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M.Sc. Thesis

Seasonal variation of fitness levels in professional youth soccer players over a competitive season

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October 2009

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Contents

Summary

The use of applied sports science in soccer is growing rapidly. Fitness testing and monitoring of training intensities are now becoming common place in the modern game. Anecdotally it appears that fitness may decrease over the season after initially being high following pre-season. While field tests also suggest this, more precise measures made in controlled lab settings are scarce. Therefore, the current study considered the seasonal variation in fitness parameters of footballers over the course of a professional season.

Nineteen professional youth players from Celtic Football Club (age = 18.2 $\pm$ 0.3 years; height = 175.4 $\pm$ 6.2 cm; weight = 66.8 $\pm$ 2.56 kg) completed lab-based tests of aerobic capacity, muscle strength and power at three times throughout the season. Aerobic measures of VO_{2max} were among the highest values for soccer players reported in published literature (at the end of pre-season). Body weight changes occurred in the younger players over the season, and appear to be largely dependant on maturation status. Maximal strength parameters increased across the season and this was reflected in maximal jump heights. However, in the older players increased strength did not improve sprint performance over 5m and 10m. In younger players increasing maximal strength did correlate with improvement in sprint performances.

The results suggest that fitness levels can be maintained across the season in older age groups or more mature players. Changes seen in younger players are primarily a result of maturation and resultant changes in body morphology. Furthermore, lab-based tests appear to provide a more detailed profile of a players' physical status than field-based tests.

1. Introduction

Since the latter half of the nineteenth century, soccer has become the most commonly played code of football across the world with approximately 200,000 professional players and 240 million amateur players (Bangsbo, 1994; Junge & Dvorak, 2004). It is clear that over several decades, involvement in both professional and amateur soccer has escalated worldwide and soccer is now played in every country in the world (Reilly, 1996). Similarly, sports science has steadily grown and matured as an applied science.

While the worlds of soccer and science were initially poles apart, Reilly (1996) reported that the two had merged in the early 1970s with specialists in physiology, psychology and nutrition used in the preparation of South American national squads for major international tournaments. Since then there has been a steady increase in the application of science in soccer. For example,During their preparations for the 1986 World Cup in Mexico, the Danish squad trained using equipment which lowered oxygen content of inspired air in an attempt to combat the high altitude that they faced during the competition (Hawkins, 2004). The First World Congress of Football and Science then took place in 1987 and now meet every 4 years.

1.1 Physical demands of soccer

Soccer has several conditioning challenges. The dimensions of the rectangular playing field must lie between 90m – 120m long and 45m – 90m in width (FIFA, 2005). Considering this and given that the duration of the game is of two continuous forty five-minute halves, the long performance time and large playing area would suggest a need for elite soccer players to be highly-trained aerobic endurance athletes. Despite the endurance nature of soccer, high intensity anaerobic work, such as sprints, jumps or tackles, are involved in the most interesting and the most significant events of match play.

It has been reported that aerobic metabolism accounts for 90% of the energy cost in soccer play (Bangsbo, 2006). While Astrand and Rodahl (2003) estimated that the value of aerobic metabolism value may be as high as 98% with only 2% anaerobic. Thus the physiological requirements of elite soccer comprise elements of both the aerobic and anaerobic systems (Figure 1.)

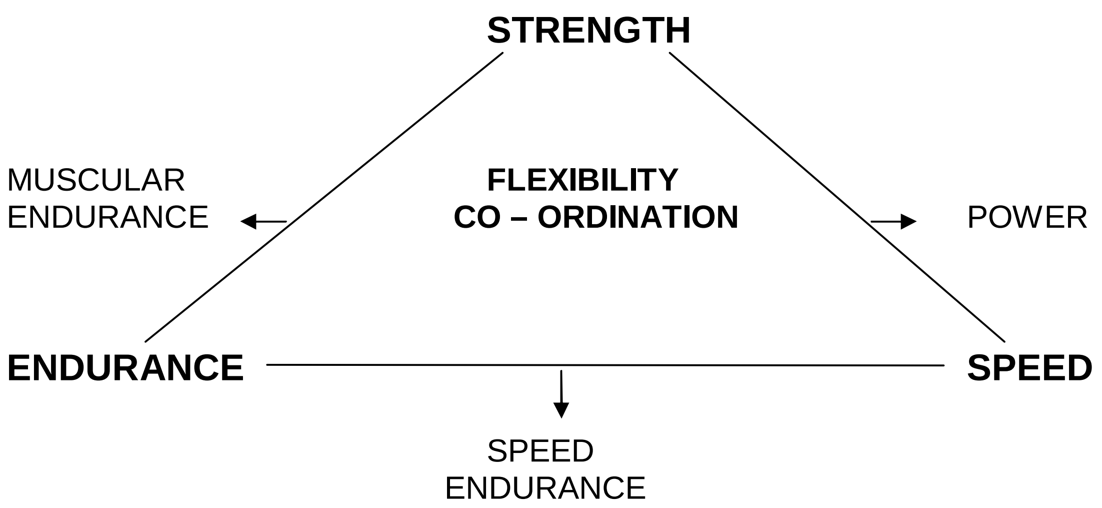

Figure 1: Fitness components contributing to the performance of football players.

1.1.1 Aerobic demands

The physical demands of outfield players have been widely reported using several different techniques, which include video analysis, hand notation and trigonometry (Bangsbo *et al*., 2006). First performed in the 1960s, time-motion analysis of soccer match play has evolved due to the fact that many spectators, coaches and players are passionately involved in the game and as a result form biased opinions (Ekblom, 1994). Utilising time-motion analysis of matches has allowed detailed and objective recordings of match events.

Total distances covered in match play today are higher than those observed in a similar study prior to the formation of the English Premier League in 1991. Reilly and Thomas (1976) suggested that top division players covered a total mean distance of 8.6 km. The physiological demands of the game have increased over the last two decades (Bangsbo, 2002; Tumility, 1993). More recent results indicate that elite level players cover significantly greater distances averaging 10-13 km per match (Bangsbo *et al*., 2006; Strudwick and Reilly, 2001; Van Gool *et al*., 1988; Ekblom, 1986). This suggests the average player's physical condition has improved over the last two decades. Several reasons exist for such changes in distances covered, such as changes in tactics and playing styles.

There have also been several new rules introduced during this time. In 1992 the rule against goalkeepers handling a pass from a team-mate was introduced. Five years later goalkeepers were instructed that they only had a limited time (6 seconds) to keep the ball in their hands before it had to be returned to open play. More recently the extra balls situated around the pitch have been introduced in an attempt to increase effective playing time. Such changes to the laws will mean that high-level soccer players are required to perform more multiple sprints and higher intensity runs and to recover from them more quickly (Dupont *et al*., 2004). Increased knowledge of fitness and conditioning programs within the coaching staff and a wider acceptance of sports science support may have also contributed to superior levels of fitness and subsequent increase in distance covered. This assertion is supported by the correlation observed between the players maximal oxygen uptake (VO_{2max}) and the distance they cover during a match (Smaros, 1980; Thomas and Reilly, 1976).

While most of the distance covered by players during a professional football match (on average 10-13 km) is low intensity running or walking (Bangsbo *et al*., 2006), it is important to focus on the high intensity exercise bouts. Mohr *et al*. (2003) concluded that the relative amount of high intensity exercise performed during a match would separate the top players from those of a lower standard. Following computerised time-motion analysis, it was reported that international players performed 28% more high intensity runs and 58% more sprints than other professional players ($p<0.05$). It has been suggested that the increased proportion of high intensity activity reflects an improved ability to recover, preventing the onset of fatigue.

There is a large variability in the physiological demands imposed on players during a game of football. On average the exercise intensity during match play is around 75% of VO_{2max} (80-90% of maximum heart rate; HR_{max}; Helgerud *et al*., 2001). However, activity by an individual during a match is influenced by factors such as physical fitness, tactics and positional role of the player. For example, Mohr *et al*. (2003) observed that during the same match one midfield player covered 12.3 km (with 3.5 km at speeds greater than 15 $km.h^{-1}$) while another midfielder covered only 10.8 km (with 2.0 km at speeds greater than 15 $km.h^{-1}$).

Research concerning positional demands in football, indicates that midfield players and full backs cover significantly greater distances than central defensive players (Strudwick and Reilly, 2001; Reilly, 1994). This is attributed to the 'link' function they serve between defence and attack - a role that requires more sustained running. The increased distance covered by midfield players may reflect more moderate intensity activity sustained over longer periods during the course of a match, which may indicate that midfield players require a more aerobic activity profile when compared to other positions. It is also possible that more tactical limitations may be placed upon them than other playing positions, due to the area in which midfielders tend to play. The critical demands of a goalkeeper are more anaerobic and are reflected in substantially lower distance covered throughout the game (4 km; Reilly and Thomas 1976).

In general, the overall work rates tend to be relatively constant in the top leagues around Europe but, given the different soccer styles and ability across nations, some variation in the average distance covered during a match has been reported. Players in the English Premier League have been shown to cover an additional 1.5 km during a match when compared to South American international players (Drust *et al.,* 1998)

Performance in endurance events is then heavily dependant on the adequate delivery of oxygen from the atmosphere to cytochrome oxidase in the mitochondrial electron transport chain, and the supply of fuels in the form of carbohydrates and lipids. Whipp *et al*. (1982) identified 4 key parameters of aerobic fitness in this process. These were namely;

1) VO_{2max}
2) Exercise economy
3) The lactate threshold
4) Oxygen uptake kinetics

While previous research has concentrated on VO_{2max} and related this to soccer performance, this is not the only parameter to consider when measuring aerobic endurance. It is widely accepted that the usefulness of VO_{2max} is limited because it measures the rate at which oxygen can be supplied to the muscles and not by the muscles ability to extract the oxygen from the blood it receives (Saltin & Strange, 1992).

VO_{2max} values for elite soccer players may be influenced by different styles of play, training regimes or phase of season (Ostojic, 2000). Given that the aerobic system is the main source of energy during soccer match play, teams with superior aerobic fitness may have an advantage, by being able to play the game at a faster pace throughout (Bangsbo & Lindquist, 1992). The broad range of recorded levels of VO_{2max} of elite soccer players is between 60 and 70 $mL.kg^{-1}min^{-1}$ (Ekblom, 1986, Davis *et al*., 1992; Bangsbo, 1994; Al - Hazzaa *et al*., 2001)

The return of the muscle to its pre-exercise state following exercise is a process known as recovery and insufficient recovery leads to fatigue (Ekblom, 1994). Fatigue during match play is often temporary but may be crucial to the final outcome of a match. Bangsbo and Mohr (2005) found that sprints over 30 m demanded markedly longer recovery than the average sprints (10 – 15 m) during a game. Considering the effects of fatigue, it is important that a player can recover as quickly as possible from high intensity exertion. Hamilton *et al*. (1991) showed a relationship between aerobic capacity and recovery from high intensity exercise. They found that endurance trained runners (VO_{2max} 60.8 $\pm$ 4.1 $mL.kg^{-1}min^{-1}$) consumed significantly more oxygen during repeated sprints and demonstrated a significantly smaller decrement in a 10 second all out power test (post exercise) than games players (VO_{2max} 52.5 $\pm$ 4.9 $mL.kg^{-1}min^{-1}$). It is therefore apparent that higher values of VO_{2max} would prevent the likelihood of fatigue in the later stages of match play through enhanced recovery from high intensity exercise (Tomlin and Wenger, 2001). Bangsbo and Mohr (2006) have shown that the amount of sprinting, high intensity running and general distance covered are lower in the second half than the in the first. Bangsbo et *al*. (1992) studied Danish league players and found that distance covered in the second half of a game was 5 - 9% less than that in the first half. However, the high intensity performance of more aerobically conditioned players does not appear to suffer (Helgerud et *al*. 2001; Tumilty, 1993).

Furthermore, Apor (1988) found a direct rank order relationship with the five most successful teams in the Hungarian league (Table 1).

Team	Mean VO_{2max}($mL.kg^{-1}min^{-1}$)	Position in championship
Ujpesti Dozsa	66.6	1st
FTC	64.3	2nd
Vasas SC	63.3	3rd
Honved SE	58.1	5th

Table 1. Relationship between mean VO_{2max} ($mL.kg^{-1}min^{-1}$*) and finishing position in the league in top Hungarian clubs.*

Wisloff *et al.* (1998) supported this VO_{2max}-success relationship by demonstrating a clear difference in VO_{2max} between the top team (Rosenborg; mean VO_{2max} - 67.6 $ml.kg^{-1}min^{-1}$), and a lower placed team (Strindheim; mean VO_{2max} - 59.9 $ml.kg^{-1}min^{-1}$) in the top Norwegian division.

Helgerud *et al.,* (2001) found that after an 8-week period of intense aerobic conditioning, VO_{2max} increased from 58.1 $ml.kg^{-1}min^{-1}$ to 64.3 $ml.kg^{-1}min^{-1}$. Video analysis demonstrated that this increased aerobic capacity was associated with an increase of 1.7 km in the distance covered by players during the match. In addition, the players increased the time they were directly involved with play by an average of 24% and doubled the number of sprints they attempted during the game. Thus improvements in aerobic performance were mirrored by improvements in soccer performance.

It would seem apparent that an aerobically adapted team, able to sustain a higher tempo during match play, would have an advantage over an equally skilled team that was unable to sustain the same intensity of exercise. Wisloff *et al*. (1998) quantified this by stating, theoretically, that if the average VO_{2max} in a team was 6 $ml.kg^{-1}min^{-1}$ greater than their opponents it would be equivalent to having an extra player on the field in terms of the distance covered. This study also reported that the highest average VO_{2max} of a professional soccer team recorded to date was 67.6 $ml.kg^{-1}min^{-1}$. It is clear that the aerobic component of soccer training is of vital importance for success and should be monitored throughout the season.

1.1.2 Anaerobic demands

Despite the endurance nature of soccer it is obvious that the game does not rely solely on one energy system. High intensity explosive actions such as heading, sprinting, tackling or shooting are, perhaps, the most interesting and often most significant events of match play. It has even been argued that different standards of player (Tumilty, 1993) and different playing positions (Davis and Brewer, 1992) are differentiated better by components of anaerobic fitness (speed, power, strength, the capacity of the lactic acid system) than by aerobic power. Apor *et al*. (1988) concluded that elite

Hungarian soccer players had a 15 – 30% higher level of anaerobic power than an age matched control group. While the difference in anaerobic work capacity between Australian National and State level players was as much as 20% (Green, 1992). Hence, strength and power share importance with endurance in top-level soccer play.

Wisloff *et al.* (1998) proposed that a high level of anaerobic and strength parameters would be desirable and would reduce the risk for injuries and allow for more powerful jumps, kicks, tackles and sprints among other factors. De Proft (1988) had previously found that kick performance could be improved by an increase in strength.

1.1.2.1 Strength

Muscle strength is defined as the amount of force or tension a muscle or group of muscles exert against a resistance at a specified velocity during a maximal contraction (Bell and Wenger, 1992). Reilly (1996) stated that the benefits of strength training in soccer players were three fold:

- To increase muscle power output during explosive activities such as tackling, jumping, kicking and accelerating
- To prevent injuries
- To regain strength post injury

Increasing upper body strength will also improve strength on the ball - important when shielding the ball or tackling. Moreover, power is heavily dependent on maximal strength, with an increase in the latter being connected with an improvement in power capabilities (Wisloff *et al*., 2004). Wisloff *et al*. (2004) indicated that increasing strength in soccer players increases parameters of power such as jumps and sprints. They found a strong correlation between squat strength, jumping height and all aspects of 0 – 30 m sprint performance in elite soccer players. Thus, it is beneficial for a soccer player to have a high level of muscular strength. Hoff (2005) found strength and power could be evaluated using a one repetition maximum test of half squat, sprint times and jump heights respectively.

