QUANTIFYING CHANGES IN AFL PLAYER GAME DEMANDS USING GPS TRACKING

2010 AFL SEASON

Ben Wisbey (FitSense Australia),
Ben Rattray (University of Canberra)
and David Pyne (Australian Institute of Sport)

CONTENTS

This study was conducted by FitSense Australia as a funded project by the AFL Research Board.

FitSense Australia thanks the Australian Football League and the AFL Research Board for their assistance during this project. Thanks also go to those AFL teams and their staff who committed to this project. Without their assistance this research would not have been possible.

The FitSense Australia researchers can be contacted on +61 2 6161 0810 or info@fitsense.com.au.

INTRODUCTION

Executive Summary

• This research extends previous investigations into the physical demands of playing Australian Football League (AFL) based on GPS data collected since 2005.

• In 2010, fourteen AFL Clubs participated in this research with a total of 1177 GPS game files captured from 267 players. Data was captured from GPSports (n=333) and Catapult (n=844) GPS devices.

• Compared to all previous years, there was a small increase in playing intensity (1.6% compared to 2009), continuing the upward trend of game intensity.

• The game intensity estimated from GPS monitoring has increased by 17% in the period from 2005-2010.

• For the first time in 6 years, there was a reduction (6.1%) in the volume of steady state running undertaken by players. This change alters the way in which players need to prepare for the game; however with the AFL introducing changes to the rotation rules in 2011, this may force steady state running volume back up as players get less off-field recovery.

• Overall playing demands were similar to what was evident in 2009.

• As in 2009, there was a moderate relationship between game intensity and rotations with those players rotated more often able to maintain a higher game intensity ($r=0.32$, $p<0.01$ in 2010 and $r=0.38$, $p<0.01$ across all years). Likewise, players who spent less time on the field had a higher average game intensity.

• The most successful teams completed less overall work. This pattern was evident when comparing top 4 to bottom 4 placed teams as well as all teams' finishing position on the ladder. This finding has important implications for recovery and injury rates as it indicates that performance level (and the underpinning factors of skill, tactics and coaching of both teams) can influence physical demands of the players.

• Workloads were substantially lower in rounds 18-22 compared with other stages of the season (home and away games, and the final series). This contradicts the 2009 finding, however it is likely this varies year to year depending on the competition for finals positions towards the end of the season.

• There was a 15% reduction in workload from quarter 1 to quarter 4.

Introduction

AFL teams have been early adopters and heavy users of GPS technology in both game and training environments. In 2005, eight of the sixteen AFL teams were using GPS to monitor player workloads. This level of activity has increased to all sixteen teams using GPS on a regular basis in 2010. In-game use has expanded quickly as teams continue to benefit from the technology and the AFL grants unlimited use within games. In 2010, approximately 30% of all players in all games were monitored during the home and away season (although not all of this data is available for this research report).

Previous research[1,2,3,4,5,6] established AFL player game demands. This longitudinal retrospective research program has revealed seasonal trends and substantial changes and differences in player demands over the last six seasons.

Key findings of the GPS analysis for the five preceding AFL Seasons (2005-2009 inclusive) were:

- The intensity of work has been gradually increasing during the course of the research period. This increase was initially associated with reduced playing time, but in 2009 both intensity and playing time increased;
- AFL is a highly intermittent game interspersing lower and higher intensity efforts and this profile may be a key factor in fatigue, recovery and injuries;
- The size and shape of AFL grounds had no substantial relationship with the running requirements of players during a game;
- The most successful teams have lower player workloads across the season then their less successful opponents;
- Players who are rotated more often were able to maintain a higher game intensity.

The aim of the 2010 GPS research report was to investigate the following relationships in the physical demands of AFL football:

- Player speeds, year to year
- Rotations and player intensity;
- Player work rate and team success;
- Quarters and distribution of work rate;
- Player performance and work rates.

In 2010, a total of 1177 usable game files were used for the results in this report. These results are presented in two parts:

- Part 1 – A long term comparison of movement patterns
- Part 2 – Player workload and performance

Further details including methods, further results and analysis methods can be found in Appendix A and B. Throughout the report, exertion index is used as a key measure of player work rate. The exertion index is an estimate developed by the researchers to quantify the level of physical work completed by players. Details are shown in Appendix B.

The information presented in this report provides specific information to three key reader groups:

- The AFL and those involved determining the impact of the rules of the game – Trends of player demands of the past six years are presented in Part 1.
- AFL coaches, fitness staff and sports scientists – An analysis of player workload, performance and team success is presented in Part 2, while Part 1 offers a summary of game demands.
- Members of the public with an interest in AFL – A summary of key game demands are presented in Part 1.

Part One
Long Term Comparison of Movement Patterns

Work Rate

The 2010 data exhibits only trivial changes from 2009 data however exertion index per minute was significantly higher than previous years. Total time was slightly less than 2009. Given the same overall workload, this resulted in the exertion index per minute increasing slightly. The 17% increase in exertion index per minute since 2005 is highlighted in Figure 2.

Table 1 shows data captured from both brands of GPS devices in 2010 compared to 2009 and 2008.

Work Variable	2010 Mean Values (n=1177 files)	2009 Mean Values (n=1642 files)	2008 Mean Values (n=1395 files)	Difference 2009 to 2010
Total Time (min:s)	105:14 ± 14:38*	106:56 ± 14:45#	100.27 ± 15.14	1.6%; trivial ↓
Total Distance (km)	13.04 ± 2.01#	13.19 ± 2.04#	12.24 ± 2.01	1.1%; trivial ↓
Average Speed (km/hr)	7.45 ± 0.63#	7.42 ± 0.64#	7.33 ± 0.64	<1%; trivial
Exertion Index	135.5 ± 24.8#	135.8 ± 25.3#	125.9 ± 24.5	<1%; trivial
Exertion Index per Minute	1.29 ± 0.18*	1.27 ± 0.18	1.26 ± 0.19	1.6%; trivial ↑

Table 1. Comparison of main work rate variables between Seasons from All data (mean ± SD).

