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Comparisons of daily energy intake versus expenditure using the GeneActiv accelerometer in elite Australian Football athletes

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INTRODUCTION

The energy requirements of athletes fluctuate in response to training-induced thermogenesis (activity thermogenesis), which is an additive energetic cost to resting metabolic rate and dietary thermogenesis.³² Athletes modulate training parameters including the volume, intensity and frequency of exercise to optimise sport-specific adaptations and achieve peak physical condition for competition.¹⁸ Athletes may also undergo nutritional periodization; a term used to describe various methods to manipulate dietary intake in response to day-to-day variances in energy expenditure (EE) with the specific aim of maximising the quality of training and promoting adaptation.¹² Understanding the energy demands to train and compete in sport is vital to provide appropriate nutritional recommendations. Currently, there is limited research investigating whether athletes adjust their dietary intake relative to the demands of each training/competition day to achieve daily energy balance.^{8, 11, 28} The paucity of existing data likely reflects the difficulties in undertaking research in the elite training environment.

Australian Football is unique amongst football codes due to very high physical demands related to sport-specific skills, match duration (~120 min) and total distances covered during match play (mean 12620±1872 m).³³ Estimating EE during training and competition is technically difficult^{5, 22} and employing methods such as doubly labelled water or indirect

calorimetry can impact ecological validity and is impractical for routine use in a daily athlete monitoring system. The only previous study to provide an estimate of EE in elite Australian Football athletes used conversion of global positioning system (GPS) data to total work capacity and found players expended an average 30.4 ± 6.5 kJ/kg or 0.42 ± 0.08 kJ/kg/min during training sessions and 58.0 ± 5.8 kJ/kg or 0.59 ± 0.06 kJ/kg/min on match day. This equated to ~ 18504 kJ and ~ 19160 kJ expended over each day when GPS derived data was combined with data from a SensewearTM armband to estimate non-training EE.³⁴ However, combining different technologies would typically increase the error of estimates and while GPS devices have good reliability for quantifying distance and velocity (coefficient of variation (CV) <6%) the precision for estimating EE has not been widely reported.^{15, 26}

Characterizing daily energy balance is important to implement appropriate dietary strategies for adequate recovery and refueling,⁹ maintenance of sport-specific body composition^{2, 4} and to maximise performance capacity.^{19, 23} Thus, complementing the practical outcomes of the athletes strength and conditioning program. The primary aim of this study was to assess the utility of the GeneActiv accelerometer to estimate EE of elite athletes, and compare this with their estimated energy intake, to improve understanding of daily energy balance associated with training and competition. The secondary aim was to evaluate professional team sport athletes macronutrient intake in comparison to sports nutrition recommendations for optimal performance outcomes.

METHODS

Experimental approach to the problem

Our experimental approach began with an initial assessment of the validity of a wrist-watch accelerometer for determining energy expenditure at high running speeds in team sport athletes. This preliminary sub-study permitted the application of a specific regression equation

to a subsequent study in professional athletes to quantify the energy expenditure and energy intake during activities of daily living and high intensity training for Australian football. Consequently, our study design enabled us to compare daily EI and EE across a periodized in-season week utilizing an unobtrusive accelerometer with low participant burden to capture sampling periods of shorter duration than those provided by other studies which employed doubly labelled water. Very little research has been conducted that quantifies energy expenditure with adequate precision concomitant with high ecological validity in professional sport. Our experimental approach to the problem of determining the daily fuel for the work required in training and competition, and potential deficiencies in matching energy intake to expenditure in professional footballers, is highly relevant to practitioners working with team sport athletes.

Subjects

Twenty-four professional Australian Football athletes (age 22 ± 1 y, height 1.89 ± 0.1 m, weight 87 ± 8 kg, sum of seven skinfolds,³⁰ 37 ± 5 mm) volunteered to participate in the study to determine the energy expenditure and intake during a 7 d competition period. Fourteen players completed the study (age 24 ± 4 y, height 1.87 ± 0.08 m, weight 86 ± 10 kg, sum of seven skinfolds 37 ± 5 mm). Reasons for withdrawal were: injury before or during data collection ($n=3$); omission from game selection ($n=4$); or technical failure during data collection ($n=3$). Each 7 d data collection period during the preseason competition was the same as a typical in-season match week, consisting of a recovery session, a cross training session, a skills and strength day, main training and strength day, a player directed pre match session and a match day (Table 1). The observation week to which each player was allocated was dependent on player match selection by the coaching panel during the four-week preseason competition period. Ethics approval was obtained through Bond University Human Research and Ethics Committee (16204). All participants provided written informed consent prior to participation.

