both ethical constraints and methodological issues, including the omission of appropriate controls required to identify any changes in fitness which cannot be attributed to growth and maturation. Meylan et al., (2013) in 11-15 year old male athletes matched for maturity reported a detraining effect after a systematically structured 8 week training program demonstrating that athletic performance may not only be induced by a training stimulus but also natural development, which is dependent on maturity status, however a lack control group made clarification difficult. Therefore while it is clear that physical training enhances physical performance in elite youth soccer players, with adolescent soccer players training during periods associated with a myriad of changes in growth and maturation that affect performance, differences highlighted in performance between elite and non-elite players may to some extent reflect not only training status and stimuli, but also the failure to adequately control for differences in biological maturation (Vaeyens et al., 2006; Malina et al., 2005). Future work which compares long-term changes in physical performance in these groups when accounting for both chronological age and biological maturation will therefore provide an important insight into the potential impact of long-term physical training on the changes in physical development of elite junior players (Sproviero et al., 2002).

2.3.4. Methods of Assessing Maturity

In light of the impact of growth and maturation on the changes in physical development of youth soccer players it is essential that valid and reliable estimates of maturity status are implemented within Academy long-term athlete development programmes.

2.3.4.1. Invasive methods

Skeletal age is said to be the most accurate method of assessing biological maturity (Le Gall et al., 2006; Malina et al., 2007). It is an indicator of biological maturation, the level of maturity of the bones of the hand and wrist (Malina et al., 2004). Assessment of skeletal age is based on standard radiographs of the hand-wrist skeleton: radius, ulna, carpals, metacarpals and phalanges. The hand and wrist is placed flat, palm down with the fingers slightly apart on the x-ray plate. With modern technology, exposure to radiation is minimal, 0.001 millisievert (mSv), which is less than natural background radiation, and radiation associated with the equivalent of 3 hours of television viewing per day (Malina, 2011). The wrist or hand is a convenient area to examine, although other joints such as the hip, knee, ankle, and foot have been used (Aicardi et al., 2000; Castriota-Scanderberg and De Micheli, 1995).

Changes in individual bones from initial ossification to the adult (mature) state are rather uniform and provide a basis for assessing skeletal age. Specific features of individual bones as noted on a posterior-anterior x ray occur in a regular and irreversible order and record the progress of each bone to maturity (Malina, 2011). Variation in radio graphical evaluation of hand-wrist bones among children of the same chronological age was noted early in the 20th century and was recommended as potentially useful tool to group boys for education, labour and sport (Roch, 1909). Three methods are commonly used to estimate skeletal age; Greulich-Pyle (Greulich and Pyle, 1959) and Fels (Roche et al., 1988) methods which are based on American children and Tanner-Whitehouse (Tanner et al., 1983) based on British children. The methods are similar in principle: a hand-wrist radiograph is matched to a set of criteria, however, the criteria and procedures adopted vary between methods. The Greulich-Pyle method was developed on American white children from Cleveland who were born between 1917 and 1942. The atlas includes 31 boys and 29 girls from birth to maturity. The method is then applied by assigning a skeletal age to each individual bone of the hand-wrist (Greulich and Pyle, 1959). Questionably the skeletal ages are generally based on the skeletal age of the standard plate to which the film the youngster most closely matches, therefore excluding variations amongst bones. In contrast the Tanner-Whitehouse method is based on (~2600) British children born between 1940 and 1955. Scores are assigned for a stage of growth of each bone and summed into a maturity score that is converted to skeletal age. While the Fels method is based on longitudinal records of 355 boys and 322 girls between 1932 and 1977 in south-central Ohio, USA. Grades and width measurements are entered into a program that calculates skeletal age and standard error (Roche et al., 1988).

Current research has indicated that skeletal age as an indicator of biological maturity has several advantages (Malina, 2011). Protocols can be applied throughout the postnatal maturation period; estimates are reliable and reasonably precise and reflect the maturation of an important biological system. However, disadvantages include exposure to low-level radiation, a need for specific training and quality control and high costs which collectively limits its application in the field (Roche, 1986; Malina, 2004; Beunen et al., 2006). It is also important to note that a single skeletal age measurement in isolation, has limited usefulness, but used in conjunction with a chronological age measurement, it has value in identifying early vs late biological maturity in individuals. However the assessment of skeletal age is not widely used to estimate the level of maturity attained by a young athlete at a specific period in time even though it would be a useful tool for any coach or practitioner (John and Freemount, 2009; Malina, 2011).

It is also important to note that a number of other methods have also been suggested as a possible tool for estimating skeletal age, but their validity can be challenged. Ultrasound assessment has been demonstrated to overestimate skeletal age in late maturing individuals and underestimate in early maturing individuals leading to the conclusion that ultrasound should not be considered a valid alternative to radiographic images (Malina et al. 2010). Magnetic Resonance Imaging (MRI) has also been used for chronological age verification in U17 soccer competitions (Dvorak et al. 2007). This approach however does not provide a marker of skeletal age, but simply can be used to identify mature individuals and in the context of U17 soccer tournaments, the identification of potentially overage players.

Other invasive methods of maturity measurement used most frequently in studies of youth maturational growth are stages of genital and/or pubic hair development (Beunen et al., 2006; Malina, et al, 2004). Clinical assessment of pubertal status requires direct examination of stage of genital and/or pubic hair, or palpation of the genitals to estimate testicular volume; the protocols are often viewed as an invasion of personal privacy (Malina et al., 2012). Many studies now use self-assessments of stage of genital and/or pubic hair. Data suggests a tendency for over estimation of early and underestimation of later stages of sexual development (Schlossberger et al., 1992). Therefore the practical application of genital assessment and /or pubic hair development it can be argued isn't a reliable or practical tool for estimation maturity.

2.3.4.2. Non- Invasive methods

Two indicators of maturity status that have minimal physical and /or psychological risk for the individual have recently been introduced in studies of young athletes (Malina et al., 2012). Firstly current age, height, sitting height, estimated leg length (height minus sitting height), weight is used to estimate time before or after peak height velocity and in turn predict age at peak height velocity (Mirwald et al., 2002). Predicted age at peak height velocity has been used in research with athletes (Sherar et al., 2007; Till et al., 2010) and has been practically utilised as central to the long-term athlete development model. However, Malina et al., (2012) using 11-14 year old Portuguese soccer players, reported small to medium ($r=0.26-0.43$; $P<0.01$) correlations between skeletal maturity (Fels method) and predicted peak height velocity. This raises questions regarding its ability to differentiate players by maturity status and therefore its practicality as a maturity indicator used by practitioners. Further research is therefore warranted regarding its validation particularly with reference to different ethical and demographic populations.

A second non-invasive method is percentage of predicted adult (mature) height attained at a given age. This requires current height and a prediction of adult height. Current height is then expressed as a percentage of the mature value. The rationale for the method is that two youths of the same age can have the same height, but one is closer to their mature height than the other (Malina et al., 2012). The youth who is closer to mature height is advanced in maturity status compared with the one who is further from mature height (Malina et al., 2004; Beunen et al., 2006). The method has been used in studies of activity levels (Cummings et al., 2009) and perceived competence in youth soccer (Cummings et al., 2006). However, Malina et al., (2012) in youth soccer players found relatively poor agreement between this method and skeletal maturation in 11-12 year old and 13-14 year olds again questioning the validity of non-invasive measures as an indicator of maturity status in junior soccer players. Conversely it is important to note that the results of this study are limited to a cross sectional sample of Portuguese youth soccer players 11-14 years of age. Though there was relatively poor agreement between maturity classifications based on skeletal maturity and those based on percentage of predicted mature height and predicted age at peak height velocity. There is a need for further consideration of non-invasive indictors to skeletal age based on the Greullich-Pye and Tanner-Whitehouse methods of assessment (Malina, 2011) until which care is warranted in applying non-invasive protocols.

Considering children of the same age group can differ as much as four years in skeletal age (Malina et al., 2000) and the worldwide popularity of soccer, the ethnically diverse composition of professional teams, and interest in youth players from developing countries, several factors instantly merit further investigation. Skeletal and sexual maturation and the proportions of sitting height/leg length to stature vary among ethnic/racial groups (Malina, 2011; Malina et al., 2004), and protocols for the prediction of mature height are based on populations of European ancestry. Further research with a larger sample that includes players of different ethnic backgrounds would be beneficial and aid future understanding. Further research is essential if this complex area of youth development is to be understood. This will enable practioners to not only maximise development but also match adolescence sports groups biologically rather than chronologically and may equalize competition, enhance chances of success, and possibly reduce incidence of injury.

2.4. Statistical Analysis

Previous research regarding physiological developmental in soccer have predominately been cross sectional in nature and therefore the statistical analyses have been based on this design incorporating multivariate analyses (Vaeyans et al., 2006; Vandendriessche et al. 2012). While longitudinal data analysis requiring serial measures over a period of time allows other forms of statistical analysis, such as multilevel modelling and General Linear Model, which are now well established in the social sciences where they are used for simultaneous study of relations among group-level and individual level variables (Greenland, 2000). With General Linear Modelling being suggested as the best option for analysing longitudinal data in developmental research (Arnau et al., 2010). The General Linear Model is used for modelling data associated with participants clustered into various levels of a higher level variable (e.g., level), where participants across different clusters are measured on a binary outcome (test performance) variable and one or more predictor variables (Wong & Mason, 1985) such as maturity or baseline scores. This approach enables unique relationships to emerge, which might otherwise be obscured by such variables as age or maturity (Pangelinan et al. 2011). The General Linear Model allows the researcher to assume that the age groups are random and therefore are representative of the population under study. With that, variables such as age and maturity could be dissociated as a random effect from other fixed effect predictors, such as motor proficiency and cognitive styles. This form of analysis also allows repeated samples over a number of years be studies (Hopkins, 2000).

2.5. SUMMARY

The findings of this review of literature have been directed towards the quantification of performance changes in elite youth soccer players and the impact developmental training programmes have on these outcomes. The goal of talent development programmes is to guide players towards professional status in adulthood (Elferink-Gemser et al., 2012). In elite youth soccer, clubs are investing considerable amounts of resources, financial and time, into development programs to achieve these aims. It remains unclear, however, whether this earlier talent identification selection and development is a good solution (Coelho et al. (2010). The literature reports limited research that has been conducted that quantifies this complex period of development and answers the question as to what impact these programmes maybe having on elite youth soccer players physiological development. Exercise adaptations to strength, anaerobic and aerobic training have been extensively researched in adults, however, young people appear to respond differently to such exercise stimuli compared to adults (Matos and Winsley, 2007) and little attempt has been made to quantify the relative contribution of long-term systematic training on such parameters. Future work which compares long-term changes in physical performance in these groups when accounting for both chronological age and biological maturation will therefore provide an important insight into the potential impact of long-term training on the changes in physical development of elite junior players (Impellizzeri et al., 2005; Sproviero et al., 2002). Therefore to achieve this aim, a systematic evaluation of training programmes, intensity and outcome are required (Impellizzeri et al., (2005). For since young athletes are increasingly being encouraged to train intensively from an early age in professional soccer such work is important in order to evaluate the contribution of such programmes to the athletes' development. As argued by Ford et al. (2011) what is more certain is that any future recommendations to help enhance physical athletic performance from infant to adulthood must be based on empirical evidence and if clear and analytical judgements are to be made regarding the effectiveness of any youth conditioning program growth and maturation must be considered. Therefore as a continuation of studies 1 and 2, the aims of studies 3 and 4 are to evaluate the impact of a long-term soccer specific training program and growth and maturation has on the physiological development of elite youth soccer players.

CHAPTER 3

GENERAL METHODOLOGY

3.1. General Methodology

3.1.1. Subjects

All subjects were chosen from U12, U14 and U16 teams registered at the same Premier League Academy. Across the same time period corresponding U12, U14 and U16 non-academy soccer players were monitored. The non-academy players were all school children attending the same school who were members of their respective school teams. No injured players were included in the study. All subjects were familiarised with the experimental procedures one week prior to the completion of the initial experimental trials and all testing was conducted at the same venue within the clubs training facility. Written informed consent and assent to participate was obtained from a parent or guardian and player respectively. The procedures were approved by the institutional Ethics Committee.

3.1.2. Procedures

3.1.3. Anthropometric Measures & Maturity Status

Body mass was measured to the nearest 0.2 kg (APM-150K, UWED, Taiwan), stature and sitting height were measured with a Leicester Height Measure to the nearest 0.01 m (SECA, Germany) according to procedures previously outlined by (Eston and Reilly, 2001). Maturity status of all subjects at each assessment point across the three year cycle was estimated using maturity offset (Mirwald et al., 2002). This estimates the time in years before or after peak height velocity (PHV) in years. Skeletal maturation was measured annually in the elite group in august of each year. Posterior-anterior radiographs of the left hand-wrist were taken. The radiographs were read by a single observer using TW3 method (Tanner et al., 2001). A maturity score is assigned to each epiphysis of the radius, ulna, 1st, 3rd and 5th metacarpals and phalanges and each carpal bone. The scores are given on the basis of recognizable stages of development through which each bone passes between its first appearance and mature state. For each RUS score, the corresponding RUS bone age equivalents were obtained from which predicted adult height is calculated via the equation. Predicted adult height = present height + a.RUS score + b.height increment + Residual SD (Tanner et al., 2001).

3.1.4. Field Test Measures

Tests were performed on third generation turf (indoor arena) wearing shorts, t-shirt and football boots (except for the countermovement jump in which subjects wore trainers). All participants performed a standardized warm up prior to commencing the physical assessments. This consisted of a 10-min jog and a series of stretches followed by 3x30m runs at approximately 80% of maximum perceived sprint speed. The following tests were completed in the same order on each of the two test days:

- Counter movement jump

A jump mat (Smartjump, Fusion Sport, UK) was used to measure counter movement jump. After three practice attempts, three trials were performed from which the highest jump distance was recorded as the criterion measure of performance. The participants started from an upright position on the jump mat, and following the eccentric phase (corresponding to a semi squatting position), the participants jumped vertically without using their arms to aid further height (arms remained at both sides, hands on the hip throughout the tests).

- 10m and 20m Sprint

After three practice sprints ranging from a jog to three quarter pace to near maximal sprint speed, subjects performed 3 maximal 20m sprints. Each sprint was separated by a 3-min recovery period. Participants commenced each sprint with either their right or left foot on a line 30 cm behind the start line. The fastest 10m and 20m time was used as the criterion measure of performance. Time was recorded to the nearest 100^{th} of a second using electronic timing gate (Smartspeed, Fusion Sport, UK).

- 505 agility test

Participants started in their own time and after three practice runs performed three maximal effort sprints through the course. A 3-min recovery period was permitted between each attempt. The fastest time was used as the criterion measure of performance. Time was recorded to the nearest 100^{th} of second, using electronic timing gates (Smartspeed, Fusion Sport, UK).

- Repeated sprint performance

One practice run in which the subjects were required to sprint 30 m with 20 s recovery was permitted. Participants then completed seven 30 m sprints interspersed with 20 s recovery. Mean time to complete the seven prints was used as the criterion measure of performance. Time was recorded to the nearest 100^{th} of a second, using electronic timing gates (Smartspeed, Fusion Sport, UK).

- Yo-Yo intermittent recovery test

Each participant performed Level 2 of the Yo-Yo intermittent recovery test which involved a series of repeated 20m shuttle runs with a progressively increasing running speed (15 down to 5 second intervals), interspersed with 10 s rest intervals.(Deprez et al. 2015). The speed of the shuttles is determined by an official CD, with subjects starting, stopping and turning on each ‘bleep’. When a subject failed to make a turn on the ‘bleep’ he was issued with a warning, after two consecutive warnings the player was withdrawn from the test and the level was recorded in metres.

CHAPTER 4

RELIABILITY OF ANTHROPOMETRIC AND PERFORMANCE MEASURES IN ACADEMY AND NON-ACADEMY SOCCER PLAYERS

4.1. Introduction

Physiological assessments and performance testing represent an integral part of the development programme of elite junior soccer players. Furthermore, such assessments have frequently been used for the purpose of talent identification (Janssens et al. 1998, Reilly et al. 2000) since elite junior soccer players frequently demonstrate an advantage over their sub elite counterparts in terms of body composition, speed, speed endurance, vertical jump and agility (Reilly et al., (2000). Similarly, Malina et al., (2007) reported that performance in 30-m sprint, vertical jump and an intermittent endurance test discriminated between successful and unsuccessful 13 – 15 year old soccer players.

