REVIEW ARTICLE

Sports Med 2010; 40 (4): 347-360
0112-1642/10/0004-0347/$49.95/0



# Match Analysis and the Physiological Demands of Australian Football

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## Contents



## Abstract

Australian Football, the most popular football code in Australia, is a contact sport played by two teams of 18 players who contest play over four 20-minute quarters; the object of the game is to score the most points through goal kicking. Sixteen professional senior sides compete against each other in the Australian Football League (AFL) and, similar to other football codes, game demands at the elite level in the AFL have changed considerably in recent years. Early time-motion analysis studies highlighted the long periods of time players spent in low intensity activities (standing and walking). While recent studies utilizing global positioning systems (GPS) technology are somewhat in agreement with earlier findings, available evidence suggests that the game is getting faster. For example, 'playing on' after a mark (a feature of the game where players who catch the ball on the full from a kick longer than 15 m are awarded a free kick) is now much quicker. Indeed, rule changes in recent years have increased the flow and speed of the game; there has been a reduction in the time taken for umpires to restart play, and for players to kick-in (after the opposition kicks a behind) or take a set shot at goal. Nomadic players (a broad term for midfielders and ruckmen because they follow play over the entire playing field) cover slightly greater distances (12 310 m) than both forwards (11 920 m) and backs (11 880 m) in a game. Compared with players in other positions, midfielders are consistently found to spend the most time at higher intensities (running and sprint efforts with movement velocities >4.44 m/sec), complete more high intensity efforts (~98 per game), sustain them for longer and have shorter recovery periods between high intensity exercise bouts (~90 seconds on average). ‘Ruckmen’ have similar but less intense running profiles, while forwards and backs generally have less game involvement but have a more intermittent running profile (longer recovery periods with shorter duration high intensity exercise bouts and less time spent in constant pace running). Endurance fitness remains very important for players at the elite level of competition, as does upper and lower body strength and power. In addition, given the increasing speed at which Australian Football is now played, repeated sprint ability of players is arguably more important now than it was in previous years. There are no significant differences in these measures between playing position. Similarly, speed over 10–40 m does not appear to differ between playing position. Establishing the reliability of distance and velocity-derived GPS data in highly specific game-related activities is needed; once achieved, GPS data have the potential to accurately inform coaches of the position-specific demands on their players and to drive the development of training practices that reflect the changing demands of the game.

An intense national competition coupled with the push by administrators to maintain high spectator appeal for the game has led to significant changes in the way Australian Football is now played. The impact of these changes on player demands (e.g. injury risk, playing career longevity) and on training methods has been of particular interest to sports scientists.[1] The primary aim of this article is to review the current game demands, including movement patterns and game activities in Australian Football. In addition, the physiological attributes of players is evaluated. Findings in the literature should be used by conditioning staff to better prepare players in the current competition. Injuries in Australian Football have been comprehensively addressed by others and are therefore not included in this review. The interested reader is referred to the 2007 Australian Football League (AFL) injury report[2] and an earlier review article.[3] Indeed, a recent search in 2009 of the term ‘Australian Football’ in PubMed returned 193 articles, of which 47% related to some aspect of injury, 19% were not related to Australian Football specifically and 8% discussed various physiological testing methods. Aspects of game analysis (5%), fitness attributes (5%), performance/ergogenic aids (6%), skill acquisition/decision making (5%) and sociology (5%), made up the remaining body of available literature. Given that much of the published literature is outdated and of questionable relevance to the modern game, a review of recent research utilizing current technologies is timely. Collectively, a number of recent AFL research reports describe the current changes in game structure and game demand. These reports are central to the review as they arguably best reflect the demands being placed on modern elite players. Reference is made to earlier publications for historical perspectives.

## 1. Description of Australian Football

Australian Football is currently played in over 30 structured leagues throughout 30 countries worldwide. The premier competition, the AFL, is played in all seven of Australia’s states and territories and is currently the most popular football code in Australia. Undoubtedly, its strongest following is in the southern state of Victoria where it originated in 1858. Australian Football is a contact, invasion game that generally involves less collisions and tackling than rugby union and rugby league. The objectives and game structure of Australian Football are similar to those of football (soccer), and have been described as a running game combining athleticism with speed, and requiring skilful foot and hand passing.[4] In modern Australian Football two teams contest play over four 20- to 30-minute periods with the objective of scoring more points than the opposing team to win. A team is composed of 22 players, with 18 players allowed on the field at any one time. The remaining four players make up an interchange bench and these players can be rotated onto the field as frequently as the coach deems necessary. Field dimensions and traditional playing positions are detailed in figure 1. Positions can be grouped into forwards (offensive), nomadic players and backs (defensive). Forwards and backs each include two generally taller, more stationary key position players (centre half forward/back and full forward/back) and four smaller, more mobile players (half forward/back flanks and forward/back pockets). The forwards' primary role is to mark the ball (catching it on the full from a kick longer than 15 m) in the best position possible to then take a free kick at the