* Significantly different from 2008 and 2009 ($p<0.05$)

Significantly different from 2008 ($p<0.05$)

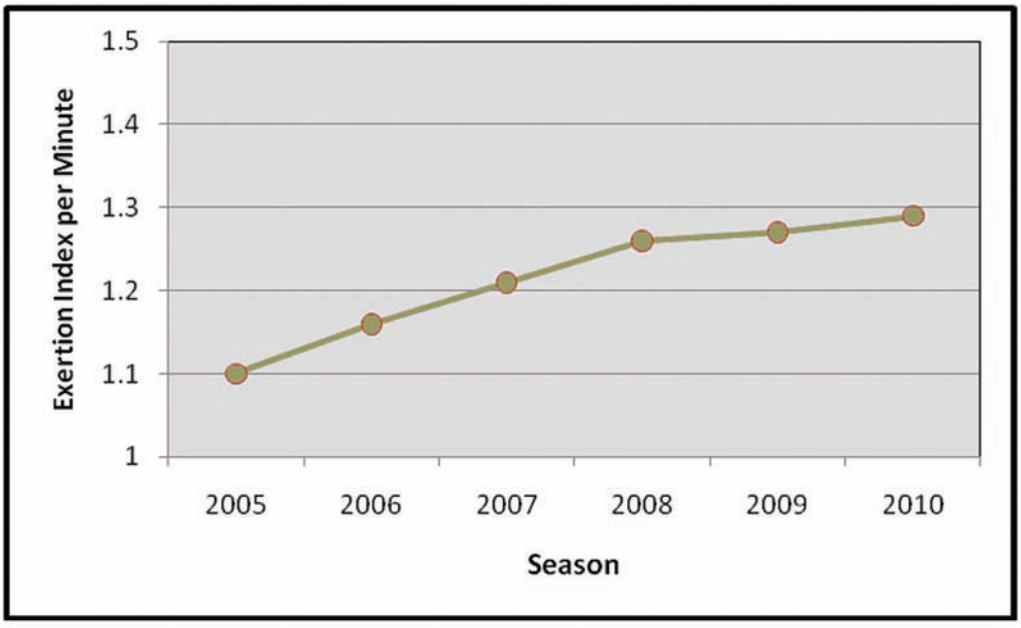

Figure 2. Systematic increase in exertion index per minute as a marker of physical workloads since the 2005 season.

Comment

There was only a trivial change in exertion index per minute from 2009 to 2010. The overall workload measures did not change substantially from 2009. However, the trend of increasing intensities continues and is 17% higher in 2010 compared with 2005. While the rate of increase has reduced in recent years, the upward trend is still evident. Increases in 2007 and 2008 were likely due to rule changes aimed at increasing the speed of the game, while the smaller increases in 2010 are likely a result of an increase in the use of rotations. During this period players have had to adapt with improved fitness and this undoubtedly has an impact on further increasing game intensity.

Movemement Pattern Profile

A seasonal comparison of movement pattern variables (i.e. acceleration characteristics, steady state running and longest continuous efforts) is presented in Table 2.

The 2010 data shows a number of distinct changes from the 2009 Season. One of the changes is a substantial increase in the number of accelerations and decelerations in 2010. This increase is associated with a 14% increase in the volume of data captured on Catapult GPS devices in 2010. When comparing the Catapult data collected in 2009 to 2010, only a trivial difference exists between the acceleration variables.

The length of efforts (longest continuous time) at lower speeds was similar to 2009, although the length of efforts above 20km/hr decreased by 5.9%. There was also a 6.1% reduction in steady state running volume.

Variable	2010 Mean Values (n=1177 files)	2009 Mean Values (n=1642 files)	2008 Mean Values (n=1395 files)	Difference 2009 to 2010
Accelerations over 4 km/hr in 1sec	402 ± 194*	322 ± 135	292 ± 87	25%; Small↑
Accelerations over 10 km/hr in 1sec	25.4 ± 19.3*	17.3 ± 14.4	14.5 ± 8.8	47%; Small↑
Decelerations over 4 km/hr in 1sec	369 ± 180*	275 ± 109	269 ± 80	34%; Moderate ↑
Decelerations over 10 km/hr in 1sec	26.8 ± 15.2*	20.4 ± 10.6	17.2 ± 8.2	31%; Small↑
LCT under 5 km/hr (min:s)	0:59 ± 1:05#	0:57 ± 0:15	1:07 ± 0:17	5.3%; Trivial
LCT over 13 km/hr (sec)	23.5 ± 51.1	22.6 ± 6.3	23.7 ± 7.1	4.0%; Trivial
LCT over 15 km/hr (sec)	19.2 ± 41.2	18.8 ± 5.9	19.7 ± 6.7	2.1%; Trivial
LCT over 17 km/hr (sec)	15.6 ± 27.5	15.7 ± 5.5	16.5 ± 6.5	<1%; Trivial
LCT over 20 km/hr (sec)	11.2 ± 4.2*	11.9 ± 5.3	12.6 ± 6.2	5.9%; Trivial
Steady State Time above 8 km/hr (min:s)	25:36 ± 5:36*	27:15 ± 5:26	24:05 ± 5:24	6.1%; Small↓

Table 2. Comparison of movement pattern variables between Seasons for all GPS data (mean ± SD).

* Significantly different from 2008 and 2009 ($p<0.05$)

Significantly different from 2008 ($p<0.05$)

LCT = Longest Continuous Time.

Comment

Steady state running volume decreased in 2010; this is the first season since monitoring started in 2005 that such a reduction has been evident. Until 2010, steady state running volume has been increasing in conjunction with the increase player work rate. Steady state running is seen as on field active recovery; with the increase in rotations over recent years, players are getting greater off-field recovery and thus steady state running volume is decreasing. This change alters the way in which players need to prepare for the game; however with the AFL introducing changes to the rotation rules in 2011, this may force steady state running volume back up as players get less off-field recovery.

Time In Speed Zones

A seasonal comparison of speed zone profiles is presented in Table 3.

In 2010, there was a significant reduction in the time spent at walking speeds below 8 km/hr. Time in other speed zones was similar to 2009, and all were greater than 2008.

Time Zone	2010 Mean Values (n=1177 files)	2009 Mean Values (n=1642 files)	2008 Mean Values (n=1395 files)	Difference 2009 to 2010
Time Under 8 km/hr (min:s)	66:22 ± 11:48*	68:03 ± 11:55	65:04 ± 12:18	2.5%; Trivial
Time 8-10 km/hr (min:s)	8:38 ± 1:50#	8:32 ± 1:53	7:11 ± 1:43	<1%; Trivial
Time 10-12 km/hr (min:s)	8:05 ± 2:03#	8:07 ± 1:37	7:37 ± 1:40	<1%; Trivial
Time 12-14 km/hr (min:s)	6:50 ± 1:34#	6:56 ± 1:38	6:32 ± 1:37	1.4%; Trivial
Time 14-16 km/hr (min:s)	5:14 ± 1:23#	5:17 ± 1:23	4:56 ± 1:22	<1%; Trivial
Time 16-18 km/hr (min:s)	3:44 ± 1:09#	3:44 ± 0:59	3:28 ± 0:59	<1%; Trivial
Time Over 18 km/hr (min:s)	6:20 ± 1:51#	6:18 ± 1:54	5:40 ± 1:40	<1%; Trivial

Table 3. Comparisons of time in speed zones between Seasons for all GPS data (mean ± SD).

