Introduction and Overview

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Investment in team sports performance, and in particular soccer, is substantial, with player salaries alone costing some soccer clubs in millions of dollars annually (www.transferleague.co.uk, 2011). Financial investment in sports science for team sports lags behind player salaries. This is despite the importance placed on decreasing team injuries and player availability for matches.

From a scientific perspective, the strongest form of argument for implementing appropriate practice is evidence based. However, implementing sound sports science practice based on robust scientific rigour has been traditionally difficult. The reasons for this are understandably numerous. Sports science and in particular general fitness principles (training 'fads', diets, training equipment etc) have evolved from marketing power and commercial success rather than from research. Additionally, teams implementing 'successful' sports science principles have been reluctant to publish details due to the highly competitive nature of professional team sports. The majority of existing sports science research is arguably laboratory-based and the transfer of results to applied settings is often problematic. In fact, in most cases transferring laboratory-based results to applied team sports settings removes the validity accrued through the removal of the controlled environment. Finally, the evidence that remains transferrable to an applied environment might be difficult to introduce into team sports due to possible conflicts with traditional practice or managerial/coach philosophy.

Resources directed into sports science remain largely focussed on elite level teams. This philosophy is possibly short-sighted. Re-allocation of focus into the next generation of elite level players can provide more robust investments in future talent. Greater scientific support for youth development would also allow these young players to become more aware of appropriate practice as they progress through the various talent pathways. An emphasis on player education from a young age is postulated to produce more independent elite players.

Available technology has been predominantly utilised to describe movement patterns within team sports. Once acceptable reliability and accuracy have been established, broader application of these technologies is encouraged. Several domains such as injury prediction, tactical analysis and talent development remain 'under-researched', yet feasible applications of tracking technology. In particular, promoting longevity of players and talent development should be a primary, rather than secondary use of resources. Understanding the unique physical needs of aspiring elite players will greatly assist strategies for improved talent development and player longevity.

There is a clear discrepancy between the physical, emotional, and psychological requirements of elite and aspiring elite team sports. Sports scientists can assist in quantifying and understanding this gap. Once the gap is understood, the challenge is to prescribe appropriate evidence-based methodologies and programs to reduce this gap or, perhaps more appropriately, successfully navigate it. Creating benchmarks for a smooth transition into elite level play will assist coaching at all levels.

1.1 Rationale

The three original research publications were founded on an extensive review of the team sport talent development literature. This published review is presented as Part 2 of the Literature Review.

Essentially the rationale behind these publications argued that

1. Sports science, and the appropriate application of technology, can be useful for team sports to improve player longevity, enhance physical performance and prevent injury.
2. Scientific-based evidence of player demands can be a worthwhile addition to existing measures of talent identification and development
3. Applications of recent technologies will strengthen the evidence base required for improved performance, appropriate transitions, and player longevity for team sports

Each of the publications sought to add to existing knowledge and provide applied evidence to guide practitioners toward appropriate use of portable tracking technology in a team sports environment. Specifically, these publications attempted to reveal:

1. how objective data could assist current Talent Development practices, specifically in AF
2. updated knowledge on match intensities in the Australian domestic soccer competition and provide direct comparisons between this league and international competitions
3. the match loads U18 AF players are exposed to. Once established, these could then be compared to senior AF match intensities across time to identify any comparison trends
4.

1.2   Aims

The overall aim of this body of work is to examine the efficacy of tracking technology to assist in talent development of team sports players. Specifically, the projects focussed on identifying the discrepancies between elite competition in team sports and those aspiring to be elite.

A primary aim of Study 1 was to determine the gap between top level soccer in Australia and various international competitions. Most Australian soccer players aspire to play professionally in various European competitions, so quantifying this gap would enable players to understand the physical and tactical differences between playing domestically and abroad. Additional aims of this study were to profile the movement demands of Australian soccer, comparing positional requirements as well as any decrease in intensity between first and second half of play.

Study 2 profiled the game demands of Under 18 AF and Senior AF across two timespans, 2003 and 2009. The aim of this study was to compare the trends in match movement profiles and game speeds across time between Under 18 and Senior AF.

The purpose of Study 3 was to determine associations between five year career success as well as injury rates in the AF and physical draft camp tests, final draft selection order and previous match physical performance.

1.3   Hypothesis

General hypothesis – advanced player and game movement technologies will provide useful information for sports scientists, coaches and player development managers in team sport

Specific hypotheses:

Study 1: High speed running requirements in Australian soccer matches would be less than those of international matches. Total distances travelled in matches between Australian players and their overseas counterparts were expected to be similar.

Study 2: Under 18 AF physical match requirements would be less than Senior AF requirements at both 2003 and 2009 time slices. Senior AF match intensities would increase between 2003 and 2009 at a greater rate than Under 18 levels.

Study 3: The draft order will have good predictability of early career success in AF. Adding objective data to traditional talent identification practice would improve prediction of five year career success in AF.

1.4   Limitations
Limitations are factors and conditions outside the control of the researcher. The following key limitations for the research conducted in this thesis were identified

- The technology available during the time of Study 1 was limited to Computer Based Tracking (CBT). The thesis was conducted on a part time basis and as such, technology available at the start of the candidature has changed markedly. Therefore, during the first study, the software was limited to Trak Performance Software, (Sportstec, Australia). It has established construct validity with other measures of movement (Edgecomb & Norton, 2006). However, a high level of expertise and intensive time demands are associated with this form of analysis.
- In all three studies, the match conditions, team strategies, injury status, psychological states, nutritional practices and fitness of players remained outside of the control of the research. All of these factors can influence physical exertion in team sports and their influence can be difficult to quantify.
- CBT was again utilised in Study 2 for the 2003 analysis, whereas global positioning satellite (GPS) tracking was used for the 2009 tracking. Although these two devices have been compared (Edgecomb & Norton, 2006), the intermixing of analysis techniques produces some error.

- The physical testing used to compare fitness levels to match physical values in Study 3 were limited to testing protocols and procedures used at the AF draft camp.

1.5 Delimitations

Delimitations refer to aspects of the study within the control of the researcher that may influence the results. The following delimitations for each study were identified:

Study 1

- Much of the analysis was collected on only one ground/field. This was due to practical reasons and ease of access to suitable filming locations for CBT analysis at this venue.
- The comparative international data was limited to data available in the public domain.
- The CBT was deemed acceptable for use in this study, albeit with construct validity external to this study.

Study 2

- Under 18 National Championship matches were used in 2003, whereas AF National U18 Championship competition matches were used for the 2009 analyses. These competitions contained similar level players (with some crossover of players) however, the fact that they are different competitions represents potential error source.
- The number of games/players analysed was limited by both the practical time limits required to collect a large number of match files (Teal Cup) and the number of games available in a tournament scenario (Under 18 Nationals).

Study 3

- The career success in the AF was limited to 5 years due to practical reasons.
- The players selected for the study had to be drafted in 2002 or 2003. This cohort was selected as these were the two years of data available for analysis at the time.

1.6   Definitions

AFL - The Australian Football League.

VFL – Victorian Football League. Previously the premier competition in Australia until it became the AFL in 1996. Now, it is the premier competition in the state of Victoria.

Senior player – AF player playing in the national open age professional AF competition.

Aspiring Senior player – For the purpose of this thesis, an aspiring senior player refers to an AF player playing in either the National Under 18 AFL Championships or the National Teal Cup competition.

Rookie – Player drafted by an AFL club on a trial basis for one season who is unable to play Senior AF.

National AFL Draft Camp (Now called National AFL Draft Combine) – a four day event held annually in October where invited Under 18 players complete physical, anthropometric, psychological and skill-based assessments.

NSL – National Soccer League. The premier soccer competition in Australia until 2006 when the name changed to the A-League.

GPS Devices – Small device worn in between the scapula which uses portable Global Positioning System technology to track movements.

Trak Performance – CBT device involving a scaled version of the field placed on a drawing tablet attached to a laptop computer. The player to be tracked is followed by the researcher around the scaled pitch with the use of a computer sensitive drawing pen.

CBT – Computer Based Tracking.

AFL Draft – Annual event involving all AFL clubs selecting players in a pre-determined order based on previous finishing position and adjusted by player swapping.

Pre-Season Draft – 'Second Chance' Draft occurring approximately 2 months after AFL Draft. In this Draft a minimal number of players can be selected on the Senior AF lists with most being selected as club Rookies.

Sports Scientist – Refers to members of sports science staff working with teams. These could include fitness coaches, strength and conditioning coaches, etc.

Literature Review:

Section 1

2   Literature Review – Section 1

The literature review consists of two sections. The first section will detail the 'Applications of GPS Tracking to a Team Sports Environment' and the second section consists of a published, peer-reviewed invited review titled 'Talent Development in Team Sports: A Review'. GPS tracking was selected for Section 1 of the review as it is currently the most widely used portable tracking device within team sports settings.

Section 1: Applications of GPS Tracking to a Team Sports Environment

2.1   Rationale

Analysis of human movement patterns in sport has occurred for many years. Early pioneers used pen and paper to collect information on player movements and game involvement. More recently, camera-based technology and portable tracking devices have been utilised. Global Positioning System (GPS) technology has also enjoyed widespread growth in the team sports environment over the last decade.

Substantial research has been conducted on the various forms of player tracking that may be applied to team sports. Extensive reviews on match analysis techniques focus primarily on camera-based technology and other automated systems (Barris & Button, 2008; McGarry & Franks, 2003). Recent growth in the use of GPS in team sports has led to a large volume of research describing the use of this technology, the majority of which is reviewed in this section. Given the increasing accessibility to GPS devices, reports of research using GPS devices to measure horizontal movement outcomes have expanded exponentially. However, not all reports of GPS use are novel and discussion on applications beyond quantitative descriptive statistics is limited. A recent review describes the application of this technology to team sports (Aughey, 2011a). The current review offers additional insights into the use of

GPS and in particular, its use in team selection, tactical analysis, injury rehabilitation and talent development.

Accuracy and reliability of GPS technology has been the topic of much research and conjecture (see Section 2.2). It is important for practitioners to understand limitations of the technology and work within these parameters. It is also important for researchers to report reliability within each study to enhance sport scientists' understanding of the error associated with each result.

This review provides some detail on the extensive reliability research available on GPS (Section 2.2). However, the main purpose of the review is to outline the many applications of GPS to a team sports environment. The review will summarise the research, and provide insight into how the research can be applied in this practical environment. Through focussing on potential uses for GPS beyond descriptive statistics, it is hoped the review will demonstrate broader relevance for this technology in the science of sport.

2.2   GPS Accuracy, Reliability and Validity

Initial attempts to establish the accuracy of GPS devices for measurement of human movement were prohibited by the United States Department of Defence who downgraded the accuracy of satellite transmission (Terrier, Ladetto, Merminod, & Schutz, 2000). Once this restriction was withdrawn in 2000, initial GPS devices, albeit impractical at 4 kg in mass, demonstrated reasonable accuracy in velocity estimation (Terrier et al., 2000).

More practical devices were introduced into the commercial market in 2003, and a multitude of research has since attempted to determine the accuracy and reliability of these devices for use in team sports. Initial studies examined devices sampling at 1 Hz (Edgecomb & Norton, 2006), with further studies also estimating the accuracy and reliability of 5 Hz (Coutts & Duffield, 2010; Duffield, Reid, Baker, & Spratford, 2009b; MacLeod, Morris, Nevill, & Sunderland, 2009) and current devices sampling at 10 Hz GPS (Castellano, Casamichana, Calleja-Gonzalez, San Roman, & Ostojic, 2011b).

Logically, devices measuring at higher sampling rates will provide greater accuracy for distance estimation. To date, this assumption has been demonstrated in the research, with

Standard Estimate Error (SEE) for distances of 1 Hz devices being higher than 5 Hz (32.4% compared to 9%) (Coutts & Duffield, 2010; Duffield et al., 2009b; Jennings, Cormack, Coutts, Boyd, & Aughey, 2010a), and SEE for total distance using 5 Hz devices being considerably higher than 10 Hz devices (Castellano et al., 2011b). Although these studies used slightly different methodologies, an increase in sampling rate appears to improve accuracy of distance estimation. The reliability of devices also seems to be affected by sampling rate with 10 Hz devices showing superior reliability over 5 Hz devices across a range of team sports-specific distances and speeds (7.1% v 3.6%) (Jennings et al., 2010a; Petersen, Pyne, Portus, & Dawson, 2009a; Portas, Harley, Barnes, & Rush, 2010).

Velocity accuracy of GPS devices has also been estimated. The devices appear to be less accurate and less reliable as velocity increases, with sampling rate having only a minor effect on accuracy (Jennings et al., 2010a; Petersen et al., 2009a). Increased inaccuracy is problematic given the high velocities associated with team sport activity. Interestingly, across a range of velocities, GPS devices appear to be more accurate as the duration of the activity increases (Jennings et al., 2010a; Portas et al., 2010). This is perhaps because over the course of prolonged activity, the total magnitude of discrepancies may be reduced due to the multitude of samples being taken.

Many issues need to be considered when evaluating the reliability and accuracy of these devices for use in team sports. Most importantly, the issue of criterion-related validity in identifying which instruments the devices should be compared against when estimating the precision of distance and or speeds has recently been raised (Aughey, 2011a). The majority of studies have compared GPS with a combination of timing gates and/or trundle wheels (Barbero-Alvarez, Coutts, Granda, Barbero-Alvarez, & Castagna, 2010; Coutts & Duffield, 2010; Jennings et al., 2010a; MacLeod et al., 2009; Waldron, Worsfold, Twist, & Lamb, 2011). Additional studies have also compared GPS with computer-based tracking (Edgecomb & Norton, 2006), camera-based technology (Harley, Lovell, Barnes, Portas, & Weston, 2011; Randers et al., 2010), custom built speedometers (Witte & Wilson, 2004), and the highly precise VICON biomechanical analysis system (Duffield et al., 2009b).

Although the reliability of devices in team sports has been inconsistent within the literature, the variability associated with two devices attached to the same player during team sports was

estimated at 10% (Jennings, Cormack, Coutts, Boyd, & Aughey, 2010b). This variability compares favourably to between-subject variability for high velocity running in a variety of team sports (Aughey, 2011b; Gregson, Drust, Atkinson, & Salvo, 2010), as well as some reports on the reliability of more accepted forms of player monitoring, such as Heart Rate analysis (Terbizan, Dolezal, & Albano, 2002). However, this GPS variability increased with sprint velocities, particularly when distances included a standing start (Jennings et al., 2010b). Clearly there are some inherent reliability issues within current model, as well as previous GPS devices. Further research is required using precise, standardised methodologies and definitions, in order to establish exact error rates associated with GPS tracking.

The real time or 'wireless' feature of more modern GPS devices contains an option for monitoring physical outputs 'live', using a radio frequency (RF) antenna. The actual or 'raw' logged data can then be downloaded from the device at a later stage. Although initial reliability of wireless data was questionable (Aughey & Falloon, 2010), more recent firmware upgrades have, according to product manufacturers (http://www.catapultsports.com/research-validation), improved discrepancies between wireless and logged data.

The ability of GPS devices to recruit satellites and identify horizontal position has also been examined (Williams, 2009). It appears that time of day and surrounding infrastructure can affect the number of satellites transmitting positional data, which in turn, alters the accuracy and reliability of location (Williams, 2009). This has ramifications for match day collection of information, as stadium infrastructure can clearly restrict access to satellites and therefore, positional accuracy.

An additional feature of recent GPS devices is the introduction of triaxial accelerometry. These accelerometers have a high sampling rate (100 Hz) and the ability to operate both indoors and outdoors. This instrumentation does not rely on GPS satellites for the acceleration information it provides. Rather, it provides both independent information on g-forces associated with player movements as well as being incorporated with GPS-based information to improve the accuracy of position and velocity. These newer GPS devices may therefore be more sensitive to some of the movements that can contribute to structural stress on the body and the accumulation of fatigue such as change of direction, accelerations and decelerations. This technology has already been used to describe the physical demands of elite basketball in

Australia (Montgomery, Pyne, & Minahan, 2010). The reliability of the contemporary accelerometers for measurement of g-forces the body is subjected to during movement within the current model GPS devices has been reported to have a coefficient of variation (CV%) of less than 2% (Boyd, Ball, & Aughey, 2011). In another study, examining linear speed and accelerations, the CV of the accelerometers was approximately 5% (Waldron et al., 2011).

Research shows there is a consistent trend for GPS devices using a range of sampling rates to be less accurate and reliable as velocity increases. However, much of this research is disparate and has involved a variety of activities to check reliability, as well as multiple manufacturers who are typically secretive about the specific construction specifications and algorithms used. In applied settings such as those used by the majority of major football codes at the elite level, the current model (10 Hz) GPS devices offer a relatively cost effective, portable device, that can appropriately provide an accurate and reliable method to estimate the various movement patterns associated with team sports. Although camera-based technology may possess faster sampling rates at 25 Hz, the difficulties with portability and lack of facilities to mount cameras in a stadium, provide GPS users with a significant advantage (Witte & Wilson, 2005). Sports scientists are encouraged to be aware of the limitations associated with GPS use and assess the reliability of their own devices and where possible, make appropriate adjustments (e.g. use large velocity zones) during the interpretation of results.

2.3   Applications of GPS in Team Sports

To date, the majority of research utilising GPS technology has either attempted to validate the devices, or used the devices to describe movement patterns and activity profiles of various sports. This is not surprising given the relatively new use of this technology in sporting environments. The accuracy of GPS devices has been discussed in Section 2.2 of this review. The following section forms the largest section of this review and focuses on the literature relating to both the current applications and potential future applications of this technology to team sports-related activities.

Before discussing the applications of GPS devices to team sports, there are a number of issues (in addition to issues raised in Section 2.2) worth considering:

- There are two major brands of devices listed in the literature, Catapult Minimax and GPSports. These brands are evenly distributed within the literature, yet provide different values and, other than a single report comparing values in soccer (Randers et al., 2010), are yet to be comprehensively validated against each other. This leads to difficulties with direct comparisons within and between sports because of the unknown compatibility of the devices.

- The definition of speed zones used varies quite considerably within the research. This restricts exact comparisons between the literature.

- The presentation and interpretation of results within the literature vary also. Time spent in various speed zones, distances travelled within these zones, number of entries within zones, total distance travelled, and all of these values relative to time have been reported in various research.

- There are numerous claims about the capacities of GPS devices that appear to lack scientific validation. For example, accelerometer-based devices measuring 'Body Load' or ('Player Load') have been evaluated in Rugby Union (Cunniffe, Proctor, Baker, & Davies, 2009), and compared with RPE (Gomez-Piriz, Jimenez-Reyes, & Ruiz-Ruiz, 2011), without any true validation of the information that body load represents. Body Load is claimed to refer to a complex equation combining all accelerations and decelerations performed by each of the three accelerometers contained within the devices. Accelerometry values describing "body load" represent

additional data produced by GPS manufacturers that require further scientific investigation.

As a result of these issues, combined with limitations raised in Section 2.2, there is some resistance both in the literature (Williams, 2009) and implicitly in directly applying the data collected from GPS devices. However, it could be argued that the benefits of being able to quantify movements in any environment far outweigh any potential limitations associated with the use of GPS equipment in team sports. It is possible that in an applied setting, the practitioner is capable of understanding the potential limitations of specific devices and applying the results of data collected accordingly. Intra-group comparisons will remain valuable, if standardized procedures and analyses apply.

2.3.1 Player and Position Profiling

Perhaps the most popular use of GPS within team sports has been the profiling of movement demands of the sport by players wearing the devices during training and/or matchplay. In particular, analysis of activity profiles during matches provides information on the physical requirements of the sport being analysed. Once a sufficient number of games per team, player, or position are evaluated, accurate physical profiles can be created. These profiles can be used for a range of purposes including talent identification, on-field fitness assessment and evidence-based support for the design of appropriate training loads.

Youth soccer (Castagna, Manzi, Impellizzeri, Weston, & Barbero Alvarez, 2010; Harley et al., 2010), beach soccer (Castellano J & D., 2010), rugby union (Cunniffe et al., 2009), basketball (Montgomery et al., 2010), field hockey (Macutkiewicz & Sunderland, 2011), rugby league (McLellan, Lovell, & Gass, 2010; Sirotic, Knowles, Catterick, & Coutts, 2011), and AF (Coutts, Quinn, Hocking, Castagna, & Rampinini, 2010; Duffield, Coutts, & Quinn, 2009a), have each had GPS analyses of various movement patterns described. This information should be treated with some caution due to the reasons outlined in Section 2.2. However, at its most elementary level, the data can be used to form the basis of training programs and periodization planning.

One of the common issues associated with profiling sports using GPS is the definition of speed zones used for analyses. To date, no uniform definition exists between or within sports for any speed category. As a result, comparisons between studies remain problematic.

A relatively new application of these microtechnology devices to team sports is the application of the accelerometer to profile activity demands. To date, AF (Aughey, 2010) and basketball (Montgomery et al., 2010) have used the built-in accelerometers within GPS to assist in profiling their respective sport. Accelerometry technology offers an ability to more closely examine the acceleration, deceleration and change of direction demands of team sports. The technology also permits additional analysis of movement profiles (e.g. number, nature and density of accelerations during matches) as well as fatigue patterns (e.g. magnitude of accelerations over the duration of the game/training).

2.3.2   Talent Identification

The ability to quantify exact match loads allows coaches and sports scientists to profile elite athlete movement patterns during games and/or training. Once established as a true profile (through multiple measures), this profiling can act as a target for aspiring young players, as well as an indication of the demands of elite performance in that sport. Additionally, this profile can be compared with physical assessment data to indicate any relationship between testing and match physical performance.

Within adolescent soccer, GPS has been used to assess the validity of a number of endurance based field tests (Castagna, Impellizzeri, Cecchini, Rampinini, & Alvarez, 2009; Castagna et al., 2010). Field tests such as the Yo-Yo intermittent recovery test (Yo-Yo IR1) (Castagna et al., 2009; Castagna et al., 2010), the Multistage Shuttle Run (MSSR) (Castagna et al., 2010), and the Hoff test (Castagna et al., 2010) were compared to physical match outputs assessed via GPS. Despite the Hoff test involving ball-use, the Yo-Yo IR1 and MSSR had a closer association with GPS-derived physical match variables (Castagna et al., 2010). As a result of the quantification of match loads using GPS, sports scientists can select appropriate physical tests for identifying and developing the next generation of players who ideally, may be able to cope with physical demands of match play.

Identifying young players with similar physical traits to elite players is a crucial component of talent identification. Appropriate application of GPS technology may allow for more precise assessment of match demands, player profiles and load quantification, all of which can greatly assist this process.

2.3.3 Talent Development

Talent development practices traditionally involve the mixture of objective, often laboratory-based physical assessments combined with subjective evaluation of match performance (Burgess & Naughton, 2010). A subjective evaluation of career potential is formed and (hopefully) appropriate training is then administered over a period of time. The process of turning talented junior team sports participants into elite players can only be enhanced by the understanding and knowledge of match and training loads, especially longitudinally.

Within soccer, GPS has been used to analyse elite matchplay in players as young as 12 years of age (Harley et al., 2010). Players aged between 12 and 16 years were evaluated using 5 Hz GPS and the authors concluded that, primarily due to differing maturation rates, the variation in match intensities discovered should be considered when prescribing training drills for each age group. This quantification of the physical gap between elite junior and senior players has also occurred in AF (Burgess, Naughton, & Norton, 2012). Possessed with knowledge of these differences, the sports scientist can then progress training loads as the players respond, enabling a more gradual approach to physical preparation. Club academies allow this progression in training as players advance through the age ranks within clubs. Elite team sports with no academy structure (such as AF, rugby union, basketball) are encouraged to acknowledge physical differences of recently acquired young players and advance training loads accordingly.

