Methods of Identifying High Velocity Growth in Youth Soccer Players

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ABSTRACT

Soccer has been played as a competitive sport for more than 100 years. Recently, however, physical preparation has become increasingly important for elite players. Now more than ever, many young players are being encouraged to train intensely from an early age in order to prepare them in the best possible way to cope with the demands of the game and to increase their chances of becoming a successful professional soccer player. Yet adolescence is a stage of development characterised by unprecedented physiological changes in the musculoskeletal, cardiorespiratory and reproductive systems of the body. This has raised concerns that perhaps the specific practice of increasingly early soccer involvement and a greater training volume could put youth elite soccer players at risk of injury, in particular overuse injuries and strength disorders, especially during the adolescence growth spurt. The primary aim of this study was to establish a method of identifying soccer players going through high velocity growth (HVG) based on their physical and functional data, and to assess the effect to which this period of rapid growth has on muscle function and performance.

Twenty-four male youth soccer players from Rangers Football Club's U-14's, U-15's and U-17's Youth Academy squads (Glasgow, Scotland, UK) were tested at three separate stages throughout the course of a year. Height, seated height, weight, body mass index, skinfold thickness (4-sites) and growth rates were collected as well as functional data on speed, agility, power, strength, flexibility and isokinetic concentric and eccentric muscle strength. Players going through the adolescence growth spurt were identified as having a growth rate two standard deviations outwith the average for their chronological age group. The results revealed that at the time of the study six out of the twenty-four players were going through a period of adolescent growth. The physical data showed that these players were smaller, weighed less and had a lower percentage body fat and body mass index compared to those players not going through HVG. There was no difference when comparing seated to standing height ratios and there was no evidence of a 'fattening up' period prior to HVG. The functional data showed that HVG players tended to be slower over 10 and 20m, have poorer agility, flexibility, power and strength compared with their peers. These results proved not to be statistically significant and it seems that the most accurate method of identifying players going through the adolescent growth spurt is with the use of retrospective physical data and calculating growth rates over a period of time.

The results of this study do provide normative data for coaches, trainers and clinicians working with youth soccer players.

In conclusion, youth soccer players especially from the age of 13-16, are continually growing and maturing and during this phase muscle function and performance are compromised. Players going through the adolescent growth spurt may be more susceptible to injuries as immature musculoskeletal system is less able to cope with repetitive biomechanical stress involved in youth soccer training and this is demonstrated in the poorer results shown in the HVG group functional tests. The adolescent growth spurt varies considerably in timing, tempo and duration and so trainers and coaches should be aware of the individual characteristics of the adolescent growth spurt. It is therefore essential in a professional sporting environment to continually carry out physical and functional testing on youth players in order to identify those who are going through the adolescent growth spurt and ensure they are closely monitored.

TABLE OF CONTENTS

Page Number

LIST OF TABLES

Page Number

LIST OF FIGURES

Page Number

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AUTHOR'S DECLARATION

I declare that this thesis embodies the results of my own special work, that it has been composed by myself and that it does not include work forming part of a thesis presented successfully for a degree in this or another University.

DEFINITIONS/ABBREVIATIONS

BMI – Body Mass Index

CMJ – Counter-Movement Jump

CPM – Continuous Passive Motion

Dom – dominant leg

HVG – High Velocity Growth

nDom – non-dominant leg

PHV – Peak Height Velocity

PWV – Peak Weight Velocity

ROM – Range of Motion

SJ – Squat Jump

SSC – Stretch-Shortening Cycle

1. INTRODUCTION

1.1 Soccer fitness

Soccer is a very physically demanding team sport which involves intermittent bursts of high intensity aerobic activity. During a match elite players cover an average distance of about 10–12 km (Bangsbo, 1994) in a series of starts, stops, sprints, jumps, tackles and quick changes of direction, at an average intensity close to the anaerobic threshold (Helgerud *et al*., 2001; Hoff *et al*., 2002). Recently, due to the increased professionalism within the sport and the introduction of sports scientists, fitness training has become increasingly more important for elite players. In turn, youth coaches are continually looking for the safest and most successful methods of developing talented young players to compete at the highest level. Compared with training studies in adults, relatively less is known about the trainability of adolescents, yet children are not simply young adults. The adolescence stage of development is a time of rapid growth and development over a relatively short period of time and at this stage adolescents are particularly vulnerable to injuries (Naughton, 2000). This has raised concerns that perhaps the specific practice of increasingly early soccer involvement, due to a 'catch them young' philosophy being adopted, and a greater training volume during this development stage could put youth and junior elite players at a greater risk of both short term and long term injuries.

1.2 Growth and development

As soccer is a multi-player sport, players from the same team can differ considerably in physique due to their individual pace in development. In an ideal world each player would have an individual training programme in order to best cater for their needs, in youth players however this is very difficult to implement. Youth players, especially from the age of 13-16, are continually growing and maturing. The adolescent growth spurt varies considerably in timing, tempo and duration due to each individual having an inborn biological clock that determines the rate of growth (Philippaerts *et al.,* 2006b). An adolescent's progress to full maturation does not necessarily proceed in tandem with chronological age, and as youth soccer teams are divided into players of the same age a large degree of variation will occur in biological age, in some cases between individuals in the same team skeletal age can differ by as much as four years from chronological age (Johnson *et al.,* 2009).

In a sporting environment there are clear benefits of being an early-maturer as from about 14 years of age, boys advanced in maturity status are better represented on youth soccer teams (Malina *et al*., 2007). The estimated average peak height velocity (PHV) of soccer players is approximately 9.7 ± 2 cm/year (Philippaerts *et al.,* 2006a). Data from previous studies on adolescent males suggest that, on average, running speed increases dramatically before PHV, peaks in strength and power are attained after PHV, and maximal aerobic power reaches a maximum almost coincident with PHV (Beunen & Malina, 1988). Despite this, during high velocity growth players may have a reduced physical co-ordination and balance and an increased risk of injury (Helms, 1997), however at present there is very little literature supporting this or describing the injury mechanisms involved.

1.3 Isokinetics and strength assessments

Soccer is a strength related sport and therefore requires both absolute strength (e.g. for kicking and body contact with opponents) and relative strength (e.g. running and jumping). The power output of the forceful and explosive activities in soccer is related to the strength of the muscles involved. Despite the fact that the aerobic system is utilised within the game for 90% of the time the most decisive actions are made by means of anaerobic metabolism and matches are usually decided by short powerful bursts (e.g. saves, sprint and shot, recovery run and tackle) (Stølen, 2005). Thus it would appear that muscular strength is a very important component of physical performance in soccer, in terms of both high-level performance and injury occurrence.

The isokinetic method of assessing strength in the lower extremities is often used in the soccer environment for testing, training and rehabilitation. It has been used in testing and performance enhancement for over 40 years and in this period thousands of articles have been published with the use of isokinetics as part of the testing methodology or for training. It should be noted however that the majority of these studies have focused mainly on adults with very few studies being carried out on youths or children. Furthermore, most of the subjects involved were recreational as opposed to elite athletes therefore it would not be reliable or accurate to compare this data with the results in the present study.

Assessing athlete's isokinetically provides valuable information that may be used for performance enhancement. The uses for dynamometers that Keating and Matyas (1996) reported are as follows:

- to collect normative values for muscles from various types of subjects
- to classify muscle performance as normal or abnormal by comparisons with the performance contralateral muscles, with normative data, or with muscle performance on a control group
- to establish the relative efficacy of various treatment and training regimens
- to investigate the relationship between dynamometric measurements and measurements obtained with other tests.

Isokinetic testing has the potential to further our understanding of muscle mechanics during growth and development. To date, surprisingly little research has been performed examining isokinetic strength in youth elite athletes and what affect the high velocity growth spurt may have on muscle performance and function.

1.4 Aims and hypothesis

Taking a youth player's growth and development into consideration, still very little is known regarding training the different physical fitness components during this sensitive period of unprecedented physiological change. For instance, it may not be possible to enhance physical performance by training during the growth spurt, in which case players should be removed from training altogether or have training loads reduced to prevent short and long-term injuries. On the other hand, there may be a particular maturational stage and a window of opportunity at which the benefits of carrying out certain aspects of soccer-specific training are maximised. Sports scientists and soccer coaches are reasonable to be cautious in developing and implementing training regimes to improve youth athlete's physical capabilities and skill level within the sport, however at this period of time more research is required to fully understand the trainability of youths. For example, it would be very beneficial for both players and coaches if there was a method of identifying when a particular player is at the early stages of, or is about to undergo the adolescent growth spurt, this way the players can be carefully monitored and their training loads adjusted accordingly.

This study was carried out in order to establish the importance of taking individual growth velocities into account in youth soccer players and being able to identify those players who may be more at risk due to their stage of development.

The main aims of this study were:

1. To establish a method of identifying players who are going through the adolescent growth spurt based on functional and physical data.
2. To identify players currently going through HVG and to assess what affect this has on isokinetic strength, functional performance and body morphology.
3. To establish the duration of HVG and the exact period of time at which youth players may be most susceptible to increased risk of injury.

The hypothesis is that the isokinetic strength and the functional performance tests will not be a good indicator of stage of growth due to a number of other factors that can influence these results. Body morphology, on the other hand, may be a much more accurate method in detecting players who are about to undergo or are in the process of HVG and this data could perhaps be useful in adjusting training loads. It would be expected that within a chronological age group, the boys who are advanced in sexual and skeletal maturity will perform, on average, better in strength, power and speed tasks compared to boys who are later in sexual and skeletal maturity, thus suggesting that there is a correlation between isokinetic and functional performance. Furthermore players who have already gone through the high velocity growth spurt would be expected to have greater strength, power and speed relative to those who are currently still developing or are late-maturers. This is due to the fact that the adolescent spurt in muscle mass occurs shortly after peak height velocity. The players who are currently going through HVG would be expected to have a decreased muscle function and this would be apparent in the results for the range of performance indictors. These players may also be more susceptible to injuries as muscle mass development lags behind limb growth and therefore the muscle is stretched and is at greater risk of damage. Furthermore, there may also be a proprioception issue which can affect co-ordination and balance, this can bring about missed timed challenges and again result in injury. It may not be possible to establish the exact duration of HVG due to the fact that it is only a year long study but the period of time in which functional performance is most affected may be identified.

2. LITERATURE REVIEW

2.1 The physiological demands of soccer

Over the past few decades soccer has undergone numerous changes and the exercise intensity in professional soccer has improved with recent research showing that players are now faced with increased physical demands during the course of a competitive soccer match. An English Premiership player now covers an average distance of 1.5km more than a counterpart playing ten years ago (Reilly and Gilbourne, 2003), there has been an increase in endurance capabilities and the players are faster, resulting in the game's quicker tempo (Reilly *et al*., 2005). This increased demand has occurred due to a number of rule changes over the years in order to develop the sport, improve the standard and make the game more exciting. For example, the creation of the pass back rule and the continuous flow of match balls have allowed soccer to become a more free-flowing game. This has led to an increased demand placed on the players and a high aerobic capacity and quick recovery time is now vital, more than ever, for most professional soccer players (Svensson *et al*., 2005).

Furthermore, the anthropometric and physiological predispositions for elite soccer players have changed over the last 20 years due to increased professionalism within the sport. The somatotype for elite players has changed from 2.6 endomorphy, 4.2 mesomorphy and 2.7 ectomorphy in 1980 to 2.0, 5.3 and 2.2 in 1998 (Reilly *et al*., 2000). This demonstrates that today's game requires a higher level of physical fitness and that present day soccer players are more athletic and required to keep their body weight to a minimum. The increased mesomorphy is also associated with a better diet, due to the introduction of sports nutritionists, and the strength and conditioning work now carried out by many clubs, due to the realisation that maximal strength training aids in the improvement of aerobic endurance performance (Hoff *et al*., 2002a).

2.2 Trainability of youths

Due to the increasing demands of the game, now more than ever, many young players are being encouraged to train intensely from an early age in order to prepare them in the best possible way to cope with the demands of the game and to increase their chances of becoming a successful professional soccer player. Due to the current financial difficulties that many professional clubs are facing, more pressure is being placed on coaches to produce elite youth players who have the potential to make the grade at 1st team level. Many teams cannot afford to buy players and so are now relying heavily on their youth academy players to bring success to the club and to also bring in a high transfer fee when they are eventually sold on.

The general consensus seems to be that 10,000 hours of coaching over a period of 10 years are required to reach the highest level in any sport (Baker *et al.,* 2003). Compared with training studies in adults though, relatively less is known about the trainability of adolescents. Regular physical activity is often assumed to be important to normal growth and maturation with many previous studies suggesting that it has a stimulatory influence on growth and maturity (Hui-Jing *et al.,* 2006). At the same time however concerns have also been expressed about the potentially negative influences of physical activity, specifically of intensive training for sport during childhood and adolescence. During the adolescent growth spurt a period of clumsiness in motor coordination of some adolescent boys has often been described, suggesting a temporary period that these boys are more susceptible to injuries due to miss timed tackles and loss of balance and coordination (Tanner, 1978, Hodson, 1999). There are however limited data on the epidemiology of injuries in adolescent soccer across all levels of play, and particularly in elite youths training full-time to become professional players.

2.3 The adolescent growth spurt

An increase in the velocity of growth in height marks the beginning of the adolescent growth spurt and over time the velocity of growth in height eventually reaches a maximum and then gradually declines. The adolescent growth spurt usually begins about the age of 12.5-13 years in boys and it lasts for approximately 2-2.5 years. Furthermore, reported mean ages at peak height velocity in North American and European boys vary between 13.3 and 14.4 years (Malina, 2004a). Retrospective height data is required to estimate age at PHV, and boys can be classified as early, average or late maturing based on when PHV occurred. The biggest variation in maturity status occurs between the ages of 10-14 and it is during this period at which these players may be more at risk of injury, therefore body morphology and functional data should be closely monitored (Sinclair ad Dangerfield, 1998). In youth sport, chronological age is the usual method of dividing adolescents into age related training and competitive groups. This is in spite of the fact that youths enter the adolescent phase of growth at varying ages and proceed through it at varying rates. As of yet there is very little in the literature regarding the exact duration of the growth spurt and the period of time at which youths may be more susceptible to increased injury risk and reduced muscle function. Furthermore, no study so far has been able to establish a method of identifying when a certain individual is beginning high velocity growth based on one set of results alone. It would be highly beneficial to be able to target players who are about to go through the growth spurt and to be able to alter their training accordingly in order to reduce the injury risks. Hopefully by carrying out this study there may be a number of indicators that can be used to predict when the growth spurt may be about to occur in certain individuals.

2.4 Potential methods of identifying HVG

Growth prediction can be assessed using physiological parameters such as, pubertal markers, dental development, and radiological analysis of skeletal maturation. While physiological markers do not allow precise growth prediction, evaluation of skeletal maturation with the help of radiographs is considered to be the more reliable approach because it spans childhood through adolescence (Beunen *et al.,* 1990). Unfortunately, the method requires a small radiation exposure and specialized training in the use of one of the available systems. Furthermore, many clubs cannot afford and do not have the resources to carry out this form of screening on all its youth players, therefore an alternative method has to be used. To date there has been very few studies researching a method of identifying the adolescent growth spurt based on functional and body morphology data alone. The accuracy and reliability of assessing HVG using the following measurements will be evaluated in the present study.

2.4.1 Height

Assessing maturity by using body measurements is not possible, because body size by itself is not an indicator of maturity. However, by collecting longitudinal data over the course of a year, specifically for height, the inflection in the growth curve can be used to determine those players going through the adolescent growth spurt. In this study longitudinal data taken over the course of a year will be used in order to calculate players' growth rates and to identify those players who are currently going through HVG and the age at which this is occurring. This is a standard method of determining a period of HVG in an individual and in this study it will be used to analyse the accuracy of other methods, however it requires data being collected over a long period of time and one single measurement is not very informative. Its usefulness may therefore be restricted in a professional sporting environment due to the large turnover of players throughout the course of a season.

2.4.2 Seated height

Seated height will also be monitored at different stages, more specifically the seated height to standing height ratio. Peak velocity for estimated leg length occurs earlier than that for height, whereas peak velocity for sitting height or trunk length occurs after that for height (Geithner *et al*., 1999). This ratio will therefore be at its lowest during the early stages of the adolescent growth spurt due to the fact that rapid growth of the lower extremities is characteristic at the onset of HVG. As growth in seated height continues into latter adolescence the appearance of having relatively long legs disappears and the ratio increases. In theory this should be a very reliable method of identifying HVG however as of yet there has be few studies testing its accuracy.

2.4.3 Weight

Traditionally, stature has been primarily used for growth assessment, but changes in body proportion and composition are also essential elements of growth, especially of maturation. Weight is a useful indicator of HVG as gains in stature, skeletal tissue, and muscle mass are apparent. Peak weight gain follows the linear growth spurt by approximately 3-months and this is due to gains in bone tissue and skeletal muscle (Malina, 2004a). As of yet there is no way of determining exactly when or how long an adolescent will go through HVG due to individual variability's. By collecting data on height, weight and seated height over the course of a season it may be possible to identify a method of predicting the exact time at which high velocity growth occurs in a player and its duration.

2.4.4 Body mass index

The body mass index (BMI) expresses an individual's body weight relative to stature and it is primarily an indicator of heaviness and only indirectly of body fat. During the adolescent growth spurt the relationship between height and weight is temporarily changed. The growth spurt occurs, on average, first in height and then in weight, so the relationship between the two measurements is altered. BMI could be a very useful indicator of high velocity growth due to the fact that it is independent of height. In players going through the early stages of the adolescent growth spurt BMI values would be expected to drop due to the increase in height relative to weight and so this could potentially be used to determine an individual's stage of growth and the onset of the adolescent growth spurt.

