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Metabolic power and energetic costs of professional Australian Football match-play

Aaron J. Coutts[a,b,*], Thomas Kempton[a], Courtney Sullivan[a,b], Johann Bilsborough[a,b], Justin Cordy[b], Ermanno Rampinini[c,d]

[a] *Sport & Exercise Discipline Group, Faculty of Health, University of Technology Sydney (UTS), Australia*
[b] *Carlton Football Club, Australia*
[c] *Human Performance Laboratory, MAPEI Sport Research Center, Italy*
[d] *Department of Sport, Nutrition and Health Sciences, Faculty of Exercise Sciences, Università degli Studi di Milano, Italy*

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ABSTRACT

Objectives: To compare the metabolic power demands between positional groups, and examine temporal changes in these parameters during Australian Football match-play.
Design: Longitudinal observational study.
Methods: Global positioning system data were collected from 39 Australian Football players from the same club during 19 Australian Football League competition games over two seasons. A total of 342 complete match samples were obtained for analysis. Players were categorised into one of six positional groups: tall backs, mobile backs, midfielders, tall forwards, mobile forwards and rucks. Instantaneous raw velocity data obtained from the global positioning system units was exported to a customised spreadsheet which provided estimations of both speed-based (e.g. total and high-speed running distance) and derived metabolic power and energy expenditure variables (e.g. average metabolic power, high-power distance, total energy expenditure).
Results: There were significant differences between positional groups for both speed-based and metabolic power indices, with midfielders covering more total and high-speed distance, as well as greater average and overall energy expenditure compared to other positions (all $p < 0.001$). There were reductions in total, high-speed, and high-power distance, as well as average metabolic power throughout the match (all $p < 0.001$).
Conclusions: Positional differences exist for both metabolic power and traditional running based variables. Generally, midfielders, followed by mobile forwards and mobile backs had greater activity profiles compared to other position groups. We observed that the reductions in most metabolic power variables during the course of the match are comparable to traditional running based metrics. This study demonstrates that metabolic power data may contribute to our understanding of the physical demands of Australian Football.

1. Introduction

Australian Football is a physically demanding, high-intensity intermittent team sport. Time–motion analyses of Australian Football League (AFL) competition matches are now common as the use of global positioning system (GPS) technology is widespread throughout the League. Indeed, several studies have examined the physical demands of AFL competition match-play, particularly with reference to playing position,[1] match outcome,[2] player ability,[3] match-to-match variability[4] and match-related fatigue.[5] These studies have used common match activity profile metrics such as total distance, high speed running (HSR) and sprint activities. More recently, investigations have shown that acceleration efforts may also contribute to the match demands of Australian Football; however, this is yet to be empirically assessed.[6,7] Collectively, these applied match analysis studies have assisted in developing our understanding of the physical demands associated with competitive match-play.

Recent research from professional soccer has shown that metabolic power calculations can estimate the power output and energetic costs of intermittent running.[8,9] These investigations provide additional insight to previous studies which

* Corresponding author.
E-mail address: aaron.coutts@uts.edu.au (A.J. Coutts).

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have employed traditional time–motion analyses of the activity demands of training and match-play.[8,9] These metabolic power calculations are based on a theoretical model[10] that allows the estimation of the energetic cost of accelerations and decelerations during intermittent running, and can be applied to a variety of sports involving similar activity profiles. Briefly, the model considers accelerated running on a flat surface to be metabolically equivalent to incline running at a constant velocity, where the angle of the incline is equal to the extent of forward acceleration. This method provides an "equivalent slope" which is used to calculate an instantaneous measure of the energy cost of accelerated running and an estimate of metabolic power output. In contrast, traditional time–motion analyses report variables based on distances travelled in specific speed zones such as higher speed running ($\gtrsim$15 km h^{-1}) and total distance which do not account for the high energetic cost of these accelerations and decelerations.[11] Whilst no studies have directly validated this method for estimating energy cost and metabolic power, the approach has been reported to provide energy cost estimates similar to directly determined measures.[9] Moreover, Manzi et al.[12] recently reported large to very large correlations between aerobic fitness variables and metabolic power estimates of HP distance during Serie A soccer matches in 17 professional Italian soccer players, providing evidence for concurrent validity of this novel approach. Accordingly, this new has been suggested to be superior the traditional time–motion analysis variables as it provides a better estimate of the overall energy demands of team sport activities. This new approach can be used to complement traditional time–motion analysis approaches to provide new information on the power production, metabolic costs and match-related fatigue profiles in team sports such as Australian Football. In particular, this information may assist practitioners better understand of the positional demands of competition, the distribution of work during match-play and the energy requirements following match-play and training.

