Australian Football Player Work Rate: Evidence of Fatigue and Pacing?

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Previous research has suggested elite Australian footballers undertake pacing strategies to preserve high intensity activity later in matches. However, this research used GPS with slow sample rates, did not express performance relative to minutes played during games and used lowly ranked players. **Methods:** Therefore in this study movement was recorded by GPS at 5 Hz. Running performance was expressed per period of the match (rotation) divided into low-intensity activity (LIA, 0.10 to 4.17 m·s⁻¹); high-intensity running (HIR, 4.17 to 10.00 m·s⁻¹) and maximal accelerations (2.78 to 10.00 m·s⁻²). All data were expressed relative to the first period of play in the match and the magnitude of effects was analyzed with the effect size (ES) statistic and expressed with confidence intervals. **Results:** The total and LIA distance covered by players did not change by a practically important magnitude during games (ES< 0.20). High intensity running was reduced in both rotations of the second quarter, Q3R2 and both rotations of the fourth quarter (ES −0.30 ± 0.14; −0.42 ± 0.14; −0.30 ± 0.14; −0.42 ± 0.14; and −0.48 ± 0.15 respectively). Maximal acceleration performance was reduced in Q1R2, and each rotation of the second half of matches. **Conclusion:** When expressed per minute of game time played, total distance and low intensity activity distance are not reduced by a practically important magnitude in AF players during a match. These data are therefore inconsistent with the concept of team sport players pacing their effort during matches. However, both high intensity running and maximal accelerations are reduced later in games, indicative of significant fatigue in players.

**Keywords:** motion analysis, functional performance, physical performance, sport physiology

Recent research on the match demands of elite Australian Football (AF)¹,² has seemingly agreed with previous findings in soccer that players fatigue during matches³–⁵ and therefore adopt a pacing strategy to mitigate the fatigue experienced later in matches.¹,² However, there are a number of methodological issues in recent studies that must be addressed before accepting these findings.

The recent AF studies relied on 1 Hz global positioning systems (GPS) for the recording of running activities of players during matches.¹,² As most high intensity
activities in team sports are of a very short duration, it is unlikely a 1 Hz sample rate offers sufficient resolution to accurately measure high intensity, and thus match activity. When directly compared with data with a 5 Hz sample rate, 1 Hz data less reliable and less valid for measuring distance in a variety of team-sport specific movement patterns. GPS technology is heavily used in AF, commercially available units now sample at 5 Hz, which may enhance the ability to measure short duration high intensity activities.

Australian Football is different to soccer with unlimited substitutions allowed during matches. This means that individual players may get significant periods of recovery during matches. It is therefore not uncommon for players to have two periods of play within each quarter of a match, with each team having up to one-hundred substitutions during matches (Aughey, unpublished observations). In AF the terminology applied to this is player rotations. Therefore, players may have rotations during match play of varying durations, and all movement data should be standardized per unit of time to allow comparisons to be made. Merely reporting the absolute distance covered by players during a full, half or quarter of a match may misrepresent the actual work rate or suggested pacing of players during individual rotations of AF.

The data in two recent AF studies was sampled from a team ranked in the lower 25% of the competition during the 2005 to 2007 seasons. It is possible that the profile of running in this team was different to more successful teams. As the authors of that recent AF study point out, less successful soccer teams have a higher activity level than more successful teams and are less efficient at some technical skills. It is therefore possible that the data presented is skewed due to the level of ability of the participants in that study.

While the idea of team-sport athletes pacing efforts early in a match is an attractive hypothesis, if similarly true to strategies adopted by individual athletes, the highest work rate of players should be achieved in the final periods of a match, as described by the “end spurt” phenomenon. There is no evidence to date of team sport athletes achieving this end-spurt.

Finally, there is increasing evidence that the running demands of AF players have increased in the past few years, with a 7% increase in both the mean running velocity and steady-state running over 8 km·h⁻¹ from the 2005 to 2008 seasons. Therefore, findings from matches sampled during the 2005 to 2007 seasons may no longer be relevant.

The aims of this study were therefore to: (1) quantify player work rate in AF with 5 Hz GPS devices; (2) express player work rate per unit of game time played; (3) analyze results per rotation; and (4) sample players from a team ranked in the top 25% of the competition.