2.4.5 Skinfold thickness

It has been shown that prior to HVG there is a fattening up stage at which there is an increase in fat mass (Spear and Bonnie, 2002). Subcutaneous adipose tissue measured as skinfold thickness on the trunk and extremities changes differentially during the adolescent growth spurt. Males gain more subcutaneous fat on the trunk, while fat on the extremities decreases, therefore both subscapular and abdominal skinfolds tend to increase in thickness just before or at PHV, whereas the triceps skinfold tends to decrease in thickness at this time (Malina *et al.,* 1999). In this study measurements of subscapular, abdominal, triceps and biceps skinfolds will be measured at different periods throughout the season in order to analyse these variations in fat distribution. Furthermore, by calculating an individual's body fat and monitoring it over a period of time again it may be possible to identify players who are about to go through a growth spurt based on this 'fattening up' period.

2.5 Assessment of strength

Soccer can be characterised as a team sport which lies somewhere in the middle along a continuum of strength/power importance. In youths there is a steady increase in strength over time up to the age of puberty when during the growth spurt a more rapid increase occurs (Round *et al.,* 1999). This is due to an increase in muscle fibre size leading to muscular hypertrophy and a greater fibre cross-sectional area. The adolescent spurts in strength and muscular endurance appear to begin about 1.5 years before PHV and reach a peak about 0.5 to 1.0 year after PHV (Malina, 2004a). In soccer players strong quadriceps muscles are a prerequisite for success as they play a major role in many crucial aspects of the game including sprinting, jumping and ball-kicking. Hamstring strains are one of the most common injuries in professional soccer players due to the high intensity nature of the game and the speed at which it is played (Arnason *et al*., 2008). The hamstring muscle contributes to the knee flexion, acts as a break during the deceleration phase and stabilise the knee joint (Zakas *et al*., 1995). Due to the nature of soccer one-sided activities, such as kicking with one leg or jumping off one leg, are fairly common and asymmetries in muscle strength between the two legs are possible. It is now well established that soccer players quadriceps and hamstring strengths are regularly tested and monitored as it may helped to detect potential injuries in the future (Croisier *et al*., 2005). Early studies have shown that players with a bilateral leg strength difference of 10% may be much more susceptible to injury. Moreover, Knapik *et al.* (1991) stated that "players with a strength imbalance of greater than 15% were 2.6 times more likely to suffer injury in the weaker leg."

2.5.1 Isokinetic dynamometry

Essentially, the possession of strong hamstrings is an important requirement for playing soccer and preventing injury. There is however contrasting evidence on the relationship between isokinetic and functional testing. Some research indicates that there is not a correlation between isokinetic and functional performance (Wrigley, 2000); on the other hand there are numerous studies that indicate a positive correlation (Newberry *et al.,* 1997, Pincivero *et al.,* 1997). This is perhaps due to differences in methodology, testing protocols and subjects studied, very few studies have analysed this correlation in elite athletes.

Changes in body size, physique and body composition associated with growth and maturation are important factors that affect strength and motor performance. Strength and motor performance generally improve with age, increasing linearly until 13 to 14 years of age in boys when there is acceleration in muscle mass and development (Malina, 2004a). This increase in muscle mass has a direct effect on the absolute anaerobic power output that can be generated. Similarly, instability in motor performance during adolescence may reflect individuality in the timing and tempo of the adolescent growth spurt and variations in functional performance (Hodson, 1999). Results reported in the literature indicate that participation in athletics influences force production so the participants are generally stronger due to prior training. As all subjects in the current study played for Rangers F.C. and trained three times a week it would not appropriate to compare normative data on an athletic population to that of a non-athletic population.

Isokinetic strength testing was carried out in this study primarily to compare peak torques and the angle of peak torque in players at different stages of maturation. The angle of optimal strength is perhaps a better indicator of a player's stage of growth as the same peak torques may be achieved by simply adjusting body position, whereas the angle of peak torque will alter according to the bone and muscle development. The change in length-tension relationship associated with HVG at that specific period of time will result in the optimal angle being adjusted. A secondary aim was to analyse the correlation between isokinetic and functional performance and lastly asymmetries in muscle strength were compared to determine if HVG has an effect on strength imbalances between dominant and non-dominant legs and in turn further increase the risk of injury.

2.5.2 Pre-testing considerations

Prior to actually performing any isokinetic testing a number of considerations had to be made in order to optimise the testing process and to produce relevant and accurate data. Establishing the purpose of the testing in order to determine the specific testing protocols, the data that is to be collected and how the data is going to be used is essential. Calibration of the various transducers within isokinetic dynamometers is also a prerequisite for test-retest reliability and for comparisons between athletes. As isokinetic assessment involves movement of a limb segment through a gravity-dependent position, gravity correction procedures must be implemented to ensure that movements against gravity will not be underestimated and movements aided by gravity are not overestimated (Osternig, 1986). It is also crucial that the starting position be defined and kept consistent across all testing in order to ensure reliability in comparisons and repeated testing over the course of the year. Each subject must be stabilised appropriately throughout the testing in order to isolate the desired muscle group without any contribution from other actions. This is particularly important in isokinetic testing in youths as the majority of dynamometers are designed for adults and so a number of adjustments have to me made to ensure reliability of results.

Furthermore, providing feedback to the subject enhances performance, therefore, the examiner should be consistent in either providing visual/verbal feedback or not when performing the testing (Baltzopoulos *et al.,* 1998). A study by Kellis (1999) suggested that children perform better when they are given visual feedback of the force output. This is possible on most modern isokinetic dynamometers that offer real-time visual feedback and several studies have used it to motivate children. In the present study visual feedback of the muscular performance during the test was given as it was a maximum strength assessment. Verbal motivation was also used to produce a maximum effort; however this motivation was standardised and consistent across all subjects. For consistency of results and to increase the reliability of the measurements the same tester was present at each test. As re-testing was carried out at three different stages throughout the season it was particularly important that a detailed record of all the test settings to ensure high repeatability and accurate conclusions.

2.5.3 Counter movement jumps and squat jumps

Counter movement jumps (CMJ) and squat jumps (SJ) were also carried out as an indicator of muscular power and strength. Power is the product of speed and strength, and there is a relationship between strength and acceleration and movement velocity (Wisløff *et al*., 1998). In soccer, players are required to carry out rapid changes of direction and quick stop and start movements in a game, this suggests that strength and power are just as important as endurance in terms of the basic physiological requirements of a soccer player (Hoff, 2005). With subjects having to place their hands on their hips, this reduces the skill/co-ordination requirement of the test and focuses the effort on the leg extensor muscles; therefore it is a good test of muscular co-ordination and power. If the proper technique is adhered to then the CMJ is a good indicator of muscular power and the SJ an indicator of muscular strength (Petsching *et al.,* 1998). A significant correlation exists between vertical jump performance and percent body fat and age (Davis *et al.,* 2003). On average, performance in the standing vertical jump increases linearly with age until 18 years old in boys, however, players going through a growth spurt may be expected to have reduced strength as it is intuitive that the linear growth of the skeleton precedes the growth of the muscles needed to move these lengthening levers. At this point in time the CMJ and SJ results may be more similar due to a decreased ability to use stored potential energy in order to generate strength. The data from these tests can also be used to calculate whether a player's increase in weight is due to increased muscle mass and an improved jump score or due to an increase in bone mass when a decreased score would be expected. These will be dependent on their current stage of development and so data can be used to potentially identify players going through a period of HVG.

2.6 Field tests

2.6.1 Agility 505-test

Agility is a result of a combination of strength, speed, balance and coordination, and is increasingly crucial in the modern game due to the intense pace at which the match is played. The ability to change direction at speed is a key element of soccer fitness, as is the ability to decelerate rapidly (Stølen *et al.,* 2005). Both can determine the outcome of crucial plays within the game: excellent agility is a necessity with regards to 50-50 tackles or outpacing the opposition to gain possession first. Agility tests were carried out using a 505-test. This test is designed only to be 10m in order to minimise the influence of speed and maximise the effect of acceleration immediately before, during and after the change in direction. Performance improves from 5 to 18 years of age in boys, and again the data suggests an adolescent acceleration after 13 years of age (Malina *et al.,* 2007). From these results information can be gathered regarding the effect that HVG has on a player's ability to carry out sudden changes in direction. A growth spurt may bring about diminished co-ordination of movement and reduced balance ability and so one would expect a poorer performance on this test. It is these fast direction changes which increases the chance of injury the most, when excessive repetitive actions of this type are performed.

2.6.2 10m and 20m sprints

Players very rarely cover distances over 25m in a match, but speed, and the ability to accelerate, can decide important outcomes of the game. As soccer players are required to repeat fast bursts of speed, a high anaerobic capacity is essential in order to play at a high tempo (Bangsbo, 1994). Acceleration and speed tests were carried out with the use of timing gates placed at different distances. In soccer, regardless of position, players very rarely sprint for more than 20m in a straight line, therefore in this study speed and acceleration over 10m and 20m was measured as this is most relevant to the demands of the game. Furthermore, players started the sprints from a standing start primarily to rule out any factors of reaction time but also due to the fact that players are often required to run from a stationary position in matches. As with running agility, speed improves from 5 to 18 years of age in boys, with acceleration in performance after the adolescent growth spurt. Again during HVG speed and acceleration may be reduced due to a decrease in muscle function.

2.6.3 Sit and reach test

This test only measures the flexibility of the lower back, hip and upper thigh, and is a valid measure of this. It is the most commonly used test of flexibility and is influenced by anatomical and functional changes in the joints during adolescence. Also, it is an easy and quick test to perform and there is lots of data for comparisons. A study by Malina (2004a) showed that among boys, lower back flexibility declines linearly with age from 5 years, reaches its lowest point at 12 years of age, and then increases through 18 years of age. The low point in the sit-and-reach performance of boys is generally coincident with the adolescent growth spurt in leg length, and the subsequent increase appears to coincide with the adolescent growth spurt in sitting height and upper extremity height. This data may help to detect those players going through a growth spurt as a diminished score would be expected due to a reduced flexibility caused by the uneven development of bone and soft tissue at this stage of development. It can not be used solely as an indicator of HVG, however along with the physical and other functional data collected it could potentially be an accurate aid in determining an individual's stage of maturation.

3. METHODS

3.1 Subjects

Twenty-four male youth soccer players from Rangers Football Club's U-14's, U-15's and U-17's Youth Academy squads (Glasgow, Scotland, UK) participated in the study. The players studied competed in the highest division for their age group, trained three times a week and played one or two matches a week. The Glasgow University Ethics Committee approved the study and consent was given for access to and use of data generated. Subjects were informed about the testing protocols, but without being informed about the aim of the study. All subjects were free of injury and subjects with any known lower extremity musculoskeletal pathology were excluded from the study. The players were grouped on the basis of chronological age into approximately one year age categories: under-14 (13.0–13.9 years), under-15 (14.0–14.9 years) and under-17 (15.0–16.9 years). The players' physical characteristics at the beginning of the study are presented in Table 1.

Table 1 – Physical characteristics of players (n = 24)

Age Group	Age (years)	Height (cm)	Weight (kg)
U-14 (n=10)	13.5 ± 0.1	159.5 ± 2.5	48.4 ± 2.9
U-15 (n=9)	14.8 ± 0.1	171.6 ± 1.6	63.9 ± 1.9
U-17 (n=5)	15.6 ± 0.1	177.0 ± 1.4	67.1 ± 2.1

Values are mean (SE).

3.2 Design

Testing was carried out at three separate stages throughout the year. The players were measured and tested during the months of January, April and August. The performance testing was carried out over two days and the isokinetic testing over a 2-week period. All subjects were instructed to refrain from any physical activity 24-hours prior to testing and each player wore the same standard training clothes of shorts, t-shirt and running shoes for the duration of the testing. On arrival at the lab each player's height, seated height and body mass were measured with standard techniques to the nearest 0.1 cm and 0.1 kg, respectively. Skinfold thickness was also measured at 4-sites (biceps, triceps, subscapular and iliac crest) with the use of calipers, again to the nearest 0.1mm. To ensure precision and consistency each player was measured by the same accredited International Society for the Advancement of Kinanthropometry (ISAK) member. Furthermore, rather than converting the data measured into percentage body fat, it is now common practice to monitor body mass and the sum of skin-folds of an athlete as this rules out any error that the conversion formula may bring.

3.3 Functional tests

An acceleration and speed test was carried out using timing gates placed at different distances (Figure 1). Each subject started 70cm behind the first timing gate and began the sprint in their own time from a static position, thus eliminating reaction time. Another two timing gates were positioned at 10m and 20m intervals, with a split time and final time being recorded when the subjects intercepted each gate. Each player carried out the sprint test three times and was instructed to sprint as fast as possible making sure not to slow down before the finish line, the best time for each distance was recorded to the nearest 0.01s. All sprints were performed on an indoor synthetic surface, thus, ensuring consistency and reliability and each player had adequate recovery time prior to each sprint.

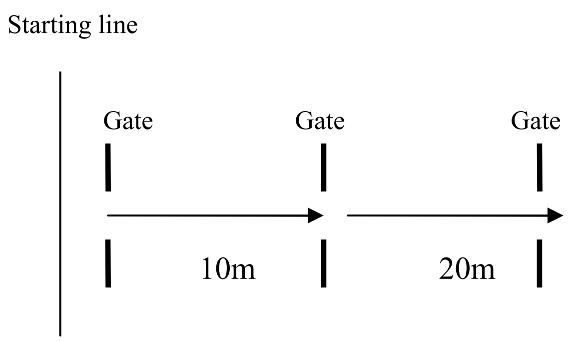


Figure 1 – 10m and 20m sprints

Agility sprint tests were carried out in the form of a 505 test. Using measuring tape and masking tape a 10m distance was set out and timing gates were positioned at the 5m mark (Figure 2). Each player was then instructed to sprint from the starting line through the line gates to the turning point, where they are required to turn on either foot and then accelerate off the turning point back through the gates again. Players were instructed to not slow down until they were through the light gates. Each player carried out 6 sprints, 3 turning on the left foot and 3 turning on the right foot. The best time taken to cover the 10m distance from the light gate to the turning point and back was recorded to the nearest 0.01s. Again the players started from a standing start in their own time to rule out any reaction times.

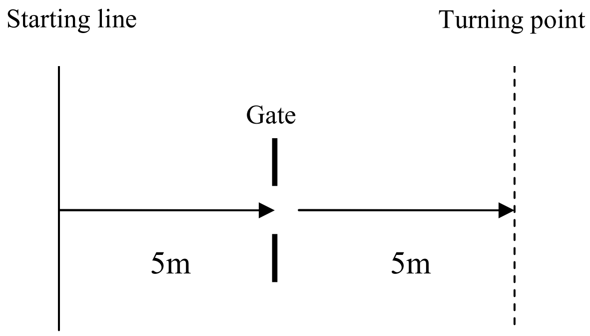


Figure 2 – 505-agility test

Two different types of jumps were tested using a force platform to determine both time and displacement of the jump. The counter-movement jump (CMJ) consisted of the players keeping their hands on their hips for the duration of the jump and to execute a countermovement with 90 degree knee flexion immediately before the upward propulsion in order to reach as maximum a height as possible. The subjects were instructed to land on the balls of the feet in an upright extended position and the knees are allowed to bend to soften the impact of landing. For the squat jump (SJ) the players were instructed to execute a countermovement with 90 degree knee flexion, hold it for a second and then jump as high as possible, again without the use of arm swing. The best jump from three attempts was recorded to the nearest 0.01cm for each technique and this determined leg strength and power of the subjects.

The last field test carried out on the players was a flexibility test in the form of a sit-and-reach. Prior to the test all the players were instructed to stretch their hamstrings and lower back. Subjects then sat on the floor in front of the sit-and-reach box with their legs fully extended placing their bare feet against the vertical surface of the box. The subject's then placed one hand over the other and stretched forward as far as possible, sliding their hands over the ruler of the sit-and-reach box and moving the marker as far up the box as possible. The tester applied gentle pressure above the knees to ensure that leg extension was maintained throughout the test and the subject was instructed to hold the stretch for 2-seconds in order to avoid the effect of bouncing. Each subject carried out three tests and the furthest distance that the fingers passed beyond the toes was recorded to the nearest 0.5cm.

3.4 Dynamometry

For the assessment of maximal isokinetic strength of the quadriceps and hamstrings, the Cybex NORM Testing and Rehabilitation system (Cybex, division of Lumex, Inc., Ronkonkoma, New York, USA) (1995) was used (Figure 3). This equipment has Continuous Passive Motion (CPM) mode which resists the movement of the machine, allowing for eccentric contraction of the muscle in addition to concentric. The original plan was to also carry out isometric contractions on the dynamometer in order to calculate the length-tension relationship for each subject, however due to the time constraints this was not possible.

Figure 3 - Cybex NORM testing and setup rehabilitation system

Figure 4 - Cybex NORM dynamometer setup

Each participant visited the laboratory on three separate occasions and was tested with the same protocol each time. The subject was seated on the dynamometer in an adjustable chair; the upper body was stabilized with straps secured diagonally across the chest and the hips to minimize unwanted movement. A strap was also positioned across the thigh to localize the quadriceps and hamstring muscle groups. The padded lever arm of the dynamometer was placed on the shin of leg being tested and attached tightly with straps and the contra-lateral limb was stabilized with a padded support. The seat was adjusted so that the axis of rotation of the dynamometer shaft was aligned with the anatomical axis of rotation of the knee joint, midway between the lateral condyle of the tibia and the lateral condyle of the femur. The shin pad was attached just above the lateral malleolus and the maximal range of motion (ROM) at the knee joint was set with safety stops placed at the extremes of extension and flexion (Figure 4). All players were also requested to grasp the handles at the side of the chair during testing. These positions were recorded for each participant and standardized for subsequent trials. The dynamometer was set up to only allow isokinetic exercise, i.e. for any force exerted the machine produced an equivalent resistance and thus the lower leg could only move at a prefixed speed of 60 degrees/sec. The gravity compensation procedure required the subject to extend the leg to a 45 degree angle and relax. This was performed before each test of joint function for each player in order to minimise measurement errors.