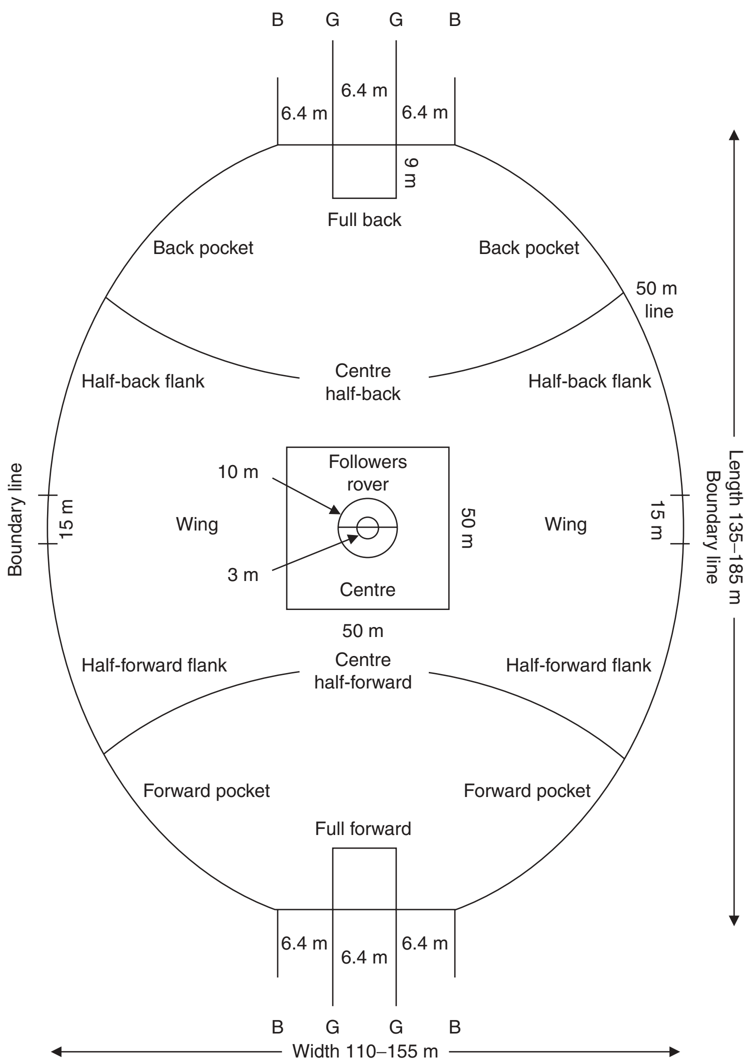


**Fig. 1.** Australian Football playing field and traditional playing positions.[5] **B** = 'behind' posts; **G** = 'goal' posts.

 

goals. The backs aim to defend against the opposition forwards, 'spoiling' their marking attempts. The small forwards and backs generally work alongside the key position players, either picking up the loose ball from the ground and kicking for goal (small forwards) or regaining possession and clearing the ball from their goal area (small backs). The traditional playing positions of centre, wings and followers are collectively termed midfielders. The midfielders and the ruckman are all nomadic players who link their offensive and defensive team mates, moving the ball up or down field. For the purpose of this review, midfielders will collectively refer to centres, wings and followers, whilst nomadic players will collectively refer to centres, wings, followers and ruckmen.[1] However, the ruckman (usually one of the tallest players) has the additional role of contesting the restart of play, where the ball is bounced or thrown up by an umpire. Two opposing ruckmen jump to 'tip off' the ball to one of their surrounding team mates who aims to 'clear' the ball by kicking or hand passing to others in more space. Permitted contact is limited to: tackling the player in possession of the ball (between the shoulders and knees); using the body or arm to push, bump or block opposition players within 5 m of the football (shepherding); and contact, which is incidental to a legitimate marking contest. Players are penalized for charging (e.g. using unnecessary force), tripping, striking and bumping a player above the shoulders. Points are awarded for kicking the ball through two centre goal posts (a 'goal', 6 points) or within the outside posts (a 'behind', 1 point). Each quarter can include about 10 extra minutes of stoppage time, which brings the total time of a game to approximately 120 minutes.

## 2. Game Evolution

### 2.1 Early Time-Motion Analysis Research

Match analysis was first used in Australian Football in 1963 by Nettleton and Sandstrom[6] who, in their discussion of skill and conditioning, commented "the content of training will depend upon intelligent analysis of the individual performance of players during a large number of games." The few published articles that have since analysed match demands in Australian Football have focused on recording and classifying the time spent and/or distance travelled by players in various movement patterns. Movement descriptors such as 'stationary', 'standing', 'walking', 'jogging', 'low intensity', 'running', 'medium pace', 'sprinting' and 'high intensity' have been used in previous studies.[6-9]

Early investigations established that much of the game was spent by players in low intensity activities. Estimates of time spent in low intensity activities ranged from 60% to 90% of the game depending on playing position and the method of analysis employed (table I).[7,8,10] Nomadic players such as ruckmen and the other midfielders spent more time engaged in higher intensities of exercise[7,8] and covered greater distances than forwards or backs.[7,8] The total distance covered by players in a game was first reported as a team average of 9591 m.[7] Later studies estimated that midfielders and backs covered over 10 000 m.[8] Hahn et al.[9] were the first to report on the intermittent exercise demands on players, finding that two midfielders completed 110 and 145 sprints in a game, over average distances of 12 m and 19 m, respectively. McKenna et al.[10] recorded 108.5 high intensity efforts during a game; 65% of these lasted <4 seconds in duration, 83% were <6 seconds and only 5% lasted >10 seconds.

Described as "patchy summaries of individual players,"[1] the findings from early time-motion studies in Australian Football are now outdated and bear little relevance to the modern game. The game is now considerably faster, played over a reduced duration (quarters reduced from 25- to 20-minute quarters in 1994) and governed by many different rules. Furthermore, small sample sizes (e.g. n = 2), data collection from only fractions of a full match (e.g. halves or quarters) and dated methods of analysis, limit the value of many

**1** Rovers or ruck rovers are now known as ruckmen. Followers typically 'follow play' across the field and are one of the midfield positions.