* Significantly different from 2008 and 2009 ($p<0.05$)

Significantly different from 2008 ($p<0.05$)

Comment

The reduction in time at walking speeds is associated with a reduction in the total playing time. Time spent at all running speeds remained similar to 2009, thus the reduced playing time was shown in reduced on field recovery time. This was also associated with the increased average intensity.

Comparison of GPSports and Catapult Data

The following section compares GPS data captured with the GPSports and Catapult devices during the 2010 Season (Table 4).

It is important to highlight that this data should not be compared directly. No player wore both devices simultaneously in any game. This limitation prevents a direct comparison from being made.

A total of 72% of data was captured on Catapult devices from eleven of the fourteen AFL teams in 2010. Three teams used GPSports devices accounting for 28% of usable data.

Similar to what was shown in 2009, only small differences were evident between brands when comparing work rate variables (e.g. distance, average speed and exertion index). In contrast there were major differences between movement pattern variables with the Catapult devices recording more than double the number of accelerations, and moderately more time and surges over 18 km/hr.

Work Variable	GPSports (n=333 files)	Catapult (n=844 files)	Difference
Total Time (min:s)	109:30 ± 14:09	103:32 ± 14:29	5.5%; Small
Total Distance (km)	13.46 ± 2.10	12.87 ± 1.95	4.4%; Small
Average Speed (km/hr)	7.37 ± 0.65	7.47 ± 0.62	1.4%; Small
Exertion Index	137.6 ± 26.8	134.6 ± 23.9	2.2%; Small
Steady State Time (min:s)	28:20 ± 6:05	24:31 ± 5:00	14%; Moderate
Accelerations over 4km/hr (number)	207 ± 39	479 ± 176	131%; Large
Time over 18 km/hr (min:s)	5:34 ± 1:40	6:38 ± 1:50	19%; Moderate
Surges above 18 km/hr	172.5 ± 47.7	235.3 ± 88.3	36%; Moderate

Table 4. Comparison of main work rate variables between GPS devices (mean ± SD).

Comment

Substantial differences were evident in the data captured on two different commercially-available GPS devices, most notably in accelerations and surges. The large difference in accelerations suggests that these values should not be compared between brands. There were only small differences evident between key work rate variables such as distance and exertion index. This finding, along with similar results presented in 2009, means that some results, especially accelerations, derived from GPSports and Catapult should not compared directly. When interpreting results derived from the different brands the magnitude of differences noted in this table should be used.

As there is no "gold standard" measure of these variables by which to compare, it is not possible to declare which brand is "more correct" or accurate.

Part Two
Player Workload and Performance

Intensity and Rotations

Results

A moderate relationship existed between the average movement intensity of a player and the number of rotations that a player had during a game in the 2010 season. As rotations increased, so did the exertion index per minute ($r=0.32$, $p<0.01$, moderate) and average speed ($r=0.30$, $p<0.01$, moderate). This is a similar magnitude relationship to 2009.

A similar relationship has existed since 2007, with multi-season results showing an increased number of rotations related to an increase in exertion index per minute($r=0.38$, $p<0.01$), average speed ($r=0.36$, $p<0.01$) and time over 18km/hr ($r=0.22$, $p<0.01$).

There were only small correlations between game intensity and total on-field playing duration. These weak inverse relationships were evident between on-field playing duration and average speed ($r=-0.12$, $p<0.01$, trivial) and exertion index per minute ($r=-0.17$, $p<0.01$, small).

Comment

There is evidence that reducing a player's on-field playing duration will allow him to maintain a higher game intensity. The correlation between rotations and game intensity (exertion index per minute and average speed) suggests that ~10% of the variance in intensity can be explained by rotations. Furthermore, on average, for each additional rotation, a player is able to maintain an average speed of 0.1km/hr higher throughout the game. High rotation rates and short frequent on-field bursts will improve a player's ability to maintain a higher game intensity although other contributors play a greater role in game intensity (e.g. player's own fitness). Increasing the number of rotations a player undertakes will also increase time spent at high speed running velocities while reducing the on-field recovery required. The greater frequency of time off the field will also allow for improved game nutrition and the opportunity to manage injuries.

Workload, Team and Success

Determining why a team is successful is difficult as performance outcomes are based on many factors. In this section we investigate selected relationships between team success and player work rate.

The exertion index for and against each team is presented in Table 7. Figure 3 shows a graphical representation of each team's exertion index profile.

Weak inverse relationships were observed between a team's workload and success in the season. Small relationships were evident between a team's ladder position and exertion index ($r=-0.16$, $p<0.01$, small), distance ($r=-0.19$, $p<0.01$, small) and steady state running volume ($r=-0.19$, $p<0.01$, small). Clearly a team's workload (as estimated by GPS monitoring) is only one of many factors contributing to performance outcomes (winning or losing).

The difference between exertion index of the team and the exertion index of their opponent, averaged across the season, was also examined. No substantial relationship was observed between exertion index and the ladder position of the team.

No substantial relationship was observed between the result of an individual game and the average workload of the team.

Team[a]	Number of Files Captured	Exertion Index of Team	Number of Files as Opponent	Exertion Index of Opponents
1	159	137 ± 20	60	135 ± 25
2	91	132 ± 27	86	135 ± 24
3	27	133 ± 24	65	138 ± 24
4	175	136 ± 28	58	140 ± 23
5	2	153 ± 7	76	134 ± 24
6	58	116 ± 25	85	140 ± 25
7	150	128 ± 22	81	142 ± 26
8	8	143 ± 23	111	130 ± 29
9	83	127 ± 23	90	136 ± 23
10	120	135 ± 26	89	131 ± 24
11	12	157 ± 32	35	139 ± 23
12	86	141 ± 18	99	133 ± 25
13	184	147 ± 22	54	138 ± 25
14	22	134 ± 25	82	137 ± 24
15	0	N/A	77	131 ± 27
16	0	N/A	29	136 ± 19
Total	1177	135 ± 25	1177	135 ± 25

Table 7. Exertion Index by team and opponent (mean ± SD).