Strength training causes neural adaptations and hypertrophy to occur in the affected muscles. Stolen *et al*. (2005) observed that apparent increases in strength may partially be dependent on similar techniques being used in training and in testing. This may be, in part, due to changes in the nervous system and neuromuscular adaptations (Gabriel *et al*., 2006). Increases in cross sectional area of the muscle are associated with an increase in potential for force production due to increased myofibril content of the fibres and are known as hypertrophy (Baechle and Earle, 2000). Fast-twitch muscles appear to hypertrophy more readily than slow twitch fibres. With hypertrophy, an increase in body mass is evident which may impair ability to develop torque at high velocity).

Strength tests often involve multiple or single repetition maximum tests (1RM). A multiple repetition maximum test is often utilised when the lifter has limited experience or injury history in the affected area. Isokinetic tests do not reflect the movement of the limbs involved during soccer, as muscle movement *in vivo* is not isokinetic (Stolen *et al*., 2005). Isometric strength may not be truly reflective of the ability to exert force in dynamic conditions. It may therefore be a poor predictor of performance in a game (Reilly, 1996).

However, tests that involve free barbells will reflect the functional strength of players more accurately (Hoff and Helgerud, 2004). Also, free barbells are more widely accessible for teams for both training and testing purposes. Hoff (2005) stated that strength testing should take place for the upper and lower body and should be evaluated using a 1 RM test of half squat and benchpress. This gives an indication of the greatest amount of weight an individual can lift for each exercise, and also provides information on the athletes training loads calculated as a percentage of the 1 RM.

Wisloff *et al*. (2004) conducted maximal strength test of benchpress and half squats on players from Rosenborg F.C in Norway to establish that, for a 75 kg male, it would be reasonable to anticipate half squat values of approximately 200 kg or greater. Similarly in the benchpress exercise values of 100 kg or greater can be expected. Other published results have not been as high. This may reflect training strategies and starting values (Stolen, 2005).

1.1.2.2 Jumps

As stated previously, anaerobic actions account for a small proportion of match-play. However, explosive movements such as jumping to head, tackling or even kicking are key aspects of the game and are often the most decisive to match outcome. Jump ability is essential to soccer activities such as heading. Measuring this parameter gives a marker of lower body power. Ostojic (2000) stated that vertical jump test results were related to positional role, phase of training and level of play, with elite soccer players performing significantly higher jumps than non elite players (47.6 ± 5.7 .v. 46.2 ± 5.5 cm). Wisloff *et al*. (1998) tested top level professional players competing in the UEFA Champions League and concluded that mean vertical jump heights are between 50 cm and 60cm.

To an extent, different jumps measure different leg power qualities. The Countermovement jump (CMJ) is where the jumper starts from an upright standing position, makes a preliminary downward movement by flexing at the knees and hips, then immediately extends the knees and hips again to jump vertically up off the ground. It is a measure of slow stretch shortening cycle performance (>250 millisecond) and has also been found to have a high correlation with sprint time (Hennesy and Kilty, 2001).

The CMJ protocol can take two forms:

1) CMJ (no arm swing) – hands are placed on hips throughout the jump.
2) CMJ (with arm swing) – arms are permitted to assist in gaining maximum height (Lees *et al*., 2004).

The CMJ (no arm swing) is often taken as an absolute measure of leg power while the CMJ (with arm swing) is often viewed as a more football specific test. Lees *et al.* (2004) found CMJ (with arm swing) to produce a higher jump by 8.6cm on average. The Swedish national male team also found differences between the two jumps. The mean ratio between CMJ (with arm swing) and CMJ was 1.14 (Ekblom 1994). These results are due to a complex series of events at take-off in the CMJ (with arms swing) which allows the arms to build up energy early in the jump. This energy comes from the shoulder and elbow joints as well as from extra work done at the hip and is transferred to the rest of the body during the later stages. Therefore, during the CMJ good jumpers are able to coordinate their arm swing to drive the body upwards.

Squat jumps are performed in a similar manner to that of the CMJ (no arm swing). However, after the initial downward movement there is a 2 second pause to eliminate the stretch shortening cycle which may increase jump heights in the CMJ action.

1.1.2.3 Sprint

Players have to possess the ability to accelerate to meet the physical, tactical and technical components of the game. Sprinting constitutes 1 – 11% of total distance covered during match play with a sprint bout occurring every 90 seconds and lasting 2 – 4 seconds (Bangsbo *et al*. 1994; Reilly and Thomas, 1976). Single sprint tests have been found to differentiate between different standards and between different positional roles within a team (Kollath and Quade, 1993). Krustrup *et al.* (2006) considered repeated 30m sprint performance during and after matchplay and concluded that sprint performance was reduced both temporarily during a game and at the end of match-play. The latter finding may be explained by low glycogen levels. However, while no single energy system provides the complete supply of energy, the energy required for a single sprint of duration less than 10 s is derived principally via anaerobic pathways by means of breakdown of intramuscular phosphocreatine and glycogenolysis with lactate as an end product (Gaitanos *et al*.,1993). Therefore the energy provision during a single sprint is different from that during repeated sprints performed in an intermittent exercise pattern and has to be tested for separately. This is most accurately determined by light timing gates rather than by manual stopwatch. Explosive acceleration can be measured over 5m, while 10m sprint times may be more representative of activities seen in match play (Strudwick *et al*., 2002).

1.2 Fitness testing

Athletes strive to be at an optimal physiological and psychological state for competition. Hence, it appears that coaches and trainers have gradually become more welcoming to scientific approaches in preparation for soccer match play. Such approaches include physiological testing to assess fitness and to monitor training to ensure optimum performance. Aspects such as body composition, endurance, balance between anaerobic power and aerobic power, are of primary importance in evaluation of soccer performance (Reilly, 1996). Injuries, and the sequelae from previous injuries, can also affect the players' ability to perform (Arnason *et al*., 2004). Prior to a testing programme objectives must be clearly defined and an appropriate test selected (valid and reliable; Ekblom, 1994).

In the past, the majority of fitness testing with soccer players has consisted of a battery of field tests. Fitness tests performed in the field enhance the specificity of the evaluation, use minimal equipment, and are more cost efficient (Svensson and Drust, 2005). However, if performed outdoors these tests may not be truly reflective of physiological capabilities since they may be influenced by environmental factors.

Traditionally, aerobic capacity has been evaluated by the multistage fitness test originally designed by Leger and Lambert (1982). The test has been used extensively by English football clubs (Davis *et al*., 1992; Strudwick *et al*., 2002) and the Australian Olympic Squad (Tumility, 2000). This test consists of completing repeated shuttle runs between 2 lines 20m apart. The running speed is incremental and determined by audio signals from a tape recorder. The aim is to complete as many runs as possible and this gives an estimation of VO_{2max}.

However, several problems exist with this method of evaluating VO_{2max}. When a 20m multistage shuttle run test to assess aerobic power is conducted outdoors, conditions underfoot, temperature and wind speed have to be considered. Even when the test is conducted under controlled conditions the expired air is not collected and hence the value given for VO_{2max} is an estimated rather than a precise measure. Furthermore, it appears that the test is not sensitive to training interventions and their adaptations, or to differences in playing standard. Odetoyinbo and Ramsbottom (1997) found no significant improvement in the multistage shuttle run test following an 8-week training intervention consisting of high intensity aerobic training. No significant difference was found in 20m shuttle run performance between English academy scholars and recreational soccer players (Edwards *et al*., 2003).

The sprints a football player makes during match-play are mostly 10-25 m in length, or 3-5 s in duration and as such testing for sprint ability usually takes the form of a 10m, 20m or 30m sprint (Apor, 1988; Kollath and Quade, 1993; Strudwick et al., 2002). However, explosive acceleration over 5m may also be of great importance when considering soccer performance. Similar to a test for aerobic endurance, sprint ability tested outdoors will be affected by factors such as underfoot conditions and wind speed. As a result, using light gates indoors would be the most suitable valid and reliable test for sprint ability.

Previously, the relationship between soccer specific endurance and conventional laboratory tests of aerobic and anaerobic parameters was unclear. As the majority of energy provision is derived from the aerobic system the determination of a player's VO_{2max} is important for soccer play (Bangsbo, 1994). Hoff (2005) concluded that VO_{2max} should be tested for directly on a treadmill or in the field. After considering lactate responses throughout a season McMillan *et al*. (2005) support this contention. Unlike field tests, standardised laboratory protocols can be used to establish whether maximal values have been reached. For example, has a plateau been achieved in VO_2? has respiratory exchange ratio (RER) risen above 1.15? or has HR risen to approximately age predicted maximum values? (Shephard, 1984).

Hoff (2005) stated that this test for VO_{2max} should be supplemented with an assessment of running economy. The ability to sustain a high work rate is likely to be determined by a combination of aerobic factors including VO_{2max} and running economy (RE; Ekblom, 1994). Running economy is commonly defined as the steady state oxygen consumption (VO_2) in $ml.kg^{-1}min^{-1}$ at a standard velocity or as energy cost of running per metre in $ml.kg^{-1}$ (Hoff and Helgerud, 2004).

External factors are eliminated when physiological testing takes place in a controlled laboratory setting. Currently, all English Premiership clubs and 96% of English Football League clubs used some form of fitness tests in athlete preparation, assessing fitness and rehabilitation (Erith, 2004). However, only 7% of these clubs used laboratory-based tests (Erith, 2004). As a result of soccer players not frequently visiting the laboratory studies of repeated measures in professional soccer are scarce (Casajus, 2001). Svensson and Drust (2005) stated that laboratory tests are often carried out only at the beginning and end of a season due to the time consuming nature of such tests.

1.3 Seasonal variation in fitness levels

In most sports training for successful competition has become a year-long challenge. To assist in preparation, an athlete's year is often periodised or divided into distinct phases where training is reduced or increased according to competition commitments. Measuring physiological parameters throughout a competitive season and across consecutive seasons give an assessment of how fitness fluctuates across the year. It is important to assess existing training schedules through rigorous sport specific fitness testing of athletes at defined points in the competitive season. This will evaluate both physical performance and the existing training strategies. Astorino *et al*. (2004) evaluated changes in physical fitness parameters during a competitive field hockey season and found that VO_{2max} was maintained across the season while maximal strength declined. They concluded that this reflected the nature of in-season training where emphasis was on aerobic training, match-play and recovery.

In soccer, prior research into training and its responses has tended to concentrate on physiological adaptations after a period of intensive training such as during the pre-season. Alternatively, others have considered detraining effects from final game of one season to the initial training days of the next (Amigo *et al*., 1998). However, considering physiological parameters throughout the course of a season may be of greater value when considering performance. McMillan *et al*. (2005) stated that it was important to monitor the aerobic endurance performance of soccer players periodically throughout the soccer season. This will not only present information on the relative deterioration, maintenance or improvement in soccer specific physiological variables but can also be utilised when evaluating training methods. This would allow for frequency, intensity, duration or overload to be manipulated for success in future seasons.

Professional players are not frequent visitors to the laboratory (Erith, 2004). Therefore, it has been difficult to provide regular and periodic testing under a controlled environment, with few studies repeating measures over a season. This has resulted in anecdotal suggestions that fitness decrements occur during the second half of the season. Existing scientific research to substantiate these claims is scarce. Ostojic (2000) found that training regimes or phase of season affected values of $VO_{2max.}$

Brady *et al.* (1995) considered lactate values and heart rate responses of professional players over the course of two seasons and suggested these variables fluctuated over the course of a season. After an initial increase in parameters of endurance after pre-season training, the peak values obtained decreased over the following months. This was attributed to the fact that coaches may be reducing the training stimulus towards the end of the season.

Similarly, Mercer *et al*. (1995) stated that pre-season conditioning did provide sufficient stimulus to improve aerobic capacity but that this inhibited explosive leg strength (vertical jump height). This seemed most likely to be a direct effect of the highly aerobic nature of the conditioning programme; 80% distance running and 20% high intensity shuttle running/game-specific conditioning. However, Kraemer *et al.* (1995) demonstrated an attenuation in muscle power and strength adaptations after concurrent strength and endurance training compared to a single mode of training. They concluded that this was related to the lack of change of some aspects of skeletal muscle morphology and the response of certain serum hormones to exercise. Bell *et al.* (2000) support this contention that endurance training can suppress some of the adaptations to strength training and augment some aspects of capillarisation in skeletal muscle. Another plausible explanation is that athletes had diminished leg power at the conclusion of pre-season as a direct result of overtraining.

McMillan *et al.* (2005) found that after an increase in markers of aerobic capacity over pre-season, these values were maintained over the course of the season. This supports earlier work that stated that endurance levels increased during the first third of the season and remained relatively stable during the remainder of the season (Thomas & Reilly, 1979)

Natal Rebelo & Soares (1995) stated that playing matches (either competitively or in training) and completing training drills were an important way of improving intermittent endurance capability. McMillan *et al.* (2005) indicated that complementing in-season training with the physiological strain of competing in two competitive matches per week might be sufficient to maintain endurance levels. This highlights the importance of additional individual training to maintain aerobic fitness in players who are not participating regularly in competitive matches.

Casajas (2001) considered top-level Spanish players many of whom were internationalists. Tests were conducted at the beginning of the championship (September) and at the beginning of the second round of fixtures (February). It was found that VO_{2max} was maintained throughout the season with values of 65.5 ± 8.2 ml.kg^{-1}min^{-1} and 66.4 ± 7.6 ml.kg^{-1}min^{-1} at the two testing sessions.

Similarly, squat jump and CMJ (with arm swing) showed no change across the two time points.

Therefore, it appears that VO_{2max} may be highest at the start of the season after a period of aerobic conditioning in the pre-season, with a maintenance but no further improvment following throughout the season. In contrast, any improvements made in strength or power seems to be maintained or enhanced during the season.

1.4. Youth football and maturation

In recent years, Scottish football has seen increasing financial constraints. With limited financial resources for transfers to add players to first team squads, clubs have been forced to invest more heavily in their youth academies. In some cases this has lead to a more scientific and individualised approach to training, giving careful consideration to maturation and players' individual responses to different modes of training. Differences in morphology and maturation must be considered when both implementing training interventions and when evaluating physical performance at different time of the season.

Human growth can be described at a base level as measurable changes in body size, shape and composition (Stratton, 2005). At a functional level, it can be described as the development of the nervous, skeletal and muscular system. Figure 2. illustrates the hypothetical variation in the rate that these components grow. There is considerable inter-individual variation in the timing of these changes, however, the sequence and process is on the whole common to all youths (Baechle and Earle, 2000).

