PHYSIOLOGICAL ASSESSMENT IN TALENT IDENTIFICATION WITHIN AUSTRALIAN FOOTBALL

Submitted by

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ABSTRACT

Predicting long-term success in talented athletes at an early age requires a multi-factorial, longitudinal approach that combines both scientific observations and intuitive judgements in the identification process. Traditionally, the measurement of physiological characteristics in the team sport environment is conducted in one-off testing sessions, with results used to discriminate performance outcomes for team selection. Nevertheless, the changing nature of Australian Football (AF) has raised questions over the specificity of currently used field test protocols. Therefore, the aim of this thesis was to validate newly designed physiological field tests specific to AF, measuring its discriminatory ability within a longitudinal research design, incorporating body compositional changes, at the elite junior AF level.

Newly designed field tests included a reactive agility, repeat sprint ability, running vertical jump (single and double leg) and yo-yo intermittent endurance. Reliability and validity testing were performed on these tests, in males (16.6 ± 0.5 years), between elite, sub-elite AF junior players and a healthy control population.

This novel test battery was then implemented in a longitudinal (two-year) research design (eight measures every three months). Furthermore, dual energy x-ray absorptiometry (DEXA) scans were conducted on four occasions (half-yearly) over the two year period, correlating growth and physical development to physiological test performance. Results demonstrated the ability of each test to measure changes in performance over time, whilst also discriminating performance differences between elite and sub-elite AF athletes. Body composition analysis also identified trends towards the selection of leaner athletes at the elite level of competition, with moderate correlations between an increased fat weight and negative physical test performances also identified. Further research is required into the other characteristics that make up successful athletic performance (technical, tactical, psychological). However, this research has demonstrated the value of specific physiological testing for identification and assessment of athlete development in AF.

DECLARATION

Doctor of Philosophy Declaration

“I, James Veale, declare that the PhD thesis entitled “Physiological Assessment in Talent Identification within Australian Football” is no more than 100,000 words in length including quotes and exclusive of tables, figures, appendices, bibliography, references and footnotes. This thesis contains no material that has been submitted previously, in whole or in part, for the award of any other academic degree or diploma. Except where otherwise indicated, this thesis is my own work”.

Signature: Date: 25/07/2011

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Thank you

James Veale

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Chapter 3

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Chapter 7

Veale JP, Pearce AJ, Buttifant D, Carlson JS. (2010) Anthropometric profiling of Elite Junior and Senior Australian Football Players. *International Journal of Sports Physiology and Performance* **5**, 509-520.

CONFERENCE ABSTRACTS ARISING FROM THIS THESIS

Chapter 7

Veale JP, Pearce AJ, Buttifant D, Carlson JS. Anthropometric profiling of Elite Junior and Senior Australian Football Players. International Journal of Sports Physiology and Performance. 2009_0138. (In Press). Invited presentation at the Australian Football League National Coaches Conference, Adelaide, Australia, 2010.

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GLOSSARY OF ABBREVIATED TERMINOLOGY

AF	Australian Football
AFL	Australian Football League
ATP	Adenosine tri-phosphate
BMC	Bone Mineral Content
BMD	Bone Mineral Density
CMJ	Counter-movement Jump
COD	Change of direction
DEXA	Dual Energy X-ray Absorptiometry
CV	Coefficient of Variation
ES	Effect size
FFM	Fat-free mass
FI	Fatigue Index
FM	Fat mass
ICC	Interclass coefficient
IR	Intermittent Recovery
IR1	Intermittent Recovery Level 1
IR2	Intermittent Recovery Level 2
LM	Lean mass
MSFT	Multi-Stage Fitness Test
RAT	Reactive agility test
RM	Repetition max
RSA	Repeated sprint ability
RVJ	Running Vertical Jump
RVJL	Running Vertical Jump from a Left foot take-off
RVJR	Running Vertical Jump from a Right foot take-off
SSE	Single sprint effort
SVJ	Standing Vertical Jump
SW	Shapiro-Wilks
T1 – T8	Test 1, Test 2, Test 3, Test 4, Test 5, Test 6, Test 7, Test 8
TEM	Typical Error of Measurement
TID	Talent Identification

U16	Under 16
U18	Under 18
VJ	Vertical Jump
VO_2max	Maximum aerobic capacity

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND AND PURPOSE OF THE THESIS

A highly valued component within the field of sports science is the role of talent identification (TID) and the development of future elite performance (Williams & Reilly, 2000). Williams and Reilly (2000) proposed four key stages involved in the identification and development process of talent (Figure 1.1).

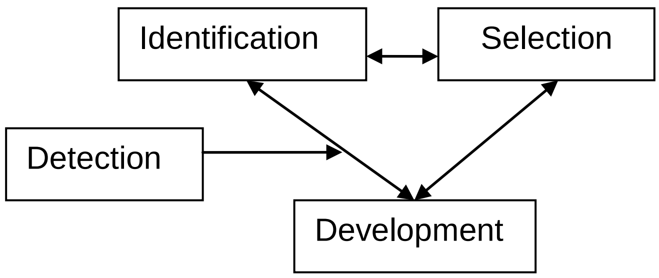

Figure 1.1 Talent identification and development model (Williams & Reilly, 2000).

The discovery of potential athletes not currently involved in the particular sport is referred to as “talent detection”, whereas “talent identification” refers to the recognition of current participants observed to posses the potential to become elite athletes. Once identified, “talent development” implies the subsequent provision of an optimal learning environment to enhance the realisation of potential, with the final element, “talent selection” involving the ongoing inclusion of such talented athletes into squads and/or teams (Williams & Reilly, 2000). Despite the lack of consensus within the literature as to the optimal method of “talent identification”, commonalities exist within the research using the analysis of anthropometric, physiological, psychological and sociological attributes over a period of time (Règnier *et al.*, 1993; Howe *et al.*, 1998;

Williams & Reilly, 2000). Consequently, sport science has been shown to provide an objective contribution to the TID pathway in identifying an individual's strengths and weaknesses, complementing any subjective observational assessment (Williams & Reilly, 2000).

This thesis will contribute to the small but increasing research focus into the role of physical development and physiological testing in the TID pathway within junior sport (Malina, 1994; Pena Reyes *et al.*, 1994; Malina *et al.*, 2000; Reilly *et al.*, 2000b; Williams & Reilly, 2000). Currently, the value of fitness testing has been shown in assessing and monitoring the development of young Australian Football (AF) players and their progression into the elite senior competition (Pyne *et al.*, 2005; Pyne *et al.*, 2006). Employing a physical test battery that combines currently used AF protocols (Keogh, 1999; Pyne *et al.*, 2005; Young & Pryor, 2007; Veale *et al.*, 2008) with the incorporation of new validated field tests, this thesis assessed the longitudinal progress of an elite junior AF playing group over two consecutive competitive seasons. Over this time frame, body composition development analysis was also conducted, measuring changes within elite junior AF players as they progressed towards a senior playing career. Such research aims to improve the AF talent development system by complementing the current available research in educating conditioning staff, coaches and recruiters on key anthropometric and physiological attributes in identifying talented AF athletes at an early age. Furthermore, identifying development changes within these attributes over time will cultivate a deeper level of understanding into the physical expectations placed on elite junior AF athletes, ascertaining key physical components for training focus within this age group.

1.2 RESEARCH AIMS

The primary aim of this thesis was

- To determine the role of physiological testing and body composition analysis within the elite junior AF TID pathway, via the design and implementation of a sport specific test battery that will be used over a two year period.

The secondary aim of this thesis was:

- To measure the reliability and validity of a novel physiological test battery and the ability of these tests to discriminate elite junior AF athletes against their sub-elite AF counterparts;

Specific aims of each study will be listed in the proceeding chapters.

1.3 THEORETICAL FRAMEWORK

To date, a variety of physiological test batteries have been used across the different AF competition levels in an attempt to discriminate within and between the participating athletes. This thesis further explored the use of physiological testing within the TID and development pathway by measuring the following physical attributes:

- Agility;
- Repeated Sprint Ability (Speed);
- Power;
- Aerobic Capacity; and
- Body composition.

As this is the first thesis to use a longitudinal analysis technique in tracking the physical development and growth of a group of elite junior AF athletes, research methodology was modeled upon and results compared with appropriate levels of competition across other team sports (soccer, rugby, hockey etc.). Adapting commonly used methodology (Brady *et al.*, 1995; Dunbar, 2002; Aziz *et al.*, 2005a), seasonal testing of athletes was conducted on return from an off-season of no AF training (November / December), at the completion of the pre-season training phase (March), mid-season (June) and at the conclusion of the competitive season (September) over two consecutive years (2008 and 2009, [Figure 1.2]). Using a single day test design for the completion of the physical test battery at each of the nominated testing time points (Walker & Turner, 2009), athletes had the capacity to collect eight data points over the duration of the study. In conjunction, body composition analysis was conducted via dual energy x-ray absorptiometry (DEXA). Body composition measures were taken on four occasions throughout the course of the study; at the completion of each pre-season (March 2008, 2009) and each competitive season (September 2008, 2009; [Figure 1.2]). The following measures were recorded as total (whole body), regional (segmental body analysis) and as a percentage of total body mass:

- Lean mass,
- Fat mass,
- Bone Mineral Content (BMC),
- Bone Mineral Density (BMD) and
- Bone Area

Correlation analysis was conducted to measure the relationship between changes in body composition with changes in physiological test performances over the two years. Furthermore, between groups analysis was conducted to identify any trends that may exist in performance and body composition development between athletes identified prior to the study as elite (represented their state at a junior national competition), sub-elite (invited to try out but failed to be selected to represent their state) and healthy participants (were not invited to try out for the state representative team).

A diagrammatical representation of the theoretical framework of the research is shown in Figure 1.3, demonstrating the physical variables measured within this thesis and the competition pathway of talented elite junior AF participants.

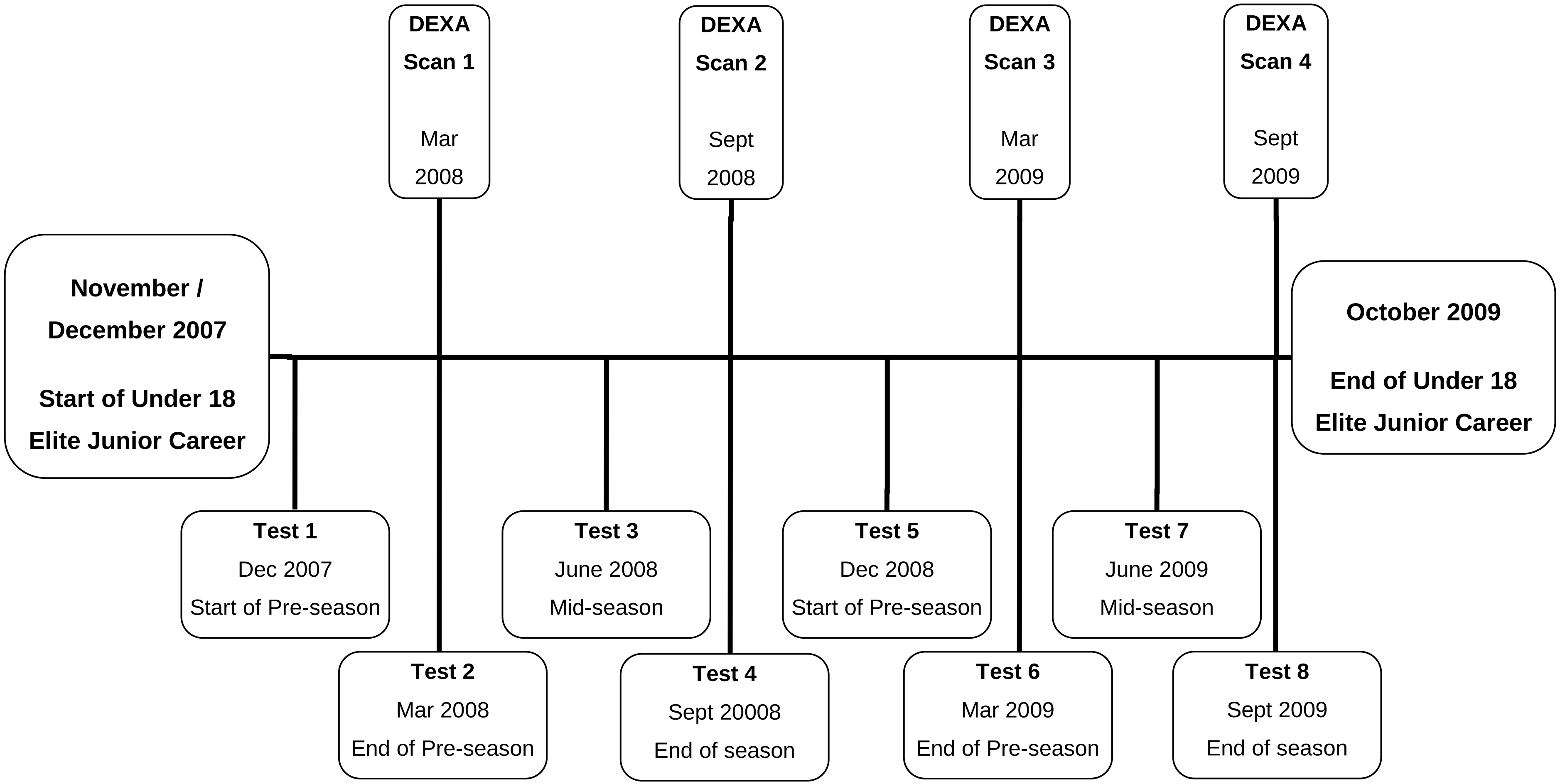

Figure 1.2 Timeline of the research.

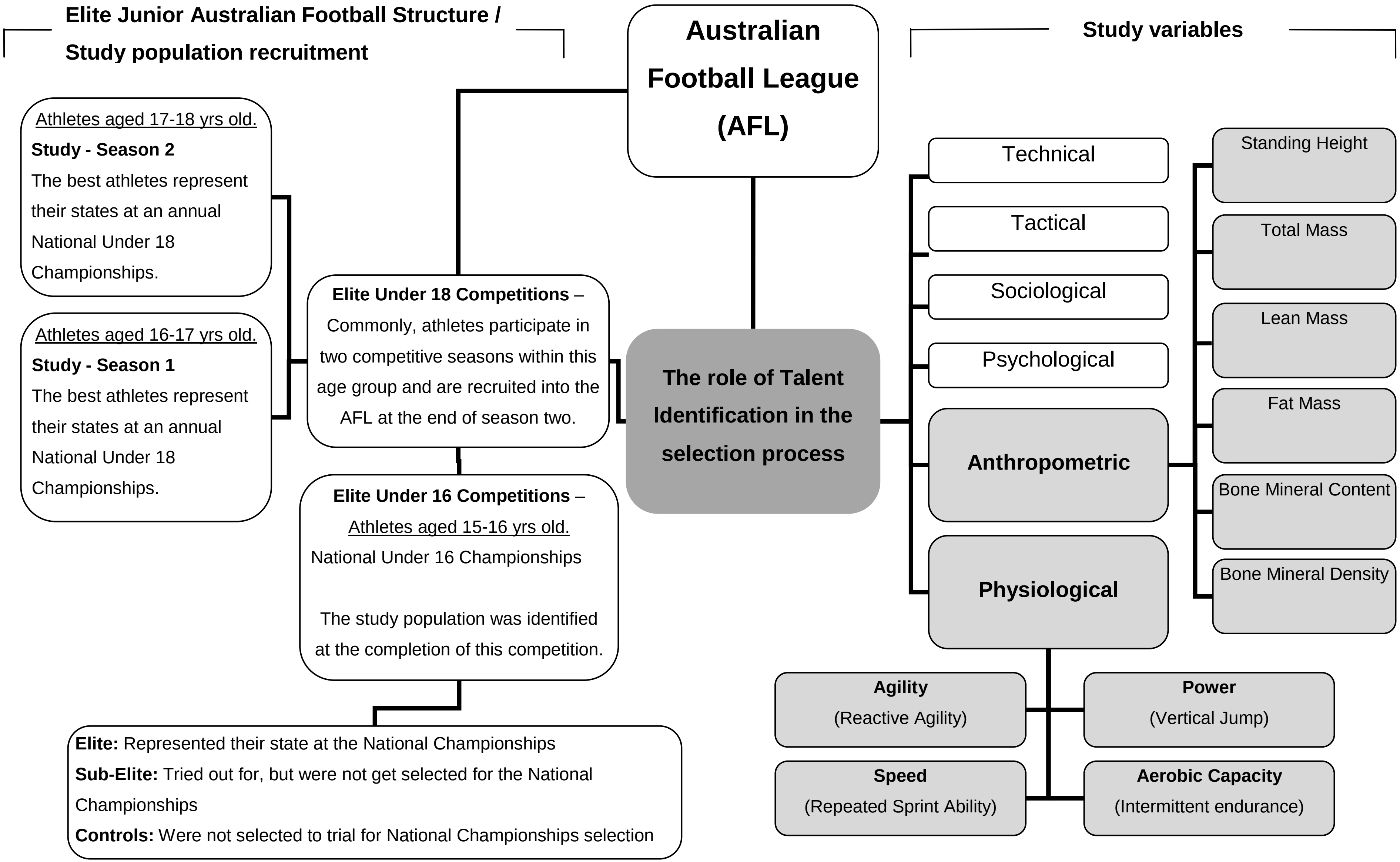

Figure 1.3 Theoretical framework of the research.

CHAPTER 2

LITERATURE REVIEW

2.1 AUSTRALIAN FOOTBALL

Established in 1896, Australian Football (AF) started as a state league competition (Victorian Football League), expanding to include teams from around the country in the late 1980s and early 1990s. A following name change to the Australian Football League (AFL) in 1997 resulted in the official development of a national AF competition. Combining facets of a number of internationally played sports, AF is a unique blend of the many 'football codes' recognised around the world including, but not limited to: soccer, rugby (both union and league codes), American and Gaelic Football (Douge, 1988). Currently, AF is played over four quarters, with short breaks (6 mins) after the first and third quarters and an extended half time break (20 mins) after the second quarter. Over time, changes to the number of players available per team and the game duration have influenced the manner in which modern AF is played (Norton *et al.*, 1999). Whilst AF has constantly fielded a maximum of eighteen players at any stage throughout a quarter, the interchange has grown from no players prior to 1930, to one player until 1947, two until 1977, three in the 1990s until the current four of today and an unlimited number of player rotations (Norton *et al.,* 1999). Australian football was changed from four 25 minute quarters plus stoppage time (extra time during each quarter to account for periods when the game is stopped due to activities that halt its natural flow; e.g. injury requiring a stretcher or waiting for the ball to be returned from the crowd) to four by 20 minute quarters plus stoppage time in 1994, no considerable change in total game time has been recorded (Norton *et al.,* 1999).

Over the last four decades (dating back to 1961), despite no systematic change in total game time (not including the quarter time breaks), there has been a marked reduction in the time spent in ‘play time’ (time periods where the ball is in movement or dispute). However according to Norton and colleagues (1999), while the fraction of time available for play has decreased, the increased number of shorter periods of play interspersed by more frequent and longer stop periods has seen the velocity of ball travel almost double since 1961. As a result, the speed at which game-play activities are now being completed has increased, with a greater reliance placed on an athlete’s ability to complete repeated short distance sprints interspersed by brief recovery periods. In the only direct comparison between eras, games played in 1961 and 1997 reported an increase in player speed by 30% and a total increase in ground coverage of 460 m when participating at this high-intensity of movement (Norton *et al.,* 1999). Furthermore, the average body mass reported across the elite senior AF competition has gradually increased by 5% per decade since 1961, with a predicted estimate of 3.7-4.1% increase in bone mass (Norton *et al.,* 1999). However, in comparison to the other football codes, only a small number of studies have been conducted within AF, delving into issues including applied physiological and movement pattern analyses, talent identification (TID) and injury rates (Buttifant, 1999; Keogh, 1999; Appleby & Dawson, 2002; Braham *et al.*, 2004; Dawson *et al.*, 2004b, a; Pyne *et al.*, 2005; Young *et al.*, 2005; Pyne *et al.*, 2006; Veale, 2006; Veale *et al.*, 2007a; Young & Pryor, 2007; Veale *et al.*, 2008; Young *et al.*, 2008; Veale *et al.*, 2009c, b). Consequently, the increased physical demands within the modern version of AF highlights the need for greater analysis of the role of each physiological component deemed necessary for successful athletic performance.

2.1.1 TALENT IDENTIFICATION FROM JUNIOR SPORT

With the development of a national AF competition in 1997, state leagues around Australia became secondary competitions for contracted Australian Football League (AFL) players to participate in when they were not selected to play for their AFL team. Furthermore, these competitions provide an avenue for senior AFL clubs to monitor the progress of athletes for possible drafting (selection onto an elite senior AFL playing list) at the end of each season. In a similar structure, elite junior competitions across the country provide the most talented junior AF athletes an opportunity to participate at the highest level, with the potential to represent their state at an annual national carnival (at both under 16 [U16] and under 18 [U18] levels). In 1992 in the state of Victoria, an U18 program was developed as a standalone competition for junior athletes in accordance to the location of their primary residence. After participating in this competition (or any junior competition around Australia), athletes older than 18 years of age can nominate for the national draft. Through the national draft, each AFL club signs a number of ‘new’ athletes to their list, ensuring that the future of their club and the competition is continued. This highlights the significance of identifying and selecting the most talented junior athletes from amongst their peers.

Similar to soccer (Williams & Reilly, 2000), anecdotal evidence suggests AF clubs invest significant amounts of money in identifying and nurturing potentially elite players in order to remain competitive within the senior national competition. Within the soccer development structure, early identification of athletic potential ensures players have access to specialised coaching and training, accelerating their development and minimising the pool of junior athletes to effectively manage (Williams & Reilly, 2000). Whilst the pursuit of excellence can be classified by four key stages (Detection, Identification, Development and Selection [Pienaar *et al.*, 1998; Williams & Reilly, 2000]), 'identification' and 'development' were the two focus areas of this research. Detection and selection refer to the stages of discovery of potentially elite athletes and their subsequent involvement within the sport in question. Identification however, differs from this process by recognising within current participants those with the potential to become elite, involving the prediction of performance based on measurements and test performances across a variety of categories (e.g. physical, physiological, psychological, sociological [Règnier *et al.*, 1993; Williams & Reilly, 2000]). Once identified, talent development involves the provision of a suitable learning environment for each athlete to maximise their potential. Consequently, research is often aimed toward the identification of characteristics that differentiate between elite and sub-elite athletes and the ability of tests to monitor their physical progression (Williams & Reilly, 2000). This systematic collection of information over time would ensure coaches and talent scouts are better informed about the physical and physiological development of young athletes, increasing the predictive utility of fitness test batteries (Williams & Reilly, 2000; Elferink-Gemser *et al.*, 2006).

However, the lack of validity across many proposed TID models limits the ability of test results and scientific observation to complement the intuitive judgments made regarding young talented athletes (Reilly & Stratton, 1995; Pienaar *et al.*, 1998; Reilly *et al.*, 2000b). As a result, Reilly and colleagues (2000b) highlighted the combined need of understanding the requirements for playing at an elite standard with a longitudinal profile of successful prototypes. In an all-encompassing TID model, Reilly *et al.* (2000b) used a multivariate analysis technique involving anthropometric, physiological, psychological and soccer-specific skill measures to assess talent in young (15.8-16.7 years of age) soccer players and the ability of these testing procedures to distinguish elite from sub-elite athletes. Of the ten physiological measures used, eight (maximum oxygen uptake, standing vertical jump, 15 m- 25 m- and 30 m sprint and agility times, fatigue tolerance and repeated sprint ability) recorded significant differences. In a stepwise discriminant analysis, agility and 30 m sprint time were deemed to be the physiological attributes that successfully discriminated between the elite and sub-elite junior players, with the need for longitudinal research to examine the validity of their use as talent predictors over time.

Nevertheless, the progressive improvement in the physiological capacities of team sport athletes as their playing level increased from junior to senior levels ensures physiological test results remain a useful tool in the monitoring of physical development (Gabbett, 2006a). Differing from individual athlete sports (e.g. track and field, cycling and rowing) that provide discrete objective measures of performance, the complex nature of team sports requires a multivariate approach in the identification and development of talent from an early age (Reilly *et al.*, 2000b; Williams & Reilly, 2000; Vaeyens *et al.*, 2006). Considering the impact of external factors including access to coaching, facilities and practice, injuries and a host of personal, social and cultural factors, only a few all encompassing TID models within the team sport environment have been produced and validated, with most multidisciplinary research conducted in the sport of soccer (Reilly & Stratton, 1995; Pienaar *et al.*, 1998; Reilly *et al.*, 2000b; Elferink-Gemser *et al.*, 2006; Vaeyens *et al.*, 2006). To date, common elements measured within the various TID models include a combination of anthropometric, physiological, neuromotor, cognitive-perceptual and psychosocial variables (Williams & Reilly, 2000; Vaeyens *et al.*, 2006). However, due to a variety of limitations involved in completing all encompassing TID research, it is more common to find a large number of studies identifying relationships between individual attributes (e.g. physical test performance) and team selection within elite junior and senior competitions (Keogh, 1999; Edwards *et al.*, 2002; Gabbett, 2002a; Pyne *et al.*, 2005; Young *et al.*, 2005; Pyne *et al.*, 2006; Young & Pryor, 2007; Gravina *et al.*, 2008; Veale *et al.*, 2008). Such research has resulted in the development of reference data for successful performance via the measurement of differences between various standards of sporting competition (e.g. elite vs. sub-elite [Rigg & Reilly, 1988; Keogh, 1999; Reilly *et al.*, 2000b; Gabbett, 2002b, a, 2005; Hoff *et al.*, 2005; Pyne *et al.*, 2005; Young *et al.*, 2005; Gabbett, 2006a; Young & Pryor, 2007; Gravina *et al.*, 2008; Veale *et al.*, 2008; Gabbett *et al.*, 2009]). Subsequently, whilst a wide ranging view of TID and development would involve areas of psychological profiling and sport-specific skills testing, this research limited its focus to the longitudinal application of a physiological test battery to monitoring the physical development of and to discriminate between elite and sub-elite junior AF athletes.

2.1.2 PHYSICAL TESTING OF ELITE JUNIOR AUSTRALIAN FOOTBALLERS

With similarities to the other football codes, AF encompasses the basic physical characteristics of agility, speed, power and aerobic capacity required for successful participation within the team sport environment. Nevertheless, within the limited AF research to date, a consensus has yet to be achieved on the level of importance of each physiological quality towards game day performance or successful team selection. As a result, a variety of tests have been used to measure each physiological characteristic, creating different test batteries aimed at identifying talent (Keogh, 1999; Pyne *et al.*, 2005; Pyne *et al.*, 2006; Young & Pryor, 2007; Veale *et al.*, 2008). Endurance has been measured via the multistage fitness test ([MSFT], Keogh, 1999; Pyne *et al.*, 2005) and a 3km time trial (Veale et al., 2008), while straight line acceleration and speed has been measured via 5 m, 10 m and 20 m sprint times (Pyne *et al.*, 2005; Young & Pryor, 2007; Veale *et al.*, 2008). A planned agility run was used in the studies by Pyne and colleagues (2005), Young and Pryor (2007) and Veale *et al.* (2008) and lower limb power has been measured by a standing vertical jump (SVJ) test (Keogh, 1999; Pyne *et al.*, 2005; Young & Pryor, 2007; Veale *et al.*, 2008) and a running vertical jump (RVJ) test (Pyne *et al.*, 2005). A study by Keogh (1999) is the only research to incorporate a strength test within a test battery (a 3 repetition max (RM) bench press), potentially due to the difficulty in designing tests to measure strength that replicate AF specific muscular function (Young *et al.,* 2005).

Currently, only two case studies have compared the physical characteristics of athletes selected and not selected onto an elite junior AF squad. Keogh (1999) reported selected athletes were significantly taller, heavier, stronger (3RM bench press) and possessed a greater SVJ ability, whilst Veale *et al.* (2008) reported only SVJ scores were significantly greater in identifying athletes who were selected. However when test performance was viewed holistically, Veale *et al.* (2008) determined athletes who performed consistently better across all physical measures were significantly more likely to be selected than not. In a study comparing physical test performance scores to subsequent game performance across an elite junior AF competition, Young and Pryor (2007) reported those selected to play in the first round of the season were significantly heavier, faster, more agile and possessed a greater SVJ and maximum aerobic capacity (VO_2max). Furthermore, Pyne *et al.* (2005) has identified across a cohort of the most talented junior AF athletes, straight line speed (5 and 10 m) and endurance (MSFT) were distinguishable characteristics between those drafted and those not into the AFL competition. Although jump tests recorded no substantial differences at this level of comparison, RVJ scores were reported as the only likely difference in physical characteristic between those athletes who went on and made their debut at the senior level compared to those that never played a game.

Despite these results, a major limitation within the small amount of research involving elite junior AF athletes is the current lack of validation connecting the popular field tests used in the TID and selection process with the specific game and movement demands experienced at this level of competition. As a result, it is vital for the involvement of each physiological characteristic within the game of AF to be studied, measuring their importance at this level of competition. Furthermore, the field tests chosen to measure each identified physical characteristic must be specific to the game demands and movement patterns at the elite junior AF level of competition to provide reliable and valid sport specific data for use in the TID process. Longitudinal research is then required to analyse development patterns over time (Impellizzeri & Marcora, 2009). This literature review will cover each physiological attribute studied within this thesis, whilst also assessing the limited longitudinal research currently conducted across the team sport environment.

2.2 AGILITY

Sprinting patterns of team sport athletes involve rapid directional changes in comparison to the straight line running of their track and field counterparts (Gambetta, 1996; Twist & Benicky, 1996; Young *et al.*, 2002; Dawson *et al.*, 2004b). However, the complexity of team sport activities has resulted in a common use of agility tests despite a precise definition of sport-specific agility (Sheppard & Young, 2006). In a review of the literature, Sheppard and Young (2006) found that a change in body position during a dynamic sporting action was commonly used to describe the term agility (Draper & Lancaster, 1985; Fulton, 1992; Hastad & Lacy, 1994), whilst sprinting with directional changes was the most common application (Rigg & Reilly, 1988; Fulton, 1992; Gambetta, 1996; Twist & Benicky, 1996; Reilly *et al.*, 2000b; Meir *et al.*, 2001; Gabbett, 2002b). This definition of agility, also referred to as change of direction (COD) speed or planned agility (Farrow *et al.*, 2005; Sheppard & Young, 2006; Sheppard *et al.*, 2006), has successfully discriminated between athletes of varying playing standards in soccer (Reilly *et al.*, 2000b), AF (Sheppard *et al.,* 2006), netball (Farrow *et al.,* 2005) and rugby league (Gabbett & Benton, 2009; Gabbett *et al.*, 2009). Displaying vast similarities, the term quickness (the ability to cover sport specific running patterns in the shortest possible time) has also been used when studying differences between straight line and sport specific speed (Young *et al.*, 1996; Dintiman *et al.*, 1998; Baker, 1999). Nevertheless, considering directional changes whilst sprinting in team sports are in response to a stimulus (e.g. movement of an opponent or the ball [Docherty *et al.*, 1988; Reilly *et al.*, 2000a; Meir *et al.*, 2001; Dawson *et al.*, 2004b, a]), recent development has seen agility defined as a rapid whole-body movement with change of velocity or direction in response to a stimulus (Sheppard & Young, 2006; Oliver & Meyers, 2009). With the increasing speed of the modern game of AF (Norton *et al.,* 1999), understanding the role of agility movements has become more important when assessing performance and developing young athletes. This component of the literature review will briefly cover the use of agility testing within the identification and development of athletes in the team-sport environment.

2.2.1 CHANGE OF DIRECTION ("Closed Skill") TESTING

Closed-skill tests involving pre-planned courses that comprise a set number of changes of direction while running at high speed are the most commonly reported measures of agility within the team-sport research (Draper & Lancaster, 1985; Rigg & Reilly, 1988; Fulton, 1992; Gambetta, 1996; Murray, 1996; Twist & Benicky, 1996; Young *et al.*, 1996; Buttifant *et al.*, 1999; Reilly *et al.*, 2000b; Meir *et al.*, 2001; Gabbett, 2002b; Quarrie & Williams, 2002; Pyne *et al.*, 2005; Oliver & Meyers, 2009). Such tests measure an athlete's ability to rapidly change direction whilst maintaining balance and without losing speed. Time lost whilst decelerating and re-accelerating and the lateral force produced to change direction have been deemed responsible for slowing the time to complete a course in response to an increase in severity of the angle of directional change (Young *et al.*, 2002). Subsequently, muscular power and acceleration are key components within agility performance, with closed-skill agility courses invariably influenced by individual differences in running velocities preceding and post the directional change (Draper & Lancaster, 1985). In a study evaluating the reliability and validity of the T-test, a measure of 4-directional agility and body control (Figure 2.1), Pauole *et al.* (2000) reported that leg speed contributed substantially to the variability in test results.

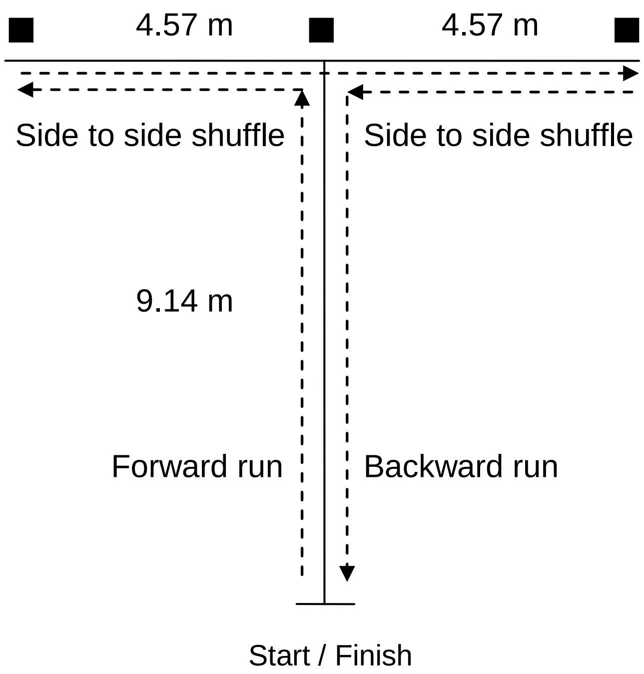

Figure 2.1 The change of direction T-test design (Moreno, 1995).

Furthermore, a number of studies have measured the transference between performance in straight sprint and COD tests of varying complexities, reporting systematically longer times with the increase in angle of direction change and the number of changes involved (Young *et al.*, 1996; Baker, 1999; Buttifant *et al.*, 1999; Young *et al.*, 2001c). In earlier research, Buttifant and colleagues (1999) determined that sprinting speed accounted for only approximately 10% of the mean time in a "closed skill" agility test (Figure 2.2), discriminating between speed and agility of elite junior soccer players. The other 90% of the COD test that was not accounted for was attributed to the 'agility' of the player; including components such as anticipation, the ability to react and decelerate quickly, as well as eccentric leg strength (Buttifant *et al.,* 1999). However, with the nature of the test being pre-planned and involving only closed skills, the assumption of anticipation and reaction within this test as a measured component of agility is questionable. Nevertheless, Young *et al.* (2001c) also demonstrated a limited transfer between straight sprint training and COD tasks, with only COD training resulting in significant gains in test performance across all agility tests.

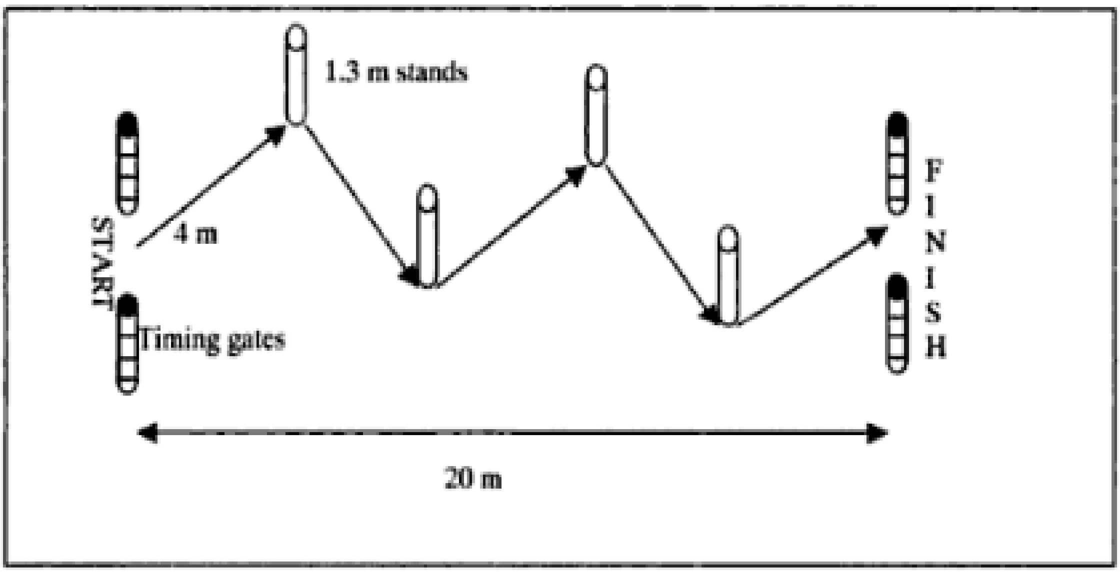

Figure 2.2 Buttifant and colleagues (1999) change of direction test.

Studying the transference of speed and game related tasks to agility performance, Young *et al.* (1996) tested community level senior AF players on separate speed and agility activities, including straight line 20 m sprinting, 20 m sprinting with three 90º COD and a 20 m sprint with three 120º changes. When comparing straight line sprinting with COD performance, Young *et al.* (1996) reported an increased 20 m time of 65% in the 90º COD condition and 86% in the 120º condition. Furthermore a low correlation with straight sprint performance was recorded (r = 0.27 and r = 0.19), indicating the independent nature of each running track. This was deemed an expected difference as the degree of direction change increased in response to the greater need to decelerate into and accelerate out of each turn (Young *et al.*, 1996). Highlighting the uniqueness of COD speed in comparison to straight sprinting speed, players that are fast in straight sprints may not be able to transfer this speed into situations involving directional changes (Young *et al.*, 1996). Nevertheless, the fact that the terminology of agility within these tests simply measured COD without a cognitive component poses the question of whether quickness was being measured and not agility.

Reporting similarities to COD speed, Baker (1999) reported a decreased ability of the junior rugby league athletes (ranging between 4 to 9%) on quickness tests (involving two or three directional changes), despite no differences in straight line running speeds. It was therefore suggested that the younger athletes had a lesser ability to harness their speed in sport specific situations. Greater training experience, general strength and lumbo-pelvic stabilisation strength within elite senior level athletes has been suggested responsible for superior breaking ability, body stability and positioning when completing directional changes at high speeds (Baker, 1999). Moreno (1995) also used the definition of quickness as a multi-planar skill (involving several directions), representing an athlete's ability to keep their speed under control and change direction with as little loss of speed and balance as possible. This ability is often found to a greater extent in smaller athletes in comparison to taller, bigger athletes (Moreno, 1995).

Presently, the most prevalent issue in researching agility is the lack of a "gold-standard" to compare agility test results against. Nevertheless, a variety of COD tests measuring components of agility have widely been incorporated into physiological test batteries at both the junior and senior levels of team-sport competitions, reporting both successful and non-successful discriminatory abilities (Reilly *et al.*, 2000b; Gabbett, 2002b, 2005; Pyne *et al.*, 2005; Pyne *et al.*, 2006; Young & Pryor, 2007; Gabbett *et al.*, 2009). In a study applying a multivariate test battery to distinguish between elite and sub-elite junior soccer players (mean age = 16.4 years), Reilly *et al.* (2000b) used a simple COD test (40 m sprint with two 180º turns, designed by Borrie and Bradburn [1998]) to measure the physical attribute of agility. Compared to the sub-elite group, this test for agility was able to distinguish the elite junior athletes as more agile via the completion of significantly faster times (mean difference of 1.75 s). In fact agility, as defined in this study, was found to be the most powerful discriminator between the two levels of junior competition, despite eight of the ten physical measures reporting significant differences. This further supports previous research that reported agility, measured by the Illinois agility test (Figure 2.3), discriminated senior professional soccer players from their age-matched controls better than other tests for strength, power and flexibility (Raven *et al.*, 1976).

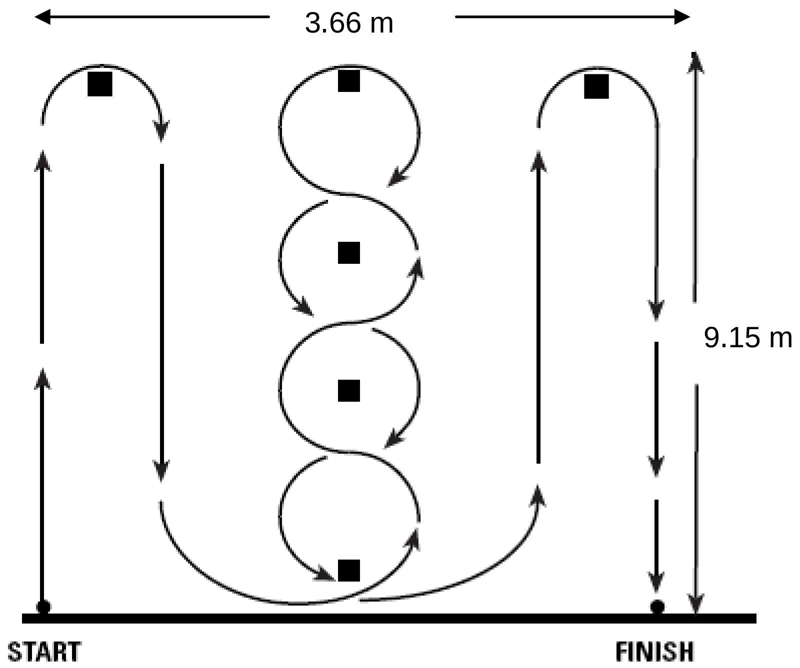

Figure 2.3 The test design of the Illinois agility test (Cureton, 1951).