Procedures

GeneActiv tri-axial accelerometers (Activeinsights Limited, Kimbolton, Cambridgeshire, UK) were used to obtain data 24 h/d for seven consecutive days without removal during the experimental period (Table 1). The GeneActiv accelerometers recorded data at a rate of 100 Hz. This device is an unobtrusive wristwatch, which can be worn during field training, matches and recovery sessions and is therefore suitable for use in Australian football, and does not disrupt sleep patterns. The activity data bands are defined for sleep (<1.5 METS), light intensity (1.5-3.99 METS), moderate intensity (4-6.99 METS) and vigorous physical activity (>7 METS). The technical reliability for the GeneActiv tri-axial accelerometer (n=47) has been previously reported as an intra- and inter-device coefficient of variation of 1.4% and 2.1%, respectively, with a correlation coefficient of $r=0.98$ ($p<0.001$) over 15 different frequency and acceleration conditions.¹⁷

In a separate sub-study, we recruited 14 sub-elite male AFL football players (age 23 ± 4 y, height 1.83 ± 0.06 m, body mass 82 ± 9 kg, VO_2 peak 56 ± 3.7 mL/kg/min) to undertake an incremental exercise test on a treadmill with gas analysis using a Parvo Medics True One 2400 metabolic cart (Parvo Medics Utah, USA) whilst wearing the GeneActiv on their left hand. Prior to the test, participants were weighed and height was measured before completing a self-selected warm up. Three $\times$ five min stages at nine, 12 and 15 km/h were undertaken followed by a ramped increase of one km/h every minute until volitional fatigue. Energy expenditure for indirect calorimetry was recorded from a 60 s VO_2 plateau achieved between minutes 3-5 of each steady state stage, and the highest 60 s average obtained during the ramp stage.

The software Cobra (University of South Australia) was used to plot the GeneActiv $g\cdot min^{-1}$ with indirect calorimetry plateau for matched 60 s epochs. A regression equation for the prediction of EE across a range of exercise intensities using GeneActiv accelerometers was derived (Figure 1). The VO_2 data was converted into METs using the following equation.²⁰

$METS = \frac{VO_2(mL/kg/min)}{3.5}$. METs were then converted into kilojoules. Prior to the commencement of this sub-study, participants provided their written informed consent and ethics approval was obtained through the University of South Australia Human Research and Ethics Committee (200984).

After completion of the 7 d data collection during the experimental period of AFL training and competition the data collected by the GeneActiv accelerometers was downloaded onto the analysis platform provided by Activeinsights LTD (version V.3.2, United Kingdom). The regression equation from the sub-study was then used to calculate EE during all field training sessions undertaken in the experimental period. Given the limited data available on the capacity for accelerometers to estimate EE during resistance training, 5 MET.mins⁻¹ was applied to resistance training sessions.^{1, 35}

A triple-pass 24 h food recall¹⁴ conducted by an accredited practicing dietitian was used to quantify dietary intake following each day of accelerometry data collection. Dietary intake was analyzed using Foodworks (Xyris software, version 9, Australia) to determine total energy and macronutrient intake over the 7 d period and data was then compared to values outlined in the current Position Stand of the Academy of Nutrition and Dietetics, Dietitians of Canada, and the American College of Sports Medicine recommendations for athletes.³² Specifically, calculated daily recommended values were 4 g/kg carbohydrate for low training load or recovery days (days 1 and 5), 6-11 g/kg carbohydrate for higher training load, match preparation or match days (days 2-4, 6 and 7), 1.8-2 g/kg protein per day, and <30% daily contribution to total energy from fats. Energy availability was calculated as energy intake minus expenditure and expressed relative to fat free mass (kJ/kg/d) derived from skinfold measurements.

Statistical Analysis

Residuals from the GeneActiv validation data were plotted for visual inspection of appropriateness of linear regression. EE and EI data were analysed using two way repeated measures analysis of variance (EI vs. EE, macronutrient intake vs. recommendations) with Bonferroni post hoc tests (Prism Version 7.0d). The level of significance was $p < 0.05$ and data were presented as mean $\pm$ standard deviation. Cohens d statistics were obtained using JASP software (Version 0.9.1.0, University of Amsterdam), and interpreted using accepted threshold values: 0.2 small, 0.5 moderate, and 0.8 large effects¹³

Results

GeneActiv validation

There was a significant relationship between metabolic equivalents calculated via indirect calorimetry and GeneActiv $\text{g} \cdot \text{min}^{-1}$, and the standard error of the estimate of the GenActiv for calculating metabolic equivalents during exercise was 1.77 METs ($r^2 = 0.64$, $p < 0.0001$; Figure 1). The regression equation was: $y = 0.001x + 4.4329$. Where y represents metabolic equivalents and x is GeneActiv $\text{g} \cdot \text{min}^{-1}$. Residuals plot showed non-homogenous variability with random dispersion around the horizontal axis indicating a linear regression model was appropriate (Figure 2).