3.5 Testing Details

All isokinetic strength tests were performed at test velocity of 60 degrees/sec. Four repetitions were executed in each of the isokinetic tests and as the main energy demands of isokinetic strength testing comes primarily via the ATP-PC system, the optimum rest interval between each set of repetitions is 60 seconds, as this is sufficient time in order for replenishment of the energy stores (Parcel *et al.,* 2002,).

3.6 Subject Education and Familiarisation

Subjects were educated regarding execution of the test and how the testing will benefit them with regards to performance in soccer and prevention of injury. Constant angular velocity movements are rarely performed during exercise therefore it was crucial to familiarise the subject with the joint movements prior to the test as part of a warm-up. The complete range of angular velocities to be used in the test was included in the familiarisation warm-up session. Standardised instructions were given to each subject explaining the isokinetic testing and stressing the importance of maximum effort during each test. To ensure the well-being of the subject, a tester with experience of the equipment, a thorough understanding of the testing procedures and an understanding of how to stabilize the subject was present at all times. The warm up consisted of five minutes on a cycle ergometer followed by the players stretching the muscles surrounding the joints to be tested, i.e. the quadriceps and hamstrings. A warm up specific for the muscles being tested prepares the muscles for the demands of the testing and helps to prevent injury. Each subject then carried out practice repetitions on the isokinetic dynamometer increasing the effort after each repetition and building up to a near maximal effort on the last practice repetition. Subjects then carried out the testing protocol shown in Figure 5.

3.7 Protocol

Figure 5 – Isokinetic dynamometry test protocol

Isokinetic test (knee flexor/extensor)

ROM – Safety stops placed at the extremes of extension and flexion
Speed – 60 deg/sec

Warm Up

- 5mins on bike plus stretching quads and hams
- 6 sub-maximal concentric quads/hams contractions (increasing effort)
- 6 sub-maximal eccentric quads/hams contractions (increasing effort)

Test A – Concentric hams/quads strength

- isokinetic 60deg/sec
- 4 maximal reps of concentric quads/hams
- subject instructed to "kick" and "pull back"
- 60 second recovery

Test B – Eccentric hamstring strength

- in CPM mode, 60deg/sec
- 4 maximal reps of eccentric hamstrings
- subject instructed to "resist the machine"
- 60 second recovery

Test C – Eccentric quadriceps strength

- in CPM mode, 60deg/sec
- 4 maximal reps of eccentric quadriceps
- subject instructed to "resist the machine"
- 60 second recovery

End of isokinetic assessment

- Repeat for other leg (subject warms up other leg while new testing positions are set up)

Test A: Concentric hamstring and quadriceps

Test A involved measuring concentric strength of the hamstring and quadriceps. Subjects were instructed to perform four continuous repetitions, to "kick forward" fully extending their leg until they hit the safety stop and then "pull back" as hard and as fast as possible. Each maximal contraction was executed throughout the safe range of motion for each player.

Test B: Eccentric hamstring strength

Test B measured eccentric hamstring strength. Here the dynamometer operated in CPM mode where the lever arm applied a constant force to the leg and the subject had to resist the force. The dynamometer lever arm moves in a continuous cyclic motion at 60 degrees/sec and the subject was instructed to "resist the machine" by kicking up when the lever arm reaches 90 degrees and keep resisting as the leg is forced toward the 10 degree position. Four maximal efforts were executed.

Test C: Eccentric quadriceps strength

Eccentric quadriceps strength was measured using similar methods to those in test B. Again, CPM mode was employed for these contractions. Each subject resisted the machine when the lever arm motion reaches 10 degrees and rotates downwards to 90 degrees. Again four maximal efforts were executed.

3.8 Post-testing calculations

BMI was calculated by dividing players weight by their height squared. The functional hamstring: quadriceps ratio was calculated by dividing peak eccentric torque scored for the knee extensor (quadriceps) by the peak concentric torque of knee flexors (hamstrings). All ratios were calculated for both dominant and non-dominant legs.

3.9 Statistical analysis

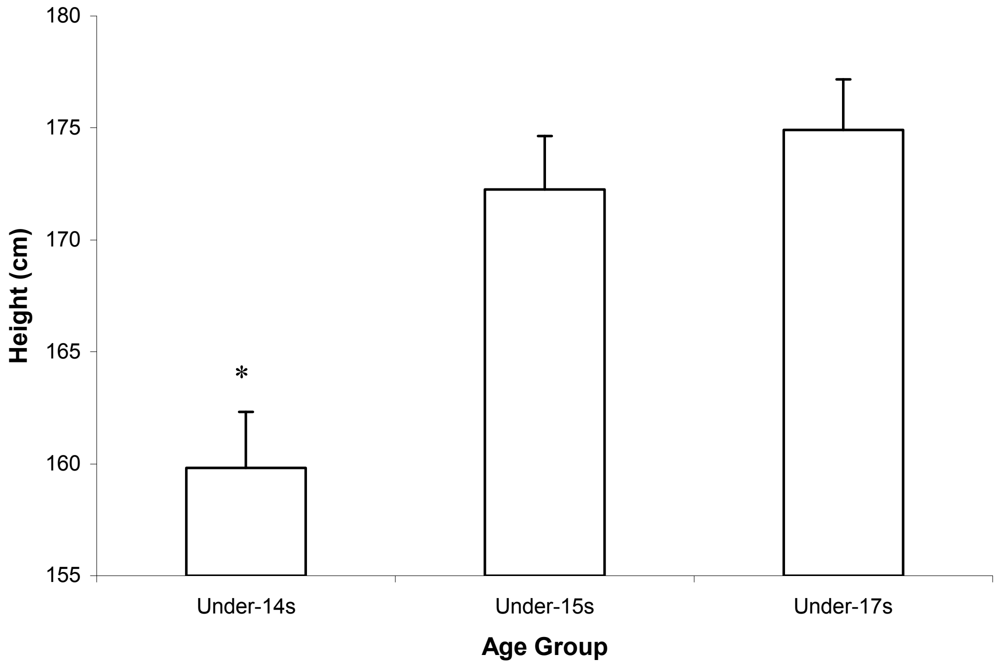
Descriptive statistics were used to report normative data. Two sample t-tests (95% confidence intervals) were performed to analyse the significance between two different groups of players both physically and functionally. Significance was accepted at $P < 0.05$ and data are presented mean ± standard error.

4. RESULTS

4.1 Physical characteristics of squads

Descriptive data on the physical characteristics of the three different age groups at the beginning of the trial are presented in the graphs below:

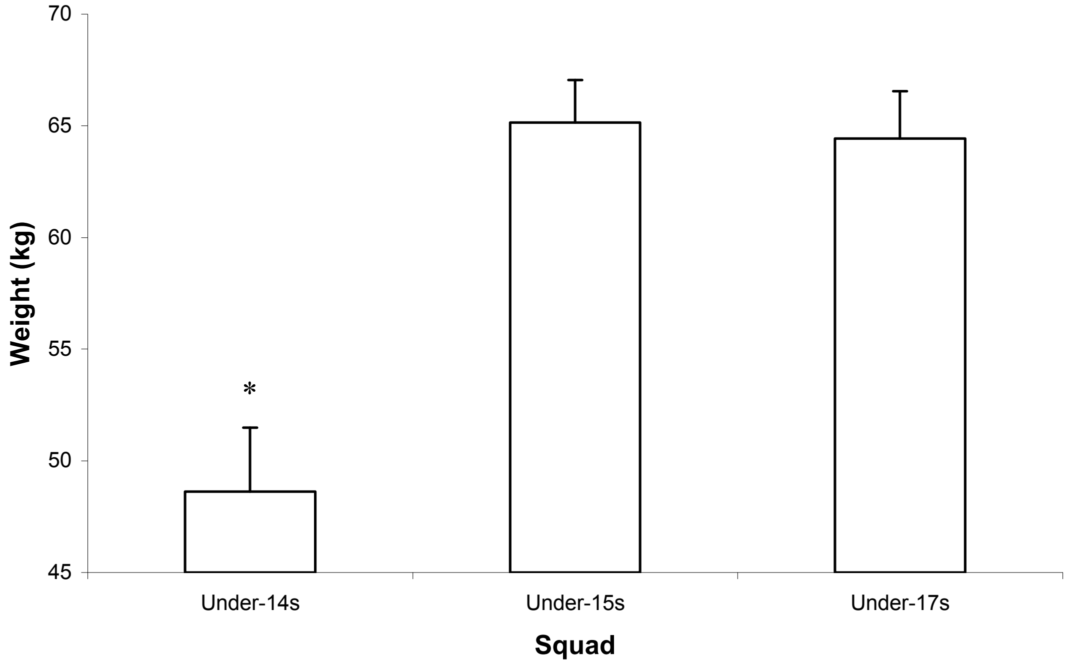
Figure 6 – Average height of each squad at beginning of trial



**U-14s significantly different to age groups U-15 and U-17 (P<0.05).*

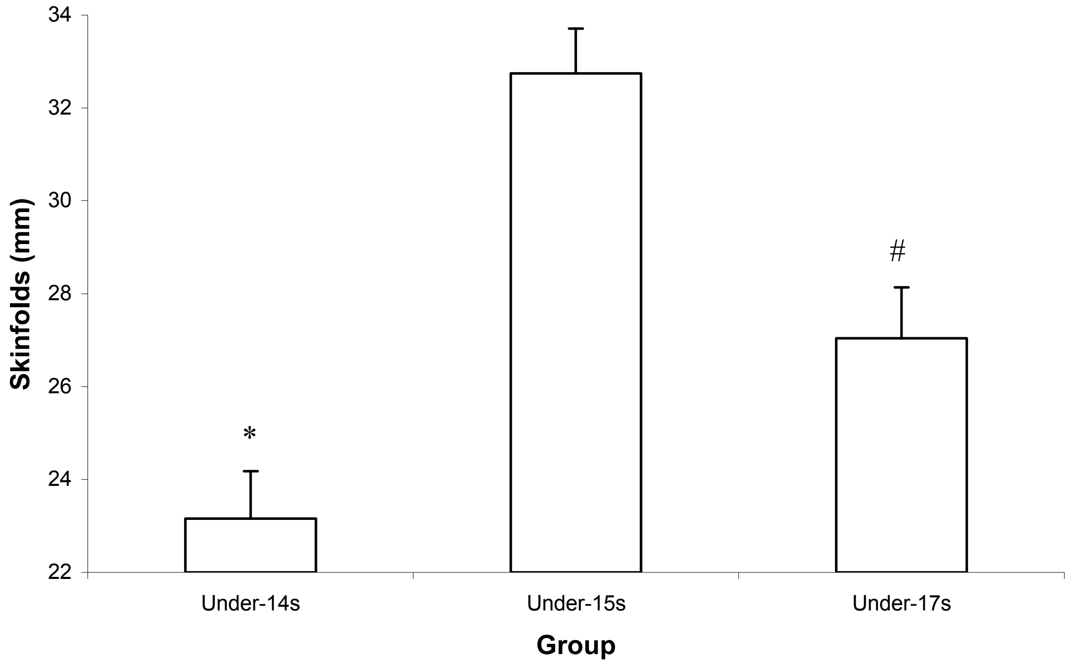
Figure 6 shows that, on average, there was a significant difference in height (P = 0.01) when comparing the U-14s age group (159.9 ± 2.5cm) to both the U-15s (172.2 ± 1.6cm) and U-17s groups (174.9 ± 1.4cm) at the beginning of the study; however, there was no significant difference between the 15s and 17s squads (P = 0.23). The initial weight of each squad at the beginning of the trial is presented in Figure 7. The heaviest group on average was the U-15s at 65.1 ± 1.9kg with the U-14s weighing 48.6 ± 2.9kg and U-17s 64.4 ± 2.1kg. Again there was a significant difference when comparing the U-14s age group to both the U-15s and U-17s groups (P = 0.01) and as with the height there was no significant difference between the 15s and 17s squads (P = 0.81).

Figure 7 – Average weight of each squad at beginning of trial



**U-14s significantly different to age groups U-15 and U-17 (P<0.05).*

Figure 8 – Mean skinfold thickness at 4-sites of each squad at beginning of trial

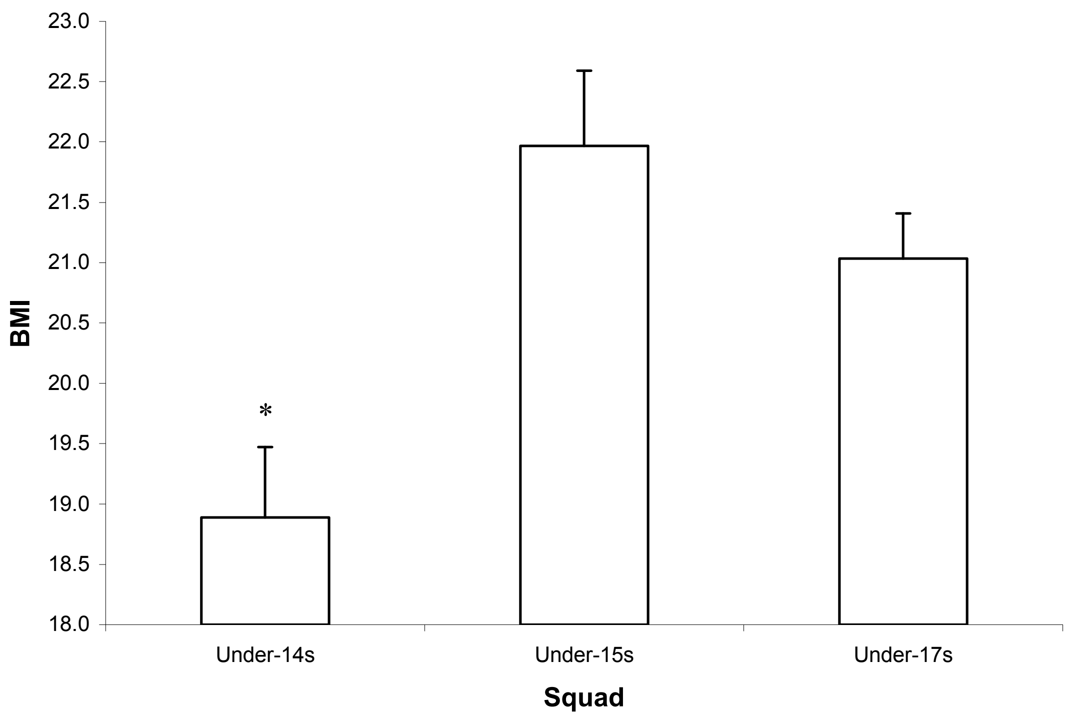


**U-14s significantly different to age groups U-15 and U-17 (P<0.05).*

#U-17s significantly different to U-15s (P<0.05)

The skinfold thickness at 4-sites (Figure 8) was similar to the weights in that the squad with the highest body fat was the under-15s with 32.7 ± 1.0mm compared to the U-14s at 23.2 ± 1.0mm and the U-17s at 27.0 ± 1.1mm. There was a significant difference between the U-15 squad and the U-14 squads (P = 0.00) and the U-17 and the U-14 squads (P = 0.03) and there was also a significant difference between the 15s and 17s (P = 0.04). Furthermore, BMI was significantly different (P = 0.01) when comparing the U-14s age group (19± 0.6 kg/m^2) to both the U-15s (22 ± 0.6 kg/m^2) and U-17s groups (21 ± 0.4 kg/m^2) at the beginning of the study (Figure 9); however, there was no significant difference between the 15s and 17s squads (P = 0.23).