Comparing the physiological characteristics of junior and senior rugby league players at the sub-elite level, Gabbett (2002b) also reported the significant effect of age and playing level on performance in the Illinois agility test (Figure 2.3 [Hastad & Lacy, 1994]). Ranging from under 13 to under 19 age groups, junior players were recorded to be 3 to 27% slower than their senior counterparts, reporting a linear relationship between improved test performance and increased age. Differences in performance were suggested to be reflective of the normal adaptation associated with the onset of puberty and moderate increases in age, greater training loads and increased training and playing intensities of the higher playing levels. However, Illinois agility test performance reported no significant difference between first and second grad semi-professional rugby league players, suggesting test performance at this level does not influence team selection (Gabbett, 2002a; Baker & Newton, 2008). Nevertheless, the results obtained have provided a useful tool in the physical development process of talented athletes in the junior rugby league system (Gabbett, 2002b).

Within AF, a planned agility test (Figure 2.4) has successfully reported a weak positive relationship (r = 0.21) with being drafted into the elite senior professional competition, reporting a discriminatory ability of COD speed within a cohort of the most elite junior AF athletes (Pyne *et al.*, 2005). Measured over a 21.8m long predetermined course marked by poles, the test comprises one left 225° turn, two right and one left 90° turns and one left 135° turn. With similarities to previous research, Pyne and colleagues (2006) also reported that the short midfield players were in general more agile than the taller key position forward or defensive players. Implementing the same test for agility across a state wide elite junior competition, significantly faster test performance was found within athletes selected for round one of a competitive season in comparison to squad members over-looked (Young & Pryor, 2007). In spite of this, agility performance as measured by this test did not correlate with specific measures of individual playing or team performance (Young & Pryor, 2007), potentially due to the absence of a reactive and decision making component.

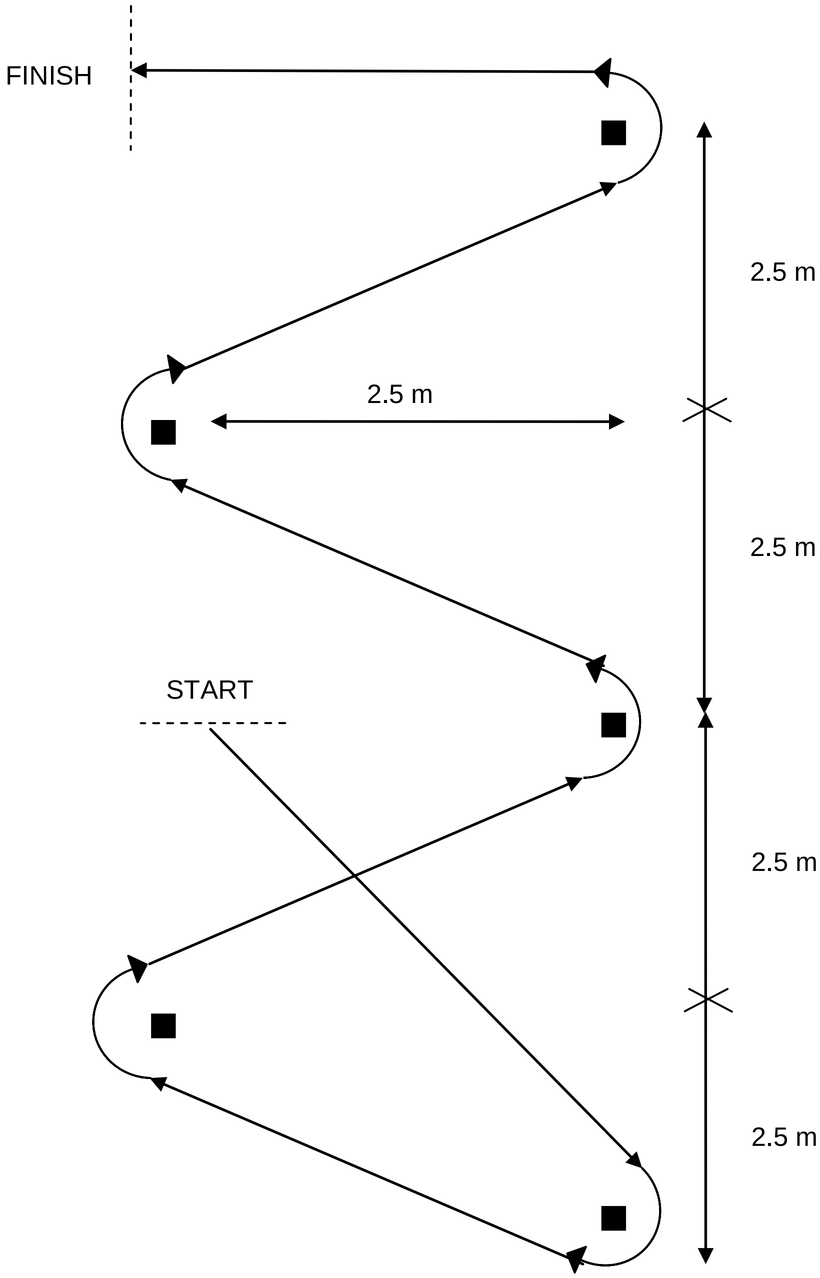

Figure 2.4 The AFL agility run test design (Pyne *et al.*, 2005; Young & Pryor, 2007).

2.2.2 REACTIVE ("Open Skill") AGILITY TESTING

Agility has recently been re-defined as a rapid whole-body movement with change of velocity or direction in response to a stimulus (Sheppard & Young, 2006; Oliver & Meyers, 2009); such as reacting to a moving ball, or to evade or pursue an opponent (Young *et al.*, 2002). This definition has grown in complexity, incorporating neuropsychological factors including anticipation (Williams *et al.*, 1994; Williams, 2000), intuition (Williams *et al.*, 1994), sensory-processing (Williams, 2000), and decision making (Farrow & Abernethy, 2002; Vaeyens *et al.*, 2007); and with physiological factors such as response time (Farrow *et al.*, 2005; Sheppard *et al.*, 2006; Gabbett & Benton, 2009), acceleration and maximum speed (Young *et al.*, 2001c; Sheppard *et al.*, 2006), COD speed and mobility (Sheppard & Young, 2006). Moreover, these factors interact with each other to varying degrees dependent upon the sport specific context. Whilst drills involving athletes running a set pattern around stationary objects have regularly been used as a common measure of agility performance (Gambetta, 1996; Murray, 1996), Murray (1996) reported the automatic response in the execution of such traditional agility skills minimises or removes entirely the uncertainty involved in the task. Consequently, sports specific agility is more recently being viewed within the context of "open skill" activities (Sheppard & Young, 2006; Oliver & Meyers, 2009).

According to Cox (2002), open skills require athletes to respond to surrounding sensory stimuli, producing a response that is not automated or rehearsed (e.g. evading an opponent in football [Murray, 1996; Sheppard & Young, 2006]).

Such measures have used generic cues (including a light bulb or computerised direction indicators [Sheppard *et al.,* 2006]) as well as specific cues (e.g. human participation [Sheppard *et al.,* 2006]) to evaluate an unplanned mode of agility requiring a direction change in response to a stimulus provided mid-test (Oliver & Meyers, 2009). As the nature of the stimulus (timing and location) has been shown to influence performance in agility tasks, demonstrating the significance of perceptual factors in open-skill agility activities (Chelladurai *et al.*, 1977; Cox, 2002; Young *et al.*, 2002), Sheppard and Young (2006) suggested the need to provide agility testing and training that mimics game-day reactivity to increase their sports specificity. Therefore, the inability of many tests to measure both the physical and cognitive components involved in the act of executing agility defined movements has been suggested a limitation to the current use of COD speed tests within the sporting context (Sheppard & Young, 2006). Hence, tests of an "open skill" nature have more recently been incorporated into the assessment of agility within team sports, influencing both test initiation and COD in response to an external (single or multiple) stimuli (Farrow *et al.,* 2005; Sheppard *et al.,* 2006). In agility tasks specific to team sports, research across a variety of settings has repeatedly demonstrated the superior ability of elite athletes in identifying useful anticipatory information from early in their opponent's movement patterns (Williams *et al.*, 1994; Reilly *et al.*, 2000b; Williams, 2000; Meir *et al.*, 2001; Vaeyens *et al.*, 2007). As a result, visual processing, anticipation and reaction time are all now commonly accepted elements important to team sport agility performance (Williams *et al.*, 1994; Williams, 2000; Young *et al.*, 2002; Farrow *et al.*, 2005; Sheppard & Young, 2006; Vaeyens *et al.*, 2007).

Referred to as advanced cue utilisation, the superior ability of a player to make accurate predictions based on information provided by their opponent's posture and bodily orientation has been shown in experienced versus inexperienced soccer players and also in talent identified junior soccer players (Williams *et al.*, 1994; Williams, 2000). Due to the time constraints placed on an athlete during game situations in fast team sports such as soccer and AF, the less proficient use of advanced cues in novices, whereby an entire skill may need to be executed before the correct decision and response is made, has been deemed a limiting factor to successful performance (Williams, 2000). Therefore, the specific nature of the movement patterns and game related activities within team sports require all three components of agility; physical demands, cognitive processes and technical skills to be present within an agility test to allow a direct comparison to be made between test and game situations (Sheppard *et al.,* 2006). As a result, there is a need for the continued development of tests to measure this component of fitness within the team sport environment.

The relevance of reactive agility testing is mainly based on logical validity (Rampinini *et al.,* 2007), eliminating the ability for pre-planning and practicing of the task (Cox, 2002). To date, a limitation in many "open skill" tests is the use of generic cues such as a light bulb and computerised direction indicators, or two dimensional film-based scenarios rather than a real-life stimuli (such as an opponent moving towards the athlete) to evaluate an unplanned mode of agility testing (Williams, 2000; Farrow *et al.*, 2005; Sheppard & Young, 2006). Consequently, the use of these generic cues within an athletic population is questionable (Abernethy & Russell, 1987; Farrow *et al.,* 2005; Sheppard &

Young, 2006), as perceptual expertise is linked to visual search rates, specific search cues and accuracy of domain-specific responses (Abernethy & Russell, 1987; Farrow *et al.,* 2005; Sheppard *et al.,* 2006). Furthermore, such generic cues remove the element of anticipation, whereby sport specific stimuli allow athletes to recognise and react to different cues earlier in the stimulus appearance in comparison to the inability to anticipate when a light will turn on or off (Abernethy & Russell, 1987; Williams *et al.*, 1993; Sheppard *et al.*, 2006). As a result, not only should logical validity be addressed in a reactive agility test (RAT) design, but also construct validity, where the test should be able to discriminate between experts and novices based on advanced cue utilisation.

Employing the paradigm of cue utilisation to measure sport-specific forms of response (Helsen & Pauwels, 1988), Farrow *et al.* (2005) combined the elements of decision making and COD speed in a RAT to compare performance both between players of differing netball skill standards and also between a reactive and traditional agility test (Figure 2.5). Reacting to a life-size image projected in front of the athlete when changing direction, the RAT was completed significantly slower than performance on the same course when the directional change was pre-planned. However, whilst no significant difference was reported in performance on the pre-planned agility test between the high, moderate and less skilled groups, both the high and moderately skilled groups performed significantly faster on the RAT compared to the less skilled players (Farrow *et al.,* 2005). Further analysis identified the decision-making element within the RAT was the key difference between sprint times, suggesting the superior ability to anticipate and predict earlier the COD required existed within the high-skilled playing group (Helsen & Pauwels, 1988).

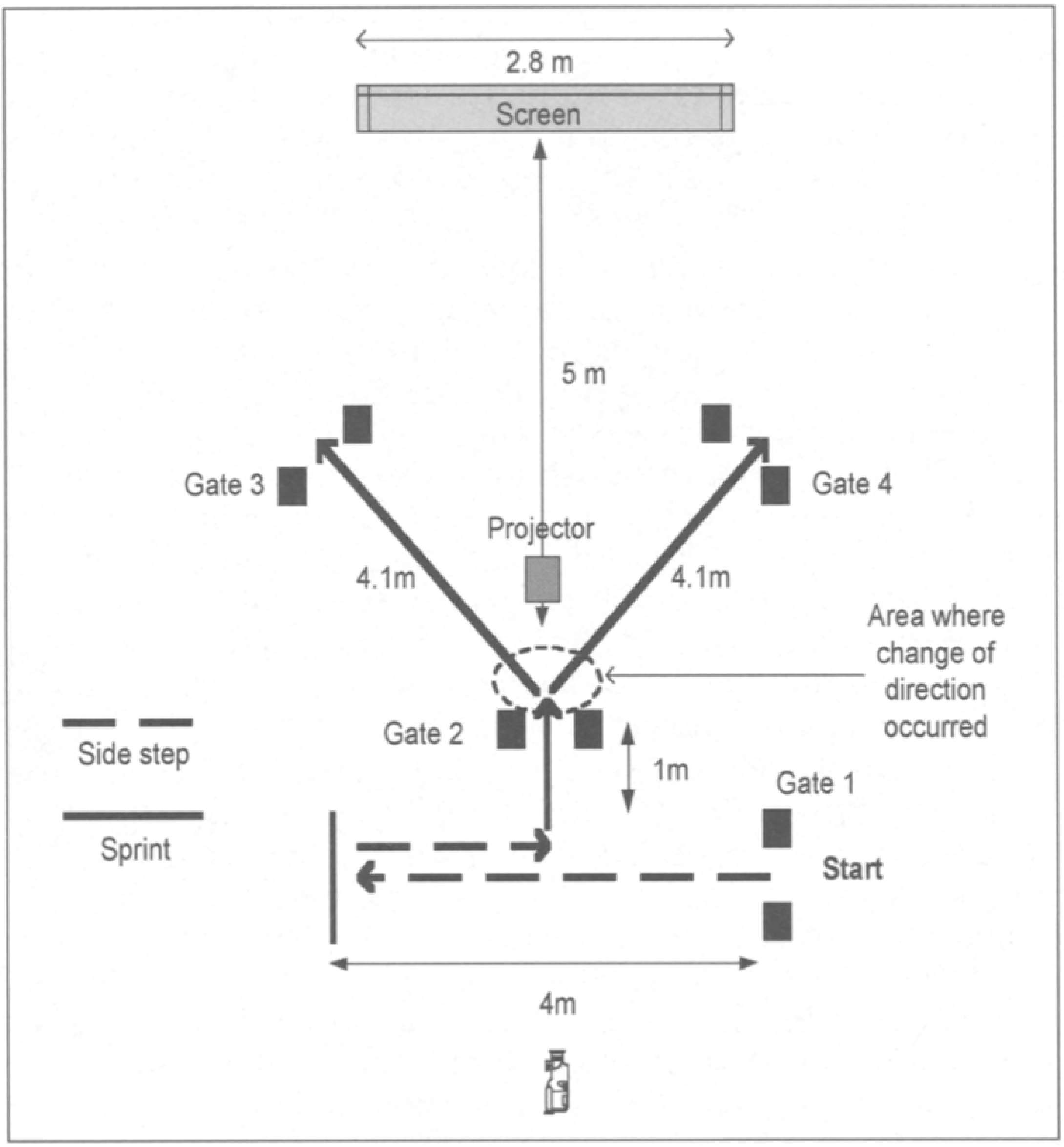

Figure 2.5 The reactive agility test set-up designed by Farrow *et al.*(2005)

In response to the absence of a field test involving a sport-specific stimulus for the measurement of agility, Sheppard *et al.* (2006) designed and tested a RAT specific to the football codes that involved the components of perceptual, decision-making and movement response (Figure 2.6). Using a one-COD test, the participant was required to react in direct response to the movements of the tester (researcher), who both initiated the start of the test and then the direction in which the participant was required to run (Sheppard *et al.,* 2006). Comparing the results of state level division one senior AF players to their second division counterparts, the RAT within this study displayed a significantly faster performance in the high performance group, whilst straight line and a simple closed-skill COD test over the same course did not (Sheppard *et al.,* 2006). Therefore, it was suggested that a simple and traditional "closed skill" sprint with directional change test is not adequate in distinguishing between players of different competition standards. As a result, Sheppard *et al.* (2006) suggested that the differences displayed between the two groups in the RAT could be in direct response to the cognitive abilities of the high performance group in reading and reacting to the stimulus supplied. This was further supported by the superior anticipatory skills, decision making ability and movement time of elite level national rugby league athletes in comparison to their sub-elite counterparts, without compromising their response accuracy (Gabbett & Benton, 2009).

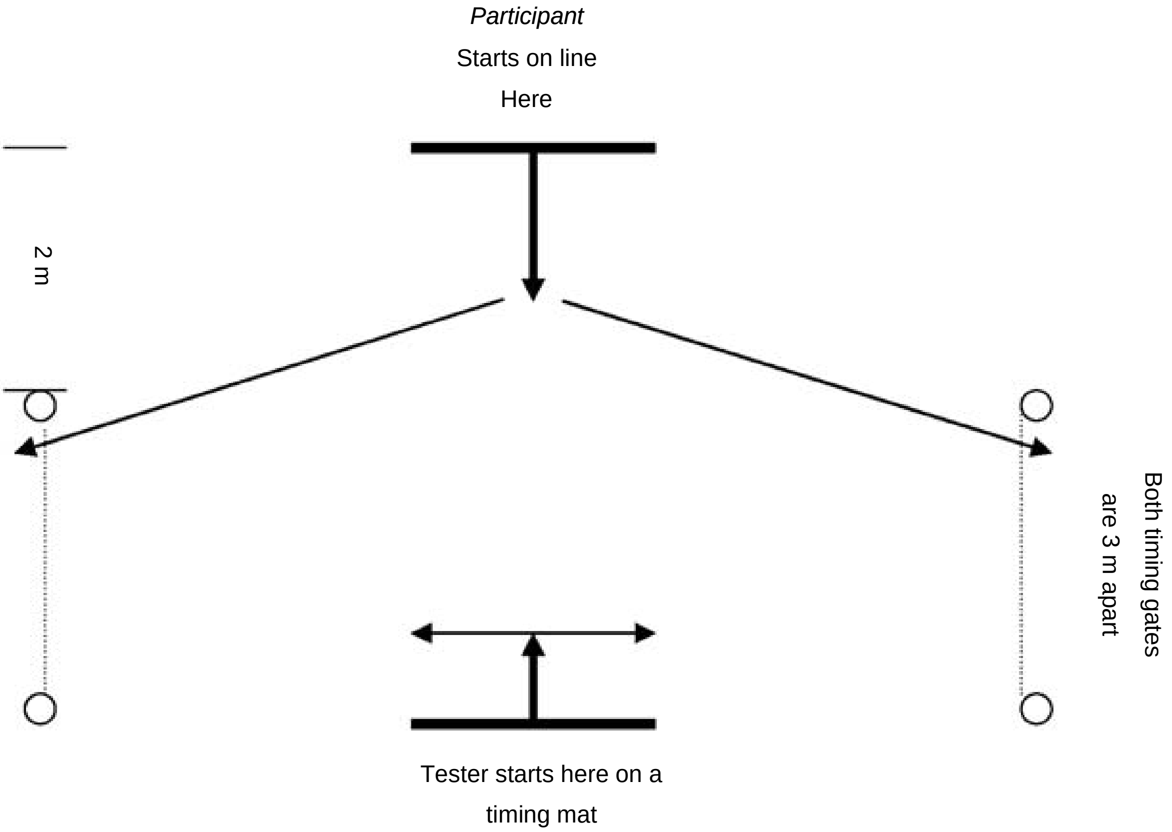

Figure 2.6 The reactive agility test designed by Sheppard *et al.*(2006)

Therefore, within the team sport environment, development continues towards improved sport-specific measures of agility (Young & Pryor, 2007; Gabbett & Benton, 2009). Recent research has identified the importance of including sport-specific cue recognition in agility testing, supporting the need for further reliability and validity testing into reactive agility testing within the team sport environment (Sheppard *et al.*, 2006; Young & Pryor, 2007; Gabbett & Benton, 2009). Whilst variations in test designs may create future possibilities in measuring reactive agility in team sport populations, future investigations into the sensitivity of these tests to measure agility performance changes over time would also be beneficial (Sheppard *et al.,* 2006).

2.3 SPEED

Defined as the ability to move the body or parts of the body through a range of motion in the least amount of time (Gambetta, 1990), acceleration (Duthie *et al.*, 2006a), maximum running speed / velocity (Duthie *et al.*, 2006a) and speed endurance / maintenance the ability to maintain velocity against the onset of fatigue [Little & Williams, 2005]) are three distinct phases within a sprint performance and are all required physical attributes of team sport athletes (Baker, 1999; Young *et al.*, 2001a; Duthie *et al.*, 2006b). Analysis of sprint performance has suggested the duration of each phase is a characteristic of differing athletic abilities (Delecluse *et al.*, 1995; Delecluse, 1997; Ross *et al.*, 2001; Moir *et al.*, 2007), with the components of acceleration and maximum speed key attributes within AF performance in light of the large number of short distance sprint efforts (McKenna *et al.*, 1988; Dawson *et al.*, 2004b) and the increasing speed and tempo of the modern game (Norton *et al.*, 1999; Pyne *et al.*, 2005). Furthermore, the developing importance of high-speed efforts toward game success is supported across the football codes, whereby a high number of repeated sprint efforts has recently been suggested a more realistic application in quantifying individual performance in comparison to other commonly used parameters (including total distance covered [Fitzsimons *et al.*, 1993; Bishop *et al.*, 2001; Dawson *et al.*, 2004b; Oliver *et al.*, 2009]).

Consequently, testing of the individual components of sprint performance is common within both individual and team sport competitions (Young *et al.*, 1996; Parsons & Jones, 1998; Baker, 1999; Baker & Nance, 1999; Gabbett, 2000;

Young *et al.*, 2001a; Gabbett, 2002a, b; Little & Williams, 2005; Pyne *et al.*, 2005; Pyne *et al.*, 2006; Baker & Newton, 2008; Gabbett *et al.*, 2008a; Gabbett *et al.*, 2008b; Gravina *et al.*, 2008; Veale *et al.*, 2008; Young *et al.*, 2008; Chaouachi *et al.*, 2009; Gabbett *et al.*, 2009). Within these studies, sprint tests are regularly conducted in an indoor facility, controlling the potential environmental influences to the detriment of reducing game-specific conditions (e.g. variable grass surfaces and footwear choices [Young *et al.*, 2008]). In conjunction with a variety of test protocol distances used, starting techniques have also demonstrated variation across sporting codes (Duthie *et al.*, 2006b), ranging from a standing position in AF (Pyne *et al.*, 2005) to a three point start in American Football (Sierer *et al.*, 2008). However when consistently used in test-retest scenarios, these starting methods have all produced reliable sprint results and therefore must not be used interchangeably when assessing change in individual athletes or when comparing between teams (Duthie *et al.*, 2006b). This area of the literature review focuses its discussion on the importance of measuring speed, in particularly repeated sprint ability within team sport athletes.

2.3.1 SINGLE SPRINT EFFORT

Acceleration and maximal speed are fundamental components necessary for success within team sports (Delecluse, 1997; Baker & Nance, 1999; Little & Williams, 2005; Duthie *et al.*, 2006a), with sprint testing regularly used as a predictor of athletic potential and in measuring reliable changes in an athlete's performance over time (Nesser *et al.*, 1996). Commonly defined as the product of stride length and stride frequency (rate), sprint performance and the development of speed are both dependent on powerful extensions of all the leg joints (Mero *et al.*, 1981; Delecluse, 1997; Dowson *et al.*, 1998; Ross *et al.*, 2001; Young *et al.*, 2001a; Murphy *et al.*, 2003; Brown *et al.*, 2004; Moir *et al.*, 2007). However, whilst the relative importance of stride length (Chapman & Caldwell, 1983; Weyand *et al.*, 2000; Murphy *et al.*, 2003; Moir *et al.*, 2007) and frequency (Mero *et al.*, 1981; Brown *et al.*, 2004) during the acceleration and maximal speed phases are still debated (Moir *et al.,* 2007), it is agreed that any changes in sprint performance within team sport athletes will result from a change between their interaction (Young *et al.*, 2001a; Moir *et al.*, 2007). Nonetheless, it is in these sports that high-speed actions constitute the more crucial moments of a game, contributing directly to the ability of an athlete to get to the ball first, providing them with a distinct advantage over their direct opponents (Sayers, 2000; Benton, 2001; Murphy *et al.*, 2003; Little & Williams, 2005; Duthie *et al.*, 2006a; Duthie *et al.*, 2006b).

Given the importance of maximal speed in team sports, single sprint effort (SSE) tests have frequently been included in physical test batteries within both the elite senior and junior AF competitions (Pyne *et al.*, 2005; Young *et al.*, 2005; Pyne *et al.*, 2006; Veale *et al.*, 2008; Young *et al.*, 2008; Oliver *et al.*, 2009). Covering various distances, one common element across these SSE test protocols is the recording of multiple split times, as total time only provides a general overview of sprint performance and cannot accurately discriminate between the sprint characteristics of two athletes with the same end result (Brown *et al.,* 2004). According to Dintiman (1998) the use of split times enables weaknesses in sprint performance of an athlete to be identified by assessing the different phases of acceleration and anaerobic metabolism. Using a 30 m maximal sprint test, Wisløff and colleagues (2004) reported similar total sprint times between elite soccer players, despite significant differences in split times over the first and last part of the test. Therefore, as acceleration and maximum speed are two distinct phases in sprinting performance (Docherty *et al.*, 1988; Bangsbo, 1992; Deutsch *et al.*, 1998; Dawson *et al.*, 2004b; Spencer *et al.*, 2004b; Duthie *et al.*, 2005), the use of split time recordings can aid in differentiating the focus of sprint training towards individual athletes within the team sport environment (Young *et al.*, 2001a; Wisløff *et al.*, 2004; Young *et al.*, 2008).

Furthermore, the use of split time recordings has enabled a relationship between the elements (acceleration and maximal speed) of a sprint performance to be analysed. Reporting a low coefficient of variation (39%) between stationary 10 m and flying 20 m (30 m split minus the 10 m split time) sprint efforts in professional soccer players, Little and Williams (2005) suggest acceleration and maximum speed are independent attributes in sprint performance. This notion is supported by Young *et al.,* (2008) where the 10 m split time recorded in a SSE test shared a strong correlation with the 20 m, 30 m and 40 m times (r = 0.94, r = 89 and r = 0.81 respectively), reflecting significant elements of acceleration speed within these distances. However, a moderate correlation was demonstrated between the 10 m and flying 10- and 20 m split times (r = 0.65 and r = 0.50 respectively) within this AF playing group, indicating flying times are influenced by, and are therefore distinct measures of maximal speed. In addition, maximum speed achieved during a sprint effort in team sport conditions is substantially affected by the commencement speed of each effort (Duthie *et al.*, 2006a). Sprint efforts completed by AF players in game situations are most commonly initiated from a jogging or striding start rather than a stationary position, allowing the attainment of 96% to 99% of maximum velocity to be achieved in 20 m (Benton, 2001). As a short distance sprint (10 m) may be initiated from a jogging start within team sport competitions, a higher percentage of maximum speed is attainable when compared to the initial acceleration phase of pure athletic sprinting events (Young *et al.*, 2001a; Little & Williams, 2005), highlighting the need for its analysis within field test results.

According to Mero (1992) and Young *et al.,* (1995) the distance of the acceleration phase required by elite sprinters (30-50 m) is much greater than that of field sport athletes, with average sprint distances performed in sports such as rugby league and AF averaging between 10-20 m (McKenna *et al.*, 1988; Meir *et al.*, 1993; Baker & Nance, 1999). Within a Brazilian soccer league, 96% of sprint bouts during a soccer game were reported to be shorter than 30 m, with 49% being less than 10 m in distance (Barros *et al.*, 1999; Wisløff *et al.*, 2004). These such sprint performances in team sports have been labelled as acceleration runs, with athletes rarely being required to sprint for longer than 30-40 m in distance (Faccioni, 1993). In spite of this, speed over longer distances of 40-60 m, although uncommon, is still required and important within various team sports and across playing positions (Baker & Nance, 1999). Analysis of sprint performance at the sub-elite senior AF level demonstrated 82% of maximal speed was attained after 10 m of a 60 m SSE test from a stationary start, increasing to 93.1% by 20 m and 99.0% at 30 m (Benton, 2001; Young *et al.*, 2008). Consequently, Young and colleagues (2008) concluded that 30- or 40 m distances are long enough to separate acceleration (0 to 10 and 20 m splits) and maximum speed (20 to 30 m split) qualities when analysing sprint performance from a stationary start in team sport athletes (Young *et al.*, 2008).

At the elite senior AF level (Young *et al.*, 2005), both 10 m and 40 m (maximum speed) sprint testing has reported a significant difference ($p = 0.02$) between starters and non-starters at the beginning of a competitive season, whilst 20 m sprint testing within the elite junior competition has demonstrated varying relationships between test performance and team selection (Pyne *et al.*, 2005; Pyne *et al.*, 2006; Veale *et al.*, 2008). In a case study of one elite junior AF team, Veale and colleagues (2008) reported no difference ($p = 0.16$) between SSE performance of athletes selected compared to not selected onto the final squad list for a competitive season. In comparison, Young *et al.* (2005) reported athletes who were selected to participate in round one across an entire elite junior AF competition were significantly faster than those not selected (5 m split; $p = 0.018$, 20 m split; $p = 0.005$). Furthermore, measuring a three year national cohort of the most elite junior AF athletes, Pyne and colleagues (2005) reported faster 5- , 10- and 20 m sprint times of athletes attending the end of season AF national draft camp who were subsequently selected onto an elite senior AF playing squad. Nevertheless to date, no study at the elite junior AF level has measured the sprint quality of maximum speed via the use of flying split times.

Whilst only a small number of longitudinal studies measuring seasonal changes in physical attributes exist, significant changes in sprint performance over a competitive season within team-sport athletes has been reported (Thomas & Reilly, 1979; Brewer, 1990; Heller *et al.*, 1992; Rebelo & Soares, 1997; Reilly & Keane, 1999; Dunbar, 2002; Mohr *et al.*, 2002; Aziz *et al.*, 2005a). Consistent improvements in 50 m sprint times from the start of the pre-season training period to the conclusion of the competitive season have been reported in both Gaelic football (Reilly & Keane, 1999) and soccer (Ostojic, 2003), with mean results within the study by Ostojic (2003) returning to pre-season levels after a second off-season period. Aziz *et al.* (2005a) reported consistent and significant improvements in 5- and 20 m sprint performance in soccer players on the return from off-season to the completion of the following competitive season, attributing these improvements to the in-season training focus throughout the season, emphasising repeated short bursts of high-intensity sprints. Significant correlations have also been reported between changes in sprint times and a decrease in body fat and total mass over the course of a competitive season (Reilly & Keane, 1999; Ostojic, 2003; Aziz *et al.*, 2005a). However, whilst the components of SSE have been reported to discriminate between AF athletes, recent game-day movement pattern analysis (Dawson *et al.*, 2004b; Veale *et al.*, 2009c) suggests a greater importance of repeated, short duration efforts on game-day performance, with the measurement of repeated sprint ability (RSA) currently an under-researched physiological attribute within this sport.

2.3.2 REPEATED SPRINT ABILITY

According to Oliver and colleagues,(2006) the analysis of movement patterns and game activities within team sports has lead to their common description as multiple-sprint based sports (Williams, 1990; Lakomy & Haydon, 2004; Oliver *et al.*, 2006). Time-motion analysis of rugby (Docherty *et al.*, 1988; Deutsch *et al.*, 1998; Duthie *et al.*, 2005), soccer (Mayhew & Wenger, 1985; Bangsbo, 1992; O'Donoghue, 2002; Gabbett & Mulvey, 2008), AF (McKenna *et al.*, 1988; Dawson *et al.*, 2004b; Veale *et al.*, 2007a), basketball (McInnes *et al.*, 1995), Gaelic football (O'Donoghue & King, 2003) and hockey (Spencer *et al.*, 2004b) suggest these sports are characterised by short duration (1 to 7 s) maximal sprints interspersed with brief recovery periods (< 30 s), repeatedly completed over an extended game duration (60 to 120 min [Fitzsimons *et al.*, 1993; Bishop *et al.*, 2001; Bishop *et al.*, 2003; Bishop & Spencer, 2004; Lakomy & Haydon, 2004; Spencer *et al.*, 2004a; Spencer *et al.*, 2004b; Bishop & Edge, 2005, 2006; Rampinini *et al.*, 2007]). Therefore, whilst a variety of definitions have been used to describe RSA in the team sport environment, one common definition is the ability of an athlete to recover and reproduce a high power output during repeated short-duration sprints over a brief period of time (Dawson *et al.*, 1993; Fitzsimons *et al.*, 1993; Reilly *et al.*, 2000b; Wragg *et al.*, 2000; Bishop *et al.*, 2003; Bishop & Spencer, 2004; Bishop & Edge, 2005; Oliver *et al.*, 2006; Rampinini *et al.*, 2007; Castagna *et al.*, 2008a; Oliver *et al.*, 2009).

Despite only accounting for 4-6% of the total movement time in AF games, Dawson *et al.* (2004b) recorded more than 150 high-intensity efforts by each position analysed, demonstrating an increase in comparison to past research in the 1970s by Hahn *et al.* (1979) (110-115 high-intensity efforts) and McKenna *et al.* (1988) in the 1980s (98 high-intensity efforts). Revealing a similar change in game-day movement intensity, research in soccer has reported an increase of 37% in sprinting movements during a game when compared to previous research (Bangsbo *et al.*, 1991; Mohr *et al.*, 2003), with higher standard soccer players performing more high-intensity running (28%) and sprinting (58%) during game play conditions than players of a lower competition standard (Mohr *et al.,* 2003). Consequently, high-intensity running rather than total game distance has been suggested to be of more practical importance and significance to game performance in AF (Dawson *et al.*, 2004b). It has thus been concluded that superior RSA performance in both speed maintenance and fatigue resistance is a characteristic of better team sport athletes (Fitzsimons *et al.,* 1993), with RSA tests designed to replicate these movement patterns and physiological demands (Psotta & Bunc, 2005; Oliver, 2009).

To date, a number of RSA test protocols have been designed and used within the sporting environment (Wragg *et al.,* 2000). Repeated sprint ability test protocols have employed both running and cycling protocols (Fitzsimons *et al.*, 1993; Bishop *et al.*, 2001; Watt *et al.*, 2002; Bishop *et al.*, 2003; Bishop & Spencer, 2004; Spencer *et al.*, 2004a; Bishop & Edge, 2005, 2006; Mendez-Villanueva *et al.*, 2007; Mendez-Villanueva *et al.*, 2008), with running protocols commonly ranging between 20-40 m in length, using repetitions between 6-18 in total and involving recoveries lasting from 15-30 s in duration (Dawson *et al.*, 1998; Lakomy & Haydon, 2004; Dupont *et al.*, 2005; Psotta & Bunc, 2005;

Hughes *et al.*, 2006; Oliver *et al.*, 2006; Rampinini *et al.*, 2007; Oliver *et al.*, 2009). Within each study protocol, common measures of interest have included total running / cycling time (sum of all sprints), mean sprint time and a percentage decrement score (used as a measure of fatigue [Dawson *et al.*, 1998; Psotta & Bunc, 2005]). Furthermore, RSA test protocols have been used across the research to determine the impact of recovery modalities on subsequent performance (Hamlin, 2007; Castagna *et al.*, 2008a), decipher physical predictions for game performance (Bishop *et al.,* 2003), identify physiological and metabolic responses to performance (Spencer *et al.*, 2005), report training adaptations on test performance (Spencer *et al.*, 2004a) and measure the correlation between test and game day sprint performance (Rampinini *et al.,* 2007). However, limited research has employed the use of RSA testing within TID studies (Reilly *et al.*, 2000b), with AF studies reporting the use of SSE tests only (Keogh, 1999; Pyne *et al.*, 2005; Young *et al.*, 2005; Young & Pryor, 2007; Veale *et al.*, 2008).

For RSA test protocols to be specific and relevant to field-based team sports, they must replicate the sprint and recovery durations of these sports (Spencer *et al.,* 2005). Any large differences between protocols and activity patterns involved within the team sport may subsequently bring into question the validity and sport-specific relevance of these protocols (Spencer *et al.,* 2005). Consequently, exercise mode, sprint duration, number of sprint repetitions, recovery duration and type of recovery can significantly affect performance outcomes during a RSA test protocol (Spencer *et al.,* 2005). Due to the random activity patterns and varying tactics employed during any given team sport game, it is difficult to establish relationships between fitness measures and game performances (Oliver *et al.*, 2009). Care must also be used when determining the most appropriate RSA test protocol from the movement patterns of team sport athletes, as total mean game data is often not reflective of the variation in patterns of play that occur throughout a game (Fitzsimons *et al.,* 1993). As a result, high stress periods of game play in team sports have been used as a foundation for the design of numerous RSA test protocols, resulting in relatively short test durations (< 3 min [Fitzsimons *et al.*, 1993; Wragg *et al.*, 2000; Bishop *et al.*, 2001; Oliver *et al.*, 2006]).

The specificity of RSA testing has also been suggested by Dawson and colleagues (1991) to more closely replicate a game situation than one-off tests of endurance (12 or 15 min run test), SSE speed (10 m and /or 40 m time) or sustained sprint ability (e.g. 200-400 m sprint [Fitzsimons *et al.,* 1993]). This notion is supported by Rampinini and colleagues (2007), who reported a moderate inverse relationship between the mean sprint time of a RSA test and the total distance covered during a soccer game at very high intensity running ($r = -0.60$) and sprinting speeds ($r = -0.65$). Furthermore, the absence of a significant relationship between the best SSE within the RSA test protocol and physical game performance was deemed appropriate to justify the use of RSA testing to provide more accurate physiological and metabolic responses to those during actual game play conditions (Rampinini *et al.,* 2007). Consequently, it was concluded that the physiological attributes demonstrated in RSA performance within this study reflected those required to maintain high-speed and sprinting performance during a soccer game (Rampinini *et al.,* 2007).

A valid assessment of team-sport repeated sprint activity must reflect the mean duration of sprints commonly reported in game-day movement pattern analysis (Balsom *et al.*, 1992b; Spencer *et al.*, 2005). Previously common laboratory RSA tests have used a repeated 5 or 6 s cycle test (Hamilton & Nevill, 1991; Fitzsimons *et al.*, 1993; Dawson *et al.*, 1997; Dawson *et al.*, 1998; Bishop *et al.*, 2001), suggesting that this protocol may represent the duration of sprints performed in team sports (Spencer *et al.,* 2005). However, Bishop *et al.* (2001) suggested an inconsistency in test protocol and game performance as sprint distances reported in team sports such as soccer (Barros *et al.*, 1999) and AF (McKenna *et al.*, 1988; Dawson *et al.*, 2004b) are commonly less than 6 s in duration. Furthermore, the use of cycle ergometry (Dawson *et al.*, 1993; Fitzsimons *et al.*, 1993; Bishop *et al.*, 2001; Bishop *et al.*, 2003; Spencer *et al.*, 2004a) as a laboratory measure of RSA has also been suggested to lack sport specificity for team sport players and is thus another limiting factor to these such protocols (Fitzsimons *et al.*, 1993; Oliver *et al.*, 2006). Consequently, the development of basic indoor track repeated sprint tests (Balsom *et al.*, 1992b; Fitzsimons *et al.*, 1993; Dawson *et al.*, 1998) has enabled team sport specific repeated sprint running protocols to be adapted to the field.

The number of sprint repetitions used in a RSA test can also have a substantial impact on the performance measured throughout the exercise protocol (Spencer *et al.,* 2005). According to Fitzsimons and colleagues (1993), providing all efforts completed during a RSA test are performed at maximal capacity, six sprint efforts is sufficient to produce a measurable performance decrement and subsequently allow for the discrimination between participants

(Holmyard *et al.*, 1988; Balsom *et al.*, 1992b; Lakomy & Haydon, 2004). Whilst RSA tests can be extended to eight repetitions to generate a greater overload, it has been suggested that the use of many sprint repetitions may diminish the correlation to the game-day repeated sprint activity of team sports (Spencer *et al.,* 2005). Anecdotal evidence based on the number of sprints involved within a RSA test protocol has suggested athletes involved in a 20 repetition RSA test protocol participated in an activity termed “pacing”, subsequently not sprinting maximally during all sprints in an attempt to successfully complete the entire test (Dawson *et al.*, 1991). This has further been supported by 4.8% slower performance in the first sprint of a 10 x 20 m RSA test protocol to that of a single sprint effort in a population of youth soccer players (Psotta & Bunc, 2005). When combined with the increasing aerobic contribution to adenosine tri-phosphate (ATP) resynthesis during the concluding sprints in a RSA protocol (Gaitanos *et al.*, 1993), a high number of sprints within a test protocol may reduce the validity of the test as a direct measure of RSA (Wragg *et al.,* 2000).

Oliver and colleagues (2009) further suggested the amount of recovery has a direct impact on RSA test performance. Measuring the effect of different recovery durations, Balsom and colleagues (1992a) reported within a 15 x 40 m RSA test, acceleration results over the first 15 m were reduced when recovery time was limited to 30 s but not when the recovery time was 60 s and 120 s long. However, speed over the last 10 m (maximum speed) of each sprint was reduced in all recovery conditions, with comparable results reported by Wragg *et al.* (2000). It was thus concluded that restoration within an athlete’s force generation capacity was more readily made than their endurance capacity

(Balsom *et al.*, 1992a; Oliver *et al.*, 2009). Fitzsimons *et al.* (1993) used a running protocol of 6 x 40 m sprints departing every 30 s, whereby the 24 s of recovery was suggested to only allow partial replenishment of ATP-PCr stores, as full repletion has been reported to occur in three to four minutes (Fitzsimons *et al.,* 1993). Furthermore, multiple bouts of intense exercise have been reported to impede the phosphagen resynthesis process, increasing the reliance on the glycolytic energy system in the resynthesis of ATP with each successive effort (Spriet *et al.*, 1989; Jansson *et al.*, 1990). Whilst RSA testing has demonstrated a decrement in performance as fatigue occurs (Dawson *et al.*, 1991; Balsom *et al.*, 1992b; Fitzsimons *et al.*, 1993), Lakomy and Haydon (2004) also measured the effect of deceleration on repeated sprint performance in elite hockey athletes, as fatigue should be exacerbated by rapid deceleration (Clarkson & Sayer, 1999). However, the absence of differences in test performance in the shortened deceleration condition (6 m vs. 10 m) was suggested to be reflective of the elite level game-play, with training experience of the participants closely replicating the demands of the test (Lakomy & Haydon, 2004).