Energy intake vs expenditure

EI ranged from 73-316 kJ/kg/d and EE from 84-362 kJ/kg/d during the 7 d experimental period, with a mean daily energy intake and expenditure of 154 ± 40 kJ/kg/d (13359 ± 1917 kJ/d) and 178 ± 26 kJ/kg/d (15332 ± 2836 kJ/d), respectively (Figure 3A). The highest mean relative EI occurred on match day (199 ± 40 kJ/kg/d, 17083 ± 3280 kJ/d) but the highest mean EE occurred on day 4 (225 ± 42 kJ/kg/d, 19313 ± 3072 kJ/d). Lowest mean EI and EE occurred on day 1 which

was the only day where EI exceeded EE but the difference was trivial (EI 136 ± 30 kJ/kg/d, 11651 ± 2504 kJ/d and EE 134 ± 32 kJ/kg/d, 11594 ± 2992 kJ/d $d = 0.03$; Figure 3A). There was a large effect for mean difference between EI and EE, which was -24 kJ/kg/d (-1973 kJ/d; $p < 0.05$; $d = -0.9$) throughout the 7 d experimental period. However, only days 3 and 4 showed a significant difference (day 3: EI 137 ± 31 kJ/kg/d, 11763 ± 2646 kJ/d and EE 186 ± 14 kJ/kg/d, 16018 ± 1973 kJ/d $p < 0.05$, $d = -1.4$; day 4: EI 179 ± 44 kJ/kg/d, 15413 ± 3960 kJ/d and EE 225 ± 42 kJ/kg/d, 19313 ± 3072 kJ/d; $d = -0.7$), with a moderate effect evident on match day (EI 199 ± 40 kJ/kg/d, 17083 ± 3280 kJ/d and EE 224 ± 12 kJ/kg/d, 19339 ± 2569 kJ/d; $d = -0.5$). The calculated energy availability of each day where exercise occurred was low (day 1: 181 ± 38 kJ/kg/d, day 2: 193 ± 59 kJ/kg/d, day 3: 59 ± 42 kJ/kg/d, day 4: 80 ± 84 kJ/kg/d, day 5: 189 ± 59 kJ/kg/d, day 6: 185 ± 67 kJ/kg/d and match day: 76 ± 50 kJ/kg/d). When data were expressed as percentage macronutrient contribution to daily EI, carbohydrates were consistently highest in energy contribution (35-50%), with moderate contributions from protein (20-25%) and fats (25-40%) (Figure 3B).

Carbohydrate

Carbohydrate intake (CI) ranged from 1.5 g/kg/d to 8.5 g/kg/d between participants with a mean daily intake of 3.8 ± 0.8 g/kg/d over the 7 d period. Lower than recommended daily carbohydrate intake (CR) occurred on five of seven days ($p < 0.05$) but intake was not different from athlete dietary CR on day 1 and 5 (Figure 4A). The highest average carbohydrate intake occurred on match day (5.5 ± 1.0 g/kg/d). Large effect size for difference between CI and CR was evident on all days except day 5 where a moderate effect was shown. The average difference when daily CI was compared to CR was -0.8 g/kg/d on day 1 ($d = 1.0$), -2.8 g/kg/d ($p < 0.05$; $d = 1.6$), -4.7 g/kg/d ($p < 0.05$; $d = 4.1$), -5.5 g/kg/d ($p < 0.05$; $d = 2.4$), -1 g/kg/d ($d = 0.6$), -7.2 g/kg/d ($p < 0.05$; $d = 4.5$) on days 2-6 and -5.5 g/kg/d ($p < 0.05$; $d = 1.7$) on match day.

Protein

Protein intake (PI) met protein recommendations (PR) on each day of the 7 d experimental period with the exception of day 6, but the low protein intake on day 6 (1.7 ± 0.5 g/kg/d) was not statistically different from the minimum daily PR of 1.9 ± 0.1 g/kg/d (Figure 4B). Individual PI ranged from 0.9 g/kg/d-3.8 g/kg/d, with a mean intake of 2.1 ± 0.1 g/kg/d across the 7 d experimental period. PI was higher on day 2 (2.1 ± 0.7 g/kg/d; $d = -0.3$) and day 5 (2.2 ± 0.6 g/kg/d; $d = -0.4$), compared with PR values, but was significantly higher on day 4 (2.7 ± 0.4 g/kg/d; $p < 0.05$; $d = -2.1$) and match day (2.4 ± 0.4 g/kg/d; $p < 0.05$; $d = -1.0$).