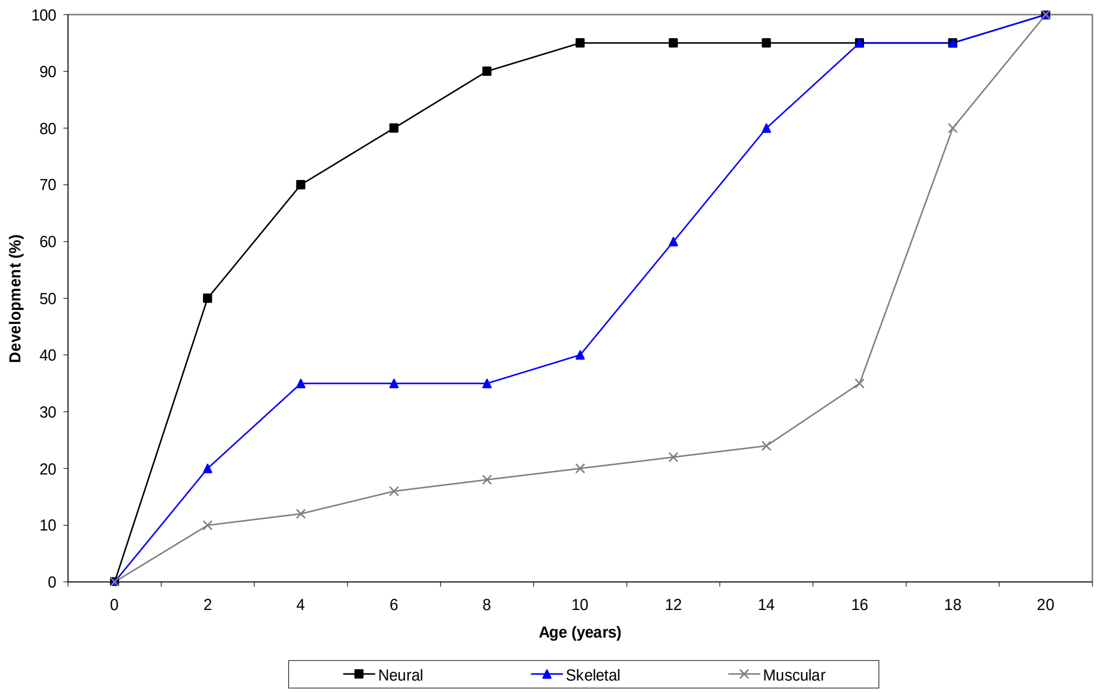

Figure 2. Rates of neural, skeletal and muscular growth patterns (Wilmore & Costill, 1999)

The pubertal phase of peak height velocity normally occurs around ages 15 – 18 in males and lasts approximately 12 – 18 months (Stratton, 2005). This in itself brings several conditioning challenges and may account for changes in fitness levels across the season. Therefore we must be aware that under-21s may still be in the latter phases of puberty and may adapt more slowly if they are on a generic training programme, such as may be used in a football academy.

1.4.1. Maturational changes in muscle strength

Muscular strength is closely related to muscle size or cross sectional area, with a larger muscle being able to generate more force. There is a natural increase in strength approximately 18 months after an adolescents' growth spurt (Stratton, 2005). This increase is linked to increasing levels of circulating androgens – particularly testosterone. This may play a significant role in increasing muscular strength in footballers at academy level. Care must be taken when interpreting effects of training interventions or when evaluating fitness levels throughout the season.

1.4.2 Maturational changes in aerobic capacity

Aerobic capacity is largely dependent on the cardiac output and the arterio – venous oxygen difference. Improvements in either oxygen intake or extraction improve aerobic capacity. With an increase in organ size with normal growth, the heart is capable of pumping more blood. This allows an adolescent who is more developed to rely less on the heart rate to pump blood and more on increased stroke volume. Increase in stroke volume improves aerobic capacity because of the positive impact on cardiac output and, thus, VO_{2max}. Anthropometric changes during puberty will also impact on measures of relative $VO_{2max.}$

1.5 Aims and hypothesis

Increasing endurance capacity can led to several positive effects on field adaptations such as increased distance covered, intensity of play, number of sprints performed and number of ball involvements. Similarly, increasing parameters of strength and power can influence performance through increasing ability to sprint, jump and tackle as well as strength on the ball.

These variables should be assessed at different time points across the season to evaluate training, monitor fitness and to provide details of any seasonal variation in fitness. There is an anecdotal perception that fitness peaks in the early season (post pre-season), is maintained throughout the mid-season and declines towards the end of the season. However, few studies have considered soccer specific parameters in a controlled lab setting over the course of a season. Lab-based testing may provide a more detailed insight into whether current beliefs are indeed correct and if field based test results give results that are partially determined by environmental factors. Similarly, understanding the seasonal profile of successful players could give the coach, trainer and exercise scientist a better working knowledge of this particular group of athletes.

Therefore this study aims to consider aerobic, anaerobic and strength parameters, periodically tested over the course of a competitive soccer season. These tests will be conducted in controlled lab settings and will be undertaken by professional youth footballers from a Scottish Premier League team.

It is likely that similar changes will be seen to those already observed in field tests and we will test the hypotheses that:

- Aerobic parameters will increase after pre-season training and be maintained across the season.
- Strength parameters will increase over the season and will result in increased power performance.
- The younger squad players may see the greatest level of variation due to the potential differences in stage of growth and maturation.

2. Methods

Physiological testing was administered on three occasions throughout the soccer season; pre-season (July), mid-season (December) and end of season (May). Each session was approximately 15 – 20 weeks apart. Lab conditions were set at a controlled room temp (21 – 22 °C) for all testing sessions. In each session, subjects mass (Seca 770, UK) was recorded and height (stretch statue method; Norton & Olds, 1996) was measured on a standard mounted stadiometer upon entering the laboratory.

On the first test day, a warm up period, sprint, jump and aerobic capacity tests were conducted. On the following day one repetition maximum (1RM) of benchpress and half back squat were established. Time of testing on each of these days was kept consistent for each individual across the season.

2.1 Subjects

Nineteen male soccer players from Glasgow Celtic Football Club participated in the study and completed three testing sessions throughout the season. They were either a member of the under 17, under 19 or of the reserve (under 21) youth academy squads (Table 2). Fourteen were full time professional players and trained on a daily basis. Goalkeepers were omitted from the study due to the highly specific needs of the position.

Squad	n	Age (years)	Height (cm)	Weight (kg)
Under 17	5*	16.2 (± 0.2)	169.8 (± 6.9)	57.5 (± 1.8)
Under 19	6	18.3 (± 0.3)	176.4 (± 8.2)	71.0 (± 3.3)
Under 21	8	19.9 (± 0.4)	180 (± 3.5)	71.8 (± 2.6)

Table 2. Subject Characteristics. (denotes part-time players).*

All of the study group were familiar with the testing procedures, as the administration of the tests involved had been an integral part of the youth academy fitness programme in previous seasons.

Prior to testing, informed written consent (Appendix 1.) was obtained and pre-screening and physical activity questionnaires were completed (Appendix 2.). Players under the age of eighteen required consent from a parent/guardian along with assent from the individual undergoing testing (Appendix 3.). Each subject was made aware that they were free to withdraw from the study at anytime. The study had been given ethical approval by the Glasgow University Ethics Committee for Non Clinical Research Involving Human Subjects (Appendix 4.).

All players had been given a medical examination by the club doctor and have undergone electrocardiogram and echocardiogram tests to detect cardiac abnormalities. Prior to each test, subjects were instructed to refrain from ingesting caffeine and alcohol for at least 24 hours and to attend fasted in the 90 minutes prior to testing. On the day of testing the subjects had not undertaken any physical training.

2.2 Training

Training throughout the season was based on successful interventions within the club and on previously published research. Aerobic sessions were conducted twice per week and were based upon the findings from Helgerud *et al.* (2001). The programme had been shown to produce significant increases in endurance capacity with no changes to parameters of speed or strength. This training was high intensity in nature and included 4 bouts of 4 minutes exercising at around 95% maximum heart rate (HR_{max}). Strength training was again based on previous research using elite level soccer players. Hoff and Helgerud (2002) found their training intervention produced large increases in strength over an 8-week period which also improved sprint and jump performance. Their weight training programme consisted of 4 sets of 5 reps at 85% of 1 repetition maximum (One rep max). These sessions were also conducted twice weekly. Figure 3 outlines a typical week for both U19 and U17 squads. As match days varied for the U21 squad they had a less rigid timetable, however undertook similar sessions throughout the week.

	MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY	SATURDAY	SUNDAY
8am			RECOVERY				
9am	Coaches Meeting	U19Gym Strength and Power		U19 Gym Strength and Power			
10am	U19 Low Intensity	U19 Speed & Agility		U19 Speed & Agility	U19 Low Intensity	U19 MATCH	U17 MATCH
11am	Remedial Session	4 x 4min High Intensity Running		4 x 4min runs high intensity	Technical Session		
12pm	U19 Flexibility	Technical		Technical	Flexibility	U17 RECOVERY	U19 RECOVERY
1pm	LUNCH	LUNCH		LUNCH	LUNCH		
2pm	U19 Low intensity	U19 Small Sided Games & Technical		U19 Technical and Analysis	U19 Match Day		
3pm	Tactical/ Technical	U19 Flexibility			Preparation		
4pm				U19 Flexibility			
5pm		U17 Gym Strength and Power		U17 Gym Strength and Power	U17 Low Intensity		
6pm		U17 Speed & Agility 4 x 4min runs		U17 Speed & Agility 4 x 4min runs	Technical Session		
7pm		U17Technical		U17Technical	U17 Match Day		
8pm		U17 Flexibility		U17 Flexibility	U17 Flexibility		

Figure 3. Typical weeks training for U19 and U17 squads

2.3 Warm up

Subjects performed a 15-minute warm up. The first 10 minutes were conducted on a cycle ergometer at approximately 70% HR_{max}, monitored using Polar Team System heart rate belts and monitor watches (Polar Electro, Kempele, Finland). Maximum heart rate was based on the HR_{max} from the previous testing session. For the initial pre-season testing, HR_{max} from the last testing session of the previous season was used. Following this subjects were given a 5-minute period in which they were instructed to perform any stretching exercises that they felt necessary.

2.4 Jump tests

Players performed two types of vertical jump whilst standing on a measurement mat (Just Jump, Probiotics Inc, Huntsville, USA). Each jump was tested three times with a 2 min rest period between each jump. The aim of each jump was to jump as high as possible and the best jump of the three was recorded.

2.4.1 Squat Jump

Subject assumed the following position on the jump mat: hands on hips, legs fully extended at knee and hip joints, feet shoulder width apart, toes pointed ahead and head focused ahead and tilted upward (Figure 4i).

Subjects then flexed knees to approximately 90° between femur and tibia (Figure 4ii). When this position was reached they were instructed by the tester to pause for 2 seconds before jumping. This eliminated the stretch shortening cycle response. The stretch shortening cycle combines mechanical and neurophysiological mechanisms. A rapid eccentric muscle action stimulates the stretch reflex and storage of elastic energy, which increases the force produced during the subsequent concentric action.

Hands were kept on hips throughout the jump. Chin was tilted upwards with the head focussed ahead and the back was flat. Keeping hands on hips, subjects explosively extended legs (both knee and hip joints) to jump into air. Legs were not flexed in mid flight. Hands remained on the hips Figure 4iii). It was recommended that at take off, the subject left the mat with the hips, knees and ankles extended and landed in a similarly extended position. Subjects landed and height measured was recorded.

Figure 4. Squat Jump

Figure 4i. Start position.

Figure 4ii. Downward phase.

Figure 4iii. Flight phase.

2.4.2 *Counter movement jump (with arm swing)*

Starting in a standing position, subjects assumed a relaxed upright stance with feet shoulder width apart, legs fully extended at hip and knee joints and arms positioned free by their side (Figure 5i).

The subject quickly descended by flexing the knees and hips and raising and sustaining the arms back (Figure 5ii). No instructions were given as to speed or amplitude of arm swing or countermovement.

The arms were then swung forward at the subject's preferred timing. The take-off was to be completed as a continuous movement with no observable pause between downward and upward movement. Subjects were instructed to explode upwards as high as possible, extending the hips, knees and ankles to maximum length as quickly as possible (Figure 5iii). Legs were not flexed in mid flight. Subject landed and height measured was recorded.

Figure 5. CMJ (with arm swing)

Figure 5i. Start position.

Figure 5ii. Downward phase.

Figure 5iii. Flight phase.

2.5 Sprint Test

Sprint times were measured using electronic sprint gates (Newtest Powertimer, Oulu,Finland) on an indoor running track. Players started in a static position 40 cm behind the first light gate. The fastest 5 metre and 10 metre sprint times are recorded from 3 maximal attempts. A two-minute recovery seperated each attempt during which subjects were instructed to remain active.

2.6 Aerobic capacity

Subjects then underwent a treadmill test (Technogym RunRace, Gambettola, Italy) to establish running economy (RE) and to determine $VO_{2max.}$ Running economy was measured at 9 km.h^{-1} at a treadmill inclination of 5.0%. The average value of oxygen uptake between 4 and 5 minutes was used to calculate RE. This gave a measure of oxygen consumption and HR for the selected speed.

After this five-minute-period, treadmill speed was increased to 12 $km.h^{-1}$ and then by 1 $km.h^{-1}$ every minute thereafter until volitional exhaustion. Typically, this took approximately a further 5–6 min. Inclination of the treadmill was kept constant at 5.0% throughout.

During this test, subjects heart rate was determined using short-range radio telemetry (Polar Accurex Plus, Polar Electro, Kempele, Finland). The Highest HR recorded was regarded as $HR_{max.}$ VO_2, minute ventilation, and breathing frequency were measured using a Cortex Metamax II device (Cortex, Leipzig, Germany), a portable metabolic test system that has been previously validated by Torvik and Helgerud (2001). To decrease the error the metamax system was calibrated prior to every individual test using both calibrated gas and ambient air. The volume transducer was calibrated using a 3-litre syringe.

2.7 Strength Tests

Subjects carried out 1RM half squat and bench press exercises the following day. All subjects had previous experience in performing the techniques required in 1 RM testing of half squat and benchpress.

Initially a warm up of 10 reps at 40% of perceived maximum took place (ACSM, 2000). The perceived maximum was based on average scores from the last test session. This prepared muscle groups for the following tests and allowed subjects to familiarise themselves with equipment and techniques involved.

After a 5 min rest period, 5 reps of 60% perceived max took place. Weights were then increased in 5kg increments after each successful lift until the player failed to lift a given resistance. Rest periods of 2 minutes were given between lifts and all maximum lifts were attained within 5 attempts.

At all times clear communication between subjects and tester was required to facilitate determination of the 1 RM. The testers were experienced in maximal testing. This ensured subjects technique was closely monitored to provide consistent results and prevent injury.

2.7.1 Half Squat

As a high bar position was used, the bar was placed evenly above the posterior deltoids on the trapezius and removed from the squat rack using a closed pronated grip. The grip was just outside of the shoulders. The elbows were elevated to create a 'shelf' with the upper back and shoulder muscles for the bar to rest upon. This also prevented the bar slipping down the back. Subjects were instructed to keep their feet one shoulder width apart with toes pointing forward. The torso was erect with shoulders back, head tilted slightly upwards and chest up and out (Figure 6i).

The exercise was initiated by allowing the hips and knees to flex slowly. The bar descended in full control. A flat back and high elbow position were essential to inhibit leaning forward or rounding the upper back. Focusing ahead with the head tilted upwards slightly, ensured body weight was over the mid foot area. Heels were not permitted to leave the ground. Shoulders and knees were kept over the feet as they flexed. The downward movement continued until the tester deemed a 90° angle had been attained between femur and tibia (Figure 6ii). Subjects were advised to keep the body tight throughout by stiffening the rib cage (filling the lungs with air), contracting abdominal and lower back muscles and extending the spine.

The bar was raised forcefully yet under control by extending the hips and knees (Figure 6iii). Keeping the back flat, head tilted upwards and focused forward and maintaining the 'shelf' created earlier. Hips were directly under the bar at all times, with weight distributed evenly between heels and forefoot to ensure they stayed in contact with the floor. Unlike training exercises in back squat the subject's body weight was not allowed to move towards the toes. Knees were positioned over the feet and did not move in or out as they extended. The lower body joints continued to extend at a consistent controlled speed until the standing position was achieved. On completion the subject (with the aid of the tester) returned the bar to the support pins of the rack.

Figure 6. One Repetition maximum - Squat

Figure 6i.Start position.