While this approach has been previously applied to soccer competition[13] and training,[9] no studies to date have investigated the metabolic power demands of AFL match-play. Moreover, no studies have applied this method to examine match-related fatigue in team sports such as Australian Football. Therefore, the aims of this study were to: (1) describe the metabolic demands of AFL match-play for different position groups; (2) examine temporal changes in metabolic power indices during a match; and (3) compare the match activity profile information from traditional speed-zone methods with those derived from metabolic power calculations.

2. Methods

Data were collected from 39 AF players (age: 24.6 ± 2.9 y; mass: 88.7 ± 8.7 kg; stature: 188.4 ± 7.2 cm) from the same club during 19 AFL competition games over two seasons. A total of 342 player match files were obtained for analysis. The mean (±SD) number of observations for each player was 8.8 ± 5.4 (range 1–18). Players were categorised into one of six positional groups, depending on where they played the majority of game time: tall backs, mobile backs, midfielders, tall forwards, mobile forwards and rucks.[1] The total match observations for each positional group were 35, 70, 145, 23, 48 and 21 respectively. Informed consent and institutional ethics approval were obtained prior to testing.

Player movements during the matches were measured using portable GPS systems (Team Sport 2.5, Firmware 6.54, Catapult Innovations, 10 Hz Melbourne, Australia). The GPS unit was fitted within a custom made pouch that was positioned between the scapulae in each player's jersey prior to the match. All players wore the same GPS unit for each match during the season to minimise inter-unit error.[13–15] The reliability of these GPS devices has previously been reported.[13,16,17]

Following each match, GPS data were downloaded using the same proprietary software (Catapult Sprint v5.0.6). Each file was trimmed so that only data recorded during each quarter when the player was on the field was included for further analysis. The proprietary software provided instantaneous raw velocity data at 0.1 s intervals, which was then exported and placed in a customised Microsoft Excel spreadsheet (Microsoft, Redmond, USA). The spreadsheet calculated the distance covered in the following categories; total distance; high-speed running (>14.4 km h^{-1}, HSR); very high-speed running (>19.8 km h^{-1}, VHSR); and sprinting (>24.0 km h^{-1}, Sprint). Acceleration and deceleration efforts were classified as two consecutive samples (0.2 s) exceeding the threshold of 2.78 m s^2 and 2.78 m s^2, respectively.[18] The metabolic power equations for estimating instantaneous energy cost and metabolic power,[9,10] were integrated into the spreadsheet and formed the basis for all variables related to metabolic power. The calculations were used to estimate average metabolic power (W kg^{-1}, P_{met}) and total energy expenditure (kJ kg^{-1}), as well as the distance (m), time (min) and energy expenditure (kJ kg^{-1}) produced above high power threshold (>20 W kg^{-1}, HP). Calculations were provided for the equivalent distance (ED), which represents the equivalent steady state distance required match the estimated energy expenditure during exercise; and the equivalent distance index (EDI) representing the ratio between ED and total distance.[9]

The assumptions of normality were verified prior to parametric statistical analysis. Multivariate analysis of variance (MANOVA) was used to compare differences in physical performance variables between positional groups (6) and playing quarter (4). When significant main effects were observed, Scheffe's post hoc test was applied. Standardised effect sizes (ES) were calculated with <0.2, 0.21–0.6, 0.61–1.20, 1.21–2.00 and 2.01–4.0 representing trivial, small, moderate, large and very large differences, respectively.[19] Statistical analyses were conducted using Statistica software package (StatSoft. Inc., Tulsa, USA) or Microsoft Excel (Microsoft, Redmond, CA). All data are reported as mean and 95% confidence interval (CI) unless otherwise stated. Statistical significance was set at $p < 0.05$.