[a] Each team has been randomly assigned a number to maintain anonymity – this list is NOT the finishing order of teams in the 2010 AFL season.

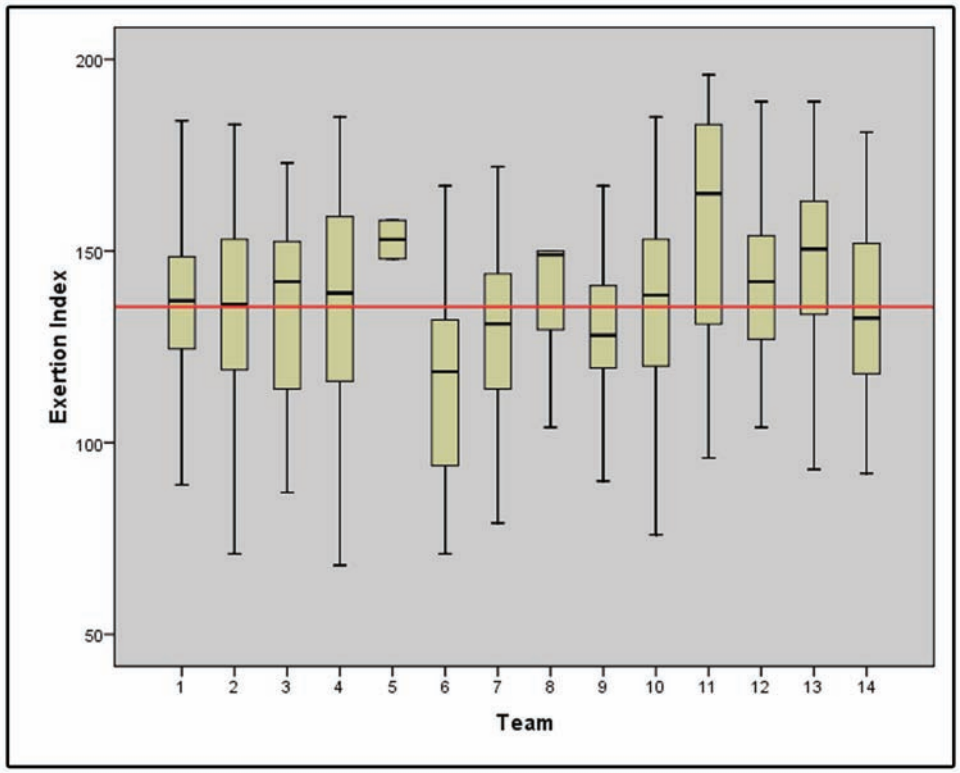

Figure 3. Box and Whisker of Exertion Index by AFL Team.
The order of teams has been randomised to maintain confidentiality of results. The median value is indicated by the thick black line, the standard deviation by the box, the mean for all teams by the red line, and the range by the vertical error bars.

Comment

In 2010, there were no strong relationships between a team's success and GPS variables. However, the small relationships that were observed indicate that the more successful teams are likely to have lower workloads across the season. This may not be surprising given that teams with lower workloads are likely to have improved recovery each week and potentially less injuries. This finding has important implications for recovery and injury rates as it indicates that performance (and the underpinning factors of skill, tactics and coaching of both teams) can influence physical demands of the players.

Top 4 Teams v Bottom 4 Teams

The relationship between team success and work rate was also investigated by evaluating data from the first four teams versus that of the bottom four teams at the end of the Premiership season (Table 8).

A small but substantial difference was observed between measures of exertion index, exertion index per minute, distance and steady state running volume. The most substantial difference was the lower volume of steady state running completed by the top four teams, however the higher exertion index, distance and exertion index per minute for the bottom four teams is substantial.

Variable	Top 4 (n=119)	Bottom 4 (n=570)	Difference
Exertion Index	127.4 ± 28.4	138.8 ± 26.1	8.9%; Small
Exertion Index per Minute	1.26 ± 0.22	1.31 ± 0.19	4.0%; Small
Distance	12.37 ± 2.18	13.37 ± 2.15	8.1%; Small
Steady State Time above 8 km/hr (min:s)	23:32 ± 5:21	26:34 ± 5:58	13%; Small
Time Over 18 km/hr (min:s)	6:13 ± 2:15	6:13 ± 1:55	<1%; Trivial

Table 8. Comparison of GPS Work Variables for the Top 4 and Bottom 4 teams on the Premiership Ladder at the end of the Season (mean ± SD).

Comment

The results support the findings of Table 7, showing an inverse relationship between player workload and team success. It appears advantageous for a team to have a lower work volume and a lower intensity.

Workloads Across The Season

To examine changes in workload during the season, the 2010 Premiership Season was divided into five stages: rounds 1-5, 6-11, 12-17, 18-22 and finals. The average exertion index of each was analysed (Figure 4).

A significant difference in exertion index was evident with lower workloads in rounds 18-22 when compared to the rest of the season ($p<0.05$), excluding finals. The average workload for these rounds was over 5% less than the season average.