Figure 6ii. Downward phase.

Figure 6iii. Finishing position.

2.7.2 Benchpress

Subjects lay supine on a flat bench. They achieved a five contact body position consisting of: head, shoulders/upper back, buttocks firmly and evenly placed on the bench, right and left foot on the floor. Subjects were instructed not to move from this position and that it must be maintained throughout the exercise. The bar was grasped with a closed pronated grip (Figure 7i). Subjects were instructed to move the bar down slowly and under control towards the chest. The elbows moved slowly down past the torso and slightly away from the body. Wrists were kept rigid with forearms perpendicular to the floor and parallel with each other.

The upward movement began when the subject had lightly touched the chest, at approximately nipple level, with the bar. Care was taken not to bounce the bar on the chest or hyperextend the lower back to raise the chest to meet the bar (Figure 7ii). Maintaining the same body position, the bar was pressed upwards and very slightly backwards. Similar to the downward motion the wrists were kept rigid, forearms perpendicular to the floor and parallel to each other. The bar was pressed upwards until the elbows were fully extended but not forcefully locked (Figure 7iii). On completion of the set the bar was returned to the rack with the aid of a spotter positioned behind the subjects' head. The subject was advised to keep grip until both ends were stationary and instructed by the spotter.

Figure 7. One repetition maximum - Benchpress

Figure 7i Start position. *Figure 7ii. Downward phase.* *Figure 7iii. Finishing position.*

2.8 Statistical analysis

All data are represented as mean ± SD. Statistical analyses were calculated using minitab 14 software (Minitab Ltd., Coventry, UK). Pearson correlation coefficients were used to evaluate the relationship among the variables and ensure data normality. Differences in results were then analysed by a mixed design 2-way analysis of variance (ANOVA). This considered within subjects effects of time and between subjects effect of age group. Post-hoc analysis using Student t-tests were completed where significant main effects or interactions were observed. Significance was accepted at $p<0.05$.

3 Results

3.1 Body Mass

There was no significant change in body mass during the season when all the players were considered together (p= 0.781; Figure 8).

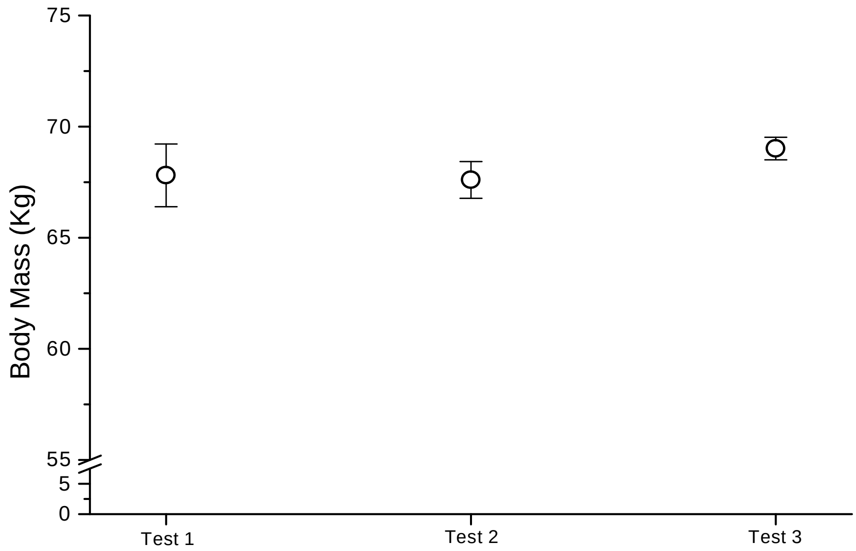

Figure 8: Changes in body mass over the season for all players tested.

However, a subgroup analysis demonstrated that players in the under 17 squad increased body mass from Test 1 to Test 3 ($p<0.05$; Figure 9).

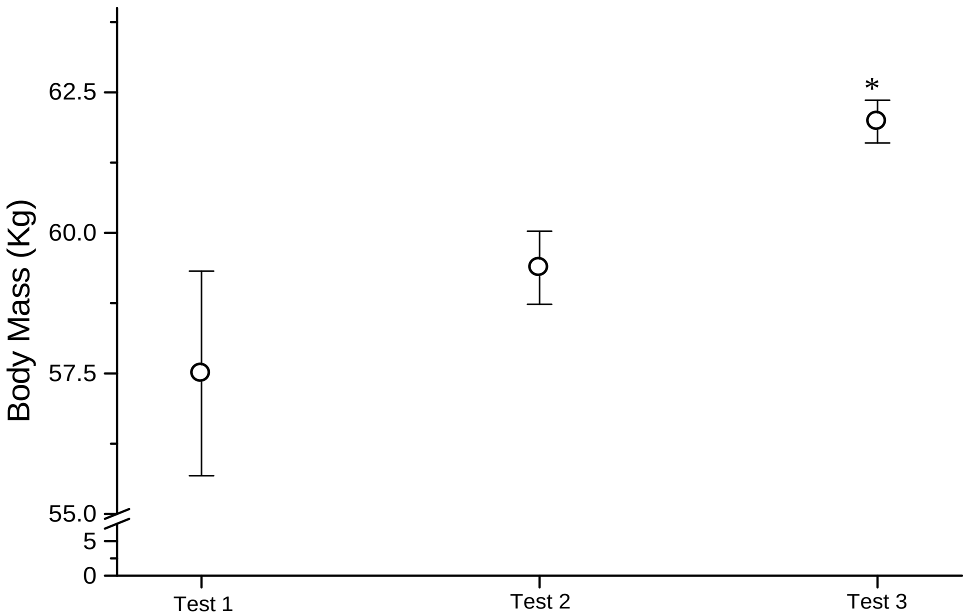

Figure 9 *: Changes in body mass over the season for the under 17 squad.*
** indicates significantly different from Test 1 (P<0.05)*

3.2 Maximum aerobic power

Similarly, there was no difference in absolute VO_{2max} ($l.min^{-1}$) measured during the season when all players were considered together (p=0.540; Figure 10).

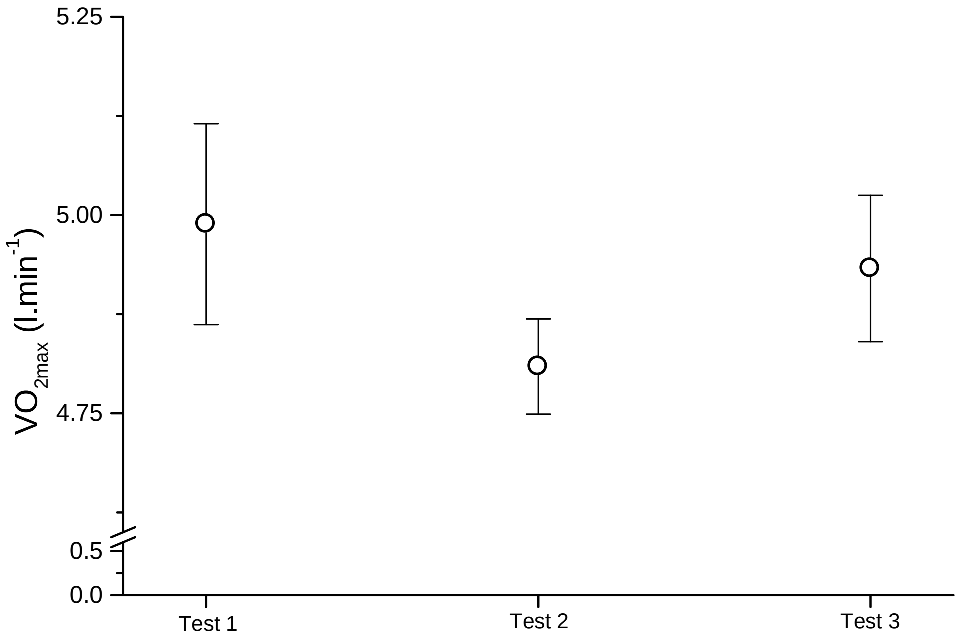

Figure 10 *: Changes in absolute maximum aerobic power over the season for all players tested.*

During subgroup analysis, none of the squads displayed significant changes across the season (Table 2). However, absolute values of VO_{2max} were significantly higher for the under 21 squad throughout the season when compared to the under 17 squad ($P<0.05$).

	Phase of season		
	1	**2**	**3**
U17	4.26±0.10	4.23±0.12	4.33±0.16
U19	5.22±0.23	4.91±0.23	5.33±0.30
U21	5.27±0.21	5.09±0.03	5.01± 0.20

Table 2: Changes in absolute maximum aerobic power ($l.min^{-1}$) over the season for all subgroups.

However, the changes in body mass during the season observed in the subgroup analysis may influence relative measures of VO_{2max} ($mL.kg^{-1}.min^{-1}$). Relative VO_{2max} did not change significantly during the season when all players were considered together (p=0.195; Test 1 = 73.9$\pm$0.4mL.kg^{-1}.min^{-1}, Test 2 = 71.2 $\pm$ 0.9 mL.kg^{-1}.min^{-1}, Test 3 = 71.1$\pm$0.6 mL.kg^{-1}.min^{-1}; Figure 11).

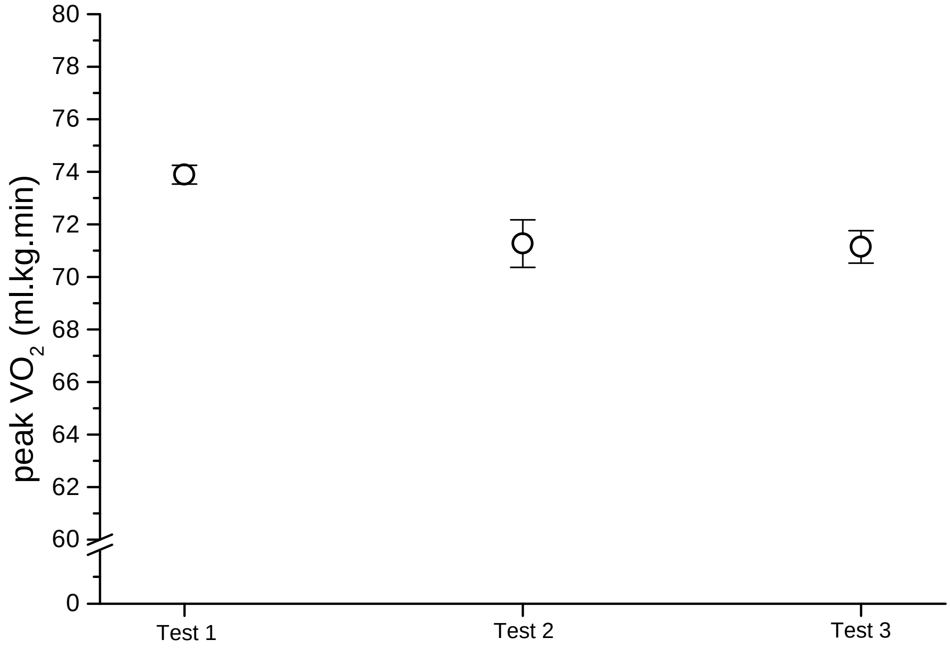

Figure 11: Relative peak aerobic power over the season for all players tested.

As expected, however, the increased body mass of the under 17 squad lead to a decline in the $VO2_{max}$ (p<0.01; Test 1 = 74.1$\pm$ 0.6 mL.kg^{-1}.min^{-1}, Test 2 = 71.24 $\pm$ 2.56 mL.kg^{-1}.min^{-1}, Test 3 = 69.6$\pm$2.0 mL.kg^{-1}.min^{-1}; Figure 12).

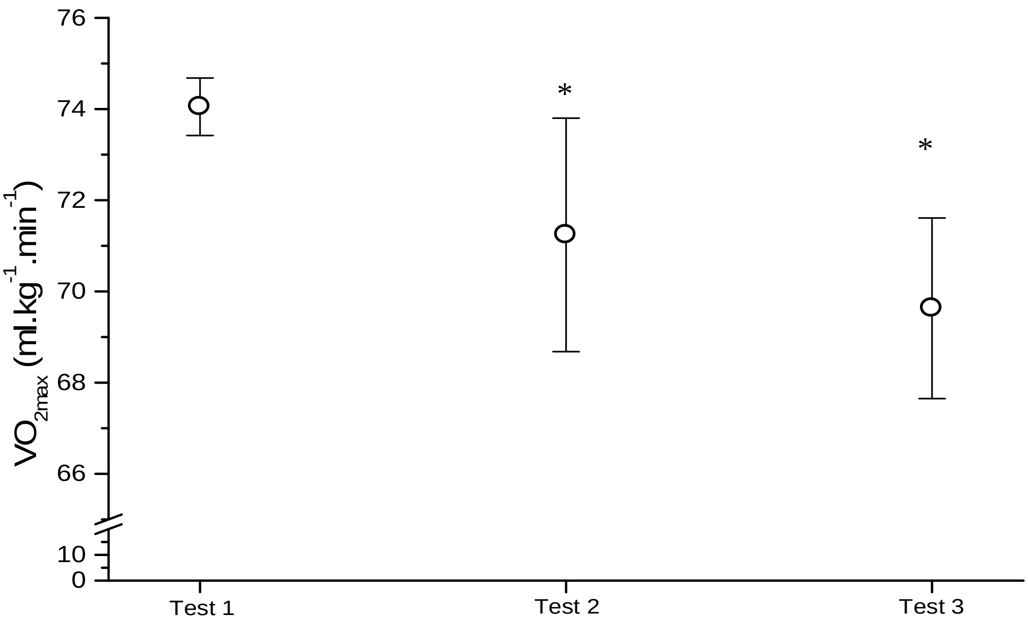

Figure 12 : *Changes in relative maximal aerobic power over the season for the under 17 squad. * indicates significant differences compared to test 1*

Unexpectedly, the under 21 squad also demonstrated a significant decrease in VO_{2max} ($P<0.05$; 73.6$\pm$0.4 to 68.9$\pm$1.2 ml.kg^{-1}.min^{-1}; Figure 13).

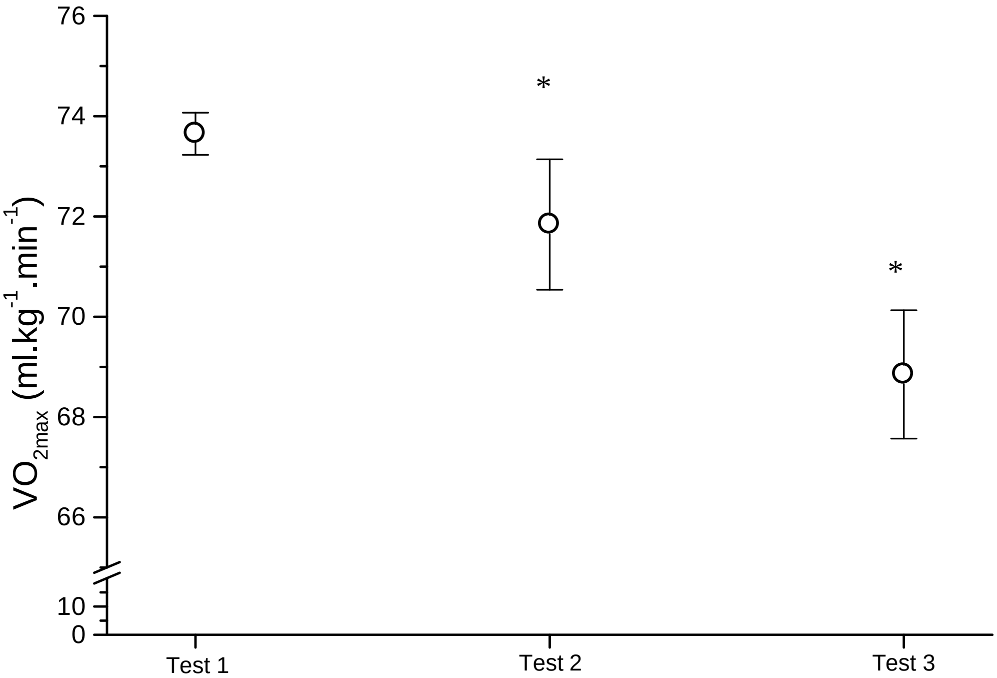

Figure 13 *Changes in relative maximal aerobic power over the season for the under 21 squad. * indicates significant difference to test 1*

3.3 Sub-maximal Running Economy

The oxygen uptake required to sustain a constant running velocity (9 $km.h^{-1}$ & a treadmill inclination of 5.0 %) was reduced over the season when all players were considered together. Relative VO_2 reduced from 50.1 ± 0.6 at test 1 to 45.3 ± 1.0 $mL.kg^{-1}.min^{-1}$ at test 2 and to 42.3 ± 0.8 $mL.kg^{-1}.min^{-1}$ at test 3 ($p<0.01$; Figure 14).