3. Results

Selected distance and metabolic power variables for each playing position are shown in Table 1. MANOVA revealed significant main effects for playing position ($F = 12.8$, $p < 0.001$). Post hoc analysis revealed that midfielders covered greater total distance compared to all other positions except for mobile backs (ES = 0.72–1.39). Similarly, midfielders also had higher relative distances compared to all other positions (ES = 0.71–2.14), while higher values were observed for mobile backs compared to tall forwards (ES = 1.25) and tall backs (ES = 1.06) only. Midfielders also had greater HSR distance compared to all other positions (ES = 0.80–2.37), while mobile backs (ES = 1.04–1.65) and mobile forwards (ES = 1.16–1.73) covered more HSR distance than the other remaining position groups only. Mobile forwards covered more VHSR (ES = 0.55–4.08) and sprint distance (ES = 0.65–3.46) compared to all other positions, followed by mobile backs (ES = 0.93–2.83; 0.86–2.87) and midfielders (ES = 1.06–2.74; 0.28–2.48), which recorded higher values compared to the remaining position groups. Tall forwards had less acceleration efforts than both midfielders (ES = 1.34) and mobile backs (ES = 1.23); while tall forwards (ES = 1.46) and rucks (1.23) had fewer decelerations compared to mobile forwards. Midfielders spent less time on the field compared to both tall (ES = 1.06) and mobile backs (ES = 0.57). In contrast, the highest P_{met}, energy expenditure and equivalent distance was observed for midfield

Table 1
Match distance and metabolic power parameters by playing position (mean ± 95% CI).