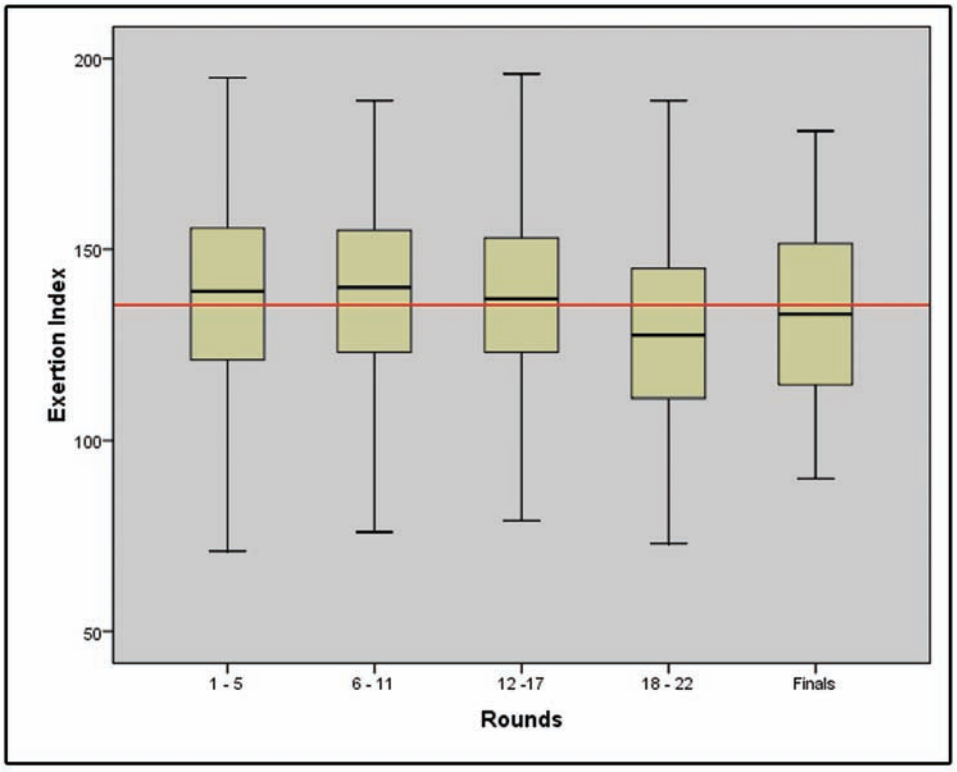

Figure 3. Box and Whisker of Exertion Index by AFL Team.
The order of teams has been randomised to maintain confidentiality of results. The median value is indicated by the thick black line, the standard deviation by the box, the mean for all teams by the red line, and the range by the vertical error bars.

Comment

The findings of 2010 differ to that of 2009. In 2010, workload remained steady across the season, with the exception of rounds 18-22 which displayed a lower overall workload. In 2009, the opposite trend occurred with the latter part of the home and away season displaying the highest workloads. This discrepancy between the 2009 and 2010 seasons may be related to a clearer finals outcome for most teams prior to the latter part of the season.

Key Work Measures

Given the variety of GPS work variables on offer, this research identified which variables had the best relationship with game performance. Due to limitations in available data, possessions were used as a general measure of player performance.

The strongest correlation with possessions was exertion index ($r=0.29$, $p<0.01$, moderate) and then steady state running volume ($r=0.25$, $p<0.01$, moderate). Additionally, a weak relationship also existed between possessions and rotations ($r=0.13$, $p<0.01$).

Comment

Players who completed a higher volume of work were more likely to be rewarded with more possessions. In order for a player to obtain a high number of possessions, they must have substantial playing time, and work hard during on-field work bouts. A greater number of rotations appears to assist in maximising on-field work rate and gaining more possessions.

Quarter By Quarter Analysis

In addition to whole of game data, where possible, playing periods were identified as being in quarter 1, 2, 3 or 4. The results of key work variables by quarter are shown in Table 9.

These results show a moderate decrease in playing intensity between the 1st and 4th quarter as indicated by both average speed (7%, moderate) and exertion index per minute (12%, moderate). An apparent reduction in the volume of work completed between quarter 1 to 4 was also moderate (15%, moderate).

Variable	Q1 (n=935 files)	Q2 (n=999 files)	Q3 (n=959 files)	Q4 (n=932 files)	Effect Size From Q1 To Q4
Total Time (min:s)	26:05 ± 4:12	25:24 ± 4:36	24:47 ± 4:33	25:00 ± 4:40	4%; trivial
Total Distance (km)	3.35 ± 0.59	3.18 ± 0.64	3.09 ± 0.63	2.99 ± 0.64	11%; moderate ↓
Average Speed (km/hr)	7.74 ± 0.77	7.53 ± 0.77	7.50 ± 0.79	7.20 ± 0.84	7%; moderate ↓
Exertion Index	35.5 ± 7.5	33.1 ± 8.0	32.0 ± 7.7	30.1 ± 7.8	15%; moderate ↓
Exertion Index per Minute	1.37 ± 0.22	1.30 ± 0.22	1.29 ± 0.22	1.21 ± 0.23	12%; moderate ↓

Table 9. Comparison of main work variables between quarters (mean ± SD).

Comment

The most intense period of the game is the first quarter; intensity then stabilises in the second and third quarter at 5% less than the 1st quarter. A further decrease of 7% is then seen in the fourth quarter. This pattern is undoubtedly influenced by fatigue, however it is also important to consider the reduction in workload in the later stages of a game that has a convincing winner resulting in the game intensity from both sides decreasing.

Conclusions and Future Directions

Conclusions

Since the GPS report for AFL started in 2005, substantial changes in player workloads have been observed. The increase in player intensity, estimated as the exertion index per min, increased 17% between 2005 and 2010.

The other key change from 2009 was a reduction in the volume of steady state running. This is the first year in which a reduction has been seen. The volume of steady state running has previously been associated with the increasing intensity. This change alters the way in which players need to prepare for the game; however with the AFL introducing changes to the rotation rules in 2011, this may force steady state running volume back up as players get less off-field recovery.

Despite these changes, only minor changes are evident in overall playing demands from 2009 to 2010.

As in 2009, weak relationships show a link between the number of rotations and playing intensity, and an inverse link between total playing duration and average game intensity. This indicates that the recent rule changes by the AFL in which there will be one less player for interchange, may limit further increases in game intensity and player speed.

In 2010, there were no strong relationships between a team's success and most GPS variables. However, the weak relationships indicated that the more successful teams are more likely to have lower workloads across the season, possibly as they force their opponent to chase. Additionally, teams with lower workloads are likely to have improved week to week recovery. This indicates that coaching, skill and tactics have a greater bearing on the outcome of a game then player fitness, however with increasing game intensity, player fitness levels need to continue to rise to ensure they can continue to meet the requirements of the game.

Workloads remained quite stable throughout the year, with the exception of reduced workloads in the last quarter of the home and away season. Workloads in the finals then returned to levels seen in the earlier part of the season.

Looking at individual games, the most intense period of the game is the first quarter; intensity then stabilises in the second and third quarter at 5% less than the first quarter. A further decrease of 7% is then seen in the fourth quarter. This is undoubtedly influenced by fatigue; however it is also important to consider the reduction in workload in the latter stages of a game that has a convincing winner.

Future Directions

AFL clubs continue to increase their use of GPS in both games and training. The goal of each of these clubs is to use the information from GPS to improve the performance of players and the success of their team. However, very little is known about the relationship between player workloads and individual, and team, success. Therefore, further research into this relationship would be beneficial. Initially this would involve gaining a greater understanding of individual player workload and performance using measures such as Champion Data's player ranking. Further investigation into team workload and individual game outcomes would then determine the impact of workload on game outcomes. This approach could then be further expanded by examining fourth quarter workload in close games.