When selecting any performance measure, test validity or the degree to which a test relates to performance must be an essential consideration (Svensson and Drust, 2005). Another important factor in the test selection, which can be considered of primary importance, is the test reliability. The reliability of performance test refers to the consistency or reproducibility of performance when an individual undertakes the test repeatedly (Hopkins, 2000). Factors that influence reliability can come from several sources. Sources of variability can occur because of changes in the mental or physical state of the individual between trials (biological variability). The methodology used to collect the data as well as the equipment may also contribute to the variability of the measurements. When the same individual is re-tested on different equipment or by different operators, additional error (due to differences in the calibration or functioning of the equipment or the ability of the operators) can surface (Hopkins, 2000). A test with poor reliability is unsuitable for tracking changes in performance between trials and lacks precision for the assessment of performance in a single trial (Tunstall et al., 2005). Therefore, researchers and practitioners who assess performance of athletes or other clients should utilize tests with high reliability.

Tests that more closely reproduce the demands of competition provide the best indication of performance (Hopkins et al., 2001). As a consequence, field tests are used extensively for evaluating the fitness of elite junior and senior soccer players (Svensson and Drust 2005). A problem inherent in delivering sports-specific performance tests in outdoor settings is the difficulty in controlling for environmental factors (e.g. wind speed and temperature) that influence test reliability and ultimately performance. However, the development of state of the art training Academies with purpose built indoor arenas now permit accurate assessment of performance under controlled conditions using protocols that simulate competitive events.

A number of studies have previously evaluated the reliability of relevant field tests in soccer players. For example, Gabbett et al. (2008) reported coefficient of variations (CV) of 1.3%, 3.2% and 1.9%, for 10m, 20m and 505 agility test. Similarly, values of 4.9% have previously been reported for soccer-specific endurance tests (e.g. yo-yo intermittent endurance test; Krustrup et al. 2003) These relatively small CV`s therefore suggest that such tests not only represent valid measures of performance in soccer players but provide a simply means of deriving reliable performance indicators. In line with such observations, the aim of the present was therefore to assess the reliability of a battery of anthropometric and field based performance tests in a group of academy and non-academy soccer players. This test protocol will enable the longitudinal changes in the physical development of these players to be monitored in later work.

4.2. Methods

4.2.1. Subjects

Eleven academy (mean ± s: age 11 ± 1 year, stature 1.52 ± 0.10 m, body mass 40.7 ± 9.0 kg) and non-academy soccer players (mean ± s: age 11 ± 1 year , stature (1.47 ± 0.11 m, body mass 42.1 ± 6.9 kg) were studied. All subjects were competitive soccer players and were familiarised with the experimental procedures and the associated risks. Though assent was not obtained from each individual player written informed consent to participate was obtained from a parent or guardian for each participant. The experimental procedures were approved by Liverpool John Moores University Ethics Committee.

4.2.2. Experimental design

All participants were fully familiarised with the anthropometric and field tests one week prior to completion of the main experimental trials. The familiarization protocol consisted of all participants completing all of the anthropometric and performance assessments in an identical way to that used during the experimental trials at the same time of the day. Stature, sitting height and body mass of the elite and sub-elite groups were measured on three separate occasions (48 hours apart). Performance trials were performed by each group on two separate occasions 48 hours apart. All trials were conducted at the same time of the day in order to avoid any circadian effects on performance (Reilly and Brooks, 1986).

- Anthropometric Measures

Anthropometric measures were conducted as described in the general methods section (3.1.4).

- Field Test Measures

Field test measures were conducted as described in the general methods section (3.1.4.)

4.2.3. Statistical Analysis

All data are expressed as mean ± *s.* A one-way within-participants general linear model (GLM) was used to determine if any large systematic bias was observed between repeated trials for the anthropometric variables. *Post- hoc* analysis by paired t – tests (with Bonferroni correction of alpha) was undertaken to examine which trials were significantly different from each other. Paired t-test was used to determine the occurrence of any systematic bias for the performance measures. Both anthropometric and performance data were further exported using the standard error of measurement (SEM), percentage SEM (Hopkins, 2000) and the limit of agreement (LOA) (Atkinson and Nevill, 1998) techniques. The difference in the anthropometric measures and performance outcomes between trials relative to the mean score was examined using Pearson product moment correlation coefficients. The alpha level for evaluation of statistical significance was set at $P < 0.05$.

4.3. Results

Anthropometric data

Table 4.3.1 shows the mean body mass, standing height and sitting height of the academy and non-academy players across the three trials. Body mass (academy, $p = 0.262$; non-academy $p = 0.63$), standing stature (academy, $p = 0.59$; non-academy, $p = 0.628$) and sitting height (academy, p = 0.034; non-academy, p = 0.157) were not significantly different between the three trials.

Table 4.3.1.Body mass, stature and sitting height across three trials for the academy and non-academy soccer players (Mean ± SD; n = 11)

Group	**Body Mass (kg)**			**Stature (m)**			**Sitting Height (m)**		
	Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3
Academy **(n =11)**	40.1 ± 9.00	40.2 ±8.9	40.2 ±9.0	1.51 ±0.1	1.52 ±0.1	1.52 ±0.1	0.77 ±0.06	0.77 ±0.05	0.77 ±0.05
Non-academy **(n = 11)**	42.09 ±6.87	42 ±6.48	41.9 ±6.4	1.47 ±0.11	1.47 ±0.11	1.47 ±0.11	0.76 ±0.05	0.76 ±0.05	0.76 ±0.05

The SEM for body mass, stature and sitting height across trials 1 to 3 was 0.34kg, 0.20cm and 0.03cm respectively for academy and 0.54kg, 0.04cm and 0.04cm for the non-academy players. When expressed as a coefficient of variation (CV) (percentage of the mean) values of 0.91%, 0.13% and 0.05% for the academy and 1.3%, 0.03% and 0.06% for non-academy were observed. The SEM and CV for the academy players between trails 1 and 2 and 2 and 3 was 0.3 kg and 0.1 kg (0.1 % and 0.1 %) for body mass, 0.2 cm and 0.1 cm (0.1 % and 0.1%) for stature and 0.1cm, 0.1cm (0.05% and 0.06%) for sitting height. For the non-academy group, values of 0.5 kg and 0.3 kg (1.1% and 0.8%) for body mass, 0.1 cm and 0.1 cm (0.03% and 0.03%) for stature and 0.1cm, 0.1cm (0.05% and 0.06%) for sitting height were observed).

The limits of agreement for body mass, standing stature and sitting height across the three trials were 0.93 kg, 0.55 cm and 0.09 cm for the academy group and 1.49 kg, 0.12 cm and 0.12 cm for the non-academy group respectively. Limits of agreement for body mass, standing height and sitting height between trial 1 and 2 and trial 2 and 3 for the academy players were 0.9 kg and 0.2 kg, 0.5 cm and 0.1 cm and 0.1 cm and 0.1 cm respectively. For the non-academy group values of 1.3 kg and 1.0 kg, 0.1 cm and 0.1 cm and 0.1 cm and 0.1 cm were reported. No significant correlation was observed between the difference in body mass (academy, r = 0.275 ; non-academy, r = 0.429), height (academy, r = 0.104 ; non-academy, r = 0.234) and sitting height (academy, r = 0.299 ; non-academy, r = 0.061) between trials 1-3 relative to the mean value in either group.

Figure 4.3.2.

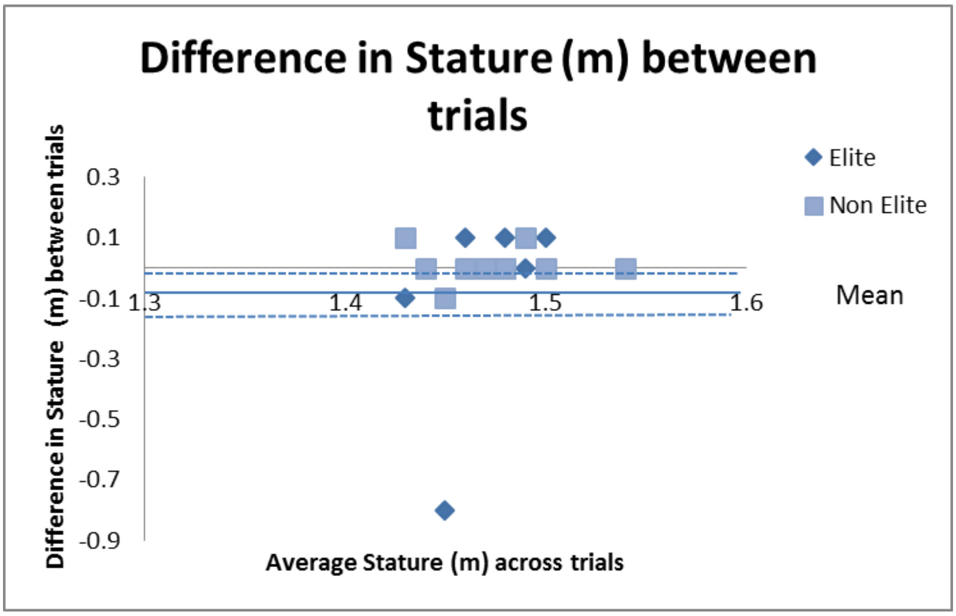


Figure 4.3.3.

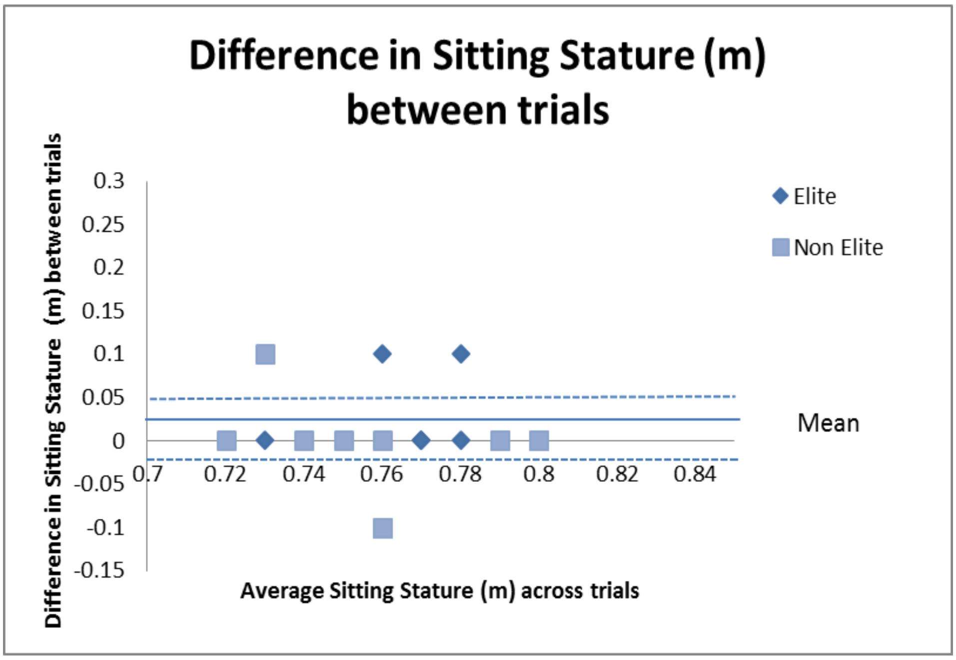
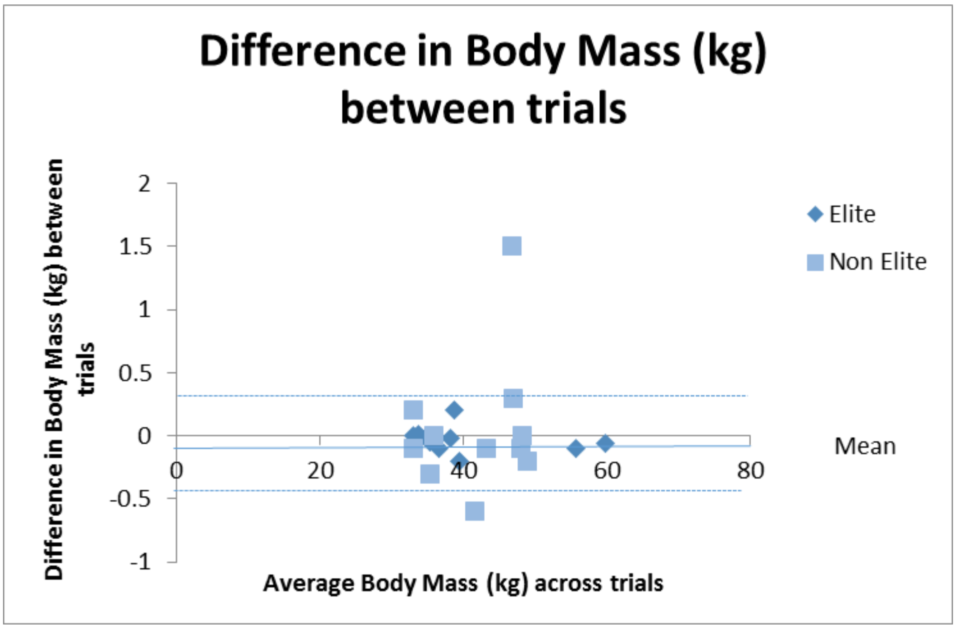


Figure 4.3.4



Performance Data

Table 4.3.5. shows the mean scores across the two trails for each of the physiological tests in both the academy and non-academy groups. Ten (academy p= 0.221, non-academy p = 0.770)

and 20 m (p= 0.423, p = 0.556) sprint time, vertical jump (p=0.585, p= 0.075), agility time (p= 0.429, p = 0.323), mean 30 m sprint time (p=0.251, p = 0.220) and performance in the Yo-Yo test (p= 0.193, p =0.225) for the academy and non-academy athletes were not significantly different between trials one and two.

Table 4.3.5. Physiological Tests across two trials for the academy and non-academy junior soccer players (Mean ± SD; n = 11)

Group	**10m (secs)**		**20m (secs)**		**Vertical Jump (cm)**		**Mean 6 x 30 m (secs)**		**Agility (secs)**		**Yo-Yo (m)**	
	Trial 1	Trial 2	Trial 1	Trial 2	Trial 1	Trial 2	Trial 1	Trial 2	Trial 1	Trial 2	Trial 1	Trial 2
Academy	1.95 ±0.1	1.98 ±0.16	3.38 ±0.12	3.34 ±0.15	26 ±5.9	26.4 ±6.5	7.51 ±0.23	7.58 ±0.2	2.6 ±0.3	2.64 ±0.52	1244 ±287	1213 ±148
Non-Academy	2.14 ±0.1	2.16 ±0.09	3.76 ±0.15	3.73 ±0.19	26 ±2.1	27.2 ±3.5	8.44 ±0.32	8.60 ±0.42	2.78 ±0.3	2.74 ±0.35	436 ±146	453 ±148

The SEM for 10 m, 20 m and 30 m average were 0.06 s, 0.11 s and 0.13 s for the academy group and 0.07 s, 0.11 s and 0.23 s for non-academy. When expressed as CV, values of 2.9 %, 3.2 %, 1.8 % was observed for elite and 3.5 %, 3.0 % and 2.7 % for the non-academy. The limits of agreement for 10 m, 20 m, and 30 m average were 0.2 s, 0.3 s and 0.4 s for the academy and 0.2 s, 0.3 s and 0.6 s for non-academy. The SEM for vertical jump, agility and the Yo-Yo test were 1.08 cm, 0.1 s and 46.9m for the academy group and 1.16 cm, 0.08 s and 27.6m for the non-academy. When expressed as CV, values of 3.2 %, 3.6 % and 1.8 % were observed for the elite and 2.9 %, 2.7 % and 6.2 % for the non-academy were observed. The limits of agreement for vertical jump, agility and Yo-Yo test were 3 cm, 0.3 s and 128.7 m for the academy and 3.2 cm, 0.2 s and 75.7 m for non-academy.

No significant difference in correlation was observed between any of the performance data results, 10m sprint time between was (0.581 academy, 0.308 non-academy) vertical jump (0.052 academy, 0.637 non-academy) 20m (0.865, academy and 0.308 non-academy) agility test (0.657, academy, 1 non-academy). 30m test (0 for academy, 0.297 non-academy) and yo –yo test (0.386, academy, 0.013 non-academy) between trials 1and 2 relative to the mean value in either group.