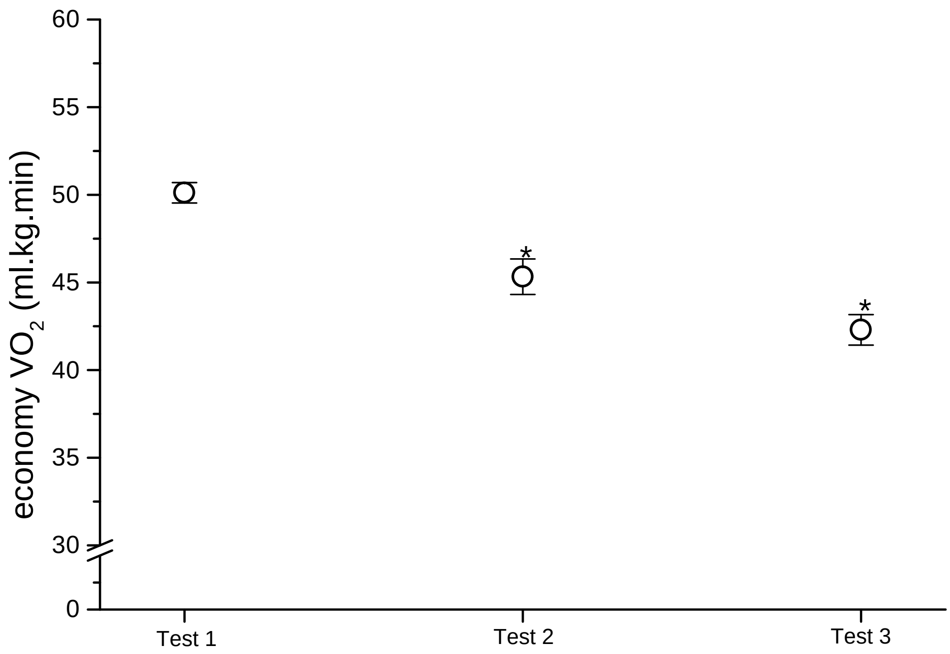

Figure 14: Changes in sub maximal VO_2 over the season for all players tested.
** indicates significantly different to Test 1*

This measurement of sub-maximal running economy was observed to improve in all the sub-groups analysed across the playing season (Table 3.)

	Phase of season		
	1	**2**	**3**
U17	52.8±0.4	46.2±0.7	43.5±0.6
U19	48.8±0.8	43.6±0.2	43.3±2.0
U21	49.4±0.1	46.1±1.0	40.8± 0.5

Table 3: Changes in submaximal VO_2 ($ml.kg^{-1}.min^{-1}$) over the season for all sub-groups.

The improvement in sub-maximal running economy is further supported by analysis of heart rate data at the constant running velocity. The heart rate required to sustain the constant running velocity was reduced over the season ($p<0.01$; Test 1 = 172.7 $\pm$ 1.9 v Test 3 = 162.1 $\pm$ 1.1 beats per minute) and was consistent across all sub-groups with no significant difference found across the squads ($p=0.07$). While this could be due to a change in aerobic fitness, no change in peak aerobic power was observed.

However, this decline in submaximal running economy may appear unduly large. Using regression equations to predict VO_2 (Equation 1; ACSM, 2000) at the given speed and gradient may suggest that the initial test may have overestimated VO_2.

Equation 1 ACSM (2000) Regression equation to predict VO_2 at known speed and gradient

$$\mathbf{VO_2\ (ml.kg.min^{-1})} = [0.2 \times \text{speed } (m.min^{-1})] + [0.9 \times \text{speed}(m.min^{-1}) \times \%\ \text{grade (as a fraction)}] + 3.5$$

$$= [0.2 \times 150] + [0.9 \times 150 \times 0.05]$$

$$= 40.25\ ml.kg.min^{-1}$$

The standard error of estimate may be as high as 7% e.g. 2.82 $ml.kg.min^{-1}$. It is important to also remember that the variance of a predicted value is much larger than the standard error estimate.

3.4 Jump Tests

The performance in squat jump test improved throughout the season when all players were considered together ($p=0.05$; Test 1 = 46.9 $\pm$ 0.9 cm, Test 2 = 46.5 $\pm$ 0.9 cm, Test 3 = 48.5 $\pm$ 0.2 cm;). Sub-group analysis demonstrated that this was due mainly to a significant improvement in the U17 squad ($p<0.05$, Test 1 = 44.6$\pm$1.2 cm, Test 2 = 46.9 $\pm$ 1.4 cm, Test 3 = 48.9$\pm$0.4 cm). and was despite the fact that performance did not change significantly in the U19 ($p = 0.08$) or U21 ($p = 0.06$) squads during the season.

The performance in counter movement jump test did not change significantly throughout the season when all the players were considered together ($p=0.39$; Figure 15).

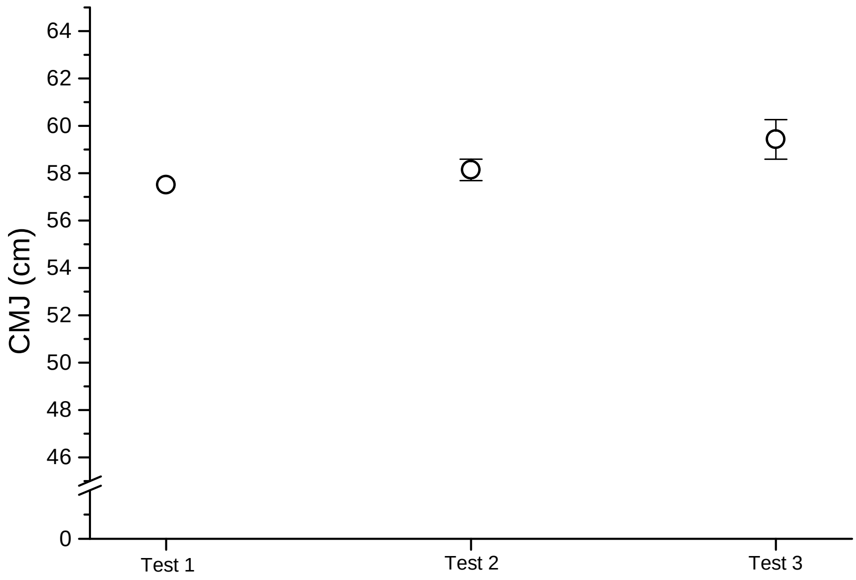

Figure 15: Changes in CMJ over the season for all players tested.

However, sub-group analysis of the counter movement jump performance showed similar changes to the squat jump tests through the season in the squads. The U17 squad increased their jump heights from 54.6$\pm$0.3 cm at Test 1 to 57.9$\pm$0.8 cm at Test 3 ($p<0.01$). The U19 and U21 squads did not change their performance during the season ($P=0.20$).

3.5 Sprint test

Acceleration, assessed by the time taken to cover the first 5-m during a sprint trial, did not significantly change when all the players were considered together or during sub-group analysis ($p=0.69$; Figure 16).

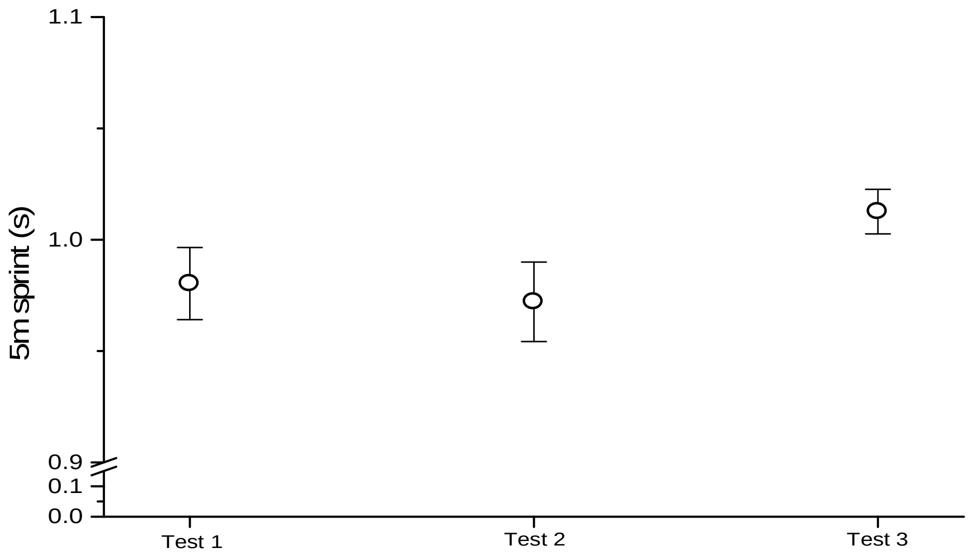

Figure 16: Changes in 5 m sprint times over the season for all players tested

A similar result was observed with running speed, assessed by the time taken to cover 10 m during a sprint trial, with no change in performance being observed across the season (p=0.15; Figure 17).

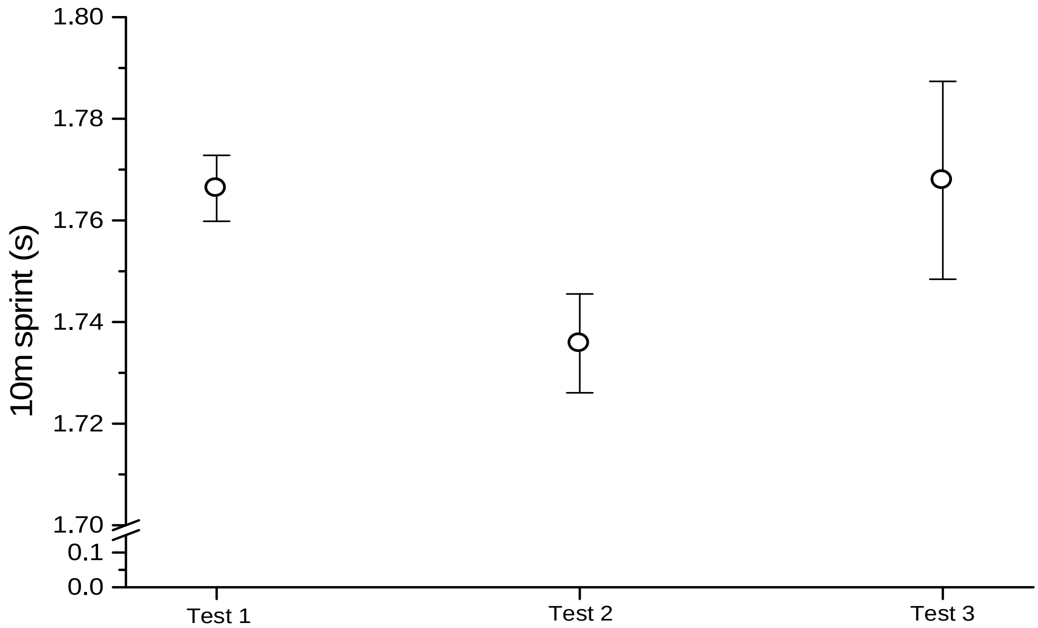

Figure 17 : *Changes in 10m sprint times over the season for all players tested*

3.6 Strength Tests

Figures 18 and 19 illustrate that, when all players were considered, strength increased significantly over the season. Performance in a 1 repetition maximum squat increased from 141.6 $\pm$ 1.6 kg at visit 1 to 169.7 $\pm$ 2.4 kg at visit 3 ($p<0.01$; Figure 18). Similarly, 1 repetition maximum for bench press performance also increased from 67.6 + 5.7 kg at visit 1 to 80.0 $\pm$ 4.8 kg at visit 3; ($p<0.01$; Figure 19).

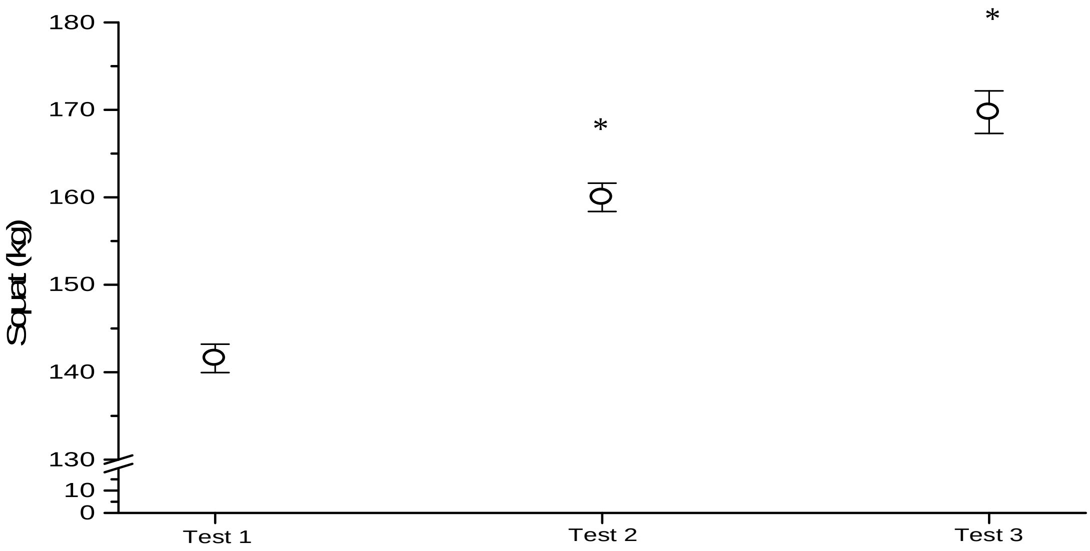

Figure 18: Changes in squat strength over the season for all players

**indicates significant difference to Test 1*

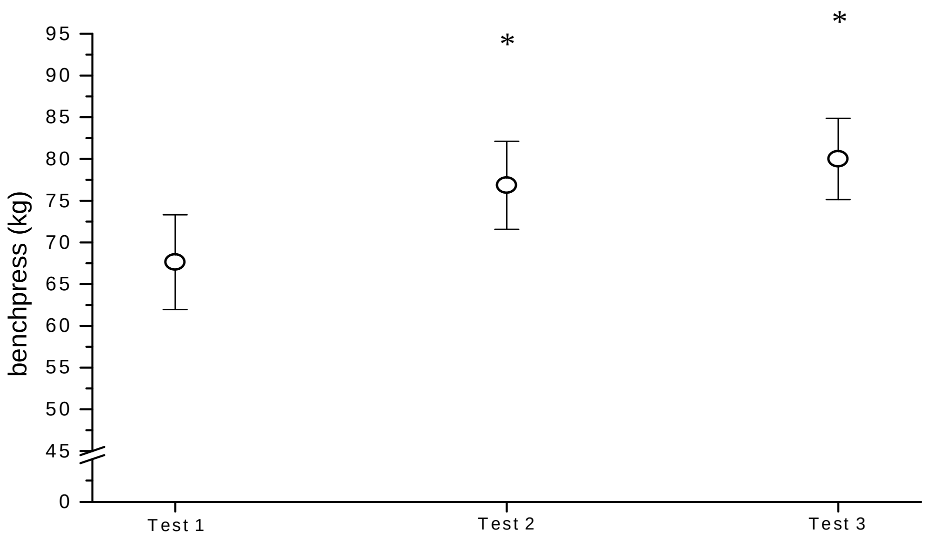

Figure 19: Changes in benchpress strength over the season for all players tested.