 

**Table I.** Major findings of time-motion analysis in Australian Football

| Study (year) | Collection period per game/s | No. of players | Position | Movement pattern (mean % of time in activity) | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | low intensity | | | high intensity | |
| | | | | stationary | walk | jog | run | sprint |
| Jaques and Pavia[7] (1974) | 1/4 | 5 | Ruckmen | 14 | 61 | 21 | 5 | |
| | | 3 | Followers | 9 | 58 | 28 | 5 | |
| | | 3 | Centre and wings | 17 | 60 | 16 | 7 | |
| | | 4 | Forwards | 11 | 71 | 15 | 4 | |
| | | 5 | Backs | 12 | 67 | 18 | 3 | |
| Pyke and Smith[8] (1975) | 1/2 | 1 | Midfielder | | 62 | | 38 | |
| | | 1 | SB | | 76 | | 24 | |
| McKenna et al.[10] (1988) | 1 | 4 | Midfielders | 8.8 | 44.5 | 40.9 | 4.1 | |
| Schokman et al.[11] (2003) | 16 | 5 | | 22 | 43 | 24 | 10 | 1 |
| Dawson et al.[12] (2004) | 4–6 | 2–3 | FF/FB | 23.2 | 53.7 | 18.7 | 3.4 | 1 |
| | | 2–3 | Midfielders | 10.8 | 48.2 | 34.7 | 5.6 | 0.7 |
| | | 2–3 | Ruckmen | 13.9 | 52.4 | 25.4 | 4.7 | 1 |
| | | 2–3 | SF/SB | 16.5 | 52.4 | 25.4 | 4.7 | 1 |
| | | 2–3 | CHF/CHB | 11.1 | 49.3 | 34.4 | 4.6 | 0.6 |

**CHB** = centre half back; **CHF** = centre half forward; **FB** = full back; **FF** = full forward; **SB** = small back; **SF** = small forward.

of the early findings when attempting to understand the game demands of modern Australian Football.

### 2.2 Changes in Game Speed and Structure

The game structure and speed of Australian Football have changed significantly over the last 4 decades; video analysis of selected games between 1961 and 1997 found that ball velocity (whilst 'in play') increased from approximately 3.3 m/sec in 1961 up to approximately 6.6 m/sec in 1997. However, the fraction of time that the ball is in play has decreased.[1] In 1961, the ball was in play for 81 minutes (69.2%), with 36 minutes (30.8%) of stoppage time. In 1997, the ball was in play for 59 minutes (49.3%) and stoppage time was calculated to be 61 minutes (50.7%). Australian Football now comprises more frequent shorter periods of play (at higher intensities) interspersed by more frequent and longer stoppage periods.

Changes in game tactics have paralleled rule changes over the past 40 years. During the late 1960s, coaches began challenging the traditional 'kick and mark' type game and introduced the concept of 'possession' football, moving away from traditional positions and getting players to move in groups.[4] This style of play still remains effective today and is likely to be the most influential coaching strategy on increasing game demands.[4] Additionally, rule changes such as disallowing deliberate kicks out of bounds (1968) and the introduction of the centre square (1973) have tended to reduce congestion around the ruck and improve the flow of the game.[4] Increasing professionalism, the start of a national competition and the greater size and skill of current players have also contributed to changes in game demands.[1]

Whilst Norton et al.[1] reported an increase in the mean number of total bounce downs per game (reflecting stoppage time) from 11 in 1961 to 30 in 1997, analysis of more recent game statistics revealed that this increased further to 60 per game in the following 6 years (2003).[13] Over the same period there was a reduction in long kicks (–23%) and contested marks per game (–27%), with corresponding increases in short kicks (22%) and uncontested marks per game (17%).[13] Thus, the trend toward increasing intermittent play had continued. Characteristic elements of the game that appealed to spectators and supporters (high flying contested marks from long kicks and flowing play) were fading, and the AFL had growing concerns. The response of administrators has included the progressive introduction of rule changes from the 2004 season onwards (see table II).

Although no further research on such game trends has been published in peer-reviewed journals, a number of AFL-commissioned projects investigating game structure, player game demands (using global positioning systems [GPS] technology) and trends in game statistics (to monitor the impact of interventions) from recent seasons are available.[13-18] Collectively, these reports provide an assessment of the influence recent rule changes in Australian Football have had on game demands. However, the use of the GPS-based research[15-18] to identify seasonal changes in game demand is limited. For each season, game files from all positional groups were pooled; however, since 2005 the relative proportions of forwards, nomadic players and backs have changed markedly. In 2005, approximately 44% of all game files were for nomadic players, while in 2008 this increased to approximately 82%. Thus, values from the 2007 and 2008 seasons generally reflect the game demands of nomadic players only. Any apparent trends over the last four seasons should therefore be considered with this in mind; in light of this bias, we have chosen to exclude these data from this section of the review.