When assessing RSA performance, it has previously been reported necessary to analyse both the absolute (total accumulated time of all efforts completed) and relative (% decrement or fatigue index [FI]) scores recorded.(Fitzsimons *et al.,* 1993) Low absolute values (reflected by a low total time score) reflect a high level of anaerobic power, whilst a lower % decrement score indicates a greater level of consistency across the running repetitions. As described by Fitzsimons *et al.,* (1993) the absolute test score provides a measure of a participants initial and RSA by analysing each participant's performances (individual sprint times) after each repetition. This score will also, in part, indicate the rate at which each participant's anaerobic energy system can resynthesise the required ATP for work within each repetition. When comparing RSA test performance across population groups, Lakomy and Haydon (2004) demonstrated lower mean sprint times in an elite hockey team compared with the amateur-level team sport players used in previous studies (Dawson *et al.*, 1993; Fitzsimons *et al.*, 1993). Lakomy and Haydon (2004) thus concluded that the increased involvement in RSA activities and subsequent physiological and metabolic adaptations within the elite athlete would result in improvements in RSA test performance when compared to their amateur-level counterparts.

Alternatively, relative test scores are based solely on the comparison of each repetition result against the best score during the test (Fitzsimons *et al.,* 1993). The FI is the calculation process that determines the drop-off in performance from best to worst effort during a set of repeated sprints, whilst percentage decrement scores compare the actual performance to the ideal performance (the replication of the best sprint every time [Oliver, 2009]). These measures are therefore suggested an indication of the muscles' ability to recover quickly from short maximal efforts, including factors related to the rate of ATP, PCr and myoglobin replenishment, glycolysis generated ATP, fibre type and muscle oxidative and buffer capacity (Fitzsimons *et al.,* 1993). However, although the measurement of fatigue experienced during a RSA test in theory is a valid concept, reliability issues and large variability is evident when calculating the percentage decrement score (CV ranging between 11 and 50%, Hughes *et al.,* 2006; McGawley & Bishop, 2006) or FI (CV ranging between 18.5 and 46%, Fitzsimons *et al.*, 1993; Oliver *et al.*, 2006; Oliver, 2009) leading Oliver (2009) to question their relevance when reporting test performance outcomes. Therefore, direct performance measures of total test and mean sprint time have been deemed to provide the best reflection of test and subsequent sport performance, via measuring the ability of a player to repeatedly produce maximal sprint efforts (Oliver, 2009).

Recording strong test-retest reliability scores using a 6 x 40 m RSA test, Fitzsimons and colleagues (1993) suggested six sprint efforts using a 1:4 work to rest ratio was sufficient to measure an athlete's RSA (Dawson *et al.*, 1998). Employing their RSA protocol, Oliver and colleagues (2006) measured sprint performance as the fastest 10 and 30 m times and the mean 10 and 30 m times from seven sprint efforts. Completing five separate testing sessions to measure the reliability of the test protocol, Oliver and colleagues (2006) reported reliable field test results (CV 1.6-2.7%) when measuring fastest and mean split times, with the mean 30 m sprint times reporting the lowest variability (CV 1.6%, Fitzsimons *et al.*, 1993; Wragg *et al.*, 2000; Paton *et al.*, 2001). Therefore, to measure RSA, Reilly (2001) recommends the use of 30 m sprint distances (4 to 5 s in duration), repeated seven times interspersed with 15 to 25 s recovery intervals.

Time motion analyses of elite senior and junior AF has demonstrated support for this RSA protocol, with virtually all game-day high intensity running and sprinting efforts lasting less than 6 s in duration and nearly half of the recovery periods lasting 0-20 s and approximately 70% lasting between 0-60 s (McKenna *et al.*, 1988; Dawson *et al.*, 2004b; Veale *et al.*, 2009c). In line with these parameters, Pyne *et al.* (2008) measured the relationship between performance on a 6 x 30 m RSA test starting every 20 s and single sprint and endurance (MSFT) performance. Demonstrating an approximate decrease in performance of 4-6% over the test duration, whilst also reporting a moderate relationship with SSE performance ($r = 0.66 \pm 0.12$). Consequently, whilst SSE tests have been used with varied success in the AF TID process to date, further investigation into the use of a RSA test to discriminate between talented athletes is necessary, with seasonal changes in speed and RSA test performance in AF athletes conducted via longitudinal research.

2.4 POWER

Muscular power, defined as the rate of muscular force production throughout a range of motion, is a component of individual performance in many sports (Carlock *et al.*, 2004; Maulder & Cronin, 2005; Peterson *et al.*, 2006). As peak power is the highest instantaneous value achieved during a movement, it is typically the most important variable associated with success in sports involving sprinting and jumping activities (Harman *et al.*, 1991; Garhammer, 1993; McBride *et al.*, 1999; Carlock *et al.*, 2004). An increase in power enables a given muscle to either produce a greater magnitude of work in the same time or the same amount of work in less time, both contributing to the importance and necessity of muscular power in sports (Peterson *et al.,* 2006). In the team sport environment, the role of jumping for height is based on the nature of the sport in focus (Young *et al.*, 1997), where superior vertical jump (VJ) ability provides team sport athletes an advantage over their direct opponent (e.g. in a marking contest in AF or when heading the ball in soccer). Nevertheless, the preceding movement characteristics are vital to jump performance (Gabbett & Benton, 2009), and as such, a test of VJ ability should measure power output during a type of movement that best reflects activities performed within the sport of interest (Harman *et al.,* 1991).

The power output of an individual during a test depends on the muscle groups, joint range of motion and the type of movement involved (concentric, eccentric, single-, multi-joint etc. [Harman *et al.,* 1991]). Usually preceded by a countermovement, described by Harman and colleagues (1990) as a quick bend of the knees during which the body’s centre of mass drops before being propelled upwards, jumping in the team sport environment may be executed from a single or double leg take-off, from a standing position or from various run-up lengths (Young *et al.*, 1997). Nevertheless, the common measurement techniques of power usually involve sophisticated and expensive equipment (e.g. force plates) that are typically not available to most coaches or athletes (Carlock *et al.,* 2004). Thus, alternative field tests to estimate power via jumping and landing tasks can be used to examine various parameters of performance, identify talent and track physical development (Bobbert *et al.*, 1987a, b; Carlock *et al.*, 2004; Ford *et al.*, 2005; Walsh *et al.*, 2006).

It is suggested that a number of different VJ test protocols allow the measurement of a variety of physical qualities (Maulder & Cronin, 2005). The squat jump has been described as a measure of leg explosiveness under concentric only conditions, whilst the countermovement jump (CMJ) assesses leg power under slow-stretch shorten cycle and low stretch load conditions (Maulder & Cronin, 2005). Alternatively, the drop jump is suggested to measure fast stretch cycle behaviour (Carlock *et al.,* 2004). Meanwhile, VJ tests that contain an arm swing and / or a free-leg drive have been suggested as measures of jumping capability only, with CMJ involving no arm-swing deemed more suitable for directly assessing local muscle function (Harman *et al.*, 1990; Harman *et al.*, 1991; Young, 1995; Young *et al.*, 1997; Young *et al.*, 2001b; Carlock *et al.*, 2004). However, although the CMJ may improve the assessment of power in the lower limbs, the movements involved have been suggested to take considerably longer to perform than non-CMJ, decreasing the tests specificity to team sport activities (Harman *et al.,* 1990). In sporting situations such as rebounding in basketball (or a boundary throw-in in AF), athletes may positions themselves with bent knees whilst trying to anticipate the direction in which the ball will re-enter play (Harman *et al.,* 1990). If maximum jump height is not needed to reach the ball, then the decreased time to jump from a non-CMJ has been suggested to provide a clear advantage in movement time (Harman *et al.,* 1990). Therefore, when choosing tests to measure the lower limb power of team sport athletes, a compromise between replicating game specific jumping characteristics or the ability to localise muscular performance is required.

Significant effects on VJ performance with various lengths of run-up for both single leg and double leg take-offs has also been reported (Enoka, 1972; Ae *et al.*, 1983; Dapena *et al.*, 1990). Young and colleagues (1997) reported double leg jump height was significantly higher from a standing position and higher, though not significantly off a one-step approach in comparison to three-, five- and seven-step run-ups. In comparison, single leg jump height was significantly higher from approach distances of three or more steps, with peak height reached off five-steps (Young *et al.*, 1997). The greater performance off the single leg when jumping from a three or more step run-up was suggested to occur due to the greater vertical ground reaction forces when executing the take-off (Young *et al.*, 1997). It has therefore been suggested that an optimum run-up length and speed exists in measuring peak height for both a single and double leg take-off (Young *et al.*, 1997). Furthermore, the incorporation of an arm swing has commonly reported a 10% gain in VJ performance (Luhtanen &

Komi, 1978; Khalid *et al.*, 1989; Oddsson, 1989; Shetty & Etnyre, 1989; Harman *et al.*, 1990), with the free leg and arm swing biomechanics contributing approximately 10-30% of running single-leg VJ performance (Ae *et al.*, 1983; Young *et al.*, 2001b).

Nevertheless, previous research has reported relationships between lower limb power and other physiological attributes important within teams sport athletes, with high correlations recorded particularly between VJ performances and sprinting speed (Mero *et al.*, 1983; Young, 1995; Nesser *et al.*, 1996; Kukolj *et al.*, 1999; Maulder & Cronin, 2005). In a study amongst young collegiate athletes, Peterson and colleagues (2006) found the highest correlation to sprint acceleration and velocity was from VJ performance (r = 0.89 and 0.91 respectively), whilst Wisløff and colleagues (2004) also reported moderate to strong correlations between VJ (measured by a force platform) and both 10 m (r = 0.72) and 30 m sprint performance (r = 0.60) in a population of elite junior soccer players. Similarly, Mero and colleagues (1983) reported significant correlations between the acceleration phase (10 m) of male sprinters and both vertical squat jump (r = 0.65) and vertical CMJ (r = 0.70) performance.

In addition, lower limb power has been shown to discriminate between age groups and training experience in team sport athletes. Within a population of rugby league athletes, Baker (2002) compared lower limb power between junior-high, senior-high, college-aged, and elite professional players, with the junior-high population divided into those who had previously weight-trained and those who had not. No difference in jump squat (with a resistance of 20 kg) ability was reported between the junior and senior-high school players, while college-aged players jumped significantly higher (11-14% more, $p < 0.05$) and the elite professional players performed significantly higher again (19-36% more, $p < 0.05$ [Baker, 2002]). It was concluded that weight training programs within the high-school groups are commonly directed toward the development of strength and hypertrophy, containing no specific power training, a distinguishable element within the college-aged program. Therefore, whilst lower-limb power levels may not discriminate between rugby players at the high-school level, they do provide strong discriminators as both playing and training experience increase (Baker, 2002).

At the elite competition level of AF, a number of studies have implemented VJ testing protocols with varying results in discriminating performance outcomes (Keogh, 1999; Pyne *et al.*, 2005; Young *et al.*, 2005; Pyne *et al.*, 2006; Veale *et al.*, 2008). Using a battery of anthropometric and fitness tests to discriminate between players selected and not-selected into an elite junior AF squad, both Keogh (1999) and Veale *et al.* (2008) measured lower limb power via the standing CMJ test with arm swing (Seminik, 1990). However, only Veale *et al.* (2008) reported successful athletes recorded a significantly higher VJ than their unsuccessful counterparts ($p = 0.031$). This was supported by the significantly higher ($p = 0.001$) SVJ ability across athletes selected to play in the early rounds of an elite junior competition compared to those who were not (Young & Pryor, 2007). Whilst it is commonly assumed that a more powerful VJ is needed to out-mark or spoil an opponent during a marking contest (Woodman & Pyke, 1991; Keogh, 1999; Young *et al.*, 2005), no difference in VJ ability was reported between the high and low marking and hit-out groups across the first eight games of a competitive elite junior AF season (Young & Pryor, 2007). Furthermore, no relationship was reported with high and low possession groups or within vote winners (athletes deemed best players during the game), whilst the top four teams reported a significantly lower average jump height ($p = 0.007$) compared to the bottom four (Young & Pryor, 2007). It was therefore suggested that the ability to jump from a run-up is more related to AF performance and thus should be tested (Pyne *et al.*, 2005; Young *et al.*, 2005; Young & Pryor, 2007).

In the only study to implement both a SVJ (CMJ with arm swing) and RVJ protocol (assessed allowing a 5 m run up and jump off the outside leg using both legs [Hrysomallis *et al.*, 2002]) across elite junior AF athletes, Pyne and colleagues (2005) measured the relationship between fitness test outcomes and drafting into the elite senior AF competition, reporting no statistically significant difference between the VJ performance of drafted and non-drafted athletes (Pyne *et al.*, 2005). In spite of this, drafted athletes who subsequently made their senior AF debut had a better RVJ off their right leg and recorded a smaller asymmetry between left and right foot jump heights (Pyne *et al.*, 2005). In a secondary study, Pyne and colleagues (2006) used the same elite junior AF athletes to determine the magnitude of playing position differences in anthropometric and fitness characteristics. Using the same VJ measures, it was reported that the tall players and ruckmen had a greater running jump height than the small and medium size players, recording large effect size (Hopkins, 2000) differences of 1.25 – 1.85. Furthermore, when comparing a new sample of athletes over a five year period, only trivial changes were reported in VJ height performance at the elite junior AF level. It was subsequently concluded that whilst jumping ability is somewhat secondary in nature to the physical capabilities of speed and endurance, it still demonstrates a relevance within fitness testing protocols and should be trained for (Pyne *et al.*, 2005). As weight and plyometric training programs have lead to significant increases in strength and muscular power (Adams *et al.*, 1992; Baker, 2002), greater emphasis on this type of training may enhance performance of AF juniors, highlighting the need for longitudinal research documenting performance changes over time (Keogh, 1999).

2.5 AEROBIC CAPACITY

Aerobic performance is characterised by both aerobic power (the ability to produce aerobic energy at a high rate) and aerobic capacity (the ability to sustain exercise for a prolonged period [Bangsbo & Lindquist, 1992; Reilly *et al.*, 2000a]). Intermittent movement patterns and the ability to repeatedly perform intense exercise are components of team-based ball sports, requiring athletes to maintain well-developed aerobic and anaerobic energy systems (Reilly, 1997; Reilly *et al.*, 2000a; Krustrup *et al.*, 2003; McMillan *et al.*, 2005b; Bangsbo *et al.*, 2006; Castagna *et al.*, 2006; Thomas *et al.*, 2006). Linked with game-related work-rates and recovery from high-intensity intermittent activities (Bangsbo & Lindquist, 1992; Reilly, 1997; Impellizzeri *et al.*, 2005; Impellizzeri *et al.*, 2006), aerobic performance has demonstrated a positive relationship with total game day distance covered ($r = 0.55$,[Impellizzeri *et al.*, 2006] $r = 0.53$, [Krustrup *et al.,* 2003]) in the sport of soccer. Furthermore, improved maximum oxygen uptake (VO_2max) scores have been positively linked to the increased total time spent and increased number of efforts recorded in high intensity movement activities ($p < 0.01$, Helgerud *et al.*, 2001) resulting in an increased time in possession of the ball ($p < 0.05$) by a group of elite junior male soccer players (Helgerud *et al.,* 2001). These results highlight the major influence of a superior aerobic capacity on technical performance and tactical choices during competition (Chamari *et al.,* 2005). Consequently, aerobic training has traditionally been an important component of physical preparation within these sports (Reilly, 1997), with VO_2max considered to be the most important characteristic of endurance performance (Grant *et al.*, 1999; Hoff & Helgerud, 2004; McMillan *et al.*, 2005b).

Team sport athletes utilise the aerobic energy system in general play during submaximal activity periods (such as walking or jogging) and in the restoration or energy stores after intense work periods (Dowson *et al.*, 1999; Reilly *et al.*, 2000a; Meir *et al.*, 2001; Gabbett, 2006a). Historically, early studies of team sports including AF have emphasised aerobic conditioning (specifically through endurance running) during the pre-season training phase in response to the high percentage of total game day distance covered at a submaximal speed (Hahn *et al.*, 1979; Smith, 1983; Jones & Laussen, 1988). The attainment of high levels of aerobic fitness was also suggested to be position specific (Keogh, 1999), with movement pattern results now suggesting a varied focus on aerobic and anaerobic energy systems is required (Ackland *et al.*, 1985; Woodman & Pyke, 1991). As a result of the large number of brief high intensity activities (sprinting, jumping) interspersed by longer periods of low to moderate activities (walking and jogging, McKenna *et al.,* 1988) the pre-season training program has evolved, increasing the focus on the anaerobic energy system (strength, power and speed development [Woodman & Pyke, 1991; Cormack & Jarrett, 1995; Keogh, 1999]) Nevertheless, in a recent game-day movement pattern analysis study within AF, Dawson *et al.* (2004b) reported trends towards a larger number of high intensity efforts and greater total distance covered within the modern game, suggesting players required superior aerobic fitness capabilities to meet these increased demands. Soccer, rugby and basketball games have also demonstrated a high aerobic loading based on heart rate recordings and movement pattern analysis, coupled with specific game periods producing a high turnover of anaerobic energy (Bangsbo *et al.*, 1991; Meir *et al.*, 1993; McInnes *et al.*, 1995; Deutsch *et al.*, 1998; Gabbett, 2000; Bishop *et al.*, 2001; Gabbett, 2002b, a; Coutts *et al.*, 2003; Atkins, 2006; Krustrup *et al.*, 2006a; Krustrup *et al.*, 2006b). Therefore, whilst sports such as AF can be described as a fast moving intermittent based team-sport, aerobic capacity remains a vital physiological attribute for participation at all levels of competition (Hahn *et al.*, 1979; Ackland *et al.*, 1985; Woodman & Pyke, 1991; Norton *et al.*, 1999; Ebert, 2000; Dawson *et al.*, 2004b; Young *et al.*, 2005; Veale *et al.*, 2009c).

As with all components of fitness, testing the physiological attribute of aerobic capacity must demonstrate a strong relationship between test results and game day movement characteristics (Bangsbo & Lindquist, 1992). With the transport and subsequent use of oxygen by active muscles deemed a significant limitation of an athlete's VO_2max capacity, the use of appropriate testing protocols could provide valuable information to coaches regarding the effect of aerobic training on subsequent performance (Van Gool *et al.*, 1988; Bunc & Psotta, 2001; Casajus, 2001; Hoff, 2005; Impellizzeri *et al.*, 2005). However, the ability to tolerate high rates of energy expenditure over time, a capacity for intense activity, has been reported as one of the most difficult components of athletic performance to objectively quantify (Bouchard *et al.*, 1991; Bangsbo & Lindquist, 1992; Inbar *et al.*, 1996; Cooper *et al.*, 2004). Considered accurate measures of aerobic power and capacity, VO_2max tests have involved continuous exercise protocols within the laboratory (treadmill tests) or in the field (multi-stage fitness test [MSFT]) to evaluate or predict the physical status of individual athletes (Ramsbottom *et al.*, 1988; Leger & Gadoury, 1989; Bangsbo & Lindquist, 1992; Bangsbo, 1994b; Bishop *et al.*, 2001; Krustrup *et al.*, 2003; Chamari *et al.*, 2004; Castagna *et al.*, 2005; Krustrup *et al.*, 2005; Svensson & Drust, 2005; Castagna *et al.*, 2008b). Whilst the "gold standard" measurement of aerobic fitness has long been obtained via a laboratory testing protocol that measures VO_2max at volitional exhaustion (Leger *et al.*, 1988; Ramsbottom *et al.*, 1988; Grant *et al.*, 1999; Cooper *et al.*, 2004; Aziz *et al.*, 2005b; Chamari *et al.*, 2005), these procedures are time consuming, require trained personnel and use expensive equipment (Grant *et al.*, 1999; Aziz *et al.*, 2005b; Cooper *et al.*, 2005; Castagna *et al.*, 2008b). Consequently, laboratory testing has often been limited to research studies or within elite level senior sporting teams (Bangsbo & Lindquist, 1992; Chamari *et al.*, 2004; Impellizzeri *et al.*, 2005).

Therefore, field-tests (commonly continuous in nature) have been designed as practical alternatives to laboratory testing, evaluating aerobic capacity by using prediction equations to calculate VO_2max at volitional exhaustion (Ramsbottom *et al.*, 1988; Leger & Gadoury, 1989; Grant *et al.*, 1999; Chamari *et al.*, 2005; Impellizzeri *et al.*, 2005). With test validity based on their correlations with VO_2max (criterion validity) and displacement specificity (logical validity [Ramsbottom *et al.*, 1988; Leger & Gadoury, 1989; Cooper *et al.*, 2005; Castagna *et al.*, 2008b]) maximal and sub-maximal tests have been conducted in non-laboratory environments via the use of walking (Kline *et al.*, 1987), cycling (Åstrand & Rhyming, 1954) and running protocols (Leger *et al.*, 1988;

Ramsbottom *et al.*, 1988; Cooper *et al.*, 2005). Aiming to simulate a continuous incremental exercise test to volitional exhaustion (Leger *et al.,* 1988), the 20 m MSFT is the most common field test for the prediction of VO_2max requiring little equipment, is easy to administer and can assess large numbers of participants at any one time (Cooper *et al.*, 2005; Flouris *et al.*, 2005). However, studies evaluating the accuracy of this field test in predicting laboratory determined VO_2max have reported contradictory results as a consequence of the variety of prediction equations in use (Boreham *et al.*, 1990; Grant *et al.*, 1995; Grant *et al.*, 1999; Stickland *et al.*, 2003; Flouris *et al.*, 2005). Nevertheless, this test is still commonly performed as a measure of athletic ability, training adaptations and in the selection of athletes at both senior and junior competition levels (Dowson *et al.*, 1999; Keogh, 1999; Gabbett, 2002a, 2005; Pyne *et al.*, 2005; Young *et al.*, 2005; Young & Pryor, 2007; Gabbett *et al.*, 2008a).

Most often used to measure aerobic capacity within AF athlete servicing and research, the MSFT has been employed at both the elite junior and senior levels of competition to establish relationships between test performance and both team selection and game day outcomes. Within the TID and development research at the elite junior AF level, the MSFT has reported inconsistent results. Whilst Keogh (1999) reported no difference between athletes selected and not selected onto one elite junior AF season playing list, Young and Pryor (2007) recorded across an entire competition, a significantly greater aerobic capacity in those who were selected to participate in game one of the competitive season compared to those who were not. Reporting similar trends by discriminating between athletes drafted and not-drafted into the elite senior AF competition from within an elite cohort of junior AF athletes, Pyne *et al.* (2005) reported a slightly higher (0.8 ml/kg^{-1}/min^{-1}) predicted VO_2max via MSFT performance by athletes who were successfully drafted. Furthermore, despite the absence of statistical presentation of data, Pyne *et al.* (2005) asserted that only trivial differences were reported between those who subsequently made their debut at the elite senior AF level compared to those who did not.

Using the MSFT, trends have also been reported toward positional differences in estimated VO_2max results within AF research. Athletes classified as small or medium size players, filling the more 'nomadic' field positions, have reported a slightly better aerobic capacity than the taller key position players and ruckmen (Pyne *et al.*, 2006). This finding supports the research of Young and Pryor,(2007) who reported athletes comprising a high-possession group (athletes likely to be in the 'nomadic' field positions as defined by Pyne *et al.* 2006) were also found to have a significantly greater predicted VO_2max. This has been suggested a reflection of the playing position and one characteristic of the type of player who is suited to this game style (Young & Pryor, 2007). Furthermore, junior players tested by Keogh (1999) were found to have values similar to senior AF athletes (Cormack & Jarrett, 1995), suggesting the difference in estimated VO_2max reported to be minimal. Consequently, the development of a high aerobic capacity has been deemed necessary to sustain the increased work-rates required at higher standards of competition (Reilly *et al.*, 2000b).

However, with the intermittent nature of movement patterns reported in sports such as soccer (Mohr & Bangsbo, 2001; Mohr *et al.*, 2003; Svensson & Drust, 2005; Castagna *et al.*, 2006; Krustrup *et al.*, 2006a; Krustrup *et al.*, 2006b), rugby (Docherty *et al.*, 1988; Meir *et al.*, 1993; Gabbett, 2002b; Coutts *et al.*, 2003; Atkins, 2006), basketball (McInnes *et al.,* 1995) and AF (Dawson *et al.*, 2004b; Veale *et al.*, 2009c), continuous exercise tests have recently been questioned to pose a potential threat to the content and construct validity of performance results (Bangsbo, 1994a; Krustrup & Bangsbo, 2001; Krustrup *et al.*, 2003; Castagna *et al.*, 2005; Atkins, 2006; Krustrup *et al.*, 2006a; Krustrup *et al.*, 2006b; Castagna *et al.*, 2008b). Reported to be a precise measure of physical performance during a soccer game, high-intensity exercise is thus a significant physical component worth measuring (Ekbolm, 1986; Bangsbo *et al.*, 1991; Bangsbo & Lindquist, 1992; Mohr & Bangsbo, 2001; Krustrup *et al.*, 2003). The Yo-Yo Intermittent Recovery (IR) Test was developed to consequently evaluate the ability of an athlete to repeatedly perform intense exercise and their capacity to recover during such an activity (Bangsbo, 1994a; Krustrup *et al.*, 2003; Thomas *et al.*, 2006). Performed to voluntary exhaustion, the Yo-Yo IR test is a sport specific field test of aerobic capacity and has been closely related to the physical performance of top-class soccer players and referees (Krustrup & Bangsbo, 2001; Krustrup *et al.,* 2003). The Yo-Yo IR Level 1 (IR1) Test (designed for lesser trained individuals) involves the completion of repeated exercise bouts (20 m shuttles; up and back) at progressively increasing speeds controlled by audio bleeps, interspersed with 10 s active recovery periods that commonly lasts for 10-20 min in duration (Bangsbo, 1994a; Krustrup *et al.*, 2003; Krustrup *et al.*, 2006a; Thomas *et al.*, 2006).

Designed to further stimulate the aerobic and anaerobic energy systems simultaneously, the Yo-Yo IR Level 2 (IR2) test (aimed at well trained and elite athletes) follows the same protocols to the IR1 test, however lasts 2-10 min in duration in response to more rapid increases in speed intervals (Bangsbo, 1994a; Krustrup *et al.*, 2006a). Studies measuring the reliability of the Yo-Yo IR1 (Krustrup *et al.,* 2003) and IR2 (Krustrup *et al.*, 2006a) tests via a test-retest protocol have reported no difference between test performance on two occasions separated by 1 week, suggesting the tests have a high reproducibility rate. Furthermore, using elite level athletes from AF, cricket, hockey as well as a population sample of healthy males who participate in recreational sporting activity, Thomas and colleagues (2006) reported that both levels of the Yo-Yo IR tests were reliable, with IR1 recording an interclass coefficient (ICC) of 0.95 and IR2 an ICC of 0.86.

Demonstrating essential physiological components of a number of team sports by placing a high stress on both the aerobic and anaerobic pathways (Meir *et al.*, 1993; Brewer & Davis, 1995; Gabbett, 2002a; Atkins, 2006), the Yo-Yo IR1 test has been used in response to its ability to assess recovery from high-intensity running efforts (Bangsbo, 1994a; Krustrup *et al.,* 2003). Furthermore, whilst performance in team sports, such a basketball, has been attributed to a players' anaerobic ability (Stone & Steingard, 1993), VO_2max is considered important in the recovery from in-game anaerobic efforts (Tomlin & Wenger, 2001) and in preparing players to sustain their training and competition load volume (Stone & Steingard, 1993). Measuring the validity of the Yo-Yo IR1 test in a population of junior male basketball players (mean age 16.8 ± 2 years), Castagna and colleagues (2008b) reported a significant relationship between test performance and VO_2max measured by a laboratory incremental running test (r = 0.77). Consequently, it was concluded that the shared variance of 59% confirms the validity of the Yo-Yo IR1 test as a generic measure of aerobic fitness (Castagna *et al.*, 2008b). Nevertheless, when employing the use of an intermittent (Yo-Yo IR1) and continuous field test (12 min run test) of aerobic capacity, Castagna and colleagues (2005) reported no significant difference in total distance covered during the 12 min run test of three levels of soccer referees (top-, medium-, and low-level), whilst the top-level referees performed significantly better than the other two levels on the Yo-Yo IR1 test. It was therefore suggested that performance differences at the three levels of sport participation was directly a result of the referees ability to endure progressive high-intensity intermittent running efforts interspersed by brief recovery periods.

Similar findings have been reported across team sport athletes. Field positions (fullbacks and midfielders), who have previously recorded covering the largest game day distances of high-intensity running during top-class soccer games (Mohr & Bangsbo, 2001), have also reported 14-17% better Yo-Yo IR1 test performance in comparison to the other field positions (central defenders and attackers, Krustrup *et al.,* 2003). Furthermore, a low to moderate (but significant; $p < 0.05$) correlation between test performance and the amount of high-intensity running (r = 0.71) and sprinting performed (r = 0.58), as well as the total distance covered (r = 0.53) has been reported (Krustrup *et al.,* 2003), suggesting this test is a sensitive measure of variations in soccer performance. Superior Yo-Yo IR2 test performance have also been reported by international elite level soccer players (Krustrup *et al.*, 2006a), corresponding with the recording of 25% more high-intensity running and 35% more sprinting during competitive games in comparison to their professional counterparts at a moderate elite level (Mohr *et al.,* 2003). It was therefore concluded that the Yo-Yo IR2 test is also capable of evaluating an athlete's ability to perform intense intermittent exercise that requires a significant contribution from both aerobic energy production and the anaerobic energy system (Krustrup *et al.*, 2006a).

To date, limited research utilising a Yo-Yo IR test protocol has involved AF athletes, currently only comparing performances in the Yo-Yo IR2 test to that of the MSFT (Thomas *et al.*, 2006) and their subsequent relationship with team selection for game one of a competitive season (Young *et al.*, 2005). Thomas and colleagues (2006) reported strong associations between test scores of elite AF participants when comparing Yo-Yo IR2 shuttle and distance results with MSFT and predicted VO_2max results (*r* values > 0.80), suggesting a significant contribution in both tests from the aerobic energy system in athletes of higher aerobic fitness capacities (Thomas *et al.*, 2006). However in contrast, Young and colleagues (2005) demonstrated a significantly better Yo-Yo IR2 test performance (747 ± 128 vs. 547 ± 61 m; p = 0.023) in athletes selected to play in game one of the competitive season, whilst no difference was reported between the two groups for MSFT predicted VO_2max scores (p = 0.46). It was subsequently suggested that the Yo-Yo IR2 test demonstrates a stronger relationship with AF performance in response to the game simulated movement patterns involved (Young *et al.*, 2005).

Whilst one-off testing is commonly used in the AF TID pathway, seasonal changes in aerobic performance has reported variable trends. McMillan and colleagues (2005a) examined professional youth soccer players over the duration of a soccer season, reporting significant improvements in aerobic endurance performance from the start of the pre-season training phase to early in the competitive season due primarily to the detraining that occurs over the off-season break (McMillan *et al.*, 2005a). In a similar fashion, Krustrup and colleagues (2003) recorded an improvement of 25% in Yo-Yo IR1 test performance of elite level soccer players and 42% in Yo-Yo IR2 test performance (Krustrup *et al.* 2006a) over the pre-season training period, whilst elite level soccer referees recorded an improved performance (31%) after an 8 wk intense intermittent training program despite a negligible change in VO_2max (Krustrup & Bangsbo, 2001). Throughout the competition phase, the maintenance of endurance fitness levels has been reported by McMillan and colleagues (2005a) and has been attributed to the increased game loads experienced nearing the end of the competitive season, despite the drop-off in training time. However in contrast, Brady and colleagues (1995) reported a deterioration in endurance performance and Bangsbo (1994a) and Krustrup *et al.* (2006a) reported a decline in Yo-Yo IR2 test performance throughout the season, suggesting the periodised scaling back of training nearing the end of the season may have resulted in the reduction of aerobic fitness levels. Nevertheless, both Yo-Yo IR1 and IR2 tests have demonstrated sensitivity in recording training adaptations and improvements in performance, along with the ability to report seasonal changes in aerobic performance.

Therefore, combined with the ability of the Yo-Yo IR tests to evaluate game-related aerobic-anaerobic physical capacity in soccer players (Krustrup *et al.,* 2003), intermittent recovery and endurance tests have provided important information in the TID, development and selection process (Castagna & D'Ottavio, 2002; Helsen & Bultynck, 2004; Castagna *et al.*, 2005). With trivial differences currently reported within the AF research using continuous exercises tests (Keogh, 1999; Pyne *et al.*, 2005; Young & Pryor, 2007), the use of alternative tests to discriminate between talented athletes via the physiological attribute of aerobic capacity should be investigated. Furthermore, in the absence of research documenting the seasonal variation of aerobic performance in AF athletes, longitudinal studies will therefore enhance the TID and development process at the elite junior AF competition level.

2.6 THE INFLUENCE OF SPORT PARTICIPATION ON CHANGES IN BODY COMPOSITION AND THEIR RESULTING EFFECT ON TEAM SELECTION

When testing the various fitness components (described earlier in this chapter) of junior athletes, it is commonly accepted that biological maturity (comprising of chronological age and musculoskeletal maturity) is an influencing factor on physical test performance (Malina, 1994; Jones *et al.*, 2000). Rarely progressing at the same rates, chronological age and skeletal maturity may vary considerably, influencing early TID and selection through the potential delay in development of many physiological qualities until late in adolescence (Bouchard *et al.*, 1976; Fisher & Borms, 1990; Pena Reyes *et al.*, 1994; Katzmarzyk *et al.*, 1997; Williams & Reilly, 2000). To date, body composition analysis within AF studies has been limited to reporting only total body mass and skinfold anthropometry in the TID and selection process (Keogh, 1999; Pyne *et al.*, 2005; Young *et al.*, 2005; Pyne *et al.*, 2006; Young & Pryor, 2007; Veale *et al.*, 2008). Therefore, as AF research has been limited in the methodology of analysing the body composition at all levels of competition, this section of the literature review will focus on sports that show similarities to the demands of AF.

The three major components that make up the human body include bone mineral, lean mass ([LM] also known as fat-free mass [FFM]) and fat mass (FM [Gotfredsen *et al.*, 1986; Madsen *et al.*, 1997]). These components are important in a wide variety of settings and research studies. Clinical settings have focused research on the measurement of total and regional bone mineral density (BMD) and soft tissue composition, whilst the fields of physiology, rehabilitation and sports medicine commonly use the monitoring of regional tissue composition to provided relevant measures of change (Madsen *et al.,* 1997). Within these areas of research, understanding the skeletal development and physical maturity of a young athlete is critical in creating a complete assessment of their performance abilities. One method that has the potential to provide this information is the technique of dual energy X-ray absorptiometry (DEXA [Madsen *et al.,* 1997]). Expanding on the two-compartment model (FM and LM) for assessing body composition, DEXA provides a three-compartment model of body composition by measuring bone mineral mass in addition to FM and LM (Kohrt, 1998; Van Der Ploeg *et al.*, 2003).

A general consensus across the research suggests the most effective stimulus for bone mineral acquisition and adaptation appears to be the imposition of mechanical stresses exerting high peak strains on the skeleton (Rubin & Lanyon, 1985; Jarvinen *et al.*, 1998; Pedersen *et al.*, 1999; Calbet *et al.*, 2001), most commonly via forces exerted by muscular contraction or external loads from ground reaction forces (Nordström *et al.*, 1998; Kohrt *et al.*, 2004; Smathers *et al.*, 2009). In addition, the most critical period of skeletal mineralisation is reported to be within the childhood and adolescent years (Slemenda *et al.*, 1994; Fehling *et al.*, 1995; Kannus *et al.*, 1995; Bennell *et al.*, 1997; Bradney *et al.*, 1998; Nordström *et al.*, 1998; Bailey *et al.*, 1999; Pettersson *et al.*, 1999; McKay *et al.*, 2000; Karlsson *et al.*, 2001), with studies reporting almost half of the skeletal adaptation observed in adult soccer players (Calbet *et al.,* 2001) is already present within their prepubescent counterparts

(Vicente-Rodriguez *et al.,* 2003). In a longitudinal study, Bailey and colleagues (1999) reported a 9 to 17% greater total body mineral content (BMC) in active boys and girls one year after their peak BMC velocity compared to their inactive peers. When assuming total adult BMC values, Bailey and colleagues (1999) further suggest that roughly 26% of final adult bone mineral status is accrued in the two adolescent years around peak BMC velocity. It was therefore concluded that the bone mineral accumulated during the adolescent years is substantial in those participating in high physical activity levels (Bailey *et al.,* 1999). However, based on an observed similarity in BMD between an elite soccer population of varying playing experience (Wittich *et al.,* 1998), it was concluded that a plateau occurs around 20 years of age, with no significant further increment expected thereafter.

Skeletal tissue response to exercise has been linked to the duration, intensity and type of exercise completed (Suominen, 1993; Marcus, 1998; Calbet *et al.*, 2001). Currently, research suggests that the intensity of the exercise rather than the duration is the main determinant of BMD development (Fehling *et al.,* 1995; Karlsson *et al.,* 2001), with moderate- to high-intensity weight-bearing physical activity positively related to an increased BMD (Bailey & McCulloch, 1990; Hamdy *et al.*, 1994; MacKelvie *et al.*, 2002; Kohrt *et al.*, 2004; Smathers *et al.*, 2009). Subsequently, it is widely agreed that intense physical training during an individual's growth period markedly increases their BMD and appears to be the preferred prescription for the increase in peak BMD to occur (Slemenda & Johnston, 1993; Fehling *et al.*, 1995; Heinonen *et al.*, 1995; Lee *et al.*, 1995; Alfredson *et al.*, 1996; Duppe *et al.*, 1996; Haapasalo *et al.*, 1996; Karlsson *et* *al.*, 1996; Nordström *et al.*, 1998; Wittich *et al.*, 1998; Calbet *et al.*, 2001; Karlsson *et al.*, 2001; Hind & Burrows, 2007). Furthermore, areas of the skeleton that receive a direct physical load have been found to have a greater exercise increment of BMD (Vuori, 1996; Wittich *et al.*, 1998; Calbet *et al.*, 2001). Although athletes tend to have a higher BMD than control participants, this is particularly the case in "impact" loaded sports (Hetland *et al.*, 1993; Lee *et al.*, 1995; Alfredson *et al.*, 1996; Duppe *et al.*, 1996; Wittich *et al.*, 1998; Calbet *et al.*, 2001), with strength- and power-trained athletes reporting higher BMD than endurance-trained athletes (Bennell *et al.,* 1997; Smathers *et al.,* 2009). Furthermore, when measuring the BMC and BMD ratio between unloaded (arms) and exercise-loaded (legs) limbs within soccer athletes, a significantly higher leg to arm ratio emphasised the sports trend towards leg BMC and BMD enhancement (Haapasalo *et al.*, 1998; Nordström *et al.*, 1998; Calbet *et al.*, 2001; Karlsson *et al.*, 2001). As a consequence, soccer rather than constant intensity long distance running has been suggested to elicit greater bone adaptations in the lower limbs and axial skeleton (Calbet *et al.,* 2001). Comparing professional, third and sixth tier soccer players and a control group (with mean group ages ranging between 21.8-24.4 years), Karlsson and colleagues (2001) demonstrated, despite a difference in average training hours between the three soccer groups (11.9, 7.7 and 6.0 respectively), no BMD differences between the groups, suggesting the skeleton will adapt to the intensity and type of training in order to maintain strength, with increasing duration above established levels resulting in no additional benefit.

Team sports such as AF and soccer are categorised as intermittent high-intensity sports, whereby considerable ground reaction forces are elicited during sprinting, COD, jumping and kicking activities (Freychat *et al.*, 1996; Nordström *et al.*, 1998; Wittich *et al.*, 1998; Calbet *et al.*, 2001; Vicente-Rodriguez *et al.*, 2003; Ginty *et al.*, 2005). Therefore, the movement patterns and game demands of soccer players have been deemed responsible for increases observed in femoral neck (Alfredson *et al.,* 1996; Calbet *et al.,* 2001; Vicente-Rodriguez *et al.,* 2003) and lumbar spine BMD (Bobbert *et al.*, 1987b; Alfredson *et al.*, 1996; Duppe *et al.*, 1996; Calbet *et al.*, 2001; Vicente-Rodriguez *et al.*, 2003), as well as total lower limb BMC and BMD when compared to their non-active counterparts (Wittich *et al.,* 1998). Comparing a group of highly trained male soccer players to an age-matched control group for skeletal variables and body composition, Wittich and colleagues (1998) measured total body BMC and BMD and analysed the sub-regions of head, arms, trunk, pelvis and legs. When compared to their age and body mass index matched control counterparts, the elite soccer athletes, while weighing in an average of 2.2 kg more, reported 4.7 kg less fat ($p = 0.002$), 6.6 kg more lean mass ($p < 0.001$) and 0.6 kg more bone mass ($p < 0.001$ [Wittich *et al.,* 1998]) Furthermore, the BMC of the soccer athletes was 18% higher ($p < 0.001$), with a 12.3% ($p < 0.001$) increase of BMD and 5.2% elevation of the projected area ($p < 0.05$). The legs of the soccer athletes recorded a 24.5% higher average BMC as a consequence of an 8% difference of bone size and a 15.7% increase of bone density when compared to their control counterparts (Wittich *et al.,* 1998). Similar tendencies were reported in the pelvis, where the soccer athletes reported a 34.2% higher BMC and a 20.2% elevation in BMD. However, within groups analysis reported no significant difference between the BMC and BMD amongst the soccer athletes when separated into those with less than seven years of intensive training and those with more than seven years (Wittich *et al.,* 1998). Reporting similar body composition results, Calbet and colleagues (2001) recorded 13% greater whole body BMC ($p < 0.001$), with significantly higher BMC and BMD in the lumbar spine, femoral neck regions, pelvis and leg regions (ranging from 16 to 27%), but no difference in the arms.