Figure 4.3.6.

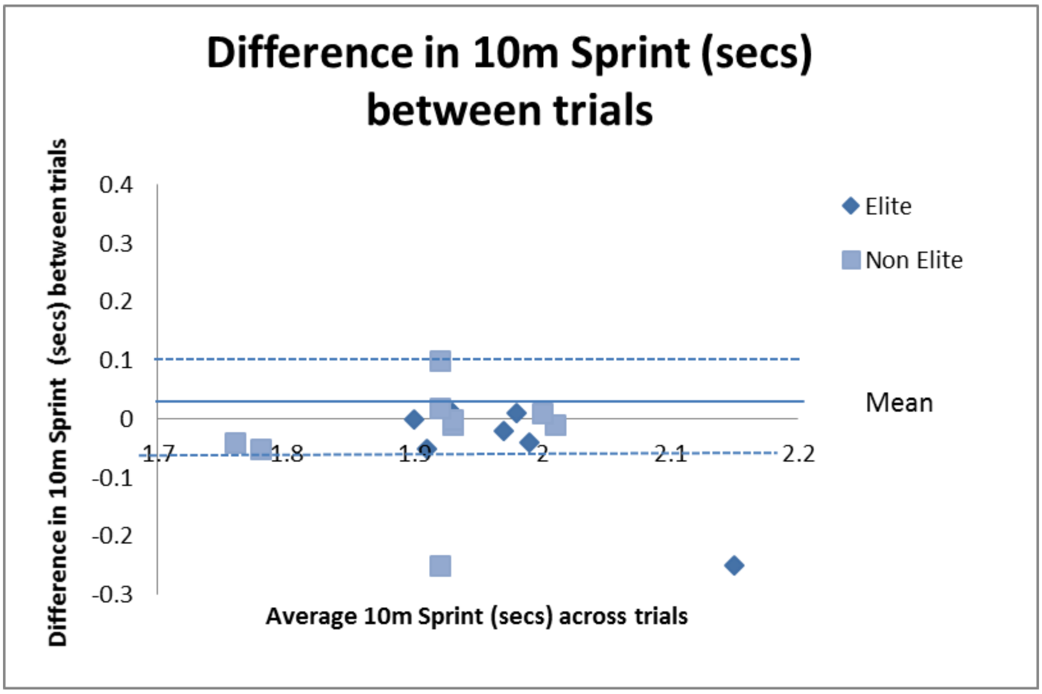


Figure 4.3.7

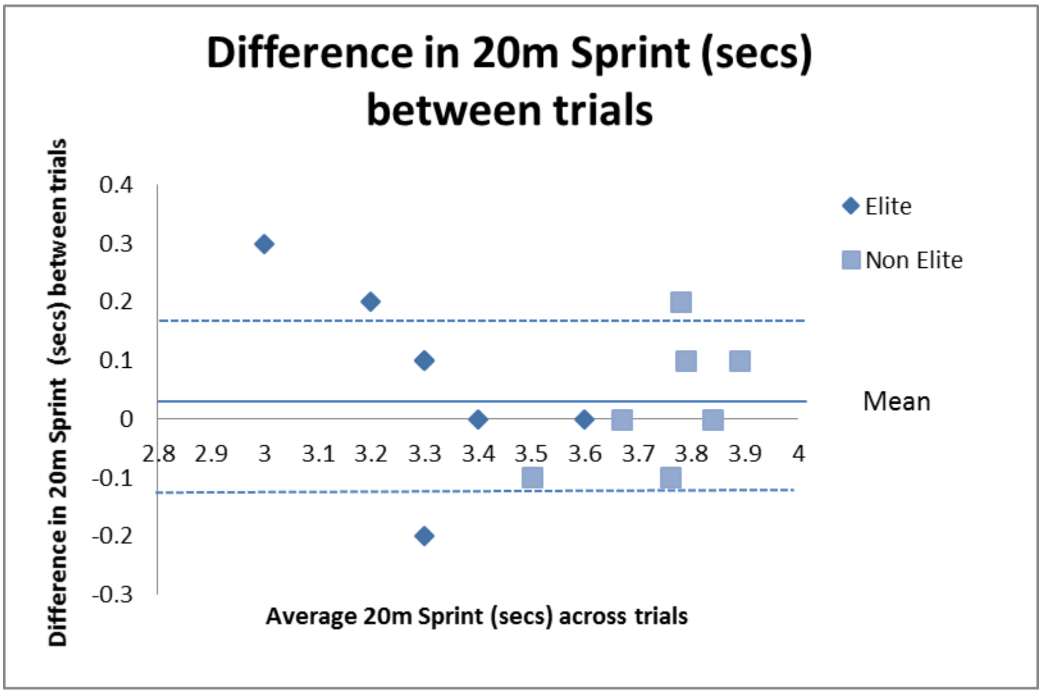


Figure 4.3.8.

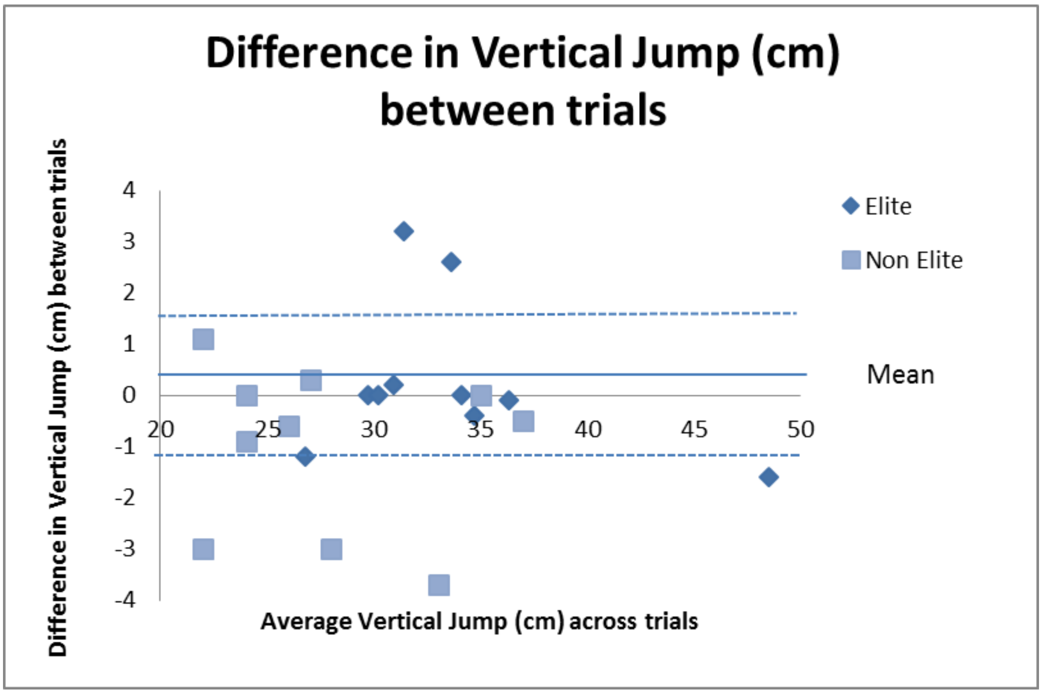


Figure 4.3.9.

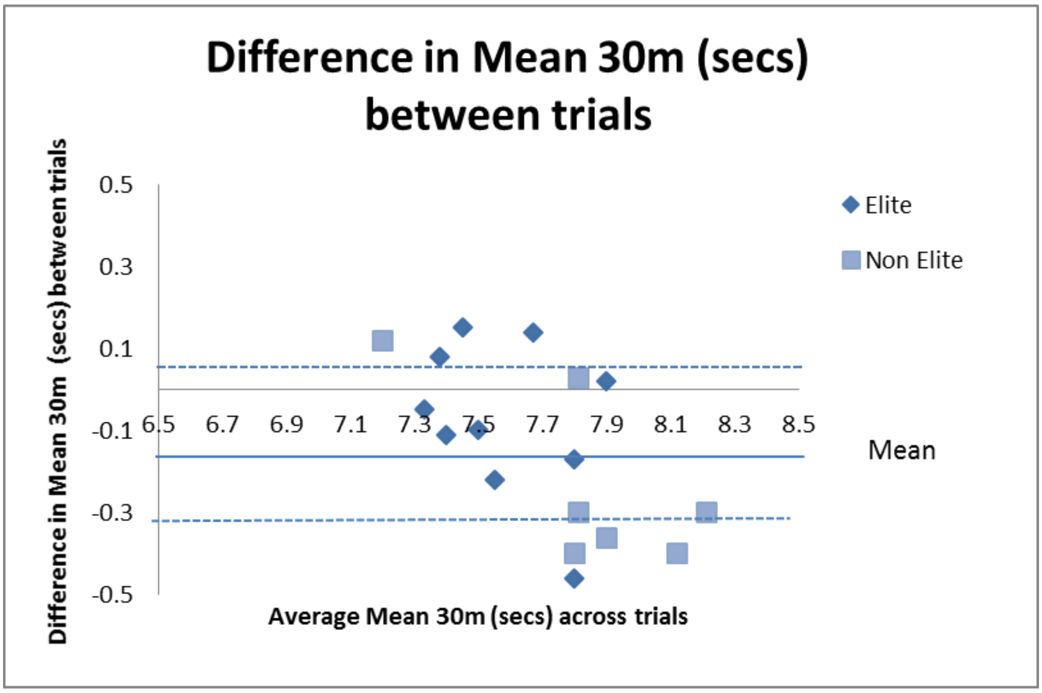


Figure 4.3.10.

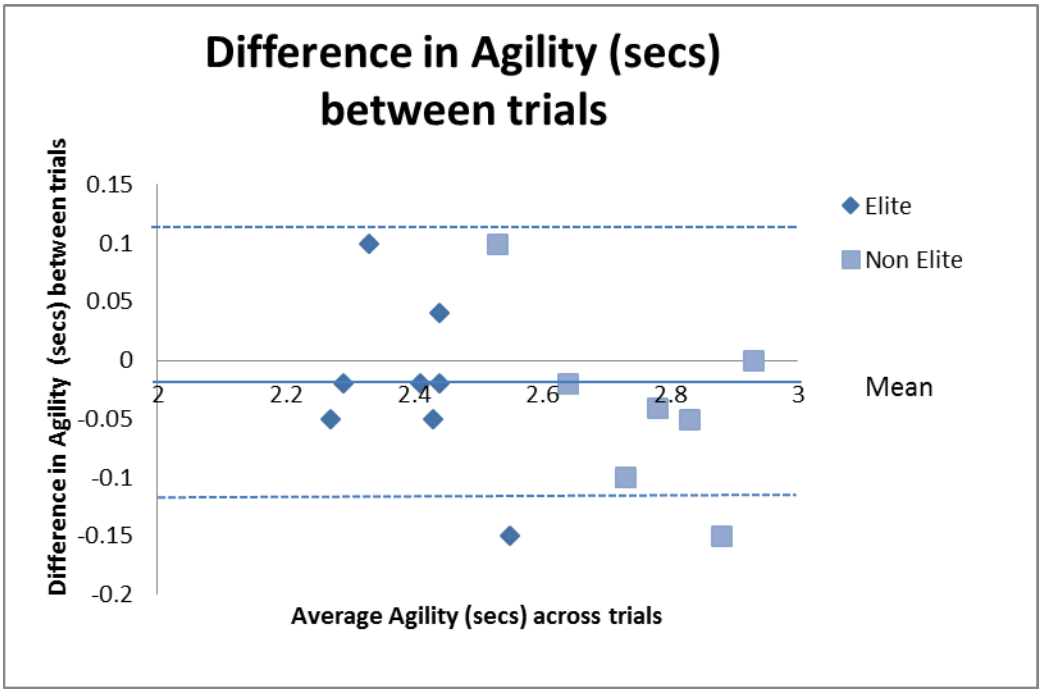
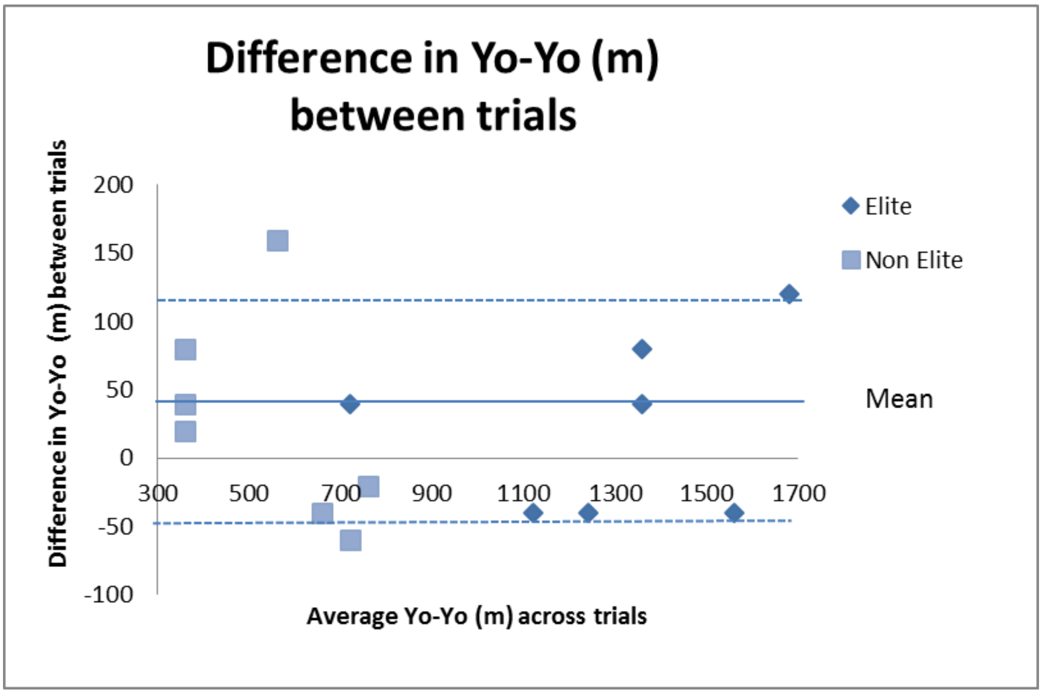


Figure 4.3.11.



4.4. Discussion

The aim of the current study was to assess the reliability of both anthropometric measurements and performance tests in academy and non-academy soccer players. This would permit investigations into the longitudinal evaluation of soccer-specific training on the physical development of elite junior soccer players.

No significant differences in mean body mass, stature and sitting height was currently observed between trials (Table 1.5.1). The SEM for body mass, stature and sitting height of the subjects across trials 1 to 3 was 0.34 kg, 0.20 cm and 0.032 cm respectively for the academy and 0.54 kg, 0.04cm and 0.04 cm for the non-academy subjects. This SEM for standing height compares favourably with 0.22 cm previously observed by Malina et al. (2005) in youth football players.

When expressed as a coefficient of variation (CV) (percentage of the mean) values of 0.91%, 0.13% and 0.05% respectively for academy players body mass, stature, and sitting height were observed and 1.3%, 0.03% and 0.06% for non-academy across the three measurements. The reliability of these values are supported by Klipstein-Grobusch et al. (1997) who found CV values of 0.0-6.4% for body mass, stature and sitting height measurements. Collectively these observations indicate that the estimated variability in anthropometric assessments undertaken by the present practitioner are similar in magnitude to previous observations.

Performance in any of the field test currently employed was not significantly different between trial 1 and 2 in either the academy or non-academy group (Table 4.2.2). This suggests that the present protocol and familiarisation process was sufficient in reducing the variability associated with the equipment and the testing procedure as well as the learning effects on any of the performance measures. As such, reproducible measures in these tests can be obtained in future studies by simply ensuring prospective subjects complete the present familiarisation process.