**Methods**

**Participants**

Eighteen elite Australian footballers (age 25.9 ± 3.5 y; height 188.4 ± 7.8 cm; body mass 90.6 ± 8.8 kg at commencement of the study (mean ± SD) gave informed consent to participate in this study. The study conformed to the Declaration of Helsinki. Participants were all registered players of an elite Australian Football club, ranked in the top 25% of the elite Australian Football League competitions in the 2008 and 2009 seasons.
Data were collected from the eighteen players between 1 and 17 occasions from 29 individual matches during the 2008 and 2009 seasons. Files were only included if the following criteria was met: (1) Players played ≥ 70% of total game time; (2) players were rotated twice per quarter; and (3) each rotation was at least 5 min in duration. A 75% game time minimum criteria as recently described was not used in this study, as it would have excluded approximately 15 match files that were representative of common game times for those players. A total of 147 individual match files were included for analysis.

**Player Work Rate**

*Traditional Time Motion Analysis.* Player work rate was measured via a small global positioning system (GPS) sampling at 5 Hz (MinimaxX Team Sports 2.0, Catapult Innovations, Melbourne, Australia), using proprietary software (Logan Plus, v4.1, Catapult Innovations, Melbourne, Australia). The devices were worn in a custom pocket in the player uniform, located between the scapulas. The player movement variables analyzed, expressed in meters and distance per unit of game time (m·min⁻¹) were total distance; low-intensity activity (LIA, 0.10 to 4.17 m·s⁻¹); and high-intensity running (HIR, 4.17 to 10.0 m·s⁻¹). All movement data were expressed per quarter and per rotation. That is, in AF players are often rested, or rotated to the bench during quarters of play. A rotation equals a period of play within a quarter of football that a player is on the field. All rotation data were compared with the first rotation in the first quarter, which should have had the highest work rate. Periods were numbered Q1R1, Q1R2, Q2R1, Q2R2, Q3R1, Q3R2, Q4R1 and Q4R2 for individual rotations.

*Changes in Velocity.* The number of maximal (2.78 to 10.00 m·s⁻²) changes in velocity (accelerations) were calculated from GPS data using the manufacturers software (Logan Plus, v4.1, Catapult Innovations, Melbourne, Australia). In piloting the reliability of these GPS units to measure these accelerations, the CV was large at approximately 50% (Varley and Aughey unpublished observations). To enhance the ecological validity and reliability of this measure, our software rules required two consecutive measures (ie, 0.4 s) at the same rate of change in velocity to classify as acceleration. The statistical method we employ here can also account for this uncertainty in measurement. The definition of accelerations here differs from the only other studies to use acceleration data from GPS. One study counted accelerations of greater than > 1.11 m·s⁻² as moderate accelerations and another counted accelerations > 4 m·s⁻² as maximal accelerations. World-class 100 m sprinters accelerate at a rate of approximately 6 m·s⁻² in the first second of a race, and subsequent to that first second acceleration occurs at a maximum rate of approximately 2 m·s⁻². Further, elite team sport athletes accelerated from a standing start at a maximal rate of approximately 3 m·s⁻². In recent pilot testing, trained but subelite team sport athletes accelerated maximally at a rate of between 2.5 and 2.7 m·s⁻² measured by laser (Varley, Fairweather and Aughey unpublished data). Finally, these elite AF players only accelerate maximally in matches from a moving start. It is, therefore, likely that 4 m·s⁻² is too high a threshold for elite team sport athletes and a rate of between 2.7 and 3 m·s⁻² is appropriate. Based on this, and the observation of >1000 GPS files from elite AF matches and training sessions, this researcher believes 2.78 m·s⁻² is an appropriate threshold for maximum acceleration in elite AF players.
Statistical Analyses

Variables were log transformed to reduce bias due to nonuniformity of error and analyzed using the ES statistic with 90% confidence intervals (CI) and percentage change to determine the magnitude of effects using a custom spreadsheet. Magnitudes of change were classified as a substantial increase or decrease when there was a $\geq 75\%$ likelihood of the effect being equal to or greater than the smallest worthwhile change estimated as $0.2 \times$ between subject standard deviation, and classified as small 0.2 to 0.6; moderate 0.6 to 1.2; large 1.2 to 2.0; and very large 2.0 to 4.0. Effects with less certainty were classified as trivial and where the $\pm 90\%$ CI of the ES crossed the boundaries of ES $-0.2$ and 0.2, the effect was reported as unclear.