Within the limited research across both elite senior and junior AF competition levels, body mass and anthropometric assessment has reported trends toward heavier athletes being selected into a squad playing list (Keogh, 1999; Veale *et al.,* 2008) or the team for the first round of a competition season (Young *et al.*, 2005; Young & Pryor, 2007). It has subsequently been proposed that an increase in primarily muscle tissue may have played a role within the selection process (Young & Pryor, 2007). However, despite the absence of statistical data presented, Pyne *et al.* (2005) asserted only trivial differences in anthropometric and body mass measurements were found when discriminating between elite junior athletes who were drafted into the elite senior AF competition and those not, or between those who subsequently made their senior debut. Even so, discrete differences in anthropometric attributes have been suggested to be dependent on field positional roles (Pyne *et al.*, 2005; Pyne *et al.*, 2006), with variations also reported in relationships between body mass and game day performances, individual player and team rankings (Young & Pryor, 2007). Whilst junior AF athletes have reached biological maturity (e.g. Tanner stage 5), variable growth rates and physical responses to training continue to provide a confounding factor when predicting future performance (Pearson *et al.,* 2006). As such, and in response to commonly reported lighter body mass results in comparison to their senior counterparts, an increase in body mass accompanied with an increase in strength is suggested the greatest challenge in preparing these players to compete at an elite senior level (Keogh, 1999).

Within the research of junior sporting athletes, skeletal maturity is reported to be in advance of chronological age (Lariviere & Lafond, 1986; Malina *et al.,* 2000). As a result, common benefits of such physical maturity include larger body size, greater muscular strength and power, and greater absolute peak VO_2 in young adolescent males (Malina & Bouchard, 1991). However, research has also identified a relative age effect across team sport athletes, with participation rates during childhood and adolescence frequently skewed towards those born early in the selection year (Baxter-Jones, 1995; Musch & Grondin, 2001; Mujika *et al.*, 2009). In sports where superior physical attributes (such as body size, power and strength) are important to athletic performance, older athletes are presumably at an advantage due to physical superiority, resulting in earlier TID, higher quality of coaching and a greater experience from participating in advanced competition levels (Malina, 1994). Within a study of 13,519 male European soccer players, Mujika *et al.* (2009) reported a bias towards a higher number of births early in the selection year, with 43.9% of senior athletes and 46.6% of elite youth athletes born in the first three months. Furthermore, nearly 65% of AF athletes attending an annual national physical testing camp were born in the first half of the selection year. Nevertheless, no substantial differences were shown between athletes subsequently selected or not selected into the AFL, suggesting an equal chance existed within the most elite junior talent (Pyne *et al.*, 2006).

Consequently, whilst a combination of factors have been suggested as possible reasons behind these physical trends, Malina and colleagues (2000) concluded that soccer systematically excludes late maturing boys as chronological age and sport specialisation increase. It has also been suggested that a short-term focus on winning rather than long-term development often excludes late-maturing junior athletes who lack the additional support to reduce the age-bias difference (Mujika *et al.,* 2009). This raises the need for greater in-depth body compositional analysis and coach awareness of the basic principles of growth and development to ensure talented, late maturing boys are nurtured through junior sporting programmes, maximising the physical development of all athletes involved within a sport. Such research should also consider the contribution of genetics to physical performance and physical responsiveness to a training stimulus (Pearson *et al.,* 2006), providing further understanding in the talent detection process as to the varying rates of development between two talented athletes of the same age. However, whilst the measurement and role of genetics is outside the scope of this thesis, the absence of in-depth body compositional assessment within AF has limited the analysis of performance changes in physical attributes. Furthermore, the limited number of longitudinal studies (including none currently conducted within AF) documenting physical development changes over time highlights the need for increased analysis within elite junior team-sport programs.

2.7 LONGITUDINAL RESEARCH IN FOOTBALL CODES

Team sport athletes, such as those participating in soccer and AF competitions are required to be in peak or near optimal physical fitness each week throughout an entire playing season (Brady *et al.*, 1995; Aziz *et al.*, 2005a). Currently, only a small number of season long physiological studies have been conducted within team sport competitions, with scheduling issues in response to extensive training and game involvements (including major championship games), as well as injuries, common barriers confronted (Thomas & Reilly, 1979; Brady *et al.*, 1995; Reilly & Keane, 1999; Dunbar, 2002; Aziz *et al.*, 2005a; McMillan *et al.*, 2005a). Whilst team sport training programs aim to maximise the physiological development of athletes over the pre-season training phase and maintain an optimal level of fitness over the course of a season, fluctuations in training volume and intensity throughout the competition phase will result in alterations in fitness levels and performance outcomes (Brady *et al.,* 1995). Subsequently, seasonal testing of athletes is commonly conducted on return from an off-season of no training, at the completion of the pre-season training phase, in the middle and at the conclusion of the competitive season (Brady *et al.*, 1995; Dunbar, 2002; Aziz *et al.*, 2005a). A variety of other approaches have also been administrated (Thomas & Reilly, 1979; Brady *et al.*, 1995; Reilly & Keane, 1999; Ostojic, 2003; McMillan *et al.*, 2005a), such as a three test battery occurring at the commencement of pre-season training, during the middle and at the completion of the competitive season (Thomas & Reilly, 1979; Brady *et al.*, 1995). Irrespective of the design used, physiological testing over the duration of a competitive team sport season has reported significant changes across performance outcomes (Thomas & Reilly, 1979; Brady *et al.*, 1995; Reilly & Keane, 1999; Dunbar, 2002; Aziz *et al.*, 2005a; McMillan *et al.*, 2005a).

Aziz *et al.* (2005a) tracked forty-one professional soccer players within the top Singapore soccer competition over their nine month training and playing season. Testing the players on their return from the off-season, at the completion of the pre-season training phase, in the middle and at the completion of the season, height, body mass and percentage body fat, aerobic endurance (MSFT), sprinting ability (20 m sprint) and jumping performance (CMJ) were all measured. Although no significant difference was demonstrated in body mass and percentage body fat changes, a slight decrease in weight and body fat occurred over the course of the season, reporting a moderate correlation ($r = 0.43$) with improved sprint times over the first half of the competitive season. Despite no correlation being demonstrated with vertical jump or aerobic endurance performance, independently vertical jump performance was at its lowest on return from the off-season ($p < 0.01$) and continued to improve into the middle of the season ($p < 0.05$), whilst aerobic endurance also recorded its lowest levels upon return from the off-season and maintained pre-season levels over the course of the season (Aziz *et al.,* 2005a).

A high correlation ($r = 0.98$) has also been reported by Ostojic (2003) when using the sum of seven skinfold and 50 m maximum sprint tests. Furthermore, sprint times were reported the main improvements in season long fitness profiles of senior Gaelic football players (Reilly & Keane, 1999). These changes in speed were attributed to be in response to the in-season training emphasis on repeated short burst and high-intensity sprints, in conjunction with the decreased body fat being carried (Aziz *et al.,* 2005a). In response to low aerobic endurance scores on the return to training, significant improvements are commonly reported over the duration of a pre-season training period,(Aziz *et al.,* 2005a) whilst VJ performance has also reported significant improvements over the first half of the competitive season (Thomas & Reilly, 1979; Brady *et al.*, 1995; Dunbar, 2002; McMillan *et al.*, 2005a). Changes in aerobic performance are commonly attributed to the revised training focus from high volume throughout the pre-season phase to low volume and high intensity work throughout the competitive season (Thomas & Reilly, 1979; Brady *et al.*, 1995; Dunbar, 2002; McMillan *et al.*, 2005a).

Implementing a test battery over a two year period, Elferink-Gemser *et al.* (2006) measured anthropometric, physiological, technical, tactical and psychological characteristics of junior (13.9 ± 1.3) field hockey athletes. Measured at three time points over a two year period, the elite players were reported to perform better than their sub-elite counterparts on the physiological, technical, tactical and psychological characteristics. However, there was a significant main effect across both groups regarding development of performance over the two year study duration (Elferink-Gemser *et al.,* 2006). When considered as a single group, the study participants were found to be taller, heavier and recorded less body fat, were faster on peak, repeated and slalom shuttle sprint performance and had an improved interval endurance capacity and slalom dribble performance. Despite these improvements in performance across all the testing protocols, only one athlete was elevated from the sub-elite to elite competition level over the course of the study, whilst five were demoted from the elite to sub-elite and 30 from the sub-elite to club level standards. Consequently, 25% of the participants could not meet the expectations of the playing standard they were participating in over the two year period (Elferink-Gemser *et al.,* 2006). Despite the conclusion that one single domain of performance does not solely distinguish between elite and sub-elite players, elite young players did report better initial test results and demonstrated greater improvements in test performance over the duration of the study in comparison to the sub-elite group (Elferink-Gemser *et al.,* 2006).

2.8 CONCLUSION

To date, research using a variety of one-off physiological test batteries within the TID process at the elite junior AF development level have been conducted, reporting the discriminatory abilities of physiological variables toward selection onto final squad lists (Keogh, 1999; Veale *et al.,* 2008), team selection for competition games (Young & Pryor, 2007), performance within such games (Young & Pryor, 2007) and even selection onto an elite senior professional AFL list at the conclusion of a junior career (Pyne *et al.*, 2005; Pyne *et al.*, 2006). Such information has been used in the development of age specific fitness and conditioning guidelines, whilst also being useful for athletes in their pursuit of success and for recruiters in their assessment and identification of future talent (Pyne *et al.*, 2005). Whilst physical testing has shown an ability to discriminate within AF athletes (Keogh, 1999; Pyne *et al.*, 2005; Young *et al.*, 2005; Pyne *et al.*, 2006; Young & Pryor, 2007; Veale *et al.*, 2008), the continued evolution of the modern game of AF (Norton *et al.,* 1999) has resulted in the need for further exploration into the use of various new physical tests within the TID process.

Presently, testing within the AF talent pathway has been dominated by a core battery of field tests measuring agility, speed, power and aerobic capacity (Pyne *et al.*, 2005; Pyne *et al.*, 2006; Young & Pryor, 2007; Veale *et al.*, 2008). Whilst these tests have previously discriminated within the elite junior AF pathway, recent research has questioned their specificity and validity in response to the changing nature of AF. In response to the evolving definition of agility and the increasingly important measurement of a reactive component (Sheppard &

Young, 2006; Sheppard *et al.,* 2006), combined with the conflicting angles of direction change within the test to those within a game (Dawson *et al.*, 2004b; Young & Pryor, 2007), the specificity of the current AF agility test has been questioned (Young & Pryor, 2007). Furthermore, with the modern version of AF comprising an increased number of high intensity efforts (Dawson *et al.*, 2004b), the specificity and validity of single sprint effort testing (in light of the discriminatory capacity of repeated sprint ability test protocols [Dawson *et al.*, 1998; Lakomy & Haydon, 2004; Dupont *et al.*, 2005; Psotta & Bunc, 2005; Hughes *et al.*, 2006; Oliver *et al.*, 2006; Rampinini *et al.*, 2007; Oliver *et al.*, 2009]) is also questionable in the identification of future talented athletes. In addition, the consistent use of the MSFT (a continuous exercise test), despite the intermittent movement patterns of AF (Dawson *et al.*, 2004b; Veale *et al.*, 2009c), suggests the need for future research into the use of newly designed tests within the AF TID pathway. Recent research at the elite senior AF level has demonstrated the successful implementation of new field tests for the measurement of the physiological components of reactive agility (Sheppard *et al.,* 2006), speed and repeated sprint ability (Young *et al.*, 2008) and aerobic capacity (Young *et al.*, 2005), These studies have reported the usefulness of these tests in discriminating between performance and team selection, in contrast to measures currently used within the talent pathway (MSFT [Young *et al.*, 2005]) Therefore, it is paramount that if new tests are designed or chosen for use within the AF TID pathway, they first must be proven reliable and valid within the AF sporting context, with the implementation of a longitudinal design further enhancing their usefulness in the selection of future elite athletes.

Despite the limitations involved when conducting longitudinal TID and developmental research in the team sport environment, seasonal research highlights the need for analysis of athlete physical and physiological development to be a continual year-round process (Thomas & Reilly, 1979; Brady *et al.*, 1995; Reilly & Keane, 1999; Dunbar, 2002; Aziz *et al.*, 2005a; McMillan *et al.*, 2005a) rather than a once-off occurrence. Commonly, all physical measures have reported significant improvements over the pre-season training period (Thomas & Reilly, 1979; Brady *et al.*, 1995; Reilly & Keane, 1999; Dunbar, 2002; Aziz *et al.*, 2005a; McMillan *et al.*, 2005a), with some studies demonstrating the capacity of athletes to maintain this level of fitness throughout the entire competitive season (Aziz *et al.,* 2005a), whilst others have questioned this ability (Thomas & Reilly, 1979; Brady *et al.*, 1995). Moreover, Brady *et al.* (1995) demonstrated greater improvements in physiological attributes over the course of the second season within their longitudinal study program, suggesting a longer analysis time frame is required for an accurate reflection of development within the junior sporting population. Furthermore, with body composition analysis commonly documenting differences within athletes of various ages within other football codes (Wittich *et al.*, 1998; Malina *et al.*, 2000; Calbet *et al.*, 2001), the absence of any in-depth body composition analysis within AF research highlights a significant hole in the current literature (Keogh, 1999). Subsequently, longitudinal research into the physical and physiological progression of junior AF athletes, correlating these performance results to changes within their body composition (lean mass, fat mass, bone mineral content, bone mineral density) is imperative for the successful development of future generations of elite senior athletes.

CHAPTER 3

Reliability and Validity of a Reactive Agility Test for Australian Football

3.1 Introduction

Agility, commonly defined as an individual's ability to change direction whilst at speed, has been deemed as an identifiable athletic quality in the development of individual and/or team success in field and court sports (Draper & Lancaster, 1985; Young *et al.*, 2002; Sheppard & Young, 2006). Nevertheless, it is generally accepted that many current tests used to measure agility performance within field-based team sports are not matched with known game-day movement characteristics (Sheppard & Young, 2006). To date, a number of time-motion studies have documented common change of direction angles undertaken when athletes are moving at high speeds in field sports such as Australian Football (AF [Dawson *et al.*, 2004b]) rugby (Docherty *et al.,* 1988; Meir *et al.,* 2001) and soccer (Bloomfield *et al.,* 2007). However, agility is now regarded to be more complex, incorporating neuropsychological factors including anticipation (Williams *et al.*, 1994; Williams, 2000), intuition (Williams *et al.*, 1994), sensory-processing (Williams, 2000) and decision making (Farrow & Abernethy, 2002; Vaeyens *et al.,* 2007); with physiological factors such as response time (Farrow *et al.*, 2005; Sheppard *et al.*, 2006; Gabbett & Benton, 2009), acceleration and maximum speed (Young *et al.*, 2001c; Sheppard *et al.*, 2006), change of direction (COD) speed and mobility (Sheppard & Young, 2006). Therefore, as the time-motion research has not reported the number of high intensity COD that are made in direct response to a stimulus (e.g. evading or pursuing an opponent, or reacting to a moving ball), the data produced so far have only allowed for the identified closed-skill nature of agility to be assessed from self-initiated starts and pre-determined COD (Young *et al.*, 2002; Farrow *et al.*, 2005; Sheppard & Young, 2006; Sheppard *et al.*, 2006).

According to Murray (1996), prior knowledge of the test design in the execution of many commonly used COD agility skills removes the uncertainty involved in the test, resulting in evaluating COD speed only; a skill influenced by individual differences in running velocity preceding and post the directional change (Sheppard & Young, 2006). Therefore, whilst studies using closed-skill tests have shown the ability to distinguish between elite and sub-elite players (Reilly *et al.*, 2000b; Pyne *et al.*, 2005), the pre-planned nature of these tests limits their applicability to real game demands and subsequently their use in identifying potential talent under typical sport situations (Sheppard *et al.,* 2006). Moreover, these factors (including anticipation, intuition, sensory-processing and decision making) interact with each other to varying degrees dependent upon the sport specific context. It is now commonly accepted that visual cue processing, anticipation and reaction time are all important to team sport agility performance (Williams *et al.*, 1994; Williams, 2000; Young *et al.*, 2002; Farrow *et al.*, 2005; Sheppard & Young, 2006; Vaeyens *et al.*, 2007). In agility tasks specific to team sports, the timing and location of the stimuli have been reported to influence performance (Young *et al.*, 2002). Furthermore, research across a variety of settings has repeatedly demonstrated the superior ability of elite athletes in identifying useful anticipatory information from early in their opponent's movement patterns (Williams *et al.*, 1994; Reilly *et al.*, 2000b; Williams, 2000; Meir *et al.*, 2001; Vaeyens *et al.*, 2007).

Referred to as advanced cue utilisation, the superior ability of a player to make accurate predictions based on information provided by their opponent's posture and body orientation has been shown in experienced versus inexperienced soccer players and also in talent identified junior soccer players (Williams *et al.*, 1994; Williams, 2000). Consequently the relevance of reactive agility testing is mainly based on logical validity (Rampinini *et al.,* 2007) as, according to Cox (2002), "open skill" tests eliminate the ability for pre-planning and practicing of the task, making it more sport specific (e.g. evading an opponent) by producing a test response that is not automated or rehearsed. Therefore not only should logical validity be addressed in reactive agility test (RAT) design, but also construct validity, where the test should be able to discriminate between experts and novices based on advanced cue utilisation. However to date, a limitation in many "open skill" tests is the use of generic cues such as a light bulb and computerised direction indicators, or two dimensional film-based scenarios rather than a real-life stimulus (such as an opponent moving towards the athlete) to evaluate an unplanned mode of agility testing (Williams, 2000; Farrow *et al.*, 2005; Sheppard & Young, 2006).

While a variety of open- (anticipatory) and closed- (COD) skill testing has been independently used to successfully discriminate between elite and sub-elite athletes (Williams *et al.*, 1994; Reilly *et al.*, 2000b; Williams, 2000; Young *et al.*, 2002; Farrow *et al.*, 2005; Pyne *et al.*, 2005; Sheppard & Young, 2006; Vaeyens *et al.*, 2007), sport-specific field tests for agility involving physical performance and decision-making using a three-dimensional stimulus is limited in both research and test design (Sheppard *et al.,* 2006). Specific to the football codes and simple to reproduce in the field, Sheppard *et al.* (2006) recently designed a RAT that involves the components of perception, decision-making and movement in direct response to the behaviour of another person. However, whilst this test has shown an ability to discriminate between elite (first division athletes from one team participating in an elite senior state league competition) and sub-elite (reserve grade athletes from the same team) AF players (Sheppard *et al.,* 2006) and rugby league players (comparing national and recreational rugby league athletes [Gabbett & Benton, 2009]), it is limited to the use of a single COD. Extra directional changes and the assessment of more split times would allow the complexities involved in changing direction at speed in response to open or closed skill activities, as well as different techniques used on approach and exit speed in each COD, to be assessed. Such a design could be suggested to improve the sport specificity of the test by returning the athlete to their initial course of direction, which in a sporting situation is most commonly towards the goals. Furthermore, the use of an auditory beep presents a confounding factor due to the faster processing of auditory versus visual information cues (Welford, 1980). Therefore, whilst previous research at the elite junior AF level has studied speed and COD abilities within the talent identification process (Keogh, 1999; Pyne *et al.*, 2005; Pyne *et al.*, 2006; Veale *et al.*, 2008), the aim of this study was to systematically test the design of a novel RAT specific to the elite junior AF population. This evaluation provides test-retest reliability data and assesses the construct validity of the test design by comparing the results of two AF population groups to a control group of age-matched non-athletic healthy males.

3.2 Methods

All participants involved in both studies I (Reliability testing) and II (Construct validity testing) were provided with verbal and written communications of the study's requirements. Ethical approval was granted by the University Human Research Ethics Committee (in accordance with the Declaration of Helsinki) and each participant and parent provided written informed consent prior to their participation.

Study I – Reliability Testing

Participants

A homogenous group of twenty athletes (Age 17.44 ± 0.55 years; Height 183.4 ± 7.4 cm; Weight 78.5 ± 8.2 kg) from one team competing in the Victorian Under 18 (U18) AF league were tested on two occasions separated by one week.

Test Procedures

The reactive agility test (RAT) designed for this study (Figure 3.1) involved two changes of direction (COD) and 12 m in total distance. It was assessed on an indoor basketball court. Six electronic timing gates (Custom built, Sick Electronics, Germany) were set up in the following manner; the first gate at the start line (0 m) and the second 2 m in front of the start line, the third and fourth gates 5 m to the left and right at 45° angles to the centre of the second gate. The fifth and sixth gates were placed a further 5 m away at 45° angles in an opposite direction to the corresponding second and third gates. One run involved an initial left and then right 45° COD, whilst the alternate option involved an initial right and then left 45° COD (Figure 3.1).

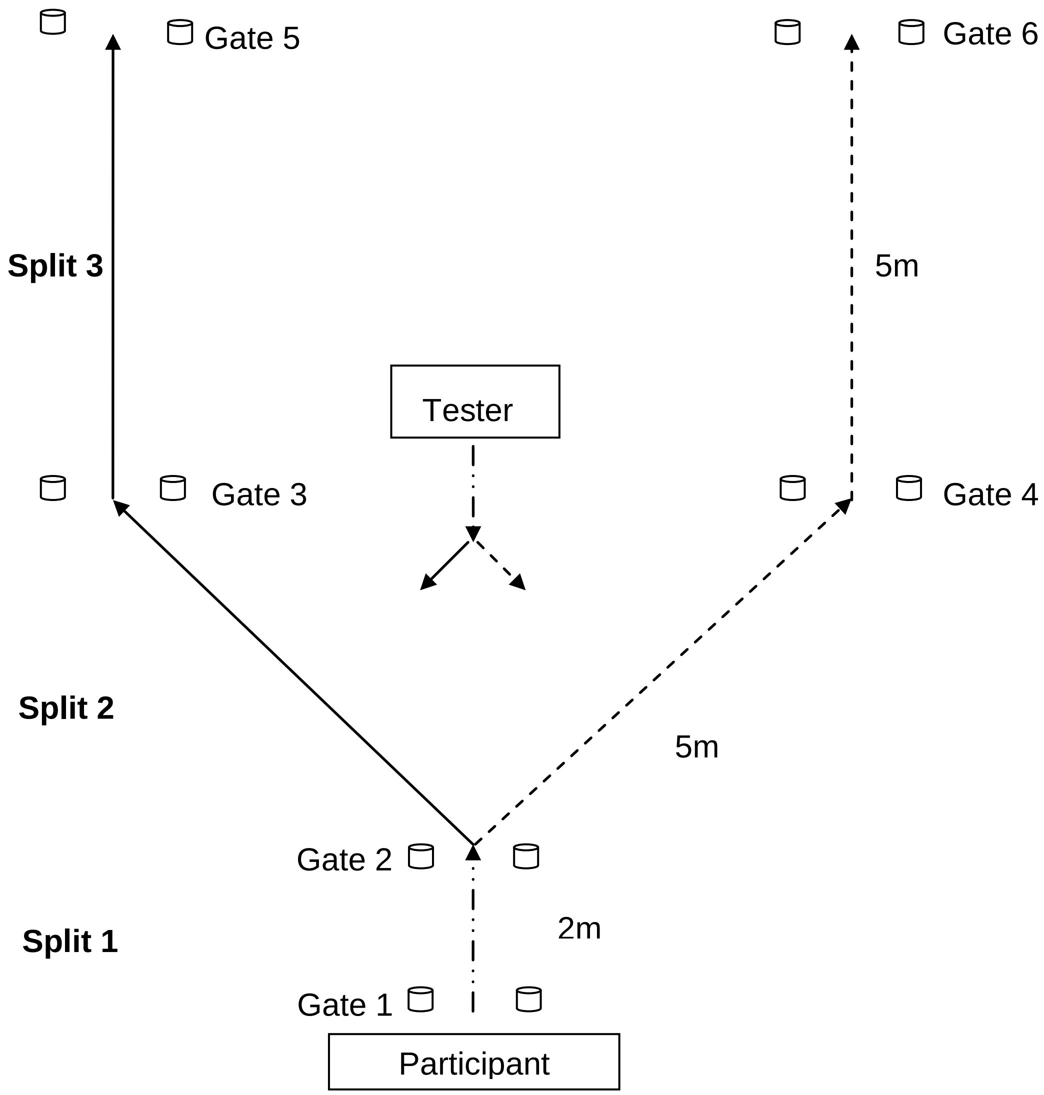

Figure 3.1 The reactive agility test (RAT).

Following the same protocol of Sheppard *et al.* (2006) and Gabbett and Benton (2009), the tester (who was the same researcher used in all test protocols) stood 6 m in front of the starting line and initiated the test in a randomised order of one of four ways:

- Step forward with right foot and change direction to the left
- Step forward with the left foot and change direction to the right
- Step forward with the right foot, then left, and change direction to the right
- Step forward with the left foot, then right, and change direction to the left

Participants were instructed to sprint forward prior to any COD (through gate 2) in response to the tester moving forward and then to the left or the right in response to, and in the same direction as, the left or right movement of the tester. Participants were directed to respond to the COD cues as they would in a game situation (Gabbett & Benton, 2009), moving as quickly as possible to intercept the tester to the left or to the right (gates 3 or 4) and to then continue this path through the final gates (gates 5 or 6).

Reliability assessment of the test design involved each participant completing 12 trials on two occasions separated by one week. After the completion of a standardised ten minute warm-up (comprising basic run-throughs at an increasing tempo, dynamic stretching and simple COD activities), each participant completed three trials each of the four possible tester initiated movements in a randomised order.

Study II – Construct validity testing

Participants

Using the known group difference method to measure the construct validity of the designed RAT, sixty aged matched participants (16.6 ± 0.5 years) were recruited from the following; 20 athletes participating in a State under 18 (U18) AF league who had represented their state at a national competition (elite group; Height 185.7 ± 5.9 cm, Weight 77.1 ± 4.4 kg), 20 athletes participating in the same state U18 AF league but had not represented their state at a national competition (sub-elite; Height 184.6 ± 6.8 cm, Weight 75.8 ± 6.0 kg) and 20 healthy age matched males who did not play AF (controls; Height 179.2 ± 0.5 cm, Weight 67.1 ± 11.5 kg). Through pre-screening of participants, all AF athletes (elite and sub-elite) reported an average pre-season weekly training volume of eight hours per week and no competitive games. An *a-priori* power analysis (GPower V3.0.10) revealed that a minimum sample size of 14 participants in each group would result in statistical power at 0.80 at an alpha level of 0.05 and effect size of 0.50. A sample of 20 participants was recruited for each group in case of participant drop out and to account for the risk of type 2 statistical errors.

Test Procedures

Using the basic RAT test protocol described above, each of the groups (elite AF players, sub-elite AF players and non-athletic active controls) were tested separately at the same venue. Each group was tested only once and no athlete had prior exposure to the RAT. After the same standardised ten minute warm-up, each participant was allowed three familiarisation runs of the test, prior to completing three attempts with their fastest overall time recorded as their best attempt. Each trial was conducted in a randomised and counterbalanced tester initiated direction.

3.2.1 Data processing and statistical analysis

Study I - Reliability testing

The mean time for the twelve trials completed, which was an average of the six trials to the left and the six to the right, was recorded for the two COD split times (split 2 and split 3) and for the total time taken (split 2+3) as the final score for the RAT during the test and re-test conditions. Test-retest reliability was assessed by applying *t* test, Pearson correlations (r value) and Typical Error of Measurement (TEM) calculations to the data obtained from the first and second testing sessions. Descriptive data for each split and the overall test time are presented using group mean (± SD). For all statistical testing, alpha was set at $p \leq 0.05$.

Study II – Construct validity testing

All data were first screened to assess normal distribution. In order to have sufficient data to test for questions of normality, all data and splits (1-3; splits 2+3, total time) from the 60 trials were used to establish the distributional properties. Each variable’s z-score of skew or kurtosis were observed to be negatively skewed which were confirmed with Shapiro-Wilk tests demonstrating statistical significance, suggesting each split (split 1 SW = 0.89, *df* = 60, $p < 0.01$; split 2 SW = 0.83, *df* = 60, $p < 0.01$; split 3 SW = 0.75, *df* = 60, $p < 0.01$;

split 2+3 SW = 0.76, *df* = 60, $p < 0.01$; total time SW = 0.85, *df* = 60, $p < 0.01$) were not normally distributed. Consequently, Kruskal-Wallis and Mann-Whitney tests were used for statistical analysis with Cohen's effect size (ES) conventions used to illustrate magnitude of the differences between groups for each split and total time; small (0.25), medium (0.5) and large (0.8) comparative effects (Cohen, 1988). Stepwise discriminant analyses were used for all RAT split times and total test time, with competition level as the dependent variable (Vaeyens *et al.,* 2006). Descriptive data for each split (1-3; splits 2+3) and the overall test time are presented using group mean (± SD). For all statistical testing, alpha was set at $p \leq 0.05$.

3.3 Results

Study I - Reliability testing

Results of the reliability testing reported a strong correlation ($r = 0.91$) between the two testing sessions conducted a week apart, with no significant difference ($p = 0.22$) between the mean results (1.74 ± 0.07 s and 1.76 ± 0.07 s; TEM = 0.011) obtained for total test time (split 2+3). Furthermore, moderate correlations ($r = 0.71$ and 0.72) were recorded between the results for split 2 (0.90 ± 0.05 s and 0.92 ± 0.05 s; TEM = 0.008) and split 3 (0.84 ± 0.06 s and 0.84 ± 0.05 s; TEM = 0.008) on both testing occasions. No significant difference was reported between the times recorded for each of the four tester initiated movement directions ($p = 0.11$).

Study II – Construct validity testing

The results for the three groups are presented in Table 3.1. A Kruskal-Wallis test revealed a main effect of group, with Mann-Whitney post-hoc tests indicating that the AF groups were significantly faster than the non-athletic healthy group for all split times recorded (1-3, 2+3 and total time; $p < 0.01$). Analysis between the AF groups reported the elite athletes were significantly faster over split 2 ($p < 0.01$), split 3 ($p < 0.05$), split 2+3 ($p < 0.01$) and in total time ($p < 0.01$). Furthermore, ES comparison showed moderate to large differences at Split 2 and Split 3 (ES = 0.86 and 0.55 respectively), Split 2 + 3 (ES = 1.13) and total time (ES = 1.10) between the two AF groups. Stepwise discriminant analyses found RAT total time discriminated between the three population groups ($p < 0.01$), correctly classifying 75% of the participants. Power analysis showed a high power associated with the differences between the elite and sub-elite groups (ranging between 0.80 and 0.95 across the split times recorded).

Table 3.1 Mean (± SD) results of the three groups (elite, sub-elite and non-athletic healthy males) tested during the study.

	Split 1 (s)		Split 2 (s)		Split 3 (s)		Split 2+3 (s)		Total Time (s)	
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
Elite (National Level, n=20)	0.63^	0.07	0.93^‡	0.08	0.86^‡	0.07	1.79^‡	0.10	2.42^‡	0.10
Sub-Elite (State Level, n=20)	0.65#	0.07	0.99#	0.06	0.89#	0.04	1.88#	0.06	2.53#	0.10
Non-athletic Healthy Males (Control, n=20)	0.76	0.13	1.10	0.15	1.10	0.19	2.20	0.30	2.96	0.31

^ denotes elite footballers were significantly faster than the control group ($p < 0.05$).

‡ denotes elite footballers were significantly faster than the sub-elite footballers ($p < 0.05$).

# denotes sub-elite footballers were significantly faster than the control group ($p < 0.05$).

3.4 Discussion

The aim of this study was to test the reliability and construct validity of a novel reactive agility test (RAT), modified from the protocol of Sheppard *et al.* (2006) for use within the elite junior AF population. Importantly, within the same population on two occasions separated by one week, the results of the RAT demonstrated no significant difference ($p = 0.22$) and good reliability ($r = 0.91$) between test results, suggesting no learning effect via ‘test practice’ (Murray, 1996; Young *et al.*, 2002; Sheppard & Young, 2006; Sheppard *et al.*, 2006). Discriminating between the abilities of junior AF athletes compared to aged-matched non-athletic healthy male participants (Table 3.1), the RAT used in this study also discriminated between AF athletes of a higher competition standard (Table 3.1). Furthermore, moderate to large ES differences between the times recorded by the two AF groups demonstrated the existence of a practical significance, with the observed difference translating to the elite group completing the 12 m course on average 0.52 m ahead of the sub-elite group (Pyne *et al.*, 2005). These results suggest a sport specific nature and construct validity of the RAT design. The RAT also reported similar trends to previous research evaluating the effectiveness of “open skill” agility tests in distinguishing between performance abilities of AF athletes at the elite and sub-elite level (Sheppard *et al.,* 2006).

Within team sports, skills that require COD and agility (for example evading an opponent or receiving the ball) are preceded by high intensity movement (Sheppard & Young, 2006; Sheppard *et al.,* 2006). The RAT used within this study was made up of two key components; reactive acceleration (split 1) and reactive change of direction (COD) at speed (split 2+3). Subsequently, unique to this RAT design was the two metre acceleration distance (rolling start) prior to the first directional change. Designed to imitate the AF specific nature of the test design, the AF populations recorded significantly faster split times from a stationary start over the first 2 m in response to the researcher's initiated movement (split 1) compared to the non-athletic healthy controls, equating to a measureable distance of 0.35 m (Table 3.1). This faster response and acceleration might be a sport specific training response as a result of the importance of gaining optimal field position during a game situation (e.g. getting to the ball first or closing down the distance to an opposing player quicker [Pyne *et al.*, 2005]). In the absence of a difference between the two AF groups, of noticeable importance was the recording of a faster response time in the direction of the tester's movement by the elite compared to the sub-elite group (split 2 and split 2+3 [Table 3.1]). Therefore, despite no difference in reactive acceleration, the elite group displayed a superior ability to 'read and react' to the tester's movements, covering the total test distance significantly faster than their sub-elite counterparts (Sheppard *et al.,* 2006). This further suggests the importance of decision making and superior cognitive abilities within reactive COD activities performed by AF athletes (Sheppard *et al.,* 2006).

According to Young *et al.* (2002) COD speed and perceptual decision-making factors are the two main components of agility performance. Within adult populations, straight line and COD speed have previously been demonstrated as distinct and specific individual abilities (Draper & Lancaster, 1985; Young *et al.*, 1996; Buttifant *et al.*, 1999). Therefore, it can be suggested from the data presented within this study, that AF athletes possess a superior ability to alter movement speed to change direction when reacting to a stimulus, with performance improvements across athletes of a higher competition standard (Table 3.1). Furthermore, via the use of high-speed video footage, Gabbett *et al.,* (2007) reported faster decision making abilities within elite rugby league athletes without compromising response accuracy in comparison to their sub-elite counterparts. Although our study did not measure kinematic movement patterns or the athlete groups' perceptual cues, it is suggested that better performance was due to a combination of optimal adjustment of stride pattern and body position, as well as anticipating the opponent's (tester) action by observing postural cue information (Williams, 2000; Farrow *et al.*, 2005). As a result, the significantly faster test performance of the AF populations, as well as the elite level athletes within the two AF groups, suggests the RAT has specific construct validity to a team sport environment by demonstrating the superior ability of athletes compared to their non sporting counterparts at reading and reacting to an opponent's directional movement changes. Nevertheless, future research measuring both the speed and accuracy of decision making within the junior AF population is necessary.

Given the nature of the RAT design and the fact that the participant is responding to someone moving towards them, it should be stated that this test is specific to defensive situations, where future research could look into situations where a stimulus moving away from a person (e.g. attacking) might provide different results. Nevertheless, agility training within a sporting environment would benefit from the inclusion of a reactive component that varies in shape and form (e.g. a person compared to a stationary pole/object). Displaying parallels to the use of game-based training activities to provide physiological adaptations specific to the game environment (Gabbett, 2006b), game-based agility training has the potential to assist in the development of decision-making and anticipation of both player and ball movements within team sports (Sheppard *et al.,* 2006). In addition, despite measuring different abilities, closed-skill COD activities should still be incorporated as a movement training tool within the team sport environment, where improvements in an athlete's ability to decelerate into and accelerate out of a turn will aid in enhancing performance.

In conclusion, whilst this study acknowledges only a relatively small sample was measured within each group, significant differences were highlighted between the three groups for performance in the novel RAT design presented. Consequently, at an earlier age and whilst athletes are still developing in both maturity and skill abilities, this RAT demonstrated how the incorporation of physical demands and perceptual processes within a sport specific agility test can distinguish between talented young athletes. Therefore, whilst this study has reported the ability to discriminate within AF ranks, future research assessing the longitudinal validity of the RAT protocol in measuring changes over time is necessary (Sheppard *et al.*, 2006; Impellizzeri & Marcora, 2009).

CHAPTER 4

Repeated Sprint Ability between Elite and Sub-Elite Junior Australian Football players.

4.1 Introduction

Speed is a fundamental component of overall athletic ability, comprising a number of sub-components such as start speed, acceleration speed, maximal speed (Duthie *et al.*, 2006a), change of direction speed and speed-endurance (Little & Williams, 2005). Commonly used in the talent identification (TID) and development of team sport athletes (Reilly *et al.*, 2000b; Bishop & Spencer, 2004; Little & Williams, 2005; Pyne *et al.*, 2005; Spencer *et al.*, 2005; Duthie *et al.*, 2006a; Rampinini *et al.*, 2007; Veale *et al.*, 2008; Oliver *et al.*, 2009), Australian Football (AF) research has reported the ability of single sprint effort (SSE) testing to discriminate between successful and unsuccessful athletes in the selection process of elite senior (40 m test distance; Young *et al.*, 2005) and junior (20 m test distance; Pyne *et al.*, 2005) squads, as well as differences within playing positions (Pyne *et al.*, 2006; Young & Pryor, 2007). Nevertheless, in recent AF game day research, Dawson *et al.* (2004b) recorded a minimum 25-35% increase in high-intensity efforts compared to past research (Hahn *et al.,* 1979; McKenna *et al.,* 1988), with Mohr *et al.* (2003) reporting higher standard soccer players performing more high-intensity running (28%) and sprinting (58%) than their lower level counterparts. Consequently, superior repeated sprint ability (RSA) performance in both speed maintenance and fatigue resistance has been defined as a characteristic of better team sport athletes (Fitzsimons *et al.,* 1993), with RSA field tests designed to replicate these movement patterns and physiological demands (Psotta & Bunc, 2005; Oliver, 2009). To date, only SSE tests measuring both acceleration and maximum speed qualities have commonly been reported within the published literature at the elite junior AF level (Pyne *et al.*, 2005; Young *et al.*, 2005; Pyne *et al.*, 2006; Veale *et al.*, 2008; Young *et al.*, 2008), with very limited RSA research conducted (Pyne *et al.*, 2008). Therefore, the aim of this study was to evaluate the ability of a RSA test to discriminate between elite and sub-elite junior AF players. Furthermore, in the absence of available research data, a secondary aim of this study was to investigate the discriminatory ability of split times within a RSA test, assessing the test's ability to measure changes in acceleration and maximal speed across repeated bouts.

4.2 Methods

Participants

Sixty age matched participants (16.6 ± 0.5 years) were recruited from the following; 20 athletes participating in a state under 18 (U18) AF league who had represented their state at a national competition (elite group; Height 185.4 ± 5.3 m, Weight 78.0 ± 6.9 kg), 20 athletes participating in the same state U18 AF league but had not represented their state at a national competition (sub-elite; Height 184.0 ± 6.7 m, Weight 76.4 ± 6.8 kg) and 20 healthy age matched males who did not play AF (controls; Height 179.2 ± 0.5 cm, Weight 67.1 ± 11.5 kg). Both football groups (elite and sub-elite) reported, through pre-screening of participants, an average pre-season weekly training volume of eight hours per week and no competitive games. All participants were provided with verbal and written communications of the study's requirements. Ethical approval was granted by the University Human Research Ethics Committee (in accordance with the Declaration of Helsinki) and each participant and parent provided written informed consent prior to their participation.

Test Procedures

Assessment of the RSA test involved one testing session for each group, conducted early in the pre-season training phase. After the same standardised ten minute warm-up (involving basic straight line sprints of increasing distance and tempo and dynamic stretching activities), each participant completed the RSA test. Implementing the field test protocol used in the only AF research to date (Pyne *et al.*, 2008), the RSA test involved six 30 m maximal sprints from a stationary start, with each sprint departing every 20 s. Custom built electronic timing gates (Sick Electronics, Germany) able to measure in opposite directions were used, allowing each sprint to start from the end at which the previous sprint was completed. Split times were recorded at 10 m, 20 m and 30 m intervals and an 8 m deceleration zone was designated at each end (Lakomy & Haydon, 2004). Participants were instructed and verbally encouraged to sprint at a maximal intensity during each trial.