	Tall backs	Mobile backs	Midfielders	Tall forwards	Mobile forwards	Rucks
Distance						
Total distance (m)	11,878 (11,437–12,320)[a]	12,621 (12,344–12,899)[d]	12,819 (12,603–13,034)[b,d,e,f]	11,158 (10,696–11,620)[a,c]	11,986 (11,545–12,427)[a]	11,701 (11,396–12,006)[a]
HSR distance (m)	2831 (2589–3073)[a,b,c]	3524 (3374–3674)[a,d,e,f]	4314 (4166–4462)[b,c,d,e,f]	2683 (2452–2914)[a,b,c]	3658 (3449–3868)[a,d,e,f]	2598 (2380–2817)[a,b,c]
VHSR distance (m)	903 (816–990) [a,b,c,f]	1164 (1091–1237)[b,d,e,f]	1236 (1176–1295)[b,d,e,f]	792 (702–881)[a,b,c,f]	1411 (1333–1490)[c,d,e,f]	420 (323–516)[a,b,c,d,e]
Sprint distance (m)	260 (235–285)[b,c,f]	362 (326–398)[d,e,f]	290 (268–312)[b,c,f]	212 (179–245)[b,c,f]	466 (417–514)[a,c,d,e,f]	43 (21–64)[a,b,c,d,e]
Accelerations (n)	94 (86–102)	103 (98–108)[d]	101 (96–105)[d]	82 (78–87)[a,c]	101 (96–106)	96 (88–104)
Decelerations (n)	109 (99–119)	120 (114–126)	116 (112–121)	100 (95–106)[b]	125 (119–131)[d,f]	100 (90–109)[b]
Rel. distance (m min^{-1})	108 (104–112)[c]	120 (117–123)[a,d,e]	128 (126–130)[b,c,d,e,f]	108 (105–111)[a,c]	115 (111–118)[a]	115 (112–118)[a]
Field time (min)	110 (107–113)[a]	105 (104–107)[a]	101 (99–102)[c,e]	103 (99–107)	105 (102–107)	102 (99–106)
Metabolic power						
P_{met} (W kg^{-1})	9.2 (8.9–9.6)[a,c]	10.3 (10–10.5)[a,d,e]	10.9 (10.7–11)[b,c,d,e,f]	9.2 (9–9.5)[a,c]	9.9 (9.6–10.1)[a]	9.7 (9.4–9.9)[a]
Energy exp. (kJ kg^{-1})	60.8 (58.5–63.1)[a]	64.8 (63.4–66.3)[d,e]	65.6 (64.4–66.7)[b,d,e,f]	57 (54.7–59.4)[a,c]	61.8 (59.6–64)[a]	59.3 (57.7–60.9)[a,c]
Equivalent distance (m)	13,088 (12,598–13,578)[a]	13,959 (13,647–14,271)[d,f]	14,115 (13,874–14,356)[b,d,e,f]	12,275 (11,769–12,780)[a,c]	13,309 (12,832–13,785)[a]	12,775 (12,431–13,119)[a,c]
HP distance (m)	2751 (2539–2962)[a,b,c]	3343 (3207–3478)[a,d,e,f]	3965 (3838–4091)[b,c,d,e,f]	2593 (2385–2801)[a,b,c]	3482 (3297–3666)[a,d,e,f]	2505 (2317–2694)[a,b,c]
LP distance (m)	9128 (8803–9452)	9278 (9082–9475)[a,b,d]	8854 (8715–8993)[c]	8565 (8223–8907)[c]	8505 (8211–8798)[c]	9196 (8904–9487)
HP time (min)	10.2 (9.5–11)[a,b,c]	12.2 (11.7–12.6)[a,d,e,f]	14.4 (13.9–14.8)[b,c,d,e,f]	9.7 (9–10.4)[a,b,c]	12.2 (11.5–12.9)[a,d,e,f]	10 (9.4–10.7)[a,b,c]
LP time (min)	99.8 (96.7–102.9)[a,b,c]	93.3 (91.4–95.3)	86.2 (84.7–87.7)[b,c,d,e]	93.4 (89.9–96.9)[a]	92.4 (90.1–94.7)[a,e]	92.4 (88.7–96)
HP power (W)	18,585 (17,334–19,835)[a,b,c]	22,179 (21,330–23,028)[d,e,f]	25,163 (24,428–25,898)[b,c,d,e,f]	17,400 (16,159–18,640)[a,b,c]	22,693 (21,599–23,787)[a,d,e,f]	16,953 (15,788–18,118)[a,b,c]
LP power (W)	42,196 (40,703–43,689)[b]	42,646 (41,752–43,540)[c]	40,389 (39,746–41,032)[c]	39,604 (38,034–41,175)	39,112 (37,804–40,420)[c,e]	42,374 (40,993–43,756)
Comparisons						
Equivalent vs. total (%)	10.4 (9.9–10.4)[f]	10.8 (10.3–10.8)[a]	10.3 (9.9–10.3)[b,c,f]	10.3 (9.8–10.3)	11.4 (10.8–11.4) [a,d,e,f]	9.6 (8.8–9.6)[a,b,c,e]
HP vs. HSR (%)	−1.1 (−3.4 to 1.1)[b,c]	−4.4 (−5.5 to 4.4)[a]	−7.4 (−8.2 to 7.4)[b,c,d,e,f]	−1.8 (−4.4 to 1.8)[a]	−3.9 (−5.2 to 3.9)[a,e]	−1.5 (−4.9 to 1.5)[a]

HSR, high speed running (>14.4 km h^{-1}); VHSR, very high speed running (>19.9 km h^{-1}); P_{met}, mean metabolic power; HP, high power (>20 W kg^{-1}); LP, low power (<20 W kg^{-1}).
[a] Significantly different from midfielders.
[b] Significantly different from mobile forwards.
[c] Significantly different from mobile backs.
[d] Significantly different from tall forwards.
[e] Significantly different from tall backs.
[f] Significantly different from rucks (all $p < 0.001$).

players (ES = 0.64–2.10; 0.52–1.39; 0.52–1.39), followed by mobile backs (ES = 0.44–1.29; 0.44–1.36; 0.44–1.36) which were greater than all other positions. The HP variables (i.e. distance, time and power) were greater for midfielders (ES = 0.68–2.36; 0.87–2.16; 0.60–2.25) compared to all other positions, followed by mobile backs (ES = 1.00–1.68; 0.95–1.39; 1.00–1.68) and mobile forwards (ES = 1.17–1.82; 0.89–1.26; 1.11–1.78), which were greater than all other positions except for midfielders.