The SEM for the 10 m, 20 m and 505 Agility test was 0.06 s, 0.11 s and 0.10 s for the academy and 0.07 s, 0.11 s and 0.08 s for the non-academy group. When expressed as a CV, values of 2.9 %, 3.2 %, 3.6 % was observed for the academy and 3.5 %, 3.0%, 2.9 % for non-academy. These observations are consistent with reports by Gabbett et al. (2008) who previously observed CV's of 1.3%, 3.2% and 1.9% respectively in elite adult rugby league players undertaking 10 m, 20, m and 505 Agility test. The SEM for vertical jump, the Yo-Yo intermittent endurance test and mean 30 m sprint time were 1.08 cm, 46.9 m and 0.12 s for the academy and 1.16 cm, 27.6m and 0.23 s for the non-academy. When expressed as CV values of 3.2 %, 3.9 %, 1.8 % and 4.4 %, 6.2 % and 2.7 % were observed for the academy and non-academy respectively. These observations are consistent with the findings of both Stalbom et al. (2006) who reported vertical jump CV values of 1.4% on a variety of lower limb dominant adult sportsmen and Krustrup et al. (2003) who reported variability of 4.9% in elite adult soccer players undertaking the yo-yo intermittent recovery test. Finally it is interesting to note that even though physiological testing is accepted as an important part of the preparation of soccer players (Svensson and Drust 2005) and therefore used widely in elite players, no difference in reliability was found between academy and non-academy groups indicating that the protocols used across both groups in the current study are reliable.

In conclusion, the results of the current study demonstrate that both academy and non-academy soccer players are able to reproduce a variety of soccer related performance tests following completion of one familiarization trial. The current data suggests the suitability of such experimental protocols for the longitudinal evaluation of anthropometric and physiological profiles of both academy and non-academy soccer players.

CHAPTER 5

MATURITY OFFSET AS AN INDICATOR OF BIOLOGICAL MATURATION IN ACADEMY SOCCER PLAYERS

5.1. Introduction

The performance characteristics of growing children and adolescents are mediated to some extent by their biological maturity status (Beuen et al., 2006; Malina et al., 2000; Pittoli et al., 2010). Children differ greatly in the rate at which they pass through the various stages of growth with some children characterised by a rapid rate of growth and attainment of adult stature at a relatively early age, whereas others have a slow rate of growth and finish relatively late (Sherar et al., 2005). Consequently, in athlete developmental programmes coaches and practitioners need to be continually aware of changes in growth and maturity of their athletes when assessing their performance capabilities (Malina et al. 2006; Philippaerts et al., 2006; Malina et al. 2012).

The application of chronological age as an assessment of growth and maturation is of limited value (Malina et al. 2000), consequently a range of methodologies have been adopted in an attempt to provide valid and reliable estimations of maturity status (Mirwald et al. 2002). Though ultrasound and MRI have been used Skeletal age assessment via a left wrist radiograph, is considered the gold standard measure of maturation and is applicable from childhood through the entire period of growth to maturity. However, this method is costly and requires specialized equipment and interpretation (Malina et al. 2012). Another method involves the assessment of secondary sex characteristics (pubic hair, genitals, testicular volume) which is limited to the adolescent period and in a nonclinical setting is considered to be personally intrusive by adolescent children and their parents (Mirwald et al. 2002).

In light of the difficulties associated with these methods, a number of non-invasive estimates have been proposed. The use of percentage of predicted adult (mature) height attained at a given age may provide a valid estimate of adult stature in 9-15 year old soccer players (Malina et al., 2005; Malina et al. 2007). However, this approach is limited by the difficulty in obtaining biological parental heights. Peak height velocity is a non-invasive, inexpensive and simple way of assessing biological maturity and has been used in research studying activity levels (Cumming et al., 2009), perceived confidence in youth soccer (Cumming et al., 2006), and injury risk in American football (Malina et al., 2005; Malina et al., 2006). However, this method requires serial measurements of stature over a number of years surrounding the period of peak height velocity and therefore does not represent a method through which to derive an instantaneous measure of the athletes maturity timing (Mirwald et al., 2002).

In an attempt to provide an instantaneous measure of somatic maturity in the applied setting, a non-invasive method derived from chronological age, stature, sitting height, and weight has been used to predict the time before or after PHV (Mirwald et al., 2002). Frequently termed maturity offset, (Mirwald et al., 2002), this index is nonintrusive, inexpensive and represents a reliable simple means of assessing biological maturity (Sherar et al., 2005). Mirwald et al. (2002) in non-athletic children argues that maturity offset is a reliable tool that can estimate maturity offset within an error of ±1yr, with a coefficient of determination of 0.92 and a standard error of 0.24 (SD 0.65) years in 8-16 year old boys. Concluding that it could be used as a practical tool for the measure of biological maturity in adolescent athletes. However it is also important to note that these researchers did caution that more validation work was required for this prediction equation and that care must be taken when obtaining the sitting height, as this variable was used throughout the formula. Consequently, any error in this measurement would magnify the error in the maturity-offset value. Also as argued by Malina et al. (2006) it is important to be aware that all predictions have associated errors so application to individuals need to be made with care. This is clearly the case in adolescent age groups as individual differences in the timing and tempo of the adolescent growth spurt are considerable and it is therefore important to be aware that these may consequently contribute to prediction error. Alongside estimates of time before or after PHV, maturity offset may also be incorporated into methodologies to predict adult stature (Sherar et al., 2005) offering a further practical means of estimating maturity status. For example, Sherar et al (2005) demonstrated that in non-athletic adolescent boys adult height can be predicted between 5cm and 8cm 95% of the time, which corresponds closely to estimations derived via skeletal age assessment. However, to date, no attempt has been made to compare estimates of end height stature in elite youth soccer players when derived from maturity offset and skeletal maturity. Therefore the aim of this investigation was to examine the agreement between skeletal maturity and maturity offset estimates of end height stature in elite junior soccer players.

5.2. Methods

5.2.1. Subjects

Measurements from seventeen U12, twenty seven U14 and sixteen U16 academy soccer players were taken annually (September) over the course of three domestic seasons. All players were registered at the same Premier League Academy. Twenty two players were assessed across each of the three domestic seasons, eight across two and thirty players assessed on one occasion. All subjects were familiarised with the experimental procedures and the associated risks. Written informed consent and assent to participate was obtained from a parent or guardian and player respectively. The procedures were approved by the institutional Ethics Committee.

5.2.2. Experimental Design

Participants were classified into one of eight maturity offset categories (-3 to +4) constructed using 1 year intervals. Individuals were aligned on their PHV (biological age). This was done by subtracting the chronological age at time of test from chronological age at PHV (Sherar et al., 2005). Therefore a continuous measure of biological age was generated that indicates the maturity status at the time of examination (Malina et al., 2012). Cross tabulations of maturity status classification between the non-invasive measure and skeletal measure of maturation were then calculated. This enabled the calculation of agreement levels between both methods based on predicted end height stature.

Anthropometric Measures

Body mass **[**coefficient of variation (CV) (percentage of the mean) < 1 %] was measured to the nearest 0.2kg (APM-150K, UWED, Taiwan). Stature and sitting stature were measured with a Leicester Height Measure to the nearest 0.01m (SECA, Germany). Stature (% CV< 1 %) was measured with the subject standing with their feet together and their heels, buttocks and upper part of back touching the scale. The head was placed in the Frankfort plane (Jones et al. 2006). Participants were instructed to inhale whilst the head board of the stadiometer was placed down on to the Vertex. Measurement was taken prior to the participant exhaling. Sitting stature (% CV < 0.01%) was measured with the participant seated on a measuring box 40-cm high with hands rested on the subject's thighs. Procedures outlined for stature were repeated for determination of sitting stature. Care was taken to ensure the subject didn't contact the gluteal muscles or push with the legs (Eston and Reilly 2001). Chronological age (CA) was calculated from birth and measurement dates; ages ranged from 11.5 to 15.8 years.

Non-invasive maturity estimate

Maturity status at each assessment point was estimated using maturity offset (Mirwald et al., 2002). This method requires chronological age and a measurement of stature, sitting stature, and weight. It estimates the time (years) before or after peak height velocity (PHV) by subtracting the chronological age at the time of test from the chronological age at PHV. The equation consists of chronological age, leg length, weight, and trunk length and used to predict the number of years from PHV. Therefore a measure of current biological age was generated (rate of somatic growth) and compared with skeletal age (Sherar et al., 2005). Subtracting years from PHV from age at test gave a predicted age at PHV. Predicted years from PHV were used to estimate stature left to grow for each individual using maturity specific cumulative velocity curves (Sherar et al., 2005). Stature left to grow was added to stature at time of test to provide a predicted adult stature for each individual.

Skeletal Maturity

Posterior-anterior radiographs of the left hand-wrist were taken. The radiographs were read by a single observer using TW3 method (Tanner et al., 2001). A maturity score was assigned to each epiphysis of the radius, ulna, 1st, 3rd and 5th metacarpals and phalanges and each carpal bone. The scores were given on the basis of recognisable stages of development through which each bone passes between its first appearance and mature state. For each RUS score, the corresponding RUS bone age equivalents were obtained from which predicted adult height is calculated via the equation. Predicted adult stature = present stature + a.RUS score + b.height increment + Residual SD (Tanner et al., 2001). Predicted adult stature of 20 radiographs (12-16 years boys) were blindly calculated with inter observer coefficient of variation (CV) of 0.83% (published observer Tanner et al., 2001) and intra observer of 2.28%.

5.2.3. Statistical Analysis

All data are expressed as mean + SD. A linear mixed model was employed to quantify the magnitude of systematic bias between the MO and skeletal x-ray methods at each of the maturity offsets. This model took into account the replicated measurements of predicted end height. The nature of systematic and random errors was explored with the aid of a Bland Altman plot and random errors were quantified with the typical error and limits of agreement statistics (Hopkins, 2000; Atkinson and Nevill, 1998; Bland and Altman, 1999). The alpha level for statistical significance was set at $P<0.05$

5.3. Results

The mean (95%CI) difference between methods for the data pooled over all the maturity offsets was 0.8 cm (-0.6 to 2.3). This difference was not statistically significant ($p = 0.242$). The pooled mean ± SD predictions of end height were 180.7±0.9 cm and 179.9 ± 0.9cm for MO and skeletal x-ray respectively.

A significant interaction was observed between measurement method and maturity offset level ($p <0.001$; Table 1). At -3 ($p=0.333$), 0 ($p=0.379$) 2 ($p=0.291$), 3 ($p=0.769$) and 4 ($p=0.924$)

years relative to PHV and predicted end height stature was not clinically nor statistically significantly different between the skeletal and maturity offset estimates. In contrast, estimates of end height stature were larger (>2.5 cm) and statistically significantly different at maturity offset values of -2 ($p<0.001$), -1 ($p=0.036$) and 1 ($p=0.001$).

Table 5.3.1. Comparison of Maturity Offset and Skeletal Estimations of End Height Stature in Elite Youth Soccer Players Relative to Years from PHV (Mean±SD)

Maturity Offset (yrs.)	**Maturity Measure**	**Mean End Height Stature (cm)**	**Mean (95% CI) difference between methods (cm)**	**Typical Error (cm)**	**Limits of Agreement**
-3	Maturity Offset	170.6 ±6.0	2.9 (-3.0 to 8.8)	1.2	3.4
	Skeletal X ray	167.7 ±6.0			
-2	Maturity Offset	173.4 ±9.4*	-4.6 (-7.1 to -2.1)	6.3	17.5
	Skeletal X ray	178 ±9.4*			
-1	Maturity Offset	182.0 ±7.5*	2.5 (0.16 to 4.9)	4.9	13.6
	Skeletal X ray	179.5 ±7.5*			
0	Maturity Offset	183.0 ±6.7	1.1 (-1.3 to 3.5)	4.2	11.6
	Skeletal X ray	181.9 ±6.7			
1	Maturity Offset	183.3 ±5.3*	4.7 (1.8 to 7.5)	2.9	8.1
	Skeletal X ray	178.6 ±5.3*			
2	Maturity Offset	182.9 ±7.7	1.1 (-1.0 to 3.1)	2.1	5.8
	Skeletal X ray	181.8 ±7.7			
3	Maturity Offset	184.3 ±6.7	0.5 (-4.2 to 3.1)	1.6	4.4
	Skeletal X ray	184.9 ±6.7			
4	Maturity Offset	186.2 ±5.6	0.4 (-7.6 to 6.9)	0.3	0.7
	Skeletal X ray	186.6 ±5.6			

*Significant difference between mean end height stature ($p<0.05$)

Scrutiny of the Bland-Altman plot (Figure 5.3.2) revealed that the bias between methods also depended on the magnitude of predicted end heights. For relatively low values of predicted end height, MO measurements were higher than x-ray. But at relatively high values of end height, the opposite was true (Figure 5.3.2). Therefore, for every 1 cm increase in predicted end height, the systematic bias between methods decreased by approximately 0.5 cm. At the average predicted end height of approximately 180 cm, bias was very small. When this proportional bias was taking into account by applying the regression methods of Bland-Altman (1999), the typical error between the MO and skeletal x-ray for predicted end height stature was estimated to be 4 cm (95% LOA of ±11cm). It can be seen on the Bland-Altman plot that this random error is consistent across the measurement range as long as the proportional bias is taken into account.

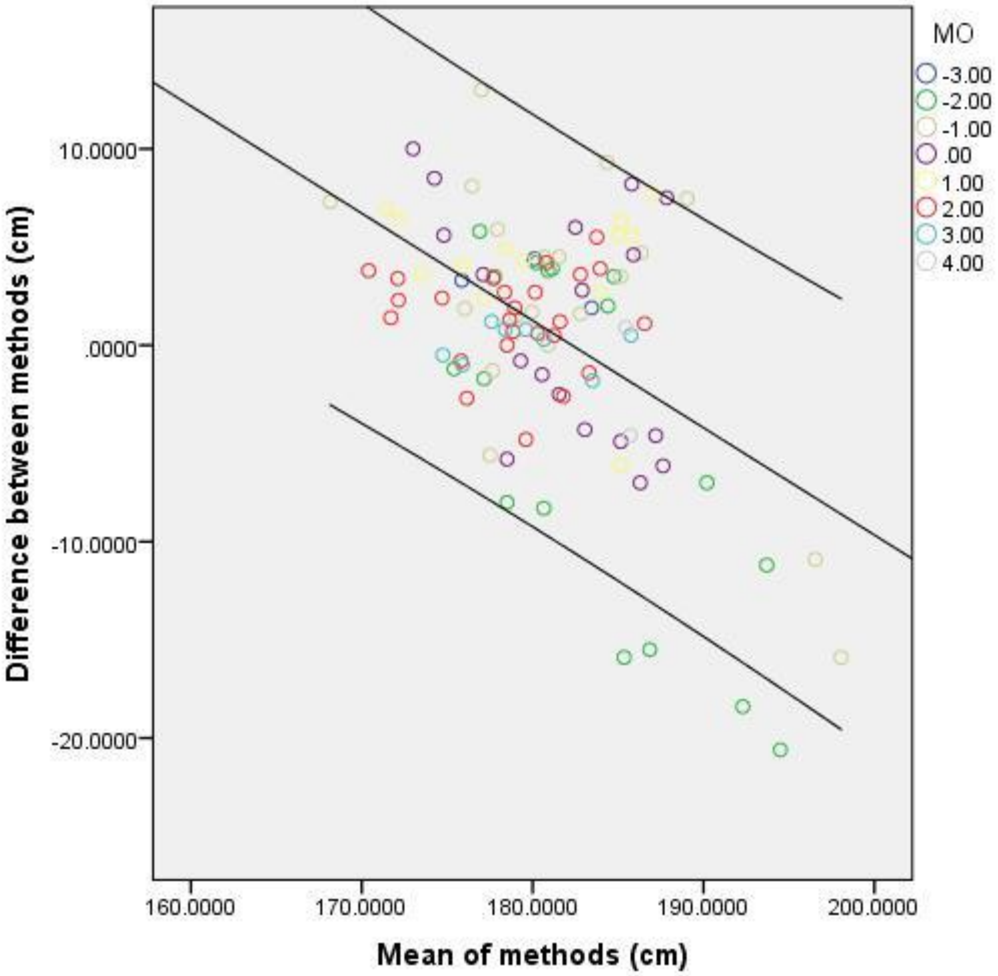


Figure 5.3.2. Bland-Altman plot showing the inversely proportional bias between methods and the 95% limits of agreement (taking into account this bias).

5.4. Discussion

The aim of the present study was to address the agreement between estimates of end height stature in elite youth soccer players' using skeletal x-ray and the maturity-offset method. Overall agreement was poor with an SEM and 95 % LOA of 4 cm and ±11cm observed respectively. Improved agreement was, however, generally observed in more mature boys. Overall, caution should be applied when utilizing maturity offset to predict end height stature in elite youth soccer players.