** indicates significant difference to Test1*

3.7 Relationships between leg strength and running economy

Further investigation into possible explanations into the decrease in submax VO_2 found that there was a negative correlation between squat strength and economy (r= -0.59; Figure 20).

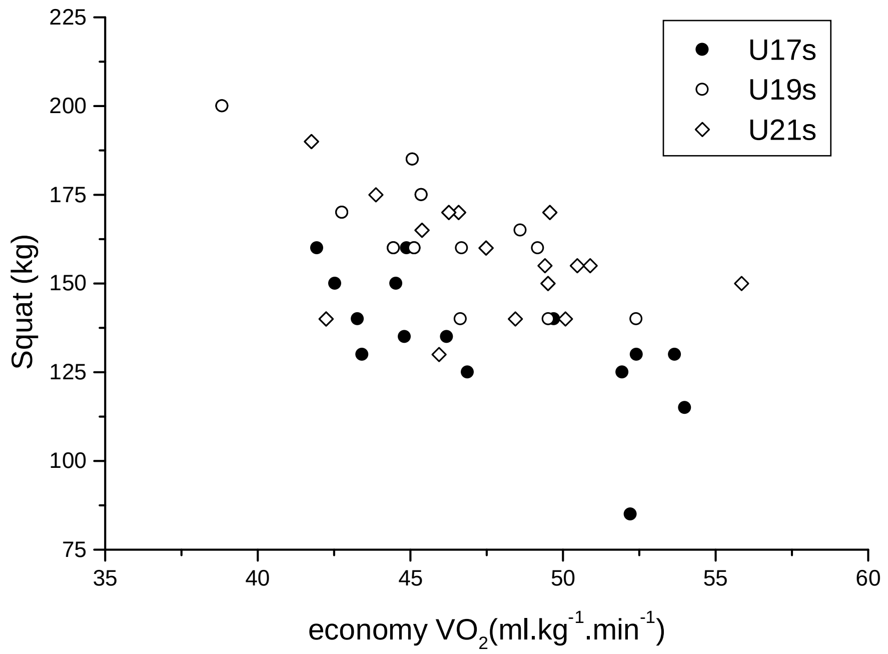

Figure 20: Relationship between leg strength and submax economy VO_2

However, increasing leg strength did not show a strong correlation to maximum aerobic capacity (r= -0.16)**.**

4. Discussion

The aim of the study was to investigate seasonal changes in fitness in youth footballers over a professional Scottish season. This was to specifically challenge the anecdotal thinking that peak condition established in the early season was maintained over the mid season with a reduction in fitness apparent in the late season phase. Lab based tests were used to provide more detailed analysis of fitness and to avoid the influence of environmental factors such as weather and field conditions.

This assessment of seasonal variation of fitness level in professional soccer players shows some significant changes in parameters measured. These may, to some extent, be explained by maturation status and consequent changes in body morphology and height. Muscle hypertrophy may account for the changes in body mass as squad values for 1RM increased over the course of the season. These changes in body weights impact on relative measures of VO_{2max}. However, on the whole the absolute values appear to be unchanged over the course of the season. Speed appears to be maintained throughout the season.

4.1 Body Morphology

In football, players with apparently very different physical characteristics have been successful, such that it would appear that there is no specific or special morphological type for top ranking football players. While Hoff and Helgerud (2004) considered the average body mass of a top level player to be 75kg, few studies have explored the effects of a competitive football season on weight and anthropometric development. In the current study body weight remained relatively constant throughout the season for the under 19 and under 21 squads. However, despite not being measured, changes in body shape may have occurred given the increases in strength recorded. This may have been a neural adaptation to weight training rather than a result of muscle hypertrophy. Alberquerque *et al*. (2005) studied seasonal variation in several kinanthropometric parameters over the course of a Spanish football season. They found a trend that body weight decreased across the season (start season = 76.3 $\pm$ 7.45kg; end season = 74.5 $\pm$ 7.62kg). Lower values of body weight were seen for all squads in the current study (compared to the Spanish study) particularly in the under 17 squad.

Alberquerque *et al.* (2005) concluded that players had an increased mass when they initially reported for pre season training after a summer off season. Body weight was found to decrease in the final phase of the season with fully mature players. As the study took place using La Liga players (Spanish top league) it is possible that the warmer climate in the final half of the season had caused a chronic dehydration thus affecting body weight and subsequent performance in physical tests. Otherwise, the reduction may have been as a result of residual fatigue due to poor conditioning at the start of the season. Alberquerque *et al.* (2005) stated that the decrease across the season was a result of 'game-overload'. Increased body mass at the initial pre season test, may have been a result of inactivity or less demanding physical activity in the off season.

None of the above phenomena were found in the current study. The initial measures made prior to pre season training were not included in this study. This was due to issues outwith the control of the football club involved. However, maintenance training programmes were presented to squad members prior to leaving for the off season. This should have ensured that an increase in body weight did not occur over the period of reduced match play. The stable measures of body mass taken across the season also indicate that there was no significant increase in the off season for the under 19 and under 21 squads. Good hydration and nutritional strategies and education may have, in part, accounted for this both in pre season and across the season.

The under 17 squad consistently scored the lowest values for body weight in comparison to the other squads. However, the under 17 squad saw an increase in body weight across the season. This increase across the season may be accounted for through their stage of maturation/growth. Chronological age is not a perfect marker of biological maturity (Reilly, 1996). Therefore, some individuals in this group may have been in the latter stages of adolescence and the changes seen were not direct effects of training or nutrition but of growth. Increases in body mass may have been due to increases in muscle cross sectional area which results after neural recruitment patterns and nervous system activation have been established. Biochemical adaptations are slower than the neural adaptations and result in muscle hypertrophy. Increases in squat and benchpress 1RM could have therefore accounted for the increase in mass in this group. Anthropometric measures could have clarified if the weight gained was lean muscle mass or adipose tissue.

4.2 Aerobic

4.2.1 Maximal oxygen uptake

Values for VO_{2max} at the start of the season were among the highest values reported for elite level soccer players. The mean value for all 19 subjects after preseason was 73.92 $\pm$ 0.37ml.kg.min^{-1}. Hoff and Helgerud (2004) stated that normal squad values for VO_{2max} lay between 55 – 67 ml.kg.min^{-1} with some individual values greater than 70ml.kg.min^{-1}. It appears that this may be the first reported group of players to have an squad average VO_{2max} above 70ml.kg.min^{-1}. Moreover, the players tested appear to have reached the recommended target level of aerobic fitness by Hoff and Helgerud (2004) who suggested that a player of 75kg should have a VO_{2max} of 70mL.kg.min^{-1}.

Pre-season is an important period of conditioning in the competitive soccer season (Natal Rebelo & Soares, 1995) and the high values of VO_{2max} at the start of the season reflect the highly aerobic nature of pre season training. Endurance training during this period, usually results in little or no muscle hypertrophy but does increase capillary and mitochondrial density, enzyme activity (creatine phosphokinase and myokinase), metabolic stores (ATP, Creatine phosphate and glycogen), connective tissue strength (ligament and tendon) (Baechle and Earle, 2000; Amigo *et al*. 1998). Astrand and Rodahl (2003) stated that aerobic training could improve or decrease an athlete's aerobic power by 5% to 30%, though this greatly depended on the athlete's starting fitness levels, with low starting levels gaining the greatest increases.

As anticipated, aerobic parameters fluctuated across the season. However, similar results were not obtained for all three squads. As hypothesised the mean relative VO_{2peak} results for the under 17 and under 21 squads fell after the initial testing session at the start of the season. This supports Brady *et al.* (1995) who reported that after an initial increase in parameters of endurance after pre-season training, the peak values obtained decreased over the course of a season. The magnitude of change in response to any training programme depends on the athlete's pre-training level and the characteristics of the programme or playing season. The reasons for this decrement most likely reflect the training stimulus. Brady *et al.* (1995) attributed the seasonal decrement to the fact that coaches may be reducing the training stimulus towards the end of the season. Vaeyens *et al*. (2006) concluded that aerobic fitness parameters of young adult players e.g. those at under 21 level, may suffer a decrement as they are in transition between two competitive teams i.e. under 21 and first team. This may have, in part, contributed to the decrease across the season. As the older youth players gain more playing experience and expertise they are subsequently moved between first team and under 21 squads. This reduces their match play time, which has been found to be important to maintaining intermittent endurance capacity (Natal Rebelo and Soares, 1995).

The increase in body mass observed in the under 17 squad had a concurrent effect on aerobic capacity. Although mean relative VO_{2max} drops in the under 17 group, the absolute value is not significantly change across the season. This suggests that despite the muscular adaptation the aerobic capacity has remained unchanged.

McMillan *et al.* (2005) found that after an increase in markers of aerobic capacity over pre-season, there was no decrement over the season. These results were supported by the under 19 squad who maintained VO_{2max} throughout the season. This maintenance of endurance capacity was previously seen in elite Spanish and elite English players (Casajas, 2001; Thomas and Reilly, 1979). Unlike the other two squads this parameter did not fluctuate in the under 19 squad. This could have been a result of an increase in the number of games (due to an extended cup run and postponed matches from earlier in the season) and would supports the findings of Natal Rebelo and Soares (1995) who had previously indicated the importance of matches in improving aerobic capacity. Concurrently, the under 19 squad went through a training programme with a high emphasis on aerobic training based on that described by Helgerud *et al*. (2001). The multi-factorial nature of football conditioning and competition is clear and it is difficult to separate the different influences on aerobic capacity in this squad.

4.2.2 Submaximal Economy

Astrand and Rodahl (2003) stated that VO_{2max} is probably the most important factor determining aerobic success. However, VO_{2max} is only one aspect of aerobic capacity measurement. Pate and Kriska (1984) described a model that incorporates three factors accounting for variance in aerobic endurance performance. These include lactate threshold and RE along with VO_{2max}. Furthermore, VO_{2max} may not be a sensitive measure of performance in important aspects of soccer match play (Bangsbo and Lindeqvisy,1992) or in the detection of changes due to training (Bangsbo and Mizuno, 1988). Therefore, the values attained during submaximal RE may provide an alternative and more accurate representation of endurance capacity.

In the present study, VO_2 and HR at $9kmh^{-1}$ and 5.0% gradient were found to decline over the season. This improved submaximal RE was seen across all squads though the under 19 squad does plateau at the final testing session. This would suggest an improved cardiorespiratory endurance. This may be due to the concurrent increase in strength training in the squads. This relationship between improved strength and running economy was also reported in a group of cross country runners (Paavolainen *et al*., 1999). The proposed mechanism was a change in the neuromuscular system whereby muscle stiffness was regulated and muscle elasticity was utilised during the stretch-shortening cycle. Behm and Sale (1993) suggested that an improvement in economy took place as a result of maximal neural adaptation for two principle reasons. These were that in order to train the fastest motor units one had to work against high loads. This guaranteed maximal voluntary contraction. Furthermore, maximal advantage would be gained if the movements were trained with a rapid action in addition to the high resistance. Hoff and Helgerud (2002) utilised this theory and found that incorporating heavy loads (85% of 1RM) and low numbers of repetitions (5) over an eight week period increased both 1RM and running economy. A weight training intervention based on this principle was employed with the three squads in the current study and found similar results, in that both 1RM and submaximal economy were improved.

However, the effect may not have been entirely due to these physiological mechanisms, and may be accounted for through changes in anatomical trait, mechanical skill, neuromuscular skill or storage of elastic energy (Pate and Kriska, 1984). Further biomechanical analysis during testing would have given a clearer indication of why these changes had occurred.

The portable metabolic test system used for gas analysis in aerobic tests was the Cortex Metamax II (Cortex, Leipzig, Germany). This system had been previously validated by Torvik and Helgerud (2001). However, the specific machine used in the current study had not been validated or tested for reliability. Using the predicted VO_2 regression formulas from ACSM (2000) it would appear that the values in Test 1 for running economy may have been unduly high. It may well have been the case that the high results reported for VO_{2max} were not a direct effect of training but through overestimation from the Metamax gas analyser. However, as this equation can only predict VO_2, inter-subject variability must be considered as the prediction interval (0.07) is greater than the confidence interval (0.05).

4.3 Strength

As no standardised protocol for testing strength of soccer players exists, it is difficult to compare results among different studies. However, free barbell 1RM tests for Squat and Benchpress have been previously conducted in elite footballers (Stolen, 2005). In the current study, 1RM tests were employed and were found to increase across the season for both Squat and Benchpress. As with aerobic training, these results may reflect training schedules incorporated throughout the season.

4.3.1 Benchpress

Upper body strength was greatest in the under 21 squad. Mean values for all squads of 80.0 ± 4.8 kg (at visit 3) were higher than those reported for elite American soccer players (73 ± 4.0kg; Raven et al., 1976) but lower than a team competing in the Champions League (82.7 ± 12.8kg; Wisloff *et al*., 1998). After testing top level European soccer players, Wisloff (1998) suggested that a recommended 1RM for a 75kg soccer player should be 100kg. When results are considered as a ratio to body mass it appears that, given these guidelines, 1RM should be 133% of body mass. When considering mean values for the season, only the under 21 squad attained scores near these values (125.83%). Both the under 19 and 17 squads reached values of around 100%. The under 17 squad recorded the lowest values of upper body strength with end season values of 66.0 ± 2.5kg. This can be attributed to two main factors. The development and maturation of the older players was more complete and therefore strength gains were more obvious. Also, the older players of the under 21 squad had had more experience and exposure to Olympic lifting and strength conditioning sessions.

4.3.2 Squat

Squat 1RM strength increased across the season with the under 19 squad having the highest level of strength through out (mean 169.17 ± 5.42kg). The under 21 squad had similarly high values of 162.5 ± 2.92kg. These results are likely to be indicative of the nature and type of weight training utilised by this squad. Hoff and Helgerud (2002) demonstrated large increases in squat 1RM over an eight week period. In the current study increases were not as dramatic but did occur over a longer period of time. Again the under 17 squad had significantly lower results which can be attributed to the reasons discussed above.

4.4 Power

In the current study, CMJ (no arm swing), CMJ (with arm swing) and 5m sprint and 10m sprint, were taken as measures of power.

4.4.1Jumps

Muscular power has traditionally been measured by means of vertical jumps, with reported values between 50 and 60cm for elite soccer players (Green, 1992; Hoff and Helgerud, 2004). Silvestre *et al*. (2006) studied American collegiate soccer players and reported similar values of 60cm. They stated that values above this figure would indicate increased level of strength that reduce risk of injury and allow for more powerful jumps, tackles, sprints and kick strength. Values for all squads were lower than these anticipated levels with the end of season displaying the highest heights. A dip in CMJ (no arm swing) performance mid season was seen in both under 19 and under 21 squads, however was not evident in the under 17 squad. Similairly, Casajus (2001) found a decline from start of season to mid season in elite Spanish players. Surprisingly, the under 19 squad performed poorly in the test, being significantly lower throughout the season than the other squads.

