THE EFFECT OF HIGH INTENSITY RUNNING TRAINING ON WORK CAPACITY IN FOOTBALL (SOCCER)

Submitted by

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Statement of Sources

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Abstract

Rationale: High Intensity Interval Training (HIIT) has been used by elite athletes for decades however, it is a relatively under researched training methodology in a team sport setting.

Aim: The purpose of this study was to evaluate the effect of a high intensity interval training protocol on aerobic power and physical performance in competitive matches.

Intervention: Twenty-five (25) players were recruited from a national Under 20 men's football (soccer) program. Players were randomly assigned to one of two intervention groups;

- A high intensity interval training intervention group
- A control group

The intervention group completed a 10 minute interval training session, three times a week comprised of two sets of eight bouts of 15 second shuttles at approximately 120% of maximum aerobic speed, for a four week period. The control group performed a juggling exercise that was matched for time with the intervention group. Participants were not blinded to the intervention.

Pre and post intervention testing involved physiological field testing including the Multi-stage Shuttle Test (MSST), vertical jump and 20 m sprint time. In addition, pre and post intervention match analysis data were derived from GPS devices. Three games were analysed pre and post intervention. Changes between the intervention and control groups, across the entire group from pre to post were analysed.

Results: Results showed a significant improvement in the intervention group over the control group for aerobic power (p=0.0089), but no significant changes in vertical jump (p=0.3823) and 20 metre sprint time (p=0.0682).

Match analyses from GPS data showed no differences between the groups for total distance, average distance covered per minute (meterage) and high intensity running variables. However, match analysis data when grouped for the all participants showed significant improvements in 1st

half meterage (p=0.0001), 2^{nd} half meterage (p=0.001), 1^{st} half versus 2^{nd} half differences (p=0.001), 1^{st} 15 minutes versus last 15 minutes meterage (p=0.026), high intensity running distance (p=0.001) and total high intensity running efforts (p=0.026) following comparisons of pre to post intervention data.

Conclusion: Overall the study showed high intensity interval training based on a percentage of maximum aerobic speed during the season provided an effective means of improving aerobic power without negatively impacting on anaerobic performance. However, the absence of a significant transfer to match performance when compared with a control group may be due to multiple factors in elite junior development squads. The match data may also indicate that playing at a higher level than previously experienced may have had a positive effect on match performance for all participants. Transferring quantifiable training outcomes into match performances remains a challenge in team sports.

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b. Acknowledgements

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Chapter 1

INTRODUCTION

1.1 Rationale

High Intensity Interval Training (HIIT) has been used by elite athletes for decades. However, it remains a relatively under researched training methodology. High intensity interval training involves training for short intervals that approximate a maximal or supra-maximal intensity. Intensity is determined as a percentage of velocity achieved when the athlete obtains maximum aerobic power (vVO_{2max}).

Existing research shows HIIT is an effective and time-efficient training methodology when compared with traditional endurance based methods, for developing aerobic power. In open-loop team sports, training time is often limited because multiple physical, tactical and technical areas require attention in a small period of time. This is even more pertinent in a youth development program in which the emphasis remains on learning and improvement for the future, as opposed to being strongly focussed on results. Any training methodology employed at the development level of performance must be time-efficient, effective and have a positive impact on performance. Research in these areas tends to favour elite adult athletes, often involving in endurance sports. Therefore, the use of HIIT training with developmental athletes to improve aerobic power and improve workload in a match team sports warrants further investigation.

In concert with professional growth in sport, performance analysis possibilities have expanded. Previous means of estimating performance changes were largely based on subjective video or real time analysis of match settings. Despite some reservations*, (Morgan and Williams, 2009, Edgecomb and Norton, 2006)* advances in technology in recent years provide more objective, comprehensive and time-efficient options for understanding changes in match performance.

It is postulated that combining match performance analysis and HIIT will advance the understanding of the effectiveness of time-efficient training methods such as HIIT.

1.2 Research Aim

The aim of this research was to evaluate the effect of high intensity interval training (HIIT) on match performance in elite youth development football players.

1.3 Hypothesis

1. A four week regime of high intensity interval training will improve aerobic power without compromising speed and vertical jump performances.

2. Improved aerobic power will result in increased high intensity running in matches compared with a control group, demonstrated via the use of GPS data

3. In developmental squad players, match performance data will be similar to reports in the literature of more professional players.

1.4 Limitations

Limitations to the study mainly developed as a result of the study taking place during the competition phase of the year. Subsequently, in-season match settings presented several limitations during the study outside the scope of this thesis. These limitations outside the control of the researcher included the following;

Injuries occurring during matches

The standard and structure of the opposition

The match strategy of the opposition

The tactics required during the game for the best possible outcome

The team line up, which was selected on the basis of form.

The intensity of each game and how it would affect the following weeks training performance.

Other limitations to the study beyond the control of the researcher, included player motivation to perform, and pre and post training nutrition. Limitations also occurred with the GPS data collection. At half time, the players would retreat to the change room and the satellite signal would be lost temporarily. The signal did not always coincide with the players return to the field. As a result, not all data could be used in the results.

1.5 Delimitations

One elite developmental squad was used in the study. Players were part of a single residential program at the Australian Institute of Sport, Canberra. This allowed easy access to the squad and greatly minimised the risk of non-compliance. The selection of only one squad of players assured strong and unified team support from the coach and training staff. Coach support for the study included an agreement to maintain similar intensity and loading throughout the intervention study. Training took place on the same surface, at the same time every session to ensure the same process was followed every session. The squad was the same sex, approximately the same age and presented to the residential program with a relatively homogeneous training history.

Although a number of possible technology analyses of match performance could have been selected, the study was delimited to GPS data. Also management of the GPS data was controlled by the same trained and experienced tester to ensure the objective& reliable protocols were followed.

The study was also delimited by the need for field based tests with standardised protocols (e.g. Multi-Stage Shuttle Run, sprint and power tests) that were familiar to the participants.

Other delimitations in the HIIT intervention included the four week duration, the use of only one protocol and a short duration of 10 minutes within three training sessions per week. Session times were standardised across the four weeks and followed a fixed warm up and cool down procedure. The same trainer was used for all HIIT sessions.

The study was further delimited to a relatively small number of pre and post intervention match analysis. A less than ideal amount of data available from matches, complied with the need to minimise interruptions to the coach's game plans. It would have been desirable to maximise match time for monitored players, but this was not possible.

1.6 Definition of Terms

Maximum aerobic speed: The speed corresponding to the maximal stead state VO_{2max} *(Berthoin, Gerbeaux,* Guerruin*, Lensel-Corbeil and Vandendorpe 1992).*

High Intensity Interval Training: "Repeated sessions of relatively brief intermittent exercise, often performed with an ''all-out'' effort or at an intensity close to that elicits VO_{2max}" *(Gibala and Magee, 2008).*

Maximum Aerobic Power: "The maximal rate at which energy can be produced primarily through oxidative metabolism*" (Thoden 1991).*

The following terms were defined within the context of this study;

High Intensity Running: Running at higher than 16km/hr

Meterage: Metres covered per minute of play

1st 15min: The first 15 minutes of the game

6th 15min: The final 15 minutes of the game.

Chapter 2

REVIEW OF LITERATURE

2.1 Introduction

Football (soccer) is among the most popular sports in the world. An estimated 100 million registered players exist worldwide in men's, women's youth and veteran competitions, with many millions more playing non-organized football *(Reilly 1997).* The FIFA World Cup, played every four years, is widely considered the world's biggest sporting event, with a following that outranks the summer Olympic Games. Football's growth in popularity over the past 20 years has seen a similar increase in the amount of research conducted in all fields of sports science *(Reilly & Gilbourne 2003).*

Traditionally, researchers have favoured "closed-loop" individual sports for investigation. This is probably due to the relative ease of analysing individual sports compared with the less predictable, multi-faceted team sports *(Reilly & Gillbourne, 2003).* Unlike closed loop cyclical sports, football is a "sport in which complex skills and intricate teamwork are required". Therefore, it is difficult to identify one dominant physical characteristic, considered mandatory for success in the sport (*Reilly 2001).* Football is a multi-dimensional sport requiring players to jog, run, sprint, accelerate, decelerate, jump, change direction and get up from the ground after falls and knocks *(Bangsbo and Michalsik, 2002).* Football-specific activities such as tackling, heading, passing, shooting, controlling the ball, maintaining balance and holding body position when under defensive pressure, jointly comprise the physical demands of the sport *(Stolen, Chamari, Castagna and Wisloff, 2005).* Collectively anthropometric, physiological, technical, and perceptual factors can contribute to successful performance in football *(Hoare & Warr, 2000).*

2.2 Movement Analysis of Football

Understanding success in football performance may be enhanced by movement analysis studies into football. For example, a player goes through an average of 1179 changes in activity during a 90 minute game *(Bangsbo, Norregand & Thorsoe, 1991).* More recent research reported an average of 1459 changes in activity during a game *(Krustup, Mohr, Ellingsgaard & Bangsbo, 2005),* which equates to a change in activity every 4 seconds *(Stolen et al. 2005).* Taking into account stoppages in play for free kicks, throw-ins, goal kicks, goals and other factors, these changes in activity probably occur even more frequently during routine match play. Furthermore, players in an elite junior match can undertake close to 1000 changes in activity through the course of a game *(Thatcher & Batterham, 2004).* The number of changes in modern football is postulated to be greater than previously reported, because it is generally accepted that the game is continuously becoming faster and more athletically challenging than before *(Al-Hazzaa, Almuzaini, Al-Refaee, Sulaiman, Dafterdar, Al-Ghamedi & Al-Khurai, 2001).*

A number of studies in recent years have investigated time-motion analysis of football *(Krustup et al. 2005, Reilly, 1996, Di Salvo, Gregson, Atkinson, Tordoff, & Drust, 2009):* The physiological demands of field games such as football can be investigated by making relevant observations during games using time-motion analysis. Scientific investigation into time-motion analysis in football dates back to the 1950's *(Bangsbo, 1994)*. One of the first methods of analysis for football involved tracking movements on a scale model of the playing surface (*Winterbottom, 1952*). Other methods have included coded commentary on audio tape *(Reilly, & Thomas, 1976)*, registering player movements on paper *(Whitehead, 1975),* analysis of cine-film obtained from overhead video cameras of total team movements *(Van Gool, Van Gervan & Boutmans, 1988)* and measures of stride length to determine the distance covered at different running speeds *(Reilly, 2001)* to determine workload in competitive games. Improvements in technology such as Global Positioning Systems (GPS) and computer-based video analysis have increased the ease and accuracy of time-motion analysis of sports such as football *(Carling, Bloomfield, Nelsen & Reilly 2008, Rampini, Impellizzeri, Castagna, Coutts & Wisloff, 2009).*

Some care needs to be taken in interpreting data obtained from time-motion analysis. The various methods of analysis and subjects in whom the analysis occurred have found large variations in the data *(Stolen et al. 2005).* Other variables also need to be taken into account when analysing data.

Factors such as match and environmental conditions, playing and coaching style, opposition, refereeing and rule changes, potentially impact on the results of any time motion analysis *(Bangsbo, 1994)*.

Similar to other field and court sports, football requires a number of strong physiological qualities, as well as superior skill levels, tactical abilities, and team work to be performed at the highest level. Psychological factors and team dynamics will also contribute to successful performance *(Reilly & Gilbourne 2003).* Football is a "hybrid sport characterized by intermittent exercise bouts of short intense activity alternated by longer periods of low-level moderate intensity exercise" *(Polman, Walsh, Bloomfield & Nesti, 2004).* Football players are generally considered to display above average performance when tested using a number of physical characteristics and are therefore able to adapt to the ever-changing physical demands of the sport *(Edwards, McFadyen & Clarke 2003).* These performances in physiological assessments are rarely equal to elite performance in sports that have one predominant physiological characteristic *(Reilly, 1997).*

Football is a multi-dimensional sport requiring constant changes in activity. The sport demands continuous changes in movement speed that can vary from being stationary, through walking, as well as low and high intensity running bouts *(Reilly, 1996, Withers, Maricie, Wasilewski & Kelly 1982).* The challenging energy demands of football emerge from requirements to perform a number of high intensity activities, such as jumping, tackling, accelerating, decelerating and getting off the ground *(Bangsbo & Michalsik 2002)*. Other game skills such as kicking and dribbling also need to be considered when determining total physical requirements for football *(Reilly, 1997).* For instance, the oxygen demand for dribbling the ball is greater than the demands imposed by running normally, while the energy demands of running backwards are lower than running with the ball *(Kemi, Hoff, Engen, Helgerud & Wisloff, 2003).* Therefore, the demands of unpredictable multiple movement patterns in football combine to generate the movement challenge and regularly change the demands on energy production and muscle action.

Football requires a number of physiological qualities to be performed at the highest intensity and skill execution with an exceptionally high standard of technical ability, as well as a tactical understanding of the game. Physical qualities include aerobic and anaerobic endurance, agility, and sprinting ability, jumping and kicking power *(Reilly, 1997).* Unlike elite sprinters or distance runners, professional football players do not generally have extraordinary capacities in one single physical quality *(Hoff & Helgerud 2004).* Physiological testing is best used as a guide to potential 'successful performance' in football, and can especially be used as a monitoring tool to determine individual's status at a given time *(Reilly, Bangsbo & Franks, 2000).* Some physiological characteristics are shared by most high-level players *(Apor 1988, Bangsbo et al. 1991, Mohr, Krustup, & Bangsbo*, *2003).* However, these qualities do not necessarily guarantee the highest level of performance. Many other factors, in particular, technical performance of skills of the sport and tactical understanding cannot be understated. In many cases, dominant technical and tactical abilities allow players to reach the highest level and teams to consistently outperform their opponents *(Rampini et al. 2009).*

Advances in technology allow coaches and sports scientists to be better placed to improve the understanding of football via movement analysis during live games. The ease of access to these technologies also permit faster and more regular analysis of the game in relation to factors such as rules changes and new training methods *(Carling et al. 2009, Barbero-Alvarez, Barbero-Alvarez, Gomez & Castagna C 2009).*

2.3 Science of Football

2.3.1 History

Organized football, formally referred to as "association football," was derived from a traditional free-for-all type game played in towns and villages in Anglo-Saxon times. The earliest known reference to the game is from 1175 and was a traditional match played on Shrove Tuesday. The original game was essentially a possession game, with very few rules; no limits on time of play, terrain, or team numbers. This violent form of the sport was often subject to bans *(Bangsbo 1994).*

It was not until the 19th century that the game we now know as football started to take shape. Differing versions of football were played in the greater British public schools, Rugby, Harrow, Eton and Charterhouse. Tables of rules were first drawn up around 1840. In 1863, the Football Association was formed, using the "Cambridge Rules" as the basis for their game, which were tabled the year before. Although the game has grown and the rules have changed extensively since, it was in this period that the 11-man game of football we see today was developed (*Bangsbo 1994*).

2.3.2 Players and Positional Requirements

A football side comprises of eleven on-field players: ten outfield players and one goalkeeper in a team. The ten outfield players can be divided into defenders, midfielders and strikers, or forwards. The number of players in each position will vary slightly depending on the team's tactical approach. As a result, the general physiological characteristics of different positions when observed will vary from team to team. Some generalizations can be drawn from collected data on positional differences in football.

2.3.2.1 Defenders

In general, the role of defenders is to prevent opposition play getting too close to the goal area and to prevent goals being conceded. When in possession of the ball, defenders are required to commence the attacking build up. Defenders tend to be the tallest and heaviest players in the team *(Al Haaza et al. 2001).* The one exception to this is the goalkeepers who are a similar height to the central defenders *(Bangsbo, 1994).* Defenders are subsequently, often used in "set piece" situations in which they try to use their height to out jump opponents and head the ball toward goal.

For the purpose of game analysis, defenders are largely divided into fullbacks (wide defenders) and central defenders due to the differing roles the two positions play. The playing role and physical requirements of central defenders and fullbacks can differ markedly. In elite level Danish players, central defenders tend to be taller and heavier than fullbacks (*Bangsbo, 1994)*. One explanation for this is that central defenders, like strikers, tends to be a target position, requiring them, more than fullbacks, to do a greater amount of heavy physical work such as tackling, heading and jumping *(Bangsbo, 1994).* However, fullbacks tend to have greater aerobic power (61.5 $ml \cdot kg.^{-1}min^{-1}$ +/- 10.0 than central defenders (56.0 $ml \cdot kg.^{-1}min^{-1}$ +/-3.5). The role of the fullbacks includes longer runs up the sides of the pitch to either commence or support the attack, in addition to their role of defending and preventing goals. Moreover, fullbacks tend to perform better in intermittent measures of performance than central defenders *(Bangsbo & Michalak, 2002)*.

Defenders tend to make more jumping and tackling movements than other players *(Reilly & Thomas, 1976, Ekblom, 1986).* Due to the important task of jockeying or directly marking an attacking player with the ball, defenders tend to spend a lot of time moving backwards compared with players in other positions *(Drust, Reilly & Rienzi, 1998).*

2.3.2.2 Midfielders

Midfielders are required to create play and move the ball up the field. They are generally expected to help out in both attack and defence and as a result are often referred to as "link players" *(Drust et al. 1998)*. Midfielders are generally considered the workers, as they are constantly involved in helping the defence, creating attacking opportunities and supporting the strikers in the attacking goal area in an effort to score. Midfielders will often take up more specific defensive, attacking or wide positions.

The overwhelming majority of studies on positional differences report midfielders cover the greatest distance in a 90-minute game *(Stolen et al. 2005)*. However, players in other positions, usually fullbacks, will sometimes undertake a similar or greater amount of high intensity running than midfielders *(Mohr et al. 2003, Bangsbo, 1994).* Subsequently, midfielders cover a greater distance at low to moderate intensities. The link role midfielders undertake, that requires them to take up positions in both attack and defence would help explain the greater distances covered at these intensities, compared with other positions on the field.

2.3.2.3 Forwards

Forwards, usually referred to as strikers, are primarily responsible for creating and scoring goals. The number of strikers or attacking players has changed regularly with differing tactics. In the 1860's, teams would be made up of up to 7 strikers, with three defenders *(Bangsbo, 1994).* Team tactics will determine how many strikers play, with variations from team to team.

Strikers are similar in stature to midfielders and fullbacks. Strikers have higher aerobic power than central defenders and goalkeepers, but marginally lower aerobic power than fullbacks and midfielders (*Bangsbo & Michalak, 1998*). Strikers will normally cover lower distances per game than midfielders and fullbacks *(Van Gool et al. 1988, Ekblom, 1986)*, but cover slightly greater distances than central defenders *(Mohr et al. 2003, Reilly & Thomas, 1976).* Despite the lower total distance covered, strikers will tend to cover a higher percentage of the distance at higher intensities than other positions *(Reinzi, Drust, Reilly, Carter & Martin, 2000, Withers et al. 1982).* Unlike midfielders, strikers are only involved in play when it is in their section of the field. Strikers are rarely required to become involved in play at the other end of the field in a defensive capacity.