In the current investigation, overall estimates of end height stature independent of time relative to PHV were not significantly different when derived from MO and skeletal x-ray ($p = 0.242$; 95% CI -0.6-2.3; ES 0.4). However, the SEM and 95 % LOA of 4 cm and ±11cm respectively are much greater than previously reported for non-athletic boys suggesting that the use of maturity offset as an indicator of maturity in youth soccer players may be limited. At -3, 3 and 4 years of PHV the 95 % LOA were within those (±5.35) reported by Sherar et al., (2005), however, all other estimations were far greater than those reported previously with LOA values of 17.5, 13.6 and 11.6 cm observed at -2, -1 and 0 maturity offset grades respectively. This further suggests that estimations of end height stature derived from maturity offset does not appear valid. Interestingly, the present results seem to be consistent with previous longitudinal observations which indicate that non-invasive measures of maturation may be different in younger compared with older players (Bielicki et al., 1984). It can be argued that this maybe a consequence of individual differences in the timing of adolescent growth and in the rate of growth during the growth spurt (tempo) which would contribute to the observed increased deviations. Interestingly Malina et al., (2012) reported greater agreement between skeletal age and predicted age at peak height velocity and percentage mature stature in 13-14 year old male soccer players than 11-12 year old and argued that this suggests a general maturity factor at ages associated, on average, with maximal growth in height during the male adolescent spurt. Interestingly the current study found no significant differences between the two measures at a maturity offset grade of -3 and 3 and 4. Therefore it could be hypothesised that this may be due the subjects being pre and post PHV and the significant period of growth which this entails. Significantly this would mean that the scores would either precede or post-date individual differences in the timing and rate of adolescent growth which would contribute to increased deviations between individuals (Malina et al., 2005). Further longitudinal research that includes a larger sample of pre-pubertal subjects at baseline would be of significant interest to help clarify this. It is also important to note that the results of the present study are also limited to a European longitudinal sample of 12-16 year old elite soccer players. Further research that includes a representative sample of players of different ethical backgrounds would therefore be informative. It should also be noted that to obtain the degree of accuracy required to make any accurate predictions or evaluations regarding levels of maturity utilizing, correct protocols of measuring sitting stature, standing stature and weight need to be followed.

In summary, given the worldwide popularity of soccer and the vast amounts of time and money professional football clubs are investing in youth development academy’s a practical measure of maturity is imperative. However, the present findings question the validity of maturity offset as a tool to estimate end height stature in youth soccer players. Therefore in future studies within this thesis, maturity offset will simply be used to provide an indication of maturity timing.

CHAPTER 6

QUANTIFICATION OF THE TYPICAL WEEKLY IN-SEASON TRAINING LOAD IN ACADEMY AND NON-ACADEMY SOCCER PLAYERS

This study was published as a manuscript in a special edition (Identifying and developing elite soccer players) of the Journal of Sports Sciences (Appendix 11.1)

6.1. Introduction

Training to improve athletic performance is an adaptative process that involves progressive manipulation of a physical training load (TL) (Manzi et al. 2009). While training should be considered a multifactorial process, enhancements in performance are achieved through a planned manipulation of the TL (a product of the volume and intensity of training) (Mujika et al. 2004; Manzi et al. 2010). As a consequence, accurate assessment of the individuals TL represents an essential component of effective training prescription.

Assessment of the daily TL has traditionally focused on external markers such as the duration and frequency of the training stimuli (Brink et al. 2010). However, the internal load, or the relative physiological stress imposed on the athlete, represents the important stimulus for training induced adaptation (Viru and Viru, 2000). It is essential therefore to use a valid measure of the internal TL to monitor and manipulate the training process. This is particularly important in team sports such as soccer where differences in individual responses to the same external workload occur (Manzi et al. 2010). Several approaches have been used in an attempt to quantify the internal TL across a range of sports. Many of these have been derived from measures of heart rate (HR) (Morton et al., 1990; Bannister, 1991). More recently, the subjective rating of perceived exertion (RPE) using the category ratio scale has become a popular tool through which to quantify the internal TL (Foster et al., 2001). This simple method (session-RPE) quantifies internal TL by multiplying the whole training session RPE using the category ratio scale (CR10-scale) (Borg et al., 1987) by its duration. This provides a valid measure of the internal TL during both aerobic soccer training (Impellizzeri et al., 2004) and anaerobic (Day et al., 2004) exercise. Consequently, it has frequently been used to assess the global internal load of training in team sports such as basketball and soccer (Coutts et al., 2003; Impellizeri et al., 2004; Manzi et al. 2010).

Previously, researchers have attempted to describe the typical internal TL associated with elite adult soccer players during the in-season competitive phase (ranging from 2-12 weeks) using both session-RPE and HR (Erling et al., 2011; Little and Williams, 2007). In contrast, little attempt has been made to characterise the TL typically undertaken by elite junior soccer players. This lack of attention towards the junior players is surprising since long-term physical development represents an important aspect of player development programs within elite clubs. Systematic progression of overall physical load is therefore likely to be essential for both enhancing physical performance and the prevention of overtraining and injury (Matos and Winsley, 2007).

Impellizzeri et al., (2004) and Brink et al. (2010) previously evaluated the TL in elite junior (~17-19 yr) soccer players during the in-season competitive phase using session-RPE and session duration. However, neither the evaluation of TL on younger players and or a comparison of TL across a range of age groups within an elite club have been reported. Ford et al. (2011) suggest that any recommendations for enhancing physical performance from infant to adult must be based on empirical evidence. With this in mind it is evident that such information is crucial if knowledge on training loads at different stages within the football academies is to be enhanced and current practices not only evaluated but maximised.

Therefore the aim of the present study was to evaluate a typical weekly training internal TL of academy and non-academy soccer players (U12, U14, U16) during the in-season competitive phase. This will provide a basis for future work that will focus on comparing changes in the long-term physical development of academy and non-academy soccer players.

6.2. Methods

6.2.1. Subjects

Six U12 (stature 1.52 ± 0.10 m, body mass 40.7 ± 9.0 kg) , six U14 (1.67 ± 0.09m, 56.7 ± 10.1kg) and six U16 (1.76 ± 0.05m, 68.1 ± 3kg) academy and six U12 (1.47 ± 0.11 m, body mass 42.1 ± 6.9 kg), U14 (1.61 ± 0.04m, 52.04 ± 6.9kg) and U16 (1.73 ± 0.06m, 66.4 ± 7.37kg) non-academy soccer players were monitored over a two week period during the first month of a competitive season, specifically the first two weeks post pre-season training schedule. (mean age ± 1 year). The non-academy players were all school children attending the same school who were members of their respective school teams. Two players were chosen from each of the three main outfield playing positions (defenders, midfielders and attackers). No injured players were included in the study.

6.2.2. Weekly Training Overview

To evaluate the weekly organisation of training sessions, specific sub-components of each session were categorized according to the specific focus of training. This categorization was made following discussion with the age group coaches. Physical training (PT) was defined as a programmed session that was devised to enable players to cope with the physical demands of match-play these included not just none football running sessions but also small sided games that were designed exclusively for physical preparation. Sessions focused on the player's tactical understanding and/or their technical ability was defined as technical/tactical (TT) (Bangsbo, 1994). When the session included both technical/tactical activities immediately followed by physical training, the session was defined as physical and technical/tactical training (PT/TT) (Bangsbo, 1994). Warm-up and cool down were also specifically defined for each training session irrespective of the training type. The duration of all sessions was recorded using a stopwatch (Timex T5G811 Stopwatch).

6.2.3. Determining the physiological load

The physiological load of all field-based training sessions and competitive matches during the two week training block was monitored using heart rate (HR). All procedures were identical for the experimental as well as the control groups. All matches for all age groups were competitive 11 v 11 and of an 80 minute duration. Heart rate was recorded every 5 s using a short-range telemetry system (Polar Team System®, Kempele, Finland). The physiological intensity of all training sessions were indicated by both mean absolute (beats•min-1) and relative values (i.e. the corresponding percentage of maximal HR; %HRmax) of HR. The time spent within specific HR zones (90-100% of HRmax, 80-90% of HRmax, 70-80% of HRmax, 60-70% of HRmax, 50-60% HRmax and <50% of HRmax) were also measured (Tae-Seok et al., 2011). The maximal heart rate of each individual player was assessed using the Yo-Yo intermittent recovery test level 2 (Bradley et al. 2009; Bangsbo et al., 2008). Testing was administered two weeks prior to data collection. The rating of perceived exertion (RPE) as session-RPE was also determined following the completion of each field-based training session, matches (Impellizzeri et al., 2004) and resistance training sessions (Day et al., 2004) using a modified 10-point Borg scale (Borg et al., 1987). To ensure the perceived effort referred to the whole training session, each subjects' RPE was recorded on an individual basis ~30-min after completion of each training session. All players were familiarised with the process of reporting RPE over a number of weeks prior to commencing the study. Training load (AU) was calculated by multiplying RPE score with the duration of each session (in minutes) to provide an index of the total load (Foster et al., 2001). Daily and weekly AU was calculated from the sum of all AU performed in a day and week respectively (Foster et al., 1998; Impellizzeri et al., 2004). Total weekly AU was taken as an average of the two weekly training cycles and match load was an average of the two matches undertaken. In order to gain further insight into the non-soccer-specific weekly activity undertaken by the non-academy group, subjects also completed a physical activity questionnaire (PAQ-C) validated by Kowalski et al., (1997) on teenage boys.

6.2.4. Statistical Analysis

After verification of normality, student t-tests for independent samples were used to compare the physiological load and RPE-based load of training and matches for each age group across the two week period in the academy and non-academy groups. A dependent t-test was used to compare physiological load and RPE-based load during training with matches within each age group. Statistical analysis was undertaken using the Statistical Package for Social Science software programme version 15.0. All data are presented as mean $\pm$ SD with p values < 0.05 indicating statistical significance.

6.3. Results

6.3.1. Weekly Training and Physical Activity Overview

An overview of the weekly training and match schedule for both the academy and non-academy are shown in Table 6.3.1. to 6.3.6. The structure and content of week one was identical to week two for all academy and non-academy age groups. The non-academy groups played twice as many matches per week as the academy. In contrast, the academy U12 and U14 groups averaged 75% more training sessions per week than the non-academy and the U16 group averaged 85% more. Over two sessions the academy groups participated in 240-min of training per week while the non-academy participated in 60-min. Durations of specific sub-components of training sessions were on average 30-min in duration and were similar between all age groups. The academy U12 group did not complete any specific physical conditioning sessions, however, the U14 and U16 groups completed one and two 30-min sessions per week respectively.

Table 6.3.1. Academy U12 Weekly Training Program

Mon	Tues	Wed	Thurs	Fri	Sat	Sun
	NON SPECIFIC ACTIVITY		NON SPECIFIC ACTIVITY	NON SPECIFIC ACTIVITY	NON SPECIFIC ACTIVITY	

Table 6.3.2. Academy U14 Weekly Training Program

Mon	Tues	Wed	Thurs	Fri	Sat	Sun
	NON SPECIFIC ACTIVITY		NON SPECIFIC ACTIVITY	NON SPECIFIC ACTIVITY	NON SPECIFIC ACTIVITY	

Table 6.3.3. Academy U16 Weekly Training Program

Mon	Tues	Wed	Thurs	Fri	Sat	Sun
		NON SPECIFIC ACTIVITY		NON SPECIFIC ACTIVITY		NON SPECIFIC ACTIVITY

Table 6.3.4. Non-academy U12 Weekly Training Program

Mon	Tues	Wed	Thurs	Fri	Sat	Sun
	NON SPECIFIC ACTIVITY		NON SPECIFIC ACTIVITY	NON SPECIFIC ACTIVITY	NON SPECIFIC ACTIVITY	

Table 6.3.5. Non-academy U14 Weekly Training Program

Mon	Tues	Wed	Thurs	Fri	Sat	Sun
NON SPECIFIC ACTIVITY			NON SPECIFIC ACTIVITY	NON SPECIFIC ACTIVITY	NON SPECIFIC ACTIVITY	

Table 6.3.6. Non-academy U16 Weekly Training Program

Mon	Tues	Wed	Thurs	Fri	Sat	Sun
NON SPECIFIC ACTIVITY			NON SPECIFIC ACTIVITY	NON SPECIFIC ACTIVITY	NON SPECIFIC ACTIVITY	

MAT WU PT TT PT/TT CD

MAT: Match, WU: Warm up, PT: Physical training, TT: Technical/Tactical, PT/TT: Physical and technical/tactical training, CD: Cool Down.

The non-academy groups also completed a PAQ-C weekly diary over the two week period to provide an overview of their supplementary activity (Figures 3.1 to 3.3). The non-academy groups only completed soccer-specific training for one hour per week. This did not include any specific focus on physical conditioning. All groups were involved in soccer sessions for the greatest amount of time, while the U12 group was found to complete a greater variety of sessions, nine, compared to four for the U14 and U16 groups.

Figure 6.3.1. U12 Non-academy activity Profile

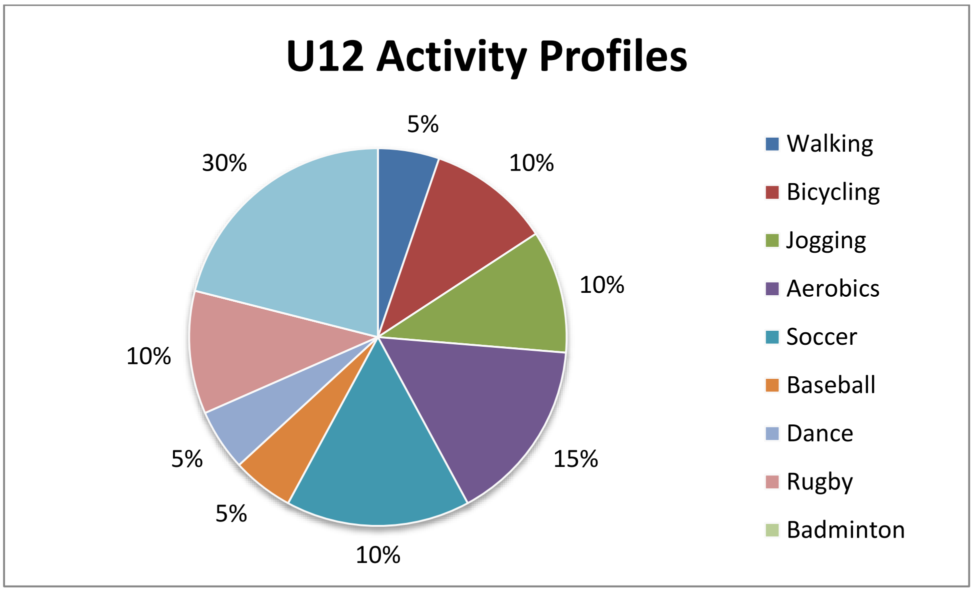


Figure 6.3.2. U14 Non-academy activity Profile

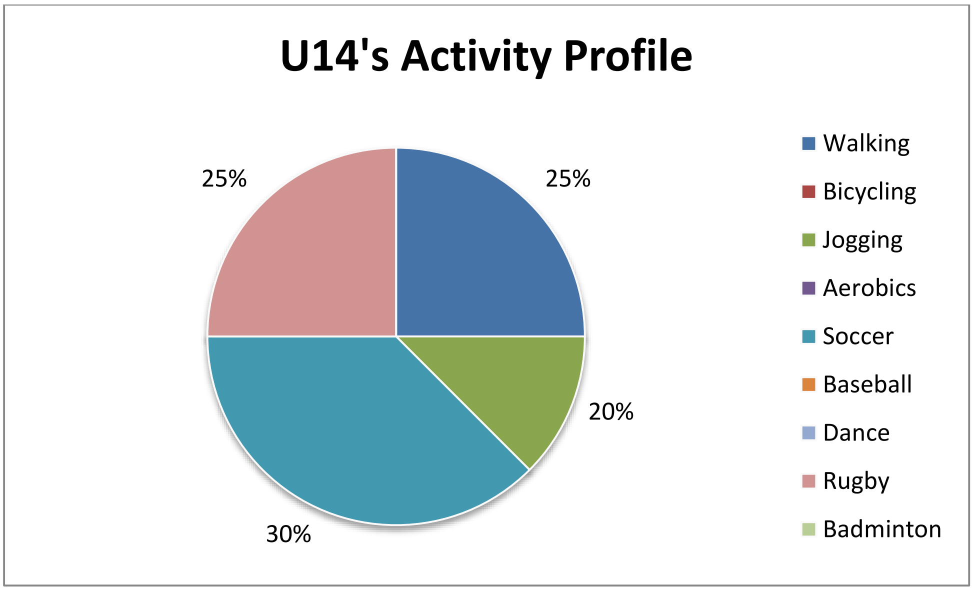
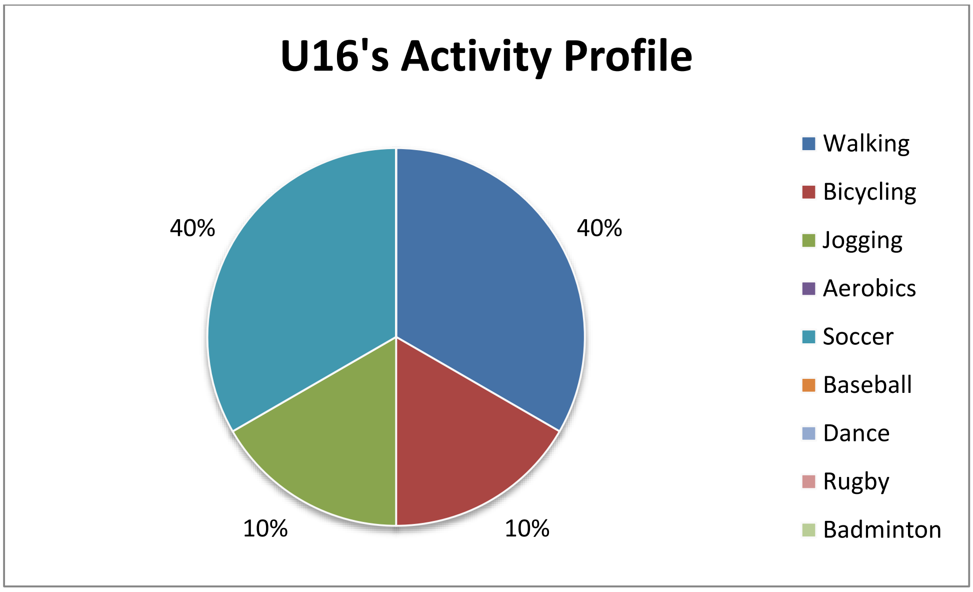