When considering the more sport specific CMJ with arm swing for all squads, there was not a significant increase as the season progressed. Similar to the strength tests, the under 19 and 21 results are highest while under 17 results are lowest. The results reported are in line with the expected values of between 50 and 60cm (Stolen *et al*., 2005) The under 17 group, when considered alone, showed an increase from 54.6 $\pm$ 0.3 cm at Test 1 to 57.9 $\pm$ 0.8 cm at Test 3. This increase in jump was as hypothesised.

As expected the CMJ (with arm swing) provided greater height results than the CMJ (no arm swing). This is due to kinetic energy being developed by the arms which increases potential energy at take off and pulls the rest of the body through the jump employing the stretch shortening cycle (Lees *et al*., 2006). The stretch shortening cycle can be defined as impulsive eccentric-concentric coupling where rapid deceleration of a mass (via muscle lengthening/eccentric action) is immediately followed by amortization (time between eccentric and concentric phase) and acceleration in the opposite direction (via muscle shortening/concentric action; Baechle and Earle, 2000).

4.4.2 Sprints

Sprint performance did not fluctuate across the season for any of the squads involved in the current study. The under 21 squad were quickest across the season ($p<0.01$). These results do not agree with previous findings that maximal squat strength is related to sprint performance (Wisloff et al., 2004). They stated that as 1RM increased across the season, and there was a linear trend with sprint performance. This hypothesis had been previously challenged in a study of rugby league players (Cronin and Hansen, 2005). They found no correlation between 3RM and 5m,10m or 30m sprint times. The present study supports their findings. It therefore appears that, in fully mature adults, sprint performance may be an aspect of fitness where it is difficult to induce an improvement through weight training. Olympic weight lifting and plyometric exercises may provide an alternative training stimulus when considering sport specific power exercise in football (Baechle and Earle, 2000). These could take the form of loaded or box jumps. Furthermore, sprint drills focusing on running technique may also benefit sprint test performance (Baechle and Earle, 2000).

The under 17 squad showed no significant changes in sprint performance across the season. Initially it appears that increased muscular strength was not reflected in improved power measures. However, Newton's 2nd law states that force is equal to the mass of the object multiplied by its acceleration. Increasing mass would therefore have a negative impact on acceleration (sprint speed). However, despite body weight increasing across the season this group showed no significant changes in sprint performance. Hence, the force production must have increased simultaneously to allow this equilibrium to occur.

4.5 Limitations and further research

The present study gave a useful insight into an area which, in the past, had largely only been explored anecdotally or by field-based assessments. However, there were several limitations to the study. Many of these were out with the control of the researcher as the football club involved had outlined which tests and protocols would be used throughout the project. For example, tests for sprints over 5m and 10m were used by the football club, where it could be argued that sprints over longer distances are of more importance during match play (Drust *et a*l., 1998). Similarly, protocols for testing submax and maximal aerobic parameters were from unpublished work which had previously been carried out within the football club.

Lab tests were used in this study to eliminate seasonal changes in environmental factors. Lab tests allow more stringent classification and profiling of players while field tests only measure relative changes between two tests. Cardiovascular, metabolic or biomechanical limitations can be identified. For example, the combined knowledge gained from the assessments of maximal and submaximal (running economy) aerobic tests provide a much more detailed analysis of aerobic capacity than the field based tests such as the multistage fitness test or Yo-Yo intermittent tests. On the contrary, the specificity of field tests may be invaluable. Lab tests such as the VO_{2max} protocol used in the current study assessed maximal aerobic capacity linearly with progressive increases in speed. This did not reflect the dynamic nature of football where turning and changes of direction occur frequently. Therefore, it may have proved insightful to measure parameters both in the field and laboratory to give a direct comparison. However, this would have been a lengthy process and one to which the subject group could not commit.

A control group may have helped to establish whether the Metamax analysis system was overestimating VO_2 and allow more definitive conclusions to be made. Further analysis on the machine used and of calibration techniques prior to testing are needed to establish whether the direct comparisons with previously published work are real or result from the equipment used.

The current study was limited due to the fact that despite being recorded, more complex anthropometric measures such as skinfolds were unavailable for analysis. This would have given a far greater indication of fluctuations of subcutaneous fat and lean muscle mass. Along with more detailed investigations into adiposity, the biological maturity status of the younger squads (under 17 and 19) could have been measured. This would have given more detail to asses whether changes in weight were a direct result of training or nutritional status, rather than maturation.

After the initial testing session, 32 subjects had completed all tests. However, only 19 completed all tests throughout the season. It is therefore debatable whether each squad subgroup therefore had sufficient statistical power due to low subject numbers. Furthermore, an age-matched control group for each squad subgroup may also have been of value to distinguish if changes were a result of training or of growth and maturation.

Thirteen athletes had an injury or illness for at least one of the testing sessions. This has to be perceived as inevitable when the nature of the sport and the group of subjects are considered. Measurement or documentation of the nature of these injuries could allow analysis into whether the increases in strength did in fact reduce lower limb muscular strains as has been previously reported (Reilly, 1996). This was beyond the scope of the current study.

5 Conclusions

The current study considered the seasonal variation in fitness parameters of footballers over the course of a professional season. Tests of aerobic capacity, muscle strength and power were analysed on three occasions throughout the season.

At the end of preseason, aerobic parameters of VO_{2max} were among the highest values reported in published literature for soccer players.

As highlighted in the hypothesis, body weight changes appear to be largely dependant on maturation status with only the under 17 sub group showing an increase in body weight over the season. The maintenance of body weight observed in the older age groups was not observed by Alberquerque *et al*. (2005) who found a decrease in body weight in the final phase of the season in fully mature players. This decrease in weight may reflect poor nutrition/hydration strategies, game overload or residual fatigue towards the end of the season. These factors were not observed in the current study.

Maximal strength parameters increased across the season and this was reflected in maximal jump heights. However, in the older players increased strength did not improve sprint performance over 5m and 10m. This supports Cronin & Hansen (2005), and may indicate that improving sprint performance in fully mature athletes cannot be achieved simply through increasing maximal strength, but may be possible by more explosive training such as Olympic weight lifting, plyometric jumps or improved running technique. In the under 17 squad increasing maximal strength did improve sprint performances.

In summary, fitness levels appeared to be maintained across the season in older age group or more mature players. Changes seen in the younger players may possibly be related to growth, maturation and resultant changes in body morphology. Furthermore, lab based tests appear to provide a more detailed profile of a player’s physical status than field based tests.

6 Acknowledgements

I would like to express my gratitude to several people who played an important role during my M.Sc. research project.

Firstly, Dr Stan Grant for his time and guidance throughout the project. Without his help, the opportunity to complete an applied research project would not have been possible. I would also like to thank Dr Niall McFarlane for his assistance, particularly in the final phase of the research and in submission of this thesis.

The playing staff and coaches of Celtic Football Club, in particular, Adam Owen, Jamie Ramsden, must also be thanked for their help and cooperation throughout the process. Adam and Jamie's experience in an applied sports setting was invaluable.

Finally, I would like to thank my family for their continued support, during my university career studying Physiology and Sports Science and for giving me the possibility to start a career within sport.

7 Appendices

Appendix 1. Information sheet and consent form for players over 18

University of Glasgow
Institute of Biomedical and Life Sciences

INFORMATION SHEET

TITLE: **Monitoring of fitness levels in professional soccer players over a competitive season.**

You have been invited to take part in a research study which will monitor the fitness of elite soccer players throughout a competitive season. In order to help you to understand what the investigation is about, please read the following information carefully. If there are any points that need further explanation, please ask a member of the research team. It is important that you understand what you are volunteering to do and are completely happy with all the information before you sign the accompanying consent form.

What is the purpose of the study?
A number of fitness components have been shown to be important in soccer. Monitoring of these components over time provides information on the effectiveness of training programmes and may identify weaknesses in some players. In addition, the player data for a particular club can be compared with players from other countries. Celtic Football Club wishes to monitor their players over a season using a battery of fitness tests designed to test a range of soccer-specific fitness components including, aerobic fitness, speed, strength, power and anthropometrical measures. The test battery will be applied three times throughout the season (post pre-season, midseason, and end-season). In addition, heart rate will be monitored during a number of training sessions to determine training intensity. While regular testing is part of the fitness monitoring procedures at Celtic Park, you have been asked to read and sign the consent form as the test results will be used not only for information on the effectiveness of the training regimes but will also be used for research and possible publication in the scientific literature. The aim of this study is to monitor the fitness of elite soccer players belonging to a Scottish Premier League Club throughout a competitive season.

Why have I been chosen?
You have been selected, as you are a player at Celtic Football Club. As the club doctor has medically screened you, it is believed that you are fit to take part in the test battery. However, before you become a subject, you will be asked to complete a medical and physical activity questionnaire.

Do I have to take part?
It is up to you to decide whether or not to take part. If you decide to take part, you will be given this information sheet to keep and you will be asked to sign a consent form (the parents of those under 18 years will sign a consent form) to show that you are

happy to participate. If you decide to take part, you are still free to withdraw at any time and without giving a reason.

What will happen to me if I take part?
You will be asked to carry out tests conducted during pre-season, mid-season (December) and at the end of the season (April/May). During testing, subjects will

undergo body composition tests, maximum vertical jump height tests, sprint performance tests and strength tests. Finally, a treadmill test to volitional exhaustion will be carried out.

Test Protocols

Body Composition Tests

Height, weight and skinfold thickness in a range of sites including arm, back, trunk and leg will be measured.

Vertical Jump

Players perform 2 types of vertical jump whilst standing on a measurement mat. The first jump is performed with the hands remaining on the hips at all times and the second with movement of the arms to assist. Each player performs 3 attempts of each jump, with the aim of jumping as high as possible. A minimum of 1-minute recovery period seperates each jump.

Sprint Tests

Sprint times are measured using electronic sprint gates. The fastest 5m and 10m sprint times are recorded from 3 maximal attempts. A minimum of two-minutes recovery seperates each attempt. Players jog gently and keep active between sprints.

Strength Tests

Players will carry out bench press and squat exercises. Weights will be increased after each successful lift until the player fails to lift a given resistance. Rest periods will be given between lifts.

Running Economy and Maximal Exercise Test

Players will be given a warm-up followed by a steady run at around 10 kilomteres per hour for 5 minutes. This test gives a measure of how much oxygen is needed for the selected speed. The lower the score the better, as this indicates that the player does not require so much energy to run at that speed compared with a higher score. Thereafter the treadmill speed will be increased by one kilometre per hour until volitional exhaustion. During these tests players will wear a mask and a carry analysers in a small rucksack so that the expired air can be anlaysed. A cool-down will be given at the end of the test.

Training

Heart rate (using Polar heart rate monitors) will be monitored during a number of training sessions to determine training intensity.

What are the side effects of taking part?

You will feel fatigued at the end of some of the tests. At the end of the treadmill test you will be tired, your legs will be very heavy and you will be out of breath. It is also not uncommon to feel a little light-headed and sometimes nauseous.

What are the possible disadvantages and risks of taking part?

Exercise has a negligible risk in healthy adults, although maximal exercise does carry a small risk of reducing the blood supply to the heart, which can cause chest pain on exertion and in extreme circumstances a heart attack. If you experience any unusual sensations in your chest during the experiment, you should cease exercising immediately. Your heart rate will be monitored via a belt placed on your chest. It is not considered that there will be any problems with the players' participation in this study as the risks are no greater than in any other testing sessions. Life support equipment will be on site and at least one member of the supervision team has attended an "Adult Basic Life Support & Advisory Defibrillation Workshop." First aid support is available.

What are the possible benefits of taking part?

The results from the study will provide information on the training status of the players, the effectiveness of training programmes and may identify weaknesses in some players. The research team will take the time to explain these results to you.

What if something goes wrong?

If taking part in this research project harms you, there are no compensation arrangements. If you are harmed due to someone's negligence, then you may have grounds for a legal action but you may have to pay for it. At least one investigator has been trained in Life Support. In the event of an untoward incident, basic life support including chest compressions and ventilation will be applied.

Will my taking part in his study be kept confidential?

All information collected during this study will be treated in a confidential manner. It is the intention of the university to publish the findings of the research in the near future. You will not be identified in any publication. The results of the fitness tests will also be scrutinised by club officials. If a weakness in any test is found, players may be given specific training in an attempt to improve performance in the tests. Results will not have any effect on team selection.

If you are worried about your involvement in this study or have any further questions about what is involved, please contact:

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E-mail: S.Grant@bio.gla.ac.uk

Monitoring of fitness levels in professional soccer players over a competitive season

Consent form

I have read and had explained to me the accompanying information sheets relating to the project entitled ‘Monitoring of fitness levels in professional soccer players over a competitive season’.

I understand that my participation is entirely voluntary and that I have the right to withdraw from the project at any time and that this will be without detriment to any care or services I may be receiving or receive in the future.

I understand the associated risks and benefits.

I confirm that I have completed a health-screening questionnaire and that I am in a fit condition to undertake the required exercise.

I have received a copy of the accompanying information sheet.

I confirm that the results of the current test can be used for academic purposes.

I agree that the results of the current tests can be examined by Celtic Football Club officials.

Name of participant ________________________ (Print please)

Signature ________________________

Experimenter ________________________

Date ________________________

Appendix 2. Physical activity questionnaire

UNIVERSITY OF GLASGOW
INSTITUTE OF BIOMEDICAL AND LIFE SCIENCES
SUBJECT QUESTIONNAIRE AND ASSENT FORM FOR HIGH INTENSITY EXERCISE TESTING

If you feel unwell on the day of a proposed test, or have been feeling poorly within the last two weeks, you are excluded from taking part in an exercise test. The considerations that follow apply to people who have been feeling well for the preceding two weeks.

NAME …………………………………………..

SEX: M/F AGE: ……….. (yr) HEIGHT: ….….. (m) WEIGHT: ……… (kg)

Playing position…………………………………………….

Have you represented your country at your ***current*** age group YES NO

(please circle)

Details of last medical examination (where appropriate):

Date: ……………..…. (*day/mo/yr*)
Location:…………………….……………………………….………………

Exercise lifestyle:
What kind(s) of exercise do you regularly do (20 min or more per session), and how often? (*Please circle the number of times per average week*):

Walking	1	2	3	4	5
Running	1	2	3	4	5
Cycling	1	2	3	4	5
Swimming	1	2	3	4	5
Skiing					
Rowing	1	2	3	4	5
Gymnastics	1	2	3	4	5
Martial Arts	1	2	3	4	5
Tune Up	1	2	3	4	5
Popmobility	1	2	3	4	5
Sweat Session	1	2	3	4	5
Weight Training	1	2	3	4	5
Field Athletics	1	2	3	4	5
Racket Sports	1	2	3	4	5
Rugby/soccer/hockey	1	2	3	4	5
Others*	1	2	3	4	5

*(*Please specify*)

……………………………………………………………..………………………

How long have you been exercising at least twice/week for at least 20 min/session?
...………years

Smoking: Never smoked……… Not for more than 6 months ……
Smoke less than 10 per day…… Smoke more than 10 per day …..
(*Please tick one*)

Illnesses: *Have you ever had any of the following? (*Please circle NO or YES*)*

Anaemia (low blood count)	NO/YES	Asthma	NO/YES
Diabetes	NO/YES	Epilepsy	NO/YES
Heart Disease	NO/YES	High Blood Pressure	NO/YES
Other*	NO/YES		

*(*Please specify*)

……………………………………………………………..……………………

Symptoms:
Have you ever had any of the following symptoms to a significant degree ***at rest or during exercise***? That is, have you had to consult a physician relating to any of the following?