Over the past 2-3 years there has been an emphasis on the relationship between rotations, player speed and the reduction of injuries. Additionally, there is an interest in maintaining a high game speed (ball speed) to maximise spectator interest. The combination of these factors leads to a need to combine data from a variety of sources to investigate the relationship between ball speed and player speed, and player speed and the incidence of in-game injury. This research would assist in better understanding how rule changes impact injury risk and viewing interest.

The future will undoubtedly lead to decisions needing to be made on a technological front. In recent years, the two GPS manufacturers have continued to release regular device upgrades. While the increased sampling frequency and chip developments have resulted in greater accuracy, a large range of models are now in use. Given the variation in results between the brands, and variation in accuracy according to the model and sample rate, it is now very difficult to create a clear comparison across all AFL teams. While improvements in accuracy are likely to continue with further developments, a wide variation in the units used across the AFL will continue to complicate further research. Furthermore, technological developments in forms of local positioning monitoring may see a reduction in the usage of GPS. It is recommended that both the clubs and the AFL monitor these developments with consideration being given to standardisation of further developments in player monitoring.

Appendix A
Methods and Further Results

Methods

Elite AFL footballers (n=267) from AFL clubs were tracked using two different GPS systems (GPSports, Canberra, Australia and Catapult, Melbourne, Australia) during the 2010 AFL Season. Players were assigned to three major positional groups nominated by their respective clubs – i.e. fixed forwards, nomadic and fixed defenders.

GPS units were fitted to the upper back of each player using a purpose-built supportive harness. In total, 1177 usable game files were captured. A file was considered usable when it was captured during the Premiership Season and included a playing period of greater than 60 minutes without substantial data errors or missing data.

Upon receiving the GPS game files (n=1177), the data was categorised according to the type of GPS device used: GPSports (n=333) or Catapult (n=844).

Comparisons were made to data from previous years. Details of the methods used in these years can be found in previous reports submitted to the AFL[1,2,3,4,5].

In 2008 and prior years, data captured on GPSports devices was collated and analysed at 1Hz, while data captured from Catapult units in 2008 was captured at 5Hz and then converted to 1Hz for analysis. In 2009 and 2010, all data has been captured and analysed at 5Hz from both GPSports and Catapult units.

Each participating club was responsible for fitting the units to players, and downloading and forwarding data to the researchers. Data was imported into custom built GPS software (Sports Tracker Analysis v2.0, FitSense Australia). All GPS game data was stored with accompanying demographic data for each player. This data was made up of individual player game possession statistics (rotations, kicks, handballs, marks, and total possessions), player position, team, opposition, venue, and date and time of game. All playing time was analysed. Non-playing periods (quarter and half-time breaks and interchange periods) were omitted from the analysed data.

Each playing period was labelled by quarter 1, 2, 3 or 4 during the import process. All quarters with a playing duration of between 10 minutes and 32 minutes were analysed. In total this left 3825 quarters of data.

To ensure consistency between files, two rules were employed to categorise objectively the data into one of two groups - ie, playing period and non-playing period. These rules were:

1. A non-playing period was triggered when the average speed was less than 3 km/hr for 2 continuous minutes; and
2. A playing period was triggered when the average speed was greater than 5 km/hr for 2 continuous minutes.

Figure 1 shows an example of how these triggers applied.

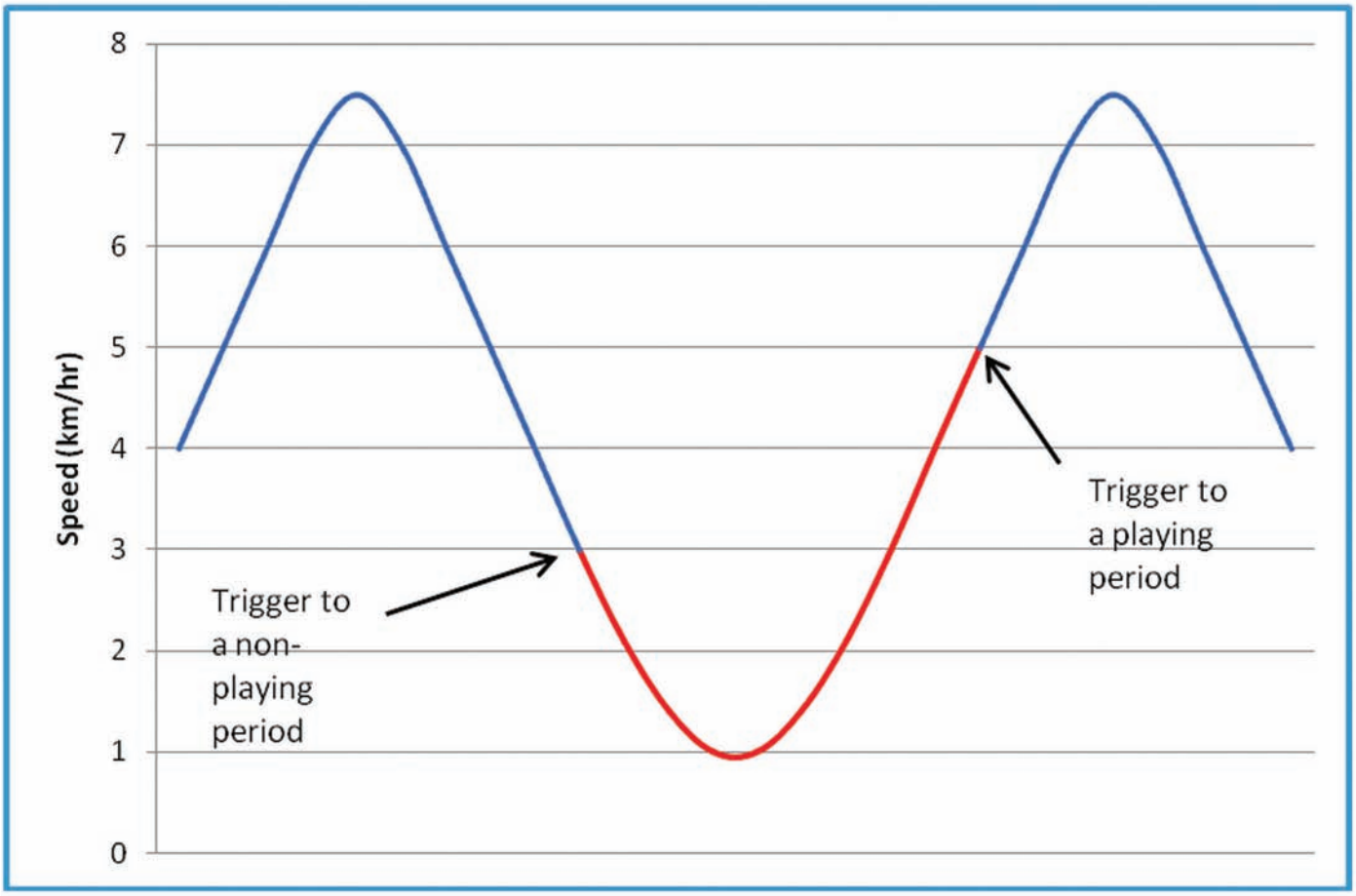

Figure 1. Line graph of the 2 minute rolling speed average showing how a playing period and non-playing period was triggered.