Figure 6.3.3. U16 Non-academy activity Profile



6.3.2. Quantification of Training and Match Loads

When comparing the academy and non-academy soccer-specific training sessions the mean %HRmax for training was only significantly higher in the academy U16 group over the two week training period ($p<0.05$) (Table 6.3.7). Mean HR also showed a tendency to be higher, however, this did not reach statistical significance. No difference in the % of time spent in the upper training zone or session RPE was observed between the two groups in any age group. The total training load (AU) over the two week period was significantly higher in the academy compared to the non-academy groups across the three age groups ($p < 0.05$; Table 6.3.7).

Table 6.3.7. Academy and non-academy mean HR, %HRmax, % time in upper zone, RPE, and AU during soccer-specific training sessions. (Mean ± SD).

	Mean HR (beats .min)		**Mean HR (%HRmax)**		**Time in Upper Training Zone (%)**		**Session RPE**		**Weekly Training Load (AU)**	
Age Group	Academy	Non-academy	Academy	Non-academy	Academy	Non-academy	Academy	Non-academy	Academy	Non-academy
U12's	141.8 ± 4.7	150.2 ± 11.8	67.5 ± 3.22	71.5 ± 5.6	7.8 ± 4.68	11.3 ± 14	6.6 ± 1.1	5.4 ± 0.9	*737.1 ± 50.9	156.5 ±27.85
U14's	153.1 ± 9	151.7 ± 9	74.7 ± 4.37	74.1 ± 4.37	11.1 ± 4.83	11.2 ± 9.01	5.4 ± 0.9	5.3 ± 1.27	*645.7 ± 105.95	160.7 ± 18.8
U16's	170 ± 11.5	145 ± 9.7	*85.8 ±4.94	72.5± 3.56	13.5 ± 7.73	10 ± 12.5	6.3 ± 0.8	6.2 ± 0.92	*758 ± 81	192.5 ± 27.5

HR: Heart Rate * Significant differences between academy and non-academy(p<0.05)

When comparing the academy and non-academy matches the mean HR and equivalent HR as a %HRmax was significantly higher in the academy U14 group ($p<0.05$; Table 6.3.8). However, the percentage of time spent in the upper training zone was significantly higher for all three academy age groups compared to the non-academy ($p < 0.05$). RPE was significantly higher in the academy U12 and U16 age groups ($p<0.05$) with similar values observed in the U14 groups. The overall match load was similar between the U12 and U14 groups, however, this value was significantly higher in the U16 academy group relative to non-academy ($p < 0.05$; Table 6.3.8).

Table 6.3.8 Academy and non-academy mean HR, %HRmax, % time in upper zone, RPE, and AU during matches (Mean ± SD).

	HR (beats .min)		**Mean HR (% HRmax)**		**Time in Upper Training Zone (%)**		**Session RPE**		**Weekly Training Load (AU)**	
Age Group	Academy	Non-academy	Academy	Non-academy	Academy	Non-academy	Academy	Non-academy	Academy	Non-academy
U12's	#166 ± 5.8	170 ± 12.2	#81 ±2.83	81.2 ±5.86	*#34.6 ±6.96	30.9 ±17.67	*#8 ±1.03	#7.6 ±0.7	#471.4 ±61	460 ±36.3
U14's	*#164 ± 2.18	156.8 ± 5.2	*#80 ±2.18	76.5 ±2.48	*20 ±11.75	16 ±5.69	#7 ± 0.53	#7.1 ± 0.63	#495 ± 37.4	498 ± 44.4
U16's	161.4 ± 12.4	166.4 ± 6.3	80.7 ±6.15	#83.2 ±2.56	*#37.56 ±19.66	32.6 ±18	*#8.2 ±0.45	7.9 ±0.68	*#656 ± 32	533 ± 174.78

*Significant differences between academy and non-academy ($p<0.05$)

Significant difference between training and match values ($p<0.05$)

The average heart rate for the academy training compared to the matches was significantly lower for the U12's and U14's ($p<0.05$; Table 6.3.7 and 6.3.8**)**. In contrast, values in the U16 group tended to be higher during training though this did not reach statistical significance. The percentage of time in the upper training zones was lower during training across all groups though a statistical difference was only observed for the U12 and U16 age groups. ($p<0.05$).

RPE was significantly lower for all three academy age groups during training compared to matches ($p<0.05$). The overall training load was significantly greater during training compared to matches across all age groups ($p < 0.05$; Table 6.3.7 and 6.3.8).

The intensity of non-academy soccer specific training compared to matches (Table 6.3.7 and 6.3.8) was lower for all three non-academy groups but was only significant for the U14's, U16's groups ($p<0.05$). The mean heart rate was lower for all three non-academy age groups though only significantly for the U16 age group ($p<0.05$) (Table 6.3.7 and 6.3.8). Percentage of time in the upper training zones across all three age groups was also lower for non-academy training compared to matches, significantly for the U12 and U16 age groups ($p<0.05$). While the RPE was also lower across all three age groups though only significantly for U12 and U14 age groups ($p<0.05$). The intensity of non-academy soccer specific training compared to matches (Table 6.3.7 and 6.3.8) was lower for all three non-academy groups but was only significant for the U14's, U16's groups ($p<0.05$).

6.4. Discussion

The aim of the present study was to evaluate the training and match loads imposed on different age groups of academy and non- academy soccer players. Findings indicate that age-related increases in the intensity of training and to a greater extent the volume of training are evident. Furthermore, differences exist in the weekly training load between groups. Such attempts to evaluate training load are important if a better understanding of the required training load needed to optimise the long-term physical development of junior soccer players is to be established.

In the present study, the total (training and matches) weekly session-RPE load was greatest in the UI6 academy age group reflecting differences in total training load (gym and field). The total weekly field training load was greater in the UI6 academy group when compared to the all non-academy age groups and the two younger academy groups. In light of the lack of differences in RPE response across age groups, the observed increase in weekly training load predominantly reflected increases in training volume (frequency), with the academy U16 age group undertaking one additional field (emphasis on physical development) and gym session relative to both the academy U12 and U14 groups. The increased training load observed in the older age group reflects the combined input both from the coaches and the sports science team and would seem to adhere to the training principles routinely advocated for the long term athletic development of adolescents (Balyi and Hamilton, 2004; Naughton et al., 2000). This suggests the training load should be structured in relation to maturity status of the athlete to maximise athletic development whilst minimising the risk of overtraining and injury (Balyi and Hamilton, 2004; Naughton et al., 2000).

Attempts to quantify the accumulated weekly training load undertaken by young soccer players (17 years) during the in-season competitive phase have previously reported mean weekly training load of 2798 + 322 AU (Impellizzeri et al., 2006). These values are higher than reported in the current study for both academy and non-academy players. The decreased weekly training load in the current investigation relative to the previous reports by Impellizzeri et al. (2006) may reflect the part time training status of the players in the current investigation and younger chronological age. The weekly training loads observed in the current investigation also lie below the range of weekly training loads (1386–3725) established in sub-elite and elite endurance athletes (Foster, 1998; Foster, Daines, Hector, Snyder, & Walsh, 1996) and elite adult basketball players (2928–2791 AU; Manzi et al., 2010) during the in- season competitive phase. Such observations may not be unexpected given the standard and age of player presently observed, as well the part-time training status. It is important to note that the data presented is only one team's two week training load and so may not be representative of youth soccer training as a whole. Whether such loads are the most effective with respect to the long-term development of players remains to be determined in future work through long-term systematic manipulations of training load.

In the present study, the match session-RPE reported across the three academy age groups (U16, 758 ± 81 AU; U14, 645.7 ± 34 AU; U12, 737.1 ± 65 AU) was greater than those previously reported (625 AU) for youth team soccer players (lmpellizzeri et al., 2006) and significantly greater than the reported non academy levels (U16, 192.5 ± 27.5 AU; U14 160.7 ± 18.8 AU; 156.5 ± 27.9 AU). The session-RPE training load is time dependant (Foster, 1998; Foster et al., 1996), however, differences in playing exposure are unlikely to account for the differences in match session-RPE since those players studied in the present study and those by lmpellizzeri et al. (2006) completed a minimum of 80 min per match. Differences in match loads would therefore seem to be as a consequence of higher reported RPE scores in the current study. This may potentially reflect cultural differences in the tactical approach to match-play between continental Europe and the UK. For example, Dellal et al. (2011) reported differences in the physical and tactical aspects of match-play between players operating in the elite divisions in England and Spain. Matches in the Premier League are frequently played at a higher tempo relative to the slower build up approach adopted on the continent which may consequently reduce the perceived demands of match-play on the players.

Alongside the accumulated weekly training loads, differences in the distribution of the daily training load between age groups were evident across the weekly micro-cycle (Tables 6.3.1-6.3.3). In the U16 group, the weekly training cycle (including a weekend game) mirrored an unloading strategy previously observed by Impellizzeri et al. (2004). This strategy was characterised by an increase in daily training load during earlier phases of the training week with lighter loads evident as the match day approaches (Table 6.3.3). This tapering strategy has frequently been shown to be the most effective approach to enhancing performance in endurance sports (Bosquet, Montpetit, Arvisasis, & Mujika, 2007). During the in-season phase, this strategy attempts to ensure an adequate physiological stimulus is provided to maintain or develop physical attributes whilst per- mitting the necessary preparation for competition (Impellizzeri et al., 2004). In contrast with the U16 weekly cycle, the U14 and U12 groups adopted weekly micro-cycles that continued to apply a uniformed training load across the week (Table 6.3.1, Table 6.2.2). This may partly reflect the part-time status of these age groups and thus attempts by the coaching staff to compensate for the limited training exposure across the week. Furthermore, the technical and physical development of the players is prioritised within these age groups relative to competition. As players become older and the focus moves towards competition rather than development, the weekly cycle is adjusted to support these different objectives. How different weekly periodisation cycles influence both competitive performance and the long-term development of adolescent soccer players has yet to be established.

Differences in the distribution of intensity of training and match-play based upon HR were observed. Overall, the percentage of time in the upper training zone (> 90% HRmax) for all academy age groups during match-play was greater compared to non-academy age groups with the highest value observed in the Ul6 academy group. During field-training, mean HR was significantly lower for the Ul6 academy group compared to all other groups which may be attributed to a greater proportion of any tactical training focusing on set piece plays that would require a lower aerobic input compared to perhaps shape of play which would be of greater tactical importance in a younger age group. As with the age related increase in weekly training load, this increased high-intensity training activity in the Ul6 players would seem to reflect a change in focus of the training stimulus administered by the coaches and sports science team. The increased capacity of the older players to operate at a higher intensity for longer periods of the match therefore likely reflects a combination of chronic adherence to the clubs long-term physical development programme (Matos and Winsley, 2007) along with the enhanced physical development which accompanies normal growth and maturation (Ford et al., 2011). For example, the exponential rise in peak oxygen uptake following peak height velocity (Baquet et al., 2003) and enhanced development of the anaerobic system (Le Gall,et al.2010, Meylan et al, 2010) would theoretically serve to enable more mature players to exercise at higher intensities.

Mean match HR responses observed in each age group were comparable and aligned closely with values previously reported in youth soccer players (Stroyer et al., 2004). When comparing match HR responses to field training, mean HR was significantly greater during match-play for all groups except the academy U16 age group. However, in line with such observations, the percentage of time spent in the upper zone was greater during matches across all academy age groups, while not for non-academy. These observations support previous research which suggests the physiological demands associated with matches and training sessions are different (Impellizzeri et al., 2005). However, an important consideration when comparing HR responses during training and match-play is that HR may overestimate exercise intensity during the latter due to increased emotional strain encountered during the early stages of competition (Bangsbo et al. 2006). Significantly particularly with regard the academy group it is also important to note that if training for soccer is to be effective it must be related to the demands of the game (Reilly, 2005).

It is acknowledged that a sample size of six is small for an overview of the physiological load of training and matches for both the academy and non-academy groups across all age groups. However due to squad sizes and injuries it was difficult to have a larger number and an even selection across playing positions for all groups. Also another limitation is that it can be argued that a two-week block in the first month of a competitive season isn't a true reflection of the intensity of training and match play over a competitive season lasting ten months. However it is important to note that it does give an indication of quantity and intensity of training and match play for the individual groups, ages and highlights significant differences. While there is evidence available to support our approach to the determination of HRmax in our population it is possible that there is some error with the use of an anaerobic based test and training zones taken from literature relevant to adult players. While separation for chronological age was used in analysis another limitation is that separation for biological age would have also been of benefit. Future work is also needed to evaluate the most effective ratio of high-intensity training to match play needed to support the long-term development of academy players. Based on the present observations, this may be more important in the older age groups where the mismatch between training and match intensity may be greatest.

In conclusion, our findings indicate that age-related increases in the intensity of training and to a greater extent the volume of training are evident within an elite academy programme. Furthermore academy players reported greater intensities and volume of training compared to age matched non-academy players. Differences in the weekly load and intensity are evident between age groups particularly with regard to the older academy players which likely reflects the increased focus on competition. Irrespective of the age group studied, the overall magnitude of the in-season weekly training load observed suggests that the present players experience relatively high degrees of stress (both training and match induced). Limited data, however, currently exists in relation to training and match loads in elite junior soccer players, consequently, further research is needed to determine the most effective training load needed to support the long term development of elite junior players.

CHAPTER 7

LONG-TERM SOCCER-SPECIFIC TRAINING ENHANCES THE RATE OF PHYSICAL DEVELOPMENT OF ACADEMY SOCCER PLAYERS INDEPENDENT OF MATURATION STATUS

This study was presented as an oral communication at the 16th European College of Sports Science (ECSS) Annual Congress, 6th-9th July 2011, Liverpool, UK and published as a full manuscript in the International Journal of Sports Medicine (See Appendix 11.2).

7.1. Introduction

The development of junior soccer players is a priority for professional soccer clubs. Clubs are therefore increasingly investing considerable resources in the recruitment of young players and the implementation of training programmes to facilitate their development. Whilst the adaptations to training have been extensively studied in adults, less attention has been given to young athletes despite the fact that they respond differently to exercise stimuli (Elferink-Gemser et al., 2012; Matos and Winsley, 2007; McNarry and Jones, 2012).