2.3.2.4 Goalkeepers

The goalkeeper is the last line of defence and is the only player allowed to use their hands to touch the ball. This can only be done in the goals area or "box." Keepers are similar in size to central defenders but have lower levels of aerobic power than all other positions (*Bangsbo, 1994, Drust et al. 1998)*. This may be explained by the fact that goalkeepers cover significantly less ground during a game than outfield players (*Reilly & Thomas, 1976).* However, the goalkeeper has a much higher involvement with the ball than any other player in the team. Most involvements tend to be explosive, short-term, and therefore anaerobic in nature (*Drust et al. 1998)*.

2.3.3 Aerobic Energy Considerations

Aerobic performance is a fundamentally important physical quality for elite football. The role of aerobic performance in football at all levels has been frequently researched (*Stolen et al. 2005*). It is generally accepted that aerobic performance is influenced by three factors, maximal aerobic power, anaerobic threshold, and work economy *(Hoff, Wisloff, Engen, Kemi & Helgerud, 2002).*

Estimates of the contribution of aerobic energy to performance have varied. Based on the length of the game (90 minutes), at least 90% of energy requirements would have to come from aerobic energy sources *(Hoff et al 2002).* In later research, it was estimated as much as 98% of all energy requirements in football come from aerobic sources, with only 2% from anaerobic sources *(Hoff & Helegerud, 2004)*. Other reports of game demands cite 8% of total game time is spent performing high intensity activities such as sprinting, jumping and tackling *(Bangsbo et al. 1991)* while other studies report as high as 12% contribution from anaerobic sources *(Rampini et al. 2007).* Such figures suggest that match performance is nearly solely reliant on aerobic performance. However, the role of the anaerobic system cannot be forgotten, as the most crucial parts of the game generally occur at high intensities requiring energy from anaerobic sources *(Edwards et al 2003, Little & Williams, 2005, Bradley, Sheldon, Wooster, Olsen, Boanas & Kustup, 2009).*

Aerobic power "reflects the ability to produce aerobic energy at a high rate and is characterized by VO_{2max}" *(Bangsbo & Michalsik, 2002)*. $VO_{2max}$is the most common method used to quantify aerobic performance in football players, with several studies examining maximal aerobic power in elite, junior, recreational, and women's football. Average aerobic power, as reported as VO_{2max} in relation to bodyweight, for elite football has been estimated to range between 55 $ml \cdot kg.^{-1} min^{-1}$ and 65 $ml \cdot kg.^{-}$

$^{1}min^{-1}$ *(Al-Haaza et al. 2001).* Higher estimates of approximately 68 ml·kg.$^{-1}$min^{-1} *(Wisloff, Helgerud & Hoff, 1998),* 69 ml·kg.$^{-1}$min^{-1} *(Nowacki, Cai & Buhl, 1988)* and as high as 74 ml·kg.$^{-1}$min^{-1} *(Apor 1988)* have been recorded in elite players. These values do not equal the levels reached by elite endurance athletes, in whom maximal aerobic power can reach over 80 ml·kg.$^{-1}$min^{-1} *(Reilly & Secher, 1990).*

The importance of high aerobic power in football appears to be a necessary condition for football (*Stolen et al. 2005)*. Many studies have investigated the role of aerobic performance as a determinant of high-level performance in football *(Mohr et al. 2003, Kemi et al. 2003, Apor, 1988, Impellizeri, Marcona, Castagna, Reilly, Sassi, Iaia & Rampinini, 2006).* Elite level footballers tend to have higher rates of aerobic power than lower level players. One study recorded VO_{2max} of the top five Hungarian league teams. The results found that the teams finished in rank order when VO_{2max} performance and finishing position on the ladder were compared *(Apor, 1988)*. Furthermore, VO_{2max} values of players in the top Norwegian team were higher than lower ranked teams *(Wisloff et al. 1998)*. Similar discriminating results were found when teams from the Swedish 1st division and 4th division were compared *(Ekblom, 1986)* and within teams competing in the 1st and 2nd divisions of England *(Whitehead, 1975).*

A comparison of two groups of players from the Italian first division and the Danish League provided insightful results *(Mohr et al. 2003)*. The Italian league is generally accepted as a higher standard than the Danish league. Compared with players from the Danish League, players in the Italian League performed better in an intermittent time to fatigue test commonly known as the Yo Yo Test *(Bangsbo et al. 1991)*. Another study compared VO_{2max} values of different leagues with Saudi Arabian players. The VO_{2max} of the Saudi players was marginally lower than other leagues considered stronger *(Al Hazzaa et al. 2001).* An aerobic "threshold" may exist, below which a player is unlikely to possess sufficient aerobic power necessary for success in professional soccer. This threshold is postulated to occur at approximately 60 ml·kg.$^{-1}$min^{-1} *(Reilly, 2000)* but more realistically, is likely to be best ascertained at an individual level.

2.3.4 Aerobic Power Assessment

Some difficulty exists in accurately determining VO_{2max}in footballers. Traditionally, the most accurate method of determining VO_{2max} was assessed using gas analysis in the laboratory. Laboratory methods of determining VO_{2max} present several problems to most football squads, due to the financial and time requirements of this method of testing. Concomitantly, the large number of players in squads makes more portable field tests predominantly more feasible for estimating $VO_{2max.}$

The Multi-Stage Shuttle Test *(Leger & Lambert, 1982)* requires players to run 20 metre shuttles at a gradually increasing pace. The pace is determined by an audio recording that necessitates players to complete each shuttle in a set time, indicated by a 'beeping' noise on the tape. The running speed commences at 8 $km.h^{-1}$ and increases by 0.5 $km.h^{-1}$ each minute approximately. Players are eliminated from the test when they fail to maintain the running speed that matches the audio recording. Aerobic power is determined using tables developed by *Léger, Mercier, Gadoury & Lambert J. (1988).* These tables are based on the mostly linear relationship between VO_{2max} and maximal running speed attained in the final stage achieved during the test *(Svennson & Drust, 2005).* Research has shown a strong correlation between laboratory-attained measures of aerobic power and the Multi Stage Shuttle Test *(Ramsbottom, Brewer, & Williams, 1988).* The Multi Stage Shuttle test has shown to be an effective and accurate tool for determining aerobic power in football populations similar to the one used in this study *(Williford, Scharff-Olson, Duey, Pugh & Barksdale, 1999).*

2.3.5 Anaerobic Requirements

Despite the lower energy contribution from anaerobic sources, the majority of critical involvements in the game are performed at higher intensities, in the form of activities high intensity running, sprinting, jumping and body contact *(Little & Williams 2005).* Football-specific skills such as heading, striking the ball, tackling and strong static contractions when holding off an opponent also contribute significantly to the anaerobic requirements of football *(Reilly, 1997).* These moments of high power requirements occur intermittently throughout the game.

Many of these activities are difficult to measure. Subsequently, the importance of anaerobic contribution to energy needs in football may be underestimated. Reliable and repeatable measures of anaerobic energy demands are not as prevalent as measures of aerobic performance. Therefore, investigations into identifying physical qualities for higher-level players remain inconclusive *(Williams & Franks, 1988)*.

2.4 Notational Analysis of Football

As a result of the intermittent nature and multiple components of movement demands, it is difficult to accurately quantify the physiological requirements of football *(Edwards et al. 2003).* One of the most popular methods of trying to quantify the demands of football occurs via direct observation time-motion analysis studies (*Mohr et al. 2003, Bangsbo & Michalsik 2002, Bangsbo, Marcello-Iaia & Krustup 2007).*

Time-motion analysis of football has produced varying results. Variability could be attributed to the diverse methods used for data collection, as well as differing levels of performance of athletes, and the context of the games in which the analyses have occurred. Summaries of the results of several time-motion analysis studies of football using several methods including hand notation, video analysis, trigonometry and cine-film analysis have been undertaken *(Drust et al. 1998, Stolen et al. 2005)*.

2.4.1 Distance Covered

Time-motion analysis of football has often focused on the total distance covered. This is based on the assumption that total energy expenditure is directly related to total work output *(Drust et al.*

1998). Numerous studies have been undertaken over several decades to determine the distances covered in professional football (*Stolen et al. 2005)*.

Early analysis of the distance covered during a game showed that players in the old English 1st division covered on average 3361 metres *(Winterbottom 1952).* Other older research into distance covered during a game showed players covering 5486 metres *(Wade 1962),* 4400 metres *(Knowles and Broke 1974)* and 8700 metres *(Reilly & Thomas, 1976).*

Independent of the different methods and players or competitions used to undertake time-motion analysis; several similarities have emerged in results. In more recent research, some agreement on distance covered has been found. Most studies have reported the average distance covered in a 90 minute game of football to be between 9000 and 12000 metres *(Bangsbo & Michalisk 2002, Saltin, 1973, Ekblom 1986, Reilly 1997, Van Gool et al. 1988).* The distance covered by goalkeepers tends to be around 4000 metres per game *(Reilly & Thomas 1976, Drust et al. 1998).*

Differences in playing and coaching styles and opposition will impact the total distance covered during a game. One research paper showed that players in the English Premier league covered over 1000 metres greater than players in an equivalent competition in South America *(Reinzi et al. 2000).* This could be explained by the differing playing styles favoured by teams in differing competitions.

Although distance covered gives a good indication of workload during competitive football games, it may not necessarily be the best measure of effectiveness during team sport play. Recent research in the English premier league that showed lower performing teams covered greater distances at higher intensity, indicating that tactical positioning may play a more significant role in better performing teams *(Di Salvo et al. 2009)*.

2.4.2 Breakdown of Distance Covered

The general agreement on distance covered indicates the sport requires a large aerobic component. However, the sport is predominantly intermittent with periods of very high intensity activity interspersed with lower intensity activities as well as several periods of remaining stationary. Therefore, the energetic requirements of football require further consideration *(Edwards et al. 2003).*

A number of different movement styles that are used to breakdown distance covered have been used. An early study identified five different movement methods; walking, jogging, cruising, sprinting and utility movements *(Reilly &Thomas, 1976).* Another study identified seven different movement categories within the game; walking, jogging, low speed running, backwards running, moderate speed running, high-speed running and sprinting *(Bangsbo & Michalisk, 2002).* Furthermore, another study used eight different movement categories, stationary, walking, jogging, low speed running, moderate speed running, high speed running, sprinting and backwards running *(Mohr et al. 2003).* Multiple studies have examined the breakdown of the distances covered in elite professional football with differing results (*Withers et al. 1982, Mayhew & Wegner, 1985, Ali & Farrally, 1991, Bangsbo et al. 1991, Di Salvo, Baron, Tschan, Calderon-Montero, Bachi & Pigozzi, 2007).* Despite variations in precise time and distances in differing movement speed ranges, it can be concluded that the sport of football is intrinsically intermittent in its energy demands and locomotion methods. These differences as well as how these how movement categories are determined, may limit generalizations from the analysis and cross study comparisons.

It has been observed that players in the Italian Serie-A (generally considered one of the best leagues in the world) cover approximately 5% greater distance than players in the Danish League, which is generally considered a lower level league *(Mohr et al. 2003)*. However, within that distance covered, it was found players in the more elite Serie-A performed 28% more running at high intensity, including covering 58% more distance when sprinting. Within the same league, two studies have shown that higher performing teams involve less distance and fewer bouts of high intensity running than lower performing teams *(Di Salvo et al. 2009, Rampini et al. 2009).* However, the number of efforts and high intensity running in possession increased in better performing teams. This may indicate the importance of skill and tactical approaches in addition to the need for movement efficiency.

Within the team, the different positions cover diverse distances and at varying intensities. Early research investigated the total distance covered by the different positional categories in football *(Reilly & Thomas 1976)*. Midfielders covered the greatest distance, presumably due to the linking role they play between the attack and defence *(Drust et al. 1998)* with wide midfielders covering more distance than central midfielders *(Di Salvo et al. 2009).* Midfielders tended to cover greater distances at lower intensities and may sprint less than strikers and fullbacks. More recent research showed midfielders did not cover significantly greater total distances than players in other positions *(Mohr et al. 2003, Di Salvo et al. 2007).*

Fullbacks cover the slightly less distance during the game than the midfielders *(Di Salvo et al. 2009)* however, some studies showed fullbacks can sometimes cover greater distances than the midfield players *(Mohr et al. 2003).* Strikers and centre backs covered less ground than the other positions *(Bangsbo et al. 1991)*. Strikers performed more frequent high intensity sprints, especially in the form of leading sprints *(Di Salvo et al. 2007).* Centre backs tended to cover the lowest distances and perform the lowest amount of high intensity running *(Drust et al. 1998).*

2.5 Intermittent Training for Aerobic Performance

Numerous studies have been carried out to investigate the role of intermittent training on physical performance in sport in general *(Laursen & Jenkins, 2002, Nubukeli, Noakes & Dennis, 2002, Billat, 2001)* and football specifically *(Bangsbo, 1994, Dupont, Akakpo & Berthoin, 2004).* Players at all levels of competitive football will vary from periods of high energy demand with periods of recovery and lower intensity activity throughout the game. This feature of the game has been well documented *(Little & Williams, 2005, Hoff et al. 2002).* Although simply training and playing without any consideration for improved conditioning has shown to maintain aerobic performance and match involvement, it does not elicit any improvement in overall conditioning *(Helgerud, Hoydal, Wang, Karlsen, Berg, Bjerkaas Simonsen, Helgesen, Hjorth, Bach & Hoff 2007).* The interval nature of football, combined with the desire to improve aerobic performance, suggest some form of intermittent training with varying intensities is crucial for preparation for elite performance.

2.5.1 Time Limitations

As previously stated, footballers must develop physiological, tactical and technical requirements to compete at elite level and to improve. Coaches are therefore challenged by the need to incorporate sufficient training load to satisfy physiological, technical and tactical needs. Paying attention to all requirements requires a blend of both sports sciences and the art of coaching to be successful.

In recent years these physiological demands have increased. The physiological requirements are tied to the tactical requirements coaches' impose on players *(Reilly, 2005).* Players in the English Premier League are required to cover significantly more distance than players in the Old (pre 1992) First Division *(Strudwick & Reilly, 2001).*

During the season, the challenges on time are even greater, at both the elite and sub elite level. Elite players can play as often as three times a week and a greater number of games across numerous competitions. Sub-elite players, such as juniors and female players often must juggle study and work commitments in addition to training and playing commitments *(Polman et al. 2004).*

Therefore it is crucial for the coach and sports scientist to investigate methods of training that will effective develop the physiological needs of the sport in a time efficient manner.

2.5.2 High Intensity Interval Training

The role of high intensity interval training as opposed to, or in conjunction with more traditional methods of developing endurance is an area of interest for many researchers in individual as well as team sports *(Billat, 2001, Franch, Madsen, Djurhuus & Pedersen, 1998).* This interest may be due to the limitation in simply increasing training volume, such as distance covered, on athletes who already have a high training load. Taking into account the plethora of training needs and high playing frequency in professional football, High Intensity Interval Training (HIIT) warrants investigation for improving aerobic power in a time efficient manner.

2.5.3 Maximal Aerobic Speed Training

Maximal Aerobic Speed (MAS) training should be considered as a method of increasing or maintaining aerobic performance for football. Specifically, MAS training involves training at intensity near to, equivalent to, or higher than the speed attained when the participant reached VO_{2max} *(Midgley & McNaughton, 2006).* For instance, if a distance runner achieved his VO_{2max} at a running speed of 18 $km.h^{-1}$, running at a speed higher than 18 $km.h^{-1}$ or higher, would be considered MAS training *(Baquet, Guinhouya, Dupont, Nourry & Berthoin S 2004).* This speed is often referred to as velocity at VO_{2max} (vVO_{2max}) *(Berthoin et al 1992).*

An important consideration with MAS training is how the speed is determined. A number of different methods exist to determine VO_{2max} which can be used to determine MAS *(Berthoin et al 1996).* These may include both field & laboratory tests. Although laboratory tests using gas analysis is generally considered a gold standard for determining VO_{2max}, certain field tests have been shown to be effective at estimating VO_{2max} indirectly *(Berthoin et al 1992).* MAS can be estimated as the last complete speed achieved in an indirect VO_{2max} test *(Berthoin et al 1996).*

The intensity of MAS generally approaches volitional fatigue. It has been suggested that training at intensities greater than 90% of VO_{2maxn}can elicit the greatest gains in aerobic power *(Wenger & Bell*

1986). The greater the time spent training at or around VO_{2max}, the greater the adaptation and improvement in aerobic power *(Tabata, Nishimura, Kouzaki, Hirai, Ogita, Miyachi & Yamamoto, 1996)*. As a result, several studies have looked into determining the ideal intensity duration and recovery periods for this type of training to improve aerobic power (*Billat, 2001, Thevenet, Tardieu-Berger, Barthoin & Prioux, 2006, Dupont, Blondel, Lensel & Berthoin 2002).*

Often MAS-based training sessions are characterized by short durations of very high intensity work, with minimal period of incomplete recovery *(Dupont et al. 2004, Berthoin, Baquet, Manteca, Lensel-Corbeill & Gerbeaux, 1996).* This method requires further research, but may be considered a valid method of training as training at high intensities, rather than a greater duration, may be a more effective method of interval training *(Fox, Bartels, Billings, Mathews, Bason & Webb W 1973, Tabata et al. 1996).*

This method of training is certainly not new and has been documented as effective with elite middle distance runners since the early 1960's *(Billat, 2001)* and more prolonged endurance athletes such as road cycling *(Creer, Ricard, Conlee, Hoyt & Parcell, 2004).* However, the application of MAS-based training in an intermittent sport such is football, has not been widely investigated.

Some of the research on MAS training has varying results. A supra-maximal interval training session was compared with regular endurance training methods to ascertain the effect on anaerobic capacity and aerobic power *(Tabata et al. 1996)*. Both training regimens resulted in significant and similar increases in VO_{2max}. It is important to take into account the total training time required to elicit similar changes, particularly in sports like football, in which time may be a crucial factor in choosing training methods. The intensity of the regimen required athletes to perform at an intensity that equated to their VO_{2max}, which, in turn, elicited a training effect and increased VO_{2max} significantly.

A similar protocol was used to measure the effect of MAS-based training with supra-maximal interval training in professional footballers *(Dupont et al. 2004)*. This research used a regimen of 12 to 15 repetitions of 15 seconds duration with 15 seconds recovery between sprints at an intensity of 120% of MAS for a 10 week period. Earlier research showed that 120% of MAS in short intervals elicited the longest performance a VO_{2max} *(Dupont et al. 2002)*. This protocol lead to improvements in the velocity achieved at $VO_{2max.}$ Interestingly, this study was conducted during the season. Improvement in team performances were observed during the course of the study. In addition, other physiological needs, such as speed and leg power were maintained during the study. This shows that physical characteristics such as aerobic power and MAS can be improved during the season without any decreased in match performance or other physiological areas of importance.