A higher level of physical ability is also required in order to progress through from semi-professional to professional ranks in most team sports. Physical gaps have been described between elite and sub-elite players in AF (Brewer, Dawson, Heasman, Stewart, & Cormack, 2010), volleyball (Gabbett & Georgieff, 2007), rugby league (Sirotic, Coutts, Knowles, &

Catterick, 2009), and soccer (Bradley, Mascio, Peart, Olsen, & Sheldon, 2009a; Mohr, Krustrup, Andersson, Kirkendal, & Bangsbo, 2008; Mohr, Krustrup, & Bangsbo, 2003).
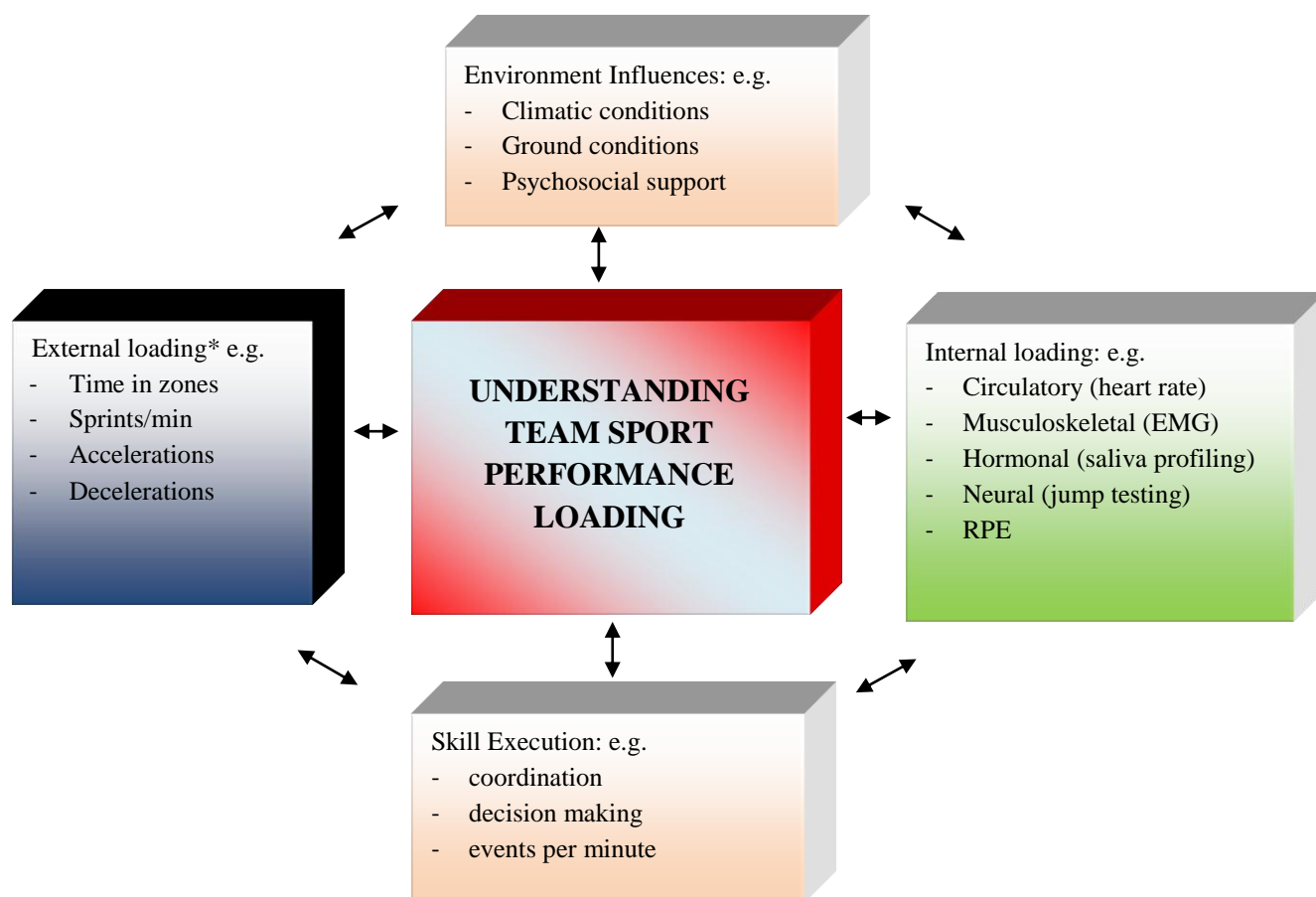
The ability to monitor physical progress in both training and matches using GPS devices provides knowledge of physical discrepancies between elite and sub-elite or junior players within junior academies or squads. This represents an innovative, practical application of GPS technology and can add the basis for a more systematic, deliberate approach to talent development.

2.3.4 Monitoring Load

The load placed on a player involved in team sports may be defined as either internal or external. The internal load of a session is the physiological responses occurring as a consequence of the activity. This includes heart rate, blood pressure, stroke volume, respiration rate, perspiration etc. The external load of a session is the physical work produced by the player as a result of the session. This may include aspects such as number of sprints, distance covered, time in various speed zones etc. The aim of most training is to maximise external load and minimise internal load. This will produce more work for minimal cost to the body.

One of the aims of the sports scientist working in a team sports setting is to understand the loads placed on players. Figure 1 outlines a theoretical framework for monitoring these loads. Estimating the physiological responses (internal load – green box) to training/matches can generate valuable information to assist the individualisation and periodisation of loads. Blood profiles (McLellan et al., 2010), subjective ratings of exertion (RPE) (Impellizzeri, Rampinini, Coutts, Sassi, & Marcora, 2004), jump scores (Cormack, Newton, & McGuigan, 2008), heart rate variability (Kaikkonen, Hynynen, Mann, Rusko, & Nummela, 2010), and heart rate (Coutts, Rampinini, Marcora, Castagna, & Impellizzeri, 2009) have all been used to evaluate internal responses to specific loads in team sports.

Figure 1: Theoretical Framework for Measures of Load in Team Sports.

Environment Influences: e.g.
- Climatic conditions
- Ground conditions
- Psychosocial support

External loading* e.g.
- Time in zones
- Sprints/min
- Accelerations
- Decelerations

UNDERSTANDING TEAM SPORT PERFORMANCE LOADING

Internal loading: e.g.
- Circulatory (heart rate)
- Musculoskeletal (EMG)
- Hormonal (saliva profiling)
- Neural (jump testing)
- RPE

Skill Execution: e.g.
- coordination
- decision making
- events per minute

* The focus of this thesis is on external loading

The quantification of physical output (external load – blue box) is the focus of this thesis and can be achieved using various tools including video analysis, multi-camera systems and portable GPS technology. Figure 1 demonstrates performance loads can be influenced by both environmental factors such as climate and ground surface as well as the ability to execute skill effectively during matchplay or training.

The affordability of portable GPS technology can now provide sports scientists with a more precise combination of parameters for comprehensive measurement of physical responses and adaptations.

Traditionally, training for team sports involved training all players the same way, regardless of age, position or playing experience. Contemporary approaches involve tailoring training according to these factors is more commonplace in an attempt to optimize performance. Individualised loading is also designed to reduce the risk of injury and overtraining, a syndrome becoming more common in elite sport today (Winsley & Matos, 2011). The ability to monitor physical output (external load) of training sessions and matches represents a new and effective load monitoring practice for team sports.

In rugby league, match loads were assessed using GPS and the response to the matches was assessed via blood sampling for the biochemical by-product of protein catabolism, Creatine Kinase (CK) and other endocrine responses (McLellan et al., 2010). Additionally, although no specific relationship between GPS variables and blood response was identified, links were established between the number of tackles performed in a match and magnitude of endocrine response in rugby players (Takarada, 2003). The introduction of GPS should enable future research to be directed towards the identification of match variables associated with altered blood borne responses to physical stress, without invasive procedures.

Some sports governing bodies prevent the use of GPS during matches. In soccer for example, GPS is prohibited by FIFA from use during matchplay, leaving clubs with the option of either purchasing expensive video-based technology, using labour intensive computer-based tracking (Burgess, Naughton, & Norton, 2006), or missing out on match profiles altogether. This gap could be interpreted as a point of division for sports science and coaching in the sport of soccer. Nevertheless, for affluent soccer clubs, the combination of video-based tracking for match evaluation and GPS for training assessment remains a viable option for total load monitoring (Osgnach, Poser, Bernardini, Rinaldo, & di Prampero, 2010). The interchangeablity of these technologies has been investigated (Harley et al., 2011; Randers et al., 2010), with 5 Hz GPS overestimating the total distance of players and underestimating sprint and high speed running distances compared with video-based tracking (ProZone ™) in one study (Harley et al., 2011). Using slightly different speed thresholds and video-based tracking provided by AMISCO™, 5 Hz GPS was not different in total and sprint distances, but also underestimated high speed running distances. Assuming sports scientists within

soccer acknowledge these discrepancies, then the combination of these technologies remains an effective tool to monitor physical training and match loads.

In soccer, players who are regularly part of the starting eleven have maintained fitness for longer periods than players not starting matches (Silva et al., 2011). An ability to quantify match loads using GPS facilitates the replication of these movement demands during training to ensure those not playing regularly are exposed to match demands and thus possibly delay any fitness decline.

As mentioned previously, accelerometry represents technology within modern GPS devices that allows the quantification of rapid changes in speed and/or direction. The combination of all accelerations and decelerations has been termed Body Load (or Player Load) and represents an additional monitoring tool provided by GPS devices. Theoretically, a greater Body Load score would represent higher physical loads placed on the muscles, bones, and joints due to the eccentric forces being exerted during acceleration and deceleration. Repeated higher than average Body Loads, both in terms of team average, positional average and player individual average, could lead to injury. Body Load has been assessed in rugby union (Cunniffe et al., 2009) however, this value was influenced by the GPS 'Impact' value and not just accelerometry.

The GPS 'Impact' value estimates the magnitude of collisions measured by the GPS. This figure relies on accelerometry and is yet to be validated in laboratory or field settings. Potentially this value could be used by sports scientists involved in collision sports to evaluate the effect of collisions on perceived indices of fatigue such as CK and RPE.

In summary, monitoring aims to ensure players are completing expected loads according to factors such as injury history, position, age and physical strengths/weaknesses. The addition of physical values to more traditional measures of physiological and psychological responses to loads, creates an added layer to the monitoring 'toolbox'. However, at present, scientists are unable to make confident decisions based on the real-time measures when playing in large stadia as the quality of GPS signal may be compromised (Aughey & Falloon, 2010). More strategic use of GPS technology enables sports scientists to evaluate a more mechanistic and cumulative contribution of load among players.

2.3.5   Injury Rehabilitation

Knowledge of players' physical movement profiles for both matches and training allows benchmarking of activities for numerous purposes. One such purpose could be to provide target values to achieve during injury rehabilitation. At a basic level, values such as maximum speed can be assessed with GPS when the player is uninjured and various fractions of this assumed maximum value can be manipulated during rehabilitation. These percentages can then be used as targets at various stages throughout the rehabilitations process.

Therefore, GPS technology can also offer more detailed values to be benchmarked for rehabilitation purposes. Specifically, accelerations, decelerations, body load, impacts etc. can all be assessed when the player is uninjured and used throughout the rehabilitation process. Additionally, various drills and standardised running patterns can be assessed when the player is uninjured and then employed during rehabilitation to provide objective markers of injury status.

2.3.6   Injury Prevention

Analysis of physical patterns that precede soft tissue injury may identify potential contributors to injury during games or training. For instance, if players are routinely wearing GPS devices during training and/or matches, the physical activity preceding any soft tissue injuries can be examined for common features. This concept was recently examined with a small sample in soccer using video tracking technology (Carling, Gall, & Reilly, 2010b). During periods in the match in which the recovery between high intensity efforts was deemed inadequate, players appeared to be at higher risk of sustaining soft tissue injury (Carling et al., 2010b).

Knowledge of this information can allow scientific and medical staff to expose players to similar periods during training sessions to hopefully ensure adaptation to this intensity of work occurs prior to matches. Additionally, sports in which live GPS monitoring is possible such as AF and rugby league may even have the possibility to rotate players out of the game when unusually demanding loads are observed.

Quantification of movement profiles can assist in performance monitoring and adjustment under various conditions. For example, if the decrease in individual movement parameters in extreme heat (Duffield et al., 2009a) can be ascertained using regular GPS monitoring, adjustment in expectations of match or training demands can be calculated. Additionally, players seemingly adopting pacing strategies both in the heat (Duffield et al., 2009a), and also in the final periods of matches (Burgess et al., 2006) can be identified and adjusted if necessary.

The identification of 'outliers' within a group setting forms an important component of player monitoring. These outliers in physical loads (or response to loads) can often represent unusually high or low training stimulus, both of which are common causes of injury in most team sports(Gabbett & Jenkins, 2011). Effective use of GPS technology assists in individually assessing loads and contributing to an informed judgement on player and team training programs.

Impact of strategies such as recovery modalities, training regimes and even supplement protocols on performance can all theoretically be assessed using GPS technology. Once a player's response to a set protocol is established, the effect of any alterations in preparation can be examined. For example, in between soccer matches, the use of a novel spa treatment (spa, cold water immersion, jacuzzi) was found to be an effective recovery intervention and reduced the deterioration in match running performances (Buchheit, Horobeanu, Mendez-Villanueva, Simpson, & Bourdon, 2011). The effect of various supplementation regimes on running performance has also been investigated in rugby using GPS technology (Minett, Duffield, & Bird, 2010). All of these strategies can assist in the identification of effective ways to increase performance and/or, reduce injuries.

2.3.7 Fitness assessment

Player tracking technology allows the sports scientist to evaluate the relationship between field or laboratory-based fitness tests and match physical performance in team sports. This relationship has been extensively investigated in soccer with match running performance being related to performances in the Yo Yo IR2 among other assessments (Bangsbo, Iaia, &

Krustrup, 2008; Castagna, Impellizzeri, Chamari, Carlomagno, & Rampinini, 2006; Impellizzeri & Marcora, 2009; Impellizzeri et al., 2006; Rampinini et al., 2007a). In AF, GPS-assessed running ability was uniquely compared with playing experience, playing position, skill execution and YoYoIR2 performance (Mooney et al., 2011). Strong performance in the Yo Yo IR2 was associated with increased skill involvements (ball disposal) in non-key position players and a larger number of ball disposal in the high intensity running (per minute) category.

Perhaps the most applied form of fitness assessment that team sports athletes can perform is the physical demands of the match itself. Using GPS technology provides an assessment of a player's ability to complete games at an appropriate intensity. For example, it has been suggested that a player's ability to complete the last quarter in AF at an appropriate physical intensity could be determined by fitness levels (Aughey, 2010). For most team sports match scenarios, GPS tracking currently provides the most practical method of assessing this ability.

Over time, databasing match activity profiles under various conditions would also allow the sports scientist to determine acceptable ranges and benchmarks for a range of movement parameters. There is clearly day-to-day or match-to-match variability within movement parameters during elite team sports (Gregson et al., 2010; Petersen, Pyne, Portus, Karppinen, & Dawson, 2009b; Rampinini, Coutts, Castagna, Sassi, & Impellizzeri, 2007b), but general trends are of interest. Once these have been established, unanticipated values can be explored.

Overall, the general work rate of a team or an individual can be affected by many factors during a game. Therefore, a large number of matches under varying conditions are required to create sufficient databases that permit the interpretation of transient effects. Even opposition work rates have been shown to affect physical performance in professional soccer players (Rampinini et al., 2007b).

A novel method of determining energy expenditure and work rate associated with training and matches is also possible, using more recent GPS devices equipped with accelerometry (di Prampero et al., 2005; Terrier, Ladetto, Merminod, & Schutz, 2001). The relationship between various forms of movement and energy expenditure was examined using a combination of GPS and indirect calorimetry. This may have potential applications in both the

general health and applied sports science domains. Energy expenditure associated with sprinting has also been determined using a number of equations associated with the mechanical properties of muscles and the angles created while sprinting (di Prampero et al., 2005). For application in a team sports environment, this concept was expanded on by using accelerations assessed by video-based tracking and soccer matches in Italian Serie A (Osgnach et al., 2010). The power generated to accelerate to, and remain in, each speed zone was calculated and the energy cost of generating this power could subsequently be estimated. This concept may easily be applied using GPS tracking to provide an alternate method, or an extra layer of assessment and analysis of energy expenditure within team sports.

The ability to discriminate between tests designed to assess physiological capacities and those directly relating to the expression of these capacities in match and training scenarios is very important for team sports. There are probably scenarios whereby the physiological capacity is of interest to the sports scientist, such as initial pre season testing or testing during the season when fitness parameters may be questioned by coaching staff. However, assessing parameters that can reflect physical performance in matches offers another layer of evidence-based support in team sports. This ability to assess physical match performance has been greatly enhanced by the widespread use of GPS technology in team sports.

2.3.8 Team Selection

Knowledge of individual player movement patterns may assist coaches in selecting teams appropriate for various opposition, climates, surfaces etc. In AF, players who physically performed exceptionally over a quarter or half were unable to sustain this intensity during the following quarter or half (Coutts et al., 2010). In a sport such as AF in which unlimited rotation (no limit to player changes) is possible, this knowledge may be used to more effectively manage player rotations and arguably create a more physically capable team during critical periods of play. The ability to monitor AF games 'live' with wireless GPS offers the coach insight into the physical status of players, which would presumably lead to more appropriate timing of player rotations.

Coaches and sports scientists working in sports that prohibit live monitoring of player work rates, such as soccer, may be facing considerable disadvantage. For example, any fatigue-influenced substitutions are made on the basis of general player fitness knowledge possibly combined with subjective assessment of match fatigue status. Match physical analysis can reveal the potential flaws in this subjective substitution practice. In French professional soccer for example, substitutes actually performed at the same work rate as the players they substituted indicating the decision to substitute was either purely tactical or possibly an incorrect assumption of physical fatigue (Carling, Espie, Le Gall, Bloomfield, & Jullien, 2010a).

One interesting aspect of team selection that GPS has highlighted is the increased intensity and physical requirements of finals matches in AF (Aughey, 2011b). This increase in physical demands of post season matches is undoubtedly experienced in other team sports (e.g. basketball, rugby league, rugby union, soccer) and the ability to actually quantify the differences allows for more objective player selection strategies during these games.

Team selection is ultimately the domain of coaches in team sports. Player and team physical capacity influences this selection to varying degrees depending on factors such as the sport, coaching philosophy, opposition, and venue. Use of GPS tracking allows the profiling of players and teams under all of these scenarios, reducing some of the subjectivity associated with team selection.

2.3.9 Training Design
Quantification of training demands using GPS technology has revealed a significant difference between training loads and match requirements in most team sports. In rugby union, a detailed study comparing adolescent training to match demands using GPS showed that training volumes and intensities were significantly lower than match values (Hartwig, Naughton, & Searl, 2011). This is concerning given the high intensity periods within team sports that generally produce the most fatigue (Gabbett, 2006b; Roberts, Trewartha, Higgitt, El-Abd, & Stokes, 2008) are not being replicated in training. Similarly, in field hockey, GPS analysis of small sided games in training was found to produce less moderate and high

intensity movements than those required for matches (Gabbett, 2010). In cricket, GPS analysis of training found that conditioning drills exceeded match demands. However, cricket skill drills and 'match simulation' drills failed to reach match demands (Petersen, Pyne, Dawson, Kellett, & Portus, 2011). In basketball, use of accelerometry in GPS determined that practice matches as part of training ('scrimmages') were substantially less demanding than live play (Montgomery et al., 2010). In most team sports scenarios, the ability to track training demands has revealed that match demands far exceed those produced during training.

During the competitive season, it might not be appropriate to replicate match volumes combined with match intensities during training. Reproducing match intensities for shorter durations at various times during a training week may offer a more effective training strategy. During pre season training, both intensity and volumes of matches should be experienced by the players. Sporadically exceeding these values may provide a greater training stimulus. This training design philosophy and process would be less accurate without the exact knowledge of match values provided by GPS devices.

The use of GPS to assist in drill design can be employed to develop a balance between skill execution and conditioning requirements of sessions. In AF, comparison of various skill execution factors (e.g. ball touches, cognitive complexity) and physiological responses (e.g. heart rate, lactate, GPS-determined movement profile, RPE) of open and closed training drills were evaluated (Farrow, Pyne, & Gabbett, 2008). "Open" drills were found to place greater physiological and cognitive demands than "closed" drills, suggesting the practice of practicing skills in a closed environment is not optimal for either physical conditioning or skill mastery.

Continual monitoring of matches and training using GPS technology can help to assess the impact of altered training regimes on match physical performance. It has been suggested that an 8 week period of aerobic interval training improves distance covered during soccer matches (Helgerud, Engen, Wisloff, & Hoff, 2001). Traditional interval training has been replaced in sports such as soccer by the use of small sided training games and as a result, much research has examined the use of these games as a conditioning tool (Casamichana & Castellano, 2010; Coutts et al., 2009; Gabbett, 2006b; Kelly & Drust, 2009; Rampinini et al.,

2007c). Continuous GPS monitoring would allow more thorough analysis of the effects of small sided games training on match physical performance.

Seasonal variations in physical performance can be quantified by use of GPS tracking. High intensity running in games, for example, is subject to seasonal variations with players performing greater high intensity distance running towards the end, rather than the start of seasons (Mohr et al., 2003; Rampinini et al., 2007b). This knowledge could be useful in adjusting training loads or even team selection during the season to allow for these trends.

In summary, training design and periodisation of both team and individuals is a critical component for success in team sports. GPS tracking of training and match loads provides a more objective analysis of training to ensure planned progressions and alterations are implemented.

2.3.10 Tactical Analysis

The use of physical information collected during matches to analyse tactical or strategic aspects of team sports is one aspect of GPS technology yet to be extensively researched. Using camera-based technology, soccer has been the subject of much research in this area (Lago, 2010). In the top league in Spain, for example, use of an AMISCO system revealed that players covered less high-intensity distance when winning than losing, yet covered more distance when winning (Castellano, Blanco-Villasenor, & Alvarez, 2011a). Players in this league also covered more low intensity activities and greater overall distance when playing at home than away (Castellano et al., 2011a; Lago, 2010). Furthermore, players were shown to cover more high intensity (Lago, 2010), and total distances (Castellano et al., 2011a) against better quality opposition than when playing against lower quality opposition. This tendency was also reflected in team movement patterns with more successful teams in the English Premier League completing less high intensity running than less successful teams (Di Salvo, Gregson, Atkinson, Tordoff, & Drust, 2009). In the Italian Serie A competition, more successful teams with greater technical ability also completed less running than less successful teams (Rampinini, Impellizzeri, Castagna, Coutts, & Wisloff, 2009a). One of the features of camera-based match analysis most appealing to coaches of team sports is its ability

to re-create player positions at any time during the match in either 2D or 3D format. This allows coaches to assess other dimensions of play such as player position outside the field of view of commercial television footage, player numbers (player density) surrounding the ball, and distances between team mates. Innovative software accessing the horizontal positioning traits of GPS tracking can also provide this feature for coaches during training and matches. This is one characteristic of GPS tracking yet to be fully utilised by coaches in team sports unable to afford or access stadium based tracking.

Traditionally, GPS analysis has been the domain of the sports scientist. Recent advances in software enabling the 2D recreation of training/match instances have the potential to provide coaches with additional impetus to utilise this technology.

2.3.11 Sport Evolvement/Trends

Quantifying movement profiles, particularly in matches, allows coaches and sports scientists to track movement trends over time. This may allow innovative coaches to anticipate future trends and alter recruitment and training strategies accordingly. In AF, GPS match information has been collected for a number of years and this has allowed comprehensive research detailing physical trends over time (Wisbey, Montgomery, Pyne, & Rattray, 2010). This research suggests between 2005 and 2008 seasons, the average running velocity and intensity of AF has increased between 8-14%. This increase in running velocity in AF has been combined with analysis of AF injury trends (Orchard & Seward, 2010), resulting in significant rule changes in the sport designed to reduce soft tissue injury risk. While these rule changes may not have occurred without the quantification of match intensities supplied by GPS tracking, some care in interpreting these data should be taken as the data was collected using different GPS devices of varying sampling rates.

In cricket, GPS analysis enabled the profiling of each form of the game (Twenty20, Test Matches and One Day Cricket) (Petersen, Pyne, Dawson, Portus, & Kellett, 2010; Petersen, Pyne, Portus, & Dawson, 2011). This research provides valuable information for sports scientists working within cricket who would need to tailor their training according to the needs of the approaching game or tournament.

Assessing the impact of rule changes on physical parameters is also possible with GPS assessment of match performance. In rugby league for example, alterations in the interchange rule (limiting the number of changes per half to 12) as well as the introduction of the 10 m off side rule have increased the high intensity running required (King, Jenkins, & Gabbett, 2009; Sirotic et al., 2011). In AF also, annual reports detailing physical data during matches collected using GPS show the changes in physical parameters associated with rule changes that have occurred annually over the previous 8 years (Wiseby, 2010). For example, overall average speed during AF matches has increased during this period as a result of, among other things, rule changes such as faster play restarts (ball ups, boundary throw ins).

Physical trends in sport are of use to sports scientists, recruitment officers, coaches and governing bodies alike. These trends can have significant impact on team sports and their participants. Knowledge of these trends, often provided by GPS tracking, should be integral in the training and future planning for those involved in team sports.

Literature Review: Section 2

3   Literature Review - Section 2

3.1   Publication Overview

This section represents a review of the team sports talent development literature completed in March 2010. The invited review discusses applications of various models of development and offers a framework for future monitoring of talent development in team sports.

The specific publication details are:

- Burgess, D. J., & Naughton, G. A. (2010). Talent development in adolescent team sports: a review. *International Journal of Sports Physiology and Performance, 5*(1), 103-116

3.2   Introduction

No clear guidelines exist for effective development of talented team sports athletes. Talent development issues are global and not exclusive to team sports athletes.(Falk, 2004) The one unifying factor is that because of the many factors associated with growth, development and maturation, the same strategies employed with elite adult athletes are unlikely to be sustainable in adolescents.

3.3   Scope of Review

Literature on adolescent athletes frequently describes identification or detection of talent. Relatively less is known about talent development, particularly in team sports. This review discusses talent development in post-pubescent adolescents involved in team sport. To this end, database searches were conducted in Ovid, Sports Discus, Web of Knowledge and the Australian National Sports Information Centre. We also contacted national (Australian) sports

organizations and institutes. Search terms were limited to *youth, adolescent/adolescence, teenage, junior, talent, development* and *young* for the target group. *Sport, soccer, football, rugby, Australian Rules, basketball, cricket*, and *netball* were the terms entered for the team sports.

3.4   Development v Identification

The identification of talented team sports' athletes in their adolescent years is, by its definition, exclusive, rather than inclusive. Talent identification is multi-faceted and often expensive, and a successful translation in adult team sports is questionable (Vaeyens, 2008). Ideally, talent identification should form part of an initial stage of a dynamic talent development model and pathway.

More than talent identification, talent development presents a number of challenges to the team sports coach. Specifically, day-to-day variations and progressions in skill and in physical and cognitive maturation require regular monitoring for valid performance appraisal. Development models should acknowledge and nurture these progressions. Holistic and progressive approaches in talent development function in contrast to the cross-sectional nature of traditional talent identification programs.

In a substantial review of the use of physical testing in talent detection and sport development (Lidor, 2009), four main observations were presented:

1. Physical skill tests can assess athletic ability and have some success in predicting future athletic success in some sports
2. Most studies on physical skill assessment of elite adolescent athletes are cross-sectional, and lack developmental relevance
3. Acceptable criteria for maturation are rarely considered in such tests
4. The nature of physical tests to detect early development in sport transferring to elite-level performances remains obscure.

Physical and biological attributes alone are poor predictors of skill in team sports. In soccer, body size, and maturity were not associated with results of skill testing in talented junior

squads (Malina, 2005). Within Australian Rules Football (ARF), a small relationship between performance measures (20 m sprint, agility, multi-stage shuttle run, and vertical jump) and future ARF success has been demonstrated (Pyne, Gardner, Sheehan, & Hopkins, 2005). In agreement with the previous study on soccer, no relationship was found between body size or shape, and ARF career success (Malina, 2005). This finding was also consistent with a study on American Football Players, in whom no substantial differences were evident in body dimensions of drafted and non-drafted players (Sierer, 2008). In volleyball, a novel skills battery (Gabbet, 2006) was used, as well as traditional physiological and anthropometric tests, to assist in predicting both selection and non-selection in a talent identified squad (Gabbett, 2007). Of these variables, subjective coach assessment of passing and serving skills were the only significant contributors to team selection, combining for a predictive accuracy of 79%.