Elite junior soccer players are physically superior to their sub elite counterparts when matched for chronological age in both cross sectional (Malina et al., 2007) and longitudinal studies (Vaeyens et al., 2006). However, the degree to which these differences are attributed to advanced growth and maturation (Vaeyens et al., 2006) relative to systematic physical training (Williams and Reilly 2000) is unclear. Adolescent athletes train during periods associated with various changes in growth and maturation that affect performance Vandendriessche et al., 2012). The adolescent growth spurt varies in timing and tempo and is closely associated with improvements in physical performance that mimic the effects of training (Philippaerts et al., 2007). Differences in maturation can therefore impact significantly on an individuals' performance and also their longitudinal changes in performance with early maturing boys scoring significantly better in tests of speed and power (Thomas et al., 2009). and also the development of aerobic performance in young soccer players being reported to be significantly related to maturity and volume of training (Vandendriessche et al., 2012) Consequently, differences in performance between elite and sub-elite players will be confounded to some extent by the failure to account for differences in maturity status (Malina et al., 2005; Vaeyens et al., 2006). In conjunction with the effects of normal growth and maturation, physical performance will also increase in response to systematic training (Matos and Winsley, 2007; Valente-dos-Santos et al., 2012b). For example elite youth soccer players have been shown to make significant longitudinal improvements across a variety of physical parameters including aerobic, anaerobic, 10m, 30m sprint and squat jump scores (Hammami et al., 2013). Buchheit et al., (2010) reported significant improvements in repeated sprint ability, 30m sprint time and countermovement jump scores in U15 year old elite soccer players after 10 weeks of systematic training. Indeed it is suggested that part of the continued physiological superiority of elite junior soccer players maybe due to the long-term systematic approach to training rather than a player's genetic ability or difference in maturity status (Reilly and Brookes, 1986). Since young athletes are increasingly being encouraged to train intensively from an early age scientific investigations are needed in order to evaluate the relative contribution of training to player development.

Since the majority of studies to date have been cross-sectional in nature, these observations have not provided a clear distinction between the effects of growth and maturation and training on physical performance. Recent longitudinal observations using multilevel regression modelling indicate that maturity status and the annual volume of training contribute to aerobic and repeated sprint (Valente-dos-Santos et al., 2012) performance in professional club level soccer players. This suggests that difference in exposure to systematic training per se may therefore contribute to the enhanced physical performance frequently observed in elite vs. sub-elite soccer players. However, no study to date has attempted to directly quantify the degree to which training influences the observed differences in performance between the two populations. In the present study, we used a field test battery to compare the magnitude of change in physical performance of Academy and non-Academy junior soccer players over a three year period that were matched for chronological and biological age. By adopting this research design we were able to determine whether systematic training alone enhances the rate of physical performance development of Academy players compared to non-academy players. It was hypothesised Academy players would experience greater improvements in physical performance across the three year period. Furthermore, these differences would partly mediated by differences in training exposure per se.

7.2. Methods

7.2.1. Subjects

Measurements from nine U12 (stature 1.47 ± 0.11 m, body mass 42.1 ± 6.9 kg), nine U14 (1.67 ± 0.09 m, 56.7 ± 10.1 kg) and nine U16 (1.76 ± 0.05 m, 68.1 ± 3 kg) academy soccer players were taken over the course of three domestic seasons. All players were all registered at the same Premier League Academy. Across the same time period six U12 (1.52 ± 0.10 m, 40.7 ± 9.0 kg), six U14 (1.61 ± 0.04 m, 52.04 ± 6.9 kg) and six U16 (1.73 ± 0.06 m, 66.4 ± 7.3 kg) non-academy soccer players were monitored. The non-academy players were all school children attending the same school who were members of their respective school teams. No injured players were included in the study. All subjects were familiarised with the experimental procedures one week prior to the completion of the experimental trials. Written informed consent and assent to participate was obtained from a parent or guardian and player respectively. The procedures were approved by the institutional Ethics Committee.

The participants were recruited as a convenience sample from a small population frame of Academy players. The primary research question was whether the mean change in performance indicators is larger in the pooled sample of academy players (n=27) vs non-academy players (n=18). It was estimated that a two group t-test with a 0.05 one-sided (academy > non-academy) significance level has 80 % power to detect an effect size of 0.77 when the sample sizes in the two groups are 27 and 18, respectively (a total sample size of 45). The data was analysed with an ANCOVA model which can be associated with greater statistical power.

Experimental design

The difference between baseline performances and the three-year follow up point was chosen as the primary outcome. All tests were administered over three domestic soccer seasons. Stature, sitting height and body mass of the academy and non-academy groups were measured on four separate occasions during each competitive season to enable an analysis of a full calendar year (August, November, February and May). Performance assessments were undertaken on three separate occasions to enable analysis of a full competitive soccer season (August, December and April). All trials were conducted at the same time of the day in order to avoid any circadian effects on performance (Reilly and Brookes, 1986). Detail regarding training loads undertaken by the Academy groups have been reported previously (Chapter 6). The weekly soccer related training programme for the non-academy groups remained constant across the three domestic seasons and consisted of one 60min training session (school team training) and two matches per week. In addition to team training and matches the non-academy group also participated in other forms of physical activity other than soccer. As a consequence, approximately 10 % of activity time of the U12s encompassed soccer-specific training/matches with values of 30 % and 40 % observed for the U14s and U16s respectively (unpublished observations). Absolute changes in performance and maturity status of the academy and non-academy groups across the three year period were derived by comparing the final assessment period in Year 3 (April and May respectively) relative to baseline performance taken at the start (August) of Year 1.

Anthropometric Measures and Maturity Status

Anthropometric measures and maturity status were conducted as described in the general methods section (3.1.4).

Field Test Measures

Field Test Measures were conducted as described in the general methods section (3.1.4).

7.2.2. Analysis

Data were analysed using a General Linear Model with age-group (3 levels) and competitive status (2 levels) as fixed factors. Two covariate-adjusted models were applied. In model I, the initial performance measurements made at baseline were added as a covariate. In Model II, the baseline performance measures and the change in maturation status over the three year period were added as covariates. Therefore, the outcomes of the model are the mean changes in performance adjusted for any differences in baseline and change in maturation status (Senn 1994). Data are presented as mean (±SD) and 95% confidence intervals. Simple effect size, estimated from the ratio of the mean difference to the pooled standard deviation (data for different age groups were pooled due to subject drop out), was also calculated. Effect size values of 0.2, 0.5 and 0.8 were considered to represent small, moderate and large differences respectively (Vincent, 2006).

7.3. Results

Mean baseline maturity and performance data (combined age groups) of the academy and non-academy players are shown in Table 7.3.1. At the onset of the three year training cycle, the Academy players were more mature (closer to PHV) than the non-academy players ($p<0.001$; Effect size 0.2). Baseline performance in the academy group was greater than the non-academy group across all assessments ($p<0.01$). Large effect sizes ($p>0.9$) were associated with all differences in baseline performance between groups.

Table 7.3.1. Influence of playing standard (academy vs. non-academy) on baseline physical performance (Mean $\pm$ SD)

Performance	**Academy (n=27)**	**Non-academy (n=18)**	**95% CI (Difference)**
Maturity Offset (years to PHV)	-0.1 ± 4.16	-0.8 ± 1.68	-0.03 to - 0.59
CMJ (cm)	34.3 ± 3.12+	31.5 ± 2.94	1.0 to 4.7
10m (s)	1.85 ± 0.05*	1.97 ± 0.08	0.08 to 0.16
20m (s)	3.24 ± 0.16*	3.5 ± 0.17	0.17 to 0.36
Agility (s)	2.37 ± 0.1*	2.63 ± 0.08	0.21 to 0.32
Repeated Sprint (s)	7.22 ± 0.36*	7.83 ± 0.34	0.42 to 0.81
YYIR2 (m)	1319 ± 234*	673 ± 218	512 to 780

*Significant difference between playing standard ($p<0.001$); + ($p<0.01$).

The absolute change in performance (combined age groups) in both the academy and non-academy players over the 3 year training cycle independent of differences in baseline performance (Model 1) and independent of both baseline performance and changes in maturation status (Model II) are shown in Table 7.3.2. In Model I, the academy group demonstrated a greater change in performance across all performance parameters compared to the non-academy group ($p<0.05$; Table 7.3.2). These differences were independent of age group (CMJ cm $p=0.943$, 10 m $p=0.225$, 20 m $p=0.511$, agility s $p=0.277$, repeated sprint $p=0.709$, yo-yo IR2 $p = 0.069$). In Model II, changes in performance remained greater in the academy group across all performance parameters compared to the non-academy group ($p<0.05$; Table 7.3.2). These differences were again independent of age group (CMJ cm $p=0.616$, 10 m $p=0.265$, 20 m $p=0.680$, s agility $p=0.253$, repeated sprint $p=0.674$, YYIR2 $p=0.060$). Large effect sizes ($p>0.8$) were associated with the difference in the magnitude of performance change between groups in both Model I and II with the exception of jump performance in Model II were a moderate effect size was observed (0.7).

Table 7.3.2. Change in physical performance across the 3 year training cycle in the elite and sub-elite junior soccer players independent of differences in baseline performance and independent of baseline and maturity changes (Mean ± SD).

Performance	**Model I Independent of Baseline Differences**			**Model II Independent of Baseline & Maturity Differences**		
	Academy (n=27)	**Non-Academy (n=18)**	**95% CI (Difference)**	**Academy (n=27)**	**Non-academy (n=18)**	**95% CI (Difference)**
∆ Maturity Offset (yrs)	1.7 ± 0.52#	2.0 ± 0.42				
∆CMJ (cm)	7.7 ± 2.6+	4.9 ± 2.5	1.1 - 4.5	7.3 ± 2.6#	5.4 ± 2.5	0.3 to 3.6
∆10m (s)	-0.16 ± 0.05*	-0.09 ± 0.04	-0.04 to - 0.11	-0.15 ± 0.05#	-0.10 ± 0.04	-0.01 to -0.09
∆20m (s)	-0.31 ± 0.16*	-0.13 ± 0.13	-0.10 to - 0.27	-0.30 ± 0.16+	-0.15 ± 0.13	-0.05 to -0.24
∆ Agility (s)	-0.20 ± 0.01*	-0.07 ± 0.08	-0.07 to - 0.18	-0.19 ± 0.01*	-0.08 ± 0.08	-0.06 to -0.17
∆ Repeated Sprint (s)	-0.60 ± 0.26#	-0.42 ± 0.21	-0.02 to - 0.34	-0.60 ± 0.26#	-0.41 ± 0.21	-0.02 to -0.36
∆ YYIR2 (m)	1122 ± 405.6*	325 ± 369.6	517 - 1078	1128 ± 405.6*	315 ± 369.6	527 -1100

7.4. Discussion

The present findings demonstrate that the rate of improvement in physical performance of academy soccer players is accelerated relative to age matched non-academy players independent of differences in baseline fitness and changes in maturity status. To the authors knowledge these findings are the first to quantify the degree to which long term player development programs accelerate the physical development of academy soccer players relative to non-academy and supports the view that maturity status influences performance but the effect can be modulated by training impetus (Sokolowski and Chrzanowska, 2012; Williams and Reilly, 2000; Wrigley et al., 2012). The present findings provide an important basis for the development of strategies which further enhance the long-term physical development of academy soccer players.

In the present study, the academy players were more mature (0.7 years closer to PHV) than the non-academy players across the three age groups. Similarly, baseline performance across all performance tests was greater in the academy players relative to non-academy (large effects). These observations confirm previous findings indicating that academy players are frequently more mature and physically superior to age matched non-academy players (Coelho-e-Silva et al., 2010; Malina, 2011). The superior baseline performance presently observed in the academy players equated on average to 2.8 cm, 0.12 s and 0.26 s for the countermovement jump, 10 m and 20 m sprint respectively. Performance in the agility, repeated sprint and YYIR2 tests was greater by 0.25 s, 0.61 s and 646 m respectively in the elite group. These differences compare favourably with previous reports (Le Gall et al., 2012) which observed a 2.2 cm increase in countermovement jump performance and a 0.03 s increase in 10 m and 20 m sprint performance in elite 14-16 years old players compared to age matched sub-elite players. In contrast, slightly greater (889 m) increases in YYIR2 performance have been observed in elite 13-15 year old soccer players who were advanced in maturation, compared to their age matched sub-elite players (Malina et al., 2007). Interestingly, in the previous (Le Gall et al., 2010), the sub-elite group were more mature (0.3 skeletal years) relative to the elite group which may partly explain the smaller difference in performance relative to those presently observed.

Attempts to accelerate and therefore maximise the performance of elite junior athletes represents a key element of long-term athlete development programmes (Ford et al., 2011). Consequently, longitudinal studies have previously been undertaken in order to evaluate the degree to which performance changes arise in elite junior soccer players (Elferink-Gemser et al., 2012; Valente-dos-Santos et al., 2012). Over the three year period the academy players performance improved by 6.4 cm, 0.13 s and 0.21 s in the countermovement jump, 10 m and 20 m sprint respectively. Performance in the agility, repeated 30m sprint and YYIR2 test improved by 0.10 s, 0.44 s and 988 m respectively. These levels of improvement in the academy players are different to those reported in previous longitudinal research. For example, improvements of 14.4 cm, 0.08 s and 0.17 s in countermovement jump, 10 m and 20 m sprint performance respectively were reported in 14 year old elite soccer players over a three year period (Gonaus and Muller, 2012) whilst improvements of up to 10.3 cm were observed in countermovement jump performance in 11-17 year old elite soccer players over a five year period (Valente-dos-Santos et al., 2012). Inter individual differences, variations in assessment methodologies and the time period over which performance changes were observed are likely to account for these differences.

Aside from any potential effect of systematic training, changes in performance of the elite junior athletes will also reflect the effects of normal growth and maturation (Banquest et al., 2003; Valente-dos-Santos et al., 2012). Consequently, any conclusions regarding the magnitude of effect of training on the rate of performance improvement of elite junior soccer players must account for maturational influences on performance. Recent observations (Valente-dos-Santos et al., 2012a; Valente-dos-Santos et al., 2012b) in elite 11-17 year old soccer players over a five year period reported that skeletal maturation status and training impetus influences developmental changes in aerobic and repeated sprint performance. Whilst these observations suggest training per se is therefore likely to contribute to the greater performance frequently observed in academy vs. non-academy players, no study to date has served to directly quantify this. Uniquely, in the current study, we compared the rate of change in a range of performance parameters in academy players exposed to high volumes of training (Wrigley et al., 2012) with those observed in age matched non-academy players over the same time period. By comparing changes in performance in the two groups over the three year period when adjusted for differences in baseline performance and changes in maturity status we were able to quantify the degree to which the greater training exposure in elite players enhances the rate of change in performance across a range of physical abilities.

We presently observed a greater rate of increase in performance across all performance measures in the academy group compared to the non-academy group (over the 3 year period) when accounting for differences in baseline performance and changes in the rate of maturation (Model II, Table 7.3.2). Over the three year period, the magnitude of change in performance was on average 1.9 cm, 0.05 s and 0.15 s superior to the non-academy players for the countermovement jump, 10 and 20 m respectively. Similarly, agility, repeated 30 m sprint and performance in the YYIR2 test was improved by 0.09 s, 0.19 s and 813 m respectively. Aside from countermovement jump performance (moderate effect) these differences were associated with large effects. The present findings extend recent reports (Valente-dos-Santos et al., 2012a; Valente-dos-Santos et al., 2012b) and support the view that any physiological superiority of academy soccer players relative to non-academy players reflects to some extent the effects of systematic high volume, high intensity training (Malina et al., 2005; Figueirdo et al., 2011). Furthermore, this improvement would seem to arise across a range of physical capacities that are important to the overall physical performance requirement of elite soccer players.

While it can be argued that the study provides significant information regarded the effectiveness of a longitudinal development program in elite youth soccer players it is important to note that the study did have a number of methodological weaknesses due to the longitudinal nature. The sample size across each age group was relatively small because over the course of the study subjects dropped out due to being released, stopping playing or being injured. Further work with an initial larger sample would legislate for this and also enable inter age group comparison to be made. It is also important to note the limitations of maturity offset as an indicator of maturation (Malina et al., 2012). While it is a useful indicator as a practical non-invasive measure its protocols for the prediction are based on limited longitudinal data on 'normal growing' children and doesn't legislate for extremes of growth. In addition, this prediction method has been developed and validated on primarily Caucasian boys and girls. Future research that utilises skeletal age as a method for predicting maturation would be extremely useful.