In partial contrast, a study compared distance running (15 km/h 20-30 minutes continuously), long interval training (and shorter high intensity interval training (16.5 km/h, 4 to 6 x 4 minutes with 2 minutes recovery) and shorter intervals (20.4 km/h, 30 to 40 x 15 seconds with 15 seconds of recovery) *(Franch et al .1998).* All three regimens lead to improved aerobic power. However, the distance running group and long interval training groups improved significantly more than the shorter higher intensity training group.

Although there is some mixed research with this type of approach, the time efficient nature of HIIT, based on MAS, warrants further investigation when used with a team sport such as football.

2.6 Summary

Elite football demands a combination of high levels of technical and tactical ability and physiological strengths. One physiological characteristic that is required is aerobic power. Higher performing players, teams and competitions tend to perform more work and have higher levels of aerobic power. It is therefore important to develop and maintain this area of performance.

Taking into account the need for strong aerobic performance in elite level football, combined with the limitations in time to develop all important physiological, tactical and skill qualities, training techniques that are time efficient as well as effective need to be investigated.

This paper will investigate the influence of a MAS based, HIIT regimen on aerobic power, speed, leg power and match performance in elite junior football players.

Chapter 3

METHODS

3.1 Study Design

The aim of this intervention study was to investigate the effect of a supra-maximal interval running program on performance in elite junior (17-18 years of age) football. The study looked at the influence of the intervention on a number of physiological and match performance parameters. The purpose was to determine if a supra-maximal interval-training regimen would have a positive effect on match play and physiological parameters. The selected physiological markers were maximal aerobic power, leg power, and sprinting speed over 20 metres.

3.2 Study Timeline

The testing and training of this study was conducted over an 8-week period. The initial testing period was scheduled over the first two weeks of the study. Physiological data were collected first, followed by match analysis data. Match data was collected during three competitive games. The team played in the Victorian Premier League competition, based in Melbourne Victoria, Australia.

A four-week controlled intervention period followed game analyses. The high intensity interval training required participants in the experimental group to perform training sessions three times a week. The control group participated in a simple skill activity for the same period of time as the HIIT undertaken by the experimental group. Intervention sessions occurred every Tuesday, Thursday and Saturday morning prior to usual training sessions.

The intervention was followed by a second testing period. Post-intervention physiological testing and match analyses of a further three games took place in this second period as well as a debriefing for the participants and coaches of the program.

3.3 Sample Strategies & Recruitment Techniques

3.3.1 Selection Criteria

Participants were selected from the Australian Institute of Sport's (AIS), national elite sports academy. The AIS program is the only elite full-time football program for players of this age in the nation. It is the training base for the Australian under-20's men's football program. Coaching staff for the 2009 national U/20 program were based at the AIS.

The cohort was selected for a number of reasons. The AIS is a residential program in which the players live and train in the one facility and therefore are available on a full-time basis. Logistical problems such as travel and unavailability of athletes would therefore be minimised. The intervention would have a negligible impact on normal training activities and weekend games. It would also be very simple to standardise the training load of all players in the study.

The AIS Men's football program is an elite junior program. Players are selected on a multi-year scholarship. The cohort was of a very high playing and athletic standard. To be offered a scholarship in the AIS football program players were expected to meet fixed athletic standards during a controlled and standardised testing regimen. The players had experienced these testing procedures several times before the commencement of the experiment.

In addition to these factors, it was felt that such a group would be fairly homogenous in terms of experience, playing level and athletic development. Recruitment of such a large group of players with minimal differences in physical characteristics, playing standard, playing experience and high athletic ability would be highly unlikely outside of setting of the Australian Institute of Sport.

All participants had a minimum of two years experience in an elite training environment, having been selected from state football academies. Selection in both the AIS and the state academies required players to gain satisfactory standards in physiological and medical testing. Thus, pre-existing medical or injury issues would have been addressed prior to selection in the national squad. Access to reliable knowledge of injury status or medical conditions increased the likelihood of players completing the study with minimal interference or difficulty. The physiotherapist and doctor of the team could be referred to easily during the intervention without any clashes of opinion that might occur if the cohort were drawn from a number of programs or teams.

3.3.2 Exclusion Criteria

Exclusion criteria were designed as part of the study methodology. Participants were excluded from the study for failing to meet any of the following three criteria:

Any athlete with a recurrent injury over the 21 days preceding the study was excluded from the recruitment phase of the study. Exclusion on the basis of injury was based on the diagnosis and prognosis made by the team's physiotherapist and doctor prior to the beginning of the testing period. However, players injured in the 21 days preceding the testing period, but returning to full training and deemed capable by the physiotherapist and doctor was included in the cohort.

Any player who had suffered an illness in the 14 days preceding the testing period requiring players to miss more than 48 hours of organised team training. The team's doctor, based at the AIS determined exclusion from the cohort on the basis of illness.

Failure to complete a minimum of 11 training sessions, testing sessions resulted in exclusion from the study. It was determined that due to the difficult nature of in-season testing, a small amount of lee-way would be given for missing at least one training session. One extra training session could be made up at the end of the study, as long as it was performed within 48 hours of the final training intervention session. Therefore, a player could conceivably complete 10 training sessions, complete one extra session within 48 hours of the completion of the study to make up and 11th session, and remain in the study.

All players in the squad continued normal training activities including games, skills training, tactical sessions and weight training activities. Players who failed to continue with normal training activities for other reasons (e.g. school, suspension from playing, discipline issues) were excluded from the study. The lead researcher on the project determined if a player was excluded from the study on the basis of non-compliance.

In addition to the three criteria for exclusion, participants were informed of their right to withdraw at any time if they felt uncomfortable with the study. However, players were encouraged to make every effort to complete the study as required. Involvement in research projects deemed appropriate and subject to joint AIS/university ethics approval, was part of the athlete scholarship agreement at the AIS.

3.3.3 Selection of study site

The study was conducted at the Australian Institute of Sport campus in Canberra, A.C.T Australia. The AIS campus was the regular training venue for the squad.

Training sessions for the intervention portion of the study occurred on an indoor soccer field, especially designed for the AIS men's football program. The surface was an artificial turf known as *Magic Carpet (Astroturf, Dalton Georgia).* The same surface was used to conduct pre and post intervention testing.

The choice of the indoor field to conduct the study was made for a number of reasons:

1. The surface remained constant and would not negatively deteriorate during the intervention period.
2. The indoor training field was permanently marked and prepared for the pre and post intervention field-testing. This ensured accurate physiological testing and training.

3. The sessions remained unaffected by extreme weather conditions such as uncomfortable heat or cold.
4. The indoor field could be climate controlled to ensure constant air temperature, humidity and barometric pressure.
5. The squad regularly used the indoor surface and were familiar with the surface and conditions therein.

In addition to the advantages of the training surface for the study, the venue for the intervention was housed next to the AIS Sports Science Sports Medicine Building. This ensured that the training intervention could be monitored and medical assistance was directly and reliably accessible during the training sessions, in case of injury. A fully equipped and staffed First Aid station was also available within the building that housed the training venue.

3.4 Recruitment process

All players attended a meeting at which they were informed of the purpose of the study. Players were also provided with a written copy of study design and procedures for their consideration at the time of the meeting. The head coach and lead researcher explained the study design with additional questions being answered by the researcher. Pre and post testing procedures, including physiological testing and match analysis were outlined in the document provided to the potential study group (Appendix 3). Potential benefits from physiological and match performance analyses of the study and the study intervention were outlined to ensure the players were well informed of the study's demands, procedures and expectations.

Players were informed that participation was not mandatory and their position in the academy would not be in question if they chose not to take part. The squad was informed by the coaching staff and the lead researcher separately to ensure they understood that there were no consequences if they chose not to be involved in the study.

At the completion of the meeting all members of the squad were provided with a written consent form and given two days to consider their involvement in the study. All potential participants were given the opportunity to approach the lead researcher as well as the AIS coaching staff during the two days if they had any questions.

Two days after the initial meeting, a second meeting was held. Any further questions were answered and the squad was formally invited to take part in the study. Players wishing to take part in the study completed and returned their written consent form at this meeting. Squad members under the age of 18 were given extra time as written permission was required from parents or guardians before younger players could participate.

3.5 Sample Size

A sample size of between 10 and 16 players in each group will permit the detection of a significant difference in the mean of the aerobic power improvement of between 0.75 and 1.00 standard deviations higher than the mean value for the control group (power = 80%, significance = 0.05) *(Peat, Williams, Xuan & Mellis, 2001).* Sample size calculations also incorporated a 90% compliance rate over the 6 weeks of the study based on previous training history records of soccer squads at the AIS.

3.6 Ethics Approval

The study was to be conducted jointly through the Australian Catholic University and AIS. Therefore, ethics approval was formally sought and obtained from the Ethics Committee of both institutions.

3.7 Current Training Load

The study was conducted during the competition period of the season for this team. This was considered an essential part of the study, as little is known about in season training and football at a high level. A typical weekly training plan can be seen in Table 3.1. Every effort was made to standardise training throughout the study period, with minimal variation from the typical weekly training program. Coaching staff agreed to keep training volume and intensity as similar to previous training volume as possible.

The squad had been in training in situ for 4 months prior to the beginning of the study. As a result the typical training week, approximate intensity and activities of each session had been developed and determined prior to the beginning of the study. This was done to minimise potential contamination of the study in normal training activities. Slight variations occurred due to games being played on a Saturday or Sunday.

Table 3.1: Typical training week for the entire study cohort

Day	AM Training	Time	PM Training	Time
Monday	Positional training	45 min	Team training	90 min
Tuesday	INTERVENTION	10 min		
Tuesday	Weight Training	45 min	Team Training	90 min
Wednesday	Positional training	45 min	Team training	90 min
Thursday	INTERVENTION	10 min		
Thursday	Weight Training	45 min	Team Training	90 min
Friday			Team Training	90 min
Saturday	INTERVENTION	10 min		
Saturday	Weight Training	45 min		
Sunday			Game	90 min

3.8 Selected field based tests

3.8.1 Anthropometric Data

Pre and post intervention anthropometric data were collected prior to the physiological data collection. The anthropometric protocol set out by *Olds & Norton (1996)* was selected. However, the protocol was modified to comply with common testing practices used in this cohort of players.

3.8.2 Physiological Data

The testing battery conducted was the same as the one routinely used with the cohort as a part of regular training. The three tests that were used were as follows:

- Counter-movement jump
- Sprint time over 5-10-20metres,
- Multi-stage shuttle run test.

A standardised warm up with which the players were already familiar was conducted prior to the first test in the battery.

3.8.2.1 Counter-movement Jump

The players were familiar with the counter-movement jump technique prior to the pre-testing date. The test was carried out in accordance with the Australian Institute of Sport, National Sports Science Quality Assurance protocol *(Ellis, Gastin, Lawrence, Savage, Buckeridge, Stapff, Tumilty, Quinn, Woolford & Young (2000) Appendix 1).*

The vertical jump was the first test in the battery. As a test of maximal lower body power, this test is normally carried out first in the testing regimen. The vertical jump was conducted using a Yardstick jump testing device (*Swift Sports, Lismore, Australia*). Players were made aware of the protocol for the sprint test prior to testing being carried out.

A countermovement jump technique was utilised in this battery. The tester assisted the players to determine “maximum reach height” before commencing the test. Using the preferred hand, the player stood under the device and reached as high as possible. The tester ensured the players were standing at maximally height, reaching with a straight arm and outstretched hand and did not retract the scapula in an effort to reduce the reach height attained.

To determine "maximal jump height" the players were instructed to make a fast counter-movement action, then jump maximally, swinging the arms for maximal benefit and reaching as high as possible. The players attempted to jump as high as possible and touch the veins on the device (1 cm apart). Each player was given three attempts at the counter movement jump with enough rest in between jumps as they required to give a maximal effort.

The distance between the reach height and the maximal jump height attained was determined to be the player's countermovement jump. The peak height of the jump was recorded in cm. Each player completed the three trials of the test with verbal encouragement from coaches, researchers and other players. The mean and the peak value were both recorded as the player's score. Countermovement jump height was determined by subtracting the maximum standing reach height from the maximum countermovement jump height obtained.

3.8.2.2 20 metre Sprint Time

Players were familiar with the 20m-sprint test protocol prior to the pre-testing date. The test was conducted in accordance with the Sprint Test, Australian Institute of Sport Protocol Manual*, (Ellis et al 2000, Appendix 1).*

The sprint test was the second test in the battery, following a standardised 10 minute break after completing the vertical jump. Each player lined up at the start, with electronic timing equipment *(Swift Acceleration, Lismore NSW)* and markers placed at 0, 5, 10 and 20 metres. A standing start was used. Players were allowed to decide the foot they placed forward when starting the sprint.

When the player was ready, he performed a maximal sprint over the 20 metres. No starting signal was supplied. A marker was placed at 22 metres and the players were instructed to sprint to this marker as opposed to the timing gates at 20 metres. This was done to ensure the players did not slow down prematurely. Each player completed three trials of the test with a standardised break between efforts and verbal encouragement from coaches, researchers and other players.

If the player broke the starting beam prior to starting or one of the timing lights failed to function, the player was given a further trial. In addition, if a player moved his weight from the front foot to the back foot prior to the start of the sprint, he was instructed to stand up and perform the start again. Players rested while the rest of the group completed their trials. The group was instructed to actively recover and not sit down between efforts. Data were recorded in seconds.

3.8.2.3 Multi-Stage Shuttle Test

Players were familiar with the 20 m-sprint test protocol prior to the pre-testing date. Testing occurred in accordance with the Australian Institute of Sport Multi-Stage Run Test protocol *(Ellis et al 2000, Appendix 1).*

The test starts with the players lined up at the end of a 20 metre running track. The track was permanently marked in the testing hall. On the signal (in the form of a loud audible 'beep') the players ran forward at a set speed of approximately 8 km/hr. On the next signal, the players ran back to the start. Approximately every minute the speed increased by 0.5 km/hr and the players had to reach the other end of the running track at the same time as the next signal. The players continued until they could no longer keep pace with the running speed required to stay with the beeps. The final result was last level successfully reached.

Some controversy remains over the validity and reliability of the Multi Stage Shuttle Test as a test of aerobic power for football *(Svennson & Drust 2005)* while other studies have supported the validity of the test *(Aziz, Tan, Yeo & Teh 2004, Berthoin et al 1996).*The MSST *(Leger & Lambert 1982, Leger et al 1988)* was ultimately selected over other tests of aerobic power for four reasons:

- The players were familiar with the MSST protocol, having used it as part of selection criterion and training methodology over a number of years. The MSST was therefore more likely to be an accurate measure of aerobic power *(Lamb & Rogers, 2007)*.

- Due to the size of the group and relative need for expediency, the MSST allowed the entire cohort to be testing at one venue, at the same time.
- The MSST, as an indirect estimation of VO_{2max} as opposed to other tests such as a time trial which does not give a defined final speed.
- The nature of the test and predetermined speeds of each level permitted the researchers to easily use the results to determine MAS target-training goals during the intervention period.
- The intervention training sessions was designed around the same 20 metre out and back shuttle protocol used in the MSST.

3.9 Selected game based notational analysis

Game-based data were used to collect match data and included the distance, speed and spacing of movement around the field during the game. During three competitive games, players wore a Global Positioning System (GPS) *(Catapult Mini-Max Team Sport v.2.0, Australian Institute of Sport, Canberra Aust).* The GPS units had a sampling rate of 5Hz, and included 3D accelerometers operating at 100Hz. The GPS unit was worn at the top of the spine in a specially designed pouch to maintain comfort and minimise movement of the GPS unit. The units were specifically designed for use in team sports. The GPS units were used to collect match data, which were then divided, into separate data sets. The units had been worn on several occasions prior to the testing period in games and in training. The players were very familiar with the units

A number of different measures were collected using the GPS information. These data are listed in Table 3.2:

Table 3.2 Categories & definitions of data collected from GPS analysis

Data Collected	Definition
Total distance	Total distance covered, regardless of movement speed
Meterage	Average meters covered per minute
High intensity running (distance)	Distance covered at a speed greater than 16 km/h
High intensity running (percentage)	Percentage of total distance covered at a speed greater than 16 km/h
High intensity efforts	Number of instances a player runs at a speed greater than 16 km/h
High intensity running (frequency)	How often an instance of high intensity running takes place
1st	Any of the above measures, 1st half only
2nd	Any of the above measures, 2nd half only
Difference	Comparison of any 1st and 2nd half measures
1st 15 minutes vs. last 15minutes	Comparison of the 1st 15minutes of the game and last 15 minutes of the game using any measure

All 10 field players wore the GPS unit during the game. Goalkeepers were involved in the physiological part of the study however, no match data were collected.

3.10 Intervention

The cohort was randomly assigned to one of two groups for the study intervention. Although players could not be blinded to the group allocation, research assistants analysing game data and assisting with testing were blinded to the groupings of players.

3.10.1 Experimental Group

Although not the ideal 25 players required for powering the study, within the context of available participants, nine players were assigned to the experimental group. The experimental group attended three training organised sessions per week. An initial familiarisation session was conducted prior to the first monitored training session. Training was conducted on the same indoor synthetic training surface on which pre-intervention physiological testing was conducted.

Each training session commenced with a standardised warm up. The warm up comprised:

- Three minutes light jogging over a 35 metre out-and-back track to start to increase core temperature.
- Commonly used low intensity exercises over a 20 metre out-and-back track to increase mobility and continue to increase core temperature. The players were familiar with the warm up drills as they had been a standard part of the training program. Drills used included jogging, skipping, sideways running, carioca, tail kicks, high knee running and skipping with various leg and hip angles. Players were familiar with these techniques.
- Two minutes of self directed short duration static stretching exercises was performed.
- Dynamic stretching exercises were also performed five times per side and held for two seconds at the end of the range of motion. A smooth action was used throughout each movement. Exercises used included walking lunge, side lunge, walking hamstring stretch, walking quad stretch & walking gluteal stretch. Players were familiar with these techniques.
- Two repeats of 10 second running efforts at approximately 75% of the nominated running speed for the intervention, with a 30 second rest between efforts.
- Players were given two minutes of time to prepare for the beginning of the intervention training session.

3.10.2 Training Session

Each training session consisted of a series of 15 second efforts over a 20 m out-and-back shuttle course. On the start command, the experimental group sprinted as hard as possible, performing a one foot turn at each end of the 20 m shuttle course. On the command stop, the experimental group ceased running and returned to the starting line. The group had 15 seconds rest before commencing the next repetition.

The experimental group followed a protocol as outlined in Table 3.3. The intervention period involved three sessions per week over a four week period for a total of twelve training sessions. Sessions were conducted on a Tuesday-Thursday-Saturday schedule throughout the four weeks.