Thus, the identification of successful attributes should serve only as a guide, rather than inclusion criteria for elite pathways into team sports. Game sense and decision making should be assessed, preferably during specific games, rather than estimated in athletic performance settings (Vaeyens, 2008). The game-inclusive approach is particularly relevant in early adolescence, during which maturation and physical attributes occur with unpredictable timing and tempo (Pearson, A., & Torode, 2006).

3.5   Talent Development Models

Talent development models vary in content. Recent reviews on talent development for applied settings provide informative summaries of existing models (Vaeyens, 2009, 2008). In this review, we provide a brief summary of models, followed by an alternate hypothetical framework (Figure 1).
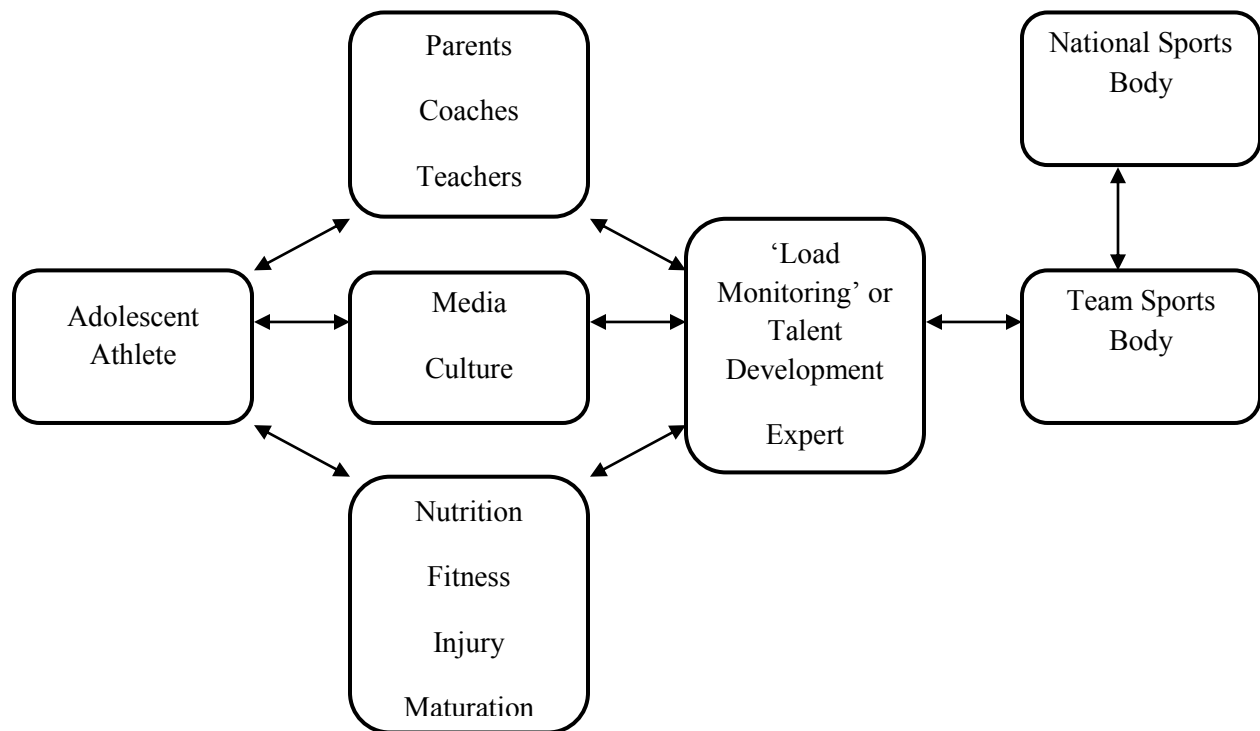
Figure 1. A proposed new framework of talent development for adolescent team sport players

Reilly and Williams (Reilly, 2000) suggested two approaches to talent development. First, athletes may succeed in a sport in which they already participate through the progressive attainment of expertise. Second, an athlete may transfer to a new or related sport, excelling in the physical, psychological and/or physiological attributes required for the new sport. Talent transfer is demonstrated by a report that 28% of Australian senior national athletes had reached their elite status within 4 y of beginning their sport (Oldennziel, 2004). Furthermore, a talent identification and development case study on the winter Olympic sport of women's skeleton showed a number of athletes successfully transferred from sprint performance testing to international standard competition (Bullock, 2009). However, talent transfer was reliant on physical measures in closed chain sports, and as a result, the application of these findings to open-chain team sports talent development may be limited.

A "deliberate practice" talent development model was proposed (Ericsson, 1993) in which national level achievement could be developed after 10 y of focused, specific practice.

According to the deliberate practice model, athletes can only succeed if, from an early age, they are exposed to skill refinement and training specificity. The early exposure model is supported by anecdotal case studies in both individual and team sports. However, given the number of aspiring junior athletes with similar early commitment, the case studies may be interpreted as outliers. The early exposure model has also been criticized for suggesting elite performance would negate any influences of factors such as genetic predisposition, coaching quality, efficacy in commitment, and parental support (Bullock, 2009). The unpredictable and dynamic nature of team sports, particularly during adolescence, provides few guarantees, even to committed individuals.

Baker et al. (Baker, 2003) contend that mastery of an athletic movement is directly related to the number of practice hours undertaken, independent of structure. This notion was taken further (Helsen, Hodges, Van Winckel, & Starkes, 2000) by postulating that athletic movement mastery, is dependent on accumulating 10,000 training hours. However, this 10,000 hour model does not dictate task specificity and has been associated with (increased) drop out in elite team sports athletes (Wall, 2007). The practical framework we have outlined in Figure 1 ignores prescribing precise training hours or regimes. Individualized training is preferred, with the ability to alter programs according to monitoring feedback from talent development specialists who in turn, work with coaches, teachers, and possibly parents.

Martindale et al (Martindale, 2005) took a more holistic approach in a review of the talent development literature. Five generic factors positively affecting talent development were identified: long-term aims and methods; wide-ranging coherent messages and support; emphasis on appropriate development rather than early selection; individualized and on-going development; and integrated, systematic, and holistic development. Despite the appeal of this developmentally appropriate model, it may be scrutinized for a lack of evidence-based validity and difficulties in quantifying some of the influences. Nevertheless, translating these factors into practical environments should be of interest to talent development staff involved in a broad range of team sports.

Talent development is multifactorial and dynamic in nature, with talent altering and adapting according to the environment in which it is nurtured (Simonton, 2001). One such multidisciplinary approach to talent identification in adolescent soccer concluded that elite

players differed from semi-elite players in body shape, aerobic power, agility, sprint time, ego orientation and anticipation skill (Reilly, 2000). This approach suggested more than just physical factors separate elite and semi-elite players. Cognitive development also appears to offer similar pathways to physical and technical development. For example, memory skills typically mature after 16 years of age and can take up to 10 y to develop (French, 1999). The importance of cognitive skills in talent development is evident in research distinguishing between levels of performance (Talbot-Honeck, 1998),(Kreiner-Phillips, 1993). Further, the rate of learning, represented by speed in the acquisition of new skills, has been identified as an indication of talent (van Rossum, 2005). Problems arise when identification of talent occurs prior to the maturation of cognitive capacity, and when selecting talent fails to consider the capacity to learn.

Some talent development models detail both the detection and development of talented athletes. For example, four domains of development (intellectual, creative, socioaffective and sensorimotor) were established within the Differentiated Model of Giftedness and Talent (DMGT) (Gagne, 2000). The model begins with a junior possessing "gifts" and ends with a fully developed talented adolescent or adult athlete. This model recognizes several domains that significantly influence dynamic and interactive responses of adolescents in team sports. Despite recent support for the DMGT model (Vaeyens, 2008), practical examples are limited.

Varied early learning experiences combined with subsequent specific training hours may represent an ideal environment in which to nurture talent. Engagement in playful, non-specific behaviours during the early stages of development, followed by more specialized training during later stages of development, may be among the most salient predictors of later skill attainment (Cote, 2002). The playful, nonspecific model is anecdotally supported in Australia by the disproportional success of indigenous players in team sports. Despite the likely absence of structured training in the first two decades of life, young indigenous males remain highly active through social participation in sports-related play. In ARF, for example, 189 players with indigenous heritage have gained senior player status. In the 2009 season, there were 72 indigenous ARF players, representing over 11% of total player numbers (AFL, 2009). By contrast, indigenous Australians represent only 2.5% of the total population (ABS, 2008).

The Developmental Model of Sports Participation (Cote, 2003) embraces the early, playful and non-specific (Cote, 2002) model of participation. Specifically, it prescribes participation in a variety of sports during the sampling years (age 6 to 12), a reduced variety during the specializing (age 13-15), and substantial investment in a single sport (above 16) years. The Developmental Model of Sports Participation asks team sport athletes not to engage in deliberate practice until at least the specializing years. The Developmental Model of Sports Participation also recognizes the potential influences from interactions with coaches, parents, schools, and peers.

An independent review of National Sport in Australia has recently been critical of under-resourced and poorly articulated talent pathways in junior sport (Independant Sports Panel, 2009). Specific observations included deficits in cooperation between key stakeholders and a lack of strategic, unified support for junior sport participants. Rather than an institute or club-centric approach, a hypothetical framework (Figure 1) with the adolescent athlete as a central focus has been proposed for the purpose of this review. The framework places a stronger emphasis on the holistic and unified management of the adolescent athlete.

3.6   Modifying Expectations of Adolescent Team Sports Performance

Expectations of training responses and performances in junior athletes should not be determined by adult standards, even if adolescents appear to function well within elite pathways. Effective pathways may be best served by a more patient approach, by first quantifying the gap between elite junior and elite senior performers, and progressively training towards closing it. Although child-specific training advice is available (Mountjoy, 2008), it is not always applicable to team sports, and can neglect fundamental physiological and maturational factors (Vaeyens, 2008).

Research differentiating the age-based physical requirements of team sports is plentiful. Substantially different scores in soccer-specific endurance (Yo YoIR1) and agility tests were found in age- and gender-differentiated elite Spanish soccer players (Mujika, 2009a). Specifically, the 15% difference in male Yo Yo scores, and the 5% difference in agility scores were postulated to reflect differences in training and competition experience. Both the Yo Yo and agility tests were reported to represent, among other variables, explosive strength in the

lower limbs (Castagna et al., 2006) and soccer-specific intermittent high-speed running ability (Krustrup et al., 2003). Compared with elite junior soccer players, agility was better in elite senior players (Lehance, 2009). However, game-specific ball drills and sprint ability did not differentiate the players in the same study. Other measures of explosive leg strength (vertical jump)(Mujika, 2009a), squat jump (Lehance, 2009) and sprinting ability (Burgess, 2005) have differentiated between elite senior and junior soccer players of both genders. Even older adolescents (approximately 17 y) are not required to meet the same physical output as adults within the same football code (Burgess, 2005).

A myriad of intrinsic neurophysiological and intramuscular properties may more likely affect explosive power performances in immature than mature athletes (De Ste Croix, 2007). Such properties remain difficult to quantify in ethically appropriate studies in adolescent athletes. Advanced technologies of intramuscular anaerobic activity (Barker, Welsman, Fulford, Welford, & Armstrong, 2008) may improve the understanding of isolated isokinetic performances in the near future, but their relationship to on-field performances remains questionable. Nevertheless, anaerobically based performances of adolescents appear to lag behind more mature performers, and expectations should remain focused on individual improvement rather than attaining team averages or elite values.

Fundamentally, adolescents achieve similar scores for aerobic capacity (V_{O2peak}) when results are expressed relative to body weight. However, field-based measures are more sensitive in showing incremental improvements in endurance performances that can occur in combination with age and training (Rowland, 2009). In male adolescents, increased lean mass may exponentially enhance the capacity for aerobic and anaerobic training. This increase has been described as the trigger hypothesis (Rowland, 2009).

The potential for adolescents to respond to strength and conditioning is also well established (Faigenbaum et al., 2009). Properly designed and supervised programs are relatively safe and can improve cardiovascular endurance, muscle strength and power, and enhance aspects of health, injury resilience, and performance (Faigenbaum et al., 2009). Progressions within periodized programs should be relatively slow and specifically monitored.

3.7 Issues with Current Talent Development Practices in Team Sports

Coaches/sports scientists in charge of elite talent development may be unfamiliar with current research models. The models can often be difficult to translate into practice. The current practice of identifying and developing adolescents likely to be successful in team sports, regardless of the talent development model employed, could be flawed at the identification level. International ice hockey players, for example, did not reach their full potential until their late twenties, indicating that "early" identification and development may not necessarily translate to adulthood performances (Sherar, Baxter-Jones, Faulkner, & Russell, 2007).

Physical assessments as a base of talent identification not only ignore team interaction, decision-making at speed with opposition, and other tactical awareness factors, but also assume physical traits such as speed and strength, transfer easily to game-based scenarios. The inclusion of early maturing boys and the exclusion of late developers is a divisive practice that reduces the talent pool for future elite teams. Junior coaches who stratify players on adolescent performance may impose irreversible rejection messages to late developers or slow learners. An inclusive strategy for future early adolescent sporting competitions is required in models of talent development even at the elite level. The framework presented here proposes a strategy in which maturation, injury status, and game sense are considered commensurate with physical fitness (Figure 1). Coaches, teachers, and parents linked with adolescent talent development programs are supported by experts who can provide coaches, in particular, with another source of information and support. Among many functions, talent development experts would ideally nurture coaches to prioritise players' goals of self-improvement, ahead of peer comparisons.

The use of performance measures to identify and subsequently develop talent, may possibly be counter-productive for long-term talent development (Martindale, 2005). In practice, many coaches-and also committees advising/employing these coaches-focus on early adolescent performance results, demonstrating a "win-at-all-costs" mentality that may, in fact, impair future individual performance (Simonton, 2001). Improved body size, speed, strength and endurance synonymous with advanced relative maturity, can alter talent perception and therefore team selection (Sherar et al., 2007). The transient nature of adolescent physical performance is also often neglected when identification is used to predict development

(Vaeyens, 2008). Analysis of training methods in soccer, for example, showed gameplay and coordination activities transferred to conventional assessment tasks such as tests for sprinting and jumping more effectively than test-specific drills in adolescents (Venturelli, 2008).

Further complicating current talent development practices is the issue of athlete dropout due to competitive pressures (Gould, 1992; Moore, 1998). A more general model, in which high-level competition takes place at later stages of development, may avoid these competition-related problems. Within Australia, the governing body for soccer, Football Federation Australia, has recently mandated small-sided games competition for which no score is recorded until the age of 12 y (FFA, 2009). This initiative attempts to provide players with more opportunity to develop "gamesense" (Bishop, 2009), greater exposure to skill execution within a game environment, improve participation numbers through increased enjoyment, and reduce the focus on results-based tactics. The attenuation of competition in football might be difficult to implement and manage when state and national primary school sport championships are played on an annual basis. It is also debatable whether team sports talent development programs focusing on isolated skill development away from competitive situations may mask critical development of decision making, game tempo adjustment, and tactical awareness.

The integration of school programs within an adolescent talent development pathway is often neglected. Typically, in countries without college-based systems, elite team sports adolescents represent school and club teams at numerous levels. This excessively competitive environment potentially exposes players to high physical and psychological loads. It is not uncommon for adolescent team sports players to exceed 10 training and competitive situations on a weekly basis (Hartwig, 2009). This practice may not only be detrimental to performance and sport retention rates, but also to young people's health, education, and overall well-being - a point largely overlooked in talent identification literature (Williams & Reilly, 2000). Additionally, most school programs recognize current levels of achievement (Bailey, 2009), without acknowledgement of future athlete success. The emergence of sporting high schools may provide gifted juniors with a highly specialised environment, preventing exposure to alternate models of talent development, and have the potential to ignore total loads placed on players external to school-based demands. Our framework (Figure 1) addresses this

"competition for time" issue by providing an adolescent development specialist within the pathway to assess and adjust, where necessary, total loads placed on talented players. Practically, this may lead to issues of prioritization and possible removal of players from current programs.

Patient development programs inherently lack the funding and support of identification programs. Typically, grant and scholarship funding is directed toward adolescent athletes already selected in representative teams, reinforcing the preference for short-term identification over long-term development (Martindale, 2005). Effective long-term, or longitudinal athlete monitoring would enable sports practitioners to assess athlete physical, psychological, and skill progress, as well as adjust training loads accordingly. The cost effectiveness of talent development programs relative to long-term investments of funding are however, infrequently debated.

3.8   The Relative Age Effect

Age grouping for selection is a common practice during the developmental years of most team sports. Presumably the intention of age grouping is to "equalize" competition by providing young athletes with, at least chronologically, a level playing field. However, age grouping has led to the predominance of selected players being from the first quartile of the selection year, a phenomena known as the *relative age effect* (RAE) (Barnsley, 1992). The RAE is particularly prevalent during the adolescent years, due to physical characteristics associated with increased chronological age (Baxter-Jones & Helms, 1994). An analysis of birth dates in elite Under 14 Spanish soccer players found 79% of players were born in the first half of the year (Carling, 2009). The RAE was further supported in large studies of elite French (Carling, 2009), Spanish(Mujika, 2009b), Japanese (Hirose, 2009), and European (Helsen, 2005) youth soccer players, for whom substantial discrepancies were found between month of birth (beginning of the year being favourable) and selection in elite academy squads of the players.

A substantial review of 246 studies involving elite male and female European soccer player birth dates also demonstrated a discrepancy in birth dates observed among quartiles of the calendar year, with quartile one providing 31.2% of participants, quartile two (26.1%),

quartile three (22.3%), and quartile four (20.6%) (Cobley, 2009). When the studies were categorised according to four levels of skill (recreational, competitive, representative and elite), differences remained, with the largest difference occurring at the representative level. A decline in the RAE following adolescence is explained by physical maturation levels becoming less variable (Lefevre, 1990), as well as the impact of intersport transfer (Baker, 2003).

In one of few longitudinal studies in team sports, elite junior soccer players were monitored over an 11-y period and showed no substantial differences in fitness parameters across birth date quartiles (Carling, 2009). Although a trend toward superior physical performance in players born in the first quarter was present, no differences in the percentage of players turning professional from any of the birthdate quartiles were apparent, once players left a development academy. The absence of substantial differences on exit from the academy implied that once the players had integrated into the academy and received similar training, any physical superiority present in the players was consumed by technical development.

Several suggestions to reduce the RAE have been made, including changing age-group periods (Boucher, 1991) and birth date quotas in team selection (Barnsley, 1992). Perhaps the most relevant suggestion is change attitudes toward talent identification and development to reflect a long-term development point of view rather than instant team success (Barnsley, 1992; Helsen et al., 2000); (Helsen, 2005);(Vaeyens, 2005). Practically, this may involve coaches ignoring enhanced physical qualities synonymous with short-term success. Coach education may hold the key to cultural change, but support from significant others such as sporting organizations, club officials, and parents would also be required. In our framework (Figure 1), coaches are supported by talent development experts who are appointed by the governing sporting body to advise on issues such as long-term prospects. This allows for evidenced-based policies, such as those involving RAE to be discussed and implemented in collaboration with relevant adults and adolescent athletes.

3.9   A Holistic Model

Physical discrepancies between successful and unsuccessful sporting teams require more scrutiny (Mujika, 2009a; Pyne et al., 2005; Reilly, Bangsbo, & Franks, 2000; Sierer, 2008). The physical development pathway of some team sports, such as Rugby Union, has been reviewed and prescribed (Duthie, 2006). However, prescriptions for early, rather than late developing adolescent players are required. Frequently, aspects of talent development such as environmental and psychological influences are neglected (Martindale, 2005). This persists despite individual psychological development and structured development pathways being identified as critical for preventing drop out and improving participation among adolescent athletes (Fraser-Thomas, 2008).

Existing models of talent development regularly evolve from case studies in closed-chain sports. Research about the strongest markers of development in team sports with less predictable demands is equivocal. Currently, talent development programs follow the results of initial selection criteria derived from isolated testing. Criteria are physically based, neglecting the crucial psychological, maturational, and gameplay influences on elite team sports success (Hyllegard, Radlo, & Early, 2001). Decision making, coachability, leadership, and cognitive competences need to be considered when constructing talent pathways for team sports. Long-term monitoring of physical and psychological loads needs to occur, with greater sports science involvement in the pathway (Hartwig, Naughton, & Searl, 2009).

The framework presented in Figure 1 has the holistic development and welfare of the adolescent team sports player as its focus and accounts for the many influences in this stage of development. It is a framework, rather than a model, allowing it to be adapted to various team sport situations. The framework (Figure 1) identifies the multiple relationships within the team sport talent development pathway, and the proactive and reactive nature of development. Financial considerations are a limitation of this framework, but it is presented in the context of a best practice scenario. Current resources could be redistributed to reflect the priority that talent development requires for long-term cost benefits.

Theoretically, three groups of influences could immediately impact on adolescent players. The first group of potential influence relates to performance aspects of nutrition, injury management and physical/athletic maturation. *Game sense*, defined as sophisticated displays

of initiatives during games, is also included in this first group of potential influences because it relates to an athlete's mental maturation within a team sport. The ability to objectively assess game sense remains limited. However, advances in technology now permit effectiveness of team play, and consequences of on-field initiatives to be more objectively assessed. By including potential influences on performance the framework enhances the traditional identification practices that focus on subjective coach ratings of on-field performances and physical tests.

The second major group of influences within the framework includes culture, media, and other competing activities. The social entrenchment of these influences should be not be underestimated and needs to be understood and, if appropriate, mediated. For example, sports psychologists may assist young athletes to see beyond immediate demands and set individual long-term goals for performance. Understanding influences is particularly pertinent for players from different cultures, of varying maturational status, and for whom opportunities to learn about the game have been lacking. It is possible that early physical maturers can be selected (and succeed at the adolescent level) in team sports despite inappropriate training and nutrition habits. Early success in team sports can lead to unnecessary local community and media pressures detrimental to longevity within the sport. To be more inclusive in development, coaches should work with an adolescent development specialist, cognisant with nutrition needs, appropriate injury management practices, and media influences in adolescents.

The third influence in the framework for talent development are the relationships among players, their peers, team mates, teachers, coaches, and parents (Wolfenden, 2005). Influences from key people in adolescents' lives are likely to impact players' decision making, motivation, training habits, skill, and game sense development. As players progress, the influence of coaches becomes more prominent (Cote, 1999). Coaches therefore, play a crucial role in team sports and individual talent development. Talent development issues should be included in coach accreditation and updates (Grund, 2006). Coach progression at this level should be based on long-term talent development rather than short-term team success. Adolescent longevity and fulfilled potential in a given sport should supersede goals of premierships in junior development.

Evaluation of pathways of talented adolescents within each sport could include a load monitoring/adolescent development specialist. This position is the next influence in the framework (Figure 1). The role of this person would include a practical understanding of physiology, biomechanics, nutrition and other sports science relevant to the talent development process. The position facilitates both proactive and reactive processes while providing an important monitoring role. Monitoring is needed to prioritize the activities of adolescents with a view to fulfilling athletic potential, preventing burnout and injury, and nurturing longevity of sports participation. The vision is as much individual as it is team. This person could be recruited with a combined background of the team sport, and physical education/sports science training. Athletes with this suggested background would understand the sport, understand and be respectful of coaching and teaching the sport, and be familiar with holistic approaches to working with adolescents. Practically, the role would involve frequently working on site with coaches and providing support and education at planning and parental meetings. Coordination, monitoring and education of competing demands (schools, clubs, representative teams) would be inherent in this role. This person would also provide links to a range of sport and medical services with expertise in adolescents. These experts should work interactively with each other and function within a network of sports science/medicine specialists. Various modes of communication can be used on a regular basis to support the specialist and their role. This network, combined with evidence-based, load-monitoring practices would provide the ideal platform for talent development. Accreditation and on-going education of the role should be the responsibility of the team sport's governing body.

The responsibility of implementing a holistic approach should rest with each team sport's governing body. Common practices between similar sports would permit wide-scale adaptation of the framework, but each sport should present and critically appraise specific benchmarks for the talent development pathway. Crucially, the responsibility at each stage of this development needs to be outlined.

Finally, the national sporting commissions should provide governance via a code of ethics surrounding talent development. Ideally, the code of ethics has player well-being and longevity, as well as ethical team sport behaviours as priorities. This code should be peer

reviewed, evidence based, and specific to team sports popular with team sports. The code should provide the framework for decision making at every level of participation in team sports by adolescents.

3.10 Conclusions

Talent development in team sports is a complex and dynamic interaction of social, performance, and educational factors. The pathway should acknowledge the careful progressions through periodised and educational training programs required for adolescents. The talent development framework presented here centres on an interactive approach, with the players' immediate and long-term welfare central to all programs and actions. The benefits of successful pathways in adolescent team sports extend beyond individuals and their sporting organizations. Talent development in team sports can be viewed as a sound national investment. Responsible talent development in team sports for adolescents does not lie with any single individual within the sports industry and is best accepted as a collective, complex but worthwhile challenge.

Study 1

Burgess, D. J., Naughton, G., & Norton, K. I. (2006). Profile of movement demands of national football players in Australia. *Journal of Science and Medicine in Sport, 9*(4), 334-341.

4   Study 1

4.1   Publication Overview

The following publication represents a study completed in January 2006. This study was completed prior to the popular use of portable GPS devices and hence presents movement analysis information using (now) superseded technology. This type of analysis represents physical match profiling in its most basic form. The information is presented in largely descriptive form, with comparisons offered between halves and positions. Information has also been extracted from similar studies on international domestic leagues.

The specific publication details are:

- Burgess, D. J., Naughton, G., & Norton, K. I. (2006). Profile of movement demands of national football players in Australia. *Journal of Science and Medicine in Sport, 9*(4), 334-341.