Fig. 1 shows temporal changes in selected distance and metabolic power variables by playing quarter. MANOVA revealed significant main effects for quarter (F = 7.26, p < 0.001), with subsequent post hoc analyses revealing that the total distance and energy expenditure in the second (ES = 0.28; 0.29) and third (ES = 0.45; 0.44) quarters were reduced compared to the opening quarter only, while the fourth quarter distance was less than both the first (ES = 0.54; 0.54) and second quarter (ES = 0.30; 0.30). There were reductions in HSR, HP distance and P_{met} in the second (ES = 0.28; 0.30; 0.31) and third (ES = 0.36; 0.37; 0.37) quarters when compared to the opening quarter, while the fourth quarter (ES = 0.31–0.65; 0.32–0.67; 0.25–0.60) values were lower than all other quarters. The EDI was lower in the second quarter compared to the third quarter only (ES = 0.24). There were no differences in on field time between the first (26.1 [25.7–26.5] min), second (26.0 [25.6–26.4] min) third (25.5 [25.2–25.9] min) or fourth (25.7 [25.2–26.2] min) quarters (ES = 0.03–0.17).

4. Discussion

The present study examined metabolic power production alongside traditional speed-based metrics during professional AFL match-play. Our results show that as with distances travelled in the various speed zones, there were differences in metabolic power indices between positional groups. In addition, reductions in both distances travelled in speed zones and metabolic power measurements were observed across playing quarters. Finally, the HP distance was lower in comparison to the HSR distance for all position groups.

Similar to previous studies in soccer and rugby league,[8,20] we observed positional differences for both speed zone and metabolic derived variables during Australian Football match-play. Specifically, we observed that midfielders covered greater total distance and relative intensity ($\mathrm{m\,min^{-1}}$) compared to other playing positions. In addition, both HSR and VSHR distances were greater for midfielders as well as mobile forwards and mobile backs in comparison to tall forwards, tall backs and rucks. These results are comparable to those that have been reported previously during AFL competition play.[1,21] A novel aspect of the present study is the analysis of metabolic power derived indices during match-play. The data show similar trends to traditional running based variables, with midfielders producing greater P_{met}, total energy expenditure and equivalent distance compared to other positional groups. Again, midfielders, as well as mobile forwards and mobile backs perform greater high-power activities (i.e. greater HP distance, time and power production) compared to tall forwards, tall backs and rucks. The differences in activity profiles can be explained by the specific tactical roles of each playing position. For example, midfielders, mobile backs and mobile forwards typically have a more nomadic role than other positions, which allows them greater space to complete high intensity activities. Additionally, these positions are usually more heavily interchanged, providing regular opportunities for recovery from the transient fatigue that occurs during match-play. It is possible that these players who receive greater recovery opportunities through greater interchange, may be at an advantage, as it may permit them to repeat more higher intensity efforts.[22] Further, players in these positions often have more direct involvement in play as their role is to win the ball, while rucks, tall backs and tall forwards are generally are often required to provide offensive "pattern" play or a direct defensive role against their opponent.

The metabolic power derived indices reported in this study offer new insights into the physical demands of professional AFL competition. The P_{met} for each positional group ranged from 9.2 to 10.9 $\mathrm{W\,kg^{-1}}$, which is higher than previous reports for soccer training[8] and rugby league match-play[20] that used the same calculations as the current study. In contrast, the EDI was actually lower than that observed in soccer training[9] and rugby league match-play,[20] suggesting a greater relative contribution of continual running over accelerated running in AFL compared to soccer and rugby league. This might be explained by the greater field size in AFL which allows players to run greater distances between each accelerations/decelerations and/or collisions. The total energy expenditure ranged from 57 to 66 $\mathrm{kJ\,kg^{-1}}$ which was similar to that previously reported for soccer match-play ~60 $\mathrm{kJ\,kg^{-1}}$.[9] The energy expenditure information may be useful when planning both pre and post-match nutritional intake, which can assist in optimising acute recovery and in the long term help to maintain body composition.