Table 3.3 Intervention protocol for the experimental group

Sets	Reps/set	Time per rep	Rest between reps	Rest between sets	Intensity
2	8	15 seconds	15 seconds	2:15 minutes	120% of V_{20MST}

It has been premised that the MAS speed obtained in the MSST will be lower than a vVO_{2max} score achieved in the laboratory or track based test such as the University of Montreal Track Test (*Berthoin et al 1992*). However as the training intervention would take place over the same 20 metre track as the MSST, the distance was not adjusted as has been recommended for MAS intervals based on a MSST assessment when training is conducted on a straight line *(Gerbeaux, Lensil-Corbiel, Branly, Dierkens, Jacquet, Lefranc, Savin & Savin 1991).*

3.10.3 Target Distance

Each player had a set distance to cover in the 15 second time for each shuttle repetition, based on the final speed they obtained in the Multi-stage Shuttle Test. The test begins at 8.5 km/hr and increases by 0.5 km/hr with each subsequent level (*Leger et al 1988*). The target distance for each player was determined by multiplying the final successfully completed speed obtained (V_{20MST}) in the Multi-Stage Shuttle Test by 120%. This was then converted to a set number of 20 metre shuttles the players had to achieve. The players' goal was to reach the target distance on each of the 16 repetitions they performed per session.

3.10.4 Control Group

After the completion of the standardised warm up, the control group would perform a time-matched juggling activity with a tennis ball. The control group juggled a tennis ball at the same time the experimental group performed the intervention. The control group used the same sets, repetitions, duration and work to rest ratio as the experimental group.

3.11 Statistical analysis

3.11.1 Normal Distribution

Parametric variables at baseline level were tested for normality. Variables were considered normally distributed if; less than 10% difference was observed between the mean and median values, the doubled standard deviation was less than the mean, skewness and kurtosis scores were within the range of -1.000 to 1.000, skewness and kurtosis scores divided by their corresponding standard error had values less than 1.96 and p values greater than 0.05 were observed in the Kolmogorov-Smirnov test for normal distribution *(Peat & Barton, 2005).* Baseline data were considered non-normally distributed if three or more breaches of the above criteria were observed.

3.11.2 Independent T-Tests

A series of two-sample *t*-tests (two tailed) were used to detect any baseline differences between groups. Similar tests were used to compare results from dependent variables (physical testing and descriptive subject data) in the two groups (experimental and control) between the pre and post phases of the intervention study. Results were reported as means and standard deviations.

3.11.3 Effect sizes and confidence intervals

To assist in understanding the magnitude of observed differences between groups, effect sizes and confidence intervals were also calculated for physical testing results *(Hopkins 2003).* The magnitudes of differences between groups were expressed as standardized mean differences (Cohen effect sizes: difference in means divided by the between-subject standard deviation). The criteria to interpret the magnitude of the effect sizes were: <0.2 trivial, 0.2-0.6 small, 0.6-1.2 moderate, 1.2-2.0 large and >2.0 large (*Batterham and Hopkins, 2006*).

3.11.4 Non-parametric testing

In the case of data failing to meet requirements for normal distribution, non-parametric tests were conducted. Specifically, median and inter-quartile ranges were reported following Mann Whitney *U* tests for game statistics data and collective (whole group) match analysis data.

Chapter 4

RESULTS

4.1 Participant Information

Twenty-five players undertook the pre-testing stage of the study. Six players were removed from the study due to injury, non-playing status, or inability to participate due to the hardness of the surface. Nineteen players were available to take part in the study. Two of the participating players were goal keepers, who were used for the aerobic power component of the study. Specifically, goalkeepers were excluded from the game analysis component of the study. Player information is outlined in Table 4.1

Table 4.1 Descriptive characteristics of players in the study

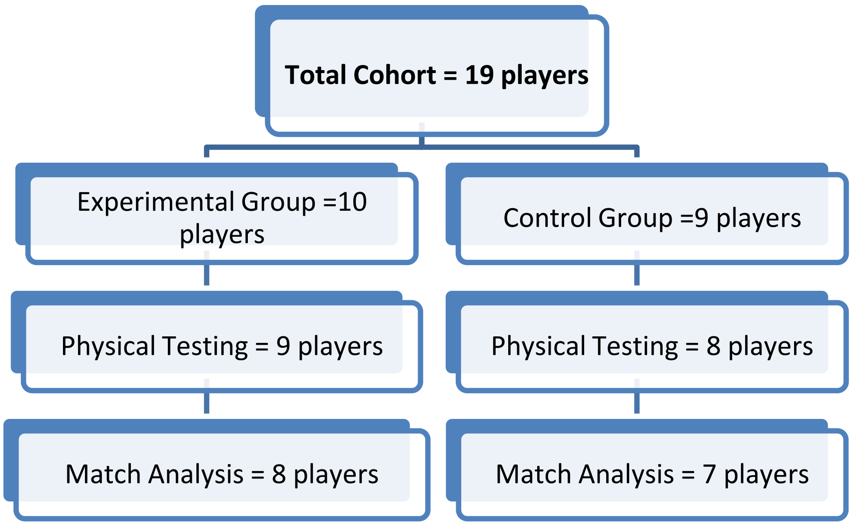
Data Field	Experimental Group	Control Group	p-value
Age (years)	17.84 (+/-0.34)	17.74 (+/-0.52)	0.63
Height (cm)	183.54 (+/-3.68)	181.50 (+/-9.04)	0.56
Weight (kg)	77.93 (+/-7.67)	71.73 (+/-6.18)	0.08
Skinfold (mm)	50.71 (+/-3.74)	52.11 (+/-8.90)	0.69
Aerobic Power (ml/kg/min)	57.16 (+/-2.89)	58.95 (+/-7.58)	0.18

4.2 Group Determination & Player Drop Out

Players were randomly assigned to experimental and control groups. Random allocation was stratified based on beep test results. (MSST) also one goalkeeper was included in each group. Ten players were included in the experimental group and nine in the control group. Independent t-tests were used to ensure parity between the groups at the commencement of the study.

The participant flow map is shown in Figure 5.1. The goalkeepers were eliminated from the match analysis component of the study. One player from each group dropped out due to non-training related impact injuries occurring during matches that precluded them from participating in the training sessions. The remaining seventeen players completed the whole study and took part in at least one game in the pre or post match analysis periods.

Figure 4.1 Progression of player drop out from the study.



4.3 Physical Performance Test Results

Testing was conducted over a two week period before and after the intervention period. Physical testing was undertaken eight days prior to the first training session. After a standardised warm up, the players completed a fixed sequence of testing involving the vertical jump, 20 metre sprint time and finally, a multi-stage shuttle run test. All players had completed the testing schedule on two previous occasions and therefore were fully familiar with the procedure of each test. Results from the physical performance tests conducted pre and post intervention are shown in Table 4.2.

Table 4.2 Results of physiological testing protocols.

Control Group	**Aerobic Power**	**Vertical Jump**	**20 m sprint**
Pre-test	58.95 (+/-2.58)	59.50 (+/-4.43)	3.01(+/-0.06)
Post-test	58.33 (+/-4.05)	58.88 (+/-5.28)	3.05 (+/-0.04)
Mean Difference	-0.65	-0.63	0.04
Standard Deviation	2.71	4.90	0.07
Percentage change	-1.06%	-1.04%	+1.33%
Experimental Group	**Aerobic Power**	**Vertical Jump**	**20 m sprint**
Pre-test	57.19 (+/-2.89)	60.00 (+/-3.48)	3.05 (+/-0.10)
Post-test	59.50 (+/-2.77)	60.78 (+/-2.30)	3.03 (+/-0.09)
Mean Difference	2.78	0.78	-0.02
Standard Deviation	1.39	2.33	0.03
Percentage Change	+4.04%	+1.3%	+0.64%
Between Group Differences	**Aerobic Power**	**Vertical Jump**	**20 m sprint**
P-Value	0.0089	0.382	0.0682
Effects Size	1.22	0.51	0.72
90% Confidence Intervals (lower)	1.5	-2.0	-0.12
90% Confidence Intervals (upper)	5.4	6.0	-0.01

A 4.04% improvement was observed in aerobic power for the experimental group and a 1.06% decrease in aerobic power for the control group. This represented a significant change between groups ($p<0.0089$). With a Cohen's *d* effect size of 1.22, the impact of the intervention could be described as large. In field-based terms, this improvement translates to an average increase of 160 metres or 8 extra shuttles on the Multi-Stage Shuttle Run test *(Leger & Lambert 1982)* following the intervention.

Non-significant changes in vertical jump and sprint time over 20 metres were observed between the experimental and control groups ($p>0.05$).

4.4 Match Analysis Results

Match analysis data were collected via GPS analysis in three games prior to, and three games post the intervention period. A number of different movement variables were derived from the available software. Match analysis data were divided into four primary categories, and then further divided into other sub-categories (Table 3.2 in the Methods Chapter).

The results of the match analysis via GPS are shown in Table 4.3. The same players were not available for both pre and post intervention game data collection due to varying line-ups, substitutions and playing times that could not coincide with the study. Therefore, independent rather than paired T-tests were used in bivariate analyses of the experimental and control groups.

No significant differences were observed between the experimental and control group in any of the GPS derived match-based measures. One measure (1^{st} vs. 2^{nd} half high intensity running distance) showed trends towards significance (p = 0 .077) in favour of the control group.

4.5 Collective Match Analysis Data

The data collected for match analysis were collated to examine possible changes across the entire cohort from the initial to the post testing periods. The developmental nature of the squad could have meant that all players were improving on a weekly basis. These data are detailed in Table 4.4.

Several significant changes occurred across the entire cohort. An 11.6% increase was observed in the metres/min covered in the first half and a 15.1% increase in metres/min covered in the 2^{nd} half, both of which were significant. Despite the increase, the 1^{st} to 2^{nd} half difference was significantly greater for the combined group after the intervention and increased by 9.5 metres/min. A significant increase was also reported in the difference between the 1^{st} 15 minutes of play and the final 15 minutes of the game, increasing by 10.3 metres/min. Effectively the increase in meters covered per minute in the first half was greater than the increase in the second half.

A 50% (500 metre) increase was also observed in the amount of high intensity running occurring during monitored matches' pre and post intervention. Additionally, 16 more high intensity efforts were apparent across the combined group before and after the intervention. Both these changes were significant.

Collective match analysis data that were not normally distributed are included in Table 4.5

Table 4.3 Results of GPS data analysis

Measure	Experimental Pre Median & interquartile	Experimental Post Median & interquartile	Control Pre Median & interquartile	Control Post Median & interquartile	Mann-	Asymp.
Distance (total Game)	10530 m (1094 - 11670)	10708 m (10148 – 11915)	10820 m (10046 – 11225)	11540 m (10940 – 11670)	22.5	0.416
Distance (1st half)	5362.5 m (4937 – 5500)	5894 m (5650 – 6438)	5438 m (5082 – 5624)	6073 m (5795 – 6147)	55.0	1.0
Distance (2nd half)	5143 m (4881 – 5425)	4751 m (4507 – 5291)	5237 m (4823 – 5639)	5489 m (5178 – 5577)	12.0	0.077
Distance Difference	-12.5 m (-93.3 – 100.8)	548 m (338 – 724)	341 m (107 – 488.4)	662 m (211.9 – 906.5)	30.0	0.874
Distance 1st 15min vs. 6th	137 m (113.5 – 209.5)	360 m (183.3 – 524.8)	213.5 m (67.3 – 261.5)	313 m (114.3 – 401)	21.0	0.699
meterage (total game)	114.7 m/min (109.1 – 121.4)	120.1 m/min (108.2 – 127.6)	122 m/min (107.5 -125.5)	126.8 m/min (121.4 – 131.9)	19.0	0.186
Meterage 1st half	118.6 m/min (109.5 – 122.4)	136 m/min (128.9 – 143.8)	120.9 m/min (113.2-125.2)	134.9 m/min (128.7 – 136.6)	47.0	0.573
Meterage 2nd half	109.5 m/min (108.7 – 120.8)	124.6 m/min (115.8 – 132.4)	118.8 m/min (107.5 – 125.5)	129.7 m/min (121.4 – 131.9)	22.0	0.556
Meterage difference	0.2 m/min (-2 – 3)	12.5 m/min (8.8-15.8)	5.5 m/min (-0.8 – 8.5)	8.6 m/min (4.6 – 20.2)	25.0	0.814
Meterage 1st 15min vs. 6th	13.9 m/min (8.3 – 14)	34 m/min (19.1 – 35.5)	8.2 m/min (4.1 – 13.8)	24.7 m/min (21.8 – 26.8)	24.0	0.427
High Intensity Distance	1022 m (856 – 1082)	1578 m (882 – 1262)	1004 m (1321 – 1670)	1518 m (1295 – 1954)	44.0	1.0
High Intensity efforts	74 (61 – 86)	87 (78 – 95)	69 (63 – 75)	83 (75 –95)	48.5	.647
High intensity % total	10.6 % (9.3 – 11.6)	13.4 % (12.1 – 16.7)	8.6 % (8.5 – 9.8)	13.9 % (11.4 – 15.1)	46.0	.526
High intensity frequency	76 sec (63 – 95)	87 sec (55 – 64)	69 sec (71 – 91)	83 sec (57 -72)	50.0	.724

Table 4.4 Results of combined groups' GPS data analysis

	Pre Intervention Mean & standard deviation	Post Intervention Mean & standard deviation	Mean Diff	Sig	Lower Confidence Levels (90%)	Upper Confidence Levels (90%)
Distance (total Game)	10279 m (+/-940)	11276 (+/-878.2)	3.89	<0.001*	5.785	1.99
Distance (1st half)	5274 m (+/-427.7)	6017 (+/-551.5)	741.81	<0.001*	1049.63	434.00
Distance (2nd half)	5116 (+/-616.4)	5233.3 (+/-503.8)	117.08	.569	532.28	298.12
Distance 1st 15 min vs. 6th	173.8 (+/-100.8)	295.6 (+/-261.8)	67.43	.081	259.70	16.13
Meterage (total game)	114.9 (+/-10.1)	121.7 (+/-9.8)	6.80	0.063	13.99	0.39
Meterage 1st half	117.1 (+/-9.4)	134.9 (+/-11.9)	17.79	<0.001*	24.37	11.21
meterage 2nd half	113.7 m/min (+/-11.1)	126.9 m/min (+/-9.4)	13.20	<0.001*	20.69	5.71
meterage difference	2.6m/min (+/-5.2)	12.1 m/min (+/-9.1)	9.47	<0.001*	14.77	4.17
meterage 1st 15 min vs. 6th	10.7 m/min (+/-6.1)	22.0 m/min (+/- 20.6)	12.24	0.026*	22.87	1.6
High Intensity Distance	1045.8 m (+/-305.7)	1568.5 m (+/-403.5)	3.89	0.001*	5.79	2.00
High Intensity efforts	69.8 (+/-16.4)	85.9 (+/-16)	12.24	0.026*	22.87	1.60
High intensity % total running	9.98% (+/-2.4)	13.9 (+/-2.9)	3.89	<.001*	5.785	1.99

- * Indicates significant difference between pre intervention and post intervention.

Table 4.5 Results of non-parametric collated GPS data analysis – combined groups

Measure	Pre Intervention Median & interquartile	Post Intervention Median & interquartile	Mann Whitney	Asymp Sig
Distance Difference	114 m (-46.3 – 380)	605 (318.5 – 906.5)	3.89	0.362
High Intensity Frequency*	83 sec (66 – 93)	64 sec (56 – 70)	741.81	0.005*

- * Indicates significant difference between pre intervention and post intervention.

Chapter 5

DISCUSSION

5.1 Review of Aims

The study had three aims. The first aim was to evaluate the effectiveness of a short-term supra-maximal interval training intervention on aerobic power on elite junior footballers during the competition phase. High intensity interval training (HIIT) was defined as "relatively brief, intermittent periods of muscle contraction often performed with an "all-out" effort or at an intensity close to that which elicits peak oxygen uptake" (*Gibala, 2009).* Although research into this form of training is not new *(Christensen, Hedman & Saltin 1960, Fox et al. 1973)*, there is not a large amount of non-laboratory based research into the practical applications of interval training on aerobic power during the competition phase of a season of a team sport.

The second aim was to determine the effects of the training intervention on a number of high intensity running measurements collected during competitive matches. These measurements were taken during competitive performances in games pre and post the four week training intervention period. Physical loading in competitive games has previously been investigated (*Di Salvo et al. 2009, Mohr et al. 2003, Bangsbo et al. 1991*). However, few studies have used game data from open chain sports such as football to evaluate the effect of a training intervention on performance *(Dupont et al. 2004).*

The third aim was to collect match data to better understand the physical demands of football on players aged less than 18 years. Match statistics are routinely collected at many levels of participation *(Stolen et al. 2005).* However, few studies in cite the use of GPS technology *(Carling et al. 2008, Barbero-Alvarez et al. 2009)* for analysis. Subsequently, one of the aims of this study was to use GPS technology to compare the physical demands of players at this level with existing information on physical performance in football. The areas of match performance investigated were distance covered, high speed running, and average meterage (metres covered per minute). Possible comparisons of match data included between total game, first half versus second half, and first 15 minutes of the game, versus last 15 minutes of the game.

5.2 Major Finding One: Aerobic power improvement

A 4% improvement occurred in aerobic power for the experimental group over the control group following the HIIT intervention. No change in aerobic power performance was observed in the control group in this investigation. The improvement was achieved using 12 bouts of 10 minutes training sessions (3 sessions per week) over 4 weeks. The HIIT represents a much lower time commitment than traditional training methodology to improve aerobic power (*Tabata et al. 1996*). These results are supported by similar research into supra-maximal interval training methods *(Tabata et al. 1996, Owen & Wong 2009, Dupont et al. 2004, Fox et al. 1973).*

A number of factors may explain the observed improvements in performance in the aerobic power test in the experimental group. One factor is the increased time spent training at or around the players' VO_{2max}. Previous studies show supra-maximal training, forces players to perform for an extended period of time at intensity similar to VO_{2max} *(Tabata, Irisawa, Kouzaki, Nishimura, Ogita, & Miyachi, 1997, Dupont et al. 2004).* The highest adaptations in aerobic power are postulated to occur at intensities ranging from 90 to 100% of VO_{2max} *(Wenger & Bell, 1986).* Supra-maximal intervals also result in greater training time spent training at intensities above 90% of VO_{2max} *(Dupont et al. 2002).* Training at approximately 120% of $VO_{2max}$and intermittent high intensity interval runs were more effective for maintaining intensities above 90% VO_{2max}than continuous efforts *(Dupont et al. 2002, 2004).* Intervals of 120% VO_{2max}were also used in the current study. The findings of improved aerobic power following HIIT in the current research has been previously supported *(Laursen & Jenkins, 2002, Billat, Flechet, Petit, Muriax & Koralsztein 1999, Tabata et al. 1996, 1997, Helgerud, Engen, Wisloff & Hoff 2001).* The improvement in aerobic power in the current study occurred in association with a very brief and short duration high intensity training regimen that may be attractive to sports scientists who have limited contact time with athletes.