The present study demonstrates that long term player development programs accelerate the rate physical development of academy soccer players relative to age and maturity matched non-academy players. These performance improvements arise across a range of performance attributes deemed important for developing soccer players. The present findings provide an important basis for the development of strategies which further enhance the long-term physical development of elite junior soccer players.

CHAPTER 8

SYNTHESIS OF FINDINGS

The aim of this chapter is to interpret and integrate the findings obtained within this thesis. The possible applications and limitations will be discussed. The realisation of the aims of the thesis will be confirmed prior to reviewing the original hypotheses. Within the general discussion and conclusions that follow, the results of the individual studies will be interpreted with respect to the impact of long-term soccer-specific training on the changes in physical development of elite junior soccer players.

8.1. REALISATION OF AIMS

The experimental sections of this thesis have fulfilled all the aims stated in Chapter 1. The reliability of anthropometric measures of stature, sitting height and weight and performance measures in academy and non-academy junior soccer players was determined (Aim 1). This permitted correct experimental procedures to be formulated for successful completion of future experimental work. The agreement between a non-invasive estimate of biological maturity (maturity offset) and a reference method was undertaken in academy junior soccer players (Aim 2). Overall agreement was poor indicating that caution should be applied when utilizing the method to predict end height stature in elite youth soccer players. The outcomes of this study informed the approach to assessing maturity in future investigations. A typical weekly in season training load of academy and non-academy junior soccer players was analysed (Aim 3). These findings demonstrated that age related differences in the volume and intensity of the weekly in-season training load are evident amongst academy and non-academy junior soccer players, with academy players being significantly higher than non-academy. These differences may reflect a systematic approach to the long-term physical development of academy players. The relative influence of long-term soccer-specific training and normal growth and maturation on the changes in the physical performance of academy soccer players was analysed (Aim 4), over three domestic seasons compared to age matched non-academy players. When corrected for differences in baseline performance and changes in maturity status, greater physical performance changes were observed in the academy players compared with the non-academy.

8.2. REVIEW OF HYPOTHESIS

A series of hypotheses were developed throughout the thesis. It is therefore necessary to examine whether the findings have led to the acceptance or rejection of the hypotheses proposed.

Hypothesis 1: A battery of anthropometric and field based performance tests are reliable measures in a group of academy and non-academy junior soccer players.

The hypothesis was accepted. The results of the current study demonstrate that both academy and non-academy soccer players are able to reproduce a variety of soccer related performance tests following completion of one familiarization trial. The current data suggests the suitability of such experimental protocols for the longitudinal evaluation of performance in academy and non-academy soccer players.

Hypothesis 2: Maturity offset is a valid measure of maturation in junior soccer players

The hypothesis was rejected. The results of the current study highlight poor agreement between estimates of end height stature in elite youth soccer players' using skeletal x-ray and the maturity-offset method. This suggests care must be taken when using maturity offset for predicating end height stature in youth soccer players.

Hypothesis 3: There are differences between weekly training and match load of academy compared to non-academy junior soccer players.

The hypothesis was accepted. The results of the current study highlight that significant differences exist between both training load and intensity of training between academy and non-academy age matched junior soccer players U12, U14 and U16. These differences may reflect a systematic approach to the long-term physical development of academy soccer players.

Hypothesis 4: Academy soccer players experience greater improvements in physical performance across the three year period than age matched non-academy players.

The hypothesis was accepted. The results demonstrate that the rate of improvement in physical performance of academy soccer players over a three year period is accelerated relative to age matched non-academy players.

8.3. GENERAL DISCUSSION

The aim of the current thesis was to investigate the impact of long-term soccer-specific training on the changes in physical development of academy soccer players and present practically orientated iniatives to practitioners working within soccer. Results from the initial investigations which assessed the reliability of a battery of anthropometric and field based performance tests in a group of academy and non-academy soccer players will be discussed, along with the reliability of a non-invasive measure of maturity and what practical implications these findings may have. This will be followed by the consideration of the quantification of the physiological loads and work rate profiles of academy and non-academy soccer players during training and match-play. Finally with, with particular reference to the longitudinal changes in the physical development of academy compared to non- academy players, the practicality and importance of findings will then be discussed.

Chapter 4 was concerned with evaluating the reliability of anthropometric and performance measures that would be used in future chapters to monitor the physical development of youth soccer players. No significant differences in mean body mass, stature and sitting height were observed between trials for both academy and non-academy subjects and %CV reported were in line with previous observations (Klipstein-Grobusch et al. 1997; Malina et al. 2005). No significant difference between trial 1 and 2 in either the academy or non-academy groups was also reported for the performance tests with %CV's observed in-line with previous observations (Gabbet et al., 2008). These findings suggest that one familiarisation session is sufficient to reduce any influence of learning effects on the performance measures. As such, reproducible measures in these tests can be obtained by simply ensuring prospective subjects complete the present familiarisation process. Significantly the current investigation therefore not only highlights the reliability of a battery of anthropometric and performance measures to be used in subsequent chapters but also evidence that practically they may be useful in the field for practitioners. Since the priority for any club and national federation is to ensure that athletes can successfully perform at the highest level in adult competition, it is crucial that any development program has the ability to differentiate between a soccer players' adolescent performance level and potential. As such, there is a need to continually evaluate the performance of the player so that the required training programs can be manipulated in order to maximise the effectiveness of the players' development.

The aim of investigations in Chapter 5 of the current thesis was to address the issue of agreement between an invasive (skeletal maturity) and non-invasive (maturity offset) estimate of end height stature in academy soccer players. Such an investigation would provide further insights regarding validity of the maturity offset as a non-invasive estimate of maturity status. Overall, poor levels of agreement were observed between the methods. Improved agreement was, however, generally observed in more mature boys, though caution should be applied when utilizing it as a measure of maturity since the observed SEM (4cm) and 95% LOA (±11) was greater than previously reported (Sherar et al., 2005). As a consequence, maturity offset was used in Chapter 7 to provide an indication of maturity timing (time to PHV) and not end height stature (Mirwald et al., 2002). It is important to note, however, that while the subjects used in this study were representative of those used in subsequent studies within the thesis (Chapter 6 and 7), it was limited given the worldwide popularity of soccer, the ethnically diverse composition of professional teams, and interest in youth players and academy's from developing countries. Skeletal and sexual maturation and the proportions of sitting height and leg length to stature vary among ethnic/racial groups (Malina, 2011), and protocols for the prediction of mature height are based on populations of European ancestry. Further research with a larger sample that includes players of different ethnic backgrounds is required. This is based on the fact that maturity offset is being used substantially in the field as an instantaneous non-invasive measure of maturity predominately due to the difficulties in applying skeletal assessments in the field. The present investigation did find poor levels of agreement and therefore indicates that any practioner currently using it to influence their practice should do so with extreme care. Particularly if decisions are being made from it regarding a players current and future developmental programs. While maturity offset is a practical tool and gives an instantaneous measure of timing, along with a serial measure of maturity over a number of years, if it is to be used practically practioners should be aware of its limitations and use it accordingly.

The aim of Chapter 6 of the thesis was to examine the typical weekly training load experienced by academy soccer players (U12, U14 and U16) during the in-season competitive period in comparison to age matched non-academy players. Total training load (AU) over the two week period was significantly higher in the academy compared to the non-academy groups, reflecting the higher volume of soccer-specific training administered to the academy groups. This was particularly the case for the academy U16 age group which demonstrated the highest total load. Similarly, the percentage of time spent in the upper training zone (>90 HRmax) was significantly higher in the current study for all three academy age groups compared to the non-academy, with again the U16 age group being significantly higher than all other groups. These findings confirmed previous reports which suggests that academy players spend a greater amount of time undertaking high-intensity work compared to non-academy (Bangsbo et al. 2006) with older players also able to operate at a higher intensity for longer periods of time. While it must be noted that the sample sizes were small and a two week period is not a true indication of a periodized program of work longitudinally, these findings do demonstrate that the volume of the weekly in-season training load and intensity of training are greater amongst academy soccer players than non-academy players with older age groups reporting significantly higher loads. This therefore may reflect a systematic approach to the long-term physical development of academy soccer players and practically indicates the importance of longitudinally monitoring training load not just inter age group but also intra, with potential justification of a control sample also if a true understanding of actual load and intensity is to be made. It is widely recognised that appropriate longitudinal periodization of training is fundamental for optimal sports performance. Therefore it appears that without such comparative longitudinal data, it would compromise the ability of any practioner to design and manipulate any program whose aim was to maximise development of any elite soccer player throughout adolescence.

The final aim of the thesis was to investigate whether systematic training alone enhances the rate of physical performance development of academy players compared to non-academy players. When corrected for differences in baseline performance and changes in maturity status, greater changes ($p<0.05$; Effect Sizes >0.7) in countermovement jump, 10 m and 20 m sprint, agility, repeated sprint and intermittent endurance capacity were observed in the academy players compared with non-academy players. Therefore it was concluded that long-term player development programs accelerate the rate physical development of academy soccer players relative to age and maturity matched non-academy players. Significantly also these performance improvements arise across a range of performance attributes deemed important for developing soccer players. The present findings not only advocate the positive impact current developmental programs are having practically on elite youth soccer players but also provide an important basis for the development of future strategies which may further enhance the long-term physical development of elite junior soccer players.

The current findings extend recent reports on sub elite soccer players (Valente-dos-Santos et al., 2012a; Valente-dos-Santos et al., 2012b) and support the view that any physiological superiority of elite soccer players relative to non-elite players reflects to some extent the previously highlighted effects of systematic high volume, high intensity training (Malina et al., 2005; Figueirdo et al., 2011) and that the continued physiological superiority of elite junior soccer players maybe due to the long-term systematic approach to training, rather than a player's genetic physiological ability or differences in maturity status (Williams and Reilly, 2000, Ford et al., 2011). However, it is important to note that the study did have a number of methodological weaknesses due to the longitudinal nature. The sample size across each age group was relatively small and further work with an initial larger sample would legislate for this and also enable inter age group comparison to be made. As mentioned previously it is also important to note the limitations of maturity offset as an indicator of maturation (Malina et al., 2012). Future research that utilises skeletal age as a method for predicting maturation would be extremely useful.

The implications arising from this thesis are related to the influence of systematic training in elite junior soccer and its long-term impact on physical development. Academy soccer players independent from baseline superiority and maturity improve their physical performance at significantly greater rate compared to age and maturity matched non-academy players. Since both training load and intensity were greater for academy soccer players across the age groups studied it seems evident that the training programs being implemented in academies are having a positive impact on the physical development of junior soccer players. The significance of this cannot be underestimated with such vast amounts of time and money being invested in elite youth soccer development. However if future initiatives are to ensure maximization of physiological development, the current investigations highlight a number a key practical initiatives that should be adhered to or developed further. Longitudinally any developmental program must be monitored and evaluated for effectiveness. If this is truly to be done the current investigation indicates the importance that without a true measure of maturity any conclusions or practical initiatives are insignificant. Currently it is indicated that while maturity offset maybe a practical measure of maturity it should be treated with caution and requires further investigation, until which the use of skeletal maturity it can be argued is practically advocated. Also it is indicated that the conclusions of any practitioner regarding the effectiveness of any development program without also legislating for some comparative control data and inter age group data longitudinally will be practically difficult. Therefore it is encouraged that such information regarding not just physiological performance but also training stimuli should be routinely collected to help such conclusions to be made. Therefore the present findings provide a significant basis for the importance of not only systematic training protocols in junior soccer but also a source to enable the development of strategies which will further enhance the long-term physical development of elite junior soccer players.

CHAPTER 9

RECOMMENDATIONS FOR FUTURE RESEARCH

The studies completed within this thesis determined the impact of long-term soccer-specific training on the changes in physical development of elite junior soccer players. In achieving this, a number of issues have arisen which have prompted the formulation of recommendations for further research.

Research proposals in response to the findings in Chapter 5:

In the current investigation overall agreement was poor between maturity offset and skeletal maturation for predicting end height stature in junior soccer players. Improved agreement was, however, generally observed in more mature boys. The results therefore seem to be consistent with previous longitudinal observations that indicate that non-invasive measures of maturation may be different in younger compared with older players (Bielicki et al., 1984; Malina et al., 2012). This suggests a general maturity factor at ages associated, on average, with maximal growth in height during the male adolescent spurt. Further longitudinal research adopting a greater sample size of subjects who at baseline were pre growth spurt would be of significant interest to help clarify this. It is also important to note that the results of the present study are also limited to a European longitudinal sample of 12-16 year old elite soccer players. Skeletal and sexual maturation and the proportions of sitting height and leg length to stature vary among ethical/racial groups (Malina, 2011; Malina et al., 2004), and protocols for the prediction of mature height are based on populations of European ancestry. Further research with a larger sample that includes players of different ethical backgrounds would therefore be of future benefit. It is also important to note that while the current findings do report that maturity offset can be used as a useful indicator of maturation, it is also important to note the limitations it also highlighted (Malina et al., 2012). While it is a useful indicator as a practical non-invasive measure its protocols for the prediction are based on limited longitudinal data on 'normal growing' children and doesn't legislate for extremes of growth. In addition, this prediction method has been developed and validated on primarily Caucasian boys and girls. Therefore a future study that extends the current protocol to utilise skeletal age as a method for predicting maturation would be extremely useful.

Research proposals in response to the findings in Chapter 6:

Current research is lacking with regards to the training loads experienced by academy soccer players and the implications of these loads for both performance enhancement and injury. In the current thesis age related differences in both training and match intensity within elite junior soccer players were observed. Future research should be undertaken which not only investigates soccer players chronologically but also incorporates biological age which would enable analysis to be made relative to levels of maturity. This would enable a greater insight into the physiological impact training loads are having on junior soccer players and what potential impacts these maybe having on their long term development. Secondly while academy junior soccer players recorded age related differences in training and match intensities as well as significantly higher loads than non-academy players it can be argued that a two week block in the first month of a competitive season does not provide a representative sample of the true training and match intensity. Therefore further investigations that encompasses a larger reflection of a whole season would be of benefit.

Research proposals in response to the findings in Chapter 7:

While the current investigation provided significant information regarded the effectiveness of a longitudinal development program in elite youth soccer players it is important to note that the study did have a number of methodological weaknesses. The sample size across each age group was relatively small and as a consequence it was not possible to examine age specific comparisons between the two groups. What impact training programs are having at specific age groups remains unclear (Ford et al., 2011). Further work with a larger sample would legislate for this and also enable inter age group comparisons to be made which in turn would from the broader talent development perspective, enable future investigations that look to identify the drivers that interact to facilitate progression at key stages in the development pathway (Mills et al., 2012).

Also the current investigation and previous research indicates that elite junior soccer players are anthropometrically and physically superior to their sub elite counterparts when matched for chronological age (Malina et al., 2007; (Vayens et al., 2006). However their ability to successfully predict a subsequent professional career is debateable (Carling et al., 2012). It would therefore seem appealing for initial talent identification and selection that further longitudinal research is required to establish the validity and usefulness of physiological test batteries to predict professional success across varying age groups, standards of ability, and stages of selection.

A further recommendation of further research is that while the current investigation highlighted the physical superiority of academy soccer players compared to their non-academy counterparts at baseline and that they also physically develop at a greater rate longitudinally over a three year period. The subjects were not studied beyond 18 years so any continued improvement in late adolescence and into young adulthood could not be addressed. Whether this improvement continues is unknown. For this to be addressed an investigation with a sample of youth players that continues into later adolescence and perhaps early adulthood would be required. Such investigations would have important implications for it would highlight if players who were identified as being the most ‘talented’ during early-adolescence who may fail to meet future expectations as late-maturing peers who persist in the sport catch up in size, strength and power (Malina et al., 2004), does this trend of physical superiority continue. The latter, of course, assumes late maturing youths continue in the sport, a trend that was not evident in the current sample and other samples of youth soccer players (Malina, 2011).

CHAPTER 10

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CHAPTER 11

APPENDIX

11.1. Quantification of the typical weekly in-season training load in elite junior soccer players.

www.ncbi.nlm.nih.gov/pubmed/22852843<http://www.ncbi.nlm.nih.gov/pubmed/22852843

11.2. Long-term soccer-specific training enhances the rate of physical development of Academy soccer players independent of maturation status.

www.ncbi.nlm.gov/pubmed/25009972<http://www.ncbi.nlm.gov/pubmed/25009972