Results

The mean movement and acceleration data for players across whole matches are presented in Table 1.

Length of Playing Periods

Players were on the field of play for $101.91 \pm 9.80$ min in matches sampled. This represented approximately $85\%$ of available game time for these matches. The second rotation was shorter than the first in each quarter played, but there were no differences between the first rotation of the first quarter and the first rotation in subsequent quarters. The length of individual rotations was $15.22 \pm 6.68$, $10.77 \pm 3.83$, $15.50 \pm 7.41$, $11.52 \pm 4.14$, $16.22 \pm 7.12$, $11.21 \pm 4.14$, $15.91 \pm 8.09$ and $11.44 \pm 4.27$ min in chronological order.

Table 1  Movement and acceleration data (mean ± SD, n = 147) for whole matches, expressed in absolute and relative to time on field terms

<table>
<thead>
<tr>
<th>Variable</th>
<th>Unit</th>
<th>Mean ± SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance</td>
<td>Total (m)</td>
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</tr>
<tr>
<td></td>
<td>m-min$^{-1}$</td>
<td>127 ± 17</td>
</tr>
<tr>
<td>LIA Distance</td>
<td>Total (m)</td>
<td>9011 ± 1137</td>
</tr>
<tr>
<td></td>
<td>m-min$^{-1}$</td>
<td>89 ± 11</td>
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<tr>
<td>HIR Distance</td>
<td>Total (m)</td>
<td>3334 ± 756</td>
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<td></td>
<td>m-min$^{-1}$</td>
<td>34 ± 9</td>
</tr>
<tr>
<td>Maximal Accelerations</td>
<td>Total (#)</td>
<td>96 ± 41</td>
</tr>
<tr>
<td></td>
<td>accel-min$^{-1}$</td>
<td>0.99 ± 0.39</td>
</tr>
</tbody>
</table>

Note. LIA is low intensity activity performed at a velocity between 0.01 and 4.17 m s$^{-1}$; HIR is high intensity running defined as running performed at a velocity between 4.17 and 10.00 m s$^{-1}$; maximal accelerations were defined as a change in velocity of between 2.78 and 10.00 m s$^{-2}$. 
Total Distance

There was a moderate reduction in total distance in absolute meters traveled in the second rotation of each quarter when compared with Q1R1 (ES −0.78 ± 0.19; −0.63 ± 0.19; −0.72 ± 0.20; and −0.75 ± 0.20 respectively, Figure 1A). When compared with Q1R1 and expressed per minute of game time, total distance was, however, maintained in subsequent periods of play (Figure 1B).

Figure 1 — Total distance per rotation expressed in meters (A) and meters per minute of game time (m·min⁻¹, B). Periods were named for the quarter of play they occurred in, and the sequential number of the rotation in that quarter (Q1R1; Q1R2; Q2R1; Q2R2; Q3R1; Q3R2; Q4R1; and Q4R2 respectively). Magnitudes of change were classified as a substantial increase or decrease when there was a ≥75% likelihood of the effect being equal to or greater than the smallest worthwhile change estimated as 0.2 × between subject standard deviation, and classified as small 0.2 to 0.6; moderate 0.6 to 1.2; large 1.2 to 2.0; and very large 2.0 to 4.0. * Denotes a small reduction from Q1R1. All data are mean ± SD, n = 147.
Low Intensity Activity (LIA) Distance

As for total distance, there was a moderate reduction in LIA in the second rotation of each quarter when expressed in absolute terms (ES $-0.71 \pm 0.19; -0.54 \pm 0.19; -0.63 \pm 0.20; \text{and} -0.67 \pm 0.20$ for Q1R2, Q2R2, Q3R2 and Q4R2 respectively). However, when compared with Q1R1 and expressed per minute of game time, LIA distance was maintained in subsequent periods of play ($90.83 \pm 17.74; 93.01 \pm 17.76; 91.32 \pm 14.65; 94.63 \pm 18.41; 88.22 \pm 17.89; 92.60 \pm 14.44; 89.91 \pm 15.95$ and $89.65 \pm 14.52$ for Q1R1, Q1R2, Q2R1, Q2R2, Q3R1, Q3R2, Q4R1 and Q4R2 respectively).