The current study used velocity at estimated VO_{2max} (V_{20MST}) to determine the distance for each player to cover in each interval. This methodology helps to ensure the athletes perform at intensity near to their individual VO_{2max} *(Laursen & Jenkins 2003).* The use of V_{20MST} is a popular method for this form of higher intensity training and has proven effectiveness *(Tabata et al. 1996, 1997, Billat V et al. 1999, Denadai, Ortiz, Greco & de Mello, 2006, Baquet, Guinhouya, Dupont, Nourry & Berthoin, 2004).* It could be assumed that the use of V_{20MST} in the current study allowed players to maintain intensity close to the estimated VO_{2max} for the majority, if not all of the 16 intervals per session.

Intervals based around time spent at VO_{2max} have been found to be an effective training measure to determine training intensity and improve aerobic power. The effect of a regime using 12-15*15 sec intervals at 120% of VO_{2max} twice a week during the season was studied *(Dupont et al. 2004).* Participants also performed repeat efforts over 40 m at all out intensity. The major similarity between this study and the current research was the 'in-season' phasing of the training. Both studies showed an improvement in aerobic power and no negative effect on other performance measures as well as no negative effect on match performance. Both studies would indicate that high intensity interval training is effective for improving aerobic performance during the season in a short period of time with minimal time requirements.

Preliminary research into HIIT compared short, high-intensity intervals with low intensity longer duration interval training and a combination of the two methods (*Fox et al. 1973*). This study showed improvements in VO_{2max} performance for the shorter interval higher-intensity group and the combination group but not the lower-intensity, longer duration group. The results suggest that training intensity was more fundamental to improvement in aerobic power than training duration.

The current study used a supra-maximal training intensity based on V_{20MST} to advance aerobic power and therefore the results are in agreement with the work of earlier researchers.

An age effect may exist in reference to using this form of training to improve aerobic power. Some studies have showed positive effects of HIIT training using vVO_{2max} to determine running velocities in children *(Baquet et al. 2004, Berthoin et al. 1996).* In these studies the improved running velocity appeared to be greater in the younger athletes and the improvements decreased as the participants became older *(Berthoin et al. 1996).* The participants in the age-related study were no older than 17 or age. The players in the current study were 17 and 18 years old and may have been more trainable than older players. Moreover, intervals at 95% and 100% of VO_{2max} in well-trained adults (average age 27.4), showed a number of measures (such as blood lactate and time trials) were improved by supplementing regular training with HIIT, but not aerobic power *(Denadai et al. 2006).* This may indicate that the players in the current study were developmentally ready for the greatest response to this type of training for improving aerobic power. Results from the current study may also indicate that greater improvements would have been possible in a younger group of subjects. Age-related responses to interval training are infrequently observed in existing literature.

A benchmark study on the effects of a six week regimen required the HIIT group to complete 8*20 second intervals at 170% of the power output at VO_{2max} with 10 seconds rest. Results were compared with a group exposed to a traditional aerobic training regimen of 60 minutes at 70% of VO_{2max} over the same time period *(Tabata et al. 1996).* The HIIT group showed a 9% improvement in aerobic power. The gain in estimated aerobic power in the current study was 5%. The higher relative percentage of VO_{2max} that was used (170% versus 120%) may partially explain the high results. The study was conducted on active young participants, as opposed to athletes in training. The potential for improvement may have been higher in this population than the already well trained status of players in the current study. Furthermore, the total training time in the current study was lower (twelve sessions total versus 30 session's total). Therefore, even though the current research had a lower level of improvement, the reduced response may be attributed to the lower number of sessions, lower selected intensity, and higher level of initial aerobic fitness in the recruited participants.

Not all studies produce similar results with supra-maximal HIIT regimens. One study compared three different training methodologies: continuous sub-maximal training, long interval training (4 minutes intervals) and short intervals (repeated 15 sec intervals with 15 sec recovery between efforts) in untrained subjects (*Franch, Madsen, Djurhuus, and Pedersen 1998).* All three groups had some level of positive adaptation to the training. The improvements were greater in the continuous and long interval training groups. The short interval group in this study however, performed between 30 and 40 repetitions. This high number of efforts may have resulted in higher perceived fatigue and the participants may have adopted a pacing strategy to complete the training. Moreover, an untrained group was recruited for this study. It could be postulated that a better trained group would have experienced better results with either of the interval regimens than the continuous training regimen. Such observations with previously trained participants have been shown in similar studies *(Laursen & Jenkins 2004).* The number of repetitions in the current research; two sets of eight, was selected in anticipation that the players would be able to maintain the intensity and not adopt a pacing strategy to merely complete the training session. The positive findings in the present study may be related to the developmental age and training status as well as selected interval strategy.

The rest period used in the current study may have had a significant impact on the improvement in aerobic power. The regimen called for the players to have a 15 sec recovery period, in which time they would walk slowly back to the starting line and prepare for the next effort. As the current research was conducted over a 20 metre out-and-back running track the same as the Multi Stage Shuttle Test *(Leger & Lambert 1982),* the distance the participants were required to cover was generally very short. The recovery was essentially passive as the players were not required to maintain any set intensity.

This recovery protocol may have contributed positively to the results for two reasons. First, the short recovery period would have meant the anaerobic energy production systems would have had inadequate time to fully restore. As a result with each subsequent repetition, the aerobic system would have been called on to make a greater contribution to energy production *(Fox et al. 1973).* If sufficient repetitions of this form of training are performed, energy production from aerobic metabolism will be challenged regularly enough for a training effect to take place *(Laursen and Jenkins 2004).* Second, it has been found that a passive recovery is a more effective strategy to adopt when performing supra-maximal HIIT *(Thevenet et al. 2006, Dupont, Blondel & Berthoin 2003).* In both these studies, participants were able to maintain the training intensity and perform greater workloads per effort with a passive rather than active recovery strategy. Due to the high energy demands of supra-maximal interval training, oxygen demands for each subsequent interval is too high for any oxygen to be used in the short recovery period. It can be postulated that the recovery strategy used in the current study contributed to the improvement in aerobic power, as more oxygen was theoretically available for the players to maintain the required intensity. The short recovery time would have progressively required a significant contribution from the aerobic system to meet energy demand.

The use of supra-maximal interval training has been established as an effective and efficient method of improving aerobic power in well-trained and youth subjects. It is generally accepted that this improvement occurs due to the time spent performing at or close to VO_{2max} intensity. However, the actual mechanism that allows the improvement to happen is difficult to determine. A number of different mechanisms have been proposed to explain the change that occurs with HIIT.

Multiple studies have outlined the changes that can occur as a result of a HIIT regimen *(Burgomaster, Heigenhauser & Gibala 2006, Forbes, Raymer, Kowalchuk, Thompson & Marsh 2008, Gibali M. 2009, Helgerud et al. 2007, Dennis & Noakes, 1998).* Identifying which adaptation took place in this study requires an understanding of the nature of the athletes used in the study, as they were a specialised group with 3 to 4 years experience in an organised training environment.

Multiple mechanistic explanations exist to explain the changes on a cellular and central level. Several metabolic adaptations occurring with traditional high volume endurance training also occur with small volume HIIT *(Gibala 2009)*. The peripheral (muscle) and central (cardiac) sites of adaptation, synonymous with traditional aerobic training, may result in similar site-specific adaptations to HIIT.

5.2.1 Peripheral Adaptations

One potential mechanism for the improvement in aerobic power is an increase in the oxidative capacity of muscle fibres *(Glaister, 2008).* Working at the intensities required when performing high intensity interval training based on V_{20MST} would likely fatigue the ATP-PC system and severely challenge the glycolytic energy system, requiring more ATP supply from the aerobic system *(Gaitanos, Williams, Boobis & Brooks, 1993).* Serial exposure to HIIT could potentially challenge, muscle fibres capacity to take on aerobic capabilities that improve the threshold permitting performance to continue *(Gibala & McGee 2009).* Increased activity of mitochondrial enzymes and an increase presence of biochemical markers of oxidative capacity were observed in similar training intervention studies *(Burgomaster et al. 2006, Gibala 2009).* The high running speeds in the current study (120% of V_{20MST}) and number of repetitions (two sets of eight efforts) would have elicited a higher metabolic load and potentially increased oxidative metabolism as a result of the training intervention. Whether or not fibres responded more oxidatively than glycolytically is beyond the scope of the present field based study.

The running speed in high intensity interval training needs to be sufficient to require greater muscle fibre recruitment than traditional aerobic development training methods *(Dudley, Abraham & Terjung 1982).* As a result a greater number of fibres, in particular fast twitch type fibres, can potentially embark on an adaptation process to the training, resulting in a greater oxidative capacity of those fibres *(Gibala & McGee 2009).* It is possible that the running speed in the current study may have been sufficient to elicit greater oxidative capacity in muscle fibre recruitment.

Conversely, some research has questioned the influence of increased oxidative capacity of muscle fibres as a result of high intensity interval training *(Dennis & Noakes 1998).* Improvement in performance tests such as time trials can occur without significant changes to aerobic power *(Hawley, Myburgh, Noakes & Dennis 1997, Lindsay, Hawley, Myburgh, Schomer, Noakes & Dennis, 1996, Billat et al. 1999).* Furthermore, the changes in performance seem to be dependent on the level of intensity at which training takes place and the ability to develop fatigue resistance at those higher intensities *(Denadai et al 2006, Tomlin & Wenger 2002).* Tomlin & Wenger showed greater performance improvements without changes in VO_{2max} with 100% vVO_{2max} intervals than 95% VO_{2max} *(Tomlin & Wenger 2002).* As the MSST is an external estimate and not a direct measure of VO_{2max}, it may be that an improvement in V_{20MST} occurred in the current study as a result of the training intervention without an improvement in VO_{2max}.

It has been postulated that improvements in performance with high intensity interval training may be a result of improved ability to work at higher intensities without a change in oxidative capacity of the muscles *(Dennis & Noakes 1998).* This may be a possibility with the current study. The nature of training (shuttle intervals over 20m) would have challenged the players' ability to perform at intensities higher than V_{20MST}. Additionally, improvements may have occurred due to an accelerated ability to recover between repetitions *(Kubukeli et al. 2002).* It may be possible that in the current study, increased work rates and improved recovery ability between repetitions contributed to the improvement in performance in conjunction with enhanced oxidative capacity of the working muscles *(Tomlin & Wenger 2002).*

5.2.2 Central Adaptation

Stroke volume; the volume of blood the heart can expel from the left ventricle is considered an important contributor to aerobic performance *(Davis, Sorrentino, Soriano & Pham, 2005).* Stroke volume has increased linearly in well trained athletes but plateaus around 40-50% of VO_{2max} in untrained individuals *(Dennis & Noakes 1998, Zhou, Conlee, Jensen, Fellingham, George & Fisher A 2001).* A similar regimen to the one used in the current study (15 second intervals with 15 seconds rest at 90-95% maximum heart rate), elicited an increase in $VO_{2max}$with a corresponding increasing in stroke volume *(Helgerud et al. 2007)* however, the number of repetitions also differed (47 versus 16 in the current study). Nevertheless, it is possible that in the current study, the resulted increases in VO_{2max} occurred as a result of improved stroke volume associated with the demands of the higher training.

Another possible mechanism associated with improvements surrounding HIIT may lie in longitudinal hypertrophy and increased contractile forces of heart muscle fibres, the cardiomyocytes. This increase can potentially increase left ventricle ejection fraction as well as increasing contraction efficiency of the heart muscle fibres *(Wisloff, Ellingsen & Kemi 2009).* Potential increases in the contractile rate of cardiomyocytes with HIIT can be as high as 60% *(Diffee & Chung 2003).* Contractile force of cardiomyocytes plateaus after two months unless training overload continues *(Wisloff et al. 2009)*. This may help explain the findings in the current study. No progressive overload of the HIIT regime took place and the intervention was completed after four weeks and 12 training session. It has been postulated that the detraining effects on the cardiomyocytes occur faster than the training effect *(Kemi, Haram, Wisloff & Ellingsen, 2004).* The training effects on the heart muscle fibres may have started to decrease during the two weeks of data collection post intervention. However, due to the field-based nature of the current study, such changes remain speculative.

5.2.3 Secondary Finding: No negative effect on other physical characteristics

No changes were observed in other physical measures included in the testing battery. These measures were the vertical jump and a maximal sprint over 20 metres, with timing splits at the five metre mark and the 10 metre mark. Jumping and sprinting tests were the typical testing regimen for the participants recruited for the present study. Maintenance of explosive anaerobic performance mirrors results from similar supra-maximal interval training regimens occurring during the competition phase of soccer players *(Dupont et al. 2004, Baquet et al. 2004).*

The maintained explosive anaerobic performances may have occurred because the intensity of total training was sufficient to maintain speed and leg power. The training regimen used by the experimental group was not fatiguing to the level that total training volume negatively impacted on high output activities such as sprinting and jumping. Finally the nature of the training regimen required players to accelerate at a high intensity. The number of accelerations (48 per week) may have contained sufficient volume and intensity to avoid decrements in speed and explosive accelerations. The increased number of accelerations may have contributed to the non-significant (p=0.068) trend towards improvements in the 20 metre test of the experimental group. However, the effect size of -0.72 (-1.36 to -0.08) would indicate a moderate magnitude based treatment effect *(Batterham & Hopkins 2006)*

5.3 Major finding two: unchanged match performances

Scientific investigation into team sports is more difficult than quantifying training and performance in closed loop locomotion sports. Specifically, the dominant physiological determinants are not as easy to define as a locomotion/racing sport and difficulties also prevail in indentifying or defining what constitutes a good performance in a multi-requirement activity such as team sports *(Mujika, 2007).* Although there is support in the relevant research, scientists continue to challenge the relevance and accuracy of objective measures such as GPS used to attempt to quantifying the training and match requirements *(Petersen, Pyne, Portus & Dawson 2009, Coutts & Duffield 2009)*. Furthermore, cumulative matches and training during the actual season compound results obtained over a shorter period of time *(Mujika 2007).*

Within the context of these challenges, GPS data showed no significant differences between the experimental and control group in any of the measures that were collected in the present study during six competitive matches (three pre-intervention and three post intervention). Multiple variables were collected from game GPS data to permit comparisons between other studies and between pre and post intervention matches. The use of GPS for movement analysis in football is a relatively recent method, with few studies across any sport *(Carling et al 2008, Dobson & Keogh, 2007).* Through GPS, a number of variables were selected to gain a better understanding of overall workload.

Performance comparisons were limited by the data selected to measure match achievements and the aforementioned limitations of GPS devices. Identifying which GPS measures was difficult and selections are not-all inclusive of factors affecting match day performance.

5.3.1 Match effect

Different positions in a football team impose varying physical loads. Despite differences in the data sets, some agreement can be found in descriptions of the demands of each position *(Bradley, Sheldon, Wooster, Olsen, Boanas & Kustup. 2009, Mohr et al. 2003, Bangsbo 1994, Bangsbo et al. 1991, Reilly et al 2000).* The differences from position to position suggest a player's position in the team has greater influence on player's workload than pre-match fitness. Positional roles are fairly well defined and stepping out of those roles can have a negative or disruptive effect on the team pattern. The demands of the position could be deemed as a deciding factor in terms of work performed in the game and not physical fitness. Objective measures of GPS fail to account for game strategies.

In the current study, the experimental group and control groups were randomised to ensure statistical parity to start of the study. The groups were not stratified for position, with the exception of goal keepers. It can be speculated that changes in aerobic power in certain positions, especially centre backs and strikers would translate to greater workload and high intensity running in the game. The small sample size and the tactical changes of players capable of multiple positional performances in any given match prevented this study collecting position-specific data. Therefore, match and positional specific demands may account for a lack of change in GPS data that was collected.

Match situation influences physical workload of all players in the open chain sport of football and is unpredictable. Huge variation occurred in game loads within an individual and across the group. Despite a player potentially having a greater capacity for high intensity running, their position, the game situation; for instance leading or trailing in the score, may dictate that any extra high intensity running is not required. For example a central defender will very rarely cover higher distances and do more high intensity running than a midfielder, independent of the relative level of fitness. Match to match variability and on-field positional demands may have therefore also contributed the lack of change recorded from the GPS analysis

Tactical adjustments also influence physical workload of all players and are unpredictable. A variety of different tactical set ups may be employed by a team. Changes in tactical set up vary the workload on players. For instance, one tactical set up may allow for a wide defender to move forward in attack and track back quickly in defence. While another playing system may require the defenders to stay in a relatively straight line and not travel forward with the play and join the attack. As a result of differing strategies, the amount of high intensity running and distance covered by defenders will differ within and between games. This tactical variation illustrates the difficulty in of performing research on open chain sports in game situations.

Another potential reason for the lack of change in game data collected from GPS was the short nature of the study. Several studies have shown that adaptations to high intensity interval training can occur in a very short period of time *(Burgomaster et al. 2006, Baquet et al. 2004).* Yet this quick adaptation is reversed quickly once this form of training is discontinued. The intervention process only lasted 4 weeks (12 sessions). Despite the duration of the intervention being sufficient to elicit a change in aerobic power performance, the changes may not have been sustainable to the extent of influencing post intervention match performance directly.

5.4 Major Finding Three: Comparisons with other reports of soccer performance from sports scientists

The average distance covered by the players in all games (three pre and three post games) was 10818 m (SD=993 m). This distance was within the normal range covered in a full match elsewhere in the literature *(Mujika, Santisteban, Impellezzeri & Castangna & 2009, Bradley et al. 2009, Reilly, 2003).* The distance covered by players ranged from 8269 metres to 12720 metres. Moreover, the distance covered by individual players in separate matches varied markedly with a range of 2034 metres from the smallest distance covered to the largest distance covered. This range indicates a high level of variability in performance from match to match for players at this national but still developmental level. The average range from smallest to greatest distance covered was 897 m, again indicating that this group of players had a high level of variability in their physical workload. Interpretation of match to match differences requires caution and performance may be dependent on factors other than the running distances, despite measured increases in field tested aerobic performance.

In agreement with other studies *(Mohr et al. 2003, Di Salvo et al. 2007)* players covered less distance in the second half than the first half of matches. Among many potential explanations is the possibility that players were aware they could be replaced at half time. As a result, these players may put in extra effort as they know they will not be playing in the second half. The average distance covered by players who were replaced at half time was 6320 metres, compared with the first half average of 5589 metres. Other explanations for first and second half differences in distance travelled may be related to motivation from scores at any given time of the match, or energy conservation strategies being more in demand in the second than first half.

Average meterage, defined as metres covered per minute of play is a relatively new statistic used to analyse performance. No studies to date have used this statistic to determine workload. The average meterage estimated from matched players across the entire study was 122.05 m/minutes. The average meterage achieved by the players increased by 11.2% from the pre to post intervention periods. Interestingly both the control and experimental groups improved their meterage by 1167.4 metres and 622.8 metres, respectively. This was not a significant difference. Minimal changes between the groups may indicate that at this level of play, a high level of learning takes place. The player may be getting a significant training effect from the total training load, independent of the intervention training regimen. Results may also be confounded by the fact that players may concomitantly have gained a training effect from the increased intensity of the games, which was likely to be higher than the intensity of competitions previously played. This was the first season this group of development players had played in a senior level competition.