Figure 9 – Mean BMI of each squad at beginning of trial

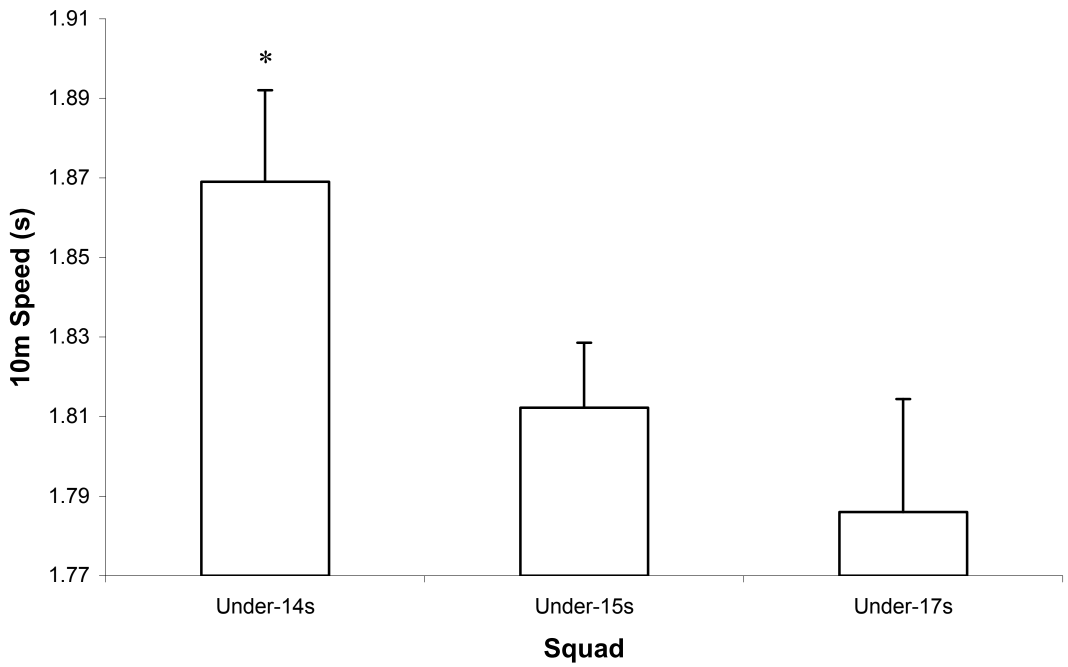


**U-14s significantly different to age groups U-15 and U-17 (P<0.05).*

4.2 Functional data

Data on the functional testing of the three different age groups at the beginning of the study are presented in the graphs below:

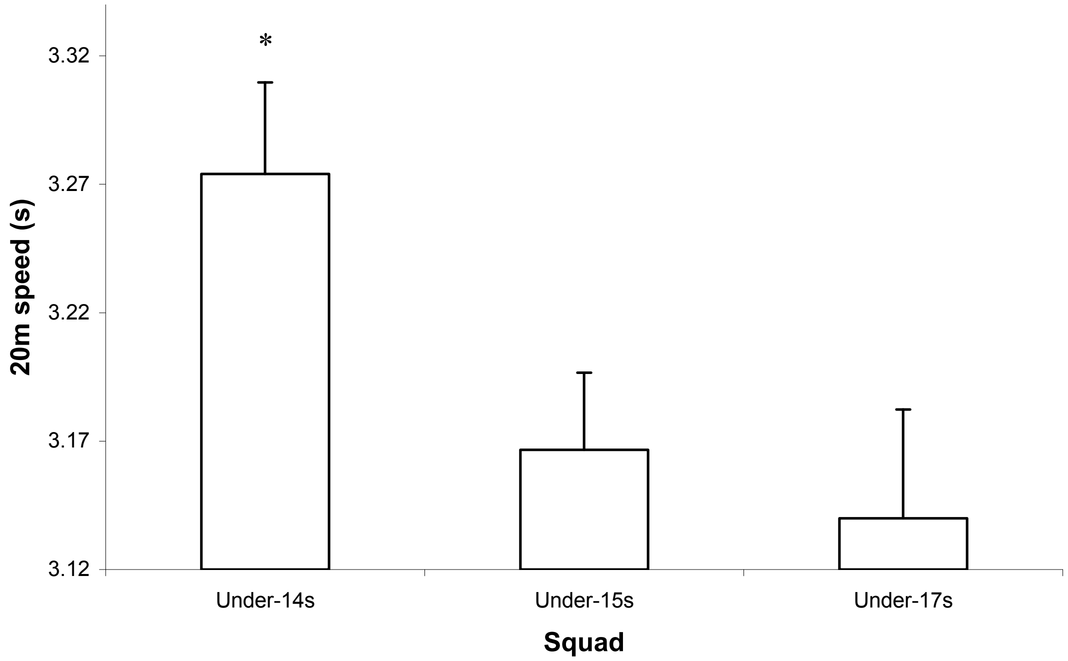
Figure 10 – Mean 10m speed of squads at beginning of trial



**U-14s significantly different to U-17group (P<0.05).*

Figure 10 displays the 10m speed times for each age group at the first set of testing. This graph shows that speed times improved with age, the fastest being the U-17s at 1.79 ± 0.03s, U-15s at 1.81 ± 0.02s and then U-14s at 1.87 ± 0.02s. The U-14s time was significantly higher than both the U-15s and U-17s (P = 0.049), however there was no significant difference between the 15s and 17s (P = 0.45).

Figure 11 – Mean 20m speed of squads at beginning of trial

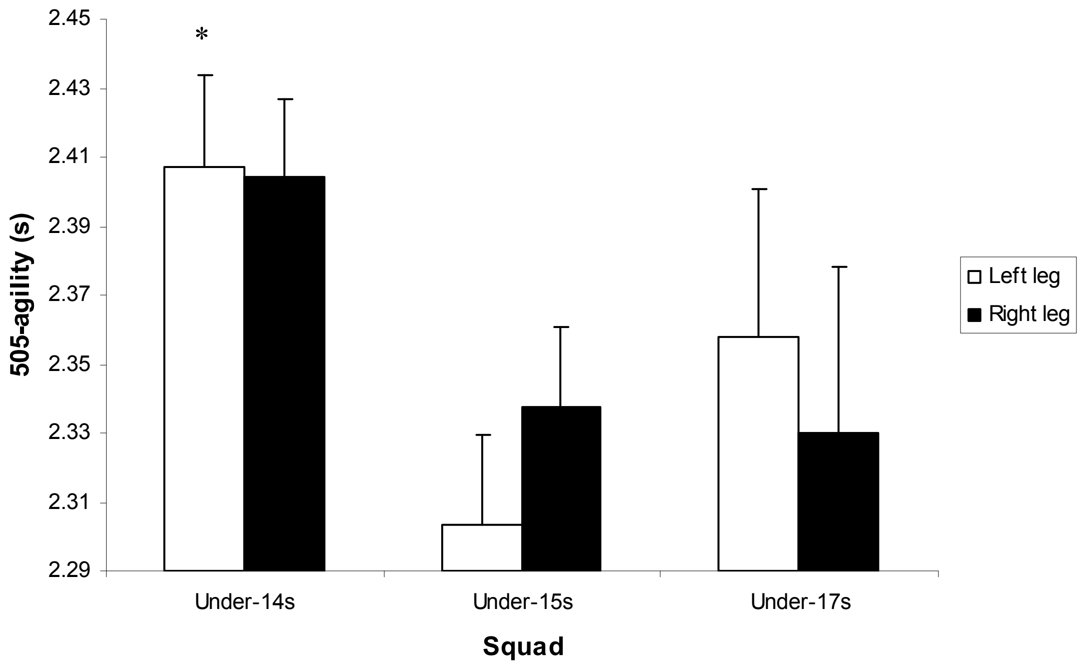


**U-14s significantly different to age groups U-15 and U-17 (P<0.05).*

This was also the case for time over 20m (Figure 11). The U-17s (3.14 ± 0.04s) and U-15s (3.17 ± 0.03s) were both significantly faster (P=0.04) than the U-14 squad (3.27 ± 0.04s) and again there was no significant difference between the 15s and 17s squads (P=0.62).

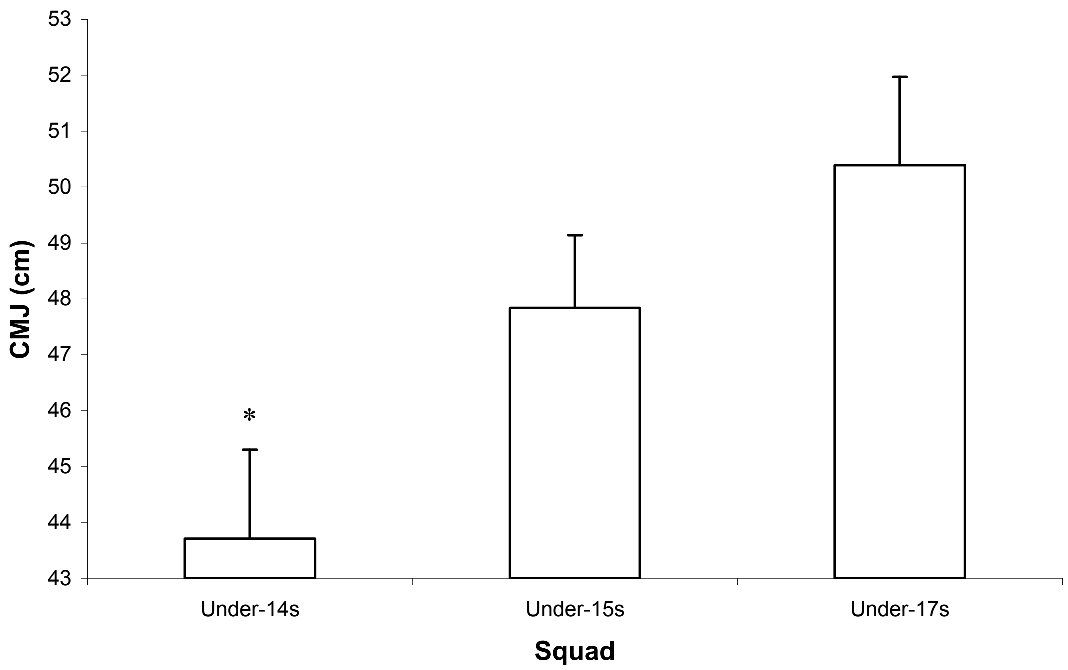
The U-14s were significantly slower (P=0.01) than the U-15s group in the 505-agility test when turning off of the left leg (Figure 12). The U-14s were the slowest with a time of 2.41 ± 0.03s turning off of the left leg and 2.40 ± 0.02s on the right leg. The U-15s recorded an average time of 2.30 ± 0.03s for the left leg and 2.34 ± 0.02s for the right leg and the U-17s were 2.33 ± 0.05s left leg and 2.36 ± 0.04s right leg.

Figure 12 – Mean 505-agility test times for left and right leg turns at beginning of trial



**U-14s left leg significantly different to U-15 group (P<0.05).*

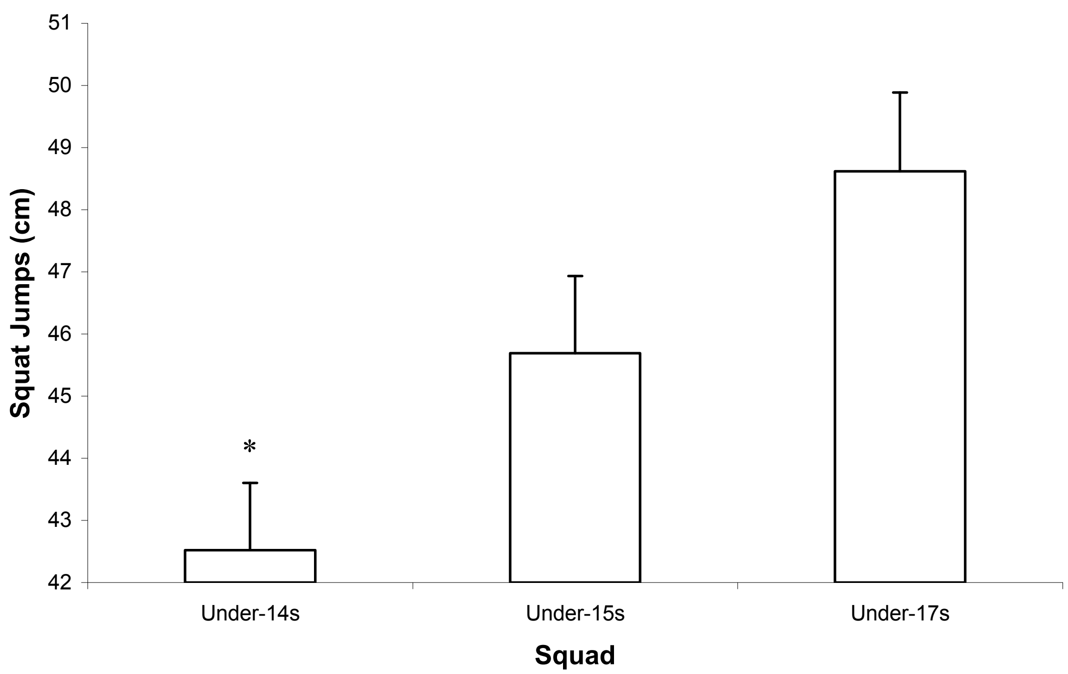
Figure 13 – Mean counter-movement jumps for each squad at beginning of trial



**U-14s significantly different to U-17 group (P<0.05).*

Figure 13 shows that there was a direct correlation (R^2 = 0.98) between age and counter-movement jump height, with the U-17s score being significantly higher (P=0.01) than the U-14s (50.4 ± 1.6cm vs. 43.7 ± 1.6cm respectively). The U-15s attained a height of 47.8 ± 1.3cm and this was not significantly different to the U-17s (P=0.24). This was also the case for the mean squat jumps (Figure 14) with both the U-17s significantly higher (P=0.01) at a height of 49.7 ± 1.4cm compared to the U-14s at 39.3 ± 1.5cm and the U-15s averaged 44.3 ± 0.7 cm which was not significantly different to the U-17s (P=0.13).

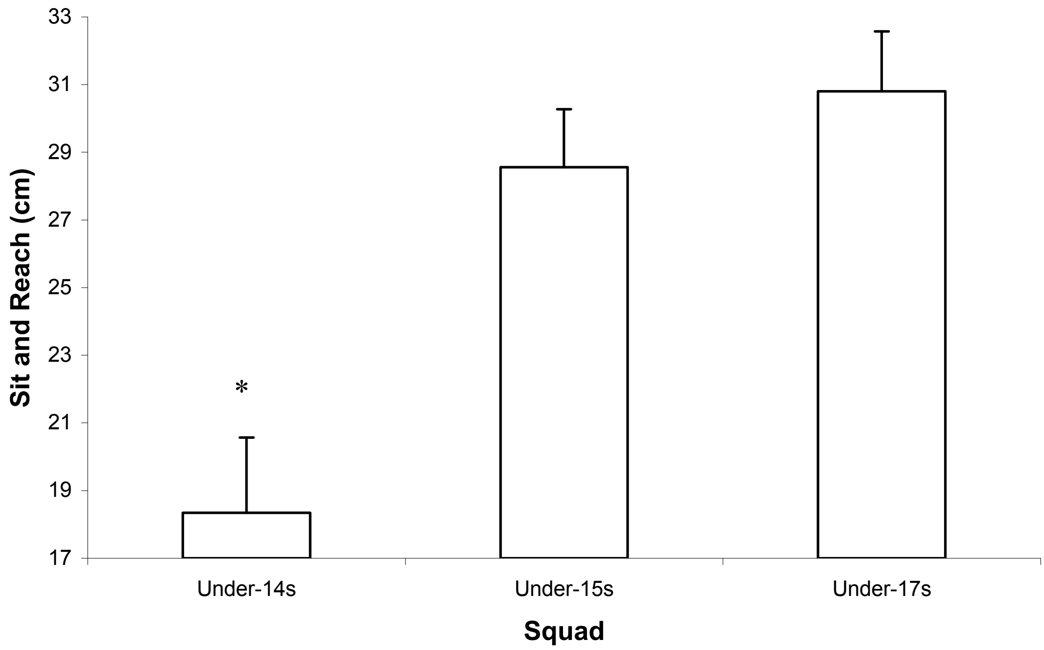
Figure 14 – Mean squat jumps for each squad at beginning of trial



**U-14s significantly different to U-17 group (P<0.05).*

Average sit and reach scores for each age group are displayed in Figure 15. The graph shows that flexibility improved with age, on average both the U-15s (28.6 ± 1.7cm) and 17s (30.8 ± 1.8cm) were significantly higher (P=0.02) than the U-14 squad (18.4 ± 2.2cm).

Figure 15 – Mean sit and reach scores for each group at beginning of trial



**U-14s significantly different to age groups U-15 and U-17 (P<0.05).*

4.3 Isokinetic dynamometry

The results for the mean isokinetic torque scores for each age group are shown on Table 2.

Table 2 – Mean isokinetic torques over the course of a season for different age groups

	Con/Hams (Nm)		Con/Quads (Nm)		Ecc/Hams (Nm)		Ecc/Quads (Nm)	
Group	Dom	nDom	Dom	nDom	Dom	nDom	Dom	nDom
U-14 (n=10)	66.1 ± 4.2*	55.2 ± 5.2*	109.6 ± 12.7*	93.2 ± 10.0*	95.1 ± 11.0#	82.4 ± 13.1#	130.8 ± 23.3#	119.8 ± 15.6*
U-15 (n=9)	114.1 ± 7.8	99.1 ± 5.5	179.0 ± 7.8	173.1 ± 10.8	165.1 ± 9.4	136.0 ± 9.9	235.1 ± 19.6	203.8 ± 18.8
U-17 (n=5)	129.8 ± 6.9	107.4 ± 13.3	191.2 ± 11.8	179.6 ± 12.4	166.6 ± 28.8	142.6 ± 22.2	203.4 ± 26.1	203.2 ± 21.5

**U-14s significantly different to age groups U-15 and U-17 (P<0.05).*

#U-14s significantly different to U-15s group (P<0.05).

There was a significant difference (P=0.00) between the U-14s compared to the U-15s and U-17s group in the Con/Hams Dom and nDom, Con/Quads Dom and the Ecc/Quads nDom. For the Ecc/Hams Dom and nDom and the Ecc/Quads Dom values there was a significant difference (P<0.05) between the U-14s and U-15s group only. The strongest group overall was the U-17s except for the Ecc/Quads values. The dominant leg is always stronger than the non-dominant leg with the exception of the Con/Quads and the Ecc/Hams measurements for the 17s group. When comparing the difference between the dominant and non-dominant leg there is a greater difference in the U-14 group.