	E*xercise*	***Rest***
Breathlessness	NO/YES	NO/YES
Chest Pain	NO/YES	NO/YES
Dizzy Fits/Fainting	NO/YES	NO/YES
Heart Murmurs	NO/YES	NO/YES
Palpitations	NO/YES	NO/YES
Tightness in chest, jaw or arm	NO/YES	NO/YES
Other*	NO/YES	

*(*Please specify*)

……………………………………………………………..……………………

Muscle or joint injury:
Do you have/or have had any muscle or joint injury, which could affect your safety in performing exercise ***(e.g. cycling or running),*** strength testing or strength training?

NO/YES*

*(*Please specify*)

……………………………………………………………..……………………

Medication:
Are you currently taking any medication?

NO/YES*

*(*Please specify*)
…………………………………………………………..…………………………………

Family History of Sudden Death:
Is there a history of sudden death in people under 40 years in your family?

NO/YES*

Can you think of any other reason why you should not take part in our tests?

(*Please specify*) ………………………………………………………..

The following exclusion and inclusion criteria will apply to this study:

Exclusion Criteria

If you have any of the following, you will be excluded from the study:

(a) Asthma, diabetes, epilepsy, heart disease, a family history of sudden death at a young age, fainting bouts, high blood pressure, anaemia (low blood count) and muscle or joint injury.

(b) If you are taking any medication that may adversely affect your performance or health in this study, you will not be allowed to take part in the study.

(c) If you take recreational drugs, you will not be allowed to take part in the study.

(d) If you have ingested alcoholic drinks in the previous 24 hours, you will not be allowed to take part in the study.

Inclusion Criteria

(a) In good health at the time of testing.

Signature ……………………………………

Date …………………………………………

Body Weight and Blood Pressure:

Body Weight …………………………………

Height: ………………………………………

BP (Resting) …………………………………

Screened by: …………………………………

Date: …………………………………………

Appendix 3. Consent and assent forms for under 18 players.

CONSENT FORM

Monitoring of fitness levels in professional soccer players over a competitive season

I have read the accompanying information sheet relating to the project entitled, Monitoring of fitness levels in professional soccer players over a competitive season.

I understand that the participation of my child is entirely voluntary and that I and / or my child have the right to withdraw from the project at any time and that this will be without detriment to any care or services I may be receiving or receive in the future.

I understand the associated risks and benefits.

I confirm that I have completed a health-screening questionnaire with my child and that he is in a fit condition to undertake the required exercise.

I have received a copy of accompanying information sheet.

I confirm that the results of the current tests can be used for academic purposes.

I agree that the results of the current tests can be examined by Celtic Football Club officials.

Name of child ________________________ (Print please)

Name of Parent / Guardian ________________________ (Print please)

Signature ________________________

Experimenter ________________________

Date ________________________

ASSENT FORM

Monitoring of fitness levels in professional soccer players over a competitive season

NAME : ________________________________

I am happy to take part in your research project, Monitoring of fitness levels in professional soccer players over a competitive season. I have had the project explained to me by Andrew Somerville.

I understand that I will be asked to perform a range of exercises including a maximum effort on the treadmill and I am happy to do this.

I understand that if I am unhappy about anything that I am being asked to do, I can say so and if I want to I can stop taking part.

If I am not sure of anything then I can ask Andrew Somerville and he will explain it to me.

I agree that the results of the current tests can be examined by Celtic Football Club officials.

Signed: ____________________________

Date: ____________________________

Investigator: ____________________________

Appendix 4. Approved ethics proposal

UNIVERSITY OF GLASGOW

FACULTY OF BIOMEDICAL AND LIFE SCIENCES

ETHICS COMMITTEE FOR NON CLINICAL RESEARCH INVOLVING HUMAN SUBJECTS, MATERIAL OR DATA

APPLICATION FORM FOR ETHICAL APPROVAL

NOTES:

THIS APPLICATION FORM SHOULD BE TYPED, NOT HAND WRITTEN.

ALL QUESTIONS MUST BE ANSWERED. "NOT APPLICABLE" IS A SATISFACTORY ANSWER WHERE APPROPRIATE.

Project Title

Monitoring of fitness levels in professional soccer players over a competitive season.

Is this project from a commercial source? Yes/**No**

If yes, give details and ensure that this is stated on the Informed Consent form.

Name of all person(s) submitting research proposal

Dr Stan Grant
Andrew Sommerville

Position(s) held

Reader
Postgraduate Student

Division **NABS**

Address for correspondence relating to this submission

Dr Stan Grant
West Medical Building
Glasgow
Glasgow University
G12 8QQ

Name of Principal Researcher (if different from above e.g., Student's Supervisor)

S. Grant

Position held

Reader

1. Describe the purposes of the research proposed.

A number of fitness components have been shown to be important in soccer. Monitoring of these components over time provides information on the effectiveness of training programmes and may identify weaknesses in some players. In addition, the player data for a particular club can be compared with players from other countries. A Scottish Premier League Club wishes to monitor its players over a season using a battery of fitness tests designed to test a range of soccer-specific fitness components including, aerobic fitness, speed, strength, power and anthropometrical measures. The test battery will be applied four times throughout the season (prior to pre-season, post pre-season, midseason, and end-season). In addition, heart rate will be monitored during a number of training sessions to determine training intensity. The aim of this study is to monitor the fitness of elite soccer players belonging to a Scottish Premier League Club throughout a competitive season.

2. Please give a summary of the design and methodology of the project. Please also include in this section details of the proposed sample size, giving indications of the calculations used to determine the required sample size, including any assumptions you may have made. (If in doubt, please obtain statistical advice).

Subjects will be recruited from the Under 17, Under 19 and Under 21 and reserve team squads of Celtic Football Club. They will largely be aged between 16 and 21 years of age, though some may be as old as 35 years old. Sixty players will be tested.

Research Design
All subjects will be asked to perform a battery of fitness tests carried out over 2 days on four occasions. Tests will be conducted prior to pre-season, post pre-season, mid-season (December) and at the end of the season (April/May). On the first day the subjects will undergo anthropometric measurements, maximum vertical jump height tests, sprint performance tests and strength tests. On the second day, running economy and aerobic power ($\dot{V}O_2$ max) tests will be carried out.

Day 1

Body mass and height will be measured. Skinfold measurements on the biceps, triceps, subscapularis, suprailiac, abdomen, thigh and calf will be carried out using a skinfold calliper (Baty, British Indicators, London, UK). Thereafter, subjects will carry out a group warm-up session prior to testing under the direction of the team fitness coach. Then tests of maximum vertical jump height will be performed. Subjects will perform 3 maximal counter movement jumps (CMJ's) (no arm-swing) and 3 maximal CMJ's (with arm-swing). A 1-minute recovery period separates each jump. Jump height is assessed using a contact mattress (Just Jump, Probotics, USA). Ten metre sprint times will be measured electronically (NewTest Power Timer System, Finland). The fastest 10m times will be recorded from 3 maximal sprints. Two minutes recovery separates each sprint attempt. Maximal bench press and squat strength will be measured using barbells. Progressive increases in resistance will be used until the subject cannot successfully complete the desired movement.

Day 2

Subjects will carry out a warm-up session on the treadmill followed by a treadmill test to assess running economy. Treadmill speed will be around 10km/h and the duration of test will be 5 minutes. Running economy is defined as the steady state $\dot{V}O_2$. Thereafter the treadmill speed will be increased by 1 kilometre per hour until volitional exhaustion. Gradient will remain at 0% throughout with running speed increasing every minute. The test lasts from approx 10 – 15 minutes depending on the individual's fitness. Players run to volitional exhaustion. Heart rate will be recorded using telemetric heart rate monitors (Polar A1, Finland). Oxygen consumption will be measured using a portable gas analysis system (Cosmed K4b2, Rome, Italy).

Training

Heart rate monitors (Polar A1, Finland) will be monitored during a number of training sessions to determine training intensity.

Statistical analysis
Statistical analysis of the data will be carried out using appropriate parametric or non-parametric tests to determine if there are any differences in test scores between the test periods.

3. Describe the research procedures as they affect the research subject and any other parties involved.

All subjects are familiar with the testing procedures, as the administration of the proposed tests is an integral part of their fitness programme. Testing sessions are already scheduled to take part 4 times throughout the football season 2005-2006.

The subjects will be encouraged to produce maximum efforts, and in the case of the incremental $\dot{V}O_2$ max test they will be asked to run to volitional exhaustion. This will mean that subjects may experience feelings of muscular fatigue and exhaustion upon completion of the tests, however recovery will occur quickly when facilitated by an active warm down. No subject will be allowed to leave the testing area until a complete recovery has been confirmed.

4. What in your opinion are the ethical considerations involved in this proposal? (You may wish for example to comment on issues to do with consent, confidentiality, risk to subjects, etc.)

Exercise has negligible risk in healthy adults, although maximal exercise has a small risk of inducing myocardial ischaemia. All players have been given a medical examination by the club doctor and have undergone electrocardiogram and echocardiograms tests. All players will complete a medical questionnaire. A blood pressure reading will be taken before each testing period.

All players will be given an information sheet and asked to sign a consent form. The under 18 players will sign an assent form and the parents of the under 18 players will sign a consent form. Test scores will not influence team selection. All data will be anonymised before leaving the club for use in the research project.

5. Outline the reasons which lead you to be satisfied that the possible benefits to be gained from the project justify any risks or discomforts involved.

The test results will give information on the effectiveness of the training programs and the possible impact of reduced training during periods when the players are involved in many matches with a reduced training load.

6. Who are the investigators (including assistants) who will conduct the research and what are their qualifications and experience?

Dr Stan Grant PhD MSc BEd, Andrew Sommerville M.Sci.(Hons). The investigators have wide ranging experience of exercise testing over periods of up to 20 years without incident.

7. Are arrangements for the provision of clinical facilities to handle emergencies necessary? If so, briefly describe the arrangements made.

The following arrangements will apply during testing:

A semi automated defibrillator, 100% oxygen, self-inflating resuscitation bag with reservoir; face-masks (2 sizes), suction to clinical specification and a sphygmomanometer to measure blood pressure are on site in the laboratory.

An individual who has current life support training will supervise all exercise tests. In the event of an emergency, approved emergency protocols will be followed.

A first aid box will be available.

The above will not apply to training sessions.

8. In cases where subjects will be identified from information held by another party (for example, a doctor or hospital) describe the arrangements you intend to make to gain access to this information including, where appropriate, which Multi Centre Research Ethics Committee or Local Research Ethics Committee will be applied to.

N/A

9. Specify whether subjects will include students or others in a dependent relationship.

The subjects are players at Celtic Football Club

.

10. Specify whether the research will include children or people with mental illness, disability or handicap. If so, please explain the necessity of involving these individuals as research subjects.

N/A

.

11. Will payments or any other incentive, such as a gift or free services, be made to any research subject? If so, please specify and state the level of payment to be made and/or the source of the funds/gift/free service to be used. Please explain the justification for offering payment or other incentive

No additional payment or incentives will be offered for participation in this study.

12. Please give details of how consent is to be obtained. A copy of the proposed consent form, along with a separate information sheet, written in simple, non-technical language MUST ACCOMPANY THIS PROPOSAL FORM.

All subjects will be provided with an information sheet. They will be asked to sign a consent form. Parents of the under 18 players will sign a consent form. The under 18 players will sign an assent form

13. Comment on any cultural, social or gender-based characteristics of the subject which have affected the design of the project or which may affect its conduct.

N/A

14. Please state who will have access to the data and what measures which will be adopted to maintain the confidentiality of the research subject and to comply with data protection requirements e.g. will the data be anonymised?

The data will be anonymised prior to statistical analysis and fully available only to the researchers.

15. Will the intended group of research subjects, to your knowledge, be involved in other research? If so, please justify.

No.

16. Date on which the project will begin **1st July 2005**

17. Please state location(s) where the project will be carried out.

Celtic Football Club, Sports Performance Department, Celtic Park, Glasgow

18. Please state briefly any precautions being taken to protect the health and safety of researchers and others associated with the project (as distinct from the research subjects) e.g. where blood samples are being taken

It is considered that there is no meaningful risk to the experimenters.

Signed____
Date ________________
(Proposer of research)

Where the proposal is from a student, the Supervisor is asked to certify the accuracy of the above account.

Signed ____
Date ________________
(Supervisor of student)

Email the completed form to: S.Morrison@bio.gla.ac.uk

And send the signed hard copy to:

Stuart Morrison
Faculty Research Office
Faculty of Biomedical & Life Sciences
West Medical Building
University of Glasgow
Gilmorehill
Glasgow
G12 8QQ

RISK ASSESSMENT

Monitoring of fitness levels in professional soccer players over a competitive season

Hazards

The test battery consists of measures to evaluate each of the following areas of fitness:

1) Anthropometric measurements
2) Maximum vertical jump height tests
3) Sprint performance tests
4) Strength tests
5) Running economy and aerobic power ($\dot{V}O_2max$) tests.

Some of these tests involve a very **strenuous** effort and place a **potential cardiac risk** to health. "High risk" individuals may be particularly prone to problems e.g. epilepsy. Venous pooling at the end of tests may result in disorientation and possible collapse.

Who might be harmed?

1) Any subject is considered to be at risk.

2) Subjects with heart disease or other chronic illness (e.g. epilepsy) are considered to be at greater risk than "normals".

3) Subjects with viral infection are considered to be greater risk than "normals".

4) Subjects and experimenters could be injured by the weights used in the strength tests.

Existing Precautions

The subjects are asked:

1) If they understand what the test involves by reading the description of the test and by asking staff questions, if they are unsure of any of the procedures and/or any problems associated with the test.

2) To complete a medical questionnaire before they undertake the tests and to make sure that the responses have been checked by a member of staff.

3) To sign a consent form, which signifies that they understand the test procedures and any dangers, associated with the test.

4) Subjects are advised that participation is entirely voluntary and that they should not participate if they feel unwell. They can drop out at any point in the tests, and must do so if they feel unwell or sustain injury.

Further precautions include:

5) Subjects are assessed on a regular basis by the club physiotherapist/medical staff and will be advised not to train/take part in testing if unwell or injured. Coaching and research staffs are also advised of any player who is recommended for exclusion.

6) Before the tests, the subjects perform a warm-up.

7) A defibrillator, an oxygen cylinder and suction apparatus are on site. At least one experimenter must be trained in the use of the above.

8) The defibrillator and oxygen equipment is checked before all test sessions. (Equipment checked by Andrew Somerville).

9) A first aid kit is also carried.

10) On cessation of the aerobic tests the subject is allowed to recover actively e.g. walking until heart rate decreases to about 120 beats.min^{-1}.

11) All barbells will be checked to ensure that the safety collars are securely tightened.

12) All strength tests will have a "spotter" who will monitor the lifts and offer support when necessary.

Emergency Procedures

The following plan of action has been agreed, should any medical emergency arise during testing:

1. The trained member of staff shall assess the situation, and carry out immediate first aid and basic life support if required.
2. A second member of staff will be instructed to contact the emergency services from the nearest telephone point (a land line phone is in the laboratory).
3. The second member of staff will arrange to meet emergency staff in the main car park and direct them to the accident scene.
4. In the absence of a parent or guardian, a member of staff will escort the casualty to hospital. The parents will then be contacted.
5. If the club doctor is available, he will be asked to help in any emergency.

The above risk assessments have been carried out by: Dr. S. Grant and Andrew Somerville.

Signature ___________ Date_________

Signature __________ Date_________

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