4.2 Publication - Profile of Movement Demands of National Soccer Players In Australia

Abstract

Descriptive data on game movement demands of contemporary Australian National Soccer League (NSL) players are lacking. The purpose of this study was to profile movement demands of NSL games and specifically analyse distance covered, time in various speed categories (e.g. walking, jogging, striding etc.), number of sprint speed efforts, and overall mean player speed. Video tapes of 45 players from the 2002 - 2003 NSL season were analysed for whole and half game movement patterns and game statistics using Trak Performance software. Bivariate and ANOVA statistics were used for between game halves and positional comparisons. Results showed no changes to the frequency and speed of high intensity demands in both halves of the game. However, a 14% slower overall speed in the second half of the game when compared with the first half was attributed to fewer observations of the low intensity movements (9.0% less walking and 12.4% less jogging) and more stationary periods. Engagement in game events such as kicking and passing was also 11.2% less frequent in the second versus first half of games. Position-specific results of higher movement speeds of midfield players (7.2 km.hr^{-1}), compared with defenders (6.1 km.hr^{-1}), agree with previous results from international professional leagues. The results provide position-specific directions for future conditioning drills and benchmark fitness requirements in high level soccer players. The results also highlight the challenge to ensure consistency of second-half performances for elite level soccer players in Australia.

Introduction

Movement analysis technology can increase the scientific understanding of players' energy demands, particularly in field sports where movement patterns are often spontaneous, unpredictable and difficult to quantify. Feedback from motion analysis also has the capacity to set benchmarks for desirable on-field performance from inter and intra-player comparisons, and can assist in quantifying the changes in sports and performances over time. Despite widespread use of a range of player tracking techniques, the potential application to training, talent development and monitoring game evolution remains relatively under-reported. For example, within Australia, a limited number of descriptive studies have profiled motion analysis in Rugby Union (Duthie, Pyne, & Hooper, 2003), Rugby League referees (Kay & Gill, 2003) and Australian Rules Football (Dawson, Hopkinson, Appleby, Stewart, & Roberts, 2004; Norton, Craig, & Olds, 1999) . In contrast, extensive investigations have been undertaken on the physiological demands in international soccer competitions (Bangsbo, 1994; Rienzi, Drust, Reilly, Carter, & Martin, 2000). The information in these studies ranges from sport-specific testing (Thatcher & Batterham, 2004), on-field and position-specific running speeds (Rahnama, Reilly, Lees, & Graham-Smith, 2003), to intrinsic substrate utilization and metabolic characteristics obtained from muscle biopsies of players during half time breaks (Saltin, 1973).

Movement analysis in field sports is becoming more reliable with the use of increasingly sophisticated technologies such as global positioning systems (http://www.catapultsports.com/research-validation) and computer-based tracking (Norton, Schwerdt, & Lange, 2001). This information, coupled with notational analysis on players' game involvement, is now used to conceptualize how game strategies, safety, tactics, new rules and player statistics are linked with player movement. Examples reported include game speed evolution and its link to player movement speed, rule changes and injury risk (Norton et al., 1999), frequency and type of game activities and training implications (Appleby & Dawson, 2002), positional comparisons and game-related events (Dawson et al., 2004), and time spent in game-related activities for work to rest analyses (Duthie et al., 2003; Norton et al., 1999).

The aims of this study were to (1) profile movement demands of National Soccer League (NSL) players during games; (2) compare movement patterns between the two 45 minute halves of the soccer game; (3) compare position differences in movement patterns among midfielders, defenders and attackers; (4) quantify key game events such as passing, heading and tackling; and (5) compare Australian data with movement patterns reported in international professional leagues.

Methods

Game performances from a convenience sample of 45 male players from eight NSL clubs were individually videotaped for the study. No player refused permission for videotaping of their game performance. Games taped were restricted to games played at Sydney-based stadiums. Players also represented three subgroups of field positions; midfielders (n = 15), defenders (n = 15), and attackers (n = 15). Completion of at least one half of a game of soccer at the NSL level in the 2002 - 2003 season was the criteria for inclusion in the study so the non-randomised sample used for analysis may be seen as representative of players with sufficient albeit subjective, pre-requisites to compete at the national level. Differences in numbers between halves (1st half = 45, 2nd half = 36) were indicative of 9 players being substituted during the second half of analysed games. The Ethics Committee at the Australian Catholic University provided institutional approval for this study.

Player movement was estimated from video footage using Trak Performance Software (SportsTec Pty Ltd, Sydney) from 45 individual game performances. Trained and practiced researchers were responsible for videotaping performances of individual players during games. This software system is most effectively applied with the use of a drawing tablet connected to a laptop computer. The researcher creates a scaled version of the exact dimensions of the playing field on the drawing tablet. The player being 'tracked' is then mechanically followed around the scaled field by the researcher with the aid of a drawing pen simulating the speed of movement and position on the field. Key game statistics, or 'events', are also entered by the 'tracker' using pre-programmed and game-specific keystrokes on the laptop. Events are the football-specific actions unrelated to speed, distance and position on the

field. Events therefore included kicking (passing, shooting, clearances), heading, and tackling. Passes were further sub-divided into effective (passes successfully delivered to a team mate) and ineffective passes (passes resulting in a turnover of possession or a situation of disputed possession). Data for position-specific movement requirements were accrued for separate halves and whole games. In addition, movement data and game statistics were expressed per minute of time on the field. Because only one researcher analysed data, the intra-observer technical error of measurement (TEM) was calculated at 4.6% when 5 halves were reviewed on two separate occasions. Inter and intra observer reliability has not previously been reported. Subjectivity linked to a single researcher use of Trak Performance software could be questioned if inter-observer reliability is not reported. Therefore results with other researchers using the same software on the same game were compared. Using three repeats of the same game, results showed a Pearson's correlation of r=0.98 for total distance travelled. Currently the Trak Performance software is able to be used with an acceptable error measurement level reported at approximately 5% for player distances (Norton et al., 1999) and has strong relative validity with recently published results from videotape analysis (Norton et al., 1999).

The Trak Performance software supports a measure of user-determined speed categories. The intervals were set at walking 0–7 km.hr^{-1}; jogging 7–12 km.hr^{-1}; striding 12–18 km.hr^{-1}; sprinting 18-24km.hr^{-1}; and max $\geq$24 km.hr^{-1} speeds. The number of two-second sprints was defined as the number of entries into the maximum speed zone (24 km.hr^{-1}) lasting 2 seconds or longer. Total distance was further classified according to speed categories and is expressed relative to the total time spent at these movement speeds.

Approximately 65 hours of video tapes of NSL games were analysed for comparisons of whole and half games and position-specific demands.

Following tests for normality, descriptive statistics were used to calculate means and standard deviations of movement demands. Players who completed both halves (n=36) were used for comparison across halves using paired t-tests. Comparisons of movement demands among positions were conducted using ANOVA and post hoc tests were applied where appropriate. An alpha level of 0.05 was accepted as significant. Data were analysed using Statview Version 5.0.1.

Results

Descriptive characteristics of the NSL players are presented in Table 1. Position-specific anthropometric characteristics demonstrated defenders were taller [F (2) = 7.417, p=0.002] and heavier [F (2) = 4.896, p=0.014] than both midfielders and attackers. There were no differences in the descriptive characteristics of midfielders and attackers.

	Age (y)		Height (cm)		Weight (kg)	
	Mean	SD	Mean	SD	Mean	SD
All players (n = 45)	25.9	3.3	181.1	6.4	78.7	6.1
Game halves						
1st half (n = 45)	25.9	3.3	181.1	6.4	78.7	6.1
2nd half (n=36)	24.1	3.1	181.8	6.4	79.7	5.7
Position						
Defenders (n=15)	24.6	3.7	185.6*	6.1	82.4*	5.5
Midfielders (n=15)	27.1	3.3	178.3	4.3	75.3	4.7
Attackers (n=15)	26.0	2.6	179.5	6.2	78.3	6.0

Table 1 Descriptive characteristics of national soccer league players (n = 45). * denotes differences between defenders and both midfielders and attackers

Table 2 shows a breakdown of movement variables for players completing either a full game (n = 45) or at least one half of a full game (n=36). During full games, players spent an average of 33.4 ± 5.5% walking, 37.8 ± 5.1% jogging, 18.3 ± 3.2% striding, and 7.0 ± 2.3% sprinting and 3.6 ± 2.5% at maximal effort. Whole game statistics are expressed as a total number of events.

	n	Mean	SD
Total Distance – Full game players (km)	36	10.1	1.4
Average speed – Full game players (km.hr^{-1})	36	6.7	0.7
Number of 2 s sprint efforts – Full game players	36	58	35
Walk – Full game players (km)	36	3.4	0.6
Jog – Full game players (km)	36	3.8	0.8
Stride – Full game players (km)	36	1.8	0.4
Sprint – Full game players (km)	36	0.7	2.0
Max – Full game players (km)	36	0.4	0.3
Events – Full game players	36	56	21
Distance per min - All Players (km.min^{-1})	45	0.1	0.01
Events per min – All Players	45	0.6	0.2

Table 2 Movement analysis summary for players of whole or half games in the NSL in Australia. Data are presented as mean ± SD.

Figure 1 shows the range of paired differences resulting from comparisons of movement between the two halves of NSL games. Comparison of total distance travelled shows a 5.0% greater distance in the first half versus the second half (n=36). Similarly, mean player speed was 14% greater in the first than second half. When the total distance was broken down into different types of movement, 9.0% more walking and 12.4% jogging occurred in the first half compared with the second. However, analyses of the faster movement categories between halves were not different for striding (4.2%), sprinting (3.8%) and maximal efforts (1.0%). The difference in relative distance travelled per min between the two halves of the game was

0.11 ± 0.04 km.min^{-1} [t (35) = 4.856, p<0.001]. Relative events per min were also 11.0% greater in the first versus second half [t (35) = 3.797, p<0.001].
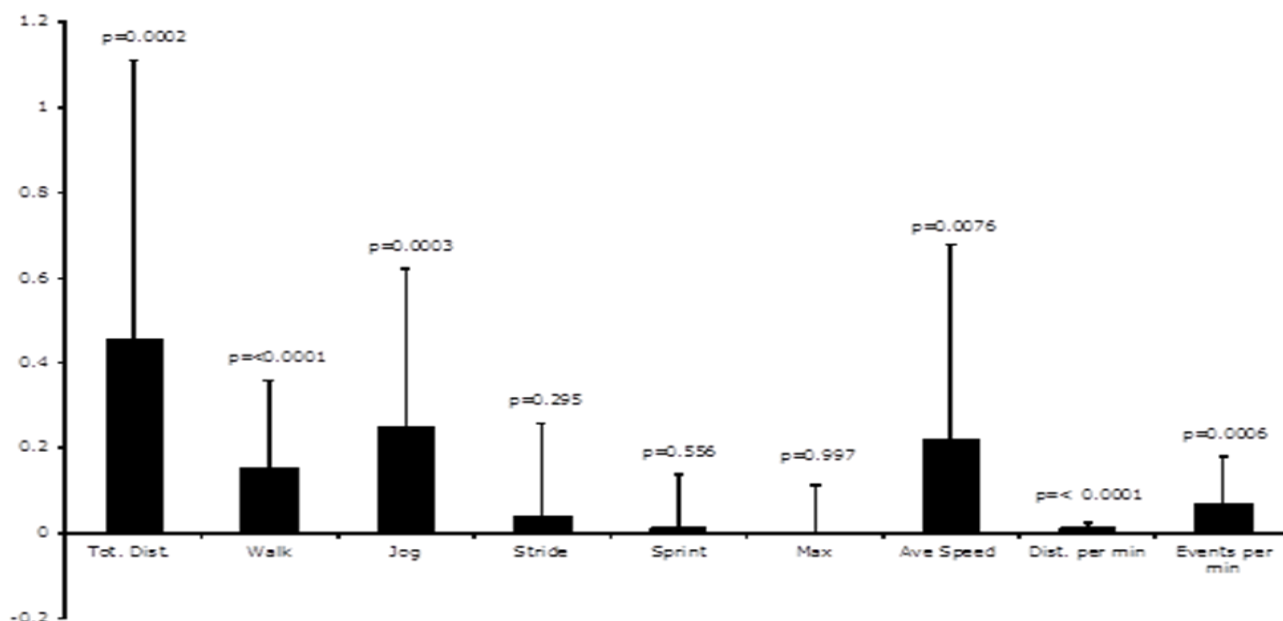

Figure 1 Range of pair-wise differences plotted for total distance, distance within each movement category and mean player speed (n=36), as well as distance travelled per minute and total game events per minute (n=45) comparing first and second halves. The figure shows standard deviation bars and p values for paired t-tests.

Table 3 demonstrates position differences as well as total values in selected movement categories and game statistics. Compared with midfield and attacking players, defenders were consistently covering less distance at a slower speed in the first half, second half, and when analysed overall. Movement analysis of midfield and attacking players across the range of movement categories presented did not differ. In contrast to movement statistics, the sum of game-related events did not differ among positions [F (2) = 2.685, p=0.07].

Measure	Defence (n=15)		Midfield (n=15)		Attack (n=15)		Total (n=45)	
	mean	SD	mean	SD	mean	SD	mean	SD
1st half speed (km.hr^{-1})	6.2	0.5	7.3*	0.7	6.9 †	0.6	6.8	0.7
2nd half speed (km.hr^{-1})	6.0	0.5	7.1*	0.7	6.9 †	0.7	6.7	0.7
Mean speed (km.hr^{-1})	6.1	0.4	7.2*	0.6	6.9 †	0.6	6.7	0.7
1st half distance (km)	4.7	0.4	5.7*	0.6	5.4 †	0.8	5.3	0.7
2nd half distance (km)	4.3	0.5	5.4	0.8	4.8	0.7	4.8	0.8
Total distance (km)	8.8	1.2	10.1*	1.9	9.9 †	1.5	10.1	1.4
1st half distance per min (m.min^{-1})	104.2	1	123.4*	1.1	117.1†	1.9	114.2	1.5
2nd half distance per min (m.min^{-1})	93.1	1.3	114.9	1.4	116.7	1.5	109.7	3.5
Total distance per min (m.min^{-1})	98.3	1.1	118.4*	1.3	115.1†	2.1	110.6	1.6
Total walking (km)	3.2	0.6	3.5	0.4	3.5	0.8	3.4	0.6
Total jogging (km)	3.5	0.6	4.3	0.9	3.7	0.9	3.8	0.8
Total striding (km)	1.5	0.3	2.1*	0.5	1.9 †	0.3	1.8	0.4
Total sprinting (km)	0.6	0.2	0.8	0.2	0.8	0.2	0.7	0.2
Total max (km)	0.3	0.2	0.4	0.2	0.5	0.3	0.4	0.3
Total events	51	9	68	15	50	18	56	21
Total events per min	0.6	0.1	0.7	0.3	0.6	0.2	0.61	0.23

Table 3. Comparison of position (defence, midfield, attack) across a number of movement and game-related variables. Values for total group are presented also.* denotes statistical differences between midfielders compared with defenders and † denotes statistical differences between attackers compared with defenders (p<0.05).

Table 4 indicates measures related to game speed and efficiency of play. During the first half, all players completed more effective passes than during the second half [t (35) = 2.895, p=0.002). The total time in play and at stoppages and the length of individual play and stop periods did not differ between halves [t (35) = 1.19, p=0.12]

Measure	First half		Second half	
	mean	SD	mean	SD
Play time (min)	29.84	3.95	28.47	2.36
Stop time (min)	16.83	3.15	19.83	2.08
Number of play periods	62	11	63	7
Number of stop periods	61	7	62	7
Average play period (min)	0.50	0.48	0.45	0.4
Average stop period (min)	0.28	0.24	0.32	0.26
Effective passes*	15.39	6.59	11.09	6.09
Poor passes	4.15	3.36	3.91	2.98
Effective passes per min	0.33	0.14	0.29	0.15
Poor passes per min	0.12	0.10	0.10	0.07

Table 4: Markers of game efficiency in players during national league soccer games (N=45). * denotes greater number of effective passes completed in first half when compared to second half [t (35) = 2.895 p=0.002].

Discussion

Advances in player tracking technology have offered opportunities for new knowledge in Australian elite level soccer. Contemporary results permit comparisons across time, within Australia, and to international professional leagues. Results also provide benchmarks for player demands in game events and movement categories that can be used for simulating competition and conditioning drills.

Player movement profiles

The present study represents one of only two studies carried out on game movement profiles in Australian Soccer. The previous study (Withers R T, 1982) analysed 20 Australian players in 1980 and found the average distance travelled was 11.5 km; 1.5 km further than the present study. The previous study used video analysis and calibrated player distances using recordings of player steps while moving across defined distances at different speeds. Decreased distances observed in the present study are unlikely to reflect greater fitness of the players in prior times. Rather, they are more likely to result from methodological changes between the studies or perhaps differences in playing style in which the contemporary coaching emphasis is on making the 'ball do the work'.

First half versus second half

Differences were found between the first and second half movement patterns. Types of movement patterns did not equally contribute to the decreased distance covered in the second half of the observed games. A greater distance was covered at low intensity such as walking and jogging in the first, compared with the second, half of the game. No differences between halves were reported in distances covered in the high intensity categories of striding, sprinting, and maximal running.

Despite equal time of both halves of the game, the second-half distances and mean speeds were lower. Since the only speed category differences were at the lowest speeds then a greater proportion of the second-half was spent standing or moving at a slower speed [figure 1].

Similar between-halves results were reported with Danish soccer professionals, who demonstrated a 5% shorter distance in the second half when compared to the first(Bangsbo,

Norregaard, & Thorso, 1991). South American professionals produced a 6% slower first than second half during domestic and international competitions (Rienzi et al., 2000). At a lower level of competition, movement analysis results from the Belgian university games showed a 9% lower distance travelled in the second half, despite negligible differences in the distance travelled at higher intensities between halves (Van Gool D, 1987). Elite Italian soccer professionals also travelled less distance in the second half when compared to the first, however, their Danish counterparts covered similar distances in both first and second half periods (Mohr et al., 2003).

Players in the present study were able to repeat an equivalent amount of high intensity running in both the first and second halves. This provided a contrast to previous elite European leagues where high intensity sprinting declined in the second half (Mohr et al., 2003). The elite Italian international players examined by Mohr and colleagues (Mohr et al., 2003) commenced the game working at much higher speeds than they finished, as indicated by high intensity running in the first 15 minutes when compared to the last 15 minutes. In our study, the game intensity may not have been high enough to significantly deplete muscle glycogen stores and elicit a significant fatigue response, and therefore high intensity running was maintained throughout the match. Second half compromises in our study were observed only in lower speed movement perhaps suggesting players may selectively spare energy for more crucial high intensity efforts and reduce the incidence of less important low intensity running (Bangsbo, 1994). In effect, energy efficiency or conservation of muscle glycogen may be a more important characteristic than fatigue per se during the second half game performances of elite soccer players in Australia. However, greater resting intervals between the high-intensity efforts in the second half would also facilitate the ability to repeat these efforts later in the game, even in the face of physiological fatigue. Given the possible advantage of greater movement ability equating to greater game involvement (Helgerud et al., 2001), this suggests the ability to prolong fatigue as probably an important variable in elite Australian soccer performance. The interactive effects of game tactics and fatigue, particularly in the second half, remain unclear.

Player effectiveness can be characterised by the combining markers of energy expenditure and direct engagement in game tactics or ball contact. Notational analysis used in the present

study permitted analysis of running intensity and overt game engagement (events per minute). Despite sustained high intensity running in the second half, overall opportunities to engage in play decreased. In addition, the number of effective passes declined in the second half when compared to the first. Therefore, decreased player effectiveness was observed during the second half. This may highlight the importance of continual player movement to create opportunities for attacking plays, and add further advantage to the player who has the ability to prolong both mental and physical fatigue. For example, in situations when a team is in possession, attacking players would be advantaged by creating open space for team members. In effect, the desire to reduce 'player density' is precisely what teams in possession of the ball want to do. Alternatively, defending teams want to increase player density by closing up open spaces for the team in possession. Overall, the more successful teams may be those who have the fitness and sustained effort to maintain movement rates across the whole game and increase the probability of strategic opportunities. Enhanced work intensity, increased distance travelled as well as a greater number of game involvements have been attributed to greater aerobic endurance (Helgerud et al., 2001).

In Australian Rules football, slower speeds in the first half when compared in the second half is reported (Dawson et al., 2004). However, the capacity to identify the types of movement slowing the action among current NSL players adds new knowledge. For example, the slower second half suggests the need for a greater focus on threshold training to delay the implementation of decisions that compromise low intensity on-field movement. Players going into the second half with expectations of increased movement and game statistics combined with sustained intensity of play may be well placed to outperform opponents. It is not known how much reduced player effort in the second half is psychological versus physiological. It is possible that factors such as closeness of scores, crowd participation, ladder position etc. could reflect effort, however further investigation of these factors is required. Interestingly, average player speeds immediately after the half-time break in Australian football have been reported as slow and gradually increasing over a period of about 5 minutes suggesting a mental element was important[11]. However, these authors also showed average player speeds were highest after other longer stop (rest) breaks and then declined in a typical human power function curve. Similar analyses are yet to be conducted on Australian soccer players,

although studies on Italian soccer players also found greater intensity after rest intervals (Mohr et al., 2003).

Positional Comparisons

In the present study, players who covered greater distances had greater involvement in game events. However, this result was not consistent among positions. When compared with midfielders and attackers, defenders were covering less distance, and at a slower average speed but with similar frequency of engagement in event statistics. Therefore, defenders may rate higher on 'effectiveness' since less overall effort (distance covered) is required for similar game involvement. It is possible that this high player effectiveness is characteristic of a defender. For example, particular game strategies may require backward passing to, and strategic moves by defenders resulting in greater events per min than other positions. Alternatively, players with a more natural ability to 'read the play' or anticipate opposition moves may be selected for the defender positions through success.

There were no differences in movement categories between midfielders and attackers in the present study. The role of the midfielder as a 'link' between forwards and backs has led to most research estimating greater distances travelled by midfielders when compared to forwards and defenders (Rienzi et al., 2000). It may be that, in Australian soccer, there is less tactical differentiation between midfield and attacking positions, possibly due to a greater defensive tendency and encouragement by coaches to have more players 'behind the ball'.

Game events

Events per minute showed higher first than second half engagement in play, in line with player movement patterns, but no differences among defenders, midfielders and attackers. The lack of differences for position-specific events per minute compare favourably with position comparisons involving tackles, headers, ball contacts, turns and jumps previously reported on Australian players (Withers R T, 1982). From a training perspective, expectations of play engagement should not differ among positions.

International comparison

Within the limitations of differing methodologies, previous international comparisons have demonstrated higher level players actually spend less time in higher intensity movements than lower league players (Van Gool D, 1987). A comparison of international players from South America and the domestic English Premier League found the English players performed at a higher intensity and travelled greater distances than the South American players (Rienzi et al., 2000). This difference was attributed to the tactical differences involved between the South American international and English domestic competitions with an overall higher speed during domestic matches. Similarly, comparisons between semi-professional Australian players in the present study and professional overseas players show greater distances covered by Australian players. More movement may be indicative of a lesser tactical influence rather than a greater physical capacity of Australian players

Our study reports maximal sprints occur 58 times during a game which equates to one maximal effort approximately every 96 seconds. Similarly, other reports estimate players sprinting all-out only once every 90 seconds (Reilly T, 2003).

The average game speed in the present study was 6.7 km.h^{-1}. The speed is again in the upper range of international player speeds. Relatively large studies have reported average speeds of 5.7 km.h^{-1} for South American players, 5.8 km.h^{-1} for English players and 7.6 km.h^{-1} for Asian players (Yamanaka K, 1987). Current trends suggest the highly skilled international league professionals are more efficient in tactical movement patterns relative to their Australian counterparts.

Limitations

A limitation of the current study is the subjectivity associated with tracking-based analysis. Despite the reporting of inter and intra-observer reliability and similarities with other studies, results need to be interpreted within the errors reported in this paper and elsewhere (Edgecomb & Norton, 2006). Generalisability of results is also restricted to recent NSL players but serves the purpose of adding new knowledge to the understanding of training specificity and efficiency.

The bias associated with one game per player needs to be acknowledged (Bangsbo, 1994) however the results from an average of 15 players per field position may be seen as acceptable representation of NSL performance (O'Donoghue, 2004).

Conclusion

The usefulness of motion analysis software extends beyond advancing the understanding of physiological demands of player position and altered sustainability in elite soccer in Australia. Training and or coaching could re-focus on event successes as a form of biofeedback to players as well as game strategies. Targets of game best practice could be duplicated or exceeded in training and definitive benchmarks set for aspiring junior players. Results from the game analyses of NSL players in Australia serve the purpose of providing reliable data to describe contemporary performance, allow international benchmarking, and help improve conditioning prescription of elite and aspiring soccer players.

We contend skill, tactical soccer game sense and movement efficiency are characteristics of elite international soccer players and should be a major focus of training and development for national league players in Australia.

Practical Applications

- Advancing technologies offer new support for sports science in Australian Soccer
- Work rates and movement profiles of players in elite Australian competition are similar to overseas profiles. However relatively few Australian players are successful in elite international soccer leagues. This suggests Australian players seeking overseas contracts should look to enhance skill and tactical awareness.
- Simultaneous decrements in work rates and effective game statistics in the second half of games imply players seeking advanced professional status may need to improve game-specific fitness.
- These results add new knowledge to the physical requirements of elite soccer in Australia.

Study 2

Burgess, D., Naughton, G., & Norton, K. (2012). Quantifying the Gap Between Under 18 and Senior AFL Football: 2003-2009. *International Journal of Sports Physiology and Performance, 7*(1), 53-58

5 <u>Study 2</u>

5.1 Publication Overview

The following publication represents a study completed in March 2011.

This paper provides an extension on Study 1 in both study design and technologies employed. The study offers movement analysis over a 5 year time period and therefore can examine trends in both U18 and senior AF. This study also introduces portable GPS devices into the thesis, providing the technology used for the 2009 analyses.