4.2.1 Data processing and statistical analysis

Total time was collected for each spilt (6 x 10 m, 6 x 20 m, 6 x 30 m and 6 x Flying 10 m), whilst individual runs were also recorded (Fitzsimons *et al.*, 1993; Young *et al.*, 2008). Flying 10 m times were recorded each run by the following equation: 30 m split time – 20 m split time (Young *et al.*, 2008). Due to the lack of evidence proving the reliability of a fatigue index (FI [Oliver, 2009]), a percentage decrement score or FI was not calculated. All data were first screened to ensure they were normally distributed. In order to have sufficient data to test for questions of normality, all data from 60 trials were used to establish the distributional properties. No variable's z-score of skew or kurtosis was excessive. Further, Shapiro-Wilks tests suggested the variables 10 m (SW = 0.96, *df* = 60, p = 0.07), 20 m (SW = 0.97, *df* = 60, p = 0.17), 30 m (SW = 0.96, *df* = 60, p = 0.06) were clearly normally distributed, while Flying 10 m was apparently non-normal (SW = 0.93, *df* = 60, $p < 0.01$). This violation appeared to be only mild from examination of frequency histograms and detrended Q-Q plots, and was not considered sufficient to warrant a more conservative analysis. Consequently, it was decided to treat the Flying 10 m data as essentially normal in distribution and a one-way ANOVA was used for statistical analysis with Cohen's effect size (ES) conventions used to illustrate magnitude of the differences between groups for each split and total time; small (0.25), medium (0.5) and large (0.8) comparative effects (Cohen, 1988). For all statistical testing, alpha was set at $p \leq 0.05$. Stepwise discriminant analyses were used for RSA test variables with competitive level as the dependent variable

(Vaeyens *et al.,* 2006). Furthermore, the times recorded across the RSA test variables of the AF groups (elite and sub-elite) were analysed with Pearson correlations as well as the coefficient of determination (r^2), with the common variance (CV) between any two variables expressed as a percentage (r^2 x 100 [Thomas & Nelson, 1990; Young *et al.*, 2008]). Variables recording a shared variance less than 50% ($r^2 < 0.71$) were deemed to possess somewhat unique characteristics (Thomas & Nelson, 1990; Young *et al.*, 2008). Data are presented as means (± SD).

4.3 Results

Mean (± SD) of the RSA test results across the three groups are presented in Table 4.1. One-way ANOVA showed significant differences between the three groups and post-hoc Sheffe's test revealed the AF groups (both elite and sub-elite) were significantly faster in RSA test total time (30 m) in comparison to the non-athletic healthy control group (7.9% or 2.38 s and 6.7% or 2.03 s respectively; $F_{2,57} = 29.898$; $p < 0.01$). Both AF groups were also significantly faster for RSA test total times at the 10 m ($F_{2,57} = 6.293$; $p < 0.05$), 20 m ($F_{2,57} = 41.541$; $p < 0.05$) and flying 10 m splits ($F_{2,57} = 8.668$; $p < 0.05$), with times ranging from 0.42 s to 1.81 s. Furthermore, when individually analysing each run (1-6) of the RSA test protocol, the AF groups were significantly faster than the control participants at all split times, excluding the 10 m split time between the elite AF and control groups for runs 1, 5 and 6, or between the sub-elite AF and control groups for runs 1, 3, 5 and 6. Results of the stepwise discriminant analyses reported correctly classifying 73.3% of the participants.

Analyses of the total RSA test time at each split reported no statistically significant difference between the elite and sub-elite AF groups, with small to moderate ES differences calculated for RSA test 30 m (ES = 0.30) and flying 10 m (ES = 0.52) total times. However, when analysing each individual run (1-6) of the RSA test protocol, the elite AF players were significantly faster than the sub-elite AF group in flying 10 m split times for runs 2 ($F_{2,57}$ = 35.955; $p < 0.05$) , 3 ($F_{2,57}$ = 1.504; $p < 0.05$) and 5 ($F_{2,57}$ = 1.751; $p < 0.05$) and for 30 m split time for run 3 ($F_{2,57}$ = 25.074; $p < 0.05$). Across the study population, correlations were high within the RSA test total times measures (ranging from r = 0. 73 to 0.98; CV = 53 to 96%), with only the RSA test total time for the 10 m and flying 10 m split times reporting a low correlation (r = 0.59; CV = 35%). Furthermore, when the control population was removed, the AF populations recorded higher correlations within the RSA test total times measures (ranging from r = 0. 80 to 0.98; CV = 75 to 96%), despite the 10 m and flying 10 m split times still reporting a low correlation (r = 0.55; CV = 30%).

Table 4.1 Mean (± SD) results of the three groups (elite, sub-elite and non-athletic healthy males) for the RSA test.

	Repeated Sprint Ability Test Total Time (s)			
	10 m	20 m	30 m	Flying 10 m
Elite (National, n=20)	$12.06^{\wedge} \pm 0.60$	$20.12^{\wedge} \pm 0.80$	$27.70^{\wedge} \pm 1.06$	$7.66^{\wedge} \pm 0.28$
Sub-Elite (State, n=20)	$12.00^{*} \pm 0.35$	$20.24^{*} \pm 0.52$	$28.05^{*} \pm 0.77$	$7.82^{*} \pm 0.30$
Non-athletic Healthy Males (Control, n=20)	12.48 ± 0.38	21.93 ± 0.76	30.08 ± 1.21	8.15 ± 0.51

$^{\wedge}$ denotes elite footballers were significantly faster than non-athletic healthy males ($p < 0.05$).

* denotes sub-elite footballers were significantly faster than non-athletic healthy males ($p < 0.05$).

4.4 Discussion

Given that SSE tests have been well published and validated in the AF research (Pyne *et al.*, 2005; Young *et al.*, 2005; Pyne *et al.*, 2006; Young & Pryor, 2007; Veale *et al.*, 2008; Young *et al.*, 2008), this study focused on, and demonstrated in part, the ability of a RSA test to discriminate between junior AF players based on their level of competition, and furthermore in comparison to their non-athletic counterparts. As expected, the AF athletes recorded significantly faster RSA test results across all variables in comparison to an age-matched non-athletic group, a result likely to occur across any reliable physical performance test. However, between groups analysis did not report a significant difference between the elite and sub-elite AF groups. Nevertheless, small to moderate ES differences in RSA test 30 m total time and flying 10 m total time suggests the possible existence of a practical significance between the two groups and a trend toward better RSA test performance by the elite AF athletes (Pyne *et al.*, 2005). Furthermore, the use of extra split times within this study generated three additional RSA test total times (10 m, 20 m and flying 10 m), of which the flying 10 m split time recorded the greatest performance difference and a moderate ES between the two AF groups.

It is well known that acceleration (Duthie *et al.*, 2006a), maximum running speed / velocity (Duthie *et al.*, 2006a) and speed endurance / maintenance (the ability to maintain velocity against the onset of fatigue; Little & Williams, 2005) are commonly known phases within sprint performance (Delecluse *et al.*, 1995; Delecluse, 1997; Moir *et al.*, 2007), and are fundamental components of success for team sport athletes. Superior performance in each phase provides an athlete with a distinct advantage over their opponent; including the ability to get to the ball first and in the evasion or pursuit of an opponent over the duration of a game (Delecluse, 1997; Sayers, 2000; Benton, 2001; Little & Williams, 2005; Pyne *et al.*, 2005; Duthie *et al.*, 2006a). Within the TID process at the elite junior AF level, Pyne *et al.* (2005) reported how substantial improvements in SSE (20 m) performance can enable an athlete to gain a competitive edge over many opponents. Subsequently, as demonstrated by the ES differences reported between the elite and sub-elite AF athletes in the RSA test 30 m and flying 10 m total times, the elite athletes demonstrated a tendency to reproduce higher speeds across the repetitive sprints (Reilly *et al.*, 2000b). Whilst the difference appears small to moderate, on average, the elite group completed each run 0.39 m in front of their sub-elite counterparts, totalling 2.34 m by the completion of the test. In a game scenario where being in front of an opponent provides first access to the ball, the ability to out-position an opponent has been reported extremely useful for AF performance (Pyne *et al.*, 2005). The finding of significantly faster split times throughout the six individual RSA test runs by the elite AF group is therefore further evidence of the usefulness of repeated sprint testing within the TID pathway.

Previous research using SSE test protocols of various distances has demonstrated the ability of different split times to discriminate between acceleration (0-10 m) and maximal speed (flying 10 m [30 m – 20 m split] or flying 20 m [40 m – 20 m] split time) abilities of team sport athletes (Young *et al.*, 2008). Reporting comparable results, low correlation and common variance scores were recorded within this study between RSA test total time for 10 m and flying 10 m split times. These results indicate a uniqueness between these distances, suggesting this RSA test protocol is also capable of measuring the distinctly different performance abilities of acceleration speed (10 m), maximal speed (flying 10 m) and speed endurance (30 m [Young *et al.*, 2008]). Nevertheless, with research still questioning the appropriate number of repeated sprints to significantly discriminate between athletes at the elite level, future research implementing a variety of repetitions (eight, ten, twelve) would provide further insight into the usefulness of repeated sprint testing at the elite junior AF level. Nevertheless, whilst TID and development in AF is not limited to the use of physical performance test results and must take into account technical and tactical skill abilities, the use of a RSA test, as demonstrated in this study despite the relatively small sample size, can provide specific information into physical characteristics that are relevant to AF at the elite level (Pyne *et al.*, 2008). Therefore, future research assessing the longitudinal validity of the RSA test protocol in documenting performance changes over time and their relationship to physical growth and development is necessary (Keogh, 1999; Pyne *et al.*, 2008).

CHAPTER 5

Standing vertical jump and running vertical jump between Elite and Sub-Elite Junior Australian Football players.

5.1 Introduction

Jumping is a characteristic that discriminates Australian Football (AF) from the other football codes. Whilst other codes involve elements of jumping in their game day movement patterns (a soccer player will jump to head the ball (Reilly *et al.*, 2000a), whilst a rugby player may jump to catch a high ball), these actions are irregular throughout the course of a game and are commonly performed by specific field positions. Conversely, AF players are required to jump in numerous ways (ruck duels, boundary throw-ins, marking contests, spoiling an opponent or attempting an interception) in order to gain possession of the ball and thus an advantage over their opponent (Woodman & Pyke, 1991; Keogh, 1999; Saliba & Hrysomallis, 2001; Appleby & Dawson, 2002; Dawson *et al.*, 2004b, a). Subsequently, lower limb power and jumping for height is a commonly involved physical component within AF game day performance, with movement characteristics commonly executed from a single or double leg take-off, from a standing position or from various run-up lengths (Young *et al.*, 1997; Appleby & Dawson, 2002; Dawson *et al.*, 2004b).

As a result, a number of vertical jump tests have been used within the TID studies conducted at the elite junior AF level (Keogh, 1999; Pyne *et al.*, 2005; Pyne *et al.*, 2006; Young & Pryor, 2007; Veale *et al.*, 2008). Reporting varying levels of success in discriminating performance abilities across playing standards (Keogh, 1999; Pyne *et al.*, 2005; Pyne *et al.*, 2006; Young & Pryor, 2007; Veale *et al.*, 2008), jumping ability has been suggested somewhat secondary in nature within AF to the physical capabilities of speed and endurance. Nevertheless, it has still demonstrated relevance within fitness testing protocols (Pyne *et al.*, 2005; Young *et al.*, 2005; Young & Pryor, 2007) and remains a physical attribute that should be trained for and used in the TID process. Therefore, the aim of this study was to evaluate the ability of a standing vertical jump (SVJ) test and running vertical jump (RVJ) test to discriminate between elite and sub-elite junior AF players competing within an elite junior AF competition.

5.2 Methods

Participants

Sixty age matched participants (16.6 ± 0.5 years) were recruited from the following; 20 athletes participating in a state under 18 (U18) AF league who had represented their state at a national competition (elite group; Height 185.4 ± 5.3 m, Weight 78.0 ± 6.9 kg), 20 athletes participating in the same state U18 AF league but had not represented their state at a national competition (sub-elite; Height 184.0 ± 6.7 m, Weight 76.4 ± 6.8 kg) and 20 healthy age matched males who did not play AF (controls; Height 179.2 ± 0.5 cm, Weight 67.1 ± 11.5 kg). Both football groups (elite and sub-elite) reported, through pre-screening of participants, an average pre-season weekly training volume of eight hours per week and no competitive games.

All participants were provided with verbal and written communications of the study's requirements. Ethical approval was granted by the University Human Research Ethics Committee (in accordance with the Declaration of Helsinki) and each participant and parent provided written informed consent prior to their participation.

Test Procedures

Assessment of the SVJ and RVJ tests involved one testing session for each group, conducted during the month of November at the beginning of pre-season training. After the same standardised ten minute warm-up (involving basic run-throughs at an increasing tempo, dynamic stretching, bounding and jumping exercises), each participant completed the SVJ test followed by the RVJ test, with five minutes of recovery separating the two protocols.

The SVJ test was assessed using a Vertec vertical jump apparatus (SWIFT Performance Equipment, Lismore, Australia). To concentrate on leg and hip explosiveness, participants were required to start with their hands on their hips and maintain this position on the downward phase of each jump (replicating the downward phase of the countermovement jump without an arm swing described by Young, 1995). Once an upward motion had been initiated by the lower limbs, participants were instructed to raise one hand and strike the Vertec at the peak height of their jump (Peterson *et al.,* 2006). Participants were provided 10 minutes prior to the test to familiarise themselves with the jump protocol, and 3-5 test jumps in order to achieve maximal jump height performance. Using the same measuring apparatus, the RVJ test involved a 5 m run up, whereby participants were instructed to jump off their outside leg and strike the Vertec at the highest point with their inside arm (Pyne *et al.*, 2005). To compare results to previous research, results were recorded as left and right foot jumps, rather than dominant and non-dominant foot jumps. The highest of 3-5 jumps each leg was recorded.

5.2.1 Data processing and statistical analysis

The highest SVJ and RVJ score off each foot was recorded. All data were first screened to ensure they were normally distributed. In order to have sufficient data to test for questions of normality, all data from 60 trials were used to establish the distributional properties. Shapiro-Wilks tests suggested the SVJ height (SW = 0.96, *df* = 60, p = 0.31) was clearly normally distributed and therefore one-way ANOVAs were used to analyse the differences between groups for jump height. The RVJ data, however, was found to be not-normally distributed, with significant Shapiro-Wilks tests confirming this (Left foot take-off [SW = 0.95, *df* = 60, p = 0.02]; Right foot take-off [SW = 0.95, *df* = 60, p = 0.03]). As a result, non-parametric Kruskal-Wallis and Mann-Whitney tests were used to compare the differences in jump height between the three groups. Cohen's effect size (ES) conventions were used to illustrate magnitude of the differences between groups for all vertical jump height variables measured; small (0.25), medium (0.5) and large (0.8) comparative effects

(Cohen, 1988). Data are presented as means (± SD). For all statistical testing, alpha was set at $p \leq 0.05$.

5.3 Results

Mean (± SD) of the three groups within this study are presented in Table 5.1. One-way ANOVA showed significant differences between the three groups for SVJ performance and post-hoc Sheffe's test revealed the elite AF group jumped significantly higher than the sub-elite (10.4%, $F_{2,57} = 7.210$; $p = 0.04$) and control groups (15.6%, $F_{2,57} = 7.210$; $p < 0.01$). A Kruskal-Wallis test revealed a main effect of group, with Mann-Whitney post-hoc tests indicating both the elite and sub-elite AF groups jumped significantly higher in the RVJ test compared to the control group (Left foot take-off 29.6 and 26.9% respectively, $p < 0.01$; Right foot take-off 39.3 and 28% respectively, $p < 0.01$). The elite AF group jumped significantly higher in the RVJ protocols from a right foot take-off (8.8%, $p = 0.04$), with a small ES (ES = 0.25) difference in jump height from a left foot take-off (2.6%, $p = 0.72$) in comparison to the sub-elite athletes.

Table 5.1 Mean (± SD) results of the three groups (elite, sub-elite and non-athletic healthy males) for vertical jump performance.

	Standing Vertical Jump (cm)	Running Vertical Jump (cm)	
		Left Foot Take-off	Right Foot Take-off
Elite (National, n=20)	55 ± 7*#	76 ± 7#	71 ± 5*#
Sub-Elite (State, n=20)	50 ± 6	74 ± 6^	65 ± 7^
Non-athletic Healthy males (Control, n=20)	48 ± 7	59 ± 6	51 ± 9

* denotes elite footballers jumped significantly higher than the sub-elite footballers ($p < 0.05$).

# denotes elite footballers jumped significantly higher than the non-athletic healthy males ($p < 0.05$).

^ denotes sub-elite footballers jumped significantly higher than the non-athletic healthy males ($p < 0.05$).

5.4 Discussion

The primary aim of this study was to evaluate the ability of SVJ and RVJ test protocols to discriminate between elite and sub-elite junior AF players. From the results obtained (Table 5.1), both SVJ and RVJ tests demonstrated a significant difference between the two AF groups and the control participants, with the SVJ and RVJ from a right foot take-off discriminating performance differences between the elite and sub-elite AF groups. Reporting similar trends in the use of SVJ test protocols in identifying a relationship between test performance and successful squad or game day selection (Keogh, 1999; Young & Pryor, 2007; Veale *et al.*, 2008), this study also demonstrated similar findings within the RVJ tests to the results produced by Pyne and colleagues (2005). Using multiple linear regression analysis, Pyne *et al.* (2005) showed athletes successfully selected into the AFL jumped higher on the RVJ tests and recorded a smaller variance in jump height between their right and left legs. Whilst this current study did not record a significant difference in jump height from a left foot take-off (the commonly preferred take-off foot in a right foot dominated game), it did highlight a significant difference in the right foot RVJ height, suggesting the elite population within this study also demonstrated a smaller variance between single limb VJ scores off each leg. Subsequently, the results of this study support the suggestion that jumping ability is an important physical attribute towards future AF success and should be measured in the TID assessment of athletic potential at the elite junior AF level (Keogh, 1999; Pyne *et al.*, 2005).

Although not measured by this study, an increased training experience and specificity towards power training has been linked with improvements in lower-body power results across the other football codes (Baker, 2002). In a rugby league study, no difference in lower limb power was reported between the junior and senior-high school rugby players, whilst college-aged players (11-14% more, $p < 0.05$) and the elite professional players (19-36% more, $p < 0.05$) jumped significantly higher (Baker, 2002). It was concluded that weight training programs within the high-school groups are directed toward the development of strength and hypertrophy, containing no specific power training, a distinguishable element within the college-aged program. As weight and plyometric training programs have lead to significant increases in strength and muscular power (Adams *et al.*, 1992; Baker, 2002), greater emphasis on this type of training may enhance performance of AF junior athletes.

Within AF, a powerful VJ performance is needed to out mark or spoil an opponent, as well as contesting ruck duels (Keogh, 1999; Saliba & Hrysomallis, 2001). Therefore, corresponding with previous research, the results of this study suggest SVJ (Keogh, 1999; Veale *et al.,* 2008) and RVJ (Pyne *et al.*, 2005; Pyne *et al.*, 2006) protocols can identify athletic attributes important within AF athletes, demonstrating the ability to discriminate between different playing standards and abilities within the elite junior AF ranks. However, the potential lack of full compliance with the specified protocols has previously been suggested as a limiting factor to erroneous results within SVJ test protocols in particular (Pyne *et al.*, 2005). Subsequently, future research assessing various means of vertical jump capacity, for example the use of force-platform technology (Wisløff *et al.*, 2004; Young *et al.*, 2005), is necessary to improve the accuracy and potential reliability of testing protocols. Despite this, with both SVJ and RVJ tests demonstrating different levels of performance relating to the level of AF participation within the junior population, longitudinal research investigating changes in vertical jump performance over an elite junior AF career is required (Keogh, 1999).

CHAPTER 6

The Yo-Yo Intermittent Recovery Test (Level 1) to discriminate Elite Junior Australian Football players

6.1 Introduction

Australian Football (AF) is a team sport that involves intermittent play periods (Thomas *et al.*, 2006), characterised by repeated high-intensity (fast running and sprinting) efforts. Across all playing positions, 150 to 200 efforts per game at the elite senior level (Dawson *et al.*, 2004b) and 93 to 200 at the elite junior level (Veale *et al.*, 2007b) have been reported. Within the AF TID pathway, continuous exercise tests such as the 20 m Multistage Fitness Test (MSFT) have demonstrated within the elite junior level a positive relationship between initial team selection (Young & Pryor, 2007), game day performance variables (Young & Pryor, 2007) and career progression (Pyne *et al.*, 2005). However, Young *et al.* (2007) suggest the possibility of other tests reporting different game related performance relationships. The Yo-Yo intermittent recovery (IR) test was designed to evaluate an athlete's ability to repeatedly complete short distance, high-intensity running efforts (Bangsbo *et al.*, 2008), characteristics of many team ball sports (Young *et al.*, 2005). The Yo-Yo Intermittent Recovery Test Level 2 (IR2) has been used within the elite senior AF competition (Young *et al.*, 2005), measuring a players' ability to recover from repeated exercise with a high anaerobic contribution. However, the Yo-Yo Intermittent Recovery test Level 1 (IR1) focuses on the capacity to carry out intermittent exercise to maximal aerobic capacity when used within a trained population (Bangsbo *et al.,* 2008). Therefore, the aim of this study was to evaluate, for the first time, the ability of the Yo-Yo IR1 test to determine intermittent endurance performance differences between elite and sub-elite junior AF players and a group of non-athletic healthy age matched males.

6.2 Methods

Participants

Sixty age matched participants (16.6 ± 0.5 years) were recruited from the following; 20 athletes participating in a state under 18 (U18) AF league who had represented their state at a national competition (elite group; Height 185.4 ± 5.3 m, Weight 78.0 ± 6.9 kg), 20 athletes participating in a state U18 AF league but had not represented their state at a national competition (sub-elite; Height 184.0 ± 6.7 m, Weight 76.4 ± 6.8 kg) and 20 healthy age matched males who did not play AF (controls; Height 179.2 ± 0.5 cm, Weight 67.1 ± 11.5 kg). Both football groups (elite and sub-elite) reported an average training volume of 8 hours per week. All participants involved in the study were provided with verbal and written communications of the study's requirements. Ethical approval was granted by the University Human Research Ethics Committee (in accordance with the Declaration of Helsinki) and each participant and parent provided written informed consent prior to their participation.

Test Procedure

Assessment of the Yo-Yo IR1 test involved three group testing sessions on an indoor basketball court, conducted one week apart during the month of November. This coincided with the beginning of pre-season training for the two football groups. The Yo-Yo IR1 test is a progressive shuttle running test involving a ten second active recovery period after every second 20 m shuttle. Running speed is dictated by an audible beep played from a CD, incrementally increasing in speed each level. Subjects must reach the 20 m shuttle line prior to, or in time with the audible beep for each shuttle to be counted. Test participation is ceased when two shuttles in succession are not successfully completed and the test score recorded as the last successful shuttle completion (Bangsbo 2008; Castagna *et al.,* 2005; Krustrup *et al.,* 2003). After the same standardised ten minute warm-up (involving basic run-throughs at an increasing tempo, dynamic stretching and change of direction activities), 10 participants at a time completed the test following the guidelines developed by Bangsbo (2008).

6.2.1 Data processing and statistical analysis

Each trial was recorded for both distance covered (m) and number of runs completed. All data were first screened to ensure they were normally distributed. In order to have sufficient data to test for questions of normality, all data from 60 trials were used to establish the distributional properties. Shapiro-Wilks tests suggested the distance covered (SW = 0.97, *df* = 60, p = 0.41) and number of runs completed

(SW = 0.97, *df* = 60, p = 0.40) were clearly normally distributed and therefore one-way ANOVAs were used to analyse the differences between groups for both variables. Where a significant difference was shown, Scheffe's Post-hoc test was used to identify differences between groups. An alpha level of $p \leq 0.05$ was accepted as significant. Data are presented as means (± SD).

6.3 Results

Results of the performances of the three groups within this study are presented in Table 6.1. The elite playing group covered a greater total distance than the sub-elite and healthy control groups (24.7% or 432 m and 59.5% or 1136 m respectively), equating to an average of 24 and 61 more completed shuttles. The sub-elite participants ran 704 m further than the non-athletic healthy control group and completed an average of 37 more shuttles. One-way ANOVA showed significant differences between the three groups and post-hoc Sheffe's test revealed the elite playing group performed significantly better in the Yo-Yo IR1 test for both total distance ($F_{2,57}$ = 66.698; $p < 0.01$) and number of runs ($F_{2,57}$ = 76.831; $p < 0.01$) completed than the sub-elite playing and non-athletic healthy control groups (Figure 6.1). Furthermore, the sub-elite playing group performed significantly better than the non-athletic healthy males for both variables ($p < 0.01$).

Table 6.1 Mean (± SD) results of the three groups (elite, sub-elite and non-athletic healthy males).

	Yo-Yo IR1 Test Performance	
	Distance (m)	No. of Runs
Elite (National, n=20)	1910* ± 230	100* ± 11
Sub-Elite (State, n=20)	1438^ ± 335	72^ ± 16
Non-athletic Healthy males (Control, n=20)	774 ± 358	39 ± 18

* denotes elite footballers ran significantly further than the Sub-Elite and Non-athletic Healthy males ($p < 0.05$).

^ denotes sub-elite footballers ran significantly further than the Non-athletic Healthy Group ($p < 0.05$).

6.4 Discussion

This study demonstrated that the Yo-Yo IR1 can clearly distinguish between the performance ability of elite junior AF players in comparison to their sub-elite counterparts despite similar weekly training volumes. Furthermore, a significant difference was also reported between trained AF players and an age matched non-athletic healthy control group. To date, only one study in AF has used a Yo-Yo test (Young *et al.*, 2005), reporting a positive relationship with successful team selection and superior performance on the YO-YO IR2 test. Prior to this study, the use within the TID process at the elite junior AF competition level of the Yo-Yo IR1 or IR2 tests have not previously been investigated. Whilst this study acknowledges only a relatively small sample was measured, it is important to emphasise that significant differences were highlighted between the three groups for performance using the Yo-Yo IR1 test. Moreover, post-hoc analyses showed a high power with the differences found between the groups (0.95). With the results of this study supporting trends reported in previous research (Krustrup *et al.,* 2003), future research involving more participants is necessary, with a key focus toward measuring the relationship between Yo-Yo IR1 test performance and team selection at the elite junior AF level.

Previously used within the AF TID research, the continuous MSFT, whilst sharing similarities in test design to the YO-YO IR1 test (requiring acceleration, deceleration and change of direction activities) has demonstrated inconsistent discriminatory results across the elite junior AF population (Keogh, 1999; Pyne *et al.,* 2005; Young & Pryor, 2007). Nevertheless, Young and Pryor (2007) reported a link between a significantly greater aerobic capacity and team selection and Pyne *et al.*, 2006 reported trends toward positional differences in estimated VO_2max results. Despite using a smaller population sample in our study, the Yo-Yo IR1 test successfully distinguished intermittent running performance abilities of an elite junior AF playing group compared to their sub-elite counterparts, whilst both groups performed better again than the non-athletic healthy aged matched participants. Due to the strong links to team-sport movement patterns (Krustrup *et al.*, 2006a) and the previously successful use of the Yo-Yo IR2 test at the elite senior AF level (Young *et al.*, 2005), the results of this study provides initial evidence for future research into the benefits for AF TID and successful team selection processes. Further research possibilities would also examine the relationship between test performances and suitability for different field positions, as demonstrated by Krustrup *et al.* (2006a) within elite level soccer players, with longitudinal analysis important to measure performance changes over time.

CHAPTER 7

Anthropometric profiling of Elite Junior and Senior Australian Football players.

7.1 Introduction

Profiling of elite sport athletes is a valuable means of TID and is critical for the development of individual strengths and weaknesses and in the design of appropriate strength and conditioning programs (Chaouachi *et al.,* 2009). Commonly, athletes across competition standards and age levels within team-sport research have all recorded greater total weight, lean mass and bone mass results, in conjunction with less total fat mass, compared to their age-matched control counterparts (Pena Reyes *et al.*, 1994; Alfredson *et al.*, 1996; Duppe *et al.*, 1996; Wittich *et al.*, 1998; Calbet *et al.*, 2001; Vicente-Rodriguez *et al.*, 2003). Greater whole body bone mineral content (BMC) and bone mineral density (BMD), with significantly higher levels recorded in the clinically relevant areas of the lumbar spine, femoral neck, pelvis and leg regions have also been reported within soccer players (Wittich *et al.*, 1998; Calbet *et al.*, 2001). In a study measuring the association between physical activity and BMD development in soccer players, greater differences were generally shown between senior athletes (18-28 yrs) in comparison to age matched controls than was recorded by a group of junior athletes (13-17 yrs [Duppe *et al.,* 1996]) As the number of seasonal exercise sessions completed by the senior and junior athletes was approximately the same, the longer history of training within the older group was suggested the most likely explanation for the differences reported (Duppe *et al.,* 1996). Nevertheless, whilst it remains contentious as to whether a particular body shape characterises the likelihood of success at the professional team sport level (Nevill *et al.*, 2009), few studies have been conducted to document the extent of any differences or map the stages of change from a junior (commonly ≤ 18 years of age) to professional rookie (commonly aged 18-21 years old during their first two or three years on a professional list) and finally professional senior athlete. As a consequence, in the absence of research identifying anthropometric profiles that characterise more successful Australian Football (AF) athletes, the current use of this factor within the TID process is based on face value appraisal of their assumed physical readiness or capacity for development (Chaouachi *et al.,* 2009; Nevill *et al.,* 2009).

It is now recognised that the game-day physical demands of AF have increased across all field positions, with players running faster, more often and for longer distances than previously recorded (Norton *et al.*, 1999; Dawson *et al.*, 2004b). With the increased speed of the modern game, soft-tissue and over-use injuries are reportedly on the rise in AF (Orchard & Seward, 2008, 2009), coupled with a slowly progressing increase in shoulder injuries related to the greater number or risk involved in tackling activities (Orchard & Seward, 2009). Furthermore, in conjunction with these game developments, anecdotal evidence suggests that younger players are being exposed to elite level senior AF quicker and earlier than ever before, despite only a four-month chronological and training age difference from their day of selection (also known as drafting) to the first round of the following senior professional season. However, although it has generally been agreed that a high percentage of athletes recruited each year are ready for senior AF based on skill level alone, it is difficult to ascertain how many are physically ready to cope with the demands of elite senior football (Gabbett, 2002a; Pyne *et al.*, 2005). Only one study within AF has compared the two population groups, reporting the lower whole body mass of selected players into one elite junior AF team in comparison to their senior counterparts (Keogh, 1999). Subsequently, while players within junior AF competitions are still developing physically, it has been suggested that an increase in body mass accompanied with an increase in strength is the greatest challenge in physically preparing these athletes to compete at an elite senior level (Keogh, 1999).

Therefore, a common under-researched area within AF is the physical preparation of elite junior athletes when making the transition from junior to senior competitions. Presently, there is an absence of evidence-based research to refute or support the observation that a young athlete is ready for the physical demands of senior AF based on their current physique. Whilst physiological measures of speed, power, endurance and agility have been broadly researched (Keogh, 1999; Pyne *et al.*, 2005; Pyne *et al.*, 2006; Young & Pryor, 2007; Veale *et al.*, 2008), the aim of our preliminary study was to a) quantify the differences in body composition (lean mass, fat mass, BMC and BMD) between elite junior and professional AF rookie and senior athletes, and b) explore trends that exist between age-matched elite and sub-elite junior AF athletes.

7.2 Methods

Participants

Fifty-seven male elite junior athletes from one state based elite junior AF competition were invited by random selection to participate in this study, of which twenty-one responded (17.71 ± 0.27 years). Forty-one male elite senior participants (22.80 ± 4.24 years) were recruited from one club competing in the Australian Football League (AFL) competition and were divided into two similar sized groups based on chronological age and training experience: 18-20 (19.44 ± 0.70 years; n = 18) and 21+ years old (25.43 ± 3.98 years; n = 23). For this study, athletes within their first two years as a professional AF athlete (18-20 years old) were classified as rookies, whilst those with a greater training experience (21+ years old) were classified as seniors. Furthermore, an exploratory study was conducted within the junior participants comparing elite (17.70 ± 0.23 years; n=11) and sub-elite (17.71 ± 0.33 years; n=10) groups, whereby elite athletes were classified as those who had represented their state at the Australian under 18 nationals on at least one occasion, whilst the sub-elite athletes had not. Dual energy X-ray absorptiometry (DEXA) scans of all participants were completed over a two week period during the early rounds of the competitive season, with all scans completed during the day. All participants involved in the study were provided with verbal and written communications of the study's requirements and gave informed consent prior to their participation. Ethical approval was granted by the University

Human Research Ethics Committee (in accordance with the Declaration of Helsinki) and each participant (and parent where required) provided written informed consent prior to their participation.

Test Procedures

Using a Hologic QDR 4000/W fan beam DEXA scanner (software version APEX 2.3, Waltham, MA), whole-body scans were used to calculate lean body mass (kg), body fat (kg), total bone area (cm2), BMC (kg) and BMD (g.cm-2 [Calbet et al., 2001]) Fat-free lean mass in the limbs only was assumed to be a surrogate measure of muscle mass (Calbet *et al.*, 1998). The total body scans were divided into sub-regions (Figure 7.1 and 7.2), following the methodology of Calbet *et al.* (2001) Previous research has reported laboratory precision errors for regional analysis of the complete body scan, defined by the coefficient of variation (CV) for repeated measures estimated in young volunteers with repositioning: BMC < 3.5%, BMD < 4%, bone area < 4.8%, and fat-free lean mass < 3.3% (Calbet *et al.*, 1998; Calbet *et al.*, 2001).

Prior to each session, a system calibration was conducted following the protocols outlined in the Hologic QDR 4000/W fan beam DEXA scanner manual. In preparation for each scan, participants were instructed to lie on their back and remaining as still as possible throughout the duration of the test (seven minutes in duration). All metal or reflective objects was removed (e.g. clothing with zips or studs, earrings etc.), with participants wearing a loose pair of sports shorts only to minimize clothing absorption (Bracco *et al.,* 1996).

Scan Information:

Scan Date:
Scan Type:
Analysis:

Operator:
Model:
Comment:

DXA Results Summary:

Region	Fat (g)	Lean+BMC (g)	% Fat
L Arm	491.1	3704.2	11.7
R Arm	525.1	4050.9	11.5
Trunk	3905.6	29928.0	11.5
L Leg	1693.7	11013.8	13.3
R Leg	1956.7	11724.9	14.3
Subtotal	8572.2	60421.8	12.4
Head	1093.7	4772.6	18.6
Total	**9665.9**	**65194.4**	**12.9**

Figure 7.1 An example page of a typical DEXA scan report

Referring Physician:

k = 1.166, d0 = 44.9
0 x 0

Scan Information:

Scan Date:
Scan Type:
Analysis:

Operator:
Model:
Comment:

DXA Results Summary:

Region	Area (cm^2)	BMC (g)	BMD (g/cm^2)	T - score	PR (%)	Z - score	AM (%)
L Arm	227.37	182.89	0.804				
R Arm	251.63	213.49	0.848				
L Ribs	162.80	112.87	0.693				
R Ribs	155.75	121.32	0.779				
T Spine	134.23	124.11	0.925				
L Spine	50.87	56.25	1.106				
Pelvis	252.81	292.54	1.157				
L Leg	398.39	525.76	1.320				
R Leg	447.31	571.12	1.277				
Subtotal	2081.16	2200.34	1.057				
Head	281.38	459.16	1.632				
Total	**2362.54**	**2659.50**	**1.126**	**-1.0**	**91**		

Total

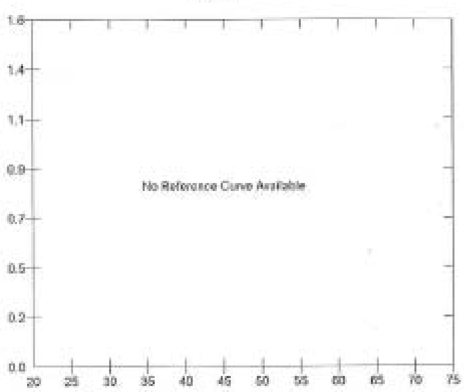

Figure 7.2 A second example page of a typical DEXA scan report

7.2.1 Data processing and statistical Analysis

Each scan was recorded and all data was first screened to ensure they were normally distributed. In order to have sufficient data to test for questions of normality, all data from 62 trials were used to establish the distributional properties. No variable's z-score of skew or kurtosis was excessive. Further, Shapiro-Wilks tests suggested the total body variables of Total Mass (SW = 0.98, *df* = 60, p = 0.45), Lean Mass (SW = 0.98, *df* = 60, p = 0.55), percentage Lean Mass (SW = 0.98, *df* = 60, p = 0.65), Fat Mass (SW = 0.96, *df* = 60, p = 0.06), percentage Fat Mass (SW = 0.98, *df* = 60, p = 0.31), BMC (SW = 0.98, *df* = 60, p = 0.45) and BMD (SW = 0.97, *df* = 60, p = 0.22) were clearly normally distributed. Therefore, a comparison between means was calculated by a one-way ANOVA to measure the variance between the elite junior, professional AF rookie and senior athletes involved in this study. Where the ANOVA detected significant differences, Scheffe's Post-hoc tests and Cohen's effect size (ES) conventions were used to determine statistical and practical significant differences between groups; small (0.25), medium (0.5) and large (0.8) comparative effects (Cohen, 1988). Furthermore, regional differences within the groups (right vs. left side) were estimated using paired *t* tests. Within the exploratory study, an independent samples *t* test was used to measure the difference between the elite and sub-elite junior athletes. An alpha level of $p \leq 0.05$ was accepted as significant. Data are presented as means (± SD).

7.3 Results

Results for the whole body composition analysis are presented in Table 7.1. Despite there being no significant difference between the elite junior athletes and their AFL rookie counterparts for mean age, height, total weight, total lean mass and total fat mass, the junior athletes were on average 5.01 kg and 4.36 kg lighter in total weight (ES = 0.72) and lean mass (ES = 0.78) respectively (Table 7.1). On average, the elite junior athletes were 7.65 kg and 5.78 kg lighter in total weight and total lean mass than their AFL senior counterparts respectively, with significant differences calculated between total body mass ($F_{2,59}$ = 6.312; p < 0.01), total lean mass ($F_{2,59}$ = 5.584; p < 0.01; Figure 1) and total fat mass ($F_{2,59}$ = 3.490; p = 0.05; Table 7.1). Furthermore, the elite junior athletes had 0.34 kg and 0.42 kg less total bone mineral content (Table 7.1) than both elite AFL population groups (rookie; $F_{2,59}$ = 8.518; p = 0.02 and senior; $F_{2,59}$ = 8.518; p < 0.01) and a significantly lower BMD compared to the AFL senior group ($F_{2,59}$ = 7.307; p < 0.01; Table 7.1). A positive linear relationship between total lean mass and bone mineral density was also demonstrated across all three population groups (Figure 7.3), whilst no difference was demonstrated between the three groups for the percentage of body mass comprised of lean mass, fat mass, or bone mineral content (Table 7.1).

Table 7.1 Mean (± SD) results of the three groups (elite junior; elite professional AFL rookies 18-20 yrs old; elite professional AFL seniors 21+ yrs old) for whole body composition analysis.

	Elite Junior (n=21)	**AFL rookies (n=18)**	**AFL seniors (n=23)**
Age (yrs)	17.71 ± 0.27[#]	19.44 ± 0.70[‡]	25.43 ± 3.98
Height (cm)	187.02 ± 8.05	188.11 ± 5.60	187.4 ± 6.73
Weight (kg)	78.40 ± 7.12[#]	83.41 ± 6.74	86.06 ± 7.63
Lean mass (kg)	67.10 ± 5.97[#]	71.47 ± 5.25	72.89 ± 6.32
% BW	85.62 ± 1.92	85.62 ± 1.66	84.72 ± 1.92
Fat mass (kg)	8.13 ± 1.88[#]	8.44 ± 1.81	9.58 ± 2.03
%BW	10.32 ± 1.92	10.06 ± 1.58	11.10 ± 1.95
Bone Mass (kg)	3.17 ± 0.29*[#]	3.51 ± 0.36	3.59 ± 0.39
%BW	4.05 ± 0.23	4.19 ± 0.21	4.17 ± 0.28
BMD (g/cm^2)	1.27 ± 0.06[#]	1.33 ± 0.08	1.36 ± 0.08

* values significantly different from those of elite professional AFL rookie footballers ($p < 0.05$).

[#] values significantly different from those of elite professional senior footballers ($p < 0.05$).

[‡] values significantly different between the elite professional AFL rookie (18-20 yrs old) and elite professional AFL senior (21+ yrs old) footballers ($p < 0.05$).