All game files were analysed using a number of steady state and movement pattern variables:

- Total distance (km)
- Average speed (km/hr)
- Exertion index
- Exertion index per minute
- Time spent in speed zones (min:sec)
- Number of surges over specified speeds
- Longest continuous time above specified speeds (seconds)
- Acceleration / deceleration profile

A brief explanation of each variable (including the exertion index formula) is shown in Appendix B.

Statistical Analysis

Statistical analysis was performed with the SPSS software package (v16.0). A Pearson two-tailed correlation was used to assess the relationship between variables with a significance of $p<0.01$. Comparisons 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 established a Bonferroni post hoc comparison was used.

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 or change was greater than the smallest worthwhile (substantial) threshold value[7].

GPS Accuracy

The accuracy of GPS devices is dependent on the sampling rate and device brand[8]. For devices sampling at 5Hz, when compared to criterion distance, GPS error ranged from 2% for long distances up to 5-20% for shorter distances at high speed[9].

Current GPS devices may be limited when assessing high speed movement, accelerations and change of direction[8]. GPS units have acceptable validity and reliability for estimating longer distance but require further development for short sprinting distances[9].

Further Results

The 1177 GPS files from the 2010 AFL Premiership Season comprised the following number of files per ground:

- AAMI Stadium, Adelaide (n=213)
- ANZ Stadium, Sydney (n=8)
- Aurora Stadium, Launceston (n=37)
- Docklands Stadium, Melbourne (n=21)
- GABBA, Brisbane (n=96)
- Manuka Oval, Canberra (n=11)
- Melbourne Cricket Ground, Melbourne (n=444)
- Sydney Cricket Ground, Sydney (n=94)
- Skilled Stadium, Geelong (n=49)
- Subiaco Oval, Perth (n=193)
- TIO Stadium, Darwin (n=11)

These files comprised the following number of files per playing positions:

- Forwards (n=88)
- Nomadic (n=1036)
- Defenders (n=53)

GPS Variables By Position

The following section compares key GPS variables by position (Table 5).

Nomadic refers to all players who are not classified as either a fixed forward or fixed defender, this includes midfielders and ruckman. Nomadic players played for significantly less game time than forwards (~4 min less) and defenders (~9 min less). Despite the reduced playing time, nomadic players completed a greater amount of work as measured by exertion index. This outcome was associated with a higher average game intensity by nomadic players compared to both forwards and defenders.

While nomadic players completed more steady state running than forwards, it was the volume of high speed running and the number of accelerations that differentiated nomadic players from players in other positions. Similar conclusions about nomadic players were presented in the 2008 and 2009 report.

Work Variable	Forward (n=88)	Nomadic (n=1036)	Defender (m=53)
Total Time (min:s)	108:56 ± 14:55	104:28 ± 14:28*	113:58 ± 13:52
Total Distance (km)	12.50 ± 2.16	13.08 ± 2.00♥	13.08 ± 2.00
Average Speed (km/hr)	6.89 ± 0.81	7.52 ± 0.58*	6.93 ± 0.58
Exertion Index	122.2 ± 27.2	137.0 ± 24.3*	127.08 ± 23.09
Exertion Index per Minute	1.13 ± 0.23	1.31 ± 0.17*	1.12 ± 0.17
Accelerations over 4 km/hr in 1sec	303 ± 185	415 ± 192*	321 ± 190
Surges above 18 km/hr	164.6 ± 67.8	224.4 ± 83.8*	170.4 ± 61.7
LCT over 20 km/hr (sec)	9.63 ± 2.88	11.35 ± 4.32♥	10.00 ± 4.03
Steady State Time above 8 km/hr (min:s)	22:52 ± 5:28	25:54 ± 5:33♥	24:16 ± 5:23
Time Over 18 km/hr (min:s)	5:09 ± 1:40	6:29 ± 1:49*	5:17 ± 1:36

Table 5. Work variables by position for All GPS Data (mean ± SD).

* Significantly different from all other positions
# Significantly different from forwards ($p<0.05$)
LCT = Longest Continuous Time.

Comment

Substantial differences were evident between playing position. The most apparent difference in 2010, as with previous years, was the higher game intensity of nomadic players. Intensity was ~16% higher for nomadic players compared with forwards and ~17% when compared to defenders. This pattern of differences may be associated with nomadic players generally getting rotated at a higher frequency and therefore having greater off-field recovery.

Unlike 2009, defenders and forwards worked at similar intensities in 2010, although defenders maintained this intensity despite greater playing time.

The increased game intensity of nomadic players is no longer just the result of more steady state running. As with the overall player average, nomadic players completed less steady state running in 2010 than they did in 2009. The key difference in the type of work completed between positions is that nomadic players completed more high speed running with a greater number of accelerations than other positions, despite a shorter playing duration. Fitness and conditioning coaches can use this information when developing position-specific training programs.

GPS Variables By Ground

A summary of key GPS variables for each ground are presented in Table 6.

Some significant differences were observed between grounds in all work variables presented. The stand-out differences include shorter playing durations at the MCG and a greater volume of steady state running time at Subiaco Oval. The exertion index per minute was highest at the MCG while the highest exertion index and distance was at Subiaco.