High Intensity Running (HIR) Distance

When examined per rotation and expressed in absolute terms, HIR was reduced by a moderate magnitude in the second rotation of each quarter (ES, $-0.78 \pm 0.20; -0.72 \pm 0.19; -0.82 \pm 0.20$ and $-0.80 \pm 0.20$ for Q1R2, Q2R2, Q3R2 and Q4R2 respectively. Figure 2A). However, when expressed in relative terms, HIR was reduced by a small magnitude in both rotations of the second quarter, Q3R2 and both rotations of the fourth quarter (ES $-0.30 \pm 0.14; -0.42 \pm 0.14; -0.30 \pm 0.14; -0.42 \pm 0.14; \text{and} -0.48 \pm 0.15$ respectively, Figure 2B).

Maximal Accelerations

When the absolute number of maximal accelerations was expressed per rotation relative to Q1R1, there was a moderate reduction in Q1R2, Q2R2, Q3R2, and Q4R2 (ES $-0.75 \pm 0.20; -0.60 \pm 0.20; -0.75 \pm 0.20$ and $-0.71 \pm 0.20$ respectively, Figure 3A) and a small reduction in Q4R1 (ES $-0.27 \pm 0.18$; Figure 3A). When expressed relative to game time, small reductions were evident in Q1R2, and each rotation of the second half of matches (ES $0.28 \pm 0.20; 0.27 \pm 0.17; -0.33 \pm 0.20; -0.46 \pm 0.18; \text{and} -0.34 \pm 0.20$ respectively, Figure 3B).

Discussion

This study uses 5 Hz GPS for the first time to quantify match performance of elite AF players. The first major finding of this study was that total distance covered by elite AF players was maintained throughout matches when expressed relative to game minutes played. Similarly, players maintained the amount of LIA throughout matches when normalized for game time. The second major finding of this study was that there were small reductions in high intensity running in the latter part of matches, even when playing time was accounted for. For the first time we have characterized the number of maximal accelerations players undertake during matches, and reported a decline in this ability in the latter stages of a match.

The findings on total distance covered by players in this study differ from the two recent studies using GPS technology to measure AF player work rate.1,2 In both of the previous studies, the authors have reported a reduction in total distance covered by players in the last part of matches. There are at least three possible explanations for the differences reported here. The first possible explanation is that these players may have had a higher level of conditioning than those in the previous studies. Players used here were from a team ranked in the top 25% of
Figure 2 — High intensity running (HIR) distance per rotation expressed in meters (A) and meters per minute of game time (m·min⁻¹, B). Periods were named for the quarter of play they occurred in, and the sequential number of the rotation in that quarter (Q1R1; Q1R2; Q2R1; Q2R2; Q3R1; Q3R2; Q4R1; and Q4R2 respectively). Magnitudes of change were classified as a substantial increase or decrease when there was a ≥ 75% likelihood of the effect being equal to or greater than the smallest worthwhile change estimated as 0.2 × between subject standard deviation, and classified as small 0.2 to 0.6; moderate 0.6 to 1.2; large 1.2 to 2.0; and very large 2.0 to 4.0. * Denotes a small reduction from Q1R1. † Denotes a moderate reduction from Q1R1. All data are mean ± SD, n = 147.
Figure 3 — The number of maximal accelerations defined as a change in velocity of between 2.78 to 10.00 m·s⁻² expressed in absolute terms (A) and per minute of game time (accelerations per minute, B). Periods were named for the quarter of play they occurred in, and the sequential number of the rotation in that quarter (Q1R1; Q1R2; Q2R1; Q2R2; Q3R1; Q3R2; Q4R1; and Q4R2 respectively). Magnitudes of change were classified as a substantial increase or decrease when there was a ≥ 75% likelihood of the effect being equal to or greater than the smallest worthwhile change estimated as 0.2 × between subject standard deviation, and classified as small 0.2 to 0.6; moderate 0.6 to 1.2; large 1.2 to 2.0; and very large 2.0 to 4.0.* Denotes a small reduction from Q1R1. † Denotes a moderate reduction from Q1R1. All data are mean ± SD, n = 147.
the competition, rather than the bottom 25% in the previous studies.\textsuperscript{1,2} It is well documented that players at a higher level of competition have superior physical capabilities. Evidence of this is presented in comparisons of athletes of different levels on team-sport specific tests such as the Yo-Yo Intermittent recovery test.\textsuperscript{22} Indeed, international standard soccer players performed approximately 10% better than other elite players playing at a lower level on this test.\textsuperscript{22} Further, in elite AF, players selected to commence on the field have an approximate 27% greater Yo-Yo IR2 performance than nonstarters.\textsuperscript{23} Finally, players in this study had a relative total distance approximately 14% higher than the previous study.\textsuperscript{1} Taken further, it is reasonable to assume that players of a higher level may also have a higher level of fatigue resistance than there less successful counterparts. The second possible explanation is that the higher ranked players used in this study did not have to run as hard, as they were more technically proficient, as noted in elite soccer players in the Italian Serie A competition.\textsuperscript{13} Finally, AF players get ample opportunity to rest during and between quarters of games. When analyzed per rotation, rather than over a whole quarter of play and expressed per minute of game time played, it is easier to measure peaks and troughs in player work rate.