The specific publication details are:

- Burgess, D., Naughton, G., & Norton, K. (2012). Quantifying the Gap Between Under 18 and Senior AFL Football: 2003-2009. *International Journal of Sports Physiology and Performance, 7*(1), 53-58

As the paper is yet to be published the details of its acceptance have been placed as Appendix 9.6

5.2 Publication – Quantifying the Gap between Under 18 and Senior AFL Football: 2003-2009

Abstract

Purpose

The understanding of the gap between Under 18 years and senior level competition and the evolution of this gap in Australian Football, lack a strong evidence base. Despite the multimillion dollars invested in recruitment, scientific research on successful transition is limited. No studies have compared individual players' movement rate, game statistics and ball speed in U18 and senior competition of the Australian Football League across time.

This project compared differences in player movement and ball speed between matches from senior AF competitive matches and U18 players in the 2003 and 2009 seasons.

Methods

TrakPerformance Software and Global Positioning System (GPS) technology were used to analyse the movement of players, ball speed and game statistics. Analysis of variance (ANOVA) compared the two levels of competition over time.

Results

Observed interactions for distance travelled per minute of play ($p = 0.009$), number of sprints per minute of play ($p < 0.001$), time spent at sprint speed in the game ($p < 0.001$), time on field ($p < 0.001$), and ball speed ($p < 0.001$) were found. Subsequent analysis identified increases in movement patterns in senior AF competition in 2009 compared with the same level of competition in 2003 and U18 players in 2003 and 2009.

Conclusions

Senior AF players in 2009 were moving further, sprinting relatively more frequently, playing less time and playing at game speeds significantly greater than the same senior competition in 2003 as well as compared with both cohorts of U18 players.

Introduction

Talented footballers are recruited in the National Australian Rules Football League (AF) draft from the age of 18 years. However, it is an exception rather than a rule that drafted players advance directly into the senior team playing in the national competition. Typically, a transition period of one to four years occurs, during which less experienced recruits play second tier games in state-based competitions and are irregularly exposed to the highest professional competition. Eventually, players with the necessary attributes to succeed in the senior competition will be more consistently included in first-grade. The transition period represents an apprenticeship during which players refine their skills and develop physically to manage the rigours of AF.

Financial investment in player development programs in professional AF environments has increased considerably as teams look to fast-track players' capabilities. However, finding the balance between appropriate physical overload and overtraining remains challenging. Therefore, modified strength and conditioning programs are common for players in both the feeder competitions such as the under 18's leagues (U18), and once they are in professional AF clubs. Although speculative, it appears most of these programs are founded on experience and subjective opinion rather than scientific evidence. However, the level of confidentiality within professional clubs means the specific program details are rarely published.

Quantifying differences between game movement patterns (distances, speeds and overall work rates) of talented U18 players and elite senior AF players may advance physical preparation for induction programs to senior competition. A smoother transition from U18 to professional AF may serve multiple goals. Targeted objectives include increased motivation, player longevity, decreasing injuries and developmentally suitable progressive loading.

Motion analysis in Australian football games is frequently reported in public and scientific domains (Wisbey et al., 2010). However, the vast majority of scientific reports and media telecasts focus on elite level competition. The first standardised benchmark of the

physiological capability for aspiring elite players occurs at the National Australian Football Draft Camp (www.afl.com.au/draft/tabid/282/default.aspx). Results from camp testing comprise mostly of objective physical, psychological and medical assessments. Traditionally, talent identification combines objective test outcomes and subjective match performance assessments conducted by AF club talent scouts and coaches.

Limitations of existing AF talent identification processes include; the relevance of selected draft tests to on-field performance (Pyne et al., 2005), an inadequate number of assessment opportunities, pressure associated with the assessment environment, and subjective scout-dependent game performance ratings. Objective measures of match performance from movement analysis technology can complement subjective player ratings and may also be useful in quantifying the progression required between U18 and senior level match performance.

A better understanding of differences in the game structure between U18 and senior games could guide training interventions for induction programs. The understanding refers to variables such as the duration of play and stop periods, number of stoppages in a game, total time played, player density and game speed assessed using ball speed analysis (Norton et al., 2001). For example, within the last decade of AF, game speed during senior matches has generally increased, while total play time has increased and stoppage time decreased and player density in the 2010 season was at the highest level measured (Norton, 2010). Changes to speed and stoppages have significant implications for player work-to-rest opportunities and overall game demands (Wisbey et al., 2010). Availability of similar, objective data at U18 level and the trends over time remain unknown. Accurate player movement data, combined with knowledge of game structure and speed experienced by both U18 and senior AF players over time should provide quantifiable benchmarks for training and playing expectations and may also influence draft selection.

Therefore, the aims of this study were to compare: (1) player movement and game speed between current U18 and senior AF players, and (2) player movement and game speed changes between 2003 and 2009.

Methods

Player Movement Analysis

Ethics approval was provided by the Australian Catholic University. A total of 64 players were analysed during competitive games at the 2003 National U18 AF Championships and 64 players during matches of the premier U18 AF competition (Teal Cup) in 2009. Data from senior AF were collected on 64 players throughout the 2003 and 2009 AF seasons. This time period was selected as it reflects the onset of popular use of motion analysis within the AF. A 5 year period is deemed an appropriate length of time to determine whether a player will be, or has been successful in AF. Match performance data were included if players completed at least 50% of playing time. Any period less than 50% may result in artificially high player speeds as greater rest for players would allow them to produce greater physical output.

Player movement was analysed for 2003 matches using computer-based tracking software (CBT; TrakPerformance, SportsTec, Australia) for senior and U18 competition. This software system relies on tracking skills and is most effectively applied using a drawing tablet connected to a computer (Edgecomb & Norton, 2006). A scaled image of the playing field was placed on the drawing tablet. The player to be 'tracked' was followed around the miniaturised field by the tracker with the aid of a drawing pen. Custom video footage of individual players was viewed after each game and retrospectively analysed. Variables of interest were; total distance covered per minute of game time (player speed in m/min), sprints per minute (where the sprint velocity was > 20 km/hr for a duration of >2 s), the percentage of total playing time at sprint speed (>20 km/hr), and the player's game time. Results expressed relative to time were used because absolute variables would be influenced by player time on field. Fundamental game statistics (kicks, handballs, marks and tackles) were also entered using keystrokes on the laptop. For trend analysis, these values were combined to represent total ball engagement by the player during the game. In 2009, data collection involved global positioning systems (GPS) and game statistics available through the public domain (Champion Data, Victoria, Australia -www.championdata.com.au).

The same GPS devices ('SpiElite', GPS Sports, Canberra, Australia) were worn by both U18 and senior AF players during matches. The CBT and GPS tracking devices have acceptable reliability when compared with an odometer for precision of distances covered (TEM = 4.7 and 5.5%, respectively)(Edgecomb & Norton, 2006). While GPS accuracy is essentially independent of the user, CBT relies on smooth and accurate movements by the tracker. In this study the trackers used repeated video analysis to track the player and had to demonstrate an intratester technical error of measurement (TEM) of less than 5% prior to data collection. The intertester reliability estimate for CBT has been shown to result in a TEM of about 5% (Edgecomb & Norton, 2006). Intertester TEMs in the present study were less than 7% using the same procedures.

Additional research suggests similar GPS technology elicits an average error 4.7% for total distance and a coefficient of variation of 5.8% for maximum speed(Coutts & Duffield, 2010). Previous CBT analysis of senior AF matches also demonstrates tracking distances were within 2% of values using video analysis of players(Dawson et al., 2004; Edgecomb & Norton, 2006). Furthermore, comparisons of CBT and GPS during a Rugby Union circuit demonstrated acceptable agreement over varying running intensities(Hartwig, Naughton, & Searl, 2010) (Hartwig et al., 2011).

Game Speed

An additional feature of CBT is the capacity to apply tracking technologies to ball movements during game play. For the U18s, 36 quarters were measured during each of the 2003 and 2009 seasons. For senior competition, 19 quarters were measured during the 2003 season and 50 quarters during the 2009 season. The ball tracking analysis allowed the following variables to be determined; game (ball) speed (m/s), distance the ball travelled during play periods (m), average number and duration of play and stop periods, and total play and stop time per quarter (s). Repeated measures using the same quarters of football found the TEM to be no different to those reported for tracking player movements (<5%).

Statistics

Results from continuous variables of player movements included player speed, number of sprints and game events per minute, and percentage of time spent sprinting. Game speed was calculated by dividing the total distance the ball travelled by the total time of each quarter. Comparisons between U18 and senior AF variables across time were assessed using ANOVA with two levels of play (U18 and AF) and two fixed time periods (2003 and 2009). T-tests assessed mean changes within each competition across time. Effect sizes (ES, Hedges ĝ) were calculated and 95% confidence intervals estimated (95%CI). Effect Sizes between 0 and 0.3 were considered small, 0.31 to 0.6 moderate and scores above 0.6 were considered large. Statistical analyses were performed using SPSS version 17.

Results

Player Speed

	U18				Senior AF				Between Groups Comparison		Year * Competition Interaction		
	2003 (mean ± SD)	2009 (mean ± SD)	p value	ES	2003 (mean ± SD)	2009 (mean ± SD)	p value	ES	2003 p value	2009 p value	f value	df	p value
Dist/ min	113.07 ± 17.1	118.94 ± 14.13	0.036	0.474 (-3.089 – 2.345)	121.19 ± 14.74	134.02 ± 12.09	< 0.001	0.951 (-3.281 – 1.389)	0.005	<0.001	6.899	1 252	0.009
Sprints/ min	0.44 ± 0.25	0.54 ± 0.29	0.052	0.369 (-0.414 – -0.320)	0.51 ± 0.28	0.65 ± 0.23	0.002	0.547 (-0.588 – -0.499)	0.163	0.015	0.648	1 252	0.421
% Sprint	3.31 ± 1.45	3.78 ± 1.27	0.052	0.345 (-0.579 – -0.107)	3.89 ± 1.11	6.22 ± 1.78	< 0.001	1.559 (-1.818 – -1.304)	0.012	<0.001	27.24	1 252	< 0.001
Stats/min	0.33 ± 0.16	0.42 ± 0.17	0.669	0.546 (-0.571 – -0.513)	0.33 ± 0.15	0.34 ± 0.17	0.581	0.063 (-0.090 – -0.034)	0.906	0.827	3.58	1 252	0.060
Game time (min)	81.13 ± 16.5	77.16 ± 16.5	0.176	0.241 (-2.619 – 3.098)	102.81 ± 20.37	93.55 ± 10.3	0.002	0.243 (-2.228 – 3.368)	<0.001	<0.001	32.94	1 252	<0.001
Game Speed (m/s)	3.186 ± 0.39	3.283 ± 0.38	0.295	0.286 (-0.343 – -0.225)	3.110 ± 0.30	4.142 ± 0.35	< 0.001	3.166 (-3.204 - -3.091)	0.471	<0.001	51.26	1	< 0.001

Table 1. Comparison of player and game profiles of senior and AF matches between 2003 and 200

Table 1 shows the variables measured in the two competitions across time. The average distance per minute players travelled increased in both levels of competition from 2003 to 2009. This was about 5 m/min in U18 and 13 m/min in AF, resulting in a year by competition interaction [$F_{(1,252)} = 6.899$, p <0.009]. Within group comparisons between years showed the magnitude of change over time for AF players (large $ES = 0.95$) was greater than U18 (moderate $ES = 0.37$).

A statistic often used is the number of sprints performed per minute of play (sprints/min). No changes in sprints per minute were observed across the seven-season time span at U18 level (moderate $ES = 0.34$), but a 12% increase occurred at the AF level (moderate $ES = 0.56$). However, no interaction between year and competition was found [$F_{(1,252)} = 0.648$, p = 0.421].

Despite minimal changes in the number of sprints per min, the percentage of time spent sprinting showed a large year by competition interaction [$F_{(1,252)} = 27.252$, p <0.001]. The increase in time at sprint speed within-group was equal to 14% at the U18 level (moderate $ES = 0.35$) and 60% for the AF players (large $ES = 1.56$).

Statistics per minute (stats/min) is a way to represent game involvement by players and includes a count of the number of tackles, kicks, marks and handballs players encounter during the game. In contrast to changes in the movement variables investigated, stats/min remained unchanged between 2003 and 2009 in both the U18 (moderate $ES = 0.546$) and AF (small $ES = 0.063$) competitions [$F_{(1,252)} = 3.581$, p = 0.06].

Differences were observed for players' average game time in both competitions across time. Year by competition interaction [$F_{(1,251)} = 32.941$, p <0.001] can be attributed to the relatively unchanged time on field for U18 (small $ES = 0.08$) players across the study but a 9% decrease over the same time for AF (moderate ES = 0.57) players.

At the U18 level, between 2003 and 2009 game speed remained similar (small $ES = 0.29$). In contrast, a 25% increase was evident in game speed across the same time period in AF (large $ES = 3.17$). The differences between the two levels of competition over time again supported a significant year by competition interaction [$F_{(1,251)} = 51.26$, p <0.0001].

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Discussion

The present study demonstrated differences for a number of player movement and match speed profiles in both U18 and senior AF competitions between 2003 and 2009. Within-group changes at U18 level were significant only for player speed (dist/min). At the AF level, increases were found in player speed, percentage of time spent sprinting, number of sprint efforts per minute and overall game speed, along with a decrease in overall time on the field. The only variable failing to show changes over time for AF players was the number of match statistics per minute. Interaction effects were found in player speed, the percentage of time spent sprinting, time on field and overall game speed. These patterns of change show the gap between the two levels of competition has widened markedly in a short period of time. Rapid evolution of game intensity and player demands are characteristic of early development in professional sport (Bradley et al., 2009b; Meir, Newton, Curtis, Fardell, & Butler, 2001; Norton & Olds, 2001; Stolen, Chamari, Castagna, & Wisloff, 2005). A significant gap between U18 and professional ranks can lead to a longer period of transition or urgent strategies are required to fast-track physical and skill development of early recruits at the elite level.

Player Speed and Movement

The physical demands of senior players in the AF have previously been objectively estimated by separate groups using video analysis (Dawson et al., 2004), and tracking software (Norton et al., 2001; Norton, 2010). Since these two studies were completed in the same season they represent relative validity in analytical methods. In the present study, physical demands were estimated from a combination of CBT and GPS tracking technologies. Despite acknowledged limitations, acceptable intratester and intertester reliability has been established with the CBT system and reasonable agreement with GPS tracking devices has been shown (Hartwig et al., 2011). The same systems and trackers were used across the duration of the present study which also helps to reduce measurement error.

The comparison between AF and U18 players over time confirmed predicted increases in player 'movement loads' during senior AF games. As expected, in 2003 the physical requirements of elite U18 competition were less than AF game demands in all variables measured. In 2009 this trend continued, but importantly the gap between the competitions in these movement loads increased significantly. Similar trends have been seen in football (Bradley et al., 2009b; Stolen et al., 2005) and Rugby League (Meir et al., 2001). In general, as sports evolve, the level of professionalism and competition for selection and game success increase, and the overall demands are also elevated (Norton & Olds, 2001). Consequently, as the AF has rapidly developed into a full-time professional sport, the game intensity and physical demands have increased substantially. Concomitantly, the part-time U18 competition has improved, but to a lesser degree.

At U18 level, only player speed increased across the seven years of the study. Within the senior AF cohort, all movement variables increased over time. Interestingly, decreases in average playing time occurred in both competitions, reaching significance for the AFL players only. However, when the playing time was combined with player speed, total distances players travel per game remained relatively stable over time. The important change was the rapid increase in time spent sprinting at the AF level (Large $ES = 1.56$). While players are spending less time on the ground, the intensity at which they work has risen dramatically. Despite the required increases in physical output, game involvement by players remained stable across time. Therefore, modern day AF players are required to work harder in games in order to achieve the same level of game involvement they had previously.

A lower absolute level of distances covered in all speed categories at the U18 compared with senior AF level has been described previously (Veale, 2009). This trend presents the AF coaches with enormous challenges when preparing U18 players for AF match play. Presumably, the U18 players are prepared physically for their match intensities. However, these intensities can be as much as 50% (in the case of time spent sprinting) below AF intensities (2 min 55 s vs. 5 min 49 s sprinting between competition levels in 2009). Moreover, in 2009 the differences in total distance (3080 m) as well as distance covered in sprinting (386 m) between the competitions were substantial. Practically, this means training of recently drafted U18 players in AF squads needs to be strategically progressed from U18 to AF

workloads and intensities. One common method of introducing recently drafted U18 players to AF match intensities is to expose these players to sub-elite games (WAFL, SAFL, VFL). These competitions have also been found to be below AF player speeds (Brewer et al., 2010), but may represent an 'mid-point' in match intensity between U18 and AF competitions.

Caution must be applied when selecting U18 players for senior matches in their first year of AF. Regular player monitoring and assessment dictates when a player is physically able to cope with AF matches and recover appropriately. Specifically, repeated sprint capacity and overall body strength should be developed and regularly assessed in order to mitigate the potential for injuries occurring in talented young players. These capacities can be monitored using a number of indices (Crewther, Gill, Weatherby, & Lowe, 2009; Dupont et al., 2010; Fulcher, Hanna, & Raina Elley, 2010; Rampinini et al., 2009b). Appropriate indices include individualised player feedback, football history, training load experience, and physical maturation.

Game Speed

Game speed (measured as ball speed) is an index of game intensity and may reflect the speed required for decision-making and physical movement. It can also represent increases in skill execution and the ability to rapidly carry the ball, or to accurately pass to other players without touching the ground. Furthermore, game speed may be a useful measure of the impact of rule changes such as those encouraging quicker re-starts after a stoppage or even game tactics such as the use of slow plays or strategies to 'waste time' (Norton, 2006). Tracking the movement of the ball is useful for monitoring the evolution of the game and quantifying the impact of rule changes and tactics on game structure (Norton & Olds, 2001; Norton, 2010). Between-competiton game speeds in the 2003 season did not differ but increases were apparent by 2009. The differences were identified by increases in the senior AF game speed (large *ES* = 3.17), but not U18 competition.

The results may be explained by differences in both game structure and physiological demands. The duration of the quarters was shorter for U18 than AF. For example, in both 2003 and 2009, the average duration of each U18 quarter was approximately 80% of the senior time. A typical 2003 quarter also had more total play time (where the ball is 'in-play')

for senior AF than U18. In 2009, the quarter length was unchanged for both levels but the fraction of play time within the quarter had risen significantly in senior AF (Norton, 2010). Since it is a well-known phenomenon that average human power drops over time (or across quarters) this suggests there should be less of a speed decrease in the U18 compared to that in AF level. Intuitively, the effect of these changes could decrease the game speed of the senior competition and not alter the U18 speed. Negligable increases in game speed were observed in the U18's but a very large increase occurred in senior AF games. In other words, despite AF games having longer play time within the quarters, game speed was elevated. This is almost certainly related to the reduced individual game time for AF players who regularly rest on the sidelines. When they return to the field after recovering they exhibit greater running intensities. This further demonstrates the impact of the relatively greater change in demands required of AF players.

One of the major strategic changes in the AF competition during the study period was the accelerated use of interchange players. The interchange rules in the AF allow unlimited players to be rotated on and off the bench during the game. This resulted in a three-fold increase in the interchange rate from an average of 27 per team per game in 2003, to 91 in 2009 (and 117 in 2010) and helped to advance the game speed because fresh players were rotated for fatigued players. Additionally, in 2006 some minor rule changes were introduced in order to reduce the time the ball is out of play. For example, reduced time has been allowed for goal shots, kick ins, free kicks, boundary throw ins and ball-ups. Subsequently, the sum of all the stop periods decreased in the senior games by 28% while it increased in the U18 games by 17% (Norton, 2010). Despite structural changes that would tend to reduce game speed in the senior games and increase it in the U18s, the reverse was found. The explanation lies in the escalated use of interchange players and probably greater training levels, fitness and game demands within the professional ranks.

The implications for the 'step-up' required for U18 players are substantial. Results for the time period analysed support greater selectivity of U18 players who can tolerate these increasing physical demands. Just as importantly, talented junior players unable to adapt would be 'de-selected' either via performance ratings or repeated injury. The ability to minimise the gap by increasing the physical capabilities of U18 players is difficult as training sessions are

necessarily less frequent here than in professional ranks. To minimise injury and increase physical resilience, training strategies such as those designed to increase maximal aerobic speed, repeated sprint training and the use of small sided games have been suggested (Dupont, Akakpo, & Berthoin, 2004; Gabbett, 2006b; Helgerud et al., 2001; Iaia, Rampinini, & Bangsbo, 2009; Sheppard, Gabbett, & Borgeaud, 2008). At this stage however, no one form of training has proven superior to others in preventing injury or maintaining career longevity, particular in the early transition phases of competitive development.

Practical Applications

Overall, the gap between U18 and senior AF movement and game demands is increasing thus making the transition from elite junior to elite senior match play more challenging today than ever before. This trend has implications for preparing talented aspiring AF players for elite senior competition. It is apparent that successful U18 players may need to be supplemented with modified conditioning and access to professional sports medicine services across the transition period from junior to elite level in order to prepare fully for the demands of AF match play.

Study 3

Burgess, D., Naughton, G., & Hopkins, W. (2012). Draft-Camp Predictors of Subsequent Career Success in the Australian Football League. *International Journal of Sports Physiology and Performance, (In Press)*

6   <u>Study 3</u>

6.1   Publication Overview

The following publication represents a study completed in June 2011.

This study is the final study in the thesis and provides broad application of the use of portable tracking technology. Here we demonstrate how quantifying match loads can assist in Talent Identification and improve current practice.

The specific publication details are:

- Burgess, D., Naughton, G., & Hopkins, W. (2012). Draft-Camp Predictors of Subsequent Career Success in the Australian Football League. *International Journal of Sports Physiology and Performance, (In Press)*

As the paper is yet to be published the details of its acceptance/review have been placed as Appendix 9.7

6.2   Publication – Draft-Camp Predictors of Subsequent Career Success in the Australian Football League

ABSTRACT

Objectives

The National Draft Camp results are generally considered to be important for informing talent scouts about the physical performance capacities of talented young Australian Rules Football (AF) players. The purpose of this project was to determine magnitude of associations between five year career success in the AF and physical draft camp tests, final draft selection order and previous match physical performance.

Design

Physical testing data of 99 players from the National Under 18 (U 18) competition were retrospectively analysed across 2002 and 2003 National Draft Camps. Physical match data was collected on these players and links with subsequent early career success (AF games played) were explored.

Methods

TrakPerformance Software was used to quantify the movement of 92 players during competitive games of the National U 18 Championships. Linear modelling using results from

draft camp data involving 95 U 18 players, along with final draft selection order, was used to predict five year career success in senior AF.

Results

Multiple U 18 match variables demonstrated large associations (sprints/min = 43% more games, %sprint = 43% more games) with five year career success in AF. Final draft order and single variable predictors had moderate associations with career success. Neither U 18 matches nor draft camp testing was predictive of injuries incurring over the five years.

Conclusions

Variability in senior AF career success had a large association with a combination of match physical variables and draft test results. The objective data available should be considered in the selection of prospective player success.

Introduction

Talent identification in team sports is a multi-million dollar activity with layer salaries in popular professional sports place increasing pressure on talent identification and player recruitment. However most talent identification practices are based on historical practice rather than use of identification models prevalent within the literature (Gabbett, Georgieff, & Domrow, 2007; Reilly, 2000; Vaeyens, 2008). Discovering new talent, ensuring productive development, and anticipating future injuries among talented young players, all form crucial elements of successful talent identification in team sports.

Talent identification is an attempt to identify athletes with the potential for success in their particular sport. In the Australian Football League (AF), the National Draft Camp (now called AF Draft Combine) provides an opportunity for the league to conduct standardised testing. The results of the tests may be used to influence draft selection order at the subsequent National Draft. The four day event is similar to the National Football League (NFL) Combine and requires invited under 18 years' competition (U 18) players to complete physical, psychological, medical and skill-based assessments. Representatives from each AF club use the testing information collected at the draft camp as part of their decision making process when choosing players to draft to their clubs. The objective measures from the draft camp usually supplement previous subjective information gathered from talent scouts who view the various players in competitive matches, often over several years.

Prediction models for single discipline sports performance are common (McLaughlin, Howley, Bassett, Thompson, & Fitzhugh, 2010; Mikulic & Ruzic, 2008), however research on

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predicting performance and injury in team sports is limited. Physical assessment at the NFL

Combine has demonstrated some predictive capabilities to draft selection order (McGee &

Burkett, 2003; Sierer, 2008). Nevertheless, a relationship between draft order and career

success in the NFL has not been examined. The number of career games in the NFL, used as

an indication of injury rates, was however, related to a combination of previous injury history

and medical screening at the NFL Combine (Brophy et al., 2008). Factors predicting career

success and injury rates in team sports have, until now, not been investigated.

Exploring the relationship between match performance data and field tests is increasingly

popular. For example, a prospective six-week study of the yo-yo intermittent recovery test

performances of 9 AF players was found to be associated with ball disposals at high intensity

running during matches (Mooney et al., 2011). However, the relationships between match

performance data, physical test results, and predictive capacity of success in the first 5 years of

a players' career are not yet established.

Within the AF, the relationship between physical draft test performances and early career

progression has been investigated (Pyne et al., 2005). Specifically, agility, 20 m running

speed, vertical jump and shuttle run were found to have small associations with early career

progression (2-3 y) in senior AF. Expanding on this research and using more objective data

(physical match profiles combined with game skill involvements) now available on U 18

match performances, draft order and five years of AF career success, provided the genesis of

the current project.

The success of the AF draft and of talent scouts attempting to select players from it, are

usually demonstrated in career success of individual players. In the AF, career success is

commonly measured by the number of games played during a players' career. The availability

of group trends provides more rigorous scrutiny of the predictive capacity of draft camp

physical test results and U 18 match performances for subsequent career success. The results

may contribute to greater understanding of theoretical models of success and longevity of

players selected.