4.4 High velocity growth players

Descriptive data on physical characteristics of the three different age groups at the different testing periods throughout the study are presented in the tables below:

Table 3 – Physical characteristics of U-14 players (n = 10)

	Age (years)	Height (cm)	Growth Rate (cm/year)	Weight (kg)	Skinfold (mm)
January	13.5 ± 0.1	159.9 ± 2.5		48.6 ± 2.9	23.2 ± 1.0
April	13.8 ± 0.1	161.2 ± 2.4	5.7 ± 1.5	50.2 ± 2.9	24.6 ± 1.1
September	14.2 ± 0.1	163.2 ± 2.3	5.1 ± 1.0	52.0 ± 2.8	26.6 ± 1.6
Average	**13.8 ± 0.1**	**161.4 ± 1.4**	**5.4 ± 0.7**	**50.2 ± 1.6**	**24.8 ± 0.8**

Values are mean ± SE.

Table 4 – Physical characteristics of U-15 players (n = 9)

	Age (years)	Height (cm)	Growth Rate (cm/year)	Weight (kg)	Skinfold (mm)
January	14.8 ± 0.1	172.2 ± 1.6		65.1 ± 1.9	32.7 ± 1.0
April	15.1 ± 0.1	173.1 ± 1.6	3.3 ± 0.4	65.6 ± 2.2	33.4 ± 0.4
September	15.5 ± 0.1	173.9 ± 1.6	2.5 ± 0.3	65.8 ± 2.0	32.1 ± 1.6
Average	**15.1 ± 0.1**	**173.1 ± 0.9**	**2.9 ± 0.2**	**65.5 ± 1.1**	**32.8 ± 0.6**

Values are mean ± SE.

Table 5 – Physical characteristics of U-17 players (n = 5)

	Age (years)	Height (cm)	Growth Rate (cm/year)	Weight (kg)	Skinfold (mm)
January	15.6 ± 0.1	174.9 ± 1.4		64.4 ± 2.1	27.0 ± 1.1
April	15.9 ± 0.1	175.9 ± 1.4	3.8 ± 0.9	66.0 ± 1.9	27.7 ± 1.0
September	16.3 ± 0.1	176.7 ± 1.4	2.7 ± 0.6	65.6 ± 1.7	25.5 ± 1.1
Average	**15.6 ± 0.1**	**175.8 ± 0.8**	**3.3 ± 0.4**	**65.4 ± 1.0**	**26.7 ± 0.6**

Values are mean ± SE.

As would be expected, the growth rate is highest in the U-14s group at a yearly average of 5.4 ± 0.7 cm/year (Table 3). This is followed by the U-17s 3.3 ± 0.4 cm/year and then the 15s averaging 2.9 ± 0.2 cm/year (Tables 4 and 5). The peak growth rate occurred between January and April therefore the data set for this period was used to compare those players going through HVG against those players who were not. Players going through HVG were identified as being two standard deviations out with the average growth rate of their squad. One standard deviation was calculated by averaging the S.D. of both the U-15s and 17s squads.

During the present study six out of the twenty-four players were going through HVG (Table 6).

Table 6 – Physical characteristics of HVG and non-HVG players in April (n = 24)

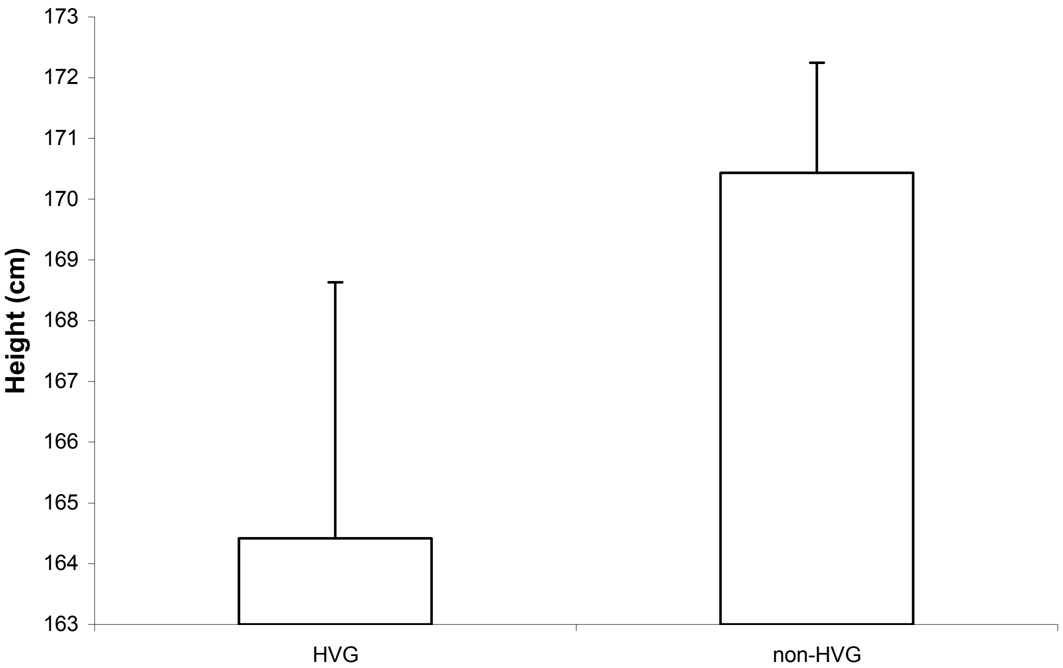
	Age (years)	Growth Rate (cm/year)
HVG (n=6)	14.4 ± 0.4	8.5 ± 1.8*
non-HVG (n=18)	14.9 ± 0.2	3.2 ± 0.3

**HVG group significantly different to non-HVG group (P<0.05).*

The two groups of players in Table 6 did not differ significantly in age, with an average age of 14.4 years in the HVG group and 14.9 years in the non-HVG players. The growth rate however in the HVG group was significantly higher (P=0.03) at 8.5 cm/year as opposed to 3.2 cm/year in the non-HVG.

Figure 16 shows that there was an average difference of approximately 6cm in height in favour of the non-HVG group (164.4 ± 4.2cm vs. 170.4 ± 1.8cm respectively) however this was not statistically significant.

Figure 16 – Mean height between HVG and non-HVG group



Both groups average weight did not differ significantly with the non-HVG group heaviest at 61.1kg compared to 54.3kg (Figure 17) and neither did the skinfolds at 29.4mm in non-HVG group compared to 26.0mm (Figure 18). The BMI value in Figure 19 shows again that there was no significant difference between both sets of players, however the non-HVG group tended to have a higher BMI of 20.9 ± 0.5 kg/m^2 compared to 19.9 ± 0.7 kg/m^2 in the HVG group.

Figure 17 – Mean weight between HVG and non-HVG group

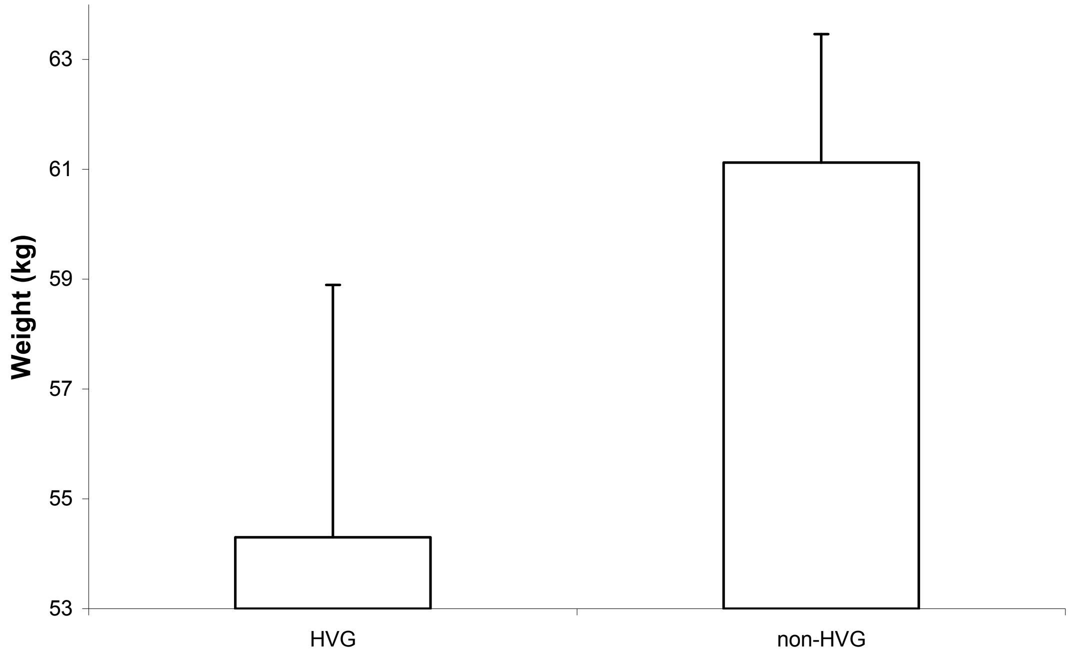


Figure 18 – Mean skinfolds between HVG and non-HVG group

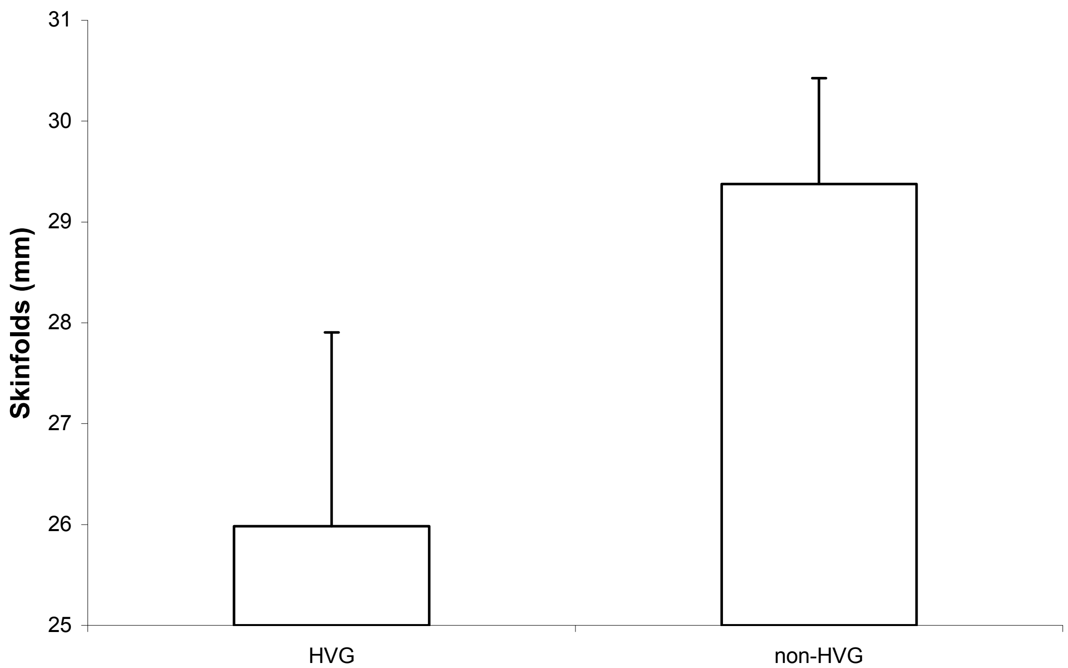


Figure 19 – Mean BMI between HVG and non-HVG group

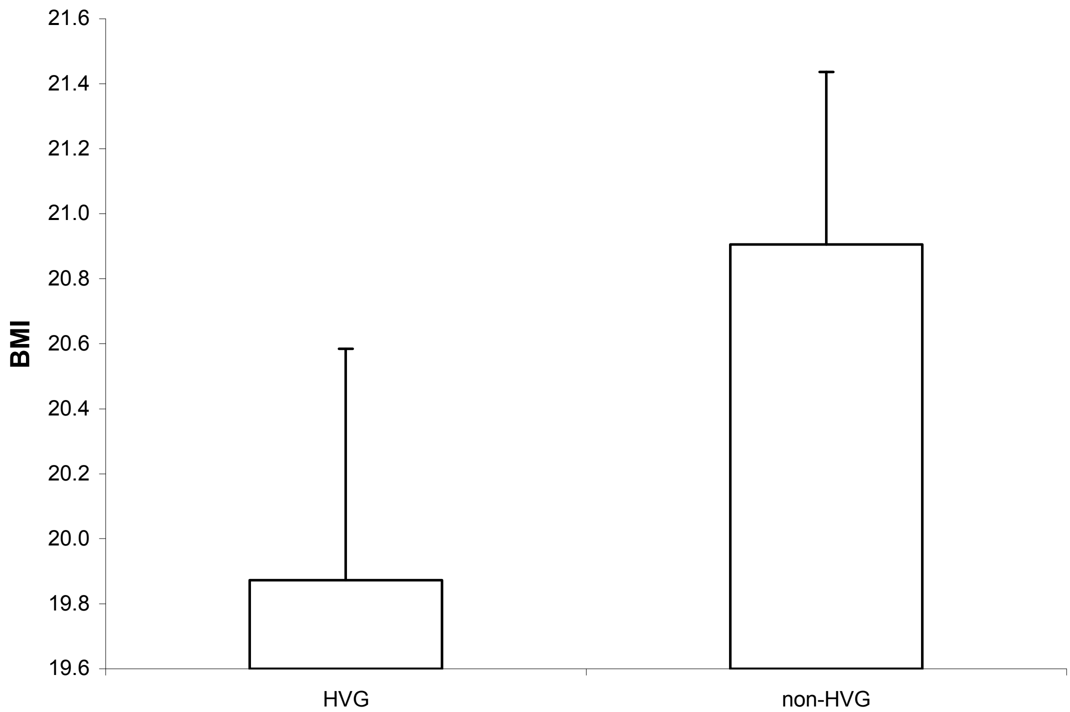


Table 7 shows that the seated to height ratio is exactly the same at 0.51 for both the HVG and non-HVG groups. The seated/leg ratio is slightly higher in the non-HVG group at 1.06 compared to 1.03.

Table 7 – Average height, seated height and ratios of HVG and non-HVG groups

	Height (cm)	**Seated Height (cm)**	**Leg Height (cm)**	**Seated/Height Ratio**	**Seated/Leg Ratio**
HVG	164.4 ± 4.2	83.5 ± 2.2	80.9 ± 2.2	0.51± 0.0	1.03 ± 0.0
Non-HVG	170.4 ± 1.8	87.6 ± 1.4	82.8 ± 0.7	0.51± 0.0	1.06 ± 0.0

4.5 Functional data comparison

Comparing data from the functional testing on both sets of groups can determine if HVG has a detrimental effect on a player's performance. The graph below shows the difference in 10m sprint time values from the players going through HVG and those who are not.

Figure 20 – Mean 10m sprint times between HVG and non-HVG group

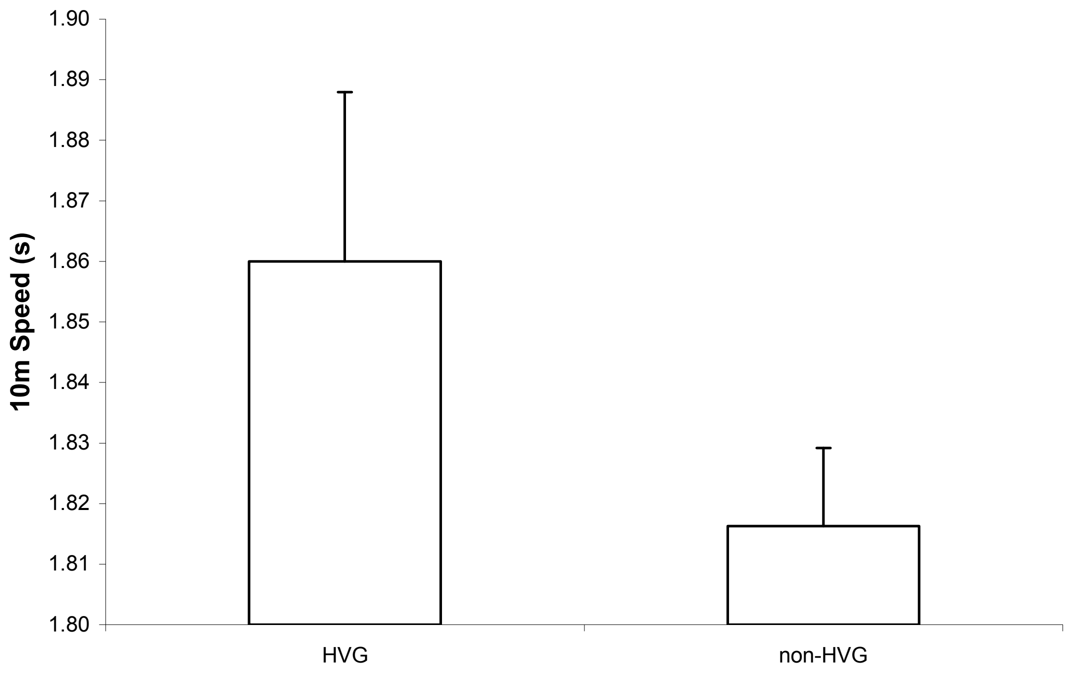


Figure 20 shows that there was no significant difference in 10m sprint time with the HVG group averaging 1.82 ± 0.01s compared with 1.86 ± 0.03s in the non-HVG group. This is also the case for the 20m sprint time (Figure 21) with the non-HVG faster with a time of 3.16 ± 0.02s compared to 3.27 ± 0.01s.