In the current study, the intervention of interval training, high intensity running statistics during the game were examined for links to game performance. The average distance covered in high intensity running in the current study was 1290 metres. The definition of high intensity running was any distance that was recorded over a speed of 16 km/hr. This was lower than the definition of high intensity running used by other studies *(Bradley et al. 2009, Di Salvo et al. 2009, Bangsbo et al. 1991).* Given the lower age and experience of the current studies participants, it was felt that a lower definition on high intensity running was required. High intensity running is an area of game analysis that has been used in several studies to determine game workload *(Mohr et al. 2003, Di*

Salvo et al. 2007, Mujika et al. 2009). One of the difficulties in comparing high intensity running from one study to another is this differing definition of high intensity running and the method with which the information is collected. None of the previous studies investigated used GPS technology to collect data. The distance covered during matches and percentage of distance covered above the 16km/h limit used to define high intensity running was lower than other studies of players in national or international leagues *(Bloomfield et al. 2007, Bradley et al. 2009).* This again may be a product of the lower age of the participants and lower standard of competition, when compared with results from more elite level leagues *(Stolen et al. 2005).*

When the data were looked at for the combined group both pre and post intervention, there were several significant changes. The 1st and 2nd half meterage both increased significantly. However, meterage difference and 1st 15 minutes versus last 15 minutes decreased significantly. Essentially the increase in 1st half meterage was much greater than the increase in 2nd half meterage. High intensity running distance and the number of high intensity efforts also increased significantly across the entire cohort.

The improvement in the entire group from pre to post intervention may be further explained by the training effect of the total training and playing load. The greater time playing at a higher intensity in a higher level competition than they had played previously could have created a training effect for the entire squad. Four games were played during the intervention as well as several training sessions, all potentially making a contribution to performance. Significantly more training time would have been invested in general training sessions and playing than the time taken to perform the intervention protocol.

Several studies have shown greater physical performance in games in higher performing teams *(Mohr et al. 2003, Apor 1988, Bangsbo et al. 1991).* These may be partially explained by the greater number of games generally played by higher performing teams in European teams.

5.5 Why is training efficiency important?

Football is a multi-dimensional sport in which success has a high number of contributors. Multiple variables can influence performance at all levels of participation, particularly during the developmental stage in which players are trying to achieve the highest possible level *(Stolen et al. 2005).* These variables can generally be divided up into technical development (skill execution), tactical development (team play, game sense activities, skill application) and physical preparation *(Mujika et al. 2009).* In locomotion or racing sports such as cycling, rowing and track and field the balance of these three factors is much easier to determine and assess *(Mujika, 2007).* However, in sports such as football, it is harder to determine the correct balance between these three development areas. The relative importance of each area will vary depending on the playing level, time of the season, and needs of the individual and needs of the team. It is crucial to get the balance among these areas correct and without progressing into a state of overtraining. Training efficiency is important to consider when designing a training regimen to balance the technical, tactical, and physical components of a team sport such as football if overtraining is to be avoided and simultaneously maintain or advance the players' capacity to meet weekly match demands.

This study was carried out during the competitive season. Few intervention studies have taken place within the competitive season *(Dupont et al. 2004).* Players in this study were in their first year in the senior competition and it was the highest level the players had competed in up to that point in their career. In an elite development team, the training emphasis is on learning the game. Training methods that are time efficient and effective therefore, warrant further investigation.

5.6 Advantages of this form of training.

Traditionally, the competition training phase concentrates on tactical development, such as team strategy, scouting and countering opponents, and perfecting set plays such as free kicks, corners and throw in strategies *(Owen & Wong 2009).* In addition, games take place each weekend. The training regimen needs to take into account recovery and preparation for each game. Subsequently, minimal time remains for developing or maintaining physical characteristics such as aerobic power. Traditional lower intensity longer duration style training may not be the most effective use of time. Therefore, to improve aerobic power for football players during the competition phase of the season in which a heavy emphasis on learning and skill development is challenging.

The training intervention used in this study comprised three training sessions per week, with each training session consisted of 2 sets of eight 15 second intervals, with 15 seconds' recovery between efforts and 2 minutes and 15 seconds of rest, between the first and second set. The total session time was 10 minutes per session, 30 minutes per week over a four week period. This did not include the time taken to complete the warm up. The 5% increase in aerobic power shown in the experimental group would suggest the intervention was effective, and the minimal time requirement suggests that it is also time efficient as well. This form of training can be considered effective and time efficient during the competition phase for this population of football players.

Despite the relative paucity of studies into this form of maximal and supra-maximal intensity interval training, existing evidence shows this form of training can elicit significant improvements in aerobic power in a short period of time *(Tabata et al. 1996, Gibala 2006).* Overall, results of this current study support the findings in other research *(Dupont et al. 2004, Baquet et al. 2004, Dennis & Noakes 1998).* Similar results would likely be achieved if traditional methods were used, but these require a much greater time commitment *(Gibala 2009).* Given the challenges of the development coach to meet all requirements for tactical and technical improvement as well as developing adequate physical preparation, HIIT should be considered.

The lower frequency, higher intensity exercise regimen that was used in the current study may have higher long-term adherence than traditional methods to improve aerobic power (*King A, Haskell W, Young D, Oka R & Stefanick M 1995).* The regime may also be attractive to players & coaches because, as it will not cut into training time. The shorter, more intense methodology may further improve motivation for physical training in players at the development level of participation. The quick nature of the regime maximised the time players could spend developing the skills and tactics that the game demands at a higher level *(Di Salvo et al. 2009, Rampini et al. 2009)*

5.7 Strengths and Limitations of the methods and outcomes.

5.7.1 Strengths

The high intensity interval training method that was central to the current study supported the findings of a high number of previous studies *(Tabata et al. 1996, Tabata et al. 1997, Dupont et al. 2002, Dupont et al. 2004, Baquet et al. 2004, Berthoin et al. 1996, Gibala & McGee 2009).* The intensity and number of repetitions were such that an improvement in aerobic power took place in a short period of time. The short time requirement of 10 minutes per session meant the intervention did not impact on other training and there was no negative impact on team performance and other physiological capacities.

The study design required passive recovery between efforts comprised of walking back to the start at no set speed, as well as passive recovery between the first and second set. This may have contributed to the positive physiological results, as passive recovery has shown to be a more effective strategy than active recovery at intensities of 120% *(Dupont, Blondel & Berthoin 2003).* This recovery strategy may have increased the time to exhaustion and allowed the players to maintain the required intensity for longer.

As outlined, any intervention study on team sports conducted during the competitive season is fraught with difficulty *(Mujika et al.2009).* The residential centralised nature of the players may have overcome many usual barriers, but challenges remained. The current study found difficulty in standardising player involvement in the pre and post intervention data collection periods. Physiological data were collected easily as standardised protocols were followed. Weekly training schedules and volumes were also standardised. However, factors such as playing time, positions, tactical approach and game situations could not be standardised during the competitive season.

5.7.2 Limitations

The different opponents and team line ups were an uncontrollable variable that will always occur during competition based research. Each week, a different opponent will change the response of the player. The most accurate responses will occur when the same opponents with same team line ups. However, playing against the same opponent would provide unrealistic information as to time-motion analysis in competition. Quantifying team sports improvement remains challenging.

The use of GPS as a time-motion analysis methodology in team sport is relatively new technology and not yet well researched. Questions remain about the level of accuracy in multi change of direction, open loop sports *(Dobson & Keogh 2007, Carling et al 2008)*. Reliability and validity trials published with the GPS units used in the current study showed the inter-units' reliability and accuracy over longer distance in determining walking, jogging and running speeds and distances. However, there was a tendency to slightly underestimate shorter faster efforts *(Petersen et al 2009).* The sampling rate of the units used in this study was limited to 5 Hz (5 samples per second). This may explain the questions about accuracy of GPS for time-motion analysis for an open chain sport such as football. Overall, the practicality and speed at which information can be assessed at least warrant further investigation of the use of GPS as a method of time-motion analysis.

Reliability trials were not acceptable due to time constraints. This decision was made by the coach as it was seen as too great a distraction during the competition phase of the year. Standard tests used in the study had been routinely performed on the squad. Subsequently the need for reliability testing was not seen as a priority for the coach who controlled the use of time for training.

One problem with most time-motion analysis is the emphasis on physiological load. GPS units can measure a player's physiological response, but not the effectiveness of that response or the perceived exertion of the player. Measuring just physiological effort alone does not provide a full profile of a player's response to the training intervention.

5.8 Future Research

Designing intervention studies for the 'in season' phase of competition is a difficult undertaking, especially in multi-faceted sports such as football. Individual sports and closed chain racing sports have generally been the most researched in the sporting sphere as they are much easier to analyse in a competitive and simulated setting *(Mujika et al. 2009).* There are several aspects in football that are very difficult, if not impossible, to control. Level of opposition, direct opponents, refereeing decisions, tactics, substitutions, score and game situation are just a few of the variables that cannot be accounted for with any great accuracy in a competitive open-chain game setting. However, research in a competition setting is of value if we are to develop improved training methodology and understand more about how training directly impacts on game performance. As football requires a synergy of physical, tactical and technical abilities *(Rampini et al. 2009),* the most thorough analysis of the sport will require investigation when all three factors are involved. The extent to which motivation, anxiety, self-efficacy can affect performance is also under researched and would be worthwhile considering in future research.

A number of other factors may need to be included in future research into influence of high intensity interval training on match performance if game data is to be utilised. The current group were a developmental squad who had only been at this level of play for a few months. The players were still establishing their position in the team and learning the coach's style of play. The team had only played a few games at this level of play, which was the highest they had played. An interesting follow up with this group would be to investigate the change once they had played at this level for a full season, had a better understanding of the team's tactical approach and variations, as well as being more established in their positions. With a more stable platform, a more accurate assessment of the players' performance and improvement as a result of the training intervention may be possible.

Analysis of GPS in terms of frequency of effort may be a valuable statistic. The current study showed no difference between the experimental and control group, in the frequency of efforts within the same team. However, research on elite level players in the English Premier League showed that the distances covered at high intensity by higher performing teams was lower than poorer performing teams, but the number of efforts performed were slightly (non-significant) higher *(Di Salvo et al. 2009).* This may indicate that quality of performance cannot just be measured by measures such as horizontal movements, even with the most advanced available technology.

The current study was carried out over a very short period of time. The structure of the study included a pre-test, followed by 2 weeks of collecting game data (3 games in a 14 day period), a 4 week training intervention, post intervention testing and a further 2 weeks of collecting game data (a further 3 games in a 14 day period). Compared to similar studies *(Tabata et al. 1996, 1997, Dupont et al. 2003, 2004, Berthoin et al. 2004)* the length and training volume of the current study was much lower. The original hypothesis of the study was to investigate HIIT in regard to training efficiency. Although the current study showed an improvement in aerobic power with no negative effect on other physiological parameters, a study with greater training frequency or increased training time may have a differing influence on match performance. It may also be worthwhile investigating a longer period of intervention. A longer intervention would also allow for a greater number of games to be analysed before after the intervention, giving an even clearer indication of the impact of the intervention. However, the likelihood of a fast detraining effect *(Wisloff et al. 2009)* may dictate that some form of maintenance program is required during the post intervention testing period.

The high number of variables capable of impacting on performance may mean that other data needs to be collected to accompany GPS or any other workload analysis technique. GPS can indicate the volume of running, speeds, high intensity running and other variables that can be selected. It does not indicate the players' perception on the workload they encounter. Subjective measures such as Ratings of Perceived Exertion or RPE *(Borg 1962),* leg heaviness and game load may be useful measures to include in understanding more about the influence of the training intervention *(Alexiou & Coutts, 2008).* Players may have a different perception of the intensity of the game. Two players may perform similar workloads in a competitive game, but one may perceive the work to be less difficult than the other. Information such as RPE could be used in future studies to further evaluate game workloads and the impact of the training intervention.

It is well established that the physical load of competitive football varies from one position to another *(Bangsbo 1994, Stolen et al., Mohr et al. 2003, Di Salvo et al. 2009).* Future research into the role of HIIT on match workloads may benefit from stratifying the experimental group and control group according to position. Future studies would require a larger participant group to allow a more accurate analysis of positions and possible changes that occur in game data as a result of the training intervention.

5.9 Were the hypotheses supported?

In the current study, the hypothesis that a short term high intensity interval training intervention would improve aerobic power when compared with a control group was supported. There was a 4.1% increase in aerobic power for the intervention group with no change for the control group. This was likely due to increased training time at intensities similar to the athletes VO_{2max}. However, the hypothesis that HIIT would increase the distance and frequency of high intensity running in competitive games when compared with a control group was not supported. Collectively, there was a significant improvement in several areas. Significant changes occurred in total distance, 1st half distance covered, 1st half meterage, 2nd half meterage, meterage difference between halves, total high intensity distance covered, number of high intensity efforts, percentage of total distance at high intensity speeds and frequency of high intensity efforts. Increased playing time, level of competition, playing style and game situation all need to be taken into account when assessing training and playing intensity.

Exposing young football players to a short program of high intensity interval training within the season, yielded aerobic improvements that were not translated into match performances, as assessed by GPS technology.

REFERENCES

1. **Alexiou H & Coutts A (2008):** A comparison of methods used for quantifying internal training load in women soccer players. *International Journal of Sports Physiology and Performance* 3, 320-330.
2. **Al-Hazzaa H, Almuzaini K, Al-Refaee S, Sulaiman M, Dafterdar M, Al-Ghamedi & Al-Khurai K** (2001): Aerobic and anaerobic power characteristics of Saudi elite soccer players. *Journal of Sports Medicine & Physical Fitness* 41(1), 54-61
3. **Ali A & Farrally M** (1991): A computer–video aided time motion analyses technique for match analysis. *Journal of Sport Medicine & Physical Fitness* 31, 82-88.
4. **Apor P** (1988): Successful formulae for fitness training. In Reilly T, Lees A, Davis K et al editors (1988) *Science and Football* Spon London 95-107.
5. **Aziz A, Tan F, Yeo A & Teh K** (2004): Physiological attributes of professional players in the Singapore soccer league. *Journal of Sports Sciences* 22(6), 522-523
6. **Baquet G, Guinhouya C, Dupont G, Nourry C & Berthoin S** (2004): Effects of short-term interval training program on physical fitness in pre-pubertal children. *Journal of Strength & Conditioning Research* 18(4), 708-713.
7. **Bangsbo J** (1994): The physiology of soccer: With special reference to intense physical exercise. *Acta Physiologica Scandinavica* 150 (supple.619), 1-156.
8. **Bangsbo J, Norregand L & Thorsoe F** (1991): Activity profile of competition soccer. *Canadian Journal of Sports Science* (16), 110-116.
9. **Bangsbo J & Michalsik L** (2002): Assessment of the physiological capacity of elite players. In Spink W, Reilly T & Murphy A, editors (2002) *Science and Football IV* Rutledge, London 53-62.
10. **Bangsbo J, Marcello Iaia F & Krustup P** (2007): Metabolic response and fatigue in soccer. *International Journal of Sports Physiology* 2, 111-127.
11. **Barbero-Alvarez J, Barbero-Alvarez V, Gomez M and Castagna C** (2009): Kinematic analysis of activity profile in Under 15 players with GPS technology. *Kronos* VIII (14), 35-42.

12. **Batterham A & Hopkins W,** (2006): Making meaningful inferences about magnitudes. *International Journal of Sports Physiology & Performance.* 1(1), 50-57.

13. **Berthoin S, Gerbeaux, M, Geurruin F, Lensel-Corbeil G and Vandendorpe F** (1992): Estimation of maximal aerobic speed. *Science & Sport* 7(2), 85-91.

14. **Berthoin S, Baquet G, Manteca F, Lensel-Corbeill G & Gerbeaux M** (1996): Maximal aerobic speed and running time to exhaustion for children 6 to 17 years old. *Paediatric Exercise Science* 8, 234-344.

15. **Billat V** (2001): Interval training for performance: A scientific and empirical practice. Special recommendations for middle & long distance running, Part 1. Aerobic interval training. *Sports Medicine* 31(1), 13-31.

16. **Billat V, Flechet B, Petit B, Muriax G & Koralsztein J** (1999): Interval training at VO_{2max}: effects on aerobic performance and overtraining markers. *Medicine & Science in Sport & Exercise* 31, 156-163.

17. **Borg G (1962):** A simple ratings scale for use in physical work tests. *Kunglinga Fysiografiska Sallskipets i Lundi Forhandlingar* 2, 7-15. Sighted in **Chen M, Fan X & Moe S (2002):** Criterion related validity of the Borg's rating of perceived exertion scale in healthy individuals: A meta-analysis. *Journal of Sports Sciences* 20, 873-899.

18. **Bradley P, Sheldon W, Wooster B, Olsen P, Boanas P & Kustup P** (2009): High intensity running in English FA Premier League soccer matches. *Journal of Sports Sciences,* 27(2), 159-168.

19. **Brookes J & Knowles J (1974):** A movement analysis of player's behaviours in soccer match performance. Paper presented at British *Society of Sports Psychology Conference,* Salford Eng.

20. **Burgomaster K, Heigenhauser G and Gibala M** (2006): Effect of short-term interval training on human skeletal muscle carbohydrate metabolism during exercise and time-trial performance. *Journal of Applied Physiology* 100, 2041-2047.

21. **Carling C, Bloomfield J, Nelsen L & Reilly T** (2008): The role of time motion analysis in soccer: Contemporary performance measurement techniques and work rate data. *Sports Med* 38(10), 839-862.

22. **Christensen E, Hedman R & Saltin B** (1960): Intermittent and continuous running. *Acta Physiol. Scand* 50, 269-287.

23. **Creer A, Ricard M, Conlee R, Hoyt G & Parcell** (2004): Neural, metabolic and performance adaptation to four weeks of high intensity sprint-interval training in trained cyclists. *International Journal of Sports Medicine* 24, 92-98.

24. **Coutts A and Duffield R** (2009): Validity and reliability of GPS devices for measuring movement demands of team sports. *Journal of Science & Medicine in Sport* 13(1), 133-135.

25. **Davis J, Sorrentino K, Soriano A & Pham P** (2005): Comparisons of stroke volume estimation for non-steady state and steady state graded exercise testing. *Clinical Physiology and Functional Imaging* 25, 47-50.

26. **Denadai B, Ortiz M, Greco C & de Mello M** (2006): Interval training at 95% and 100% of the velocity at VO_{2max}: effects on aerobic physiological indexes and running performance. *Applied Physiology Nutrition & Metabolism* 31, 737-743.

27. **Dennis S & Noakes T** (1998): Physiological and metabolic responses to increasing work rates: Relevance for exercise prescription. *Journal of Sports Sciences* 16, S77-S84.

28. **Diffee G & Chung E** (2003): Altered single cell force velocity and power properties in exercise trained rat myocardium. *Journal of Applied Physiology* 94, 1941-1948.

29. **Di Salvo V, Baron R, Tschan H, Calderon-Montero F, Bachi N & Pigozzi F** (2007): Performance characteristics according to playing position in elite soccer. *International Journal of Sports Medicine* 28, 222-227.