A recent study by Gaudino et al.[8] compared the distances derived from HSR (>14.4 $\mathrm{km\,h^{-1}}$) to HP (>20 $\mathrm{W\,kg^{-1}}$) thresholds during professional soccer training. These comparisons are possible as previous research has estimated that metabolic cost of running at a constant speed of 14.4 $\mathrm{km\,h^{-1}}$ is approximately 20 $\mathrm{W\,kg^{-1}}$.[9] Gaudino et al.[8] reported that depending on playing position, HP distance was between 62 and 84% greater than HSR distance during soccer training. On the basis of these observations, the authors cautioned that HSR distance may neglect the contribution of accelerated running and therefore underestimate the true metabolic demands of the activity. In contrast to this previous investigation, our results revealed a small reduction in HP distance (−1.1 to −7.4%, depending on playing position) compared to HSR distance during AFL match-play. This presents a somewhat unexpected result and several factors may assist in explaining this discrepancy. Firstly, the isopower relationships originally described by Osgnach et al.[9] show that running speeds yield varying power outputs depending on the degree of acceleration. Accordingly, some running efforts in excess of the high speed threshold that occur while decelerating will not reach the HP threshold. Similarly, some running efforts between approximately 14.4 and 15.5 $\mathrm{km\,h^{-1}}$ with little or no acceleration will also fall into this category. It is possible that AFL match-play provides opportunities for substantial activity of this type which reaches the HSR but not HP thresholds. This is supported by the higher number of absolute deceleration efforts compared to acceleration efforts observed in this study across all positional groups. Further differences may be related to the structure of AFL match-play, including greater opportunities for HSR due to the larger pitch dimensions and no "offside" rule meaning more space is available for players. Indeed, Gaudino et al.[8] observed that the magnitude of difference between the two methods was inversely related to the amount of high-speed activity in the session. As such, the elevated levels of high-speed activities compared to low-speed acceleration efforts present in AFL match-play may further explain these findings. Given the activity profile of Australian Football has a large emphasis on continual running bouts; the additional contribution of HP distance to Australian Football match analysis is marginal. From a practical perspective, the present results show that metabolic power estimates of HP distance provide little additional insight compared to traditional HSR distance variables.

While previous studies have examined changes in running performance during AFL match-play,[5] this study is the first to assess temporal changes in metabolic power variables during