Figure 21 – Mean 20m sprint times between HVG and non-HVG group

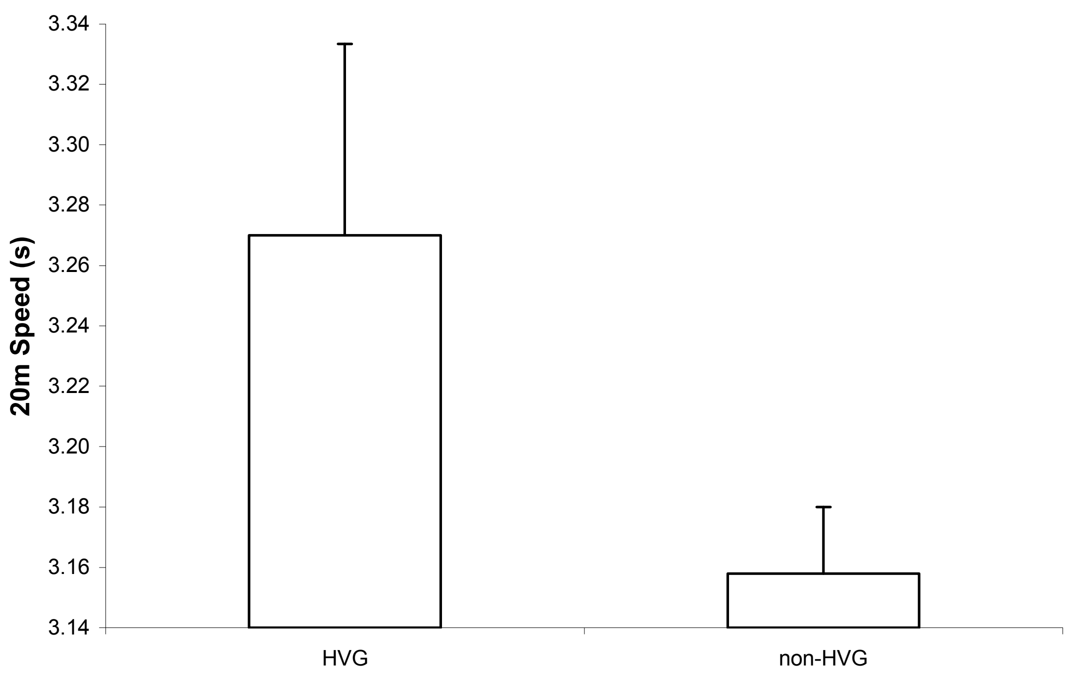
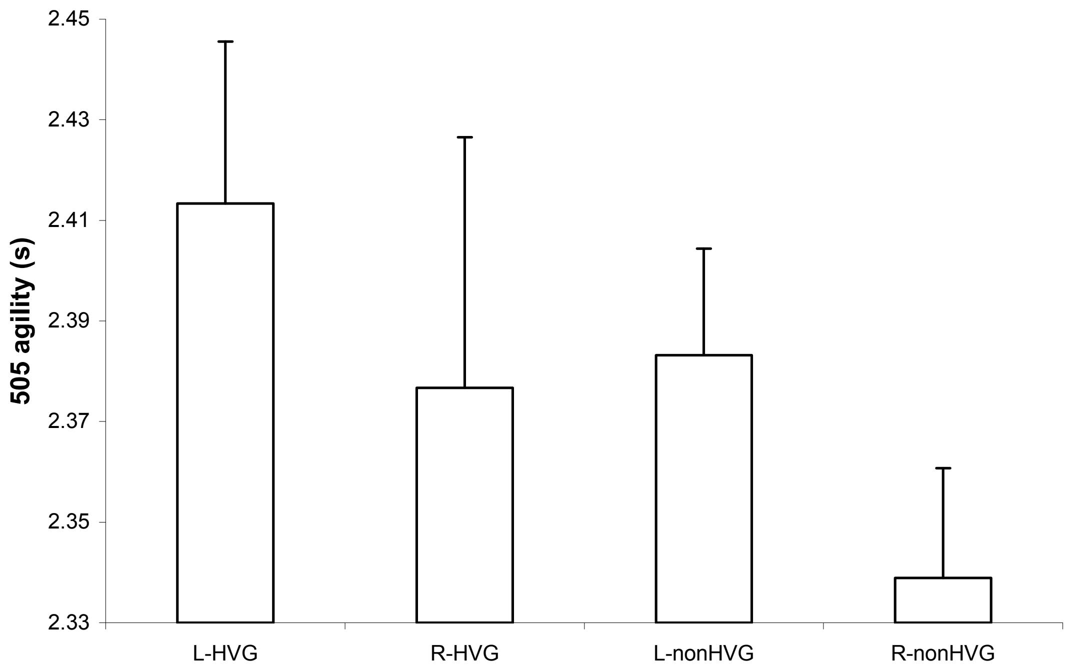


Figure 22– Mean 505 agility times on a left and right foot turn between HVG and non-HVG group



The average 505 agility test times for left and right leg in both groups is displayed in Figure 22. There was no significant difference when turning with the left leg or right leg between the HVG and non-HVG group. The HVG group had the slowest time of 2.41 ± 0.03s with a left leg turn and 2.38 ± 0.05s on the right leg. The non-HVG group on the other hand had an average of 2.38 ± 0.02s and 2.34 ± 0.02s for left and right leg respectively.

Figure 23 – Comparison in counter-movement jumps between HVG and non-HVG group

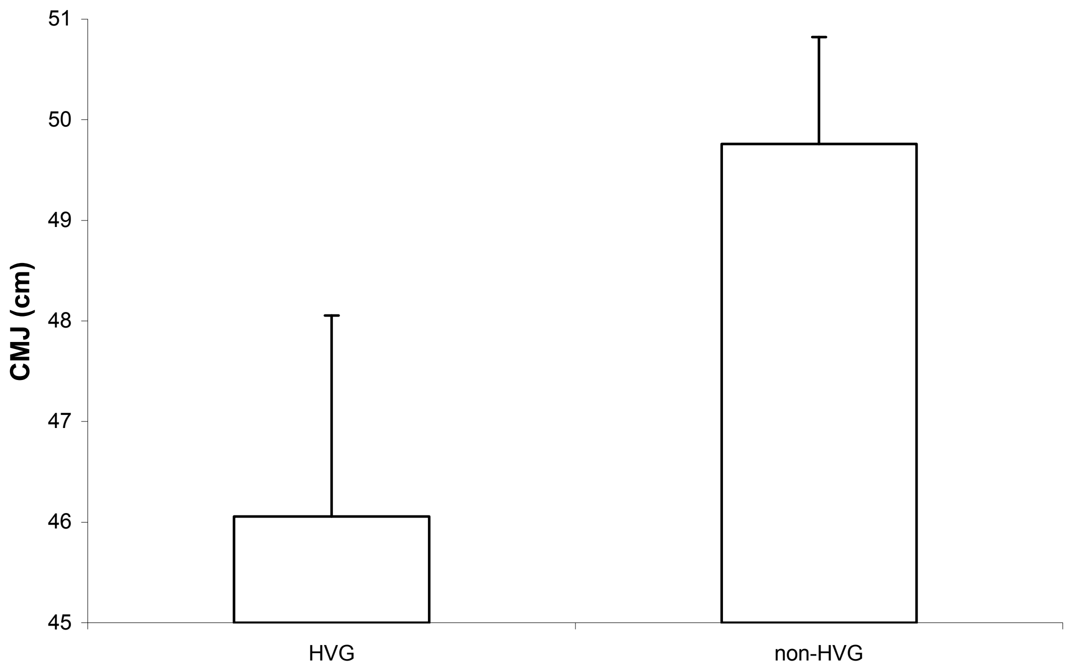


Figure 23 shows that there was no significant difference in CMJs with the HVG group averaging 46.1 ± 2.0cm in height compared with 49.8 ± 1.1cm in the non-HVG group. This is also the case for the squat jumps (Figure 24) with the non-HVG group able to jump higher at 44.8 ± 0.1cm compared with 39.8 ± 3.2cm.

Figure 24 – Comparison in squat jumps between HVG and non-HVG group

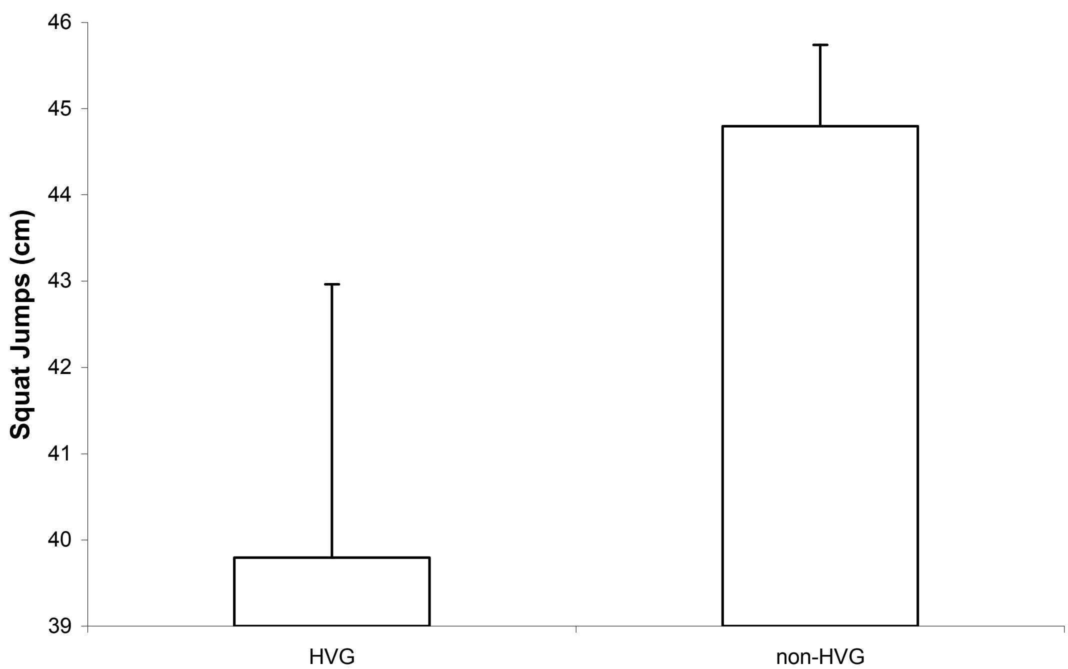
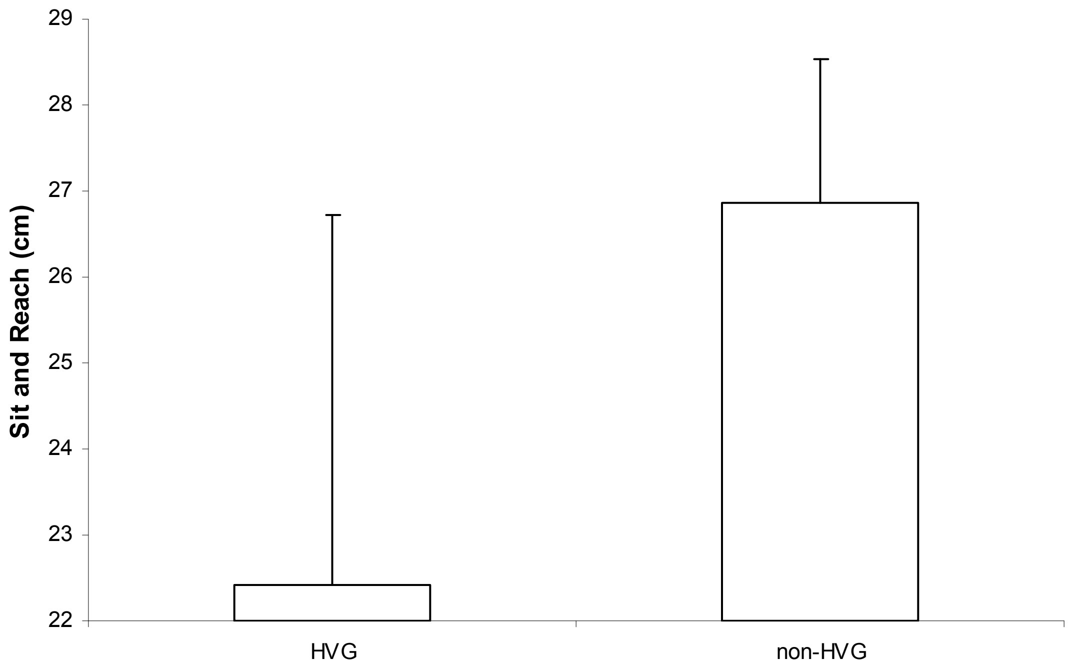
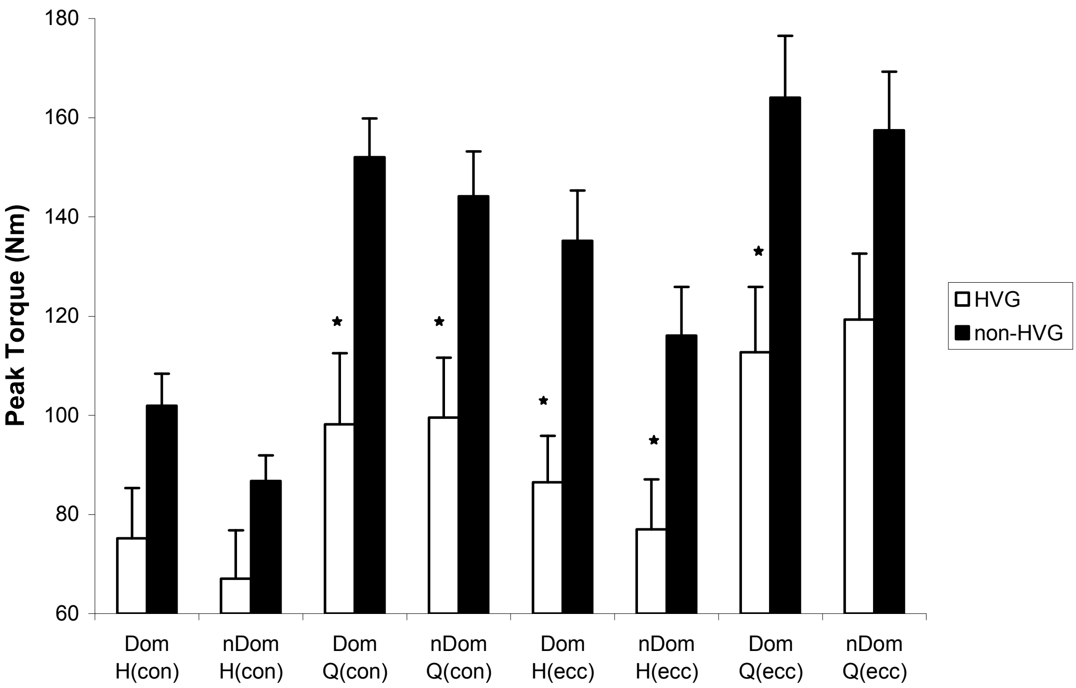


Figure 25 – Comparison of sit and reach scores between HVG and non-HVG group



The mean sit and reach score for HVG players (Figure 25) was 22.4 ± 4.3cm compared with 26.9 ± 1.7cm for non-HVG players, a difference of approximately 4.5cm but not statistically significant.

Figure 26 – Peak torques in HVG and non-HVG group

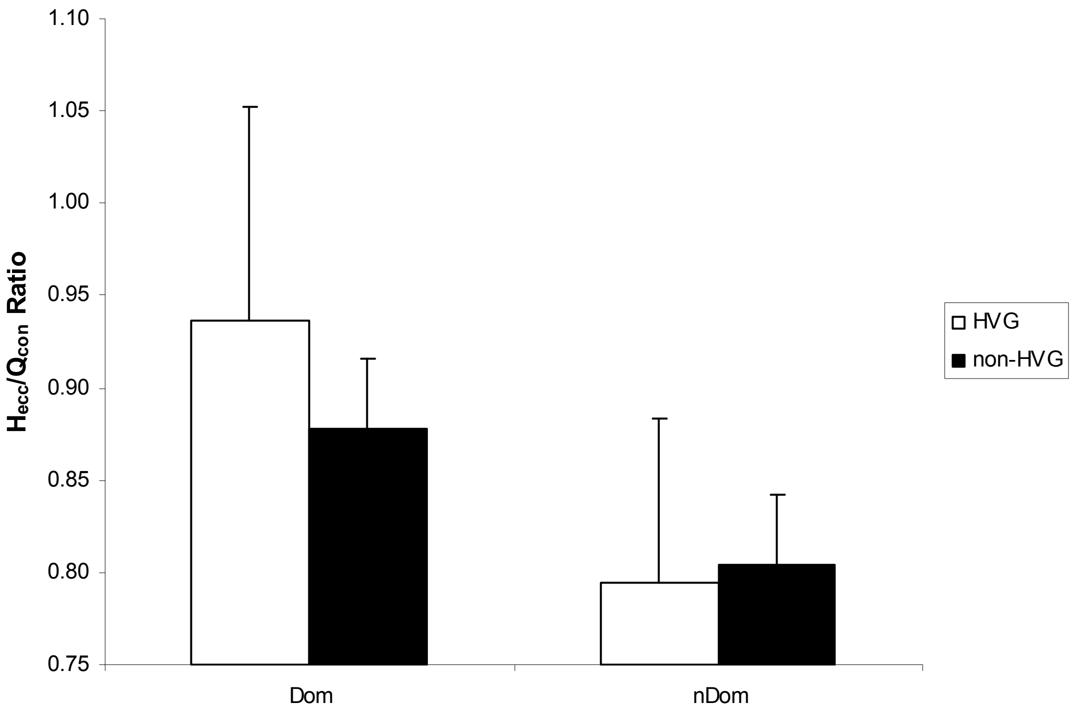


**HVG group significantly different to non-HVG group (P<0.05) 0.01*

The peak torques between the HVG and non-HVG group are presented in Figure 26. The non-HVG group achieved a greater peak torque for every movement and this is significant in the Dom and nDom Q(con) (P=0.01), Dom and nDom H(ecc) (P=0.03) and the Dom Q(ecc) leg only (P=0.01).