30. **Di Salvo V, Gregson W, Atkinson G, Tordoff P & Drust B** (2009): Analysis of high intensity activity in premier league soccer. *International Journal of Sports Medicine* 30, 205-212.

31. **Dobson B & Keogh J** (2007): Methodological issues for the application of time-motion analysis research. *Strength & Conditioning Journal* 28(2) 48-55.

32. **Drust B, Reilly T & Rienzi E** (1998): Analysis of work-rate in soccer. *Sports Exercise & Injury* 4, 151-155.

33. **Dudley G, Abraham W and Terjung R** (1982): Influence of exercise intensity and duration on biomechanical adaptations in skeletal muscle. *Journal of Applied Physiology* 53(4), 844-850.

34. **Dupont G, Blondel N, Lensel G & Berthoin S** (2002): Critical velocity and time spent at a high level of VO_2 for short intermittent runs at supramaximal velocities. *Canadian Journal of Applied Physiology* 27(2), 103-115.

35. **Dupont G, Blondel N & Berthoin S** (2003): Performance for short intermittent runs: active recovery vs. passive recovery. *European Journal of Applied Physiology* 89, 548-554.

36. **Dupont G, Akakpo K & Berthoin S** (2004): The effects of in-season, high intensity interval training in soccer players. *Journal of Strength & Conditioning Research* 18(3) 584-589.

37. **Edgecomb S & Norton K (2006):** Comparison of global positioning and computer-based tracking systems for measuring player movement distance during Australian football. *J Sci Med Sport* 9 (1-2), 25-32.

38. **Edwards A, McFadyen A & Clarke N** (2003): Test performance indicators from a single soccer specific fitness test differentiate between highly trained and recreationally active soccer players. *Journal of Sports Medicine & Physical Fitness* 43, 14-20.

39. **Ellis L, Gastin P, Lawrence S, Savage B, Buckeridge A, Stapff A, Tumilty D, Quinn A, Woolford S & Young W** (2000): Protocols for the physiological assessment of team sport players. IN Gore C (Ed) *Physiological Tests for Elite Athletes*. Human Kinetics, Champaign ILL, 128-145.

40. **Ekblom B** (1986): Applied physiology of soccer. *Sports Medicine* 3, 50-60.

41. **Forbes S, Raymer G, Kowalchuk J, Thompson R and Marsh D** (2008): Effect of recovery time on phosphocreatine kinetics during repeated bouts of heavy-intensity exercise. *European Journal of Applied Physiology* 103, 665-675.

42. **Fox E, Bartels R, Billings C, Mathews D, Bason R & Webb W** (1973): Intensity and distance of interval training programs and changes in aerobic power. *Medicine & Science in Sport & Exercise* 5(3), 15-22.

43. **Franch J, Madsen K, Djurhuus M & Pedersen P** (1998): Improved running economy following intensified training correlates with reduced ventilatory demands. *Medicine & Science in Sport & Exercise* 30(8), 1250-1256.

44. **Gaitanos G, Williams C, Boobis L & Brooks S** (1993): Human muscle metabolism during intermittent maximal exercise. *Journal of Applied Physiology* 75, 712-719.

45. **Gibala M** (2009): Molecular responses to short term high intensity interval exercise. *Applied Physiology, Nutrition & Metabolism* 34, 428-432.

46. **Gibala M & McGee S** (2008): Metabolic adaptation to short term high intensity training: A little pain for a lot of gain? *Exercise & Sports Science* Review 36(2), 58-63.

47. **Glaister M** (2008): Multiple-sprint work: Methodological, physiological and experimental issues. *International Journal of Sports Physiology and Performance* 3, 107-112.

48. **Gerbeaux M, Lensil-Corbiel G, Branly G, Dierkens J, Jacquet A, Lefranc J, Savin A & Savin N** *(1991):* Estimation de la vitesse maximal aerobie chez les eleves des college et lycees. *Science et Mortricite* 13, 6-11. Cited in **Berthoin S, Gerbeaux, M, Geurruin F, Lensel-Corbeil G and Vandendorpe F** (1992): Estimation of maximal aerobic speed. *Science & Sport* 7(2), 85-91.

49. **Hawley J, Myburgh K, Noakes T & Dennis** (1997): Training techniques to improve fatigue resistance and enhance endurance performance. *Journal of Sports Science* 15, 325-333.

50. **Helgerud J, Hoydal K, Wang E, Karlsen T, Berg P, Bjerkaas M, Simonsen T, Helgesen C, Hjorth N, Bach R & Hoff J** (2007): Aerobic high intensity intervals improve VO_{2max} more than moderate training. *Medicine & Science in Sport & Exercise* 39(4), 665-671.

51. **Helgerud J, Engen L, Wisloff U & Hoff J** (2001): Aerobic endurance training improves soccer performance. *Medicine & Science in Sports & Exercise* 33(11), 1925-1931.

52. **Hoare DG & Warr C** (2000) Talent identification& women soccer: An Australian experience. *Journal of Sports Science* 18, 751-758.

53. **Hoff J & Helgerud J** (2004): Endurance & strength training for soccer players; physiological considerations. *Sports Medicine* 34(3), 165-180.

54. **Hoff J, Wisloff U, Engen L, Kemi O & Helgerud J** (2002): Soccer specific aerobic endurance training. *British Journal of Sports Medicine* 36, 218-221.

55. **Hopkins W** (2003): A spreadsheet for analysis of straightforward controlled trials, *Sportscience 7*, Retrieved Jan 2008 from http//:www.sportsci.org/jour/03/wghtrials.htm

56. **Impellizeri F, Marcona S, Castagna C, Reilly T, Sassi A, Iaia F & Rampinini E** (2006) Physiological and performance effects of generic versus specific aerobic training in soccer players. *International Journal of Sports Medicine* 27(6), 483-492.

57. **Kemi O, Hoff J, Engen L, Helgerud J & Wisloff U** (2003): Soccer specific testing of maximal oxygen uptake. *Journal of Sports Medicine & Physical Fitness* 43(2), 139-144.

58. **Kemi O, Haram P, Wisloff U & Ellingsen O** (2004): Aerobic fitness is associated with cardiomyocyte contractile capacity and endothelial function in exercise & detraining. *Circulation* 109, 2897-2904.

59. **King A, Haskell W, Young D, Oka R & Stefanick M (1995)**: Long-term effects of varying intensities and formats of physical activity on participation rates, fitness, and lipoproteins in men and women aged 50 to 65 years. *Circulation* 91, 2596-2604.

60. **Krustup P, Mohr M, Ellingsgaard H & Bangsbo J** (2005): Physical demands during an elite female soccer game: Importance of training status. M*edicine & Science in Sport & Exercise* 37(7), 1242-1248.

61. **Lamb K & Rogers L (2007):** A re-appraisal of the reliability of the 20 m multi-stage shuttle run test. *European Journal of Applied Physiology* 100(3), 287.

62. **Laursen P & Jenkins D** (2002): The scientific basis for high-intensity interval training. Optimising training programmes and maximising performance in highly trained endurance athletes. *Sports Medicine* 32(1)53-73.

63. **Leger L** & **Lambert J** (1982): A maximal multistage 20-m shuttle run test to predict VO2 max. *European Journal of Applied Physiology* 49(1), 1-12.

64. **Léger LA, Mercier D, Gadoury C &Lambert J** (1988): The multistage 20-metre shuttle run test for aerobic fitness. *Journal of Sports Sciences* 6, 93-101.

65. **Lindsay F, Hawley J, Myburgh K, Schomer H, Noakes T & Dennis S** (1996): Improved athletic performance in highly trained cyclists after interval training. *Medicine & Science in Sport & Exercise* 28, 1427-1434.

66. **Little T & Williams A** (2005): Specificity of acceleration, maximum speed & agility in professional soccer players. *Journal of Strength & Conditioning Research* 19 (1), 76-78.

67. **Mayhew S & Wenger H** (1985): Time-motion analysis of professional soccer. *Journal of Human Movement Studies* 11, 49-52.

68. **Midgley A & McNaughton L** (2006): Time at or near VO_{2max} during continuous and intermittent running: A review with special reference to considerations for optimisation of training protocols to elicit the longest time at or near VO_{2max}. *Journal of Sports Medicine & Physical Fitness* 46, 1-14.

69. **Mohr M, Krustup P and Bangsbo J** (2003): Match performance of high-standard soccer players with special reference to development of fatigue. *Journal of Sports Sciences* 21, 519-528.

70. **Morgan S and Williams M** (2009): Horizontal positioning area in stationary GPS units. A function of time & proximity to building infrastructure. *International Journal of Performance Analysis and Sport* 9(2), 12.

71. **Mujika I** (2007): Challenges of team-sport research. *International Journal of Sports Physiology & Research* 2, 221-222.

72. **Mujika I, Santisteban J, Impellezzeri M and Castangna G** (2009): Fitness determinants of success in men's and women's football. Journal of Sports Sciences 27(2) 107-114.

73. **Norton K & Olds T (1996):** *Anthropometrica: A Textbook of Body Measurement for Sports and Health Courses.* UNSW Press

74. **Nowacki P, Cai D and Buhl C** Biological performance of German soccer players (professional and junior) tested by special ergometry and treadmill methods. In **Reilly T, Lees A, Davids K & Murphy W eds.** (1988) *Science & Football II,* E& FN Spon London, 145-157.

75. **Nubukeli Z, Noakes T & Dennis S** (2002): Training techniques to improve endurance exercise performance. *Sports Medicine* 32(8), 489-509.

76. **Owen A & Wong P** (2009): In-season weekly high-intensity training volume among professional English soccer players: A 20 week study. *Soccer Journal* April-May, 28-32.

77. **Peat JK, Williams K, Xuan W and Mellis CM (2001):** *Health Science Research: A handbook of quantitative methods.* Allen and Unwin, Sydney 2001.

78. **Petersen C, Pyne D, Portus M & Dawson B** (2009): Validity and reliability of GPS units to monitor cricket specific movement patterns. *International Journal of Sports Physiology & Performance* 4, 381-393.

79. **Polman R, Walsh D, Bloomfield J & Nesti M** (2004): Effective conditioning of female soccer players. *Journal of Sports Sciences* 22, 191-203.

80. **Rampini E, Impellizzeri F, Castagna C, Coutts A & Wisloff U** (2009): Technical performance during soccer matches of the Italian Serie-A league: Effect of fatigue and competitive level. *Journal of Science and Medicine in Sport* 12, 227-233.

81. **Ramsbottom R, Brewer J & Williams C** (1988): A progressive shuttle run test to estimate maximal oxygen uptake. *British Journal of Sports Medicine* 109, 209-216.

82. **Reilly T:** Motion-analysis and physiological demands. In: **Reilly T ed.** (1996) *Science and Soccer*. E & F N Spon London 65-79.

83. **Reilly T** (1997): Energetics of high-intensity exercise (soccer) with particular reference to fatigue. *Journal of Sports Sciences* 15, 257-263.

84. **Reilly T** (2001): Assessment of sports performance with particular reference to field games. *European Journal of Sports Science* 1(3), 1-13.

85. **Reilly T** (2005): An ergonomic model of the soccer training process. *Journal of Sports Science* 23(6), 561-572.

86. **Reilly T, Bangsbo J and Franks A** (2000): Anthropometric & physiological predispositions for elite soccer. Journal of Sports Science 18, 669-683.

87. **Reilly T & Gilbourne D** (2003): Science and football: a review of applied research in the football codes. *Journal of Sports Sciences* 21, 693-706.

88. **Reilly T & Secher N** (1994): Physiology of sport: an overview, in *Physiology of Sport* (eds Reilly T, Secher N, Snell P & Williams C) E & FN Spon London

89. **Reilly T & Thomas V** (1976): A motion analysis of work-rate in different positional roles in professional football match-play. *Journal of Human Movement Studies* 2, 87-97.

90. **Reinzi E, Drust B, Reilly T, Carter J & Martin A** (2000): Investigations of anthropometric and work rate profiles of elite South American international soccer players. *Journal of Sports Medicine and Physical Fitness* 40, 162-169.

91. **Saltin B** (1973): Metabolic fundamentals in exercise. *Medicine & Science in Sport & Exercise* 5, 137-146.

92. **Seliger V** (1968): Heart rate as an index of physical load in exercise. *Scripta Medica,* Medical Faculty Brno University, 41, 231-240. Sighted in **Bangsbo J** (1994): The physiology of soccer: With special reference to intense physical exercise. *Acta Physiologica Scandinavica* 150 (supple.619), 1-156.

93. **Stolen T, Chamari K, Castagna C & Wisloff U** (2005): Physiology of soccer: An update. *Sports Medicine* 36(6), 501-536.

94. **Stroyer J, Hansen L & Hansen K** (2004): Physiological profile and activity patterns of young soccer players during match play. *Medicine & Science in Sport & Exercise* 36(1), 168-174.

95. **Strudwick T & Reilly T** (2001): Work-rate profiles of elite Premier League football players. Sighted in Reilly T (2005): An ergonomic model of the soccer training process. *Journal of Sports Science* 23(6), 561-572.

96. **Svennson M & Drust B** (2005): Testing soccer players. *Journal of Sports Sciences* 23(6), 601-618.

97. **Tabata I, Nishimura K, Kouzaki M, Hirai Y, Ogita F, Miyachi M & Yamamoto K** (1996): Effects of moderate-intensity endurance and high intensity intermittent training on anaerobic capacity & VO_{2max}. *Medicine & Science in Sport & Exercise* 28(10), 1327-1330.

98. **Tabata I, Irisawa K, Kouzaki M, Nishimura K, Ogita F, & Miyachi M** (1997): Metabolic profile of high intensity intermittent exercise. *Medicine & Science in Sport & Exercise* 29(3), 390-395.

99. **Thatcher R & Batterham A.M** (2004): Development and validation of a sport-specific exercise protocol for elite youth soccer players. *Journal of Sports Medicine & Physical Fitness* 44, 15-22.

100. **Thevenet D, Tardieu-Berger M, Barthoin S & Prioux J** (2007): Influence of recovery mode (passive vs. active on time spent at maximal oxygen uptake during an intermittent session in young and endurance trained athletes. *European Journal of Applied Physiology* 99(2), 133-142.

101. **Thoden J (1991):** Testing Aerobic Power. In MacDougall J, Wenger H, Green H ed. *Physiological testing of the high performance athlete.* 2nd ed. Human Kinetics Champaign (IL), 107-173.

102. **Tomlin D & Wenger H** (2002): The relationship between aerobic power maintenance and oxygen consumption during intense intermittent exercise. *Journal of Science & Medicine in Sport* 5(3), 194-203.

103. **Van Gool D, Van Gervan D & Boutmans J** (1988): The physiological load imposed on soccer players during real match play. In **Reilly T, Lees A, Davids K & Murphy W eds.** (1988): *Science & Football II,* E& FN Spon London, 145-157.

104. **Wade A (1962):** Training of young players. *Medicina Dello Sport* (3) 1245-1251. Found in **Bangsbo J** (1994): The physiology of soccer: With special reference to intense physical exercise. *Acta Physiologica Scandinavica* 150(supple.619), 1-156.

105. **Wenger H & Bell G** (1986): The interaction of intensity, frequency and duration of exercise training in altering cardiorespiratory fitness. *Sports Medicine* 3, 346-356.

106. **Whitehead E** (1975): *Conditioning for Sport*. E P Publishing Yorkshire, 40-42. Found in **Bangsbo J** (1994): The physiology of soccer: With special reference to intense physical exercise. *Acta Physiologica Scandinavica* 150(supple.619), 1-156.

107. **Withers R, Maricie Z, Wasilewski S & Kelly L** (1982): Match analysis of Australian professional soccer players. *Journal of Human Movement Studies* 8, 159-176.

108. **Williams A & Franks S** (1998): Talent identification in soccer. *Sports Exercise & Injury* 4, 159-165

109. **Williford H, Scharff-Olson M, Duey W, Pugh S & Barksdale J** (1999): Physiological status and prediction of cardiovascular fitness in highly trained youth soccer players. *Journal of Strength & Conditioning Research* 13(1), 10-15.

110. **Winterbottom W** (1952): *Soccer Coaching*. Naldrett Press, London. Found in **Bangsbo J** (1994): The physiology of soccer: With special reference to intense physical exercise. *Acta Physiologica Scandinavica* 150(supple.619), 1-156.

111. **Wisloff U, Helgerud J & Hoff J** (1998): Strength and endurance of elite soccer players. *Medicine & Science in Sport & Exercise* 30(3), 462-467.

112. **Wisloff U, Ellingsen O & Kemi O** (2009): High intensity interval training to maximise cardiac benefits of exercise training? *Exercise & Sports Science Review* 37(3), 139-146.

113. **Withers R, Maricic Z, Wasilewski S & Kelly L** (1982): Match analysis of Australian professional soccer players. *Journal of Human Movement Studies* 8, 159-176.

114. **Zhou B, Conlee R, Jensen R, Fellingham G, George J & Fisher A** (2001): Stroke volume does not plateau during graded exercise in elite male distance runners. *Medicine & Science in Sport & Exercise* 33, 1849-1854.

APPENDICES

APPENDIX ONE

TESTING PROTOCOLS

VERTICAL JUMP:

(Ellis, Gastin, Lawrence, Savage, Buckeridge, Stapff, Tumilty, Quinn, Woolford & Young 2000)

Absolute and relative jumping ability incorporating arm swing is assessed using the vertical jump test. Where reactive power tests try and isolate leg power by eliminating the use of the arms, vertical jump tests are used to measure vertical power in a specific movement representative of a skill commonly performed in many sports.

Test Procedure:

Preparation/Test:

• Ensure that athlete has performed an appropriate warm-up.

• It is recommended that athlete's standing reach height be recorded by having athlete displace as many vanes on jump device as possible while standing flat-footed and side-on to the apparatus. Athlete should reach vertically with preferred hand.

• Starting from an upright position the athlete should stand side-on to the apparatus.

• Using an arm-swing and counter-movement the athlete is required to perform a vertical jump for maximal height; at the peak of the jump the athlete moves vanes on apparatus out of the way.

• Athlete should perform at least 3-5 trials.

• Record height achieved for each jump. Calculate vertical jump height by subtracting standing reach height from highest absolute jump height. Highest of all jumps performed should be recorded as maximum jump height.

Technique:

• A valid repetition is one in which athlete performs maximal vertical jump movement and moves vanes of apparatus at peak of jump.

Technical Violations:

The following technical violations will result in the trial being invalid.

• Holding of counter-movement squat position

• Excessive forward lean of upper body

Note: The yardstick® is the preferred equipment for VJ testing as it is a more familiar jumping action for athlete to perform; the athlete has no inhibitions about jumping into a wall; there are no space restriction, which can occur in vertical jump pits; and athletes reach directly upwards to displace the yardstick® veins and not to the side to touch the wall mounted board.