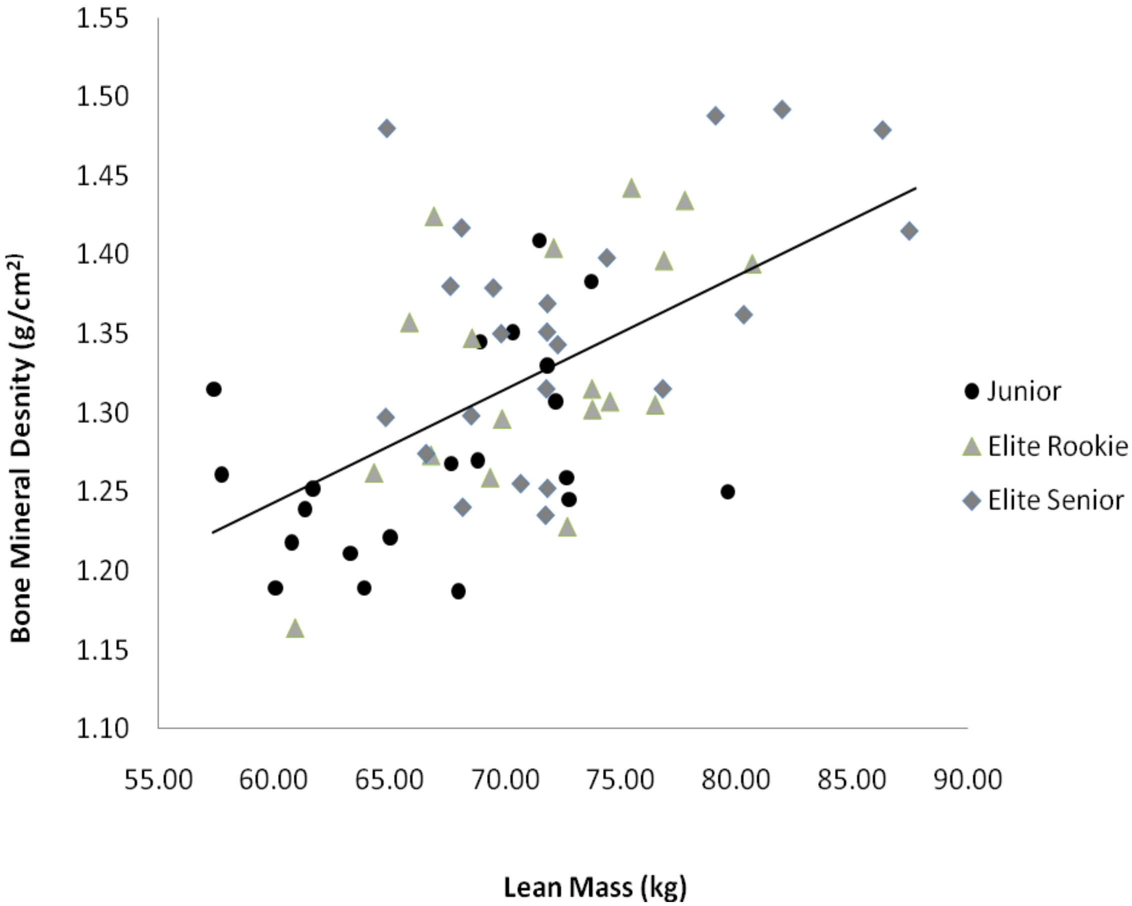

Figure 7.3 Lean mass (kg) and bone mineral density (g/cm^2) of the three population groups (elite junior, elite professional AFL rookie and senior athletes. R= 0.57, R^2= 0.32).

Segmental analysis of total body and lean mass weight demonstrated significantly greater mass in all body areas, excluding total lean mass in the right leg, between the elite junior and professional AFL senior athletes (ranging from $F_{2,59}$ = 4.062 to 12.758; $p < 0.01$; Table 7.2). Whilst only total mass and lean mass in the left arm were significantly less in the elite junior athletes compared to AFL rookies ($F_{2,59}$ = 11.732; $p < 0.01$ and $F_{2,59}$ = 12.758; $p < 0.01$ respectively), moderate to large ES differences were recorded throughout the body regions measured (ranging from ES = 0.47 to 0.80). Bone mineral content and BMD analysis demonstrated significantly lower values in all body segments, excluding BMC of the lumbar spine and BMD of the legs, in the elite junior athletes compared to their professional AFL senior counterparts (ranging from $F_{2,59}$ = 4.087 to 26.408; $p < 0.01$; Table 7.3). Non-significant differences were demonstrated between the elite junior and AFL rookie groups for BMC in the spine, pelvis and left leg and BMD in the pelvis and legs, with small to large ES differences measured (ranging from ES = 0.31 to 0.84). Paired *t* test analysis demonstrated significant differences between arms and legs for total weight ($p < 0.01$), total lean mass ($p < 0.01$; excluding elite junior legs) and BMC (ranging from $p < 0.01$ to $p = 0.04$) for all three groups, whilst significant differences in BMD were also demonstrated between the arms only (rookies; $p < 0.01$, seniors; $p < 0.01$).

Table 7.2 Mean (± SD) results of the three groups (elite junior; elite professional AFL rookies 18-20 yrs old; elite professional AFL seniors 21+ yrs old) for segmental body total and lean mass analysis.

		Elite Junior (n=21)	**AFL rookies (n=18)**	**AFL seniors (n=23)**
Total Mass (kg)	Left Arm	4.59 ± 0.44*#	5.01 ± 0.41	5.26 ± 0.47
	Right Arm	4.85 ± 0.54#	5.27 ± 0.59	5.58 ± 0.65
	Trunk	36.23± 3.34#	38.34 ± 3.04	40.08 ± 3.46
	Left Leg	13.24 ± 1.43#	14.24 ± 1.52	14.47 ± 1.55
	Right Leg	14.05 ± 1.63#	14.79 ± 1.49	15.05 ± 1.77
	Subtotal	72.97 ± 6.99#	77.71 ± 6.64	80.46 ± 7.55
	Head	5.43 ± 0.38	5.81 ± 0.64	5.60 ± 0.67
Lean Mass (kg, % total mass)	Left Arm	3.97 ± 0.42 (86.49 %)*#	4.36 ± 0.36 (87.03%)	4.56 ± 0.42 (86.69 %)
	Right Arm	4.23 ± 0.49 (87.22 %)#	4.60 ± 0.50 (87.29%)	4.86 ± 0.54 (87.10 %)
	Trunk	31.99 ± 2.97 (88.30 %)#	33.78 ± 2.57 (88.11%)	34.71 ± 304 (86.60 %)
	Left Leg	11.17 ± 1.10 (84.37 %)#	12.03 ± 1.04 (84.48%)	12.12 ± 1.28 (83.76 %)
	Right Leg	11.81 ± 1.24 (84.06 %)	12.48 ± 1.03 (83.38 %)	12.57 ± 1.37 (83.52 %)
	Subtotal	63.18 ± 5.90 (86.58 %)#	67.32 ± 5.15 (86.63 %)	68.82 ± 6.27 (85.53 %)
	Head	3.93 ± 0.29 (72.38 %)	4.26 ± 0.57 (73.32 %)	4.06 ± 0.47 (72.50 %)

* values significantly different from those of elite professional AFL rookie footballers ($p < 0.05$).

values significantly different from those of elite professional senior footballers ($p < 0.05$).

Table 7.3 Mean (± SD) results of the three groups (elite junior; elite professional AFL rookies 18-20 yrs old; elite professional AFL seniors 21+ yrs old) for segmental body BMC and BMD analysis.

		Elite Junior (n=21)	**AFL rookies (n=18)**	**AFL seniors (n=23)**
	Left Arm	0.21 ± 0.02*[#]	0.24 ± 0.03	0.25 ± 0.02
	Right Arm	0.23 ± 0.02*[#]	0.26 ± 0.04	0.27 ± 0.04
	Left Rib	0.13 ± 0.01*[#]	0.15 ± 0.02	0.16 ± 0.02
	Right Rib	0.13 ± 0.01*[#]	0.16 ± 0.02	0.16. ± 0.02
	T Spine	0.13 ± 0.02[#]	0.15 ± 0.02	0.15 ± 0.02
BMC (kg)	L Spine	0.08 ± 0.01	0.09 ± 0.02	0.09 ± 0.02
	Pelvis	0.46 ± 0.06[#]	0.51 ± 0.08	0.52 ± 0.08
	Left Leg	0.63 ± 0.08[#]	0.70 ± 0.09	0.72 ± 0.10
	Right Leg	0.65 ± 0.09*[#]	0.74 ± 0.11	0.74 ± 0.11
	Subtotal	2.65 ± 0.28*[#]	2.98 ± 0.35	3.06 ± 0.38
	Head	0.52 ± 0.06	0.52 ± 0.07	0.52 ± 0.11
	Left Arm	0.86 ± 0.03*[#]	0.96 ± 0.04	0.91 ± 0.06
	Right Arm	0.89 ± 0.04*[#]	0.94 ± 0.06[‡]	0.99 ± 0.05
	Left Rib	0.84 ± 0.05*[#]	0.91 ± 0.08	0.93 ± 0.08
	Right Rib	0.82 ± 0.05*[#]	0.88 ± 0.05	0.88 ± 0.07
	T Spine	0.95 ± 0.08*[#]	1.06 ± 0.09	1.07 ± 0.10
BMD (g/cm^2)	L Spine	1.24 ± 0.13*[#]	1.40 ± 0.17	1.46 ± 0.17
	Pelvis	1.39 ± 0.13[#]	1.47 ± 0.11	1.51 ± 0.14
	Left Leg	1.46 ± 0.12	1.52 ± 0.11	1.55 ± 0.15
	Right Leg	1.44 ± 0.12	1.51 ± 0.13	1.53 ± 0.12
	Subtotal	1.19 ± 0.07*[#]	1.26 ± 0.08	1.28 ± 0.08
	Head	1.96 ± 0.19	1.97 ± 0.20	2.02 ± 0.26

* values significantly different from those of elite professional AFL rookie footballers ($p < 0.05$).

[#] values significantly different from those of elite professional senior footballers ($p < 0.05$).

[‡] values significantly different between the elite professional AFL rookie (18-20 yrs old) and elite professional AFL senior (21+ yrs old) footballers ($p < 0.05$).

Results for the within-groups analysis of the junior population are presented in Table 7.4. The elite level junior athletes had a significantly greater lean mass as a percentage of their body mass (t[11 df]= 16.07, p = 0.03), less total fat mass (t[11 df]= 14.241, p = 0.04) and less fat mass as a percentage of body mass (t[11 df]= 16.729, p = 0.02). No significant difference was recorded for segmental analysis of total body mass, lean mass, BMC or BMD.

Table 7.4 Mean (± SD) results of the two groups (sub-elite and elite junior athletes) for whole body composition analysis.

	Elite (n=11)	Sub-elite (n=10)
Age (yrs)	17.70 ± 0.23	17.71 ± 0.33
Height (cm)	189.09 ± 7.30	184.75 ± 8.59
Weight (kg)	77.47 ± 7.47	79.43 ± 6.96
Lean mass (kg)	67.01 ± 6.86	67.20 ± 5.18
% BW	86.47 ± 1.49	84.69 ± 1.97^
Fat mass (kg)	7.29 ± 1.23	9.05 ± 2.10^
%BW	9.43 ± 1.46	11.31 ± 1.93^
Bone Mass (Kg)	3.17 ± 0.24	3.18 ± 0.36
%BW	4.10 ± 0.25	4.00 ± 0.21
BMD (g/cm^2)	1.27 ± 0.07	1.28 ± 0.06

^ values significantly different between elite and sub-elite junior footballers ($p < 0.05$)

7.4 Discussion

The aim of this preliminary study was to measure the body composition differences between elite junior AF athletes and their professional adult AFL counterparts. Supporting previous research within a different football code (Wittich *et al.,* 1998), no significant difference was recorded between the two elite professional AFL groups for total body composition measurements or most segmental analyses. Furthermore, supporting the general assumption of a greater physical development within the professional AFL senior athletic population, a significant elevation in total body mass ($p < 0.05$), comprising a significantly greater lean mass ($p < 0.05$) was demonstrated in the professional AFL senior players when compared to their elite junior counterparts. In addition, a significantly greater BMC and BMD were commonly found throughout the body in the professional AFL senior athletes ($p < 0.05$). Therefore, despite the chronological age of the junior athletes suggesting they are on the verge of participating at the elite senior level, the results of this study further demonstrates the physical disparity between the two levels of AF competition.

Anecdotal evidence demonstrates a large discrepancy in access to club facilities (including training hours) between part-time elite junior AF athletes (roughly 8 hours) to their full-time rookie and senior counterparts (roughly 40 hours). Whilst no statistically significant difference in total body mass or lean mass was recorded between the elite junior and professional AFL rookie athletes, the finding of large ES differences suggests that one or two years of training and participation (on top of further growth and individual genetic responsiveness to physical change) may have an effect on the body size of the professional AFL rookie athletes. Furthermore, despite the 6-9 kg difference in total mass, the junior and both senior populations recorded a similar proportion of lean mass, fat mass and bone mass as a percentage of total body mass, suggesting a linear progression in body composition development occurs in AF athletes from elite junior through to the professional rookie and finally senior level. Whilst future research would benefit from investigating the impact of biological maturity within the junior population via the use of a maturity offset score (Mirwald *et al.*, 2002), the differences demonstrated within this study are important for the adjustment of age appropriate physical expectations placed on these athletes (Mujika *et al.,* 2009). Such data is also useful in the design of age specific training programs targeting an increase in lean muscle mass (and therefore total body mass) of elite junior AF athletes (Keogh, 1999).

Bone adaptation occurs under the imposition of mechanical stresses, with areas of the skeleton that receive a direct physical load (such as the femoral neck) reporting a greater exercise increment of BMD (Wittich *et al.*, 1998; Calbet *et al.*, 2001; Ginty *et al.*, 2005; Smathers *et al.*, 2009). Furthermore, athletes have reported a significant elevation in total skeletal BMC as a result of combined increases in both bone size and density (Wittich *et al.,* 1998). Elite junior athletes within this study were not compared to an age-matched control group as it has previously been concluded that intensive exercise started during or before adolescence promotes bone hypertrophy and increases the BMD and BMC of the loaded skeletal areas (Haapasalo *et al.*, 1996; Wittich *et al.*, 1998; Calbet *et al.*, 2001). Subsequently, this same trend can confidently be expected within the junior athletes of this current study (Alfredson *et al.*, 1996; Duppe *et al.*, 1996; Wittich *et al.*, 1998; Calbet *et al.*, 2001). However, believed to be of greater importance was the comparison between elite junior athletes and recent graduates to the senior AF competition level (AFL rookies), with further analysis made against those of a more mature training age (AFL seniors). Interestingly, whilst previous research has reported greater differences between athletes and their age-matched control counterparts in athletes of superior training age (Duppe *et al.*, 1996; Wittich *et al.*, 1998; Calbet *et al.*, 2001), this study demonstrated a number of common body areas that were physically developed within the elite junior AF athletes to the same extent as their professional AFL counterparts. No BMD differences were demonstrated within the important areas of the legs or BMC differences in the lumbar spine, with only the pelvis region reporting significantly greater BMD and BMC development within the professional senior AFL athletes. Whilst not ignoring the natural process and rates of bone development, this finding suggests the positive effects of impact loading on bone development as a result of early participation within the team sport environment (Wittich *et al.*, 1998; Calbet *et al.*, 2001), with non-impact loaded body segments significantly weaker within the elite junior athletes (Wittich *et al.,* 1998).

Despite AF requiring the use of both sides of the body to complete key game skills such as kicking and handballing (Dawson *et al.*, 2004b), this study demonstrated significant differences in the body composition of both arms and legs within each population group analysed. Total body mass, lean mass, BMC and BMD all demonstrated significant differences in one or both sets of limbs within each group, suggesting athletes involved at the elite level of AF are one side dominant in their physical make-up. In contrast, soccer research has reported whole-body symmetry (Calbet *et al.,* 2001). The bilateral nature of soccer involving kicking with both legs and the external forces exerted on the non-dominant leg to maintain balance and support during the kicking phase was suggested to contribute to the symmetrical leg bone development (Calbet *et al.,* 2001). It can therefore be postulated that, despite the advantage of being equally skilled on both sides of the body, AF athletes tend towards using a preferred leg for kicking that exposes them to the potential for developing a muscular imbalance. Furthermore, the differences in game-day physical load experienced and kicking techniques used by the two football codes may suggest further research is required to identify possible reasons for limb and body asymmetry in AF athletes. Consequently, the use of DEXA technology can provide significant insight and assist in monitoring the physical development of young athletes within elite senior competitions, identifying asymmetry that may reduce a potential injury risk and further enhance their physical development.

Within our study, the junior population was also divided into two groups to measure the trends in physical development between elite and sub-elite athletes based on their level of competition. Whilst no significant difference in total body mass or lean mass was recorded between the two groups, the elite junior athletes recorded a significantly greater percentage body mass of lean mass, in accordance with the significantly less absolute fat mass and proportion of total body mass comprised of fat. With bone development showing no difference between the two groups (Slemenda & Johnston, 1993; Wittich *et al.,* 1998), a trend towards the selection of leaner athletes can be suggested at higher levels of competition, with these athletes holding a greater advantage towards using their lean mass, in the absence of excess detrimental fat weight, for superior physical performance (Naughton *et al.*, 2000; Reilly *et al.*, 2000a; Reilly *et al.*, 2000b; Nevill *et al.*, 2009). Therefore, future research documenting the longitudinal analyses of junior athletes will provide a more complete physical model of the more successful junior athlete (Reilly *et al.*, 2000b). Nevertheless, training programs at the junior level of AF should be aimed toward improvements in both strength and lean muscle mass, with decreasing total body fat mass a consequence of such training practices.

Whilst the aim of this preliminary study was to report the differences in body composition between athletes at different competition levels, a potential limitation was the inability to control for the effects of individual maturation. Furthermore, the authors note that this study used a population sample of elite junior athletes from one state competition and elite senior athletes from one national level AF team, potentially limiting the findings by the training practices exposed to the small number of participants involved. Therefore, a national study at the elite junior level, controlling for the effects of maturation (Mirwald *et al.,* 2002), would provide a more in-depth representation of the body compositional status of athletes preparing to make the step into the elite senior AF competition. Whilst this study has provided a preliminary comparison of the differences in body composition between elite junior and senior AF athletes, as well as trends within both the elite junior and senior populations, longitudinal analysis mapping the physical development and progression of athletes over an extended time period would provide valuable evidence in assessing their physical preparation and readiness to compete at the senior AF level.

CHAPTER 8

The Longitudinal Analysis of Physical Development of Elite Junior Australian Football players.

8.1 Introduction

The identification of future athletes in the competitive sporting environment is based on an understanding of the physical requirements for playing at an elite standard and a longitudinal profile of successful prototypes (Reilly *et al.*, 2000b). To date, a large number of studies have identified relationships between individual attributes (one being physical test performance) and team selection within elite junior and senior sporting competitions, aiding the development of reference data for successful performance (Keogh, 1999; Edwards *et al.*, 2002; Gabbett, 2002a; Pyne *et al.*, 2005; Young *et al.*, 2005; Pyne *et al.*, 2006; Young & Pryor, 2007; Gravina *et al.*, 2008; Veale *et al.*, 2008). Nevertheless, the monitoring of athletes over a prolonged period of time has been shown to improve the understanding of the factors that contribute the most to elite physical performances (Reilly *et al.*, 2000b; Williams & Reilly, 2000; Elferink-Gemser *et al.*, 2006; Vaeyens *et al.*, 2006). Due to a variety of limitations involved in completing TID research, only a small number of all encompassing TID models within the team sport environment have been produced and validated, with most multidisciplinary research conducted in the sport of soccer (Reilly & Stratton, 1995; Pienaar *et al.*, 1998; Reilly *et al.*, 2000b; Williams & Reilly, 2000; Elferink-Gemser *et al.*, 2006; Vaeyens *et al.*, 2006). A combination of anthropometric, physiological, neuromotor, cognitive-perceptual and psychosocial variables are commonly measured elements (Williams & Reilly, 2000; Vaeyens *et al.*, 2006), whilst various external factors are also suggested to impact on later success (including training opportunities, injury rates, access to coaching, personal, social and cultural factors [Reilly *et al.*, 2000b]) As such, longitudinal research adopting a multidisciplinary approach that tracks talented youth players until some of them develop into elite athletes in adulthood has been suggested as one method of obtaining an insight into the characteristics of 'tomorrow's stars' (Elferink-Gemser *et al.,* 2006).

Across the professional team sport environment, significant time and financial expense is spent annually on the TID process, searching for athletes with the potential believed necessary to participate at the highest level (Williams & Reilly, 2000). With 'new' professional athletes commonly deemed financial investments, the identification, selection and development process is a critical pathway to the sustained competitive viability of elite senior sporting teams (Williams & Reilly, 2000). Consequently, additional pressure is applied to the same process at the elite junior competition level, with an increased demand placed on the improvement of game-related technical and tactical skills in conjunction with increased rates of physical and physiological development. Within the soccer development structure, early identification of potential can result in club selection occurring at a very young age (Reilly *et al.*, 2000b; Williams & Reilly, 2000). This ensures players have access to specialised coaching and training earlier in their development years, accelerating their rate of improvement and minimising the pool of junior athletes to effectively manage (Williams & Reilly, 2000). However, an inherent issue in early talent development programs is the inability to accurately predict growth and maturation rates, consequently resulting in the systematic selection of athletes based on the 'relative age effect' phenomenon (Mujika et al., 2009 & Williams & Reilly, 2000). Alternatively, state-based elite junior AF competitions are run independently of the professional elite senior AF competition in an attempt to provide equal access to all talented athletes once they reach the age of selection (eighteen years of age or older). Whilst the pursuit of excellence within the elite junior competition can be classified by four key stages (Detection, Identification, Development and Selection [Pienaar *et al.*, 1998; Williams & Reilly, 2000]) 'identification' and 'development' are the two areas focused upon within this study.

Talent identification is the recognition of athletes with the potential to become elite amongst current participants at an elite level (Williams & Reilly, 2000). This often involves the prediction of performance based on test measurements and outcomes across a variety of categories (two being physical and physiological attributes [Règnier *et al.*, 1993; Williams & Reilly, 2000]) However, in an all-encompassing TID model, Reilly *et al.,* (2000b) reported the need for longitudinal research within the sporting environment, examining the validity of tests used as talent predictors to identify changes over time. Whilst a progressive improvement in physiological capacities has been reported within team sport athletes as their playing level and age increased from junior to senior levels (Gabbett, 2006a), limited research has been conducted within the sport of AF, with a notable absence of longitudinal study designs. Such a systematic collection of information over time would ensure coaches and talent scouts are better informed about the physical and physiological development of young athletes, complementing the intuitive judgements made regarding talented AF players (Reilly & Stratton, 1995; Pienaar *et al.*, 1998; Reilly *et al.*, 2000b), whilst increasing the predictive utility of commonly used test batteries across this competition standard (Williams & Reilly, 2000; Elferink-Gemser *et al.*, 2006).

Therefore, whilst a wide ranging view of TID and development would involve areas of psychological profiling and sport-specific skills testing, this study will limit its focus to the physiological application of a test battery in the process of identifying and monitoring the physical development of elite junior AF athletes. As earlier studies within this thesis have reported the reliability and validity of AF specific field tests, the aim of the following research was to determine the ability of a newly designed test battery to measure physical development over two competitive junior AF seasons, continually assessing its ability to discriminate between playing standards (Impellizzeri & Marcora, 2009). A secondary aim was to profile the longitudinal changes in body composition of elite junior AF athletes, quantifying the association between physical test performance and physical development.

8.2 Methods

All participants involved in both studies I (Longitudinal physiological performance profiling) and II (Longitudinal body composition development) were provided with verbal and written communications of the study's requirements. Ethical approval was granted by the University Human Research Ethics Committee (in accordance with the Declaration of Helsinki) and each participant and parent provided written informed consent prior to their participation.

Study I – Longitudinal physiological performance profiling

Participants

In total, 57 talented AF players (age 16.3 ± 0.5 years at the outset of the study) volunteered to participate in a longitudinal study profiling changes in physical test performance over a two year involvement within an elite junior AF competition. All participants were recruited from one state based elite junior AF competition (Victorian TAC Cup Under 18 [U18] competition), selected by positive invitation response (eighty-five players were invited to participate) across the seven metropolitan clubs. To measure trends in physical test performance in comparison to athletic standard of competition, the study population was divided into three groups based on the following criteria; Elite = had represented their state at the 2007 under 16 National carnival in the previous season (Height 184.8 ± 7.0 m, Weight 75.7 ± 7.7 kg; n = 16), Sub-Elite = had been selected to try out for the state team but were unsuccessful in being selected onto the final list (Height 182.9 ± 6.5 m, Weight 74.1 ± 6.1 kg; n = 21), or Control = were identified by their clubs as potential elite athletes although not identified at the under 16 level by the state program (Height 187.1 ± 6.7 m, Weight 75.4 ± 7.9 kg; n = 20).

Over the course of the two year longitudinal study, spanning the final two seasons within a state-based elite junior AF development competition, eight testing sessions (T1 – T8) were completed at the following time-points; Start of pre-season training (December; 2007 = test 1 [T1] and 2008 = test 5 [T5]), End of pre-season training (March; 2008 = test 2 [T2] and 2009 = test 6 [T6]), Mid-season (June; 2008 = test 3 [T3] and 2009 = test 7 [T7]), End of season (September; 2008 = test 4 [T4] and 2009 = test 8 [T8]). The end of season testing session was held one week after the completion of the season for each team, often varying by up to four weeks due to some teams not qualifying for the finals (regular season finishing at the end of August) and others playing in the grand final (last week in September). In between testing sessions, the participants completed periodised systematic training programs within their respective clubs, on average three times a week during pre-season and twice a week in-season, in addition to regular in-season competition games. Showing similarities to previous longitudinal research in the sport of soccer (McMillan *et al.*, 2005a), only 3 of the 57 participants within this study completed some or all of the tests across every session over the two year duration, with athletes commonly missing sessions due to injury and illness or state representative commitments. Eighteen athletes (including 13 after the first session alone) chose to drop-out of the study, whilst a further 9 athletes left the study because they were delisted (no longer a member of the talent development competition) from their respective clubs; they continued playing AF at local club level. Three athletes were also drafted (selected) by an elite AFL club at the completion of their first year in the elite junior program, no longer participating within the elite junior AF competition and thus this study post T4. Table 8.1 has a description of the number of athletes who participated in each testing session. Due to minor injuries, on certain occasions across the two years, not all players were able to participate in all tests within a given session. This resulted in a varied sample size across all the tests during most testing sessions.

Table 8.1 Number of athletes per group (elite; n = 16, sub-elite; n = 21, control; n = 20) who participated within each testing session across the two-year study duration.

		Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Involved in all eight sessions
2007 Elite	Participants	13	8	7	7	7	7	1	5	0
	Injured	3	4	3	5	3	3	5	5	
	Drop-Out		4			1				
	State commitment			2				4		
	Senior AFL					1				
	Delisted from TAC									
2007 Sub-Elite	Participants	17	13	11	12	11	13	2	6	1
	Injured	4	4	5	2	2		5	1	
	Drop-Out		4	1	1					
	State commitment				1			2	2	
	Senior AFL					2				
	Delisted from TAC							4		
2007 Control	Participants	19	12	15	11	11	9	5	5	2
	Injured	1	3		3	3	4	6	4	
	Drop-Out		5		1		1			
	State commitment									
	Senior AFL									
	Delisted from TAC							2	2	
Total Participants	Participants	49	33	33	30	29	29	8	16	3
	Injured	8	11	8	10	8	7	16	10	
	Drop-Out		13	1	2	1	1			
	State commitment			2	1			6	2	
	Senior AFL					3				
	Delisted from TAC							6	3	

Selection of Tests:

Tests were chosen based on their accuracy in best replicating game movement patterns within this population age group (Table 8.2 [Veale *et al.*, 2007a, 2009c, b]) Where a test had not been previously proven reliable and / or valid at the competition standard of the study population, exploratory research was conducted to ensure this was the case (see chapters 3-6, pages 65-103 [Veale *et al.*, 2009a; Veale *et al.*, 2010a; Veale *et al.*, 2010b]) Due to time restrictions in accessing athletes within an elite level junior sporting competition, all physical performance tests were conducted on the same day in order of Reactive Agility (see section 3.2 on pages 69-72 for a full test description), Power (see section 5.2 on pages 91-92 for a full test description), Repeated Sprint Ability (see section 4.2 on pages 82-83 for a full test description) and Aerobic Capacity (see section 6.2 on page 99 for a full test description [Walker & Turner, 2009]). At least 5 min separated the first three tests, whilst 20 min separated Repeat Sprint Ability and Endurance test participation.

Table 8.2 Description of the test battery measuring the physiological variables important to AF.

Reactive Agility	A novel reactive agility test was adapted from previous work by Sheppard *et al.* (2006) Note chapter 3, section 3.2; pages 69-72 for a further description of test protocols and measurements.
Power	Standing Vertical Jump (countermovement with hands on hips; Young, 1995; Peterson *et al.*, 2006), and Running Vertical Jump (5 m run-up jumping off the outside foot; Pyne *et al.*, 2005); measured using a Yardstick apparatus. Note chapter 5, section 5.2; pages 91-92 for a further description of test protocols and measurements.
Repeated Sprint Ability	6 x 30 m sprints starting every 20 sec, measured using electronic timing gates (Custom built, Sick Electronics, Germany). Note chapter 4, section 4.2; pages 82-83 for a further description of test protocols and measurements.
Aerobic Capacity	YO-YO Intermittent Recovery Test (Level 1). Note chapter 6, section 6.2; page 99 for a further description of test protocols and measurements.

All tests were conducted indoors on a wooden floor the size of two basketball courts situated side by side. A standardised ten minute warm-up was used prior to the commencement of the testing session (involving basic run-throughs at an increasing tempo, dynamic stretching and change of direction activities) and athletes were instructed to complete their own personal preparatory activities between each test. Where necessary, players were allowed up to three familiarisation trials in tests they had not previously completed. Raw test results were recorded for each physiological measure (Falk *et al.*, 2004), in line with the descriptions within the previous chapters of this thesis (RAT, see section 3.2 on page 73; RSA test, see section 4.2 on page 83; Power, see section 5.2 on pages 92-93 and Aerobic Capacity, see pages 99-100).

Study II – Longitudinal body composition development

Participants

In total, 25 talented AF players (16.3 ± 0.5 years) participated in a longitudinal study measuring the rate of body composition development throughout the course of a two year elite junior sporting career. All participants were also participants in Study I of this chapter. Following the same DEXA scan protocols explained in chapter 7 (see section 7.2 on page 141 for a further description of test protocols and measurements) on each occasion, four testing sessions over the course of the same two year period were conducted at the following time-points; End of pre-season training (March; 2008 = DEXA scan 1 [T2] and 2009 = DEXA scan 3 [T6]) and end of the competition season (September; 2008 = DEXA scan 2 [T4] and 2009 = DEXA scan 4 [T8]). Following the methodology of study I, between-groups analysis was also conducted across the three playing groups; elite (Height 189.3 ± 7.7 cm, Weight 78.6 ± 8.0; n = 9), sub-elite (Height 182.6 ± 5.6 cm, Weight 74.6 ± 44.9; n = 7) and control (Height 186.7 ± 7.7 cm, Weight 78.6 ± 5.0; n = 9) athletes. Of the 25 participants within the study, 12 attended all four testing sessions over the two year duration, with 7 athletes absent on one occasion, 5 athletes dropping out of the study and 1 athlete selected by an elite AFL club at the end of their first year in the elite junior program (no participation post T4).

8.2.1 Data processing and statistical analysis

Study I – Longitudinal physiological performance profiling

Each trial over the eight testing sessions was recorded and group results presented as means (± SD). All data during each testing session were first screened to ensure they were normally distributed. In order to have sufficient data to test for questions of normality, all data within each variable during each testing session (ranging from 8 to 49 trials) was used to establish the distributional properties. No variable's z-score of skew or kurtosis was excessive. Over the course of the eight testing sessions, Shapiro-Wilks tests suggested the variables RAT total time (ranging from SW = 0.94 to 0.99, *df* = 9 to 48, p = 0.135 to 0.986), RSA test total time (ranging from SW = 0.93 to 0.99, *df* = 6 to 45, p = 0.059 to

0.998), SVJ (ranging from SW = 0.84 to 0.98, *df* = 7 to 48, p = 0.099 to 0.854), RVJ (Left foot take-off [ranging from SW = 0.89 to 0.98, *df* = 7 to 48, p = 0.083 to 0.992], Right foot take off [ranging from SW = 0.95 to 0.97, *df* = 6 to 48, p = 0.218 to 0.855]) and YO-YO test (Level [ranging from SW = 0.77 to 0.95, *df* = 4 to 43, p = 0.061 to 0.686] and Distance [ranging from SW = 0.78 to 0.98, *df* = 4 to 43, p = 0.074 to 0.827]) were clearly normally distributed, while RAT T1 (SW = 0.78, *df* = 48, $p < 0.001$), SVJ T6 (SW = 0.91, *df* = 27, p = 0.024) and RVJ left foot take-off (T1 [SW = 0.95, *df* = 48, p = 0.034] and T2 [SW = 0.92, *df* = 31, p = 0.024]) were apparently non-normal. These violations appeared to be only mild from examination of frequency histograms and detrended Q-Q plots, and were not considered sufficient to warrant a more conservative analysis. Consequently, it was decided to treat these data variables as essentially normal in distribution and a mixed model ANOVA for within and between group comparisons was used for statistical analysis, with Tukey's HSD Post-hoc test and effect size conventions used to illustrate magnitude of the differences between groups (SPSS, Version 15.0). For all statistical testing, alpha was set at $\leq$p 0.05 and Cohen's ES conventions were used to illustrate the magnitude of the differences between groups; small (0.25), medium (0.5) and large (0.8) comparative effects (Cohen, 1988). The small number of participants during T7 resulted in limiting the ability of between groups ANOVA analysis during this time point.

Study II – Longitudinal body composition development

Each scan of all participants over the four sessions was recorded and data is presented as means (± SD). All data during each testing session were first screened to ensure they were normally distributed. In order to have sufficient data to test for questions of normality, all data within each variable during each testing session (ranging from 16 to 25 trials) was used to establish the distributional properties. No variable's z-score of skew or kurtosis was excessive. Over the course of the four testing sessions, Shapiro-Wilks tests suggested the total body variables of total mass (ranging from SW = 0.94 to 0.98, *df* = 16 to 25, p = 0.249 to 0.813), Lean Mass (ranging from SW = 0.95 to 0.98, *df* = 16 to 25, p = 0.431 to 0.956), percentage Lean Mass (ranging from SW = 0.94 to 0.98, *df* = 16 to 25, p = 0.133 to 0.984), Fat Mass (SW = 0.90 to 0.98, *df* = 16 to 25, p = 0.053 to 0.979) percentage Fat Mass (ranging from SW = 0.92 to 0.98, *df* = 16 to 25, p = 0.133 to 0.984), BMC (ranging from SW = 0.94 to 0.96, *df* = 16 to 25, p = 0.148 to 0.582) and BMD (ranging from SW = 0.90 to 0.96, *df* = 16 to 25, p = 0.093 to 0.380) were normally distributed. Therefore, a mixed model ANOVA for within and between group comparisons was used. with Where the ANOVA detected significant differences, Tukey's HSD Post-hoc test and Cohen's ES conventions (Cohen, 1988) were used to illustrate magnitude of the differences between groups (SPSS, Version 15.0). An alpha level of $p \leq 0.05$ was accepted as significant and Cohen's ES conventions were used to illustrate the magnitude of the differences between groups; small (0.25), medium (0.5) and large (0.8) comparative effects (Cohen, 1988). Pearson correlation analysis was also conducted, measuring the relationship between mean body composition and physiological test performance results. The correlation criteria adopted were: $r < 0.1$ trivial, 0.1-0.3 small, 0.3-0.5 moderate, 0.5-0.7 large and > 0.7 very large (Pyne *et al.*, 2005).

8.3 Results

<u>Study I – Longitudinal physiological performance profiling</u>

Over the eight testing sessions, there were performance improvements and season variations in all physical variables measured between the three playing groups within this study.

Reactive Agility Test

Between groups analysis over the two year study period demonstrated improvements in test performance by each group, with the elite AF group commonly recording superior test results (Figure 8.1). Whilst no significant difference was recorded between groups for total time over the study duration, a significant difference was recorded between groups in T6 over the 2 m split time, with the elite population faster than their sub-elite counterparts ($F_{2,26} = 3.332$; $p = 0.04$). Small to moderate ES differences were recorded across all split times, with the elite population recording superior RAT total test performances in T1 (ES =

0.41), T3 (ES = 0.28), T5 (ES = 0.18) and T6 (ES = 0.61) in comparison to their sub-elite counterparts. Furthermore, small to large ES differences were recorded in T1 (ES = 0.62), T3 (ES = 0.51), T5 (ES = 0.29), T6 (ES = 0.68) and T8 (ES = 1.18) in comparison to the control group (Figure 8.1). The sub-elite athletes also recorded superior performances to their control counterparts in T1 (ES = 0.39), T3 (ES = 0.23), T4 (ES = 0.42) and T8 (ES = 1.38).

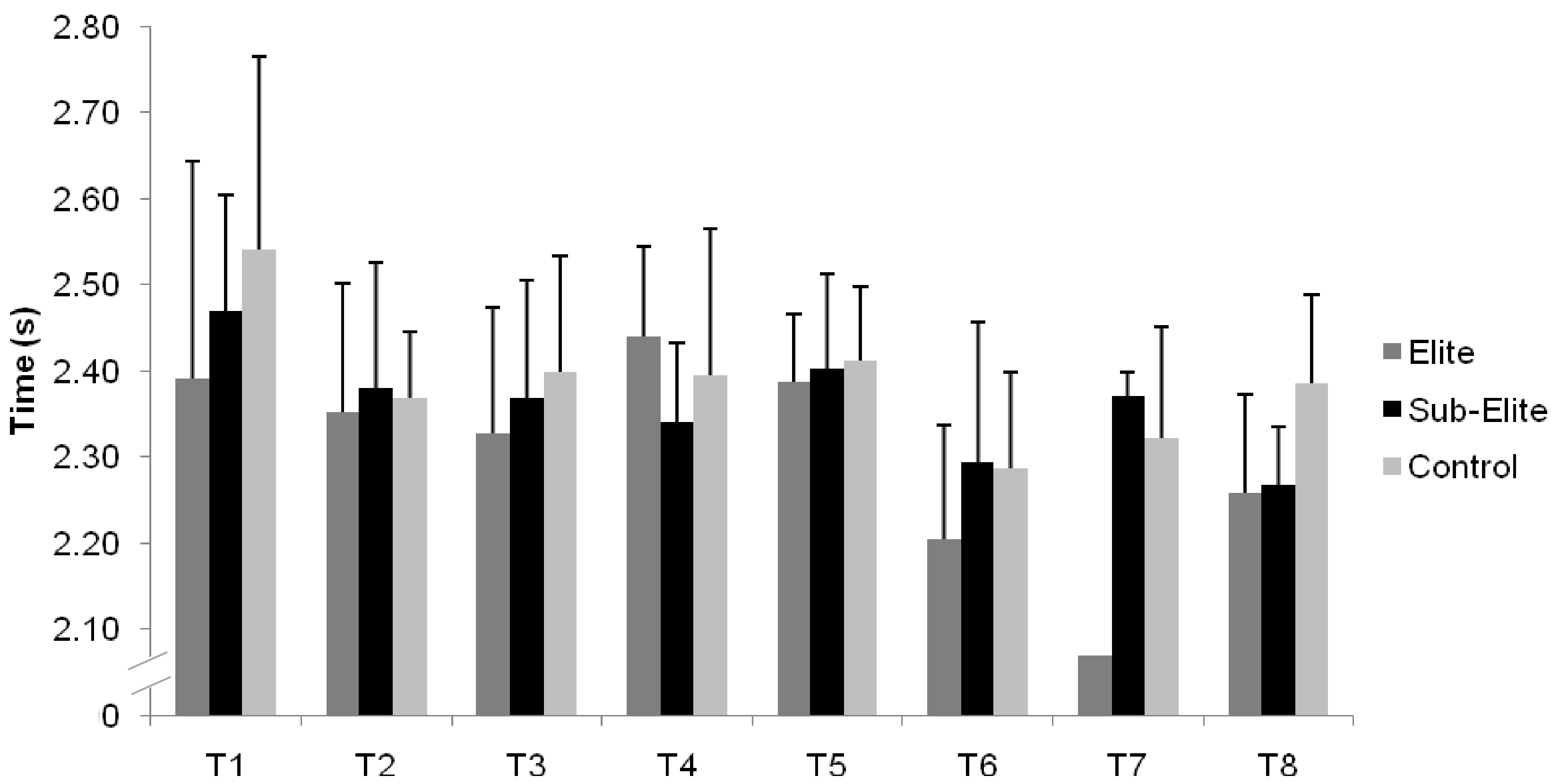

Figure 8.1 Mean (± SD) test results across the three playing groups (elite, sub-elite and healthy male controls) for the RAT total time (12 m) over two competitive elite junior seasons; Test 1 (December 2007) to Test 8 (September 2009).

Repeated Sprint Ability Test

Between groups analysis demonstrated improvements in performance by each group over the duration of the study (Figure 8.2), reporting moderate to large ES differences between the three study sub-groups across all splits within the RSA test. The elite population demonstrated superior RSA test 30 m total time results in comparison to the sub-elite athletes in T1 (ES = 0.53), T2 (ES = 0.95), T3 (ES = 0.60), T5 (ES = 0.82) and T6 (ES = 0.75), whilst the sub-elite athletes were slightly faster at the end of season testing sessions; T4 (ES = 0.50) and T8 (ES = 0.08). Whilst the elite athletes demonstrated superior RSA total test performances in comparison to their control counterparts over the study duration (T1 [ES = 0.53], T2 [ES = 0.53], T3 [ES = 0.86], T5 [ES = 0.84], T6 [ES = 0.53] and T8 [ES = 1.25]), only in T8 (ES = 1.00) did the sub-elite demonstrate a superiority over the control athletes. This trend was noted within the test variables of RSA 10 m, RSA 20 m and RSA flying 10 m total times.