Figure 27 presents the functional hamstrings to quadriceps ratios for knee extension in the HVG group compared to the non-HVG group for both dominant and non-dominant leg. The graph shows that the HVG group has a ratio of 0.94 ± 0.3 for the dominant leg compared to 0.88 ± 0.2 in the non-HVG group. For the non-dominant leg the non-HVG group has the highest ratio at 0.80 ± 0.2 compared to 0.79 ± 0.2. There is a greater imbalance between the dominant and non-dominant leg in the HVG group.

Figure 27 – Eccentric hamstring to concentric quadriceps ratio in HVG and non-HVG group



4.6 Individual player comparison

Presented in Table 8 are the physical characteristics of two players of similar heights at different periods of the adolescent growth spurt. One player is at the peak of their growth rate at 9.45cm/year, whereas the other has already gone through high velocity growth and only has a growth rate of 4cm/year. The non-HVG player is approximately a year and a half older than the HVG player and despite both players being exactly the same height at 171.3cm the non-HVG player is both 5kg heavier at 59.2kg compared to 54.3kg and has 8mm more fat than the HVG player (33.2mm vs. 25.2mm). Furthermore, BMI in non-HVG player is 20.2 compared to 18.5.

Table 8 – Physical characteristics of a HVG and non-HVG player of similar heights

	Age (years)	Height (cm)	Growth Rate (cm/year)	Weight (kg)	Skinfold (mm)	BMI
HVG	13.46	171.3	9.45	54.3	25.2	18.5
Non-HVG	14.90	171.3	4.00	59.2	33.2	20.2

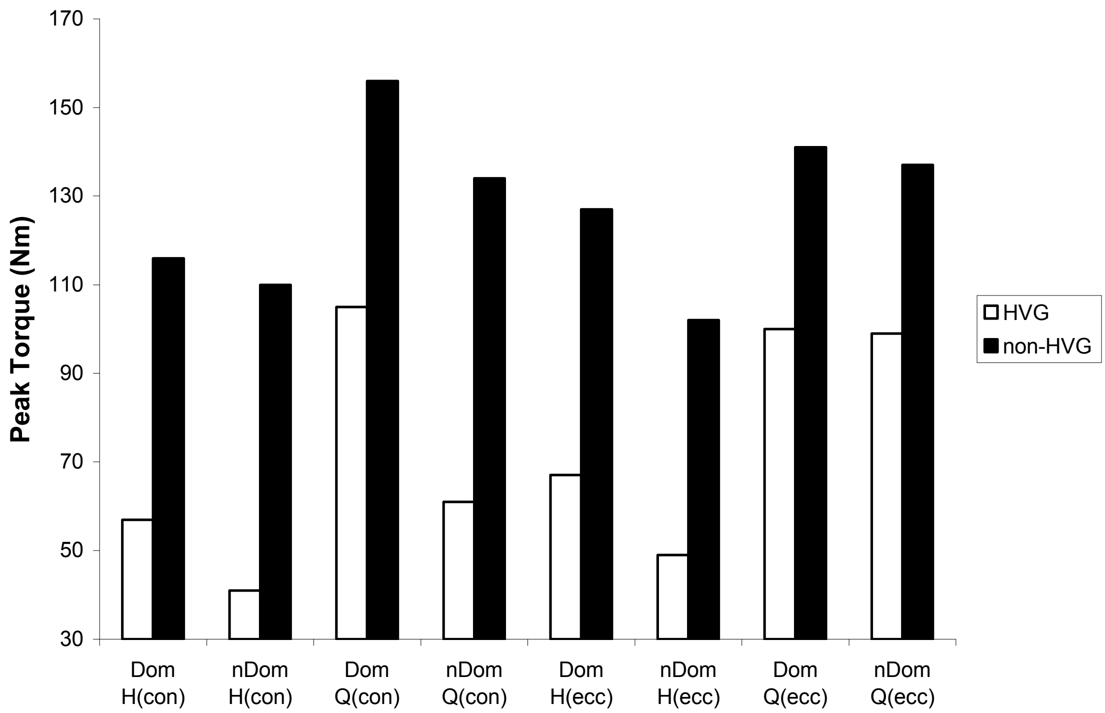
Table 9 shows the functional data of these two same players of similar heights. The non-HVG player is much quicker over both 10m and 20m (1.87s vs. 1.98s and 3.24s vs. 3.45s), their agility speed times are faster both off the left and right leg (2.45s vs. 2.50s and 2.36s vs. 2.50s) and both counter-movement jumps and squat jumps are higher (46.2cm vs. 37.6cm and 46.2cm vs. 35.8cm). Lastly, the sit and reach scores varied hugely between both players with the non-HVG player reaching a score of 22cm compared to 3cm for the player going through HVG.

Table 9 – Functional data of a HVG and non-HVG player of similar heights

	10m (s)	**20m (s)**	**505L (s)**	**505R (s)**	**CMJ (cm)**	**SJ (cm)**	**Sit and Reach (cm)**
HVG	1.98	3.45	2.50	2.50	37.6	35.8	3
Non-HVG	1.87	3.24	2.45	2.36	46.2	46.2	22

The isokinetic data between the same two players is shown in Figure 28. The non-HVG player produced far greater strength as opposed to the HVG player; in some cases the peak torque exerted was almost double. There is no real difference when comparing the bilateral muscle strengths.

Figure 28 – Peak torques of a HVG and non-HVG player of similar heights



5. DISCUSSION

5.1 Initial physical characteristics

The primary aim of the present study was to establish a method of identifying when players are going through the adolescent growth spurt. As such, the study considered both the physical characteristics and functional data of three different age groups at three different stages throughout the course of a year. The physical data from the beginning of the study showed that there was a significant difference in height, weight skinfold thickness and BMI when comparing the U-14s age group to both the U-15s and U-17s groups ($P<0.05$), however, there was no significant difference between the 15s and 17s squads except for the sum of skinfolds (Figures 6, 7, 8 and 9). This strongly suggests that the U-14s squad, who at the beginning of the trial had an average age of 13.5 years, had yet to begin or are still going through HVG, whereas the majority of the U15s and 17s will have already gone through or are at the end stages of HVG. This is consistent with the findings of Malina *et al.,* (2004b) who suggested that the adolescent growth spurt normally begins about the age of 12.5 – 13 years and boys hit their peaks of growth velocity at about 14 ± 1 years of age. Mean heights and weights of the sample also compared favourably with other samples of youth soccer players in Britain and Europe (Forbes *et al.,* 2009, Malina *et al.,* 2007). This data is useful in that it highlights the fact that a significant change occurs between the ages of 12.5-13.5 and that the majority of players going through the adolescent growth spurt should fall into this age range. It would be highly beneficial if one data set alone could be used to identify players currently going through HVG however, at this point in time there is no real accurate method of doing so.

5.2 Initial performance results

When analysing the functional data between the different age groups at the beginning of the study again there was a significant difference in all tests when comparing the U-14s squad against both the 15s and 17s ($P<0.05$) (Figures 10-15 and Table 2). Speed, strength, power and endurance are related to maturity status during male adolescence (Malina *et al.,* 2004b) and normally peak around the time of maximal growth in height in soccer players independent of age in itself (Philippaerts *et al.,* 2006a). This reflects the positive influence of maturity status on speed over 10 and 20m, counter-movement jump and squat jumping ability, 505-agility performance, flexibility and strength testing in the form of isokinetic dynamometry in adolescent boys shown in the present study. This improvement in isokinetic strength with maturity is in agreement with De Ste Croix (2003) who suggested that an increase in the length of long bones leads to a stretch of the limb muscles providing a stimulus for muscle development. Furthermore, this reinforces previously reported isokinetic strength/age curves showing a direct increase in peak torque as chronological age increased from 10 to 18 years, with the increase most evident between the ages of 13-14 (Malina *et al.,* 2003). It is worth noting that there was not a significant difference in bilateral strength comparisons across the different age groups. This is in disagreement with previous studies by Kellis *et al.,* 2001 and Rahnama *et al.,* 2005 who showed a 10% difference between dominant and non-dominant legs in youth soccer players. Again these results are very useful as a marker of the types of scores that would be expected by different players of different age group, however, they cannot be used alone to differentiate those players going through HVG and those not. There are too many other factors that have to be considered when players are carrying out these tests and therefore it is not accurate to assume that a player is going through the adolescent growth spurt if they perform poorly on these tests.

5.3 Growth rates in squads

Only after collecting another two data sets over the next 9-months on the physical characteristics of the players involved in the study could this retrospective data be used to accurately identify players going through HVG. Three parameters of the adolescent growth spurt in stature are: age at take off, age at PHV, and growth rate. The 'absolute' growth rate is defined as the amount of growth in a given period divided by the length of the period. When analysing the growth rates of the three squads between the different testing points in the season (Tables 3, 4 and 5), the U-14 squad had the highest average growth rate throughout the study as expected and also the greatest standard deviation at 5.4 ± 4.0cm/year. The large standard deviation shows the individual variability of the onset, rate, magnitude and duration of the adolescent growth spurt between the players at this age. The average growth rates of the U-17s was 3.3 ± 1.7 cm/year and surprisingly the U-15 squad had the lowest growth rate at 2.9 ± 1.1cm/year suggesting that the majority of the 15s are biologically mature and may have already gone through HVG.

Players going through HVG were identified as being two standard deviations out with the average growth rate of their squad. One standard deviation was calculated by averaging the S.D. of the U-15s and 17s squads as one would expect the majority of these players to have already gone through HVG, therefore this can be used as a comparison to analyse which stage of growth the younger players are at and it may also be used as an indicator to determine the duration of the growth spurt. From this only 6 out of the 25 players were identified as going through HVG at the time of the study, four players from the U-14s, one from the U-15s and one player from the U-17s squad. It would have perhaps been expected that more than 6 out of the 24 players would be going through HVG, however it is worth noting that talented young athletes, including soccer players, are a reasonably select group and in some instances size is a factor in the selective process, it may therefore not be a true sample of the general population. Youths who are advanced in maturity status have a distinct advantage over their peers in that they have more chance of being selected by youth soccer teams due to them being more suited to the physical element of the game (Malina, 2003).

The reason why there are so few players going through HVG is perhaps due to the fact that Rangers are one of the top teams in the country and with this reputation they are able to attract the best young players in both Scotland and abroad and in doing so choose players who are early-maturers and more biologically advanced compared to the general population of Scottish Youth players of the same age. This is confirmed in unpublished data collected by the Scottish Football Association (SFA) (Appendix A). The data gathered showed a mean height of 170.4cm for 140 U-15 Youth academy soccer players. Comparing this with the players in the present study shows that there is on average approximately a 3cm difference in height in favour of the Rangers players, they also weigh 5kg more again suggesting early maturity. Despite this the sample size for the U-15s in the present study is perhaps too small to draw any real conclusions from this data. When comparing the SFA normative data with the present studies U-14 and U-17s squads it is a very similar comparison in terms of anthropometric measurements. This suggests that there is perhaps not as much variation in body morphology in soccer players at these two age groups. This method of using retrospective data to identify certain players going through the adolescent growth spurt is accurate and reliable however it requires players to already be some way into HVG before they can be identified and it also requires regular testing over a period of time. This is therefore not ideal in a sporting environment as players training loads may not be adjusted until it is too late.

5.4 HVG and non-HVG player's physical data

An alternative method to analysing growth rates was to examine what effect the high velocity growth spurt has on body morphology, muscle function and performance in youth soccer players and to use this data to potentially identify players during HVG. The growth rates were highest in all three age squads in the testing period on April. Both the physical and functional data was therefore used at this point to compare the HVG group against the non-HVG group. The non-HVG group were approximately 0.5 years older than the HVG group at 14.9 ± 0.2 years compared to 14.4 ± 0.4 years (Table 6) and their average growth rate was significantly lower ($P<0.05$) at 3.2 ± 0.3 cm/year compared to 8.3 ± 1.8 cm/year. A study by Beunen and Malina (1988) shows that for the Scottish general population age at PHV is approximately 13.8 years and so the majority of the players in the present study may already be past PHV and it would therefore perhaps have been beneficial to have included U-13s in this study. The peak growth rate from the same study at this point was 8.9 cm/year and this is consistent with the growth rate of 8.3 ± 1.8 cm/year in the present study. As too is Malina's (2004a) estimate of 8.2 to 10.3 cm/year for peak height velocity. The non-HVG group were taller (170 ± 8cm vs. 164 ± 10cm), heavier (61 ± 10kg vs. 54 ± 11kg), had a higher skinfold thickness (29 ± 4mm vs. 26 ± 5mm) and BMI (21kg/m^2 ± 2 vs. 20 ± 2 kg/m^2) than the HVG group (Figures 16, 17, 18 and 19). This however was not statistically different due to the fact that it was only a comparison between 6 players and 18 players. These results therefore proved to be inconclusive, the non-HVG group as expected were taller as they have already gone through or at the end stages of the adolescent growth spurt, and they also weighed more. This would be as expected and in agreement with previous studies by Sinclair and Dangerfield (1998) which suggest that peak weight velocity occurs after peak height velocity and so too does fat mass accumulation. Despite this it has also been suggested that there is a "fattening up" period in the stages prior to the adolescent growth spurt in which there is an increase in fat mass (Spear and Bonnie, 2002), but this was not apparent in the present study.

BMI could potentially be used to identify HVG as one would expect a lower BMI during the adolescent growth spurt due to a change in height relative to weight. The HVG group did have a lower BMI compared to the non-HVG group however again this difference was minimal. Furthermore, the basic weakness of BMI as an index of fatness is that it ignores the possibility that muscle tissue instead of fat may contribute to excessive body weight relative to height therefore the increase in muscle mass that occurs post-HVG may obscure the data and give inaccurate results.

One potential method of identifying HVG players using physical data is by analysing the seated height and leg height of the players. It is plausible that this could be used as an indicator as relatively long legs are characteristic of early adolescence as the bones of the lower extremity experience their growth spurts earlier than those of the upper extremity. Children therefore have a more gangly appearance as the torso is lagging behind the growth of the extremities. In theory this method should prove to be reliable however in the present study again it was not statistically different and proved fairly inconclusive. The seated to height ratio was the exact same at 0.51 (Table 7). One would have expect the seated to height ratio to be lower in the HVG group due to the increase in leg length relative to the torso and perhaps with an increased number of subjects this would prove to be the case. The seated to leg ratio was slightly lower in the HVG group at 1.03 compared to 1.06. This was as expected but it was not as big a difference as would have been anticipated. Despite this it still shows that perhaps the seated to leg ratio may be a more accurate measurement of detecting HVG in youths compared to using the seated to height ratio, this would require further study with a larger sample size.

5.5 HVG and non-HVG player's functional data

These differences on physical characteristics had a large effect on the player's functional performance. Speed tests over 10 and 20m were carried out as a reduction in speed would be a good indicator of the adolescent growth spurt due to the altered length-tension relationship associated with HVG (Temfemo *et al.,* 2008). The increased limb length and the stretched muscle decrease the shortening velocity resulting in reduced speed. The HVG group were slower both over 10m and 20m (Figures 20 and 21), this wasn't statistically different however the fact that the non-HVG group were on average over one-second faster over 20m than the HVG group suggests that the growth spurt may be hindering performance. These results showed that HVG can have a detrimental effect on speed however it may not be an accurate method of identifying an individual going through HVG. Players can adjust their gait accordingly so that speed is not affected by the growth of the limbs in the lower extremities; it is therefore inaccurate to suggest that a player with decreased speed time must be going through HVG.

A 505-agility test was carried out as HVG may cause a disruption of motor coordination and balance therefore this will have a detrimental effect on a player's ability to quickly change direction when travelling at high speeds. Despite this there was no major difference in 505-agility performance between both groups (Figure 22) suggesting that the proprioception issue which can affect co-ordination and balance, which is normally associated with the adolescent growth spurt may not be as prominent as first thought, however again it is very difficult to draw any real conclusions due to the small sample size in this study.

There is contrasting data in the literature regarding the effect of HVG on flexibility. The estimated velocity curve for lower-back flexibility in the soccer players suggests a peak one year after peak height velocity (Philippaerts *et al.,* 2006b) and the results from the present study also shows that this is the case (Figure 25). The HVG group sit and reach score was approximately 4.5cm less than the non-HVG group showing that flexibility is decreased during the adolescent growth spurt. However, this is in contrast with Beunen *et al.* (1988) who found that flexibility in the lower back appears to reach maximum before PHV. A growth spurt on the leg length relative to the upper extremities will bring about a decreased flexibility in the sit and reach test as the individual will be further away from the box and their reach will not have improved. Once the upper extremities have caught up in growth with the lower limbs then performance should start improving again. This test combined with the data from the speed and agility tests could potentially be used to identify HVG however each player would have to be monitored very closely with regular testing carried out so that any major alterations in performance could be identified and analysed in closer detail.