**Table II.** Major rule changes for the Australian Football League (AFL) since the mid-1960s[4,14]

| Year | Major rule changes |
|---|---|
| 1969 | Players free kicked for kicking the ball out of bounds on the full |
| 1973 | Centre square established where only four players a side are allowed for centre bounces[a] |
| 1976 | Two field umpires used in matches for the first time |
| 1978 | Introduction of two interchange players (unlimited interchanges) |
| 1988 | Players awarded a free kick are obliged to kick the ball rather than playing on |
| 1990 | Players who are awarded free kicks again are given option of playing on |
| 1994 | Quarters are reduced from 25 min to 20 min each (plus stoppages) |
| | The introduction of three interchange players (unlimited interchanges) |
| 1998 | The introduction of four interchange players (unlimited interchanges) |
| 2005 | Players are penalized for holding up another player after a mark[b] or free kick |
| | Reduced time is allowed after marks and free kicks are awarded |
| 2006 | Players are able to kick-in[c] without having to wait for the goal umpire's flag to be waved |
| | A limit on time for players to line up for set shots on goal |
| | Umpires are instructed to perform quicker throw-ins,[d] ball ups[e] and centre bounces |

a To commence play, the field umpire bounces the ball in the centre circle.

b When the ball is caught on the full from a kick longer than 15 m. The player is awarded a free kick.

c To recommence play after a behind is scored, a player kicks the ball into play from the goal square.

d To recommence play if the ball goes out of bounds, the boundary umpire throws the ball backwards over their head into play from the boundary line.

e To recommence play at a neutral contest after a stoppage within the field of play, the field umpire bounces the ball or throws it upwards.

Recently, introduced rule changes (summarized in table II) appear to have reduced total stoppage time.[14] This has resulted from improvements in non-clearance rates from ruck contests, a reduction in the time taken for umpires to restart play (i.e. ball-ups, boundary throw-ins, centre bounce-downs), a reduction in time taken to kick-in (after the opposition kicks a behind) or take a set shot at goal, and faster 'playing on' after a mark.[14] These are essentially a reversal of trends found over the last 4 decades.

The improved flow of the game was anticipated to reduce players' on-field recovery and their subsequent ability to maintain high game speeds. This was thought to be beneficial as it could potentially reduce the severity of collision injuries and extend playing careers. However, coaches have increased their utilization of the interchange bench, and since 2000 (see table III) there has been a large reduction in the percentage of players remaining on the field for entire matches (66% in 2000 reducing to 20% in 2005).[14] Consequently, game speed during play has increased since 2002.[14] Given that the mean speed of players is highest in the first few minutes of a quarter and that players who are interchanged more frequently perform more high intensity efforts,[20] it is reasonable to conclude that there is a

 

**Table III.** Key game statistics relating to game flow and speed[14,19]

| Season (year) | Stoppages | | | Time in play (%) | Ball speed (m/sec) | Interchanges |
|---|---|---|---|---|---|---|
| | no. | non-clearance rate (%) | duration (sec) | | | |
| 2001 | 90 | 18.5 | 30.5 | 47.5 | 6.4 | 20 |
| 2002 | 94 | 23.4 | 27 | 49 | 5.8 | 24 |
| 2003 | 91 | 22.8 | 29 | 51 | 5.8 | 22 |
| 2004 | 88 | 23.4 | 28 | 50 | 5.9 | 30 |
| 2005 | 79 | 18.3 | 33.2 | 51 | 6.2 | 36 |
| 2006 | 78 | 19.0 | 21.6 | 61 | 6.5 | 46 |
| 2007 | 80 | 20.4 | 22 | 60 | 6.8 | 57 |
| 2008 | 83 | 22.0 | | | | 81 |

relationship between game speed and interchange utilization. This coaching strategy aimed at maintaining fresh, involved players in the game seems to have been employed to combat the greater demand imposed by the recent rule changes. The possible effect of limiting the number of interchanges per game is currently under review.

## 3. Modern Australian Football

### 3.1 Global Positioning Systems Match Analysis and Game Demands

Team use of GPS technology in AFL competition games was first permitted during the 2005 season; clubs were allowed to monitor five players during ten games of the season. In 2009, ten players per game could be monitored. Since 2005, many clubs have submitted their data to AFL researchers, who have subsequently assessed the seasonal game demands of players.[15-18] Despite the popularity of GPS technology in the AFL, few studies have examined the accuracy and reliability of GPS techniques in the measurement of distance and velocity in field sports.[21-24] Nonetheless, GPS technology has the potential to provide coaches and support staff in AFL clubs with detailed objective information on the movement demands of their players.

Wisbey and co-authors[15-18] used GPS data to derive an exertion index to represent the total physical game load on players in recent seasons. The exertion index is thought to encompass all aspects of a player's movement profile, summing the short high intensity efforts with low and moderate intensity jogging and running. Although it is difficult to derive detailed meaning from reported values, the simplicity of a single number to describe the overall movement demand in a game or training setting is appealing to coaches. The authors report that nomadic players (midfielders and ruckmen) consistently maintain higher indices than both forwards and backs. Similarly, variables reflecting playing intensity (average speed and exertion index/minute) are presently significantly higher for nomadic players than for forwards and backs. No consistent differences between forwards and backs were found by the authors in these variables.[18]

When all playing positions are pooled, the mean total distances covered by players during a game have been found to range from 12 030 m to 12 510 m.[15-18] Consistent with data from previous GPS reports, 2008 data confirmed that nomadic players covered a slightly greater distance (12 310 m) than both forwards (11 920 m) and backs (11 880 m). These values vary markedly from earlier estimates. Previous time-motion analysis studies used ground markings and cues[6,7,9] or stride length and frequency[8,12] to estimate the distances travelled. Dawson et al.[12] used step distance and step frequency from video footage to estimate distances travelled by selected players during the 2000 season. The reported mean distances travelled were 13 614 m, 15 393 m, 16 005 m, 16 278 m and 16 976 m for full forwards/backs, ruckmen, centre half forwards/backs, small forwards/backs and midfielders, respectively. Similarly, analysis of elite

AFL players in 2002–3 (using a drawing tablet attached to a laptop) established mean total distance covered by players to be 16 600 m.[25] The variation between the findings of Wisbey and co-authors,[15-18] Dawson et al.[12] and Burgess and Naughton[25] should be interpreted with caution, given the differences in methods employed and the changes in game speed and structure.