Therefore, the objective of this project was to determine relationships between physical draft

camp tests, final draft selection order and objective analysis of match physical performance

with five year career success and injury rates in the AF

Methods

Ninety nine male players were included in the analyses. For inclusion, players needed to complete all physical testing at the draft camp. At the time of the draft camp, the players' age was 18.0 ± 0.6 (mean $\pm$ SD) years, their height was $1.86. \pm 0.07$ m, and mass was 80.6 ± 7.1 kg. These players were invited to attend the National Draft Camp during 2002 or 2003. Permission was gained from the AF to use the data and ethics approval for secondary analyses was granted by the Human Research Ethics Committee of the Australian Catholic University, Sydney, Australia.

The National Draft Camp is a four day event held until recently at the Australian Institute of Sport in Canberra, Australia, annually in October. The physical assessment items evaluated were the Multistage Shuttle Test, vertical jump, agility, sit and reach, sum of seven skinfolds, height, weight and player speed (20 m sprint test with 5 m and 10 m splits). More specific details of each assessment protocol have been described in detail elsewhere (Pyne et al., 2005). In addition to the assessment protocols described previously, a 3 km time trial was also performed. The 3 km time trial takes place on the final afternoon of the draft camp on a 400 m tartan running track.

The National Draft, held annually in November, determines the order in which players are selected. AF clubs select players in a pre-determined order, based on previous season's finish in the AF competition. However, the selection order is also influenced by player and draft order trades between clubs. Players not selected in the National Draft, may be subsequently selected in the Preseason Draft, which held each December. In this draft, players can either be drafted onto a senior playing list as per the National Draft, or drafted as a 'rookie'. Obtaining

rookie status allows a player to train with an AF club for a year, but prevents these players from playing with the senior team, unless a long-term injury is sustained by a player within the team.

For our analysis, players were assigned the number representing the order in which they were drafted, independent of the year. Players drafted in the Preseason Draft were provided a number continuing on from the National Draft of that year. For example, if the last player selected in the National Draft was selection 90, the first player selected in the Preseason Draft was provided with number 91. Players drafted as rookies, were provided with numbers continuing on from Preseason Drafted players. Players not initially drafted were assigned '400', a number which allowed our analysis to adequately cater for the perceived difference in ability between drafted and non-drafted players.

Player physical match analysis was performed during the U 18 National Championships using computer-based tracking software (CBT; TrakPerformance, SportsTec, Australia). This tournament is held four months before the National Draft Camp and involves the players playing three games in seven days. The software system used during this tournament relies on tracking skills and was applied using a drawing tablet connected to a computer (Edgecomb & Norton, 2006). A scaled image of the playing field was placed on the drawing tablet. On-field movements of the player to be 'tracked' were followed around the miniaturised field by the tracker, with the aid of a drawing pen. Custom video footage of individual players was reviewed after each game and analysed.

Relevant variables were expressed relative to time on the field to account for varying match times. Players were tracked once only during the tournament and any player completing less

than a half of play was excluded. Variables of interest were; total distance covered per minute of game time (player speed in m/min), number of completed sprints per minute (where the sprint velocity was > 20 km/h for a duration of >2 s), and the percentage of total playing time at sprint speed (>20 km/h). Fundamental game statistics (kicks, handballs, marks and tackles) were also entered using keystrokes on the laptop and the sum of these was divided by total player game time. The CBT has demonstrated acceptable reliability when compared with an odometer for precision of distances covered (Technical Error of Measurement = 5.5%) (Edgecomb & Norton, 2006). Previous CBT analysis of senior AF matches also demonstrated tracking distances were within ±2% of values using video analysis of players (Dawson et al., 2004; Edgecomb & Norton, 2006).

Career success could have been defined in a number of ways including "Best and Fairest" votes or coaching votes. However, the subjective nature of this level of success is difficult to standardise. For the current study, each players' career success was defined as the number of games a player plays in the five years following being drafted and calculated as the percentage of 'non-final' games played in the first five years after being drafted, taking into account games missed through injury or suspension. This percentage was calculated as the total number of games played divided by the number of games missed, subtracted from the maximum number of games possible in the five year period (110 games). Information on the number of games played was retrieved from the AFL Medical Officers Association.

*Career Success % = [Total Games/(110-Games Missed Through Injury/Suspension)] * 100*

Player injury rates (retrieved from the AFL Medical Officers Association) were expressed as a percentage and estimated by subtracting the number of games a player was unavailable for selection due to injury during the first five years of his AF career from the maximum number of games possible in the five year period (110 games). For privacy reasons, no information on type or cause of injury was made available for analysis.

*Injury Rates% = [100-(Games Missed Through Injury/110)] * 100*

Logistic regression with Proc Genmod in the Statistical Analysis System (Version 9.2, SAS Institute, Cary NC) was used to estimate magnitudes of factors affecting the proportion of games played. The effect of binary nominal predictors was estimated as the difference in the percentages (%) of matches played by players with and without the characteristic of playing matches at the U 18 championships, performing tests at the camp, being drafted or belonging to the first division teams at the U 18 championships. The effect of continuous variables from the match and fitness tests was modelled as a linear effect on the log of the odds and estimated as the difference in the predicted percentages of games played by players one SD below and one SD above the mean of the variable (Hopkins, Marshall, Batterham, & Hanin, 2009). The following scale was used to interpret magnitudes of the differences in percentages: <10%, trivial; 10-29%, small; 30-49%, moderate; >49% large (Hopkins, 2010). Uncertainty in the true value of percentages is shown as 90% confidence limits. Mechanistic magnitude-based inferences were used to make assertions about the true values (Hopkins et al., 2009). but the

confidence intervals were all so small that all effects were clear and interpreted as the

observed magnitude.

Results

Table 1 shows results from match and draft camp variables, and draft order. The group

average is presented in the second column (mean ± SD). The next two columns show the

average number of games played (expressed as a percentage) by players whose scores were

categorised above and below the group average. Poor performance is presented as one SD

below the mean and good performance is presented as one SD above the mean of the variable

assessed. The difference in average games per year between good and poor performance is

expressed as a percent difference in the final column. Sprint-related variables during matches

provided the greatest discrimination (43% more games per year) between players 1 SD above

and below group averages. In contrast, results from the vertical jump test showed the least

predictability (1% more games per year) between high (+1 SD) and low (-1 SD) performances

on the test.

It is unlikely that one single attribute can explain the complexities involved in career success

denoted by games played. Therefore, combinations of variables were explored for a more

realistic explanation of successful selection in games per year (Table 2). The combination of

variables showing the greatest difference in game success were the game performance

statistics relating to sprints and the single sprint performance times performed at the draft

camp.

Table 3 presents similar analyses on various categorical variables. These variables were

whether the player was drafted (i.e. Non-rookie or pre-season draft), whether the player played

for a Division 1 team in the National U 18 championship (Victoria Metro, Victoria Country,

South Australia, Western Australia), and whether the player was invited to attend the National

Draft Camp. The results showed being a drafted player was associated with 35% more games

played than non-drafted players. Players who played in Division 1 team only played 15%

more games than other players and attendance at the draft camp equated to approximately

20% more games played than non-attendance at the draft camp.

Although the draft camp includes rigorous muscular-skeletal and medical screening that is

highly likely to be useful predictors of injury rates, confidentiality precludes access to these

data. A number of alternate injury-related variables were examined for predictive associations

with career success. However, the magnitude of these differences was considered trivial. For

instance, the variable displaying the largest association with five year injury status was a

combination of all draft variables and game statistics per minute (Table 2, g). This association

only accounted for a 7% difference in games missed through injury. Draft Order and player

draft status (whether or not a player was drafted) also resulted in a relatively trivial 9%

decrease in games missed due to injury.

Table 1: Difference in percentage of games played between players 1 SD above and below the mean of match and draft camp variables

	Mean ± SD	Proportion of games played (%)		
		at mean-1SD	at mean+1SD	Difference
Match variables				
Time spent sprinting (%)	3.4 ± 1.5	10	53	43
No. of sprints per min-	0.45 ± 0.23	11	54	43
Average speed (m.min^{-1})	122 ± 18	21	41	19
Game statistics per min*	0.34 ± 0.16	22	41	19
Draft camp variables				
Agility (s)	8.63 ± 0.27	46	24	22
Sum 7 Skinfolds (mm)	52 ± 12	43	28	14
3 km Time Trial (min)	11.2 ± 1.0	43	28	14
10 m Speed (s)	1.82 ± 0.07	41	31	10
Beep Distance (m)	2490 ± 300	32	42	10
20 m Speed (sec)	3.04 ± 0.10	40	32	8
5 m Speed (sec)	1.10 ± 0.05	40	33	7
Weight (kg)	80.6 ± 7.1	32	28	4
Sit and Reach (cm)	11 ± 6	34	37	3
Height (cm)	1.86 ± 0.07	29	31	2
Vertical Jump (cm)	59.8 ± 7.6	35	36	1
Draft Order	60 ± 33	10	52	42

Scale of magnitudes for differences: <10%, trivial; 10-29%, small; 30-49%, moderate; >49% large. Uncertainty (90% confidence limits) for differences all ~±2%.

* Fundamental game statistics such as kicks, handballs, marks and tackles gained per min

Table 2: Difference in percentage of games played with 1 SD above or below selected combined predictors

Combined predictors	Proportion of games played (%)		
	1 SD below mean	1 SD above mean	Difference
a) 5 m + 10 m + 20 m + Sprints/min +% sprint	9	67	58
b) Sprints/min + % sprint + agility	10	65	55
c) Dist/min + 3 km + beep + %sprint	11	65	54
d) All match variables	8	57	49
e) Sprints/min + % sprint	8	56	48
f) Sprints/min + Dist/min + %sprint	8	56	48
g) All draft physical variables + stats/min	16	55	39
h) All draft physical variables	19	49	30
i) Height + Weight + Sum 7	18	48	30

Scale of magnitudes for differences: <10%, trivial; 10-29%, small; 30-49%, moderate; >49% large. Uncertainty (90% confidence limits) for differences all ~±2%.

Table 3: Difference in percentage of games played for selected categorical variables

	Proportion of games played (%)		
	No	Yes	Difference
a)Player Drafted	5	40	35
b)Division 1 Team	20	35	15
c)Attendance at Draft Camp	14	35	21

Scale of magnitudes for differences: <10%, trivial; 10-29%, small; 30-49%, moderate; >49% large. Uncertainty (90% confidence limits) for differences all ~±2%.

Discussion

This is the first study to assess the efficacy of current AF talent identification practices on career success using objective methods over an extended period of time. Traditional talent identification in the AF relies on a combination of objective data collected during the National Draft Camp and subjective assessment of a players' ability by talent scouts and AF coaches. Ultimately, a combination of objectively measured physical tests and match performance profiles successfully contributed to the understanding of the five year career success of senior players in AF.

Previously, agility, vertical jump, shuttle run and 20 m speed demonstrated small associations with early AF career success (Pyne et al., 2005). Career success in this earlier research was a combination of subjective ratings of career potential combined with career games played over a limited time period. In our study, career success was defined by the number of games played over an extended period of time (five years) expressed as a percentage of those games available for selection. The addition of match activity profiles of players prior to the National Draft Camp data also represented significantly more predictive power.

The present results showed that the match activity profiles of the U 18 players provided greater indication of future games played in the AF than the physical performance tests performed at the National Draft Camp. For example, if a player spent a large percentage of time sprinting or produced a high number of sprints per minute when playing U 18 matches (demonstrated by scores one SD above the mean), he played 43% more (~9 games per season) games than a player who performed one SD below the mean in these variables. Players

performing above the mean in all match variables played 49% (or approximately 11) more

games per season than players below the mean. A single superior agility score from the

National Draft Camp, representing the physical assessment with the largest influence on career

success, only translated to 22% (five games) more of games played by players above than

below the average agility score in a season. Additionally, players performing better than the

mean in every draft test variable only played 32% (7) more games per season than those

performing below the mean in these tests.

The differences in match physical requirements between levels of competition in the AF has

recently been established (Brewer et al., 2010). For example, compared with AF players, the

Western Australian state league players performed relatively less distance (9%) and fewer

high intensity sprints (21%) (Brewer et al., 2010). Physical match values represent fitness

assessment in its most applied medium. The ability to perform efficient movement throughout

an AF match while maintaining effective skill output is the aim of all players. Match

performance from U 18 competition results therefore, may offer significant insight into talent

identification.

The combination of match and draft camp variables provided the greatest indication of career

success in AF. There were six combinations of variables (Table 2 a-f) that provided a clearer

talent identification picture than the best single predictors from Table 1 (% time spent

sprinting and sprints/min). Clearly, a more complete talent identification process combines

'isolated' fitness tests and match specific information.

Estimates of anaerobic power, as assessed by the number of sprints per minute, and percentage of time spent sprinting during matches, in combination with the speed tests (5 m, 10 m, and 20 m) provided the greatest estimate of career success. Superior performance in these scores was associated with players participating in 58% (13) more games per season than players with a lower performance at the U 18 year level of competition. The ability for players to sustain high speed efforts throughout a game appears as important in AF as it is in other team sports (Gabbett, 2005; Rampinini et al., 2009b; Reilly et al., 2000).

Draft camp tests are rigorously and frequently reviewed. The battery of tests used in the draft camp have been modified since 2002 when the present data were collected. For example, results from the repeated test sprint test (6 x 30 metres) introduced in 2006 may have strengthened the existing results. An alternate test of high speed running ability, the Yo Yo IR2, shows a strong relationship with high speed running in matches and AF match performance (represented by possessions) (Mooney et al., 2011). This finding, combined with results from the present study highlight that talented U 18 players hoping for sustained career success should aim to enhance the physical capacities that allow them to complete regular high intensity efforts during matches, as these appear to be important for career longevity in the AF.

Anthropometry has been an important component of talent identification in team sports (Gabbett et al., 2007; Gabbett, 2006a; Reilly et al., 2000). As a result, AF coaches and scouts anecdotally consider appropriate body size (taller players, low sum of 7 skinfolds, moderate weight) to be a crucial component of their talent identification strategy. However, the present findings showed that better performance in the combination of all anthropometric variables collected, only produced 30% (7) more games per season than poor performance. The impact

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of body composition variables on career success was therefore less than combinations of match and draft camp test performances.

The prediction modelling remains experimental. Prediction based on high speed performance has its limitations and may hold greater relevance for some positions than others For example, it is possible that the players who completed more sprints during U 18s did so because of their playing position (i.e. most likely midfielders).

Taller players represented a smaller percentage of players involved in this study and as such, numbers were insufficient to warrant separate analysis. Accordingly, predicting career success within a five year period may not be appropriate for the tallest players. Predicting career success in five years may be an inadequate amount of time to evaluate career success in the tallest players. Furthermore, the tallest players may take longer to develop as AF players due to the specialist nature of their position (greater contact, unique tactical requirements etc.). Sprint-based profiles may also be less predictive of career success if the tallest players are recruited to play a rucking (hit out) role which requires minimal sprinting compared to other positions. Further research on the position-specific requirements for career success may provide more clarity here.

Draft Order showed some predictive capabilities with players selected earlier playing 42% (9) more games than players selected later in the draft. However, this trend could be confounded by the "reverse" draft priorities going to the poorer performing teams. These lower ranked teams may have had more urgent need to draft player ready to play senior football sooner than the more successful teams with established playing lists.

The objective data currently available to AF scouts and coaches are theoretically represented by the values in Table 2 (g) which includes the draft variables combined with match statistics (game events but not player movement) collected per minute of game play. Above average performance in these variables produced 39% (9) more games per season than below average performance. There were six combinations of variables (Table 2 a-f) offering superior prediction values that the scouts could use in the talent identification processes. The results of the present study may hold the greatest relevance for talent identification and development officers looking to recruit high speed midfield players. Decisions by recruitment staff could be made easier or more justifiable should match performance data from aspiring elite players be available for combinations with draft camp data and their own subjective opinion. The integration of this process into AF clubs may however be limited by insufficient resources and expertise within clubs to manage these.

The absence of associations between U 18 variables and early career injury is difficult to interpret. Perhaps the open chain nature of AF makes injuries hard to predict. Injuries may be better predicted over longer timespans and from the more confidential medical reports performed by the club medical staff during the National Draft Camp. Additionally, at the U 18 level players could be more homeogenous in physical developmental characteristics and therefore prediction based on these characteristics is more difficult. Theoretically, a player's ability to maintain high exercise intensity during U 18 competition matches would provide some protection against injury during the initial 'adaptation' to the superior fitness requirements of AF football. In our analysis, none of the variables investigated had substantial association with early career injury rates in AF players. However, injury data provided for analysis were limited to the number of games missed rather than injury type or body part

injured. Data in the public domain, obtained for the purpose of this study was insufficient, but

a potential application of the approach taken in this paper could apply to injury data accessible

within a club. Broad application remains possible.

Conclusions

Five year career success in senior AF is best predicted using physical parameters assessed during match play performances in combination with sprint capacity at the end of adolescence. Specifically, superior performance in % sprint and sprints/min in matches, combined with speed assessed at the National Draft Camp (5 m, 10 m, 20m) provided the best predictor of career success. The more traditional practice of predicting success using physical draft camp parameters could be enhanced with the inclusion of more objective match performance data. The GPS data recorded in the National U18 Championships should be provided to all clubs to assist recruiters as standard practice.

Practical Implications

- Physical performance tests and anthropometry measures used to assist in talent identification were only moderately successful in predicting early career success in AF

- AF talent scouts and coaches should add objective match physical data to assist in the talent identification process

- Draft camp testing, draft order and match physical information failed to successfully predict injuries sustained during the first 5 years of AF

Discussion

and

Recommendations

7   <u>Discussion and Recommendations</u>

This section summarises the sequence and contents of the thesis and combines the individual publication discussions into collective issues and challenges. The general and specific hypothesis stated in the Introduction and Overview will be addressed and recommendations for future research will be provided.

7.1   Summary of Contents

Limited evidence exists on the application of tracking technology in an applied team sports environment. There is probably a large body of knowledge available within professional team sports environments, however sports science professionals working in such settings either lack the academic skills, have little desire to embark on the publication process, or are unable to publish due to confidentiality reasons. As a result significant gaps found in the literature were targeted by these studies.

The understanding of these gaps was strengthened by a substantial review of literature. The use of GPS tracking technology within team sports was examined in the first part of the review of literature. GPS tracking technology was primarily used in this thesis and represents current practice within professional team sports environments. This analysis of GPS strengths and weakness provided an understanding of the existing uses as well as potential applications within a team sports environment. The second part of the review of literature was published. It identified shortcomings within the literature and in talent development practices in team sports.

Within Australia, aspiring elite soccer players look beyond the domestic competition and aim to play in professional leagues in Europe, Asia or even South America. This was particularly true at the time of Study 1 when the National Soccer League (NSL) was the premier domestic competition. The NSL was a semi-professional competition that was replaced by the professional A-League in 2006. Despite its professional status, the A-League remains largely

a stepping stone for Australian players in their quest for acceptance into overseas competitions. Identifying the gap in match demands between Australian competition and more lucrative overseas leagues was designed to assist local players and their coaching staff in recognising areas for improvement. Perhaps the greatest challenge for Australian domestic soccer remains the implementation of the best possible methods to bridge this gap.

In AF a conundrum facing professional coaches and sports scientists is how best to prepare elite Under 18 players for the physical demands of senior AF training and match play. Study 2 not only quantified the gap in match demands between the two competitions, but it also identified the fact that the gap is increasing. In this study technology advanced from CBT to GPS tracking and as a result, the depth of information increased. The issue arising from this paper was the need to access the depth of understanding that movement tracking results can provide. The challenge is to broaden the access of sports scientists to the aspiring elite level. Given the importance to a club's need to successfully integrate talented Under 18 players into a senior AF setting, tailoring training programs to navigate this gap becomes critical.

Identification of talented team sports players has been largely the domain of club scouts and coaches. As such, talent identification officers have relied on subjective opinions on a player's ability combined with cross-sectional fitness assessment results. The use of portable match tracking technology (GPS) to add objective, specific data improved the predictive capabilities of early career success in AF players. Study 3 demonstrated the application of technology improved the pool of information available to assist prediction of successful players. Without this knowledge the level of evidence was less convincing in its ability to identify early career success. A major issue emerging from this study was the need to include objective match data in optimising the many factors that contribute to talent identification. Perhaps the challenge here is the integration into this process of dedicated sports science staff, without club affiliation, who can provide this information.

7.2   Addressing Specific Hypothesis

Study 1: High speed running requirements in Australian soccer matches would be less than those of international matches. Total distances travelled in matches between Australian players and their overseas counterparts were expected to be similar. Second half distance travelled would be less than first half.

Volume of high speed movement within Australian competition was similar to overseas levels, albeit with trends toward greater sprint volumes in overseas competitions. Differing methodologies made direct comparisons difficult. However a trend toward less high intensity running in Australian competition could suggest superior fitness levels of overseas players. Alternatively, the tendency toward less high intensity running could indicate the standard of competition in Australia does not require as much high intensity movement demands, independent of the fitness of players. Regardless, the hypothesis of less frequent high speed running requirements in Australian than International soccer leagues was supported.

Australian soccer players completed higher total distances to their overseas counterparts. Efficient movement is generally represented by lower distances, for the same given tactical output. Study 1 showed similar match involvements with greater total distances, which could be a function of inefficient on-field movement or, a comparative lack of tactical awareness of Australian players (Rienzi et al., 2000). Alternatively, the lack of exposure of Australian players to high tempo stimuli in the form of matches may impair this type of specific adaptation process. In Australia, soccer players participate in a competition consisting of approximately 22 matches. European Leagues for example, typically consist of 40+ matches in a season.

In agreement with the second component of the hypothesis, volumes of high intensity running in the second half were similar to first half values in Australian soccer players. Duration between each sprint effort however, was greater in the second than the first half. This suggests players had more time to recover from each sprint effort and may partially explain the maintenance of these volumes. Total distance was less in the second half than the first, indicating less movement in low intensity running categories. A trend toward less second half distance has also been found in international competition (Bangsbo et al., 1991)

Collectively, less high speed running and greater total distances travelled, combined with the fewer game involvements found, could further highlight the inefficient movement patterns of Australian soccer players compared with their international counterparts.

Study 2: Under 18 AF physical match requirements would be less than Senior AF requirements at both 2003 and 2009. Senior AF match intensities would increase between 2003 and 2009 at a greater rate than Under 18 levels.

In support of the hypothesis, in 2003 Under 18 match movement values were less than AF values. When the physical match variables (distance/min, sprints/min, % sprint) between the two competitions were compared, Under 18 players were required to perform only 88% of AF match movements. In 2009 this difference increased, with Under 18 match values equating to only 76% of AF values. In fact, in 2009 Under 18 % sprint values were only 60% of those in AF. These discrepancies were further supported by increased ball movement speeds in the AF in 2009 than 2003, while ball speeds remained constant in Under 18 competition. Both player and match speeds were therefore increasing in AF at greater rates than Under 18 levels.

The magnitude of differences in player and game (ball) speeds over time are only partially explained by AF rule changes to increase speed of play that occurred between 2003 and 2009. Increased access to advanced training facilities, improved numbers of sports science and sports medicine staff, increased recovery awareness and individualised programming at the AF level have all potentially and synergistically contributed to faster match play. This trend has significant consequences for Under 18 players as they enter AF competition.

Study 3: The draft order would have good predictability of early career success in AF. Adding objective data to traditional talent identification practice however, would improve prediction of five year career success in AF.

As suggested in the hypothesis, players selected earlier in the draft played 43% more games than those selected later in the draft. Clubs who finish nearer the bottom of the competition almost always receive earlier draft picks. These clubs are often more tempted to play these early draft picks as they seek to progress up the competition ladder. This may have some influence on the excellent predictability of draft order in this study.

Objective match physical information using GPS technology provided the greatest single prediction of early career success in AF competition. Specifically, above average performances in % sprint and sprints/min during games produced 43% more games (~ 9 games) per year over the five year period of the study. When this objective match data were added to various fitness assessments from the National Draft Camp, five year career success prediction increased to 58% games (~ 13 games) more games played per year. Thus, adding objective data from Under 18 match performances to predictions of five year playing success improved predictability, independent of draft order.

Clearly traditional talent identification strategies within the AF provide less predictive capabilities than is possible with objective match performance data. Talent prediction remains complex but is strongest when objective markers are added, particularly when those markers include match information. Without this application of GPS technology, the potential to improved success may be difficult.

7.3   Addressing General Hypothesis

Advanced player and game movement technologies will provide useful information for sports scientists, coaches and player development managers in team sport.

The general hypothesis is supported by results showing tracking technology, and in particular GPS, can accurately and reliably quantify training and match physical loads. The present collection of studies outlines the issues surrounding a number of practical applications for this load information. Specifically, these studies demonstrated numerous novel uses of the data with more detailed analyses. Identifying differences in professional and semi-professional

leagues (Study 1), assessing game trends over time at various level of play (Study 2), identifying discrepancies between Under 18 and Senior competitions (Study 2) and prediction of career success are all shown to be possible using GPS technology.

Within professional team sports environments where GPS use is prevalent, injury and career prediction as well as using information to progress talented players through to professional ranks may well be commonplace challenges. For example, within an AF club, sports scientists who know the match tracking information from local Under 18 matches combined with loads estimated from GPS on their club's AF matches, can estimate the progression required to advance recent draftees to AF level. However, in this and other similar scenarios, data sources are restricted and rigorous validation of practice is often scarce. The current thesis addresses these issues via novel, yet thorough statistical analyses using substantial data sets.

Knowledge of the difference in match demands between elite Under 18 and senior AF match play is not new information (Veale, 2009). However, Study 2 demonstrated this gap is increasing dramatically between the two levels of play. This highlights the dangers in progressing recently drafted Under 18 AF players too quickly into senior AF matches. Research on the exact training loads recently drafted players are exposed to is lacking. Practically however, these players should be progressed over numerous seasons and the information gathered from analyses such as the objective measures used in Study 2 can assist this process. For example, the % sprint value from Under 18 match play is only 60% of senior values. AF sports scientists, armed with this information, should progress this figure incrementally over a number of seasons. Perhaps a 10-15% increase in % sprint training preparation each year would be more prudent than attempting to bridge the gap in one season. This approach would ensure progressive overload and give ample time for young (and sometimes physically and cognitively immature) players to adapt to these training and match loads.