<u>5.6 HVG and non-HVG player's strength data</u>

CMJ and SJ tests were carried out as again this could be used as a potential marker for identifying HVG. Most jumping and power activities involve a counter movement during which the muscles involved are first stretched rapidly and then shortened to accelerate the body or limb. During the adolescent growth spurt the length-tension relationship may be altered giving a shorter stretch-shortening cycle (SSC) (Harrison and Gaffney, 2001). This could result in a decreased ability to use stored potential energy in order to generate strength and therefore jumping ability would be hindered (Jones *et al.,* 2004). Squat jumps were carried out as it is a direct measurement of power and HVG players would be expected to perform poorer due to a decreased power to weight ratio. As expected the non-HVG group tended to have a greater jumping height in both the CMJ and SJ tests (Figures 23 and 24). It was predicted that there would be less difference in the SJ to CMJ values in the HVG group compared to the non-HVG group due to a decreased power to weight ratio, however this did not prove to be the case. These tests are an indicator of muscular power and strength and this correlates with the fact that peak gains in strength, on average, occur about 1.2 years after PHV when there is acceleration in muscle mass and development (Malina, 2004a). Players going through the growth spurt will have a greater bone length but without an increase in muscle mass to support this, the strength and power produced by the legs is therefore less. Despite this it may still not be a reliable indicator of identifying those players at HVG. While carrying out both CMJ and SJ tests it is a very difficult task ensuring that every player is squatting to 90 degree angle prior to the take-off. As it is a subjective observation some players may get away with doing a half squat or adjusting their technique so that the growth spurt has no impact on their ability to jump.

In this study dynamometry was used to assess isokinetic concentric and eccentric muscle strength in youth professional soccer players (Figure 26). This test was carried out as force produced varies with the length of the muscle and a relationship also exists between the force that can be developed and the velocity of the movement. Force is developed between the interaction of actin and myosin filaments as they overlap and therefore the force is proportional to the extent of the overlap. During HVG the muscle is in a stretched state, due to an increase in limb length, resulting in less overlap between actin and myosin; therefore one would expect force production to be decreased significantly. The non-HVG group achieved a greater peak torque for every movement and this is most significant in the dominant and non-dominant Quads (con) and Hams (ecc) ($P<0.05$). Comparisons of the present findings with other studies of muscle strength and performance are difficult because of lack of consistency in testing speeds and subject testing positioning between studies. When comparing the difference between the dominant and non-dominant leg there is a greater difference in the U-14 group. This implies that there may be a strength imbalance as players are going through the adolescent growth spurt. A higher H_{ecc}: Q_{con} ratio was calculated for the HVG players in the dominant leg compared with the non-HVG players (Figure 27). This was not as expected as an improved muscle strength balance is normally attributed to a significant improvement in the eccentric strength of the hamstrings muscles with resistance training (Aagaard *et al*., 1996). As the non-HVG group was predominantly made up of the older U-15 and U-17 players then they would be expected to have had more resistance training experience and lifting heavier weights, whereas the U-14s practice solely on technique with lighter weights.

In assessing concentric strength it is important to understand that the degree of strength produced by the muscle across a joint depends on the angle of the joint. That is, within the range of motion there is one point at which force production will reach maximum. By comparing the angle of peak torque across the three testing period's one would expect a shift in angle in the HVG group due to the altered length-tension relationship. This however proved inconclusive as there was a large amount of variability among all players and this again questions the reliability of isokinetic dynamometry testing in youths. There was also no correlation (R^2 = 0.26) between performance in the isokinetic testing and performance in the functional testing. It was therefore concluded that in semi-professional soccer player's isokinetic muscle strength assessed in an open kinetic chain was not movement-specific enough to predict performance during a more complex movement, such as jump or sprint. This is in agreement with the contrasting evidence on the relationship between isokinetic and functional testing in past research (Wrigley, 2000).

5.7 Individual comparison

Comparing two players of similar height, with one going through HVG and one not, could theoretically show what would have been expected had there been a larger sample size. Despite being the same height, the player who has gone through HVG was 5kg heavier and therefore had a greater BMI (Table 8). This was also the same for subcutaneous adipose tissue as there was an 8mm difference in the sum of 4-skinfolds between both players. This clearly shows that there is a significant increase in weight in the period after HVG and it suggests that a 'fattening up' period at the early stages of HVG is perhaps not as prominent as first thought.

Our hypothesis that muscle function is affected by HVG and can be used as an indicator is further proved when comparing the functional data (Table 9). The player going through the growth spurt was approximately 1-second slower over 10m and 2-seconds slower over 20m. As both players are of similar height then stride length is not a factor for this difference in speed, instead speed is hindered due to a decreased shortening velocity as the length-tension relationship alters during HVG. There also appears to be a rapid development in speed after peak height velocity and this is in agreement with Yague and De La Fuente (1998) who carried out testing on Spanish youth soccer players.

Both CMJ and SJ ability were lower in the HVG player by approximately 10cm. Again this is related to a shorter stretch-shortening cycle and a decreased ability to use stored potential energy which is associated with the adolescent growth spurt. Furthermore the player who had already gone through HVG continued to show a large improvement in jumping ability suggesting that the difference between values could get even greater. This is in agreement with Beunen (1988) who showed that the adolescent spurts in strength and muscular endurance appear to reach a peak about 0.5 to 1.0 year after PHV. It therefore seems plausible that both CMJ and SJ may be the most accurate performance indicator of HVG.

The 505-agility performance differed especially when turning on the preferred leg with the player going through HVG being slower. HVG can cause a disruption of motor coordination and balance and this is termed the “adolescent awkwardness”. When comparing the whole group of HVG players and non-HVG players there was not a significant difference in agility, however, the awkwardness tends to vary from individual to individual because of its temporary character. It is for this reason that this test is not reliable enough to accurately determine a player’s stage of growth.

The flexibility measured in the form of a sit and reach test was 19cm lower in the player going through HVG. This may be purely down to individual variability, with one player being naturally more flexible, however a plausible reason as to why there is an inverse relationship between the development of flexibility and growth in height may be related to the differential timing of adolescent spurts in leg and trunk length. Peak velocity for estimated leg length occurs earlier than that for height, whereas peak velocity for sitting height or trunk length occurs after that for height (Geithner *et al*., 1999). It is possible that the later growth in lower-back flexibility is associated with late adolescent growth in the trunk and also arm length therefore ‘reach’ will be greater. This test could therefore be a potential method of identifying HVG if players are monitored and tested on a regular occasion.

When comparing the isokinetic data between both players the non-HVG player was able to produce almost double the peak torque of the HVG player (Figure 28). During the adolescent growth spurt the muscle is stretched therefore there is a reduction in the amount of force that can be produced. As previously stated strength generally improves with age and increases linearly until the adolescent growth spurt when there is acceleration in muscle mass and development. As the non-HVG player was 1.5 years older than the HVG player then these results are what would have been expected. Despite this there are perhaps too many variables involved in this type of test to ensure complete accuracy and reliability of results. Starting seat position, dynamometer arm position, straps and gravitational correction procedures all have to be exactly the same for repeated tests and accurate for every player to ensure that body position cannot be adjusted to alter results. This can prove to be a very difficult task and so this performance indicator proved to be inconclusive.

5.8 Limitations

Testing within a professional soccer club meant that a flexible approach had to be adopted. During the course of a year the player turnover is very large, with many players being released or injured and new players being brought in. This altered the initial sample size and therefore only 24 complete sets of data could be obtained. Perhaps a greater sample size would have confirmed the trends as statistically significant. Also, due to the fact that the players were from three different squads it was difficult to carry out testing, especially on the isokinetic dynamometer, at the same time of day. Due to the number of subjects, and the time it took to test both legs of each player, the strength testing was carried out over a 2-week period with the U-17s being tested during the day and the 14s and 15s in the evening. Wyse *et al.,* (1994) proposed that accurate comparisons of maximal isokinetic leg strength could only be achieved based on data obtained within 30 minutes of the same time of day. Furthermore, the main objection against the testing of muscle strength with isokinetic dynamometry is its dependence upon the motivation of the subject to exert maximal effort and this is vital for reproducible and valid strength test results. In this study all subjects were educated on the basic principals of the test and how it may be relevant to soccer performance and injury prevention. Identical visual and verbal feedback was provided for each subject, however due to the uncomfortable nature of the test some of the players may have applied themselves less than others, especially for the 2nd and 3rd sets of testing. These factors along with the questioned reliability of isokinetic dynamometry testing in youths may have given inaccurate results.

Lastly, and possibly the main limitation of the study, was the actual time scale available for data collection. It would have been potentially useful to monitor the players involved in this study over a longer period of time. As the adolescent growth spurt lasts for approximately 2-2.5 years then it would have been interesting to track muscle performance, physical data and injury rates over the course of another year. When taking into consideration that Rangers F.C. are known to pick players who are early-maturers and more physically developed compared to their peers, it may have been advantageous to have included U-13 players in this study, however this was not possible and access to this squad would have been limited. One would expect these players to be going through HVG at an earlier age as opposed to the rest of the general population. This again may be one of the reasons why only four out of the ten U-14 players were currently going through HVG.

5.9 Feedback to the soccer coach and player

The main aim of this study was to report scientific results; however the data it provides should not limited to sports scientists. Results from the functional and isokinetic testing can be appreciated, understood and utilized in the gym or training ground by both players and coaches who do not have a scientific background. As financial rewards and obligations grow there is growing pressure to produce elite athletes in professional sport. Club coaches and the medical staff are continually looking for the safest and most successful methods to develop talented young players to compete at the highest level. These tests can be used to assess the success of certain aspects of training and to analyse continued player development, it can distinguish between players who are progressing over time and those who may not have what it takes to become a professional soccer player.

5.10 Further study

The effect of high velocity growth on muscle function over the course of a year was investigated in this study. Compared with training studies in adults, relatively less is known about the trainability of adolescents and so more studies are needed to further understand the short and long-term effects of high volume training at this stage of development and unprecedented physiological change. Methods of identifying HVG in players using body morphology data should be studied in greater detail as there is a need to identify players about to undergo the adolescent growth spurt as opposed to only being able to distinguish them once they have already started growing. Further studies with a larger sample size may seek to improve on the trends that show a reduced muscle performance on those players going through the adolescent growth spurt. It is also advisable that these studies can monitor subjects for a period of time greater than a year. Lastly, further research is warranted to determine the reliability and reproducibility of strength testing in youths with the use of an isokinetic dynamometer. Again this is firmly well established in terms of adult testing however studies on youths prove to be inconclusive.

CONCLUSION

In conclusion, the present study demonstrates that Scottish youth soccer players undergo a significant period of change at about 12.5-13 years of age. This stage of development, characterised by unprecedented physiological changes, tended to bring about a reduced performance in speed, agility, flexibility, strength and power. These functional tests showed a difference between the HVG group and the non-HVG group however it was not significant enough to accurately differentiate between both sets of players. Furthermore, players can easily adjust their technique whilst carrying out these tests in order to produce the same results therefore reliability is an issue. Having looked at both the physical and functional data, it seems that the most accurate method of identifying players going through the adolescent growth spurt is with the use of the physical data and calculating growth rates over a period of time. The results of this study do however provide normative data for coaches, trainers and clinicians working with youth soccer players. The results also highlight the significant role of individual differences in biological maturity status in the functional capacity of adolescent soccer players. The identification of young talent in soccer is followed by selection into a systematic program of training designed to improve technical and tactical skills and develop specific aspects of physical fitness. Involvement in this type of training from a very young age can bring about potential muscle disorders which could be prevented if these players are rested or have their training loads reduced at certain periods of their growth and development where they may be more susceptible to injuries. If there was a way of identifying player's who may be more susceptible to injuries then a number of ethical issues surrounding preventing certain players from training with the rest of the squad would have to be addressed. It may also be very difficult in convincing the coach as to why he is unable to play certain players. All of these factors have to be considered in determining if this type of strategy can be applied in a professional soccer environment. Whether a player is more at risk of injury or not is still inconclusive, further research is required to study these players for a longer period of time and to monitor performance changes and injury rates. It is therefore essential in a professional sporting environment that a series of physical and functional tests are carried out regularly over the course of a season in order to highlight players who are going through the adolescence growth spurt and these players should be closely monitored.

APPENDIX A

National Sports Science Youth Database

This data is based on performance players at U-14 level

Age range (years): 12.48 ⟷ 14.29

	Level 1		Level 2		Level 3		Level 4		Level 5	n
	15%		20%		30%		20%		15%	
Anthropometric measures										
Height (cm)	←	153.8	↔	161.4	↔	169.5	↔	174.4	→	**131**
Weight (kg)	←	42.60	↔	49.50	↔	56.00	↔	63.10	→	**131**
Sum of skinfolds (mm)	←	25.20	↔	21.80	↔	17.30	↔	15.70	→	**131**
Balance & Flexibility										
Balance - left (s)	←	3.40	↔	4.86	↔	7.93	↔	13.99	→	**146**
Balance - right (s)	←	3.13	↔	4.62	↔	6.41	↔	11.19	→	**146**
Hamstring flexibility - left (^{o})	←	60	↔	68	↔	78	↔	90	→	**131**
Hamstring flexibility - right (^{o})	←	59	↔	65	↔	80	↔	89	→	**131**
Power & Strength										
CMJ (cm)	←	38.3	↔	41.1	↔	44.9	↔	48.2	→	**142**
CMJ^{+} (cm)	←	44.2	↔	47.3	↔	51.2	↔	55.2	→	**142**

0-10m time (s)	←	1.87	↔	1.79	↔	1.70	↔	1.64	→	**143**
10-20m time (s)	←	1.52	↔	1.43	↔	1.36	↔	1.30	→	**143**
Total 20m time (s)	←	3.33	↔	3.23	↔	3.07	↔	2.97	→	**143**
Agility										
T-sprint (s)	←	12.10	↔	11.78	↔	11.32	↔	11.00	→	**143**
Aerobic endurance										
Yo-Yo Intermittent endurance level 2 (m)	←	600	↔	720	↔	1000	↔	1240	→	**128**

These data ranges are intended as a guide to aid physical preparation and long term athlete development of Scottish footballers

Ideally testing should take place at least twice a year.

Subjects within the age range above should aim for level 5 proficency in all possible areas.

Details of the test protocols are available from the SFA or the National Stadium Sports Health & Injury Clinic

NSSD 30/05/06

National Sports Science Youth Database

This data is based on performance players at U-15 level

Age range (years) 13.26 ⟷ 14.87

	Level 1		Level 2		Level 3		Level 4		Level 5	n
	15%		20%		30%		20%		15%	
Anthropometric measures										
Height (cm)	←	158.1	↔	167.0	↔	173.8	↔	177.2	→	**140**
Weight (kg)	←	46.70	↔	56.10	↔	63.70	↔	70.30	→	**140**
Sum of skinfolds (mm)	←	31.10	↔	26.10	↔	21.50	↔	18.40	→	**139**
Balance & Flexibility										
Balance - left (s)	←	2.13	↔	3.48	↔	7.53	↔	17.07	→	**125**
Balance - right (s)	←	2.22	↔	3.56	↔	7.72	↔	13.50	→	**125**
Hamstring flexibility - left (^{o})	←	64	↔	68	↔	78	↔	92	→	**21**
Hamstring flexibility - right (^{o})	←	62	↔	67	↔	76	↔	88	→	**21**
Power & Strength										
CMJ (cm)	←	41.1	↔	43.7	↔	47.9	↔	53.1	→	**138**
CMJ^{+} (cm)	←	46.5	↔	49.3	↔	53.1	↔	56.1	→	**137**

0-10m time (s)	←	1.88	↔	1.82	↔	1.70	↔	1.62	→	**139**
10-20m time (s)	←	1.51	↔	1.42	↔	1.35	↔	1.29	→	**125**
Total 20m time (s)	←	3.32	↔	3.22	↔	3.07	↔	2.96	→	**125**
Agility										
T-sprint (s)	←	11.87	↔	11.42	↔	11.11	↔	10.67	→	**125**
Aerobic endurance										
Yo-Yo Intermittent endurance level 2 (m)	←	640	↔	880	↔	1240	↔	1680	→	**126**

These data ranges are intended as a guide to aid physical preparation and long term athlete development of Scottish footballers

Ideally testing should take place at least twice a year.

Subjects within the age range above should aim for level 5 proficency in all possible areas.

Details of the test protocols are available from the SFA or the National Stadium Sports Health & Injury Clinic

NSSD 21/12/06

National Sports Science Youth Database

This data is based on performance players at U-17 level

Age range (years) 14.90 ↔ 16.80

	Level 1		Level 2		Level 3		Level 4		Level 5	n
	15%		20%		30%		20%		15%	
Anthropometric measures										
Height (cm)	←	168.0	↔	171.7	↔	177.2	↔	181.4	→	**119**
Weight (kg)	←	60.20	↔	64.70	↔	71.40	↔	79.60	→	**119**
Sum of skinfolds (mm)	←	33.00	↔	27.30	↔	23.70	↔	19.40	→	**119**
Balance & Flexibility										
Balance - left (s)	←	1.82	↔	2.57	↔	5.60	↔	9.30	→	**105**
Balance - right (s)	←	1.88	↔	2.68	↔	4.54	↔	7.75	→	**105**
Power & Strength										
CMJ (cm)	←	45.0	↔	47.5	↔	51.6	↔	54.6	→	**117**
CMJ^{+} (cm)	←	51.1	↔	54.1	↔	57.4	↔	61.5	→	**117**
0-10m time (s)	←	1.80	↔	1.74	↔	1.66	↔	1.60	→	**119**
10-20m time (s)	←	1.44	↔	1.34	↔	1.26	↔	1.20	→	**105**

Total 20m time (s)	←	3.14	↔	3.05	↔	2.96	↔	2.87	→	**105**
Agility										
T-sprint (s)	←	11.30	↔	10.93	↔	10.63	↔	10.39	→	**104**
Aerobic endurance										
Yo-Yo Intermittent endurance level 2 (m)	←	880	↔	1040	↔	1480	↔	2040	→	**106**

These data ranges are intended as a guide to aid physical preparation and long term athlete development of Scottish footballers

Ideally testing should take place at least twice a year.

Subjects within the age range above should aim for level 5 proficency in all possible areas.

Details of the test protocols are available from the SFA or the National Stadium Sports Health & Injury Clinic

NSSD 21/12/06

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