Whilst total distance travelled in a game is of interest and can be used to estimate the volume of work a player has completed, some have suggested that it is the frequency and duration of moderate and high intensity activities that more accurately describe the game demands imposed on players, as these activities place considerable strain on the anaerobic energy systems.[26] Sprints, sustained efforts, accelerations, decelerations and work-recovery ratios collectively help define the more demanding activities expected of players during a match.

Wisbey and co-authors[15-18] have used speed zones in much the same way as movement descriptors (e.g. jog/run) to describe the intensity of play from data collected using GPS tracking. For comparative purposes, standing and walking ≈0–1.66 m/sec, jogging ≈1.94–3.88 m/sec, running ≈4.16–5.55 m/sec and sprinting ≈6.11–10 m/sec have been used. Analysis of data from the 2007 season revealed the time spent in each zone during games by forwards, nomadic players and backs[17] (table IV). It is clear that much of the current game is spent by players recovering from high intensity exercise, and that this reflects the increased speed at which the game is now played. No significant differences were found by the authors between forwards and backs across the speed zones, suggesting relatively similar movement demands for these positions.[15-18] However, nomadic players spent significantly less time (~11 minutes) moving <1.66 m/sec (i.e. standing and walking) and significantly more time running at speeds between 4.44–5 m/sec and >5 m/sec than forwards and backs ($p < 0.05$). Backs spent the least amount of time running at speeds >6.94 m/sec (i.e. sprinting) in a game (24.90 ± 16.31 seconds) – significantly less than nomadic players (33.45 ± 17.01 seconds).

These more recent findings are in agreement with those of Dawson et al.[12] relating to games played several seasons earlier. From their research, full forward/back positions were noted as being the most different from the others and were considered ‘specialist’ positions.[12] Full forwards/backs spent an estimated 23.2% of the game standing, but also covered more distance sprinting and spent a longer percentage of time sprinting when compared with other positions who were found to be more ‘mobile’ (10.8–16.5% of the game spent standing). Midfielders spent the least amount of time standing (10.8%) and the most amount of time fast running (5.6%). For all positions, fast running and sprinting (i.e. high intensity movement patterns) accounted for only 4.4–6.3% of game time.[12] The positional data from the study by Dawson et al.[12] are summarized in table I.

GPS tracking analyses reveal that players in all positions make more moderate accelerations (~250) than decelerations (~235) in a game, but

**Table IV.** Mean time (±SD) spent in speed zones by forwards, nomadic players and backs per game in season 2007 (reproduced from Wisbey et al.,[17] with permission)

| Speed zone (m/sec) | Forwards (n = 39) | Nomadic (n = 493) | Backs (n = 29) |
|---|---|---|---|
| <1.66 | 68:48 ± 10:29 (min) | 57:22 ± 11:24 (min) | 69:22 ± 12:44 (min) |
| <2.22 | 80:02 ± 11:29 (min) | 67:00 ± 12:09 (min) | 79:26 ± 13:35 (min) |
| 2.22–2.78 | 6:31 ± 1:29 (min) | 7:23 ± 1:37 (min) | 7:20 ± 1:30 (min) |
| 2.78–3.33 | 6:40 ± 1:35 (min) | 8:04 ± 1:42 (min) | 6:55 ± 1:21 (min) |
| 3.33–3.89 | 5:26 ± 1:19 (min) | 6:54 ± 1:39 (min) | 5:31 ± 1:11 (min) |
| 3.89–4.44 | 3:51 ± 0:55 (min) | 5:07 ± 1:20 (min) | 4:04 ± 0:59 (min) |
| 4.44–5 | 2:22 ± 0:38 (min) | 3:17 ± 0:53 (min) | 2:34 ± 0:53 (min) |
| >5 | 4:36 ± 1:14 (min) | 5:49 ± 1:25 (min) | 4:19 ± 1:14 (min) |
| >6.94 | 31.72 ± 16.04 (sec) | 33.45 ± 17.01 (sec) | 24.90 ± 16.31 (sec) |

 

more rapid decelerations (~15) than accelerations (~12).[17] Significantly more moderate changes in velocity occur than rapid changes, with ruckmen performing significantly less rapid accelerations and decelerations than all other positions.[16] Analysis of the number of 'surges' or running efforts at higher speeds has shown that nomadic players move into the higher speed zones (>4.44 m/sec and >5 m/sec) significantly more frequently than forwards and backs.[17,18] Nomadic players totalled $98.5 \pm 26.1$ surges >5 m/sec compared with $87.1 \pm 22.9$ and $81.0 \pm 20.7$ for forwards and backs, respectively.[18] Dawson et al.[12] had previously reported that high intensity efforts numbered between 158 (full forward/backs) and 208 (midfielders) per game, with approximately 80–85% of sprint efforts lasting <3 seconds. All were <6 seconds in duration. This is consistent with other field sports, where sprint efforts typically last 2–3 seconds, and players cover distances of 10–20 m.[27] Data from the 2008 AFL season show the longest efforts >5.55 m/sec averaged 11–13 seconds for all positions.[18]

Time spent by players in steady-state running (>2.2 m/sec) per game was significantly greater in nomadic players (24 min 40 sec) than both forwards (21 min 10 sec) and backs (21 min 28 sec).[18] Considering players average 100 minutes of on-field playing time,[18] steady-state running represents a relatively minor component of the game.