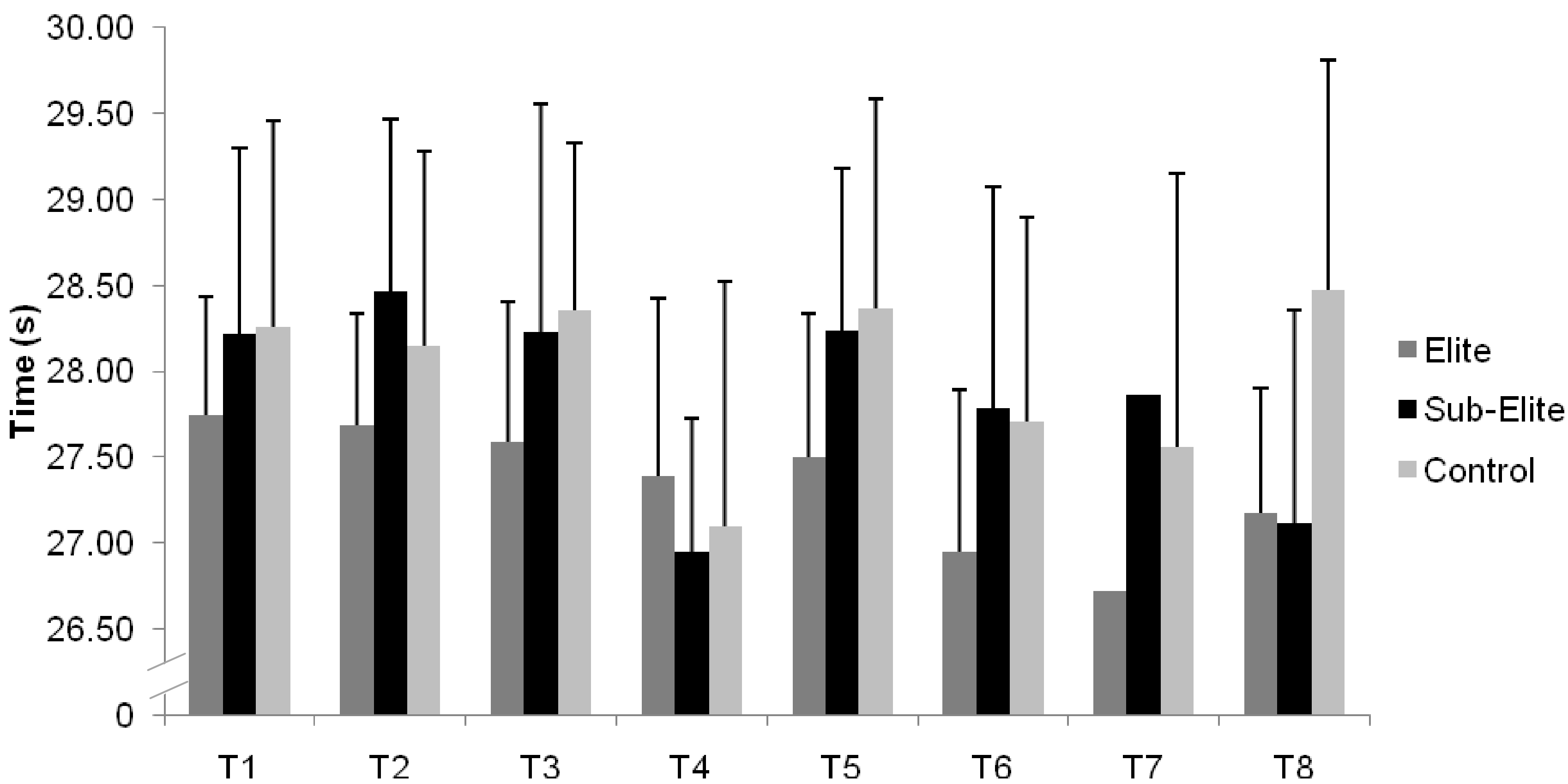

Figure 8.2 Mean (± SD) test results across the three playing groups (elite, sub-elite and healthy male controls) for the RSA test total time (6 x 30 m) over two competitive elite junior seasons; Test 1 (December 2007) to Test 8 (September 2009).

Power – Standing Vertical Jump

The SVJ test demonstrated performance improvements within each group over the study duration, with between groups analysis reporting small to large ES differences between the three groups (Figure 8.3). Elite athletes jumped higher on the SVJ on each test occasion in comparison to their sub-elite peers, most notably in T1 (ES = 0.45), T2 (ES = 0.62), T5 (ES = 0.84), T6 (ES = 0.30) and T8 (ES = 0.66). Elite athletes also jumped higher on the SVJ on each test occasion in comparison to their control peers, most notably in T1 (ES = 0.32), T2 (ES = 0.44), T3 (ES = 73), T4 (ES = 0.52), T5 (ES = 0.58) and T8 (ES = 0.38). Sub-elite athletes jumped higher on the SVJ in comparison to their control peers in T3 (ES = 0.55) and T4 (ES = 0.39), whilst the control athletes jumped higher in T6 (ES = 0.23) and T8 (ES = 0.40). Small ES differences were recorded on the other test occasions.

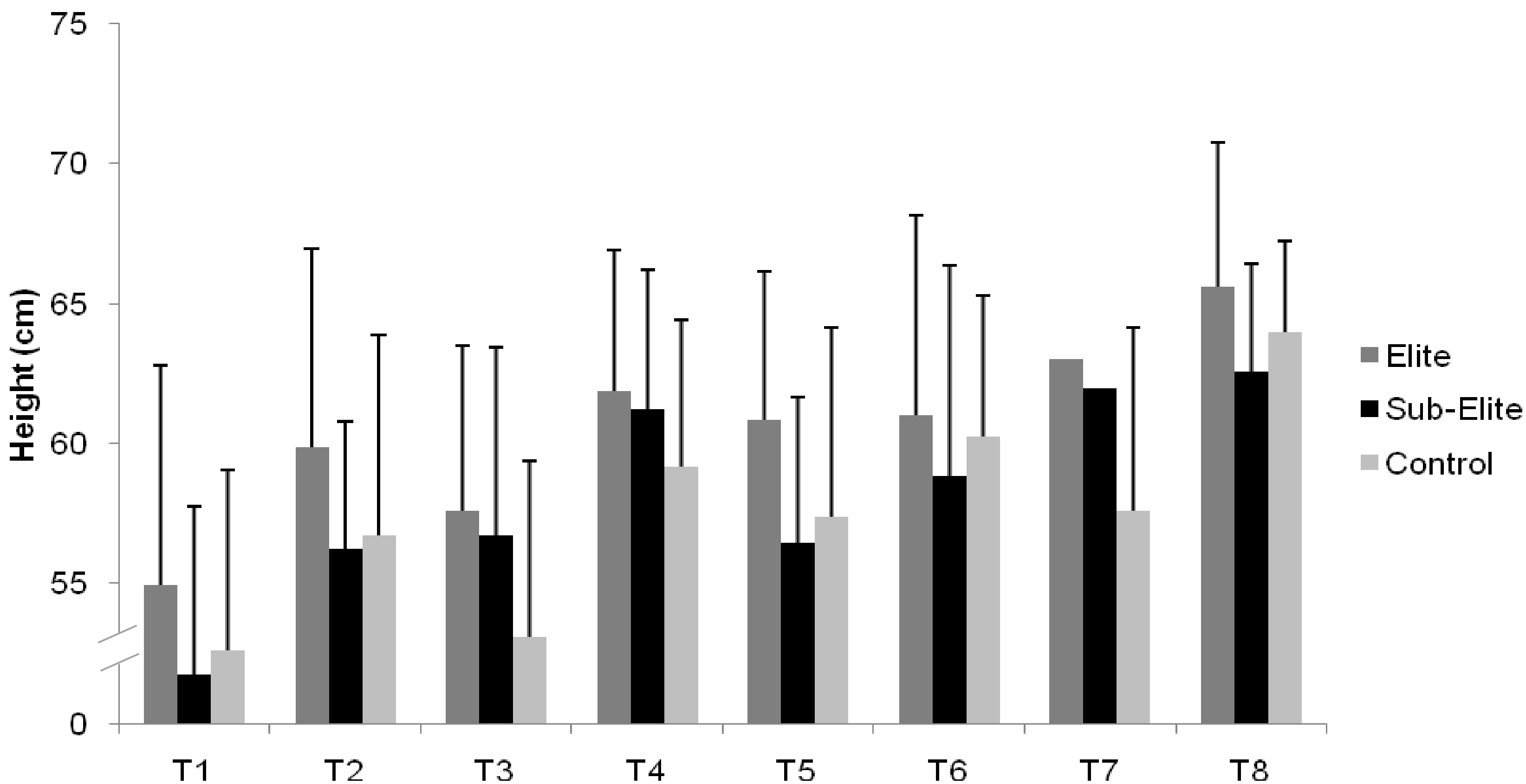

Figure 8.3 Mean (± SD) test results across the three playing groups (elite, sub-elite and healthy male controls) for Standing Vertical Jump height over two competitive elite junior seasons; Test 1 (December 2007) to Test 8 (September 2009).

Power – Running Vertical Jump

Improved RVJ test performances were demonstrated by each group over the study duration, with between group's analysis commonly reporting superior test performances (small to large ES differences) by the control group in RVJL (Figure 8.4) and RVJR (Figure 8.5) height. Whilst the elite athletes jumped higher on the RVJR test in comparison to their control peers in T1 (ES = 0.32), T3 (ES = 0.43) and T6 (ES = 0.65), the control athletes were commonly superior in RVJL (T2 [ES = 0.38], T4 [ES = 0.81], T5 [ES = 0.46], T6 [ES = 0.47] and T8 [ES = 0.28] and RVJR (T2 [ES = 0.27], T4 [ES = 0.62], T5 [ES = 0.82] and T8 [ES = 0.68] test performance. Furthermore, the control athletes jumped higher from a left foot take-off in T1 (ES = 0.52), T2 (ES = 0.61), T5 (ES = 0.53) and T6 (ES = 0.61) and from a right foot take-off in T1 (ES = 0.20), T4 (ES = 0.27), T5 (ES = 0.39), T6 (ES = 0.37) and T8 (ES = 0.22) in comparison to the sub-elite group. Over the first competitive season, the elite and sub-elite groups recorded varied performance differences for RVJL performance; elite athletes were superior in T1 (ES = 0.41) and T2 (ES = 0.32), whilst the sub-elite were superior in T3 (ES = 0.47) and T4 (ES = 1.15). Similar test results were subsequently recorded over the second competitive season. The sub-elite group however reported commonly superior RVJR test performance (T2 [ES = 0.32], T3 [ES = 0.52], T4 [ES = 0.44], T6 [ES = 0.32] and T8 [ES = 0.55]), despite a lower jump height in T1 (ES = 0.63).

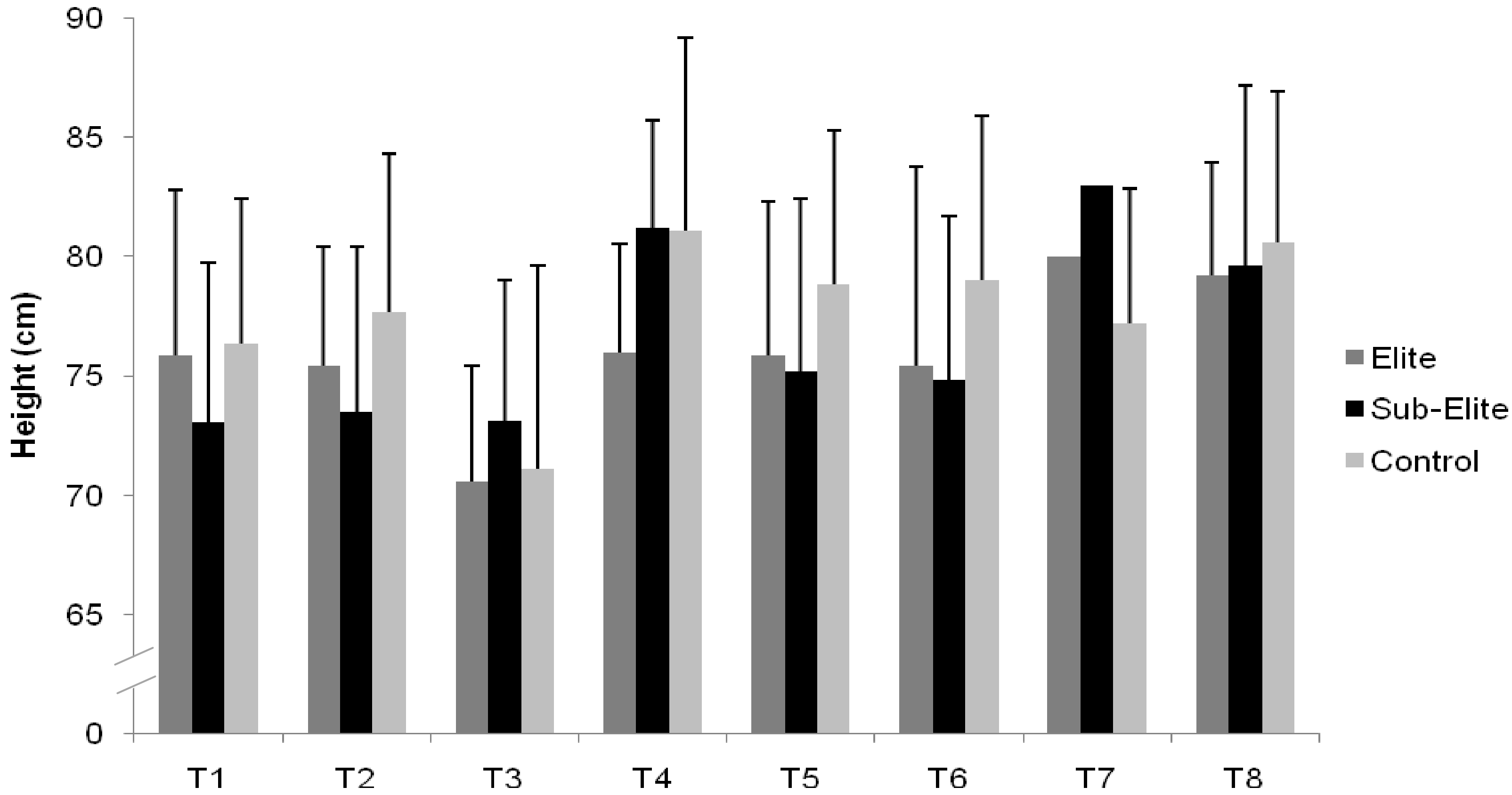

Figure 8.4 Mean (± SD) test results across the three playing groups (elite, sub-elite and healthy male controls) for Running Vertical Jump height from a Left Foot take-off over two competitive elite junior seasons; Test 1 (December 2007) to Test 8 (September 2009).

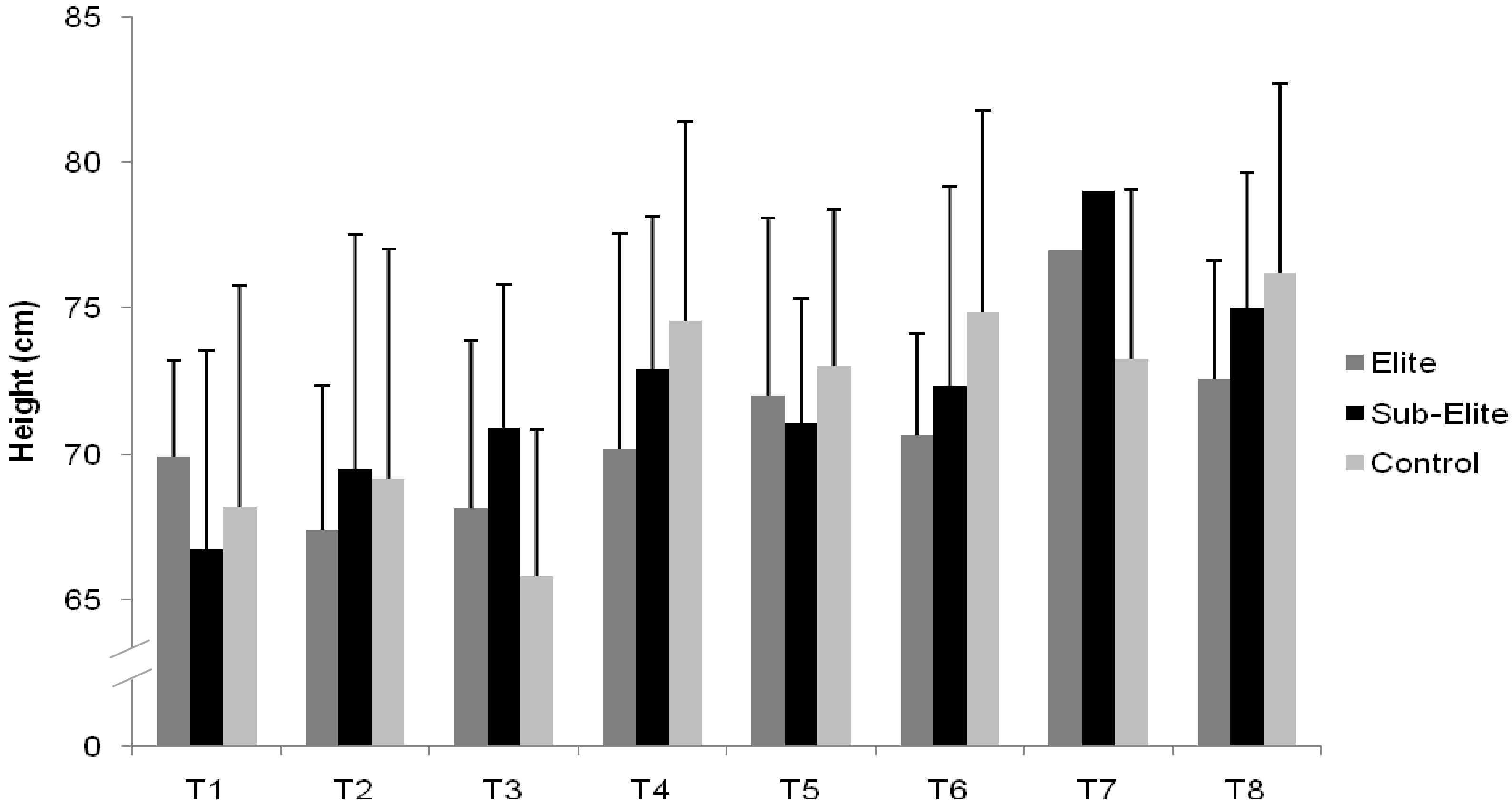

Figure 8.5 Mean (± SD) test results across the three playing groups (elite, sub-elite and healthy male controls) for Running Vertical Jump height from a Right Foot take-off over two competitive elite junior seasons; Test 1 (December 2007) to Test 8 (September 2009).

Aerobic Capacity

Between groups analysis over the two year study period demonstrated test improvements by each playing group, whilst also reporting differences in performances between the three groups. At the completion of the study period (T8), the sub-elite group recorded the only significantly superior test performance between the three groups, running further than their elite counterparts (level $F_{2,11}$ = 3.619; p = 0.05 [Figure 8.6] and distance $F_{2,11}$ = 3.842; p < 0.05;). Whilst statistically significant differences between groups were rare, small to very large ES differences were recorded across all variables. Elite athletes ran further in comparison to their sub-elite peers in T1 (level; ES = 0.51, distance; ES = 0.51), T4 (level; ES = 0.31, distance; ES = 0.33) and T6 (level; ES = 0.26, distance; ES = 0.26), whilst the sub-elite athletes ran further in T3 (level; ES = 0.45, distance; ES = 0.48) and T8 (level; ES = 2.55, distance; ES = 2.57). The elite athletes ran further in comparison to their control peers in T1 (level; ES = 0.21, distance; ES = 0.22), T2 (level; ES = 0.60, distance; ES = 0.61), T4 (level; ES = 0.86, distance; ES = 0.86), T5 (level; ES = 0.56, distance; ES = 0.53) and T6 (level; ES = 1.28, distance; ES = 1.29). The sub-elite athletes also commonly ran further in comparison to their control peers, with superior performances in T2 (level; ES = 0.55, distance; ES = 0.52), T3 (level; ES = 0.50, distance; ES = 0.54), T4 (level; ES = 0.71, distance; ES = 0.69), T5 (level; ES = 0.48, distance; ES = 0.46), T6 (level; ES = 1.44, distance; ES = 1.28) and T8 (level; ES = 0.86, distance; ES = 0.91).

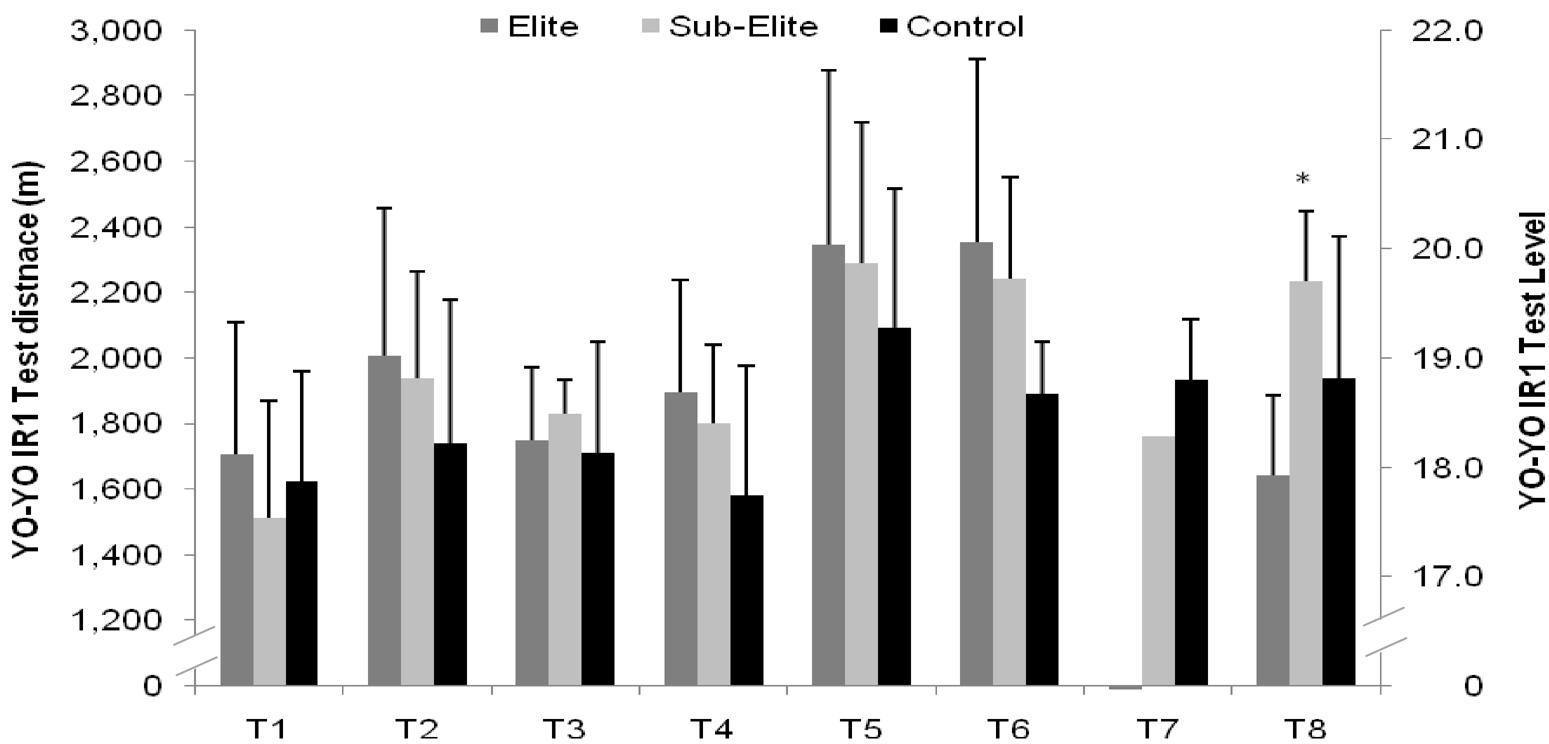

Figure 8.6 Mean (± SD) test results across the three playing groups (elite, sub-elite and healthy male controls) for the distance covered and level achieved in the YO-YO Intermittent Recovery Test (Level 1) over two competitive elite junior seasons; Test 1 (December 2007) to Test 8 (September 2009). * denotes sub-elite athletes ran significantly further compared to their elite counterparts ($p \leq 0.05$).

Study II – Longitudinal development of body composition

Between Groups Analysis

Between groups analysis recorded a small number of significant segmental differences at each scan period between the three playing groups involved within this study. In comparison to the control athletes, the elite group recorded significantly less fat in the LA in T2 ($F_{2,22}$ = 3,190; p = 0.05), as well as total fat in the Left Leg ([LL]; $F_{2,18}$ = 3.970; p = 0.03), fat as a percentage of body mass in the LL ($F_{2,18}$ = 4.588; p = 0.02) and lean mass as a percentage of body mass in the LL ($F_{2,18}$ = 3.910; p = 0.03) at scan T6. At scan T4, the control athletes recorded a greater BA of the pelvis ($F_{2,15}$ = 3.540; p = 0.05), whilst the elite athletes recorded a significantly greater BA of the thoracic spine at T8 in comparison to the sub-elite group ($F_{2,13}$ = 5.774; p = 0.02). Furthermore, small to large effect size differences were recorded across all variables.

The elite population commonly recorded less total body fat (1.18 to 16.56%, ES ranging from 0.48 to 0.69; [Figure 8.7]) and a greater development of total body lean mass over the study duration (peaking at 6.47%, ES ranging from 0.25 to 0.63; [Figure 8.8]) in comparison to their sub-elite peers. Consequently, they also reported less body fat as a percentage of weight (0.9 to 4.0%, ES ranging from 0.10 to 0.92; [Figure 8.9]) and greater lean mass as a percentage of weight (0.16 to 2.05%, ES ranging from 0.07 to 0.97; [Figure 8.10]). Furthermore, the elite athletes commonly recorded greater total bone area (1.28 to 4.65%, ES ranging from 0.24 to 0.86; [Figure 8.11]) and more growth in total body BMC (-0.14 to 2.87%, ES ranging from -0.02 to 0.36; [Figure 8.12]), despite recording less total BMD (0.90 to 1.50%, ES ranging from 0.17 to 0.32; [Figure 8.13]) in comparison to the sub-elite group. The control athletes recorded the highest levels of total body fat (3.52 to 22.51%, ES ranging from 0.17 to 2.25; $p = 0.08$), as well as the highest levels of lean mass (-0.02 to 6.95%, ES ranging from 0.10 to 0.86), resulting in greater total body mass in comparison to the elite (1.11 to 4.49%, ES ranging from 0.17 to 0.58; [Figure 8.14]) and sub-elite (0.95 to 6.78%, ES ranging from 0.12 to 0.82) athletes. Subsequently, this group commonly recorded higher levels of body fat (ES ranging from 0.04 to 1.85; $p = 0.07$) and lower levels of lean mass (ES ranging from 0.13 to 1.81) as a percentage of total body mass. The control athletes also recorded trends towards greater BA and BMC results in comparison to their sub-elite counterparts (1.22 to 5.01%, ES ranging from 0.13 to 0.77).

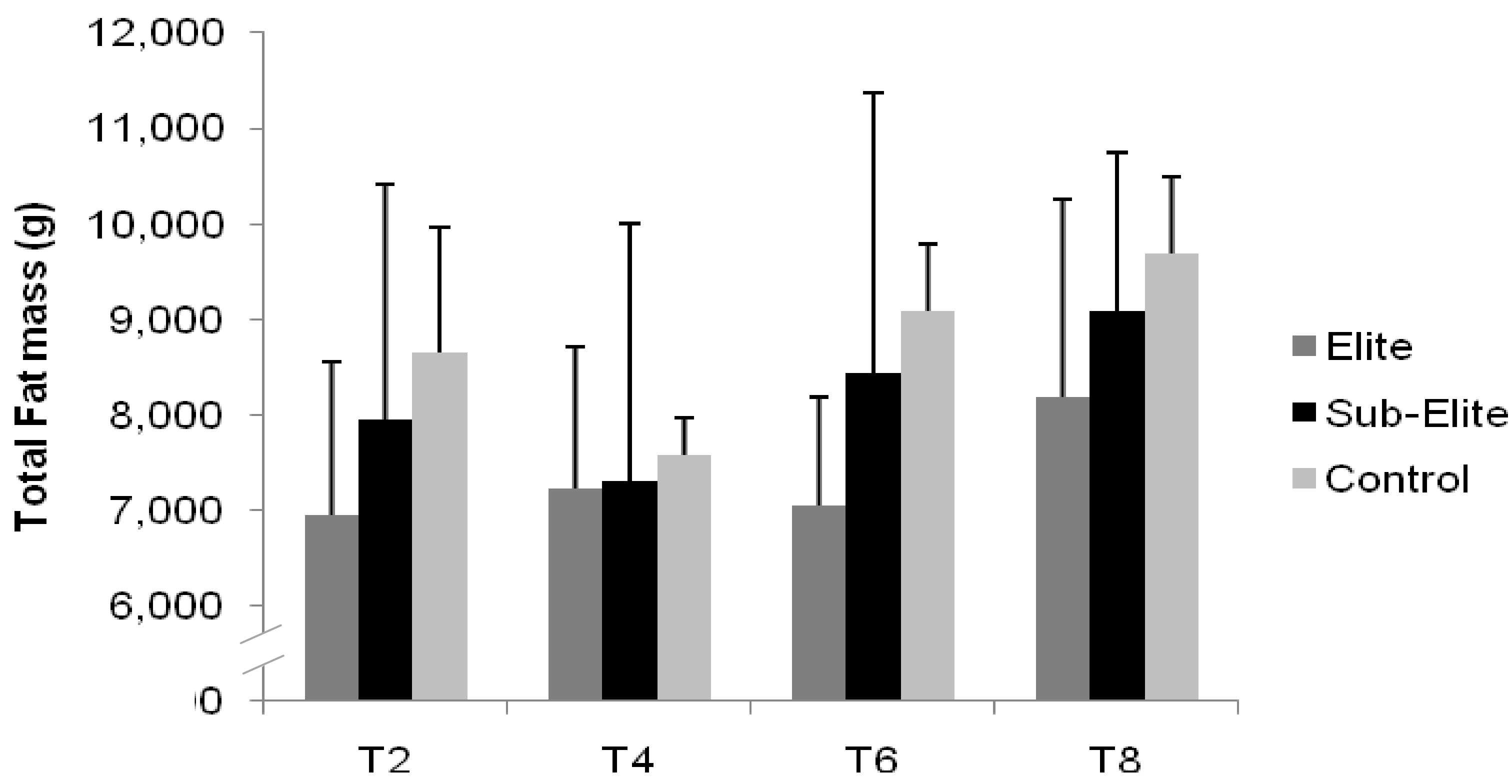

Figure 8.7 Mean (± SD) body composition results across the three playing groups (elite, sub-elite and healthy male controls) for total body fat (g) over two competitive elite junior seasons; Test 1 (December 2007) to Test 8 (September 2009).

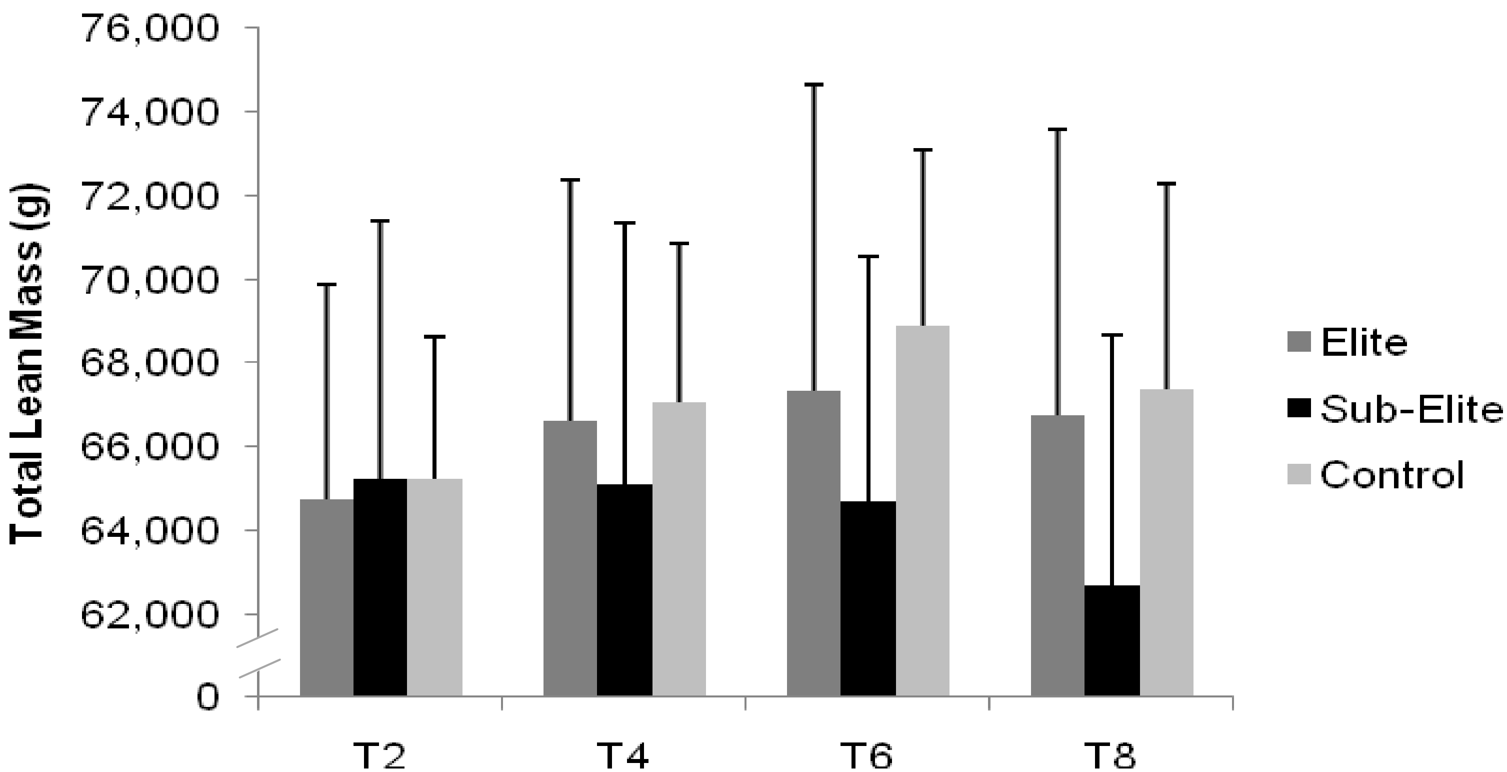

Figure 8.8 Mean (± SD) body composition results across the three playing groups (elite, sub-elite and healthy male controls) for total body lean mass (g) over two competitive elite junior seasons; Test 1 (December 2007) to Test 8 (September 2009).

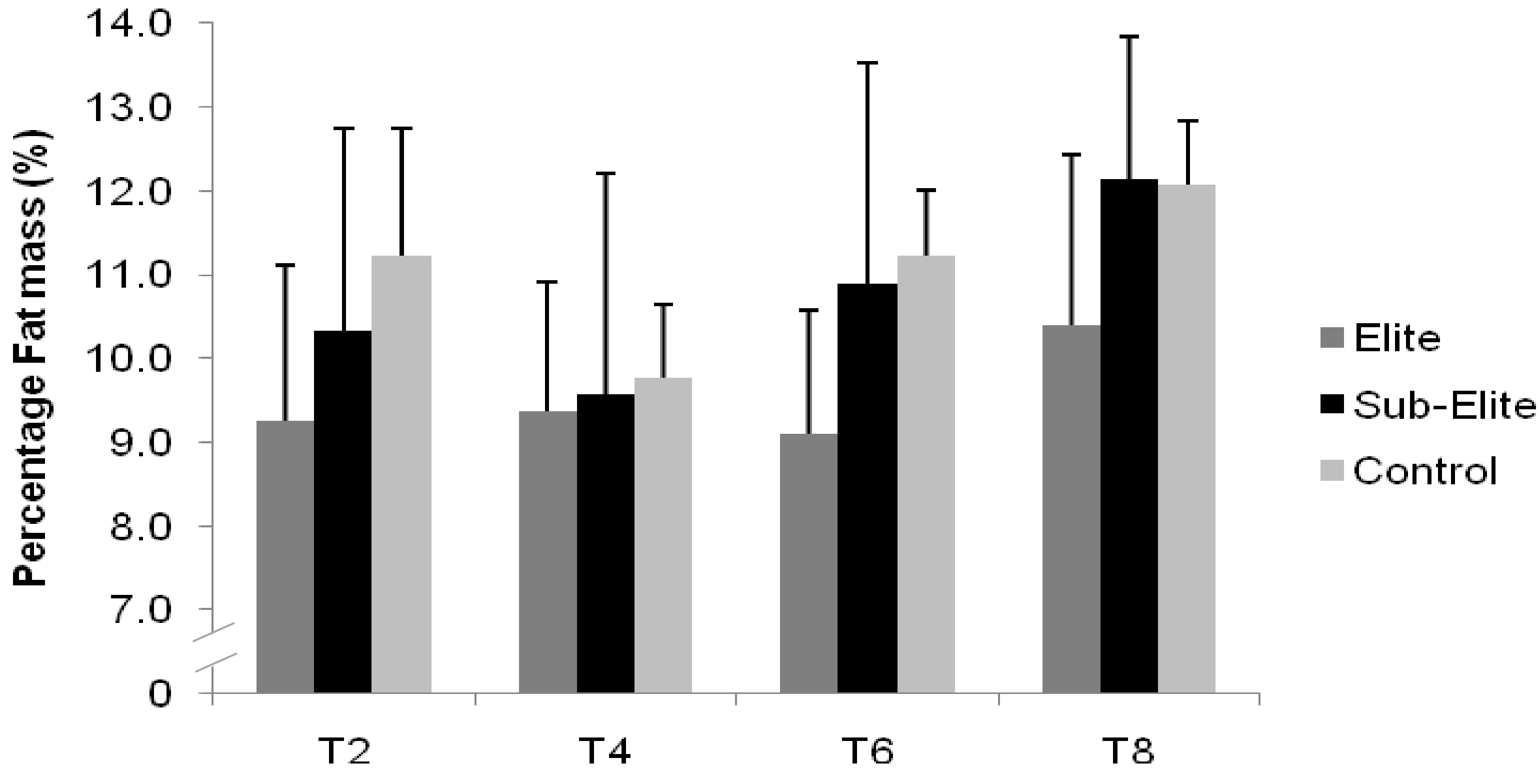

Figure 8.9 Mean (± SD) body composition results across the three playing groups (elite, sub-elite and healthy male controls) for total body fat as a percentage of total body mass over two competitive elite junior seasons; Test 1 (December 2007) to Test 8 (September 2009).

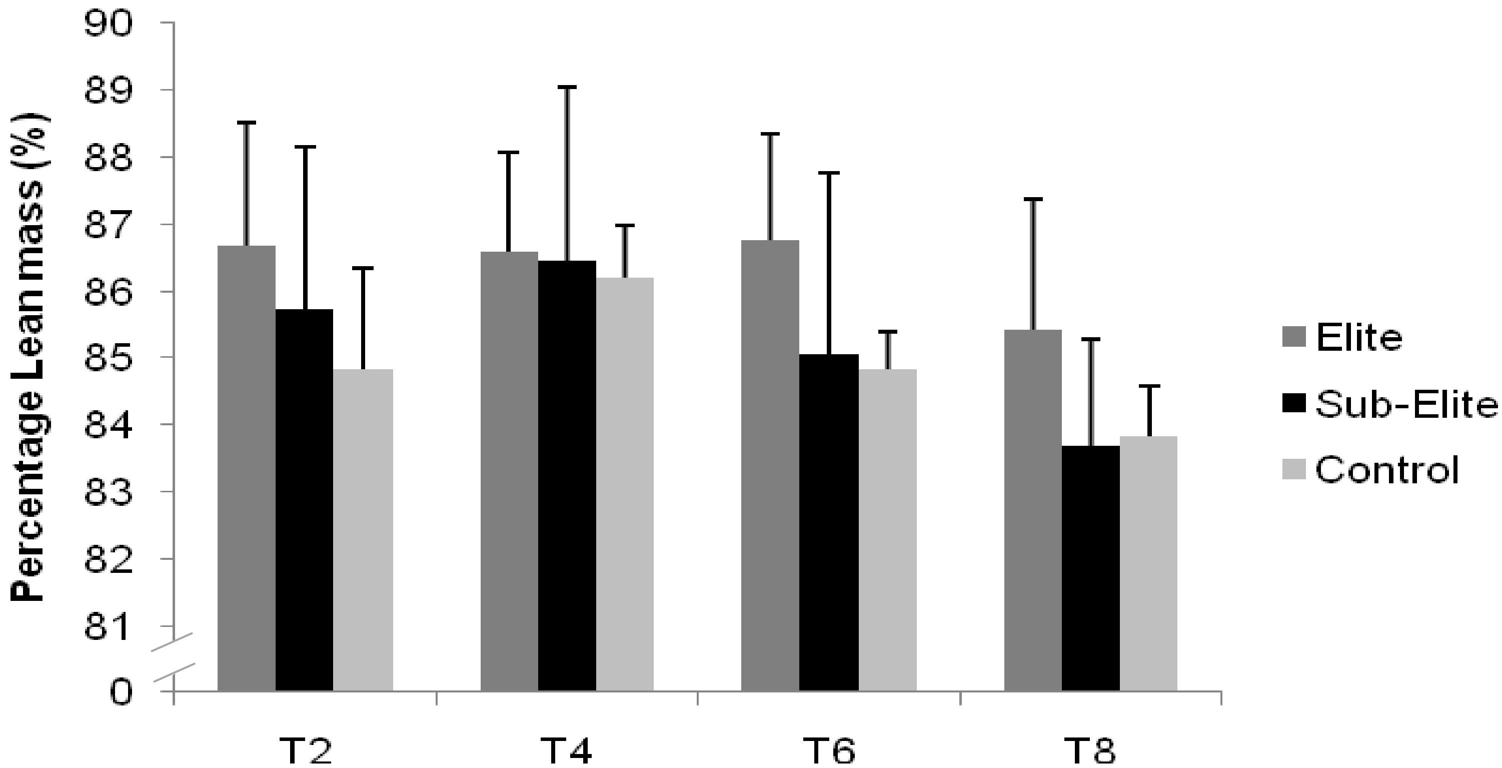

Figure 8.10 Mean (± SD) body composition results across the three playing groups (elite, sub-elite and healthy male controls) for total body lean mass as a percentage of total body mass over two competitive elite junior seasons; Test 1 (December 2007) to Test 8 (September 2009).