Fat

Average fat intake (FI) of participants ranged from 0.4 g/kg/d to 3.2 g/kg/d with a mean daily intake of 1.4 ± 0.2 g/kg/d over 7 d. When compared to the fat intake recommendation (FR) (30% of EI) which was calculated as 1.1 ± 0.2 g/kg/d to 1.8 ± 0.5 g/kg/d throughout the 7 d experimental period, FI was not different from the recommended upper limits of contribution to energy on any day. However, FI was highest on day 5 (FI 1.6 g/kg/d, FR 1.3 g/kg/d; $d = -0.4$; Figure 4C). Match day was the only day to show a moderate effect size but failed to reach statistical significance ($d = 0.7$).

Discussion

This study compared energy balance across a 7 d period during AFL competition. We report (1) the GeneActiv accelerometer provides effective utility to estimate daily EE within an elite Australian Football population with additional metabolic calibration for moderate-high running speeds (2) there is a reasonable periodization of daily EI in professional Australian Football athletes that fails to match EE on days when multiple training sessions are scheduled, and (3) periodization of daily carbohydrate intake of Australian Football athletes is limited and often

lower than current dietary recommendations for athletes, but daily protein and fat intake is typically adequate when compared with recommendations.

Studies in athletes routinely present energy balance data averaged over several days or a specific competition period and often suggest athletes fail to meet energy requirements.^{5, 22} However, such an approach does not provide the temporal resolution to implement daily strategies with the potential to enhance the quality of training and performance or improve management of body composition.^{9, 19} We employed the use of the GeneActiv accelerometer to estimate EE due to its capacity to integrate daily (24 h) activity in an unobtrusive manner. There is a paucity of data on the energy demands of training and competition for an elite AFL athlete and our findings provide new information on the daily estimated EE for a typical in-season AFL training week. Indeed, our data are in general agreement with Walker and colleagues (2016) who report EE of ~18504 kJ and ~19160 kJ for an AFL main training day and match day, respectively.³⁴ Despite the highest EI occurring when energy demand was highest on main training and match day, intake lacked precision in matching EE. Whether there was an intent from players to periodize EI to EE in response to changing daily training loads remains unclear. Nonetheless, daily EI in the current study varied, and as EE increased it was evident EI did not meet estimated energy requirements on days with multiple training sessions.

Interestingly, on days where higher training loads were prescribed (days 3 and 4) the data shows EI was different compared to expenditure but this did not occur on match day which had similar EE to day 4. Time constraints and food availability/access between training sessions, and/or exercise-induced appetite suppression may be plausible reasons for greater energy deficit on days with higher training loads.^{6, 31} Ensuring EI meets or exceeds expenditure on training days with high energy demands, particularly those including resistance training, could be an important strategic goal if maximal anabolic responses are desired.^{3, 32} Alternately, days of lower energy demands may provide an opportunity to manipulate total (weekly) EI

which may be important for a specific 7 d period where athletes are attempting to generate a positive energy balance for body composition purposes.

Our findings are consistent with previous Australian Football studies reporting low mean daily intakes of carbohydrate (4.5 g/kg) and data from other sports, where intakes fail to meet carbohydrate recommendations.^{7, 10, 16, 24, 27} Whilst the pattern of carbohydrate intake partially reflected changes in EI from one day to the next, there was a large disparity in carbohydrate intake compared with the recommendations.³² Carbohydrate intakes are routinely manipulated to achieve athlete performance goals and the recommended carbohydrate intake can range from 4-5 g/kg/d on days with no/minimal training up to 8-12 g/kg/d on days where training load is moderate to very high such as day 3, 4 or match day in the current study.^{21, 25} Moreover, there was limited periodisation of carbohydrate intake to provide 'fuel for the work required' and intake appeared largely inadequate on higher training load days, at least compared with a periodized dietary protocol.²³ The reasons for negligible increase in carbohydrate intake on days 3 and 4 are likely similar to those impacting total energy intake.⁶ However, it is important to note the significant deficit in EI compared with EE on days where both field and resistance training sessions occurred could also be related to gastrointestinal discomfort. This additional factor has potential to limit carbohydrate intake during and after exercise and restrict the associated daily EI with multiple sessions on high volume training days. Regardless, our data provide new information related to the suitability of a professional Australian Football athlete cohort's carbohydrate intake versus recommendations