The ability to extract information from GPS data is an important skill in the sports scientist's toolkit. As these studies have shown, accelerometry combined with horizontal position information can offer a wealth of detailed analysis on movement patterns and body position. Arguably more important is the ability to apply this information in a manner relevant to team performance and/or injury prevention. To do this effectively, additional assistance from other

professionals such as biomechanists or sports physiotherapists may be sought, as these people may be able to understand the information provided more completely. Experts in statistics may also be consulted as they can provide real meaning to the abundance of information collected. The final part in the process is the ability to deliver and translate the appropriate results to the players and coaches in a manner which is both relevant and easily understood.

One of the main aims of the sports scientist should be to minimise muscular injury risk. Of course this risk will never be eliminated, because exposure to the high speed demands of most team sports imposes substantial risk to soft tissue. However Study 3 demonstrated the potential for GPS technology to assist risk minimisation. Although no significant relationship was found between Under 18 match loads and early career injury, the results were heavily influenced by the lack of injury definition available. It is postulated that sports scientists employed by teams, with comprehensive access to injury files, could retrospectively examine loads leading to injuries, in order to understand more about prevention. The challenge of injury prediction is therefore currently better understood at the club than organisation level.

Additional means by which GPS technology can potentially improve injury prevention and rehabilitation are outlined in sections 2.3.5 and 2.3.6 of the introduction. These methods offer additional insight to traditional, more subjective methods of injury prevention and detection. Without this extra layer of objective data, professional team sports scientists may risk overtraining, or undertraining players, both of which may lead to injury or poor performance.

Figure 1 presents a framework by which GPS tracking data can assist player development in team sports. Subjective analyses provided by coaches and talent scouts, in addition to sports scientists are represented in Figure 1 by the large blue circle. This information is relevant and should contribute to successful player development. Player body language, game intelligence and player movement style all play critical roles in training and match evaluation processes and could never be replaced with objective data.
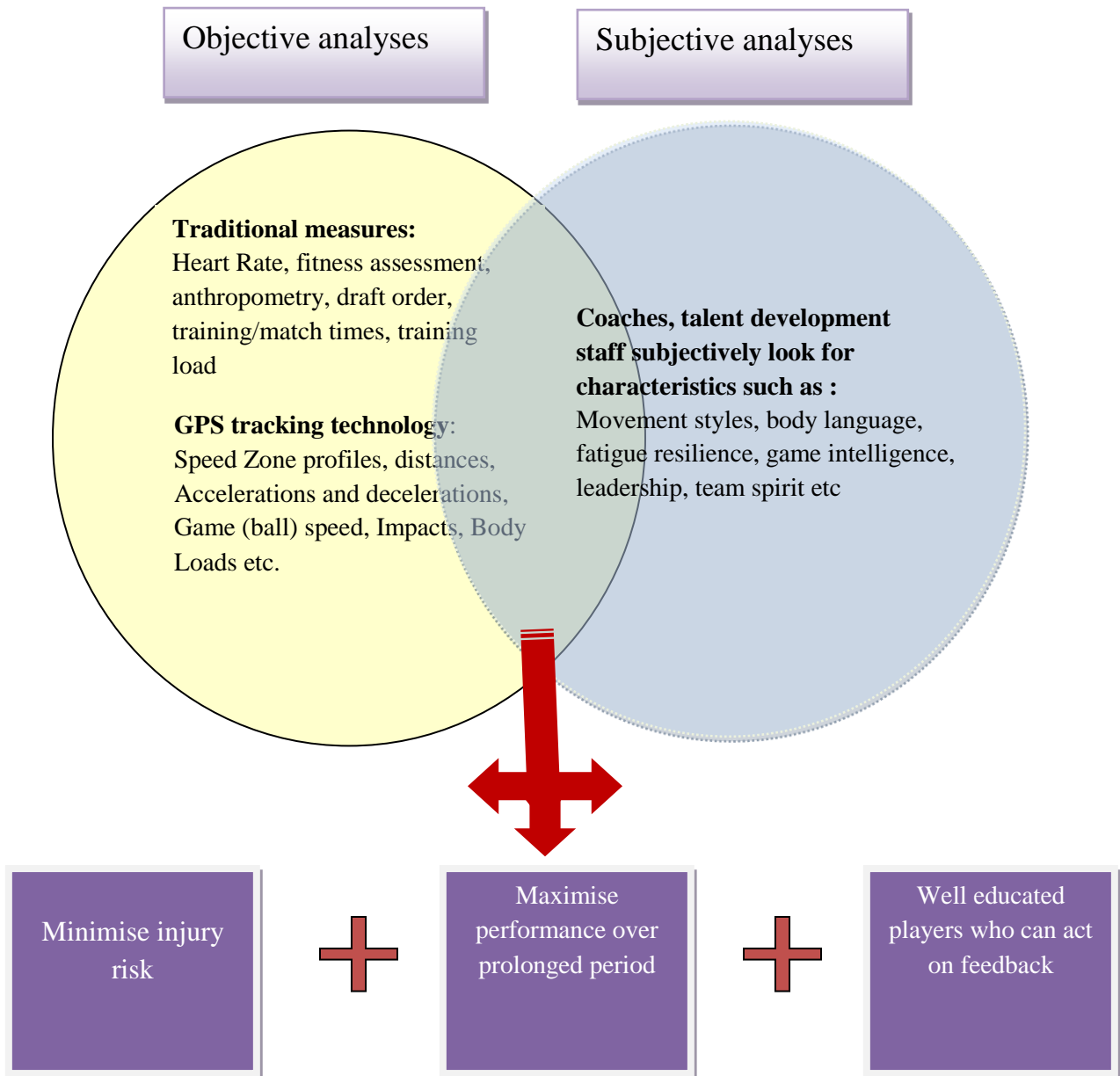

Figure 1 Framework for Player Development in Team Sports

Objective information, represented by the yellow circle in Figure 1 has traditionally consisted of volume assessment (training and match times), fitness testing and possibly training load estimation (player RPE multiplied by time). These values still remain significant and can play important roles in player development. Training load, for example, provides an important indicator of player perception of effort. Player fitness assessment can provide a cross-sectional indication of fitness status and player responses to training loads. Data collected from initial GPS use, such as time spent and distance travelled in various speed zones, can assist in defining both team program loads and individual player work rates and is therefore included in the bottom half of the Objective analyses circle of Figure 1.

Additional information provided by recent and more advanced GPS devices such as Body Load, acceleration/deceleration and impacts have the potential to add enormous depth to analyses and provide the rest of the information contained in the second half of the Objective analyses circle. These values can assist in player development in numerous areas (as discussed in the Literature Review) and should contribute to the greater understanding of training loads and individual player development. For example Study 3 indicated that, particularly in talent identification and development, GPS assessment of match loads could offer better prediction of career success than traditional fitness assessment procedures alone. Importantly, it was a combination of fitness assessment and match values (5 m, 10 m, 20 m speeds combined with sprints/min and % sprint) that provided the best prediction of career potential in AF players. Study 3 also indicated that anthropometry, traditionally an assessment item highly regarded by AF talent scouts, had minimal predictive power in career success. This provides further evidence of the risks involved in talent identification in particular, if more progressive, objective methods of player tracking are unavailable.

The area of overlap between the two circles has the most potential to deliver salient outcomes for players, sports scientists and coaches. This area represents, for example, the combination of coach intuition and sports science information support. This combination of inputs will only be successful in a team sports environment with effective communication and education.

The aims of the player development process, (to minimise injury risk, maximise performance and create educated, well-informed players) are represented by the purple boxes at the foot of Figure 1. The aim of creating educated players can only be served by providing appropriate, tailored feedback. This requires a thorough knowledge of individual and team physical goals as well as an understanding of player and coach philosophy.

The aims of maximising player and team output while minimising injury risk should be the focus of all team sport development programs. Combining subjective, coach influenced information with traditional objective data will provide useful information to assist in this process. For a more detailed, thorough approach, player tracking information, and in particular GPS technology should be explored.

7.4 Strengths and Weaknesses

In each study, strengths and weaknesses in both design and technology use were outlined. Nevertheless, the thesis emphasised the potential usefulness of the evidence-based observations in practical settings. The following are strengths and weakness of the thesis as a whole:

7.4.1 Strengths

- The review of literature was comprehensive and provided an excellent framework for the subsequent research to build upon. This review pushed the boundaries of applications of GPS use as well as identifying gaps in current talent development practice in team sports. The second part of the review was published as an invited review and the first part will be submitted for publication following thesis completion.
- The applied nature of the thesis makes this collection of work unique. One of the aims of this research was to provide practitioners with applications of tracking technologies that can be replicated and utilised with confidence in team sports environments. This was achieved through acknowledging limitations within the technology and providing a range of uses and applications in professional and talent development settings.

- The novel use of this technology provided by these studies is also a strength of this thesis. Predicting injury and performance as well as identifying match intensities across time represents a number of exciting applications of GPS tracking yet to be fully explored in the literature.

- The fact that the tracking technology was applied in two sports is a further strength of the thesis. Soccer and AF represent two of the most popular team sports in Australia among youth, amateur, and professional levels. These studies attempt to identify uses of this technology across both sports that can also be extended to other football codes and team sports.

- As more technology became available, the sequence of studies provided greater depth of analyses. Specifically, the introduction of GPS technology allowed studies 2 and 3 to provide more objective, detailed data than the results provided by the CBT device used for study 1. It was important that the studies had relevance to the technologies available in the professional marketplace to ensure successful translation of results into team sports settings.

7.4.2 Weaknesses

- There was some difficulty in getting complete data sets due to the applied nature of this research. This was particularly evident in Study 3 when exact injury information wasn't available. Incomplete injury data therefore prevented more in-depth soft tissue injury analysis.

- Limitations of technology were cited throughout the thesis, as was the need to view results within the bigger context of athlete and team performance.

- Although not totally representative of all players at senior or aspiring levels, the number of players in each study were sufficiently substantial to provide credible trends in player performances.

- None of the studies offered data from a whole season of participation for each individual assessed. Data collection of this size was outside the scope of the researcher.

7.5 Recommendations

- Technology can add important knowledge to the investigation, analysis and delivery of sports science services. The objective measures provided by technology have demonstrated usefulness in a number of areas relating to team sports performance. This type of technology should be fundamental to existing practices in a team sports environment.

- Crucially, athletes need to be educated on the benefits of this type of technology. Information should be translated and presented to athletes and coaches relative to performance improvements, injury prevention and/or talent development. This education of athletes and coaches is postulated to contribute to long term adherence and player improvement, rather than a temporary 'fad' culture.

- Coaches should be encouraged to embrace the technology as a tool for player monitoring, with a focus on performance, rather than punishment. Coaches traditionally see physical monitoring or indices such as heart rate as a basis for additional work when scores are unsatisfactory. This philosophy should be replaced, with the help of targeted education and information sharing, with one centred on player welfare, motivation and performance.

- Although this research investigated application of this technology to talent development, promoting longevity in experienced players should also form part of a successful integration of this technology into a team sports environment. This integration should potentially involve all staff involved along the player monitoring pathway. Biomechanists for example, could assess the GPS acceleration profile of the players with the assistance of video provided by the performance analysis team.

- Tracking technology should be explored further by researchers and sports scientists. Applications to areas such as injury/ performance prediction and tactical analysis should be investigated. Specifically, the role of GPS tracking in prediction is currently under-researched. Study 3 suggests that establishing match profiles of AF players, combined with some novel statistical modelling, can predict early career success. This type of analysis can be expanded to other aspects of team performance. Additionally, the role of GPS in longitudinal analysis is under-explored, possibly due to the fact that the technology has only recently been validated. However, Study 2 demonstrates that

over a 5 year period, match physical characteristics can be profiled and game trends assessed. This type of analysis is easily transferred to other team sports. However, at the present time, access to statistical expertise appears to add another layer of challenge to interpretation and innovative use of the data. Tertiary degrees with a major focus on performance analysis would complement the current need of professional sports scientists.

- Team sports not utilising this technology are being denied the opportunity for a range of applied research opportunities.

7.6   Conclusion

Comprehensive player and performance monitoring requires a combination of subjective and objective measures. Technology such as GPS should be used within its limitations to assist player monitoring through training and match load quantification. Additional applications of this technology discussed in this thesis such as injury prediction and performance profiling should be further explored with the potential to aid talent identification and development, player integration and education, and team sports performance. The technology should compliment sports science and coach intuition, to provide a more holistic approach to player development and performance enhancement.

References

8   References

ABS. (2008). Year Book Australia Retrieved 3/10/09, from http://www.abs.gov.au/ausstats

AFL. (2009). Influence of Indigenous Players Retrieved 3/10/09, from
    http://www.afl.com.au/news/newsarticle/tabid/208/newsid/82191/default.aspx

Appleby, B., & Dawson, B. (2002). Video analysis of selected game activities in Australian Rules
    Football. *Journal of Science and Medicine in Sport, 5*(2), 129-142.

Aughey, R. J. (2010). Australian football player work rate: evidence of fatigue and pacing?
    International Journal of Sports Physiology and Performance, 5(3), 394-405.

Aughey, R. J. (2011a). Applications of GPS technologies to field sports. *International Journal of
    Sports Physiology and Performance, 6*(3), 295-310.

Aughey, R. J. (2011b). Increased high-intensity activity in elite Australian football finals matches.
    International Journal of Sports Physiology and Performance, 6(3), 367-379.

Aughey, R. J., & Falloon, C. (2010). Real-time versus post-game GPS data in team sports. *Journal of
    Science and Medicine in Sport, 13*(3), 348-349.

Bailey, R., Morley, D., and Dismore, H. (2009). Talent development in physical education: a national
    survey of policy and practice in England. *Physical Education and Sport Pedagogy, 14*(1), 59-
    72.

Baker, J., Cote, J., and Abernathy, B. (2003). Sports-specific practice and the development of expert
    decision-making in team ball sports. *Journal of Applied Sport Psychology, 15*, 12-25.

Bangsbo, J. (1994). The physiology of soccer--with special reference to intense intermittent exercise.
    Acta Physiologica Scandinavica. Supplementum, 619, 1-155.

Bangsbo, J., Iaia, F. M., & Krustrup, P. (2008). The Yo-Yo intermittent recovery test : a useful tool for
    evaluation of physical performance in intermittent sports. *Sports Medicine, 38*(1), 37-51.

Bangsbo, J., Norregaard, L., & Thorso, F. (1991). Activity profile of competition soccer. *Canadian
    Journal of Sports Science, 16*(2), 110-116.

Barbero-Alvarez, J. C., Coutts, A., Granda, J., Barbero-Alvarez, V., & Castagna, C. (2010). The
    validity and reliability of a global positioning satellite system device to assess speed and
    repeated sprint ability (RSA) in athletes. *Journal of Science and Medicine in Sport, 13*(2),
    232-235.

Barker, A. R., Welsman, J. R., Fulford, J., Welford, D., & Armstrong, N. (2008). Muscle
    phosphocreatine kinetics in children and adults at the onset and offset of moderate-intensity
    exercise. *Journal of Applied Physiology, 105*(2), 446-456.

Barnsley, R. H., Thompson, A. H., and Legault, P. (1992). Family planning: Football style. The
    relative age effect in football. *International Review of Sports Sociology, 27*, 78-87.

Barris, S., & Button, C. (2008). A review of vision-based motion analysis in sport. *Sports Medicine,
    38*(12), 1025-1043.

Baxter-Jones, A., & Helms, P. (1994). Born too late to win? *Nature, 370*(6486), 186.

Bishop, D. (2009). Game sense or game nonsense? *Journal of Science and Medicine in Sport, 12*(4),
    426-427.

Boucher, J. a. H., W. . (1991). The Novem system: a practical solution to age grouping. *Canadian
    Association of Health, Physical Education and Recreation Journal, 57*, 16-20.

Boyd, L. J., Ball, K., & Aughey, R. J. (2011). The reliability of MinimaxX accelerometers for
    measuring physical activity in Australian football. *International Journal of Sports Physiology
    and Performance, 6*(3), 311-321.

Bradley, P. S., Mascio, M. D., Peart, D., Olsen, P., & Sheldon, B. (2009a). High-Intensity Activity
    Profiles of Elite Soccer Players at Different Performance Levels. *Journal of Strength and
    Conditioning Research*.

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

Brewer, C., Dawson, B., Heasman, J., Stewart, G., & Cormack, S. (2010). Movement pattern comparisons in elite (AFL) and sub-elite (WAFL) Australian football games using GPS. *Journal of Science and Medicine in Sport, 13*(6), 618-623.

Brophy, R. H., Chehab, E. L., Barnes, R. P., Lyman, S., Rodeo, S. A., & Warren, R. F. (2008). Predictive value of orthopedic evaluation and injury history at the NFL combine. *Medicine and Science in Sports and Exercise, 40*(8), 1368-1372.

Buchheit, M., Horobeanu, C., Mendez-Villanueva, A., Simpson, B. M., & Bourdon, P. C. (2011). Effects of age and spa treatment on match running performance over two consecutive games in highly trained young soccer players. *Journal of Sports Sciences, 29*(6), 591-598.

Bullock, N., Gulbin, J. P., Martin, D. T., Ross, A., Holland, T., and Marino, F. (2009). Talent identification and deliberate programming in skeleton: Ice novice to Winter Olympian in 14 months. *Journal of Sports Sciences, 27*(4), 397-404.

Burgess, D. J., Naughton, G., & Norton, K. I. (2006). Profile of movement demands of national football players in Australia. *Journal of Science and Medicine in Sport, 9*(4), 334-341.

Burgess, D. J., Naughton, G., & Norton, K. I. (2012). Quantifying the Gap Between Under 18 and Senior AFL Football: 2003-2009. *International Journal of Sports Physiology and Performance, 7*(1).

Burgess, D. J., & Naughton, G. A. (2010). Talent development in adolescent team sports: a review. *International Journal of Sports Physiology and Performance, 5*(1), 103-116.

Burgess, D. J., Naughton, G., and Norton, K. (2005). Quantifying the gap between under 18 and senior football and relationship between under 18 game characteristics in early career success in AFL (pp. 16). Melbourne: Australian Football League.

Carling, C., Espie, V., Le Gall, F., Bloomfield, J., & Jullien, H. (2010a). Work-rate of substitutes in elite soccer: a preliminary study. *Journal of Science and Medicine in Sport, 13*(2), 253-255.

Carling, C., Gall, F. L., & Reilly, T. P. (2010b). Effects of physical efforts on injury in elite soccer. *International Journal of Sports Medicine, 31*(3), 180-185.

Carling, C., le Gall, F., Reilly, T., and Williams, M. A. (2009). Do anthropometric and fitness characteristics vary according to birth date distribution in elite youth academy soccer players. *Scandinavian Journal of Medicine and Science in Sports, 19*, 3-9.

Casamichana, D., & Castellano, J. (2010). Time-motion, heart rate, perceptual and motor behaviour demands in small-sides soccer games: effects of pitch size. *Journal of Sports Sciences, 28*(14), 1615-1623.

Castagna, C., Impellizzeri, F., Cecchini, E., Rampinini, E., & Alvarez, J. C. (2009). Effects of intermittent-endurance fitness on match performance in young male soccer players. *Journal of Strength and Conditioning Research, 23*(7), 1954-1959.

Castagna, C., Impellizzeri, F. M., Chamari, K., Carlomagno, D., & Rampinini, E. (2006). Aerobic fitness and yo-yo continuous and intermittent tests performances in soccer players: a correlation study. *Journal of Strength and Conditioning Research, 20*(2), 320-325.

Castagna, C., Manzi, V., Impellizzeri, F., Weston, M., & Barbero Alvarez, J. C. (2010). Relationship between endurance field tests and match performance in young soccer players. *Journal of Strength and Conditioning Research, 24*(12), 3227-3233.

Castellano J, & D., C. (2010). Heart rate and motion analysis by GPS in beach soccer. *Journal of Sports Science and Medicine, 9*, 98-103.

Castellano, J., Blanco-Villasenor, A., & Alvarez, D. (2011a). Contextual variables and time-motion analysis in soccer. *International Journal of Sports Medicine, 32*(6), 415-421.

Castellano, J., Casamichana, D., Calleja-Gonzalez, J., San Roman, J., & Ostojic, S. M. (2011b). Reliability and accuracy of 10Hz GPS devices for short-distance exercises. *Journal of Sports Science and Medicine, 10*, 233-234.

Cobley, S., Baker, J., Wattie, N., and McKenna, J. (2009). Annual age-grouping and athlete development: A meta-analytical review of Reltive Age Effects in Sport. *Sports Medicine, 39*(3), 235-256.

Cormack, S. J., Newton, R. U., & McGuigan, M. R. (2008). Neuromuscular and endocrine responses of elite players to an Australian rules football match. *International Journal of Sports Physiology and Performance, 3*(3), 359-374.

Cote, J. (1999). The influence of the family in the development of talent in sport. *The Sports Psychologist, 13*, 395-417.

Cote, J., and Hay, J. (2002). Childrens' involvement in sport: a developmental perspective. In a. S. Silva. J. M., D. E. (Ed.), *Psychological foundations of sport* (pp. 484-502). Boston: Allyn and Bacon.

Cote, J., Baker, J., and Abernathy, B. (2003). From play to practice: A developmental framework for the acquisition of expertise in team sport. In J. a. E. Starkes, K. A (Ed.), *Handbook of sport psychology* (3rd ed.). Hoboken, NJ: Wiey.

Coutts, A. J., & Duffield, R. (2010). Validity and reliability of GPS devices for measuring movement demands of team sports. *Journal of Science and Medicine in Sport, 13*(1).

Coutts, A. J., Quinn, J., Hocking, J., Castagna, C., & Rampinini, E. (2010). Match running performance in elite Australian Rules Football. *Journal of Science and Medicine in Sport, 13*(5), 543-548.

Coutts, A. J., Rampinini, E., Marcora, S. M., Castagna, C., & Impellizzeri, F. M. (2009). Heart rate and blood lactate correlates of perceived exertion during small-sided soccer games. *Journal of Science and Medicine in Sport, 12*(1), 79-84.

Crewther, B. T., Gill, N., Weatherby, R. P., & Lowe, T. (2009). A comparison of ratio and allometric scaling methods for normalizing power and strength in elite rugby union players. *Journal of Sports Sciences*, 1-6.

Cunniffe, B., Proctor, W., Baker, J. S., & Davies, B. (2009). An evaluation of the physiological demands of elite rugby union using Global Positioning System tracking software. *Journal of Strength and Conditioning Research, 23*(4), 1195-1203.

Dawson, B., Hopkinson, R., Appleby, B., Stewart, G., & Roberts, C. (2004). Player movement patterns and game activities in the Australian Football League. *Journal of Science and Medicine in Sport, 7*(3), 278-291.

De Ste Croix, M. (2007). Advances in paediatric strength assessment: changing our perspective on strength development. *Journal of Sports Science and Medicine, 6*, 292-304.

di Prampero, P. E., Fusi, S., Sepulcri, L., Morin, J. B., Belli, A., & Antonutto, G. (2005). Sprint running: a new energetic approach. *Journal of Experimental Biology, 208*(Pt 14), 2809-2816.

Di Salvo, V., Gregson, W., Atkinson, G., Tordoff, P., & Drust, B. (2009). Analysis of high intensity activity in Premier League soccer. *International Journal of Sports Medicine, 30*(3), 205-212.

Duffield, R., Coutts, A. J., & Quinn, J. (2009a). Core temperature responses and match running performance during intermittent-sprint exercise competition in warm conditions. *Journal of Strength and Conditioning Research, 23*(4), 1238-1244.

Duffield, R., Reid, M., Baker, J., & Spratford, W. (2009b). Accuracy and reliability of GPS devices for measurement of movement patterns in confined spaces for court-based sports. *Journal of Science and Medicine in Sport*.

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

Dupont, G., Defontaine, M., Bosquet, L., Blondel, N., Moalla, W., & Berthoin, S. (2010). Yo-Yo intermittent recovery test versus the Universite de Montreal Track Test: Relation with a high-intensity intermittent exercise. *Journal of Science and Medicine in Sport, 13*(1).

Duthie, G. M. (2006). A framework for the physical development of elite Rugby Union players. *International Journal of Sports Physiology and Performance, 1*, 2-13.

Duthie, G. M., Pyne, D., & Hooper, S. (2003). Applied physiology and game analysis of rugby union. *Sports Medicine, 33*(13), 973-991.

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

Ericsson, K. A., Krampe, R. T., and Tesch-Romer, C. (1993). The role of deliberate practice in the aquisition of expert performance. *Psychological Review, 100*(3), 363-406.

Faigenbaum, A. D., Kraemer, W. J., Blimkie, C. J., Jeffreys, I., Micheli, L. J., Nitka, M., & Rowland, T. W. (2009). Youth resistance training: updated position statement paper from the national strength and conditioning association. *Journal of Strength and Conditioning Research, 23*(5 Suppl), S60-79.

Falk, B., Lidor, R., Lander, Y., and Lang, B. (2004). Talent identification and early development of elite water-polo players: A 2-year follow-up study. *Journal of Sports Sciences, 22*, 347-355.

Farrow, D., Pyne, D., & Gabbett, T. (2008). Skill and physiological demands of open and closed training drills in Australian Football. *International Journal of Sports Science and Coaching, 3*(4), 489-499.

FFA. (2009). National Curriculum. Sydney.

Fraser-Thomas, J., Cote, J., Deakin, J. (2008). Understanding dropout and prolonged engagement in adolescent competitive sport. *Psychology of Sport and Exercise, 9*, 645-662.

French, K. E. M., S. L. . (1999). Adaptations in Response Selection Processes Used During Sport Competition with Increasing Age and Expertise. *International Journal of Sports Psychology, 30*(2), 173-193.