Work Variable	AAMI Stadium (n=213 files)	GABBA (n=96 files)	MCG (n=444 files)	SCG (n=94 files)	Subiaco Oval (n=193 files)
Dimensions (m)	165 x 133	156 x 138	160 x 141	149 x 136	176 x 122
Total Time (min:s)	105:49 ± 12:35*	108:56 ± 14:09	101:38 ± 14:58♠	107:23 ± 13:18	111:26 ± 13:54
Total Distance (km)	12.91 ± 1.77*	13.17 ± 2.03	12.81 ± 2.07*	13.20 ± 1.85	13.88 ± 1.95
Average Speed (km/hr)	7.34 ± 0.59♥	7.26 ± 0.66♥	7.58 ± 0.67	7.39 ± 0.63	7.48 ± 0.54
Exertion Index	133.7 ± 22.8*	133.6 ± 25.6*	135.0 ± 25.7*	136.8 ± 23.5	143.7 ± 23.6
Exertion Index per Minute	1.27 ± 0.18♥	1.23 ± 0.19♥	1.33 ± 0.19	1.28 ± 0.18	1.29 ± 0.16
Steady State Time above 8 km/hr (min:s)	24:37 ± 4:37	25:49 ± 5:42	25:11 ± 5:45	25:49 ± 5:32	28:34 ± 5:45♠

Table 6. Work variable by AFL venue (mean ± SD).

* Significantly different from Subiaco. ♥ Significantly different from MCG ($p<0.05$).
♠ Significantly different from all other grounds ($p<0.05$).
N.B. Only grounds in which 50 or more games files were collected are shown.

Comment

A higher volume of steady state running at Subiaco was shown; this was also evident in 2009. Despite this, no significant relationship is evident between ground dimensions and player demands.

When interpreting the data by ground, it is important to consider that in some cases more than half the data captured at a given ground was captured by the home team(s). Caution must be used in the interpretation of this data which may be influenced by the team that most commonly provided data from a particular ground, as well as their choice of GPS device.

Appendix B
GPS Analysis Definitions

Work

Total Distance
Measures the total distance travelled during the playing period. Measured in kilometres.

Average Speed
Total distance divided by total playing duration in hours. Measured in $km \cdot hr^{-1}$

Total Time
The total on field playing duration. Measured in minutes.

Exertion Index
Exertion index is a quantifiable level of physical load developed by FitSense Australia. This measure allows a relationship to be drawn between game load, fatigue, and the total load between players. The exertion index used to assess GPS data in this project was based on the sum of a weighted instantaneous speed, a weighted accumulated speed over 10 seconds, and a weighted accumulated speed over 60 seconds. This ensures both short sharp efforts, and long sustained efforts are analysed equally. The weighting is based on a polynomial relationship in which high speeds achieve a higher exertion value than lower speeds. Exertion index is measured in arbitrary units. The formula to determine exertion index was:

Exertion Index = (Sum of EI^{1} + Sum of EI^{10} + Sum of EI^{60})/300

Where:

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

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

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

v = speed in kilometres per hour captured at 1 Hz. Where data was captured at 5 Hz, it was averaged to create a 1 Hz sample.

V10 = average speed in kilometres per hour of the last ten 1 Hz speed samples.

V60 = average speed in kilometres per hour of the last sixty 1 Hz speed samples.

Exertion Index Per Minute
This is a measure of game intensity and is determined by dividing exertion index by playing time.

Efficiency
A measure of the work requirements for game involvement and game impact. Measured by dividing exertion index by total number of possessions.

Maximal Speed
The maximal speed reached for a one second sample period. This measure is likely to be lower than the actual maximal speed achieved by the player due to the sampling rate and resolution of the GPS system.

Movement Pattern Profile

Surges above/below a Specified Speed (# times >/< x km·hr^{-1})
The number of times the player goes from below (above) this speed to above (below) this speed. Gives an indication of the intermittent nature of the session, and the intensity at which speed peaks occur.

Number of Accelerations (Acceleration > x km·hr^{-1} in 1sec):
The number of times the speed increases by more than x km·hr^{-1} in a 1 second time period. This gives an indication as to the accelerations undertaken and how frequently these occur. Accelerations are categorised as moderate (4 km·hr^{-1}) or rapid (10 km·hr^{-1}).

Number of decelerations (deceleration > x km·hr^{-1} in 1sec)
The number of times the speed decreases by more than x km·hr^{-1} in a 1 second time period. This gives an indication as to the decelerations required and how frequently these occur. Decelerations are categorised as moderate (4 km·hr^{-1}) or rapid (10 km·hr^{-1}).

Longest Continuous Time above a Specified Speed (LCT > x km·hr^{-1})
The longest period of time the player stays above this speed, without dropping below this speed. Time is recorded even when the player enters a higher speed zone. Provides an indication of the longest continuous effort at varying speeds.

Time at steady state > 8 km·hr^{-1} (Steady State Intensity Time)
Any time at a speed above 8 km·hr^{-1} where the players' velocity does not alter by more than 1.5 km·hr^{-1} within a 1 sec sample period. This gives an indication of time spent at continual running speeds.

Time In Speed Zones

Speed Zones (x – y km·hr^{-1})
Time spent between the speeds of x and y km·hr^{-1}. Provides information on the dispersion of speed throughout the session.

References

References

1. Wisbey B. and Montgomery P. Quantifying AFL Player Demands Using GPS Tracking – 2005 Season. AFL Research Board Report, 2005

2. Wisbey B. and Montgomery P. Quantifying AFL Player Demands Using GPS Tracking – 2006 Season. AFL Research Board Report, 2006

3. Wisbey B. ,Montgomery P. And Pyne D. Quantifying AFL Player Demands Using GPS Tracking- 2007 Season. AFL Research Board Report, 2007

4. Wisbey B. ,Rattray B. And Pyne D. Quantifying AFL Player Demands Using GPS Tracking- 2008 Season. AFL Research Board Report, 2008

5. Wisbey B. ,Rattray B. And Pyne D. Quantifying AFL Player Demands Using GPS Tracking- 2009 Season. AFL Research Board Report, 2009

6. Wisbey B, Montgomery PG, Pyne DB and Rattray B. Quantifying movement demands of AFL football using GPS tracking. J Sci Med Sport. 2010; 13: 5

7. Hopkins W 2000 – Measures of reliability in sports medicine and science Sports Med 2000 Jul; 30 (1): 1-15

8. Jennings D, Cormack S, Coutts AJ, Aughey RJ. The validity and reliability of GPS units for measuring distance in team sport specific running patterns. Int J Sports Physiol Perform. 2010 Sept; 5(3): 328-41

9. Petersen C, Pyne D, Portus M, Dawon B. Validity and reliability of GPS units to monitor cricket-specific movement patterns. Int J Sports Physiol Perform. 2009 Sept; 4(3): 381-93