It has been postulated that players regulate the amount of low-intensity activity undertaken to preserve the important high-intensity components of running during matches.\textsuperscript{2} The players in this study had unchanged low-intensity activity over the course of the game, in disagreement with the concept of pacing. Indeed, individual athletes tend to lower work rate early in races\textsuperscript{14} to allow an “end-spurt”\textsuperscript{14,15} or enhanced performance during matches. Australian Football matches are played over a period of approximately 120 min, but the exact duration cannot be known in advance by AF players, as it is dependent on how much extra time is added due to stoppages in play and strategic considerations. Further, players do not always know in advance how long each rotation will be during a match, and therefore pacing and subsequent performance are altered by the accuracy of feedback provided.\textsuperscript{24} In agreement with previous findings in elite team sport athletes, high intensity running of the elite AF players in this study was lowered in the latter part of matches.\textsuperscript{1–5,25–28} The mechanisms underlying this reduced performance are likely to be multifaceted, and were not examined in this study. However, fatigue may be caused by reductions in available substrate,\textsuperscript{29,30} disturbances in electrolytes across the muscle membrane,\textsuperscript{31} impaired calcium release from the sarcoplasmic reticulum,\textsuperscript{32} or central factors.\textsuperscript{33} For the first time we present evidence of a reduction of the ability of players to accelerate maximally during matches. It is perhaps not surprising that this ability is impaired in these athletes, as to accelerate is extremely physically demanding, even from low commencement velocities and therefore likely to induce significant fatigue. Further, accelerations are associated with key elements of the game, including the ability to accelerate toward an opponent to lay a tackle, accelerate away from an opponent to evade opponent tackle or move to space to receive the ball from a team-mate. Notwithstanding that the measurement of accelerations using GPS is less reliable than the measure of total or HIR distance,\textsuperscript{9} this may reflect an important indicator of fatigue. In this study, the measurement of normalized maximal accelerations was able to detect fatigue later in games similar to normalized HIR distance. However, subtle differences in the magnitudes of fatigue and the time course between these two measures points to the importance of measuring different
fatigue qualities in these athletes. Further, to neglect the rapid and common changes in velocity that occur in team-sports probably underestimates true high-intensity activities of players in matches.34

Practical Applications

Player work rate must be expressed in relation to a unit of time played in AF, as players can be substituted regularly during matches. When considering performance in AF, it is likely that the most high intensity actions such as sustained high-velocity running, or hard changes in velocity will be impaired in the second half of matches. To improve this performance later in games, careful management of players through regular rotations and implementation of recovery strategies during games should be undertaken. However, in the absence of data on the capability of GPS to accurately and reliably measure accelerations, care must be taken when interpreting data on this practically important parameter.

Conclusions

When expressed per minute of game time played, both total distance and low-intensity activity distance are not reduced by a practically important magnitude in elite AF players during a match. This data are therefore inconsistent with the concept of team sport players pacing their effort during matches. However both high-intensity running and maximal accelerations are reduced later in games, indicative of significant fatigue in players. Further work is needed to characterize the reliability and validity of GPS for measuring these accelerations.

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References