Fulcher, M. L., Hanna, C. M., & Raina Elley, C. (2010). Reliability of handheld dynamometry in assessment of hip strength in adult male football players. *Journal of Science and Medicine in Sport, 13*(1), 80-84.

Gabbet, T. a. G., B. (2006). The development of a standardized skill assessment for junior volleyball players. *International Journal of Sports Physiology and Performance, 1*(2), 95-97.

Gabbett, T., & Georgieff, B. (2007). Physiological and anthropometric characteristics of Australian junior national, state, and novice volleyball players. *Journal of Strength and Conditioning Research, 21*(3), 902-908.

Gabbett, T., Georgieff, B., & Domrow, N. (2007). The use of physiological, anthropometric, and skill data to predict selection in a talent-identified junior volleyball squad. *Journal of Sports Sciences, 25*(12), 1337-1344.

Gabbett, T., Georgieff, B., and Domrow, N. (2007). The use of physiological, anthropometric, and skill data to predict selection in a talent-identified junior volleyball squad. *Journal of Sports Sciences, 25*(12), 1337-1344.

Gabbett, T. J. (2005). Science of rugby league football: a review. *Journal of Sports Sciences, 23*(9), 961-976.

Gabbett, T. J. (2006a). A comparison of physiological and anthropometric characteristics among playing positions in sub-elite rugby league players. *Journal of Sports Sciences, 24*(12), 1273-1280.

Gabbett, T. J. (2006b). Skill-based conditioning games as an alternative to traditional conditioning for rugby league players. *Journal of Strength and Conditioning Research, 20*(2), 309-315.

Gabbett, T. J. (2010). GPS analysis of elite women's field hockey training and competition. *Journal of Strength and Conditioning Research, 24*(5), 1321-1324.

Gabbett, T. J., & Jenkins, D. G. (2011). Relationship between training load and injury in professional rugby league players. *Journal of Science and Medicine in Sport, 14*(3), 204-209.

Gagne, F. (2000). Understanding the complete choreography of talent development through DMGT-based analysis (2nd, Trans.). In K. A. Heller (Ed.), *International handbook of giftedness and talent* (pp. 67-79). Oxford, UK: Elsevier Science Ltd.

Gomez-Piriz, P. T., Jimenez-Reyes, P., & Ruiz-Ruiz, C. (2011). Relation between total body load and session rating of perceived exertion in professional soccer players. *Journal of Strength and Conditioning Research, 25*(8), 2100-2103.

Gould, D., Eklund, R. C., and Jackson, S. (1992). Coping strageies used by more versus less successful Olympic wrestlers. *Research Quarterly for Exercise and Sport, 64*, 83-93.

Gregson, W., Drust, B., Atkinson, G., & Salvo, V. D. (2010). Match-to-match variability of high-speed activities in premier league soccer. *International Journal of Sports Medicine, 31*(4), 237-242.

Grund, M., Ritzdorf, W. (2006). From talent to elite athlete: A study of the performance development of the finalist t the 1999 IAAF World Youth Championships. *New Studies in Athletics, 21*(2), 43-55.

Harley, J. A., Barnes, C. A., Portas, M., Lovell, R., Barrett, S., Paul, D., & Weston, M. (2010). Motion analysis of match-play in elite U12 to U16 age-group soccer players. *Journal of Sports Sciences, 28*(13), 1391-1397.

Harley, J. A., Lovell, R. J., Barnes, C. A., Portas, M. D., & Weston, M. (2011). The interchangeability of global positioning system and semiautomated video-based performance data during elite soccer match play. *Journal of Strength and Conditioning Research, 25*(8), 2334-2336.

Hartwig, T. B., Naughton, G., & Searl, J. (2009). Load, stress, and recovery in adolescent rugby union players during a competitive season. *Journal of Sports Sciences, 27*(10), 1087-1094.

Hartwig, T. B., Naughton, G., & Searl, J. (2010). Motion Analyses of Adolescent Rugby Union Players: A Comparison of Training and Game Demands. *Journal of Strength and Conditioning Research*.

Hartwig, T. B., Naughton, G., & Searl, J. (2011). Motion analyses of adolescent rugby union players: a comparison of training and game demands. *Journal of Strength and Conditioning Research, 25*(4), 966-972.

Hartwig, T. B., Naughton, G. A, and Williams, M. (2009). Motion Analyses of Adolescent Rugby Union Players: A Comparison of Training and Game Demands. *Journal of Strength and Conditioning Research, In Press*.

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

Helsen, W. F., Hodges, N. J., Van Winckel, J., & Starkes, J. L. (2000). The roles of talent, physical precocity and practice in the development of soccer expertise. *Journal of Sports Sciences, 18*(9), 727-736.

Helsen, W. F., Van Winckel, J., and Williams, M. A. (2005). The relative age effect in youth soccer across Europe. *Journal of Sports Sciences, 23*(6), 629-636.

Hirose, N. (2009). Relationships among birth-month distribution, skeletal age and anthropometric characteristics in adolescent elite soccer players. *Journal of Sports Sciences, i-first*, 1-8.

Hopkins, W. G. (2010). Linear Models and Effect Magnitudes for Research, Clinical and Practical Applications. *SportsScience, 14*, 49-57. Retrieved from Sportsci.org website:

Hopkins, W. G., Marshall, S. W., Batterham, A. M., & Hanin, J. (2009). Progressive statistics for studies in sports medicine and exercise science. *Medicine and Science in Sports and Exercise, 41*(1), 3-13.

http://www.catapultsports.com/research-validation.   Retrieved 01/10/11, 2011

Hyllegard, R., Radlo, S. J., & Early, D. (2001). Attribution of athletic expertise by college coaches. *Perceptual and Motor Skills, 92*(1), 193-207.

Iaia, F. M., Rampinini, E., & Bangsbo, J. (2009). High-intensity training in football. *International Journal of Sports Physiology and Performance, 4*(3), 291-306.

Impellizzeri, F. M., & Marcora, S. M. (2009). Test validation in sport physiology: lessons learned from clinimetrics. *International Journal of Sports Physiology and Performance, 4*(2), 269-277.

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

Impellizzeri, F. M., Rampinini, E., Coutts, A. J., Sassi, A., & Marcora, S. M. (2004). Use of RPE-based training load in soccer. *Medicine and Science in Sports and Exercise, 36*(6), 1042-1047.

Independant Sports Panel, A. G. (2009). The Future of Sport in Australia (pp. 347): Commonwealth of Australia.

Jennings, D., Cormack, S., Coutts, A. J., Boyd, L., & Aughey, R. J. (2010a). The validity and reliability of GPS units for measuring distance in team sport specific running patterns. *International Journal of Sports Physiology and Performance, 5*(3), 328-341.

Jennings, D., Cormack, S., Coutts, A. J., Boyd, L. J., & Aughey, R. J. (2010b). Variability of GPS units for measuring distance in team sport movements. *International Journal of Sports Physiology and Performance, 5*(4), 565-569.

Kaikkonen, P., Hynynen, E., Mann, T., Rusko, H., & Nummela, A. (2010). Can HRV be used to evaluate training load in constant load exercises? *European Journal of Applied Physiology and Occupational Physiology, 108*(3), 435-442.

Kay, B., & Gill, N. D. (2003). Physical demands of elite Rugby League referees: Part one--time and motion analysis. *Journal of Science and Medicine in Sport, 6*(3), 339-342.

Kelly, D. M., & Drust, B. (2009). The effect of pitch dimensions on heart rate responses and technical demands of small-sided soccer games in elite players. *Journal of Science and Medicine in Sport, 12*(4), 475-479.

King, T., Jenkins, D., & Gabbett, T. (2009). A time-motion analysis of professional rugby league match-play. *Journal of Sports Sciences, 27*(3), 213-219.

Kreiner-Phillips, a. K. O., T. . (1993). Winning After Winning: The Psychology of Ongoing Excellence. *Sport Psychologist, 7*(1), 31.

Krustrup, P., Mohr, M., Amstrup, T., Rysgaard, T., Johansen, J., Steensberg, A., . . . Bangsbo, J. (2003). The yo-yo intermittent recovery test: physiological response, reliability, and validity. *Medicine and Science in Sports and Exercise, 35*(4), 697-705.

Lago, C., Casais, L., Dominguez, E., Sampaio, J. (2010). The effects of situational variables on distance covered at various speeds in elite soccer. *European Journal of Sport Science, 10*(2), 103-109.

Lefevre, J., Beunen, G., Steens, G., Claessens, A., and Renson, R. (1990). Motor performance during adolescence and age thirty as related to age at peak height velocity. *Annals of Human Biology, 17*, 423-435.

Lehance, C., Binet, J., Bury, T., and Croisier, J. L. (2009). Muscular strength, functional performances and injury risk in professional and junior elite soccer players. *Scandinavian Journal of Medicine and Science in Sports, 19*, 243-251.

Lidor, R., Cote, J., and Hackfort, D. (2009). ISSP Position Stand: To test or not to test? The use of physical skills tests in talent development and in early phases of sport development. *International Journal of Sport and Exercise Physiology, 7*, 131-146.

MacLeod, H., Morris, J., Nevill, A., & Sunderland, C. (2009). The validity of a non-differential global positioning system for assessing player movement patterns in field hockey. *Journal of Sports Sciences, 27*(2), 121-128.

Macutkiewicz, D., & Sunderland, C. (2011). The use of GPS to evaluate activity profiles of elite women hockey players during match-play. *Journal of Sports Sciences, 29*(9), 967-973.

Malina, R. M., Cumming, S. P., Kontos, A. P., Eisenmann, J. C., Ribeiro, B., and Aroso, J. (2005). Maturity-associated variation in sport-specific skills of youth soccer players aged 13 – 15 years. *Journal of Sports Sciences, 23*(5), 515-522.

Martindale, R. J. J., Collins, D., and Daubney, J. (2005). Talent Development: A guide for practice and research within sport. *Quest, 57*, 353-375.

McGarry, T., & Franks, I. M. (2003). The science of match analysis. In T. Reilly & A. M. W. (Eds.) (Eds.), *Science and Soccer* (2nd Edition ed., pp. pp. 265-275). London: Routledge.

McGee, K. J., & Burkett, L. N. (2003). The National Football League combine: a reliable predictor of draft status? *Journal of Strength and Conditioning Research, 17*(1), 6-11.

McLaughlin, J. E., Howley, E. T., Bassett, D. R., Jr., Thompson, D. L., & Fitzhugh, E. C. (2010). Test of the classic model for predicting endurance running performance. *Medicine and Science in Sports and Exercise, 42*(5), 991-997.

McLellan, C. P., Lovell, D. I., & Gass, G. C. (2010). Creatine kinase and endocrine responses of elite players pre, during, and post rugby league match play. *Journal of Strength and Conditioning Research, 24*(11), 2908-2919.

Meir, R., Newton, R., Curtis, E., Fardell, M., & Butler, B. (2001). Physical fitness qualities of professional rugby league football players: determination of positional differences. *Journal of Strength and Conditioning Research, 15*(4), 450-458.

Mikulic, P., & Ruzic, L. (2008). Predicting the 1000m rowing ergometer performance in 12-13-year-old rowers: the basis for selection process? *Journal of Science and Medicine in Sport, 11*(2), 218-226.

Minett, G., Duffield, R., & Bird, S. P. (2010). Effects of acute multinutrient supplementation on rugby union game performance and recovery. *International Journal of Sports Physiology and Performance, 5*(1), 27-41.

Mohr, M., Krustrup, P., Andersson, H., Kirkendal, D., & Bangsbo, J. (2008). Match activities of elite women soccer players at different performance levels. *Journal of Strength and Conditioning Research, 22*(2), 341-349.

Mohr, M., Krustrup, P., & Bangsbo, J. (2003). Match performance of high-standard soccer players with special reference to development of fatigue. *Journal of Sports Sciences, 21*(7), 519-528.

Montgomery, P. G., Pyne, D. B., & Minahan, C. L. (2010). The physical and physiological demands of basketball training and competition. *International Journal of Sports Physiology and Performance, 5*(1), 75-86.

Mooney, M., O'Brien, B., Cormack, S., Coutts, A., Berry, J., & Young, W. (2011). The relationship between physical capacity and match performance in elite Australian football: a mediation approach. *Journal of Science and Medicine in Sport, 14*(5), 447-452.

Moore, P. M., Collins, D., and Burwitz, L. (1998). *The development of talent study*. London: English Sports Council.

Mountjoy, M., Armstrong, L., Bizzini, L., Blimkie, C., Evans, J., Gerrard, D., Hangen, J., Knoll, K., Micheli, L., Sangenis, P., and Van Mechelen. (2008). IOC conceses statement: "training the elite child athlete". *British journal of Sports Medicine, 42*, 163-164.

Mujika, I., Santisteban, J., Impellizzeri, F. M., and Castagna, C. (2009a). Fitness determinants of success in men's and women's football. *Journal of Sports Sciences, 27*(2), 107-114.

Mujika, I., Vaeyens, R., Matthys, S. P. J., Santisteban, J.,Goiriena, J., and Philippaerts, R. (2009b). The relative age effect in a professional football club setting. *Journal of Sports Sciences, i-first*, 1-6.

Norton, K., & Olds, T. (2001). Morphological evolution of athletes over the 20th century: causes and consequences. *Sports Medicine, 31*(11), 763-783.

Norton, K., Schwerdt, S., & Lange, K. (2001). Evidence for the aetiology of injuries in Australian football. *British Journal of Sports Medicine, 35*(6), 418-423.

Norton, K. I. (2010). AFL analysis premiership season 2010. In TrakPerformance (Ed.), *AFL Research Report*. Adelaide.

Norton, K. I., and Craig, N. (2006). Effect of changes to laws and interpretation of the laws on the 2006 AFL home & away series. In TrakPerformance (Ed.), *AFL Research Report*. Adelaide.

Norton, K. I., Craig, N. P., & Olds, T. S. (1999). The evolution of Australian football. *Journal of Science and Medicine in Sport, 2*(4), 389-404.

O'Donoghue, P. (2004). Sources of variability in time-motion data; measurement error and within player variability in work-rate. *International Journal of Performance Analysis in Sport, 4*(2), 42-49.

Oldennziel, K. E., Gagne, F., and Gubin, J. P. (2004). *Factors affecting the rate athlete development from novice to senior elite. How applicable is the 10-year rule*. Paper presented at the Proceedings of the 2004 Pre-Olympic Congress, Aristotle University of Thessaloniki, Thessaloniki, Greece.

Orchard, J., & Seward, H. (2010). 2010 Injury Report - Australian Football League. In AFL (Ed.). Australia.

Osgnach, C., Poser, S., Bernardini, R., Rinaldo, R., & di Prampero, P. E. (2010). Energy cost and metabolic power in elite soccer: a new match analysis approach. *Medicine and Science in Sports and Exercise, 42*(1), 170-178.

Pearson, D. T., A., N. G., & Torode, M. (2006). Predictability of physiological testing and the role of maturation in talent identification for adolescent team sports. *Journal of Science and Medicine in Sport, 9*, 277-287.

Petersen, C., Pyne, D., Portus, M., & Dawson, B. (2009a). Validity and reliability of GPS units to monitor cricket-specific movement patterns. *International Journal of Sports Physiology and Performance, 4*(3), 381-393.

Petersen, C., Pyne, D. B., Portus, M. R., Karppinen, S., & Dawson, B. (2009b). Variability in movement patterns during One Day Internationals by a cricket fast bowler. *International Journal of Sports Physiology and Performance, 4*(2), 278-281.

Petersen, C. J., Pyne, D., Dawson, B., Portus, M., & Kellett, A. (2010). Movement patterns in cricket vary by both position and game format. *Journal of Sports Sciences, 28*(1), 45-52.

Petersen, C. J., Pyne, D. B., Dawson, B. T., Kellett, A. D., & Portus, M. R. (2011). Comparison of training and game demands of national level cricketers. *Journal of Strength and Conditioning Research, 25*(5), 1306-1311.

Petersen, C. J., Pyne, D. B., Portus, M. R., & Dawson, B. T. (2011). Comparison of player movement patterns between 1-day and test cricket. *Journal of Strength and Conditioning Research, 25*(5), 1368-1373.

Portas, M. D., Harley, J. A., Barnes, C. A., & Rush, C. J. (2010). The validity and reliability of 1-Hz and 5-Hz global positioning systems for linear, multidirectional, and soccer-specific activities. *International Journal of Sports Physiology and Performance, 5*(4), 448-458.

Pyne, D. B., Gardner, A. S., Sheehan, K., & Hopkins, W. G. (2005). Fitness testing and career progression in AFL football. *Journal of Science and Medicine in Sport, 8*(3), 321-332.

Rahnama, N., Reilly, T., Lees, A., & Graham-Smith, P. (2003). Muscle fatigue induced by exercise simulating the work rate of competitive soccer. *Journal of Sports Sciences, 21*(11), 933-942.

Rampinini, E., Bishop, D., Marcora, S. M., Ferrari Bravo, D., Sassi, R., & Impellizzeri, F. M. (2007a). Validity of simple field tests as indicators of match-related physical performance in top-level professional soccer players. *International Journal of Sports Medicine, 28*(3), 228-235.

Rampinini, E., Coutts, A. J., Castagna, C., Sassi, R., & Impellizzeri, F. M. (2007b). Variation in top level soccer match performance. *International Journal of Sports Medicine, 28*(12), 1018-1024.

Rampinini, E., Impellizzeri, F. M., Castagna, C., Abt, G., Chamari, K., Sassi, A., & Marcora, S. M. (2007c). Factors influencing physiological responses to small-sided soccer games. *Journal of Sports Sciences, 25*(6), 659-666.

Rampinini, E., Impellizzeri, F. M., Castagna, C., Coutts, A. J., & Wisloff, U. (2009a). Technical performance during soccer matches of the Italian Serie A league: effect of fatigue and competitive level. *Journal of Science and Medicine in Sport, 12*(1), 227-233.

Rampinini, E., Sassi, A., Morelli, A., Mazzoni, S., Fanchini, M., & Coutts, A. J. (2009b). Repeated-sprint ability in professional and amateur soccer players. *Applied Physiology Nutrition and Metabolism, 34*(6), 1048-1054.

Randers, M. B., Mujika, I., Hewitt, A., Santisteban, J., Bischoff, R., Solano, R., . . . Mohr, M. (2010). Application of four different football match analysis systems: a comparative study. *Journal of Sports Sciences, 28*(2), 171-182.

Reilly, T., Bangsbo, J., & Franks, A. (2000). Anthropometric and physiological predispositions for elite soccer. *Journal of Sports Sciences, 18*(9), 669-683.

Reilly T, W. A. (2003). *Science and Soccer* (2nd edition ed.). London: Routledge.

Reilly, T., Williams, A. M., Neville, A., and Franks, A. (2000). A multidisciplinary approach to talent identification in soccer. *Journal of Sports Sciences, 18*, 695-702.

Rienzi, E., Drust, B., Reilly, T., Carter, J. E., & Martin, A. (2000). Investigation of anthropometric and work-rate profiles of elite South American international soccer players. *Journal of Sports Medicine and Physical Fitness, 40*(2), 162-169.

Roberts, S. P., Trewartha, G., Higgitt, R. J., El-Abd, J., & Stokes, K. A. (2008). The physical demands of elite English rugby union. *Journal of Sports Sciences, 26*(8), 825-833.

Rowland, T. (2009). Aerobic (un)trainability of children: mitochondrial biogenesis and the "crowded cell" hypothesis. *Pediatric Exercise Science, 21*(1), 1-9.

Saltin, B. (1973). Metabolic fundamentals in exercise. *Med Sci Sports, 5*(3), 137-146.

Sheppard, J. M., Gabbett, T., & Borgeaud, R. (2008). Training repeated effort ability in national team male volleyball players. *International Journal of Sports Physiology and Performance, 3*(3), 397-400.

Sherar, L. B., Baxter-Jones, A. D., Faulkner, R. A., & Russell, K. W. (2007). Do physical maturity and birth date predict talent in male youth ice hockey players? *Journal of Sports Sciences, 25*(8), 879-886.

Sierer, P. S., Battaglini, C. L., Mihaili, J. P., Shields, E. W., and Tomasini, N. T. (2008). The National Football League Combine: Performance differences between drafted and nondrafted players entering the 2004 and 2005 drafts. *Journal of Strength and Conditioning Research, 22*(1), 6-12.

Silva, J. R., Magalhaes, J. F., Ascensao, A. A., Oliveira, E. M., Seabra, A. F., & Rebelo, A. N. (2011). Individual match playing time during the season affects fitness-related parameters of male professional soccer players. *Journal of Strength and Conditioning Research, 25*(10), 2729-2739.

Simonton, D. K. (2001). Talent Development as a Multidimensional, Multiplicative, and Dynamic Process. *Current Directions in Psychological Science, 10*(2), 39-43.

Sirotic, A. C., Coutts, A. J., Knowles, H., & Catterick, C. (2009). A comparison of match demands between elite and semi-elite rugby league competition. *Journal of Sports Sciences, 27*(3), 203-211.

Sirotic, A. C., Knowles, H., Catterick, C., & Coutts, A. J. (2011). Positional Match Demands of Professional Rugby League Competition. *Journal of Strength and Conditioning Research*.

Stolen, T., Chamari, K., Castagna, C., & Wisloff, U. (2005). Physiology of soccer: an update. *Sports Medicine, 35*(6), 501-536.

Takarada, Y. (2003). Evaluation of muscle damage after a rugby match with special reference to tackle plays. *British Journal of Sports Medicine, 37*(5), 416-419.

Talbot-Honeck, C., and Orlick, T. (1998). The essence of excellence: Mental Skills of Top Classical Musicians. *Journal of Excellence, 1*, 61-75.

Terbizan, D., Dolezal, B., & Albano, C. (2002). Validity of seven commercially available Heart Rate monitors. *Measurement in Physical Education and Exercise Science, 6*, 243-247.

Terrier, P., Ladetto, Q., Merminod, B., & Schutz, Y. (2000). High-precision satellite positioning system as a new tool to study the biomechanics of human locomotion. *Journal of Biomechanics, 33*(12), 1717-1722.

Terrier, P., Ladetto, Q., Merminod, B., & Schutz, Y. (2001). Measurement of the mechanical power of walking by satellite positioning system (GPS). *Medicine and Science in Sports and Exercise, 33*(11), 1912-1918.

Thatcher, R., & Batterham, A. M. (2004). Development and validation of a sport-specific exercise protocol for elite youth soccer players. *Journal of Sports Medicine and Physical Fitness, 44*(1), 15-22.

Vaeyens, R., Gullich, A., Warr, C., and Philippaerts, R. M. (2009). Talent identification and promotion programmes of Olympic athletes. *Journal of Sports Sciences*(iFirst article), 1-14.

Vaeyens, R., Lenoir, M., Williams, A. M., and Philippaerts, R. M. (2008). Talent identification and development programmes in sport - Current models and future directions. *Sports Medicine, 38*(9), 703-714.

Vaeyens, R., Philippaerts, R. M., Malina, R. M. (2005). The relative age effect in soccer: A match-related perspective. *Journal of Sports Sciences, 23*(7), 747-756.

Van Gool D, V. G. D., Boutmans J. (1987). The physiological load imposed on soccer players during real match play. In L. A. Reilly T, Davids K et al (Ed.), *Science and Football* (pp. 51-59). London: E & FN Spon.

van Rossum, J. H. A., and Cagne, F. (2005). Talent development in sports. In F. A. Dixon, and Moon, S. M. (Ed.), *The Handbook of Secondary Gifted Education* (pp. 281-316). Waco: Prufrock Press.

Veale, J. P. a. P., A. J. (2009). Profile of position movement demands in elite junior Australian rules footballers. *Journal of Sports Science and Medicine, 8*, 320-326.

Venturelli, M., Bishop, D., and Pettene, L. (2008). Sprint training in preadolescent soccer players. *International Journal of Sports Physiology and Performance, 3*, 559-562.

Waldron, M., Worsfold, P., Twist, C., & Lamb, K. (2011). Concurrent validity and test-retest reliability of a global positioning system (GPS) and timing gates to assess sprint performance variables. *Journal of Sports Sciences*.

Wall, M., and Cote, J. (2007). Developmental activities that lead to drop out and investment in sport. *Physical Education and Sport Pedagogy, 12*, 77-87.

Williams, A. M., & Reilly, T. (2000). Talent identification and development in soccer. *Journal of Sports Sciences, 18*(9), 657-667.

Williams, M., and Morgan, S. (2009). Horizontal positioning error derived from stationary GPS units: A function of time and proximity to building infrastructure. *International Journal of Performance Analysis of Sport, 9*, 275-280.

Winsley, R., & Matos, N. (2011). Overtraining and elite young athletes. *Med Sport Sci, 56*, 97-105.

Wisbey, B., Montgomery, P. G., Pyne, D. B., & Rattray, B. (2010). Quantifying movement demands of AFL football using GPS tracking. *Journal of Science and Medicine in Sport, 13*(5), 531-536.

Wiseby, B., Rattray, B., and Pyne, D. (2010). Quantifying Changes in AFL Player Game Demands Using GPS Tracking. Canberra, Australia.

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

Witte, T. H., & Wilson, A. M. (2004). Accuracy of non-differential GPS for the determination of speed over ground. *Journal of Biomechanics, 37*(12), 1891-1898.

Witte, T. H., & Wilson, A. M. (2005). Accuracy of WAAS-enabled GPS for the determination of position and speed over ground. *Journal of Biomechanics, 38*(8), 1717-1722.

Wolfenden, L. E. (2005). Talent development in elite junior tennis: perceptions of players, parents, and coaches. *Journal of Applied Sport Psychology, 17*, 108-126.

www.transferleague.co.uk. (2011) Retrieved 1st December 2011, 2011

Yamanaka K, H. S., Shindo M, et al. (1987). Time and motion analysis in top class soccer games. In L. A. Reilly T, Davids K et al (Ed.), *Science and Soccer* (pp. 334-340). London: E & FN Spon.