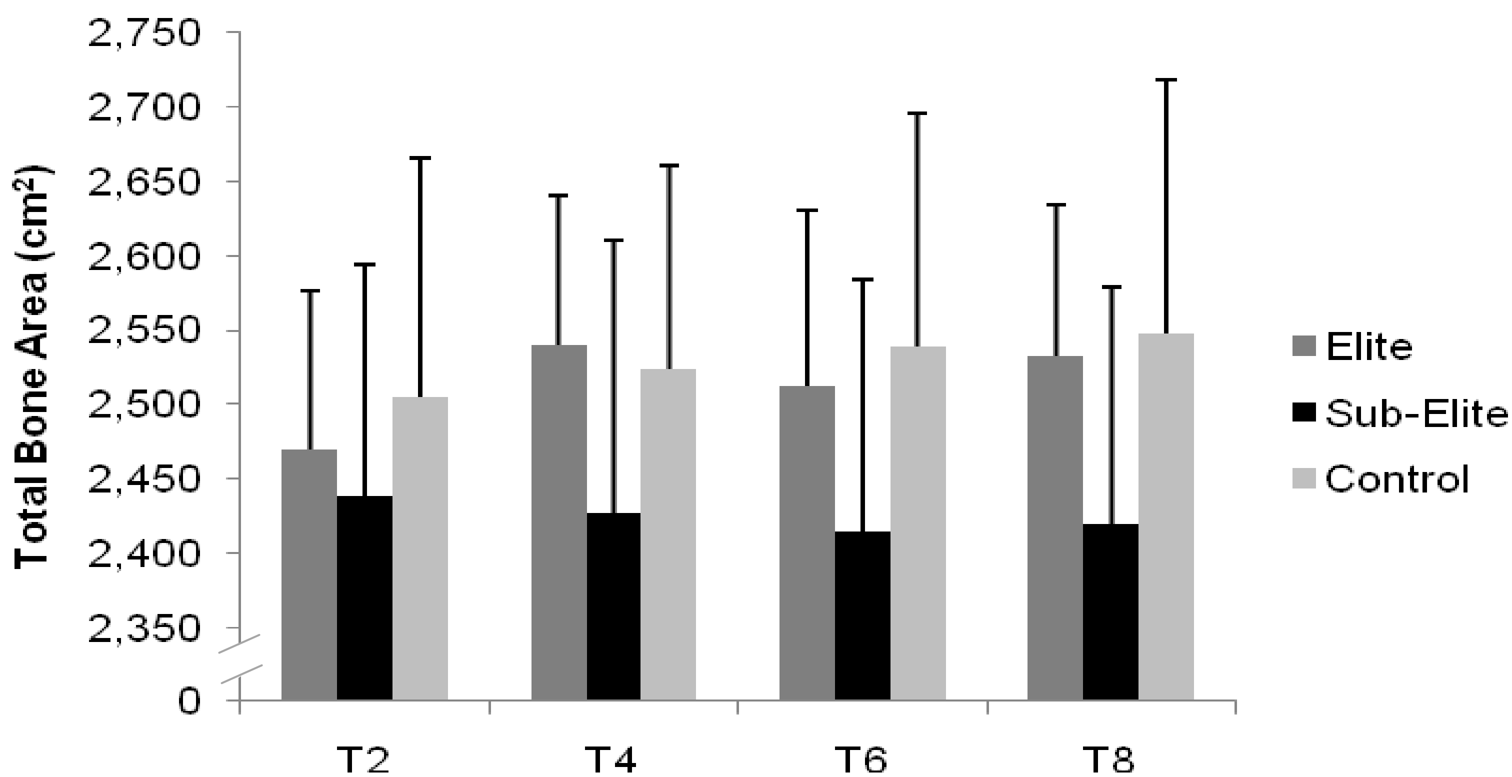

Figure 8.11 Mean (± SD) body composition results across the three playing groups (elite, sub-elite and healthy male controls) for total bone area (cm^2) over two competitive elite junior seasons; Test 1 (December 2007) to Test 8 (September 2009).

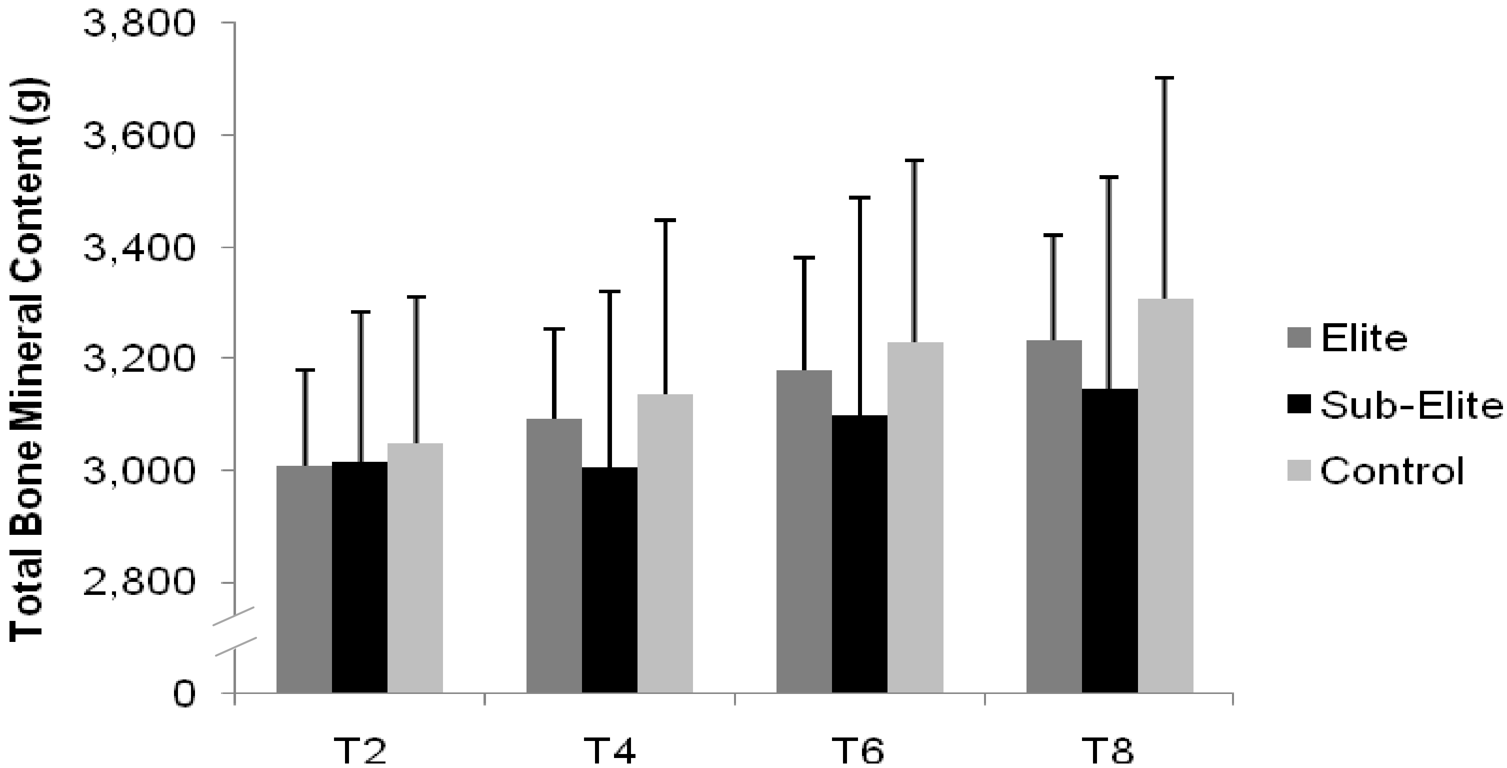

Figure 8.12 Mean (± SD) body composition results across the three playing groups (elite, sub-elite and healthy male controls) for total bone mineral content (g) over two competitive elite junior seasons; Test 1 (December 2007) to Test 8 (September 2009).

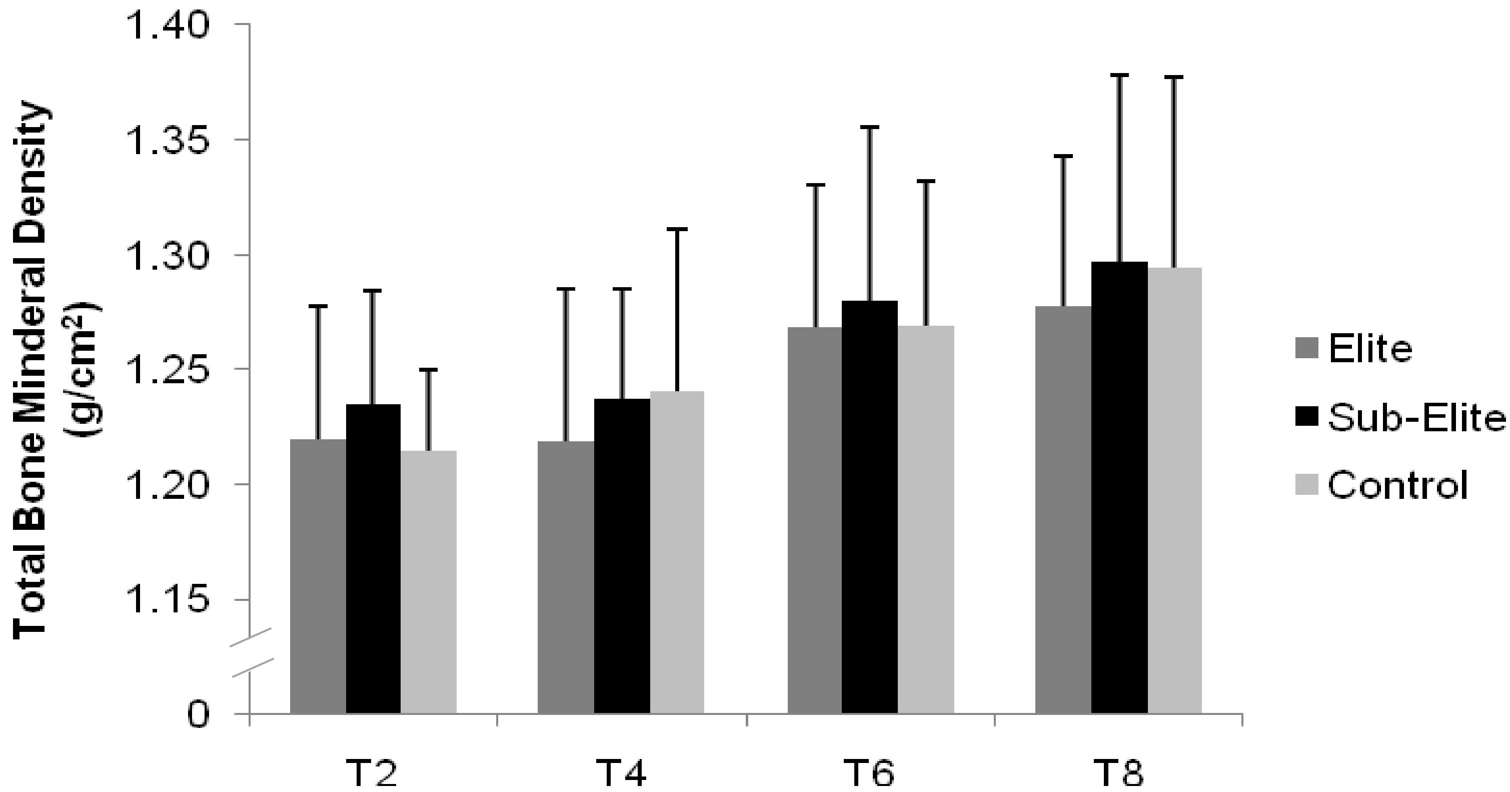

Figure 8.13 Mean (± SD) body composition results across the three playing groups (elite, sub-elite and healthy male controls) for total bone mineral density (g/cm^2) over two competitive elite junior seasons; Test 1 (December 2007) to Test 8 (September 2009).

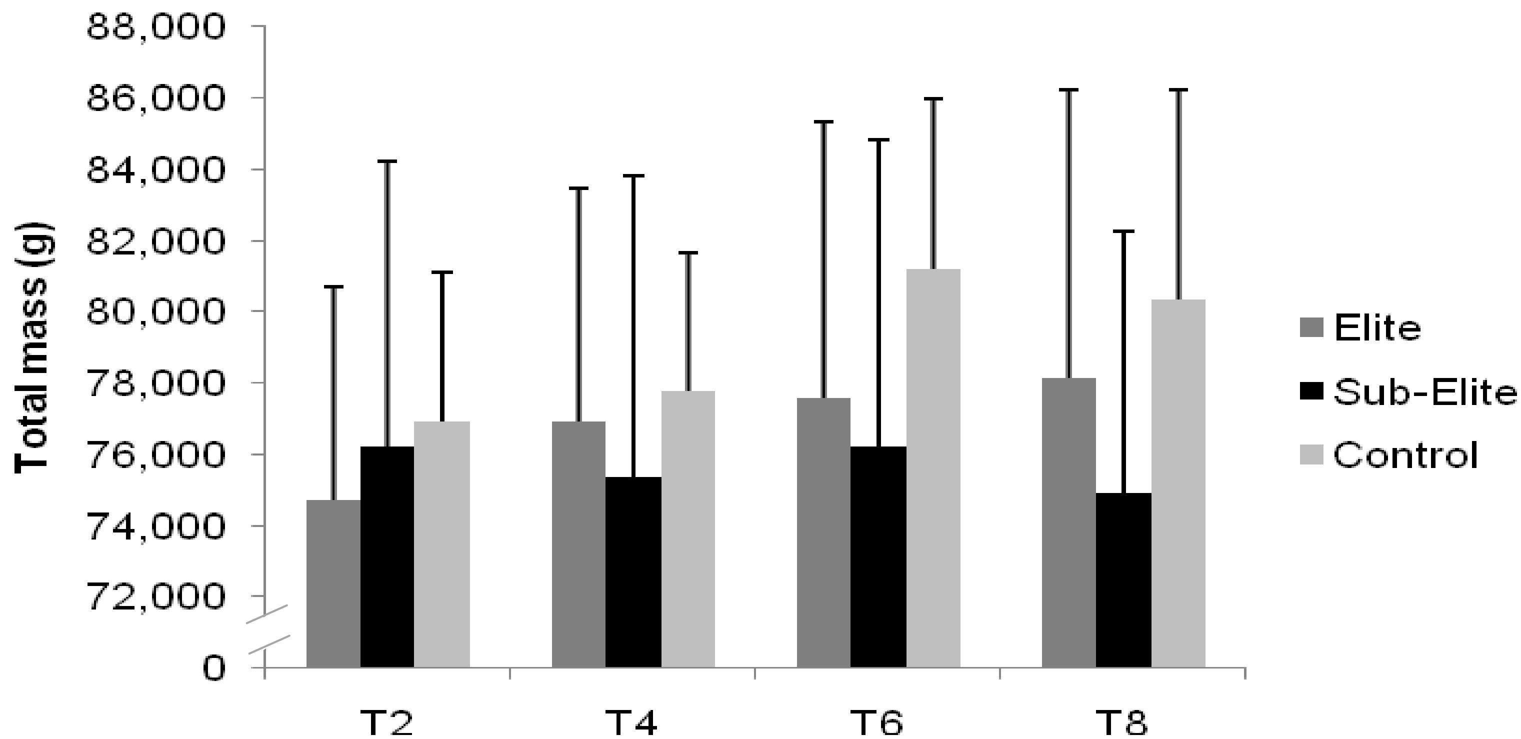

Figure 8.14 Mean (± SD) body composition results across the three playing groups (elite, sub-elite and healthy male controls) for total body mass (g) over two competitive elite junior seasons; Test 1 (December 2007) to Test 8 (September 2009).

Pearson correlation analysis reported moderate relationships between physical test performance and body composition results at each common test point (T2, T4, T6 and T8). Total body mass demonstrated a moderate positive relationship with RVJR height ($r = 0.48$, $p = 0.03$) at T2, as well as with RSAT 20 m, 30 m, F10 m total times ($r = 0.46$, $r = 0.49$ and $r = 0.52$ respectively, $p \leq 0.05$), RAT 10 m split time ($r = 0.44$, $p \leq 0.05$) and YO-YO level and distance ($r = 0.48$ and $r = 0.48$ respectively, $p \leq 0.05$) at T6.

Total and percentage body fat measures demonstrated moderate relationships with a variety of physical measures over the duration of the study. At T2, a negative relationship was observed between total body fat and RVJL height ($r = -0.44$, $p < 0.05$) and YO-YO level ($r = -0.46$, $p < 0.05$) and distance ($r = -0.47$, $p < 0.05$). In direct comparison, positive relationships between percentage body fat and RVJL height ($r = 0.43$, $p < 0.05$) and YO-YO level ($r = 0.54$, $p < 0.05$) and distance ($r = 0.54$, $p < 0.05$) was observed at the same time period. At T6, positive relationships were recorded between the body composition variables of total body fat and percentage body fat and the physical measures of RSA test 30 m total times ($r = 0.65$, $p \leq 0.01$ and $r = 0.54$, $p < 0.05$ respectively) and RAT total time ($r = 0.47$ and $r = 0.44$ respectively, $p < 0.05$). Furthermore, a positive relationship was demonstrated between percentage body fat and RVJR ($r = 0.61$, $p = 0.02$) in T8.

Total body lean mass also recorded positive relationships with the physical variables of RVJR height ($r = 0.512$, $p = 0.02$) at T2, SVJ height ($r = 0.51$, p =

0.03) at T4 and YO-YO level and distance ($r = 0.49$ and $r = 0.\ 49$ respectively, $p < 0.05$) at T6. Lean mass as a percentage of total body mass demonstrated a positive relationship with RVJL height ($r = 0.44$, $p = 0.04$), YO-YO level and distance ($r = 0.51$ and $r = 0.52$ respectively, $p < 0.05$) at T2 and SVJ height ($r = 0.52$, $p = 0.03$) at T4. At T6, positive relationships were also demonstrated with RSA test 30 m total time ($r = 0.57$, $p < 0.05$) and with RAT total time ($r = 0.44$, $p \leq 0.05$).

Elite Junior to Senior AFL progression

Over the duration of the study, there was movement between playing levels across the three playing groups (Table 8.3). At the conclusion of the study, eleven of the fifty-seven athletes (19%) were drafted into the elite AFL competition, comprising participants from both the elite and sub-elite playing groups. Across all three groups, 37% did not attain the same level of competition after two years in the U18 competition as to where they were classified when they entered the system, whilst 25% showed improvements. Of the elite playing group, 44% did not participate at the elite level again after the U16 championships. Whilst 48% of sub-elite athletes did not receive another trial invitation, 33% did play at a higher level. Of the control athletes, only 10% made it to state level competition by the end of their junior career, though no members of this group were drafted into the elite AFL competition.

Table 8.3 Participation numbers of athletes at each level of competition across the longitudinal study period (2007 [U16] = pre-study competition standard, 2008 [U18] = first year of the study, 2009 [U18] = second year of the study, 2010 [Snr] = senior AFL selection post study).

		AFL	State	Trial	TAC	Local
Elite	2007 (U16)	-	16	-	-	-
	2008 (U18)	-	4	0	12	0
	2009 (U18)	1	8	2	5	0
	2010 (Snr)	6	-	-	-	0
Sub-Elite	2007 (U16)	-	-	21	-	-
	2008 (U18)	-	0	1	20	0
	2009 (U18)	2	5	4	6	4
	2010 (Snr)	5	-	-	-	-
Control	2007 (U16)	-	-	-	20	-
	2008 (U18)	-	0	0	20	0
	2009 (U18)	0	2	4	10	4
	2010 (Snr)	0	-	-	-	-

8.4 Discussion

This study focused on the physical development (via a physical test battery and body compositional analysis) of talented junior AF athletes participating in one state based U18 development competition; a common pathway towards AFL participation. The aim of this research was to evaluate the ability of a newly designed physiological test battery to measure change and to discriminate performance abilities between different athletic playing standards. Despite reporting limited significant differences in test performances between the three playing groups, moderate to large effect sizes demonstrated the importance of longitudinal physical analysis when identifying potential future AFL athletes. Furthermore, in-depth body composition analysis identified relationships between the variables of, and not limited to, absolute body fat and lean mass and physical test performance, building on current subjective observation of the optimal AF athlete prototype. Nevertheless, due to a decline in population numbers in the later stages of the study duration, care must be taken when interpreting the strength of the research findings.

Longitudinal physiological performance profiling

Seasonal variations in fitness levels have been reported across elite level Gaelic footballers (Reilly & Keane, 1999), professional soccer players (Thomas & Reilly, 1979; Brady *et al.*, 1995; Ostojic, 2003; Aziz *et al.*, 2005a; McMillan *et al.*, 2005a) and in junior hockey players (Elferink-Gemser et al., 2006). Reporting peak test results at different points of the season and similarities to previous research, reactive agility measures were commonly best at the end of the pre-season training phase or mid-year, RSA (Reilly & Keane, 1999; Ostojic, 2003; Aziz *et al.*, 2005a) and power (Aziz *et al.,* 2005a) measures were best at the end of the season, whilst endurance performance was commonly superior at the end of the pre-season training phase (despite peaking at the start of the pre-season training program of the second year [Krustrup *et al.*, 2003; Aziz *et al.*, 2005a; McMillan *et al.*, 2005a; Krustrup *et al.*, 2006a]) Furthermore, test performances across the three playing groups were commonly superior during the second competitive season in comparison to the first (Elferink-Gemser *et al.,* 2006), with the elite and sub-elite groups often recording the greatest performance improvements.

Between groups analysis commonly demonstrated superior RAT and endurance test performances by the elite and sub-elite playing groups in comparison to the control athletes, while the RSA test also discriminated superior performances by the elite playing group. In comparison to their sub-elite counterparts, the elite athletes showed a tendency to produce superior test performances within the RAT (Sheppard *et al.,* 2006) and RSA test (Reilly *et al.*, 2000b), with similar test results recorded between the two groups across the power and endurance measures. These practical differences and performance trends suggests elite junior AF athletes may be distinguished from age matched counterparts by their superior ability in reading and reacting to the movement patterns of their opponents (Pyne *et al.*, 2005;Sheppard *et al.,* 2006; Young &

Pryor, 2007), as well as the capacity to repeat short distance high intensity sprint efforts; thus withstanding fatigue (Reilly *et al.*, 2000b).

Furthermore, both elite and sub-elite athletes covered greater distances within an endurance measure in comparison to the control group, suggesting endurance is a secondary physical characteristic capable of discriminating between different levels of football ability (Pyne *et al.*, 2005; Young & Pryor, 2007). Nevertheless, lower endurance performance within the elite group at the completion of the study suggests further research is required to measure the relationship between physical test performance and training and playing loads exposed to junior athletes at various levels of competition. With large distances covered during an AF game (Dawson *et al.,* 2004; Veale *et al.,* 2007), optimal endurance performance is required during a finals campaign (located at the end of the season). Subsequently, poor endurance test performance may suggest a negative impact to the demands of a season, resulting in decreased game day performance and potentially impacting on subsequent selection (drafting) into the elite senior AF competition.

In light of recent evidence to suggest the increasing speed and tempo of AF (Norton *et al.*, 1999; Pyne *et al.*, 2005; Gray & Jenkins, 2010) and the developing importance placed on a high number of repeated sprint efforts (Fitzsimons *et al.*, 1993; Bishop *et al.*, 2001; Dawson *et al.*, 2004b; Oliver *et al.*, 2009; Gray & Jenkins, 2010), this physical test battery demonstrated further evidence towards these characteristics deemed important in the modern versions of AF. Furthermore, with research reporting varied responses to the ability of lower limb power via vertical jump measures to discriminate within the AF population (Keogh, 1999; Pyne *et al.*, 2005; Young & Pryor, 2007; Veale *et al.*, 2008), this study also supports the need for caution when using this measure as a marker of football ability. However, the lack of traditional significant differences between physical test performances of the three playing groups over the eight testing sessions suggests care is still required when analysing the true discriminative ability of results from one-off physical test batteries (Thomas & Reilly, 1979; Brady *et al.*, 1995; Reilly & Keane, 1999; Dunbar, 2002; Aziz *et al.*, 2005a; McMillan *et al.*, 2005a). As such, further longitudinal AF research is necessary to analyse the discriminative and predictive ability of other characteristics (technical, tactic, psychological) in the AF TID process (Reilly *et al.*, 2000b). In addition, whilst this research focused on measuring physiological development within an AF specific field test battery designed to replicate game day movement patterns, a test for strength was not included. To date, strength testing within AF research has been limited to the implementation of non-specific muscular function tests (Keogh, 1999& Young *et al.,* 2005). Consequently, future research exploring new test protocols to measure upper and lower limb strength via movements specific to AF activities is required.

Body Composition Analysis

Whilst continued attention is directed towards the use of physical fitness tests to measure the physiological attributes of talented athletes, limited research has been conducted to identify the ‘shape’ or body composition of junior AF athletes (Nevill *et al.,* 2009). Within this study, between groups analysis demonstrated the elite and sub-elite playing groups were lighter in total body mass, had less total body fat and greater lean mass as a percentage of total body mass than their control group peers on each of the four testing occasions. On the other hand, the elite playing group commonly demonstrated greater total body mass, absolute lean mass and percentage body lean mass, as well as less fat mass than their sub-elite peers. Furthermore, during the second competition season (when all athletes were available for selection [drafting] into the AFL), the elite playing group demonstrated the greatest differences in total body lean mass and fat mass when compared to their sub-elite peers (Davis *et al.*, 1992; Reilly & Keane, 1999; Ostojic, 2003), supporting the link between greater muscular development and maintaining higher competitive performance standards (Thomas & Reilly, 1979).

Across the competitive team sport environment, athletes with lower body fat have been linked to superior sprint and endurance performance (Thomas & Reilly, 1979; Ostojic, 2003). Reporting similar findings over the study duration, correlation analysis reported a negative relationship between absolute and percentage body fat results and physical test variables for power and endurance (Thomas & Reilly, 1979) and a positive relationship between RSA (Ostojic, 2003) and reactive agility performance. In contrast, positive relationships were measured between the test variables of reactive agility, RSA, power and endurance and absolute and percentage lean mass. Subsequently, a trend towards the development and selection of leaner athletes is suggested at higher levels of competition, with these athletes holding a greater advantage towards using their lean mass for superior physical performance (Naughton *et al.*, 2000; Reilly *et al.*, 2000a; Reilly *et al.*, 2000b; Nevill *et al.*, 2009). Furthermore, a consistent growth in total body BMC and BMD across the three playing groups was demonstrated. Whilst it could be suggested that an increased training and competition history had a positive effect on the bone development of junior AF athletes (without discounting the effect of individual maturation rates [Slemenda & Johnston, 1993; Wittich *et al.*, 1998; Veale *et al.*, 2010a]), further research comparing AF athletes to a non sporting population group is still required. Furthermore, whilst this study was limited by not directly measuring each athletes maturation state (Vaeyens *et al.,* 2006), future research over a larger population sample and a longer study period is required to understand the extent of individual maturation and sport participation on physical growth and development (Vaeyens *et al.*, 2006; Mohamed *et al.*, 2009).

<u>Limitations</u>

Over the course of this longitudinal study, scheduling of training and major competitions (Reilly & Keane, 1999; Aziz *et al.*, 2005a), seasonal training load (Dunbar, 2002) and injuries (Thomas & Reilly, 1979; Reilly & Keane, 1999; Dunbar, 2002; Aziz *et al.*, 2005a; McMillan *et al.*, 2005a) were found to impact on the participant numbers during each testing session. As a consequence, a major limitation to our research was the small sample sizes measured in the later stages of the second competitive season. The trends reported within this study must therefore be read with caution as performances across each variable and testing session may have been influenced by physical condition, injury or the stage of recovery of each participant. Larger sample sizes at the outset of future research would enhance the likelihood of greater retention rates over a similar time duration, however such research will always be limited by injury rates and drop-out within the AF talent pathway.

In a similar scenario to the study by Aziz *et al.,* (2005a) our research was limited to the inclusion of athletes across a number of teams in the same competition, with an inability to document in detail the type, frequency and intensity of training sessions undertaken throughout the study period. Future research controlling the training activities of participants within the AF talent pathway or linking training loads to physical performance outcomes would further enhance the knowledge and understanding of how much training is enough to promote performance gains and how much is potentially too much and resulting in physical setbacks (injury or illness etc.). Nevertheless, the results of our study indicate the importance of conducting longitudinal research at the junior competition level, identifying key developmental performance trends based on talent and selection into representative squads. Furthermore, interdisciplinary (technical, tactical, physiological, psychological) research is required to accurately determine the role of physiological profiling in providing a comprehensive perspective on future talented AF athletes (Reilly *et al.*, 2000b).

CHAPTER 9

DISCUSSION

The history of research within Australian Football

Australian football (AF) is the most popular football code in Australia (Gray & Jenkins, 2010), combining the physical facets of agility, speed, power and endurance with technical, tactical, anthropometric and psychological attributes towards successful game day performance. With the increased pressure on the early identification and selection of talented athletes at a young age (Reilly *et al.*, 2000b; Elferink-Gemser *et al.*, 2006), the importance of longitudinal research within AF has become increasingly apparent. Presently, the sport of AF is scientifically under-researched, with the fields of fitness, physiological testing and game analysis making up only a small proportion of the published literature (Gray & Jenkins, 2010). Recent evidence documenting the changing nature of AF (Gray & Jenkins, 2010) and the absence of longitudinal research, coupled with questions over the specificity of currently used field tests (Young & Pryor, 2007), has highlighted the need for new research into the use of physiological testing within the AF TID pathway. Therefore, the purpose of this longitudinal thesis was to create an AF specific physiological test battery (via individual test reliability and validity analysis) and measure its capacity, in conjunction with body composition screening, to discriminate performance abilities between junior AF athletes.

The role of Reactive Agility within Australian Football

Commonly defined as an individual's ability to change direction whilst at speed (Draper & Lancaster, 1985; Young *et al.*, 2002; Sheppard & Young, 2006), agility is now regarded to be more complex in nature, incorporating neuropsychological factors including anticipation (Williams *et al.*, 1994; Williams, 2000), intuition (Williams *et al.*, 1994), sensory-processing (Williams, 2000) and decision making (Farrow & Abernethy, 2002; Vaeyens *et al.,* 2007); with physiological factors such as response time (Farrow *et al.*, 2005; Sheppard *et al.*, 2006; Gabbett & Benton, 2009), acceleration and maximum speed (Young *et al.*, 2001c; Sheppard *et al.*, 2006), COD speed and mobility (Sheppard & Young, 2006). To date, the AF TID research has commonly utilised a closed skill COD test, with recent research questioning its specificity to the movement patterns of modern AF (Young & Pryor, 2007). Therefore, expanding on a recently designed RAT (Sheppard *et al.*, 2006; Gabbett *et al.*, 2008b), this thesis systematically tested the reliability (test-retest) and construct validity (known group difference method) of a novel RAT specific to the elite junior AF population. Not only did the test avoid the occurrence of a learning effect via 'test practice', it successfully discriminated superior performance results between AF athletes and an aged matched non-AF population, as well as between elite and sub-elite AF groups. Consequently, future agility testing within AF should incorporate perceptual processes with the physical demands of COD ability.

The importance of Repeated Sprint Ability, not just speed, within Australian Football

Speed has also been demonstrated as a fundamental component of athletic ability, with SSE speed discriminating in both team selection (Pyne *et al.*, 2005; Young *et al.*, 2005; Pyne *et al.*, 2006; Veale *et al.*, 2008) and selection (drafting) into the AFL (Pyne *et al.*, 2005). Nevertheless, despite recent game day analysis reporting the increasing speed and tempo of AF (Norton *et al.*, 1999; Pyne *et al.*, 2005; Gray & Jenkins, 2010) and the developing importance placed on a high number of repeated sprint efforts (Fitzsimons *et al.*, 1993; Bishop *et al.*, 2001; Dawson *et al.*, 2004b; Oliver *et al.*, 2009; Gray & Jenkins, 2010), limited research has been conducted using a RSA test within the sport of AF. With research documenting the complexity of RSA test performance and the potential for 'pacing' to impact and detract from reaching true maximal performance in a single sprint within a RSA test protocol (Psotta & Bunc, 2005), this thesis focused only on RSA total test performance. Whilst a variety of running RSA test protocols have been implemented across the sporting environment (Dawson *et al.*, 1998; Lakomy & Haydon, 2004; Dupont *et al.*, 2005; Psotta & Bunc, 2005; Hughes *et al.*, 2006; Oliver *et al.*, 2006; Rampinini *et al.*, 2007; Oliver *et al.*, 2009), this thesis demonstrated the ability of a RSA test protocol to discriminate between junior AF and their age-matched non-AF peers, whilst also reporting a practical difference between junior AF athletes based on competition standard (elite vs. sub-elite). With further evidence to suggest recording split times during the RSA test can discriminate between the qualities of acceleration speed, maximal speed and speed endurance, this protocol demonstrated the ability to provide important information relevant to AF at the elite level. Nevertheless, future longitudinal research is required to assess the amount and rate of change in maximal SSE performance over similar longitudinal study durations.

Vertical jumping ability as a measure of power

Discriminating AF from the other football codes, lower limb power via jumping height is commonly performed from a running and standing position during AF game day activities (needed to out mark or spoil an opponent, as well as contesting ruck duels [Keogh, 1999; Saliba & Hrysomallis, 2001]). Despite being categorised as a secondary physical attribute toward successful AF performance and reporting varying levels of discriminatory success (Keogh, 1999; Pyne *et al.*, 2005; Pyne *et al.*, 2006; Young & Pryor, 2007; Veale *et al.*, 2008), this thesis recorded a positive use of vertical jump testing within the AF TID process. Not only did RVJ height discriminate AF athletes from their non-AF age-matched peers, but smaller levels of asymmetry were demonstrated by the elite athletes in comparison to their sub-elite counterparts. Furthermore, with the elite athletes performing significantly better on the SVJ test in comparison to all other participants, the vertical jump tests successfully demonstrated the importance of lower limb power and symmetry within elite junior AF athletes.

The use of an Intermittent Recovery Test to measure Aerobic Capacity

Intermittent movement patterns and the ability to repeatedly perform intense exercise are also key components of team-based ball sports, requiring athletes to maintain well-developed aerobic and anaerobic energy systems (Reilly, 1997; Reilly *et al.*, 2000a; Krustrup *et al.*, 2003; McMillan *et al.*, 2005b; Bangsbo *et al.*, 2006; Castagna *et al.*, 2006; Thomas *et al.*, 2006). Linked with game-related work-rates and recovery from high-intensity intermittent activities (Bangsbo & Lindquist, 1992; Reilly, 1997; Impellizzeri *et al.*, 2005; Impellizzeri *et al.*, 2006), to date aerobic performance has commonly been measured via continuous exercise tests (MSFT, time trials) within the AF research (Keogh, 1999; Pyne *et al.*, 2005; Pyne *et al.*, 2006; Young & Pryor, 2007; Veale *et al.*, 2008). With recent advances in field tests that increase the sport specificity and validity when measuring an athlete's ability to repeatedly perform intense exercise and their capacity to recover (Bangsbo, 1994a; Krustrup *et al.*, 2003; Thomas *et al.*, 2006), this thesis demonstrated the discriminative ability of an intermittent recovery test within the AF talent pathway (Young *et al.*, 2005).

Body Compositional analysis via Dual energy X-ray absorptiometry

Furthermore, with research to date within the sport of AF limited to the measurement of common body composition variables (height, mass, skinfolds [Keogh, 1999; Pyne *et al.*, 2005; Young *et al.*, 2005; Pyne *et al.*, 2006; Young & Pryor, 2007; Veale *et al.*, 2008]), only basic comparisons have been reported between junior and senior athletes (Keogh, 1999) or in documenting field specific profiles (Pyne *et al.*, 2006; Young & Pryor, 2007). As a consequence, the current use of body composition analysis within the TID process is limited to simple face value appraisal (Chaouachi *et al.,* 2009; Nevill *et al.,* 2009). Utilising common DEXA methodology (Calbet *et al.*, 1998; Calbet *et al.*, 2001), this thesis demonstrated trends towards the elite athletes physical profile comprising a greater percentage total body mass of lean mass and a lighter absolute and percentage of total body mass of fat mass. Moreover, whilst junior athletes were found to be lighter in total mass, lean mass, BMC and BMD, a linear relationship was demonstrated with their senior AF counterparts, highlighting the importance of considering both chronological and training age when developing physical expectations for junior athletes (Mujika *et al.,* 2009).

Longitudinal research into the development of physiological and anthropometric attributes necessary for Australian Football.

Consequently, in the absence of longitudinal AF research, this thesis measured the physical development of elite junior athletes across an AF specific test battery and body compositional analysis at regular intervals over two consecutive seasons. Over the duration of the research, the physical attributes of reactive agility, RSA, power and endurance demonstrated the ability to measure performance changes and physiological trends of junior AF athletes of various playing standard. Reporting small to large ES differences between three playing groups (elite, sub-elite and control), the elite athletes consistently demonstrated superior test performances in RAT and RSA test abilities, highlighting the importance of these characteristics in discriminating between talented junior AF athletes. Furthermore, correlations were reported between body composition variables and physical test performance, with an increased fat weight negatively affecting physical test performance. With the elite group demonstrating superior lean mass as a percentage of their total body mass in the final year of an elite junior career, a trend towards the development and selection of leaner athletes was suggested at higher standards of AF competition (Naughton *et al.*, 2000; Reilly *et al.*, 2000a; Reilly *et al.*, 2000b; Nevill *et al.*, 2009).

Nevertheless, over the study duration, five athletes (24%) from the sub-elite and two athletes (10%) from the control group improved to the playing standard of the elite group, whilst twelve of the sixteen (75%) elite athletes reached this same level of competition. At the conclusion of the first season of the study, three athletes were successfully selected into the AFL, with two making their senior debut in the following year. In addition, at the conclusion of the second season of this study, a total of 11 athletes (19%) had been selected into the senior AFL competition, with a relatively even number from the elite and sub-elite groups. Therefore, whilst it is difficult to predict who will ultimately reach elite senior status, trends within this study suggest that being identified at the U16 level as a talented AF player, irrespective of successful selection into the final representative squad, places an athlete at a greater advantage of selection into future elite junior representative teams (U18) and even into the senior AFL. However, showing similarities to previous research involving elite level junior hockey players (Elferink-Gemser *et al.,* 2006), 44% of elite and 67% of sub-elite AF athletes were not able to reach the same level of competition within their final year in the elite junior talented pathway, suggesting early state representative selection was no guarantee of success in this cohort.

As within previous TID and longitudinal research within the team sport environment, care must be taken when interpreting the extent of the performance outcomes documented within this thesis in light of the impact of training and major competitions (Reilly & Keane, 1999; Aziz *et al.*, 2005a), as well as injuries (Thomas & Reilly, 1979; Reilly & Keane, 1999; Dunbar, 2002;

Aziz *et al.*, 2005a; McMillan *et al.*, 2005a) on participant numbers. Nevertheless, the results indicate the importance of conducting longitudinal research at the junior competition level in comparison to one-off physical test batteries. As such, future research using a larger sample size of athletes nationwide would enable greater in-depth analysis of variations in performances to be investigated. Furthermore, a larger sample size will also improve the body compositional profiling of athletes within the AF TID pathway (Gabbett, 2000; Reilly *et al.*, 2000a; Gabbett, 2002b, a, 2005; Pyne *et al.*, 2006; Chaouachi *et al.*, 2009; Gabbett *et al.*, 2009; Sutton *et al.*, 2009), expanding on the trends shown within this thesis.

In addition, this study was also limited by not directly measuring each athletes maturation state (Vaeyens *et al.,* 2006) or the influence of chronological age and birth date (Hirose, 2009; Mujika *et al.,* 2009) on physical development or performance. Current research suggests the effects of individual maturation are strongly related to anthropometric characteristics (Beunen *et al.,* 1978), whilst births in the early part of the selection year place an athlete at a physical advantage with respect to body size and biological maturation (Helsen *et al.*, 2000; Hirose, 2009). Therefore, future research employing an indicator of maturation, such as a 'maturation offset' (Mirwald *et al.,* 2002; Mohamed *et al.,* 2009), would offer a more in-depth analysis of changes in body composition within this age group, providing a valuable insight into when the greatest rate of change occurs (Vaeyens *et al.*, 2006; Mohamed *et al.*, 2009). Nevertheless, the nature of elite junior AF is such that athletes commonly enter this development competition without participating in a structured AF pre-season program or strength training activities. As such, it would be expected, irrespective of changes due to maturation, that differences in body shape and composition would occur over the proceeding two AF seasons, highlighting the importance of assessing athletes on an individual case by case bases (Hirose, 2009).

Conclusion

For the first time, this study identified trends within the development of different physical characteristics of AF athletes over the course of their final years within an elite junior competition. Between groups analysis identified trends between physical performance outcomes and body composition profiles of three different population groups (based on talent and selection into representative squads). From these results, it can be suggested that an earlier demonstration of superior performance within reactive agility, RSA and endurance measures, in conjunction with their continued improvements, will place a junior athlete at a greater chance of being selected into a higher standard of senior AF competition. However, the absence of statistically significant differences in physiological attributes between talented junior AF athletes highlights the need for future longitudinal research into the role of other characteristics (technical, tactical, psychological) important in successful TID and progression into the elite senior sporting ranks (Reilly *et al.*, 2000b).

Practical Implications

- When training and testing the physical component of agility with Australian Football, it is important to include reactive elements in an open planned environment (e.g. other athletes, use of the football and use of vocal cues).
- Repetitive running and sprinting efforts are important in building the sport specific components of repeated sprint ability and aerobic capacity, both necessary for athletes to compete at the highest level of Australian Football.
- Maximising training performances in the first season of an U18 career is vital in light of the greater significant improvements in physiological test performance and anthropometric development achieved during this season compared to the next.
- Barriers to continued body composition development in an athlete's final junior season must be addressed in light of the significant differences between junior and senior athletes.
- Greater body compositional analysis on junior athletes is vital in determining the development and readiness of athletes to train and compete at the elite senior level.
- Whilst physiological and anthropometric testing does distinguish between the athletic potential of different playing groups, these tests alone are not solely capable of determining an athlete's selection potential into the elite AFL and must be accompanied by research into other abilities (technical, tactical etc.).

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