The longest continuous periods of time spent moving at velocities <1.38 m/sec (recovery periods) averaged 90 seconds, 92 seconds and 114 seconds for nomadic positions, forwards and backs, respectively.[17] Dawson et al.[12] had previously reported recovery between high intensity efforts to be relatively brief, with almost half of the recovery periods between high intensity efforts generally lasting <20 seconds. However, it was not uncommon for some low intensity work periods to be >2 minutes in duration.[12] Where 'work' was considered the total time spent >2.22 m/sec and 'recovery' was the total time below, Wisbey and Montgomery[15] found the average work-recovery ratio in the 2005 season to be 1 : 2.6, 1 : 2.3 and 1 : 2 for forwards, defenders and nomadic players, respectively (more recent data are not available). These ratios may not reflect current game demands, given the recent changes in game structure. Further analysis of GPS data is likely to reveal the frequency and lapsed time between work periods and short, moderate and long recovery periods. Such information would aid in the design of game-specific conditioning drills.

### 3.2 Heart Rate Responses

Despite the ease with which heart rate data can now be collected during exercise, only two studies have reported the heart rate response during Australian Football games. In the 1970s, Pyke and Smith[8] collected heart rate data on two positions, a 'small' back and a midfielder, over one quarter of a game. Mean heart rates were 160 bpm and 178 bpm for the back and midfielder, respectively. It was found that during intense periods of play, the heart rate of the back reached 170–180 bpm (≈94% maximum heart rate), dropping below 140 bpm during lengthy recovery periods. In contrast, the heart rate of the midfielder did not fall below 150 bpm and remained between 170 bpm and 185 bpm for most of the quarter. The authors concluded that the running demands of 'nomadic' players such as midfielders and ruckmen mean they have little opportunity to recover, taxing their cardiovascular system to a greater extent.[8] In the only other study to report heart rates, two midfielders were monitored during an entire game by Hahn and colleagues in 1979.[9] The heart rates of the players ranged from 140 to 180 bpm with averages of 164 bpm and 159 bpm reported.

Updated analysis of the heart rate responses of players during Australian Football would be of value. Such information may be used in the development and evaluation of game-specific training drills where GPS technology is unavailable. Heart rate monitoring has been used to quantify exercise intensity[28] in continuous aerobic exercise, and training load[29,30] in intermittent exercise bouts such as those performed in Australian Football. Currently, GPS is used in preference to heart rate monitoring as it is able to provide a more accurate description of the movement patterns during play. Heart rate monitoring in intermittent sports is perhaps more appropriately used to monitor weekly or monthly training loads.

## 4. Physiological and Anthropometric Characteristics

### 4.1 Mass, Stature and Body Composition

The average height of current elite Australian Football players is ~1.87 m,[31,32] with sub-elite and elite juniors slightly shorter (table V).[33,36] Young et al.[32] found that height was not significantly different between midfielders, forwards and backs. However, other studies have found substantial positional differences in height, with small forwards and small midfielders shorter than the mean height, whilst key position forwards/backs and ruckmen are all taller.[35]

A recent study investigating the relationship between anthropometric/fitness measures and playing performance found height to be the only significantly different variable between players who achieved more than six hit outs (hitting the ball clear of a ruck contest such as a bounce down) per game compared with those who achieved less.[36] This confirms the importance of having the tallest players (ruckmen) competing in ruck contests, at least at the elite junior level.

On average, body mass has been found to range between 85 and 90 kg at the elite level in the AFL with some key position players weighing more than 100 kg; draftees and elite juniors are slightly lighter and have body masses ranging from 74 to 82 kg.[32-35] This alone suggests greater mass (presumably muscle mass) is necessary to play Australian Football at the elite level and confirms the importance of strength and size. Elite juniors identified as taking significantly more marks over an eight-game period were found to be significantly heavier.[36] However, at an elite level, body mass has not been found to differentiate between 'successful' and 'unsuccessful' players in the AFL,[32] nor between young players at the national draft camp.[34]

Body mass appears to be more advantageous for competitors at the sub-elite level. It has been stated that as an elite junior, the biggest physical change needed to play in the AFL is an increase in body mass with proportionate increases in strength.[33] Interestingly, long term increases in body mass are evident especially at the junior-elite level. The average body mass of a state under-18-years squad in 1999 was approximately 75 kg, while in 2005 a larger cohort of players at the same level weighed approximately 80 kg.

Skinfold data reveal that AFL players have low levels of body fat and that these have not changed with time. However, no consistent relationship has been found between estimates of body fat and playing position,[35] nor is level of body fat able to differentiate between 'successful' or 'unsuccessful' players.[32,34] Average 'sum of seven' and 'sum of eight' skinfold data from several studies are summarized in table V.

### 4.2 Maximal Oxygen Uptake

Several studies have reported on maximal aerobic power values of Australian Football players at the elite and junior elite levels of competition.[31-36] Estimated from the 20 m shuttle run test, these studies found that the maximal oxygen uptake ($\dot{V}O_{2max}$) values of players ranged from 55 to 65 mL/kg/min with little variation existing between junior elite and elite level players. This is consistent with elite players in other running-based sports such as soccer ($57.8 \pm 6.5$ mL/kg/min)[38] and field hockey ($61.8 \pm 1.8$),[39] but greater than professional rugby league and rugby union players (~50 mL/kg/min).[26,40] In the few studies that have considered playing position, no positional differences were identified;[32] however, a high $\dot{V}O_{2max}$ has been found to be a defining quality of successful draftees to AFL clubs.[34] Physiological profiles of sub-elite or state league Australian Football players are not available for comparison. Further examination of current players from a variety of playing levels assessed in a laboratory setting may be of interest to those developing junior athletes or for talent identification purposes.

### 4.3 Muscular Strength and Power

Bumping, tackling and 'wrestling' opposition players when contesting a mark or loose ball on

**Table V.** Physiological characteristics of Australian Football players[a]

| | Study | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Buttifant[31] | Keogh[33] | Pyne et al.[34] | Pyne et al.[35] | Young et al.[32] | | | Young and Pryor[36] |
| Year of data collection | 1993–7 | 1999 | 1999–2001 | 1999–2004 | 2004 | | | 2005 |
| No. of players | 18 | 29 | 283 | 495 | 38 | | | 177–200 |
| Level of competition | AFL (elite) | State U/18 | AFL draft camp | AFL draft camp | AFL (elite) | | | State U/18 |
| Age (y) | 22.7 [1993]–26.8 [1997] | 15.9 | 17–18 | 17–18 | 22.6 ± 2.9 | | | 16–18 |
| Positions | All | All | All | All | Nomadic | Forwards | Backs | All |
| Anthropometry | | | | | | | | |
| height (cm) | 186 | 180.2 ± 7.2 | 186 ± 6.62 | 187 ± 6.6 | 188 ± 9 | 186 ± 10 | 187 ± 5 | 183.9 ± 6.9 |
| body mass (kg) | 85.7 [1993]–90.5 [1997] | 74.6 ± 8.3 | 80.5 ± 7.82 | 81 ± 7.6 | 86.8 ± 8.9 | 87 ± 7.75 | 87.7 ± 7.5 | 79.8 ± 8.3 |
| skinfolds (mm) | 55.4 [1993]–63.6 [1997][b] | | 56 ± 3.4[b] | 55.3 ± 12.6[b] | 47 ± 7.8[c] | 59.7 ± 16[c] | 53.3 ± 12[c] | |
| Endurance capacity | | | | | | | | |
| 20 m shuttle run ($\dot{V}O_{2max}$; mL/kg/min) | 53.6 [1993]–59.2 [1997] | 57.7 | 57.8 ± 3.4 | 57.8 ± 3.4 | 61.6 ± 3.5 | 57.8 ± 5.1 | 61.1 ± 3.5 | 57.3 ± 3.5 |
| yo-yo IR2[d] test (m) | | | | | 747 ± 123 | 656 ± 128 | 743 ± 142 | |
| Speed and acceleration | | | | | | | | |
| 5 m (s) | | | 1.09 ± 0.06 | | | | | 1.12 ± 0.05 |
| 10 m (s) | 1.83 [1993]–1.66 [1997] | | 1.81 ± 0.07 | | 1.9 ± 0.06 | 1.93 ± 0.1 | 1.88 ± 0.07 | |
| 20 m (s) | 3.06 [1993]–2.92 [1997] | | 3.04 ± 0.09 | 3.04 ± 0.09 | | | | 3.13 ± 0.09 |
| 40 m (s) | 5.37 [1993]–5.40 [1997] | | | | | | | |
| Flying 30 m split (s) | | | | | 3.48 ± 0.11 | 3.6 ± 0.15 | 3.49 ± 0.06 | |
| Strength | | | | | | | | |
| 3RM bench press (kg) | | 63.8 ± 10.7 | | | 97.9 ± 11.9 | 93 ± 10.4 | 98.8 ± 8.4 | |
| 3RM leg press (kg) | | | | | 399 ± 48 | 348 ± 64 | 410 ± 44 | |
| 3RM chin ups (kg) | | | | | 109 ± 10 | 103 ± 12 | 106 ± 5 | |
| Leg power | | | | | | | | |
| concentric squat jump (W/kg) | | | | | 68.3 ± 6.2 | 70.5 ± 7.4 | 68.1 ± 7.1 | |
| countermovement squat jump (W/kg) | | | | | 70.2 ± 8.8 | 65.1 ± 9.4 | 69.1 ± 7.8 | |
| Jumping ability | | | | | | | | |
| countermovement jump (cm) | | 55.2 ± 7.9 | 60.1 ± 5.76 | | 62.3 ± 3.7 | 58.4 ± 5.1 | 63.4 ± 2.4 | |
| absolute running vertical jump (cm) | | | 322 ± 11.1 | 322 ± 10.9 | | | | |
| Flexibility | | | | | | | | |
| sit and reach test (cm) | | 10.7 ± 6.4 | | | | | | 8.8 ± 7.5 |

a Performance and anthropometric values are expressed as mean ± SD.

b Sum of seven skinfolds.

c Sum of eight skinfolds.

d There are two yo-yo protocols: level 1 and level 2. Level 2 is reported here and has higher initial running speeds.[37]

**AFL** = Australian Football League; **IR2** = intermittent recovery level 2; **RM** = repetition maximum; **U/18** = under 18 y age group; $\dot{V}O_{2max}$ = maximal oxygen uptake.