Multi-Stage Shuttle Test

(Ellis et al 2000):

Introduction

The audio format of the Multistage Shuttle Run Test has evolved from the cassette tape to the compact disk to the MP3 file. The Australian Institute of Sport conduct the Multistage Shuttle Run Test using an amplifier with a MP3 player permanently mounted to the side that holds a verified MP3 audio file of the Multistage Shuttle Run Test.

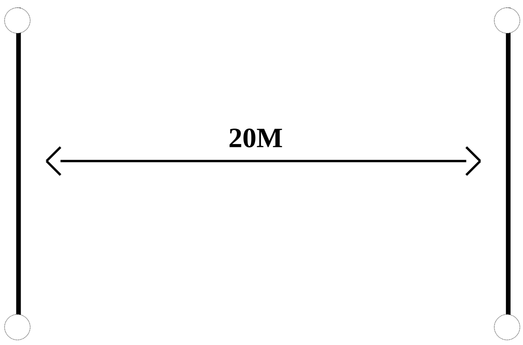
Should the physiologist wish to conduct the Multistage Shuttle Run Test using a compact disc, following points should be noted.

- Ensure the compact disk does not have any visible scratches on the surface
- Ensure the compact disk has been verified
- Ensure the compact disk player is powered by mains power, or fully charged batteries
- Ensure the compact disk player is positioned off the floor and at an adequate distance from the athletes to ensure the vibrations from the ground do not skip the compact disk.

Test Protocol

Place environmental sensor in the shade (do not use sensors in direct sunlight if outdoors) and leave to stabilize in environment for 20 minutes before taking readings. Note results down on data recording form.

Using a field tape measure and court marking tape, measure out the 20m shuttle run course as per the diagram below. Use at least one permanent line where possible (i.e. baseline or sideline). Check that the tape is not twisted during use and ensure the 20 m distance is measured to the inside edge of each line of tape.



Place two witches' hats at the each end of the 20m turning lines.

Plug the amplifier into mains power and turn on by switching the power switch.

Ensure that sound box volume is turned up.

Test Procedure

Ensure all participants complete an adequate warm up prior to commencing the test and have appropriate footwear

Give brief verbal instructions as to purpose of test, highlighting the exclusion criteria for the end of the test and recording system.

Note: Subjects are required to place one foot either on or behind the 20m line at each end of the shuttle.

Instruct subjects to assume a starting position on the starting 20m line.

Play the introductory tracks on the shuttle run MP3 file on the amplifier

Three beeps should be heard, followed by the commentator indicating the start of the test.

Subjects should begin running towards the opposite 20m line, aiming to reach it and turn as the next beep is emitted from the audio (single beep). If subjects arrive at the line before the beep is emitted, they should turn and wait until they hear the beep.

Testers are to walk along end lines watching for athletes falling short

A warning is given if a participant fails to place foot on or over 20m line in time with beep.

If a warning is given, the tester must clearly tell the athlete and signal the tester at the other end by raising one hand in the air to indicate that a warning has been given to a particular athlete. That tester then moves across to be in front of athlete coming down lane and encourages them to make the line to avoid elimination.

If athlete falls short of the line twice in succession (one warning and then another miss) they are to be eliminated.

Subjects should continue running for as long as possible, until they are unable to maintain the speed as indicated by the tape.

The level at which the subject withdraws and also the last shuttle completed should be recorded on a Post-It note and handed to the athlete for collection at the end of the test (i.e. level 8, shuttle 6).

The 20m shuttle run test is effort dependent, thus for valid results subjects must attempt to reach the highest level possible before stopping.

Verbal encouragement should be given to the subjects throughout the test.

Upon completion of the test, all participants should be encouraged to perform a warm down.

Sprint Test

(Ellis et al 2000):

Various sprint test protocols are used to assess the speed and acceleration of athletes from different sports. Electronic light gates are used for accuracy of timing and are placed at the start and finish of the sprint distance. Additional light gates may be placed at intermittent distances to provide split times.

Test Protocol

Set up

Using the measuring tape and court-marking tape, mark out the start and finish points of the course, as well as positions for intermittent light gates as per the requirements of the sport being tested.

Place two witches hats approximately four metres after the last light gate. The athletes should be instructed to run right through to the witches' hats to ensure they don't decelerate before they reach the final gate and thus increase their total time.

Place a strip of court-marking tape in line with the starting light gate (or at a measured distance behind the starting light gate for sport specific protocols). The subject must start the test with their front foot placed up to this mark.

Refer to SWIFT Timing Light Manual

Test Procedure

Instruct subject to assume starting position, with the front foot up to the starting line.

- After a signal that the light gates are set, the subject should start when ready. The light gates will start timing automatically as the subject passes through the first light gate.
- Ensure that subjects do not slow down before the finish gate, and keep sprinting through to the witches' hats.
- Record split times and total course time on the appropriate recording sheet.
- To recall previous split times, press the arrow buttons.
- Reset the timing device by pressing the [RESET] button followed by the [ENTER] button before the next subject commences the sprint.
- Allow subjects three trials. The fastest of each of the split times is combined to total the time for the prescribed distance.

Adequate rest must be allowed between sprints, usually achieved by rotating subjects through as part of a group

APPENDIX THREE:

INFORMATION FOR PARENTS AND GUARDIANS

Australian Catholic University
Brisbane Sydney Canberra Ballarat Melbourne

ACU National

INFORMATION LETTER TO PARENTS/GUARDIANS

Research project title:

The Effect of High Intensity Interval Training on Sustainable Sprinting Capacity in Football

Researchers' names:

Staff Supervisor: Professor Geraldine Naughton,

Co-Supervisor: Professor Keith Lyons

Research Student: Mr Timothy Rogers

Degree: Masters in Exercise Science

Dear Parent/ Guardian

We are conducting a research study which aims to determine the effect of 'high intensity interval training' on work capacity in men's football. Your child is invited to participate to assist us in investigating effective training methods to improve athlete performance.

What is the study about?

The study will take place as follows.

Pre-Testing

Your child will undertake physical testing including a 'Multi Stage Shuttle Test' (MSST, vertical jump and 20 m sprint tests. The results of the testing will help researchers describe the initial aerobic endurance and repeat sprint ability of the teams.

Pre testing for the whole group will take approximately 1 hour.

Your child will complete training and competition games wearing GPS movement analysis equipment. The GPS tracking device is the size of a mobile phone and is worn in a soft harness that resembles a relatively small back pack. The GPS device gives individual feedback on movement patterns such as total distance covered, number, time and distance of high intensity efforts and recovery as well as the amount of time spent at low intensity periods during normal play. Game statistics will also be accessed from videos of game play. Video taping of the games will specifically involve taping all active play within 10 metres of the ball.

Intervention

Following pre-testing, your child will be randomly divided into either an intervention or control group.

The control group will continue a normal training load.

The intervention group will undertake four (4) additional training sessions. These sessions will include a standardised 10minute warm up, followed by a 10 minute high intensity interval training session.

This session will involve high intensity interval running, conducted over a 20 m "out and back" sprint track. The high intensity interval training session will be followed by usual recovery practices.

The intervention will occur over a 4 week period, 3 times a week prior to the normal training sessions.

Post-Testing

The three tests that were that were used before the training program will be repeated at the end of the 5 week intervention. The post testing for the whole group will take approximately 1 hour also.

Outline of potential risks/reason for elimination from testing

The project uses tests and training procedures that are not new to aspiring elite level football players in Australia and the potential risks to your child are very low. However, there are some factors to consider.

To minimise the risk of injury we need to exclude players who have been injured in the past month (i.e. missed one or more competitive games) and players who have recently (previous two weeks) been ill (colds, flu, infections). This is necessary because results from players who are unable to give a maximal performance will make the results of the study inaccurate.

Testing and training sessions will include a thorough warm up and cool down to reduce the risk of injury during performance.

ACU National

Benefits to participation

Individuals participating will receive a copy of all testing results and gain a better understanding of their performance in aerobic power and sprinting performances compared with the group average. Individual feedback will also include a summary of the results of the study and implications of the results to their performance. Your child will receive ongoing education and coaching throughout the training intervention. Coaches will receive group results, but individual results will remain confidential.

If the program is successful, all players will have the opportunity to participate in this type of training in the future.

Freedom to choose

You should note that your child is free to choose not to take part in the study and to withdraw from the study, at any time without providing a reason and with no penalty. Your child's position at the AIS will not be affected should he choose not to participate or withdraw at a later date.

Confidentiality

Data collected from your child during the study will remain within the confidence of the researchers. Reports will not identify individual participants and only group results will be made available. Video analysis data will be securely kept in the database of the Australian Institute of Sport's Performance Analysis department. Other data will remain securely kept within the School of Exercise Science office at the Australian Catholic University, Strathfield.

Questions

If at any stage during the study you feel you would like to know more information then feel free to contact the supervisor by the contacts details given below.

Associate Professor Geraldine Naughton

School of Exercise Science

Australian Catholic University

Strathfield (St Mary's) Campus

25A Barkers Road

Phone: (02) 9701 4051

Fax: 9701 4290

Email g.naughton@mary.acu.edu.au

In the event that you have any complaints or concerns about the way your child has been treated by researchers in this study or if you have any query that the researcher has not been able to satisfy, you may write to the Chair of the Human Research Ethics Committee from the Research Services Unit of the Australian Catholic University:

Chair, HREC, Research Services
Australian Catholic University

Sydney Campus, Locked Bag 2002, STRATHFIELD NSW 2135

Telephone 02 9 701 4159, Fax 02 9 701 4350

Any complaint or concern will be treated in confidence and fully investigated. The participant will be informed of the outcome. If you agree to participate in the study you and your child should sign both copies of the Consent Form and Assent Form; retain one copy for your records and return the other to any one of the researchers.

CONSENT FORM **(COPY FOR PARENT/ GUARDIAN TO KEEP)**

Research project title:

The Effect of High Intensity Interval Training on Work Capacity in Football (Soccer)

Researchers' names:

Staff Supervisor: Professor Geraldine Naughton,

Co-Supervisor: Professor Keith Lyons

Research Student: Mr Timothy Rogers

Degree: Masters in Exercise Science

I .... (the parent/ guardian) have read and understand the information provided in the Information Letter to Parents/ Guardians. Any questions I have asked have been answered to my satisfaction. I understand the project involves physical testing including a 'Multi Stage Shuttle Test' and repeated sprint running tests as well as the possibility of being placed into the high intensity interval training group. I understand the project involves my son wearing a GPS device during games and also consent to the games being videotaped. I agree that my son nominated below, may participate in this activity, realizing that I can withdraw my consent at any time and withdrawing will not affect his position within the team. I agree that research data may be published to other researchers in a form that does not identify my son in any way.

NAME OF ATHLETE ....

(BLOCK LETTERS)

SIGNATURE .... DATE ....

SIGNATURE OF PRINCIPAL INVESTIGATOR... DATE ....

CHILD ASSENT

I ______________________________ (the participant aged under 18 years) understand what this research project is designed to explore. What I will be asked to do has been explained to me. I agree to take part in the project, realizing that I can withdraw at any time without having to give a reason for my decision and my position within the AIS will not be affected.

NAME OF ATHLETE ……………………………………………………………………

(BLOCK LETTERS)

SIGNATURE……………………………………………………………………………… DATE………………

Australian Catholic University Limited
ABN 15 050 192 660
School of Exercise Science (NSW)
Strathfield Campus (St Mary's)
25A Barker's Road North Sydney
New South Wales 2060 Australia
Locked Bag 2001 Strathfield
New South Wales 2235 Australia
Telephone 61 2 9701 4029
Facsimile 61 2 9701 4289
www.acu.edu.au

CRICOS registered provider:
00004G, 00112C, 00873F, 00885B

CONSENT FORM **(COPY FOR RESEARCHER TO KEEP)**

Research project title:

The Effect of High Intensity Interval Training on Work Capacity in Football (Soccer)

Researchers' names:

Staff Supervisor:	Professor Geraldine Naughton,
Co-Supervisor:	Professor Keith Lyons
Research Student:	Mr Timothy Rogers
Degree:	Masters in Exercise Science

I .... (the parent/ guardian) have read and understand the information provided in the Information Letter to Parents/ Guardians. Any questions I have asked have been answered to my satisfaction. I understand the project involves physical testing including a 'Multi Stage Shuttle Test' and repeated sprint running tests as well as the possibility of being placed into the high intensity interval training group. I understand the project involves my son wearing a GPS device during games and also consent to the games being videotaped. I agree that my son nominated below, may participate in this activity, realizing that I can withdraw my consent at any time and withdrawing will not affect his position within the team. I agree that research data may be published to other researchers in a form that does not identify my son in any way.

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NAME OF ATHLETE ....

(BLOCK LETTERS)

SIGNATURE.. DATE..................

Australian Catholic University Limited
ABN 15 050 192 660
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Strathfield Campus (St Mary's)
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00004G, 00112C, 00873F, 00885B

APPENDIX THREE:

INFORMED CONSENT

Australian Catholic University
Brisbane Sydney Canberra Ballarat Melbourne

ACU National

INFORMATION LETTER TO PARTICIPANTS

Research project title:

The Effect of High Intensity Interval Training on Work Capacity in Football (Soccer)

Researchers' names:

Staff Supervisor:	Professor Geraldine Naughton,
Co-Supervisor:	Professor Keith Lyons
Research Student:	Mr Timothy Rogers
Degree:	Masters in Exercise Science

Dear Participant

We are conducting a research study which aims to determine the effect of 'high intensity interval training' on work capacity in men's football. As a member of the squad you are invited to participate to assist us in investigating effective training methods to improve athlete performance.

What is the study about?

The study will take place as follows.

Pre-Testing

You will undertake physical testing including a 'Multi Stage Shuttle Test' (MSST), vertical jump and 20m sprint tests. The results of the testing will help researchers describe the initial aerobic endurance, power and speed ability of the teams.

Pre testing for the whole group will take approximately 1 hour.

You will complete in competition games wearing GPS movement analysis equipment. The GPS tracking device is the size of a mobile phone and is worn in a soft harness that resembles a relatively small back pack. The GPS device gives individual feedback on movement patterns such as total distance covered, number, time and distance of high intensity efforts and recovery as well as the amount of time spent at low intensity periods during normal play. Game statistics will also be accessed from videos of game play. Video taping of the games will specifically involve taping all active play within 10 metres of the ball.

Intervention

Following pre-testing, you will be randomly divided into either an intervention or control group.

The control group will continue a normal training load.

The intervention group will undertake four (4) additional training sessions. These sessions will include a standardised 10minute warm up, followed by a 10 minute high intensity interval training session.

This session will involve high intensity interval running, conducted over a 20 m “out and back” sprint track. The high intensity interval training session will be followed by usual recovery practices.

The intervention will occur over a 4 week period, 3 sessions per week prior to the normal training sessions.

Post-Testing

The two tests of repeated sprints and the multi-stage shuttle run that were used before the training program will be repeated at the end of the 4 week intervention. The post testing for the whole group will take approximately 1 hour also.

Outline of potential risks/reason for elimination from testing

The project uses tests and training procedures that are not new to aspiring elite level football players in Australia and the potential risks to you are very low. However, there are some factors to consider.

To minimise the risk of injury we need to exclude players who have been injured in the past month (i.e. missed one or more competitive games) and players who have recently (previous two weeks) been ill (colds, flu, infections). This is necessary because results from players who are unable to give a maximal performance will make the results of the study inaccurate.

Testing and training sessions will include a thorough warm up and cool down to reduce the risk of injury during performance.

Benefits to participation

Individuals participating will receive a copy of all testing results and gain a better understanding of their performance in aerobic power and sprinting performances compared with the group average. Individual feedback will also include a summary of the results of the study and implications of the results to their performance. Your child will receive ongoing education and coaching throughout the training intervention. Coaches will receive group results, but individual results will remain confidential.

If the program is successful, all players will have the opportunity to participate in this type of training in the future.

Freedom to choose

You should note that you are free to choose not to take part in the study and to withdraw from the study, at any time without providing a reason and with no penalty. Your position at the AIS will not be affected should he choose not to participate or withdraw at a later date.

Confidentiality

Data collected from the study will remain within the confidence of the researchers. Reports will not identify individual participants and only group results will be made available. Video analysis data will be securely kept in the database of the Australian Institute of Sport's Performance Analysis department. Other data will remain securely kept within the School of Exercise Science office at the Australian Catholic University, Strathfield.

Questions

If at any stage during the study you feel you would like to know more information then feel free to contact the supervisor by the contacts details given below.

Professor Geraldine Naughton

School of Exercise Science

Australian Catholic University

Strathfield (St Mary's) Campus

25A Barkers Road

Phone: (02) 9701 4051

Fax: 9701 4290

Email g.naughton@mary.acu.edu.au

In the event that you have any complaints or concerns about the way your child has been treated by researchers in this study or if you have any query that the researcher has not been able to satisfy, you may write to the Chair of the Human Research Ethics Committee from the Research Services Unit of the Australian Catholic University:

Chair, HREC, Research Services
Australian Catholic University

Sydney Campus, Locked Bag 2002, STRATHFIELD NSW 2135

Telephone 02 9 701 4159, Fax 02 9 701 4350

Any complaint or concern will be treated in confidence and fully investigated. The participant will be informed of the outcome.

If you agree to participate in the study you and your child should sign both copies of the Consent Form and Assent Form; retain one copy for your records and return the other to any one of the researchers.

Australian Catholic University
Brisbane Sydney Canberra Ballarat Melbourne

ACU National

CONSENT FORM **(COPY FOR PARTICIPANT)**

Research project title:

The Effect of High Intensity Interval Training on Sustainable Sprinting Capacity in Football

Researchers' names:

Staff Supervisor: Professor Geraldine Naughton,

Co-Supervisor: Professor Keith Lyons

Research Student: Mr Timothy Rogers

Degree: Masters in Exercise Science

I .... have read and understand the information provided in the Information for Participants. Any questions I have asked have been answered to my satisfaction. I understand the project involves physical testing including a 'Multi Stage Shuttle Test' and repeated sprint running tests as well as the possibility of being placed into the high intensity interval training group. I understand the project involves wearing a GPS device during games and also consent to the games being videotaped. I realize that I can withdraw my consent at any time and withdrawing will not affect my position within the team. I agree that research data may be published to other researchers in a form that does not identify me in any way.

NAME OF ATHLETE ....

(BLOCK LETTERS)

SIGNATURE .... DATE ....

SIGNATURE OF PRINCIPAL INVESTIGATOR... DATE ....

CONSENT FORM **(COPY FOR RESEARCHER TO KEEP)**

Research project title:

The Effect of High Intensity Interval Training on Sustainable Sprinting Capacity in Football

Researchers' names:

Staff Supervisor: Professor Geraldine Naughton,

Co-Supervisor: Professor Keith Lyons

Research Student: Mr Timothy Rogers

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NAME OF ATHLETE ....

(BLOCK LETTERS)

SIGNATURE .... DATE ....

SIGNATURE OF PRINCIPAL INVESTIGATOR... DATE ....

APPENDIX FOUR

ETHICS APPROVAL