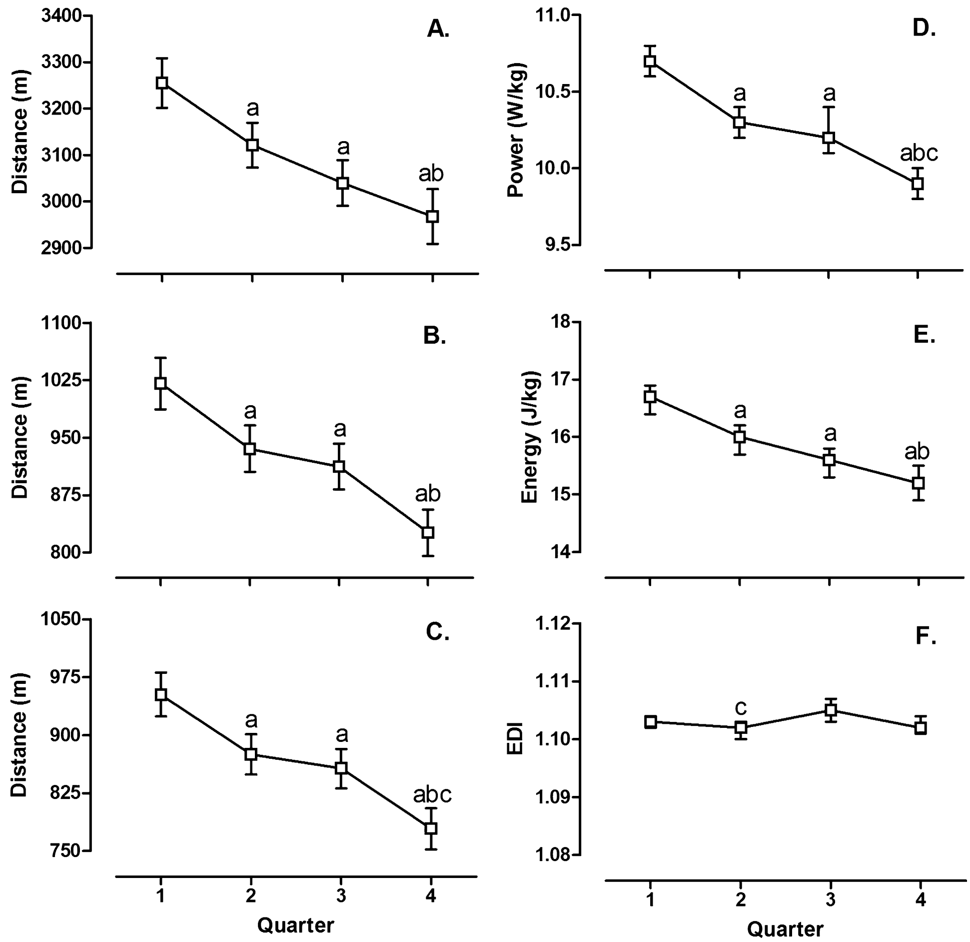

Fig. 1. Selected distance and metabolic power variables by playing quarter.

match-play in any football code. Our results show that both P_{met} and HP distance are reduced in the second, third and fourth quarters compared to the first, while in the final quarter these variables are also lower compared to both the second and third quarters. Similarly, energy expenditure decreased across the match, with lower values observed in the second and third quarters compared to the first, while the fourth quarter was significantly lower than both the first and second quarter. In contrast, there was no clear trend in EDI across the match, with a small reduction detected in the second quarter in comparison to the third. This suggests that the ratio of continuous to accelerated running bouts remains relatively constant throughout the match. In the present study, reductions of these metabolic power variables – excluding EDI – are comparable to traditional running based metrics (i.e. total and HSR distance), and indeed these broader trends are similar to previous investigations that have examined these traditional metrics in professional AFL.[5] Collectively, these results show that metabolic derived variables such as P_{met}, HP distance and energy expenditure – but not EDI – appear to be sensitive to fatigue-related reductions during AFL competition matches.

Although estimations of metabolic power production provide useful additional information regarding physical demands of intermittent team sport match-play, it is important to acknowledge the limitations associated with this approach. Firstly, there are several assumptions inherent in the equations provided by di Prampero et al. relating to the location of the centre of mass, the influence of limb movement on running energetics and the effects of air resistance.[11,14] Similarly, the ability of 10-Hz devices to accurately assess measure accelerations and movement at higher speeds has been shown to have considerable error[23] – this error should be considered when interpreting the present findings. A further limitation, which is common to all time–motion analyses, is that game specific actions such as tackling and jumping are not accounted for. As such, the estimates of metabolic power production presented in this investigation underestimate the contribution of these actions to overall energy expenditure. In addition, the effects of eccentric actions are not considered in this model, and although the actual metabolic costs of these actions are low, eccentric movements may contribute to the onset of muscular fatigue during exercise. Accordingly, the true cost of these actions may be neglected by the metabolic power approach. Finally, the present investigation is a single club case study and may be governed by the physiological profile of players and the tactical strategies used during the observation period. Nonetheless, data was obtained from 39 individual players and there were two separate head coaches during the study period. Further studies utilising large datasets derived from multiple clubs may be required to confirm out findings are present across the League. Moreover, other studies could also compare the metabolic power demands of a range of training activities with the match activity profiles presented here.

5. Conclusion

This study examined the metabolic power demands of professional AFL match-play alongside traditional running-based variables. The main findings were that positional differences exist for both metabolic power and traditional running based variables.

Generally, midfielders, mobile forwards and mobile backs had greater activity profiles compared to other position groups. Secondly, we observed that the reduced metabolic power variables – with the exception of EDI – during the course of the match are comparable to traditional running based metrics (i.e. total and HSR distance). Finally, the HP distance was slightly less than the HSR distance for all positional groups, and this is likely due to the elevated HSR demands of professional AFL match-play. This study demonstrates that metabolic power data may contribute to our understanding of the physical demands of AFL competition play.

Practical applications

- Traditional running based metrics such as HSR distance are appropriate for analysing match activity profiles in Australian Football.
- Energetic and metabolic measures provide new approaches for estimating training loads during match-play and practice sessions; however, these estimates provide little additional information than traditional running-based metrics.
- Estimations of total energy expenditure during match-play may be useful for informing energy replacement requirements for individual players.

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