the ground requires high levels of upper and lower body strength and power. Although not statistically significant, the data of Young et al.[32] suggest elite forwards and backs possess slightly greater upper body strength than elite midfielders (table V). Mean 3 repetition maximum (3RM) bench press values for players at the highest level (~95–100 kg) are far superior to junior elite players (~63 kg), reinforcing the significant gains in size and strength junior athletes must attain to be competitive in the AFL. Young et al.,[32] measured leg strength by 3RM leg press, again finding higher values for forwards and backs (~400–410 kg) than for midfielders (~350 kg). Measures of leg power and jumping ability assessed using the vertical jump are higher for Australian Football players (~62 cm) than for rugby league players (~55 cm)[26] but comparable to rugby union backs (~60 cm).[40] Pyne et al.[34] identified that junior players drafted to AFL clubs who went on to debut in the AFL had better jumping and agility qualities than those who did not. These fitness components reflect the skill demands required of the various positional groups.

### 4.4 Speed and Repeated Sprint Ability

The ability to outrun defenders and 'find space' or chase down opponents is integral to Australian Football; good acceleration and sprint ability are required by players in all positions, particularly with the speed of the game having increased in recent years. Similar to aerobic capacity, speed over 10–40 m does not appear to vary greatly between positions. Mean times over these distances for junior elite and elite players are summarized in table V. Recent estimates of maximal running speeds determined from 'flying' split times following 20 m of acceleration have been found to be 8.6 and 8.7 m/sec for two elite AFL teams.[41] In a practical sense, these players are capable of accelerating to speeds >80% of their maximal velocities in just a few seconds; a desirable quality that influences team selection at the elite level.[32]

Young et al.,[32] also found the ability to recover from intermittent high intensity exercise to be a defining quality of 'better' players in elite Australian Football. Again, given that the game is becoming faster, repeated sprint ability is becoming increasingly important for players. Surprisingly, there has been only one published article describing the repeated sprint abilities of Australian Football players. Using a $6 \times 30$ m sprint protocol (on a 20-second cycle), Pyne et al.[42] reported the mean total time of all six sprints to be $25.83 \pm 0.6$ seconds for 60 junior elite players attending the AFL national draft camp. A performance decrement of 4–6% was determined. Future research should assess repeated sprint ability at both elite and sub-elite levels of Australian Football competition. Knowledge of the degree to which repeated sprint ability varies relative to playing position would also be of value.

In addition to the acknowledged importance of aerobic fitness, strength, power and speed for players who play Australian Football at a competitive level, there is evidence to suggest that reduced flexibility may predispose athletes to soft tissue injury.[43] The importance of maintaining flexibility should therefore not be overlooked.

## 5. Practical Applications for Conditioning

Given that recent GPS research reports describe a high intensity intermittent movement profile for all playing positions, development of repeated sprint ability should be a primary focus for game-specific player preparation. However, the specific nature of repeated high intensity exercise training may need to differ across playing positions. For example, nomadic players complete a greater number of high intensity efforts during a game, sprint for longer and have shorter recovery periods between bouts compared with players in other positions. Although steady-state running represents less than a quarter of total game demands, aerobic or endurance capacity will remain an extremely important component of fitness for all AFL players; recovery from high intensity exercise (e.g. removal of lactic acid and the re-synthesis of creatine phosphate) is recognized as being strongly related to peripheral oxidative capacity.[44] This may be developed through various exercise modes.

The relatively short duration of sprint efforts (2–3 seconds) suggests players seldom reach their maximal speed in games. Thus, development of acceleration may be of greater benefit than a focus on improving maximal speed during game-specific training. Nonetheless, players with greater speed have a distinct advantage when longer efforts are required. The importance of developing maximal speed should therefore not be underestimated. Recovery periods could be manipulated to alternate between developing 'pure' speed/acceleration (e.g. long recovery with a focus on technique) and repeated sprint ability (e.g. short recovery periods between bouts mimicking game demands). Future match analysis research should aim to couple preceding movement velocities with the frequency and type of accelerations/decelerations performed. This may help assess the value of standing starts, 'flying starts' and 'varied pace' acceleration drills.

## 6. Conclusions

As is the case in most team sports, the available literature relating to Australian Football clearly reveals significant differences in game demands between different positions. The preparation of players for competition needs to reflect these positional differences and also take into general consideration the acknowledged increase in the speed of the game. It is reasonable to conclude that repeated sprint ability is more important for elite AFL players now than it was 20 or 30 years ago. Nonetheless, endurance (aerobic) fitness will remain a central determinant of the ability of the player to compete effectively in the AFL, not only given the large accumulated distances covered by all players during a game but also because of the need for players to recover rapidly between bouts of repeated high intensity exercise.

GPS technology is providing coaches with objective and detailed data relating to specific movement demands of players. However, the accuracy and reliability of distance and velocity-derived GPS data in highly specific game-related activities need to be established. Once this is achieved, GPS data that describe changes in velocity, repeated sprint intensities and subsequent recovery periods can be used to develop position-specific training programmes for players and to monitor workloads both in competition and in training. Assessment of the relationships between the workload and various overuse injuries can follow. Furthermore, the potential of GPS data to differentiate movement patterns between elite and non-elite competition may aid in the development of junior players.

## Acknowledgements

No sources of funding were used to assist in the preparation of this review. The authors have no conflicts of interest that are directly relevant to the content of this review.

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