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Original paper

Quantifying movement demands of AFL football using GPS tracking

Ben Wisbey [a,*], Paul G. Montgomery [a], David B. Pyne [b,c], Ben Rattray [a]

[a] *Fitsense Australia, Canberra, Australia*
[b] *Australian Institute of Sport, Australia*
[c] *Faculty of Health, University of Canberra, Australia*

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Abstract

Global positioning system (GPS) monitoring of movement patterns is widespread in elite football including the Australian Football League (AFL). However documented analysis of this activity is lacking. We quantified the movement patterns of AFL football and differences between nomadic (midfield), forward and defender playing positions, and determined whether the physical demands have increased over a four season period. Selected premiership games were monitored during the 2005 ($n = 80$ game files), 2006 ($n = 244$), 2007 ($n = 632$) and 2008 ($n = 793$) AFL seasons. Players were fitted with a shoulder harness containing a GPS unit. GPS data were downloaded after games and the following measures extracted: total distance (km), time in various speed zones, maximum speed, number of surges, accelerations, longest continuous efforts and a derived exertion index representing playing intensity. In 2008 nomadic players covered per game 3.4% more total distance (km), had 4.8% less playing time (min), a 17% higher exertion index (per min), and 23% more time running >18 km h^{-1} than forwards and defenders (all $p < 0.05$). Physical demands were substantially higher in the 2008 season compared with 2005: an 8.4% increase in mean speed, a 14% increase in intensity (exertion index) and a 9.0% decrease in playing time (all $p < 0.05$). Nomadic players in AFL work substantially harder than forwards and defenders in covering more ground and at higher running intensities. Increases in the physical demands of AFL football were evident between 2005 and 2008. The increasing speed of the game has implications for game authorities, players and coaching staff.

Keywords: Global positioning system; Australian football; Movement patterns; Fitness; Exertion index

1. Introduction

Global positioning system (GPS) technology is now widely used in the Australian Football League (AFL) for both game and training analysis. These data provide a detailed description of player movement demands and can assist teams from a tactical view point. The international isolation of AFL football has limited the number of time-motion studies in comparison with other football codes such as rugby union[1,2] and football (soccer),[3] or field sports such as hockey.[4] The movement patterns of AFL football can be described as highly intermittent with repeated bouts of shorter higher-intensity striding and sprinting efforts on a base of lower-intensity walking and jogging.[5,6] These video analysis studies reported 150 high intensity movements (fast-run plus sprint) in an AFL game, but these accounted for only 4–6% of total movement time. Most of the high intensity movements lasted for <6 s. The time-consuming nature of video analysis limits this method of analysis to research rather than routine monitoring from game to game.

Recent technological innovations have made GPS athlete-tracking a convenient and popular method to quantify movement patterns and physical demands in sport.[7] GPS technology has been used to quantify the physiological demands of sports such as horse racing,[8,9] orienteering,[10] triathlon,[11] Australian football,[12] field hockey,[13] and soccer.[14] The only published GPS study of Australian football was primarily focused on reliability and validity of the technology[12] and did not provide any detailed game information.

The key information on game demands sought by coaches are the basic pattern of movements (e.g. distance, running velocities, accelerations), differences between nomadic and fixed position players, and the effects of tactical changes (e.g. increased player rotations, zone defences, possession-

* Corresponding author.
E-mail address: bwisbey@fitsense.com.au (B. Wisbey).

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oriented playing style), improved fitness and conditioning, or rule changes implemented by the game authorities. A systematic evaluation of AFL football using GPS technology would provide objective evidence on these key questions for the football community. The aim of this study was to describe the movement patterns of nomadic players, forwards and defenders. Two secondary aims were to compare 2008 game demands with the 2005, 2006 and 2007 seasons to assess the changes in the physical demands that rule and tactical changes have had, and evaluate differences in playing requirements between AFL venues (grounds) to determine if different sized grounds have an impact on player demands.

2. Methods

Elite AFL footballers ($n = 179$) from 8 of the 16 AFL clubs were tracked using GPS devices during the 2008 AFL season, capturing multiple files throughout the season. This compared to 52 footballers in 2005, 85 in 2006 and 203 in 2007. While all 16 AFL clubs used GPS technology, 8 clubs used GPS units from the same manufacturer as the 2005, 2006 and 2007 research allowing a direct comparison of player workloads between seasons. Players participating in the project had signed a consent form as part of contractual arrangements with their respective AFL club. Anonymity of game data has been preserved for all players and teams.

Players were assigned to three major positional groups nominated by their respective clubs—i.e. fixed forward, nomadic or fixed defender. A GPS unit (SPI 10 and SPI Elite, GPSports, Canberra, Australia) was fitted to the upper back of each player using an elastic harness. The GPS units captured data at 1 Hz throughout the duration of each game, and recorded velocity, altitude, latitude and longitude. Where three or less satellites were found by the GPS unit during the course of the game, data for this period were omitted. The accuracy of this device is ~1–5% based on the manufacturer's[15] and independent verification[12,16] of reliability and validity established against criterion measures of speed and distance.

Each participating club was responsible for fitting the units to their players during their selected games and downloading of data to a laptop or desktop computer. GPS output with the associated demographic data was then sent electronically to the researchers. This data included individual player statistics (e.g. rotations, kicks, handballs, marks, and total possessions), player position, team, opposition, venue, playing duration and date. All playing time was analysed with custom-built GPS software (Sports Tracker Analysis v2.0, FitSense Australia). Non-playing periods (quarter breaks and interchange periods) were omitted. To ensure consistency and objectivity between files, two rules were employed to categorise the data into one of two groups—i.e. playing period and non-playing period. A non-playing period was triggered to begin when the average speed was less than 3 km h^{-1} for 2 continuous minutes, and reverted back to a playing period when the average speed was greater than 5 km h^{-1} for 2 continuous minutes.

The number of files used for analysis in the 2008 season was 793, compared to 632 in 2005, 244 in 2006 and 80 in 2007.

All game files were analysed using a number of steady state and intermittent variables including: total distance (m), mean velocity, total time (min), exertion index, exertion index per min, time spent in and above velocity zones, number of surges over 18 km h^{-1}, longest continuous time above specified velocities, maximal speed and an acceleration/deceleration profile. The maximal speed was defined as that reached for a 1 s sample period. Data from selected AFL venues used in 2008 were examined to determine if substantial differences were evident from venue to venue. Only grounds in which 60 or more games files were collected were included in this analysis.

An exertion index was established to measure cumulative physical load. The exertion index was based on the sum of a weighted instantaneous speed, a weighted accumulated speed over 10 s, and a weighted accumulated speed over 60 s. This computation ensures that both short sharp efforts and long sustained efforts were accounted for. The weighting was based on a polynomial relationship in which higher speeds were given a higher exertion value (in arbitrary units) than lower speeds. The formula used to calculate exertion index is:

$$\text{Exertion Index} = \frac{\text{Sum of EI}^1 + \text{Sum of EI}^{10} + \text{Sum of EI}^{60}}{300}$$

where

$$\text{EI}^1 = (v^4 \times 0.000009) - (v^3 \times 0.001) + (v^2 \times 0.0356) - (v \times 0.0596) - 0.0172$$

$$\text{EI}^{10} = (V10^4 \times -0.00003) - (V10^3 \times 0.0004) + (V10^2 \times 0.0477) - (V10 \times 0.0476) + 0.1056$$

$$\text{EI}^{60} = (V60^4 \times -0.00003) - (V60^3 \times 0.0004) + (V60^2 \times 0.0477) - (V60 \times 0.0476) + 0.1056$$

v = speed in km h^{-1} captured at 1 Hz.

$V10$ = average speed in km h^{-1} of the last ten 1 Hz speed samples.

$V60$ = average speed in km h^{-1} of the last sixty 1 Hz speed samples.

Descriptive data are reported as mean ± standard deviation. Comparison of variables between positions and years was performed using a one-way ANOVA, with a significance level of $p < 0.05$. Where significant differences were

Table 1
Movement characteristics of AFL football by position in the 2008 (mean ± SD).

Variable	Forward ($n=77$)	Nomadic ($n=635$)	Defender ($n=87$)
Total time (min:s)	103:28 ± 14:43	99:02 ± 14:19[a]	104:02 ± 13:12
Total distance (km)	11.7 ± 2.0	12.3 ± 1.9[b]	11.9 ± 1.7
Mean velocity (km h^{-1})	6.8 ± 0.6	7.5 ± 0.6[a]	6.8 ± 0.6
Exertion index	112.7 ± 23.9	127.0 ± 22.9[a]	114.8 ± 21.5
Exertion index per min	1.09 ± 0.17	1.29 ± 0.18[a]	1.10 ± 0.18
Accelerations over 4 km h^{-1} in 1 s	237 ± 39	248 ± 47	237 ± 40
Surges above 18 km h^{-1}	77 ± 16	89 ± 21[a]	77 ± 17
LCT over 20 km h^{-1} (s)	10 ± 2	11 ± 3[b]	11 ± 8
Steady state time above 8 km h^{-1} (min)	20:49 ± 5:20	25:11 ± 5:08[a]	22:22 ± 5:17
Time over 18 km h^{-1} (min)	4:26 ± 1:09	5:29 ± 1:3[a]	4:23 ± 1:10
Rotations (per game)	3.2 ± 1.9	4.3 ± 1.8[a]	3.0 ± 1.9

LCT = longest continuous time.
[a] Different from all other positions ($p<0.05$).
[b] Different from forwards ($p<0.05$).

established a Bonferroni post hoc comparison was used. A Pearson two tailed correlation was used to assess the relationship between variables. Magnitudes of effect sizes (ES) were assessed using the criteria of: <0.2 trivial, 0.2–0.6 small, 0.6–1.2 moderate, 1.2–2.0 large and >2.0 very large. A substantial change was accepted when there was >75% likelihood that the true value of the standardised mean difference was greater than the smallest worthwhile (substantial) change. Statistical analysis was performed with the SPSS software package (v13.0).

3. Results

The movement characteristics of AFL football for each of the three player positional groupings are shown in Table 1. In 2008 nomadic players covered 3.4% more total distance (km), had 4.8% less playing time (min), a 17% higher exertion index (per min), and 23% more time running >18 km h^{-1} than forwards and defenders (all $p<0.05$). However players typically covered ~12 km per game irrespective of their playing position. Although nomadic players had a higher mean velocity they spend less time on the ground than key position players. The highly intermittent nature of the game with repeated high intensity efforts is indicated with ~240 moderate accelerations (number of times the speed increases by more than 4 km h^{-1}in a 1 s period), ~10 rapid accelerations (number of times the speed increases by more than 10 km h^{-1}in a 1 s period) and ~85 surges above 18 km h^{-1}.

Approximately 65% of the total time was spent either walking or slow jogging at a speed less than 8 km h^{-1}. The breakdown of time in velocity or speed zones in 2008 was: <8 km h^{-1} 65:19 ± 12:10 (min:s, mean ± SD); 8–12 km h^{-1} 15:17 ± 1:31; 12–16 km h^{-1} 11:40 ± 1:31; 16–18 km h^{-1} 3:29 ± 1:00; total time above 18 km h^{-1} 5:16 ±1:30 and total time above 25 km h^{-1} 28.9 ± 15.2 s. The number of rotations a player undertook during an AFL game (Table 1) was moderately correlated with exertion index per min ($r=0.38$, $p<0.01$), mean running velocity ($r=0.36$, $p<0.01$), and inversely correlated with playing duration ($r=-0.49$, $p<0.01$). Finally, a moderate effect (ES 0.65) of cumulative fatigue during a game was indicated by the substantial 11% decline in the exertion index (per min) from first to fourth quarter: 1.33 ± 0.24, 1.26 ± 0.22, 1.24 ± 0.22, 1.18 ± 0.22 arbitrary units.

The mean movement patterns of AFL football at a selected number of venues are shown in Table 2. The primary movement measures (total distance, mean running velocity, and number of accelerations) were broadly similar between the different interstate venues. The only substantial difference was the higher exertion index at Subiaco Oval (with the

Table 2
Physical demands of AFL football in the 2008 season categorised by venue (mean ± SD).

Measure	AAMI Stadium ($n=58$)	GABBA ($n=94$)	MCG ($n=221$)	Skilled Stadium ($n=84$)	Subiaco Oval ($n=261$)
Dimensions (m)	165 × 133	156 × 138	160 × 141	170 × 115	176 × 122
Total time (min)	101:58 ± 15:34	103:39 ± 15:53[a]	97:54 ± 12:34	98:25 ± 15:10	99:53 ± 14:20
Total distance (km)	12.4 ± 1.8	12.3 ± 2.1	11.9 ± 1.8[b]	11.6 ± 2.1[b]	12.5 ± 1.8
Mean velocity (km h^{-1})	7.3 ± 0.7	7.1 ± 0.7[b]	7.3 ± 0.7b	7.1 ± 0.7[b]	7.5 ± 0.6
Exertion index	126.7 ± 22.0	123.3 ± 25.8	120.6 ± 23.2[b]	116.2 ± 25.2[b]	129.1 ± 21.5
Exertion index per min	1.25 ± 0.20	1.20 ± 0.20[b]	1.23 ± 0.19[b]	1.18 ± 0.19[b]	1.30 ± 0.18
Accelerations over 4 km h^{-1} in 1 s	249 ± 41	254 ± 52	252 ± 30	246 ± 54	242 ± 43
Steady state time >8 km h^{-1} (min)	24:55 ± 5:07	23:38 ± 5:56[b]	23:52 ± 5:20[b]	22:23 ± 5:26[b]	25:40 ± 4:59

Key: AAMI Stadium, Adelaide; Gabba: Wolloongongabba, Brisbane; MCG: Melbourne Cricket Ground, Melbourne; Skilled Stadium, Geelong; Subiaco Oval, Perth.
[a] Different from MCG ($p<0.05$).
[b] Different from Subiaco Oval ($p<0.05$).

Table 3
Change in physical demands of AFL games between 2005 and 2008 seasons (mean ± SD).

Measure	2005 (n = 80 files)	2006 (n = 244 files)	2007 (n = 561 files)	2008 (n = 799 files)
Total distance (km)	12.5 ± 1.7	12.5 ± 1.7	12.4 ± 1.6	12.2 ± 1.9
Mean velocity (km h^{-1})	6.8 ± 0.6	6.8 ± 0.9	7.2 ± 0.8	7.3 ± 0.7[a,b]
Total time (min)	111:0 ± 13:5	111:51 ± 14:13	104:19 ± 12:16	100:01 ± 14:22[a,b]
Exertion index	121.0 ± 20.4	122.7 ± 24.0	125.6 ± 21.9	124.22 ± 23.4
Exertion index per min	1.10 ± 0.18	1.16 ± 0.25	1.21 ± 0.22	1.25 ± 0.19[a,b]
Efficiency (EI per possession)	8.2 ± 3.4	8.8 ± 4.2	8.6 ± 3.6	9.1 ± 4.3[a,b]
Maximum velocity (km h^{-1})	30.3 ± 1.9	29.7 ± 2.2	30.1 ± 6.7	30.1 ± 6.7
Surges >18 km h^{-1}	89 ± 20	90 ± 24	93 ± 20	86 ± 21
Accelerations >4 km h^{-1} in 1 s	241 ± 43	251 ± 50	253 ± 41	246 ± 47
LCT >20 km h^{-1} (s)	11 ± 3	10 ± 3	11 ± 4	11 ± 4
Decelerations over 10 km h^{-1} in 1 s	16 ± 5	16 ± 7	16 ± 6	14 ± 5[a,b,c]
Steady state time >8 km h^{-1} (min)	22:38 ± 4:49	23:01 ± 5:55	24:04 ± 5:25	24:27 ± 5:23[a,b,c]

[a]Significantly different from 2005 ($p < 0.05$).
[b]Significantly different from 2006 ($p < 0.05$).
[c]Significantly different from 2007 ($p < 0.05$).

longest field length) compared with Gabba (Brisbane), the Melbourne Cricket Ground (Melbourne) and Skilled Stadium (Geelong).

The yearly pattern of physical demands of AFL football in the 2005–2008 seasons is shown in Table 3. A substantial increase in physical demands over a short period of four years was evident: an 8.4% increase in mean velocity, a 14% increase in intensity (exertion index) and a 9.0% decrease in playing time (all $p < 0.05$). The exertion index per possession (a measure of relative efficiency) was also increased in 2008 indicating the players were working harder for each possession. The only change between 2007 and 2008 was a smaller number of rapid decelerations (>10 km h^{-1} change in 1 s) in 2008 and an increased volume of steady state running. The total distance covered in games (∼12 km), maximum velocity (∼30 km h^{-1}), number of surges >18 km h^{-1} (∼n = 90) and the longest continuous high intensity run (∼11 s) were essentially unchanged over the four year study period.

4. Discussion

GPS devices are one of the newest technologies employed in football codes around the world. The availability of GPS technology has been greeted positively by all 16 AFL clubs in their quest for improved physical preparation of players, and understanding of competitive performance. The information obtained from GPS monitoring also permits football authorities to objectively evaluate trends in the game and the impact that minor rule changes have on playing demands. The data obtained in this investigation indicate the physical demands have increased substantially in the four years from 2005 to 2008. This is a very small period in the evolution of the game, but the pace of change in modern football presents challenges and opportunities for coaches, players and authorities.

The physical demands of playing positions varied substantially. Nomadic players covered more distance, had higher exertion levels, and more running at higher velocities (>18 km h^{-1}) than fixed position players. AFL players require very well developed levels of fitness comprising endurance, speed-endurance, repeated sprint ability, acceleration and maximal running velocity. However, the substantially greater demands for nomadic players may necessitate specific training. The breakdown of time into velocity or speed zones showed that the majority of time was spent walking or jogging with high intensity running and sprint forming only ∼5% of the total distance. However this 5% is almost certainly undertaken in context of possessions and critical periods of attacking and defending. This breakdown of activities by intensity is broadly similar to the physical demands identified previously via video analysis.[5] There is much debate on the relationships between ground size, physical and tactical demands, and team performance. Analysis of the 2008 GPS data indicates there were few substantial differences between ground size and key physical workload measures across several AFL venues. Player exertion levels were higher at Subiaco Oval compared with other venues.

The number of player rotations in AFL football has increased considerably in the last three or four years. One of the key reasons for rotation is to rest players so they can maintain a higher intensity upon their return to the field. Players who were rotated more regularly in 2008, not surprisingly spent less time on the field. It would appear that AFL clubs are making effective use of the interchange bench to rest nomadic players. The increased volume of steady state running (>18 km h^{-1}) might have had a negative influence on the ability of players to recover on the field. Clearly players need effective conditioning to maintain high levels of intensity on the field, then recovery quickly on the interchange bench. More frequent rotations may result in periods of increased player speed, regardless of whether it is the start of the game, post-quarter or half time, or following a break on the bench. Shorter playing periods may magnify these effects. However, the operation of the interchange bench presumably involves

both physical and tactical considerations, and increased rotations may not coincide with those functions.

There has been a substantial increase in player game demands over the four year study period. Players have to work at a higher intensity in a shorter period of time. Increases of 8–14% in mean velocity and intensity (exertion index) over four years is quite substantial. Broadly speaking a 10% increase in intensity is noticeable by players and coaching staff, and further (substantial) increases may change the appearance of the game for spectators and television viewers. The exertion index per possession (a measure of relative efficiency) was also increased in 2008 indicating the players were working harder for each possession. A 9% decrease in playing time provides the opportunity for nomadic or midfield players to recover sufficiently to maintain a higher playing intensity. The total distance covered in games (∼12 km) has not changed as the intensity has increased. These GPS data confirm the widely held belief that the physical demands of AFL football continue to increase. Some of these changes may be attributed to rule changes over this period aimed at increasing the speed of the game.

Maximising speed and limiting the effects of fatigue are key challenges for conditioning coaches. The substantial 11% decline in the exertion index (per min) from first to fourth quarter is the evidence of cumulative fatigue in the latter stages of a game. Conditioning programs must develop endurance qualities in players that limit the extent to which fatigue impacts on game performance in the important final quarter. Improvements in pre-season and in-season conditioning, and preparation and recovery practices on game day, are likely to benefit both individual players and team performance.

GPS technology appears to have superseded traditional manually coded time-motion analysis. The automation of GPS tracking permits this form of analysis to be used by AFL clubs in routine training and game settings. Clearly player workloads must be viewed in light of motivational, tactical and skill execution elements of AFL football. Further work is required to describe movement patterns in the dynamic chaotic environment of AFL football, and their relationships with key game indicators such as decision making, skill execution and outcome measures such as possessions, tackles and scoring.

5. Conclusions

The typical player in AFL football covers ∼12 km in total distance, and completes ∼240 moderate accelerations and ∼10 rapid accelerations per game. Nomadic or midfield players have greater physical demands than fixed forwards and defenders. The primary changes in recent seasons have been an increase in mean running velocity, steady state running, player exertion levels and a decrease in mean playing time. There are few differences in movement patterns between AFL venues. Further investigation into player work rates, team and player performances will yield valuable insights for training, physical preparation and game analysis of AFL football.

Practical applications

- Nomadic or midfield players have greater physical requirements, with more frequent rotations to the interchange bench.
- Fitness and conditioning coaches need to account for the increasing physical demands of AFL football.
- AFL authorities should consider the impact of rule changes on the physical demands of the game.

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References

1. Deutsch M, Kearney G, Rehrer N. Time-motion analysis of professional rugby union players during match-play. *J Sport Sci* 2007;**25**:461–72.
2. Duthie G, Pyne D, Hooper S. Time motion analysis of 2001 and 2002 Super 12 rugby. *J Sport Sci* 2005;**23**:523–30.
3. Burgess DJ, Naughton G, Norton KI. Profile of movement demands of national football players in Australia. *J Sci Med Sport* 2006;**9**(4):334–41.
4. Spencer M, Lawrence S, Rechichi C, Bishop D, Dawson B, Goodman C. Time-motion analysis of elite field hockey, with special reference to repeated sprint activity. *J Sport Sci* 2004;**22**:843–50.
5. Dawson B, Hopkinson R, Appleby B, Stewart G, Roberts C. Player movement patterns and game activities in the Australian Football League. *J Sci Med Sport* 2004;**7**(3):278–91.
6. Dawson B, Hopkinson R, Appleby B, Stewart G, Roberts C. Comparison of training activities and game demands in the Australian Football League. *J Sci Med Sport* 2004;**7**(3):292–301.
7. Larsson P. Global positioning system and sport-specific testing. *Sports Med* 2003;**33**(15):1093–101.
8. Hebenbrock M, Due M, Holzhausen H, Sass A, Stadler P, Ellendorff F. A new tool to monitor training and performance of sport horses using global positioning system (GPS) with integrated GSM capabilities. *Deutsch Tierarztl Wochenschr* 2005;**112**:262–4.
9. Vermeulen A, Evens D. Measurements of fitness in thoroughbred racehorses using field studies of heart rate and velocity with a global positioning system. *Equine Vet J* 2006;**S36**:113–7.
10. Cych P. Possibilities of and constraints on the application of GPS devices in controlling orienteering training. *Stud Phys Cult Tourism* 2006;**13**:109–15.
11. Bentley D, Vleck V. Pacing strategy and performance in elite world cup triathlon: a preliminary study. *Med Sci Sports Exer* 2004;**36**: S122.
12. Edgecomb SJ, Norton KI. Comparison of global positioning and computer-based tracking systems for measuring player movement distance during Australian Football. *J Sci Med Sport* 2006;**9**:25–32.

13. MacLeod H, Morris J, Nevill A, Sunderland C. The validity of a non-differential global positioning system for assessing player movement patterns in field hockey. *J Sport Sci* 2008;**December**:1–5 [Epub ahead of print].
14. Pino J, Martinez-Santos R, Moreno M, Padilla C. Automatic analysis of football games using GPS on real time. *J Sports Sci Med* 2007;**S10**:9.
15. *GPSports*. http://www.gpsports.com/; 2008 [accessed, 28.12.08].
16. Coutts AJ, Duffield R. Validity and reliability of GPS devices for measuring movement demands of team sports. *J Sci Med Sport* 2008;**December** [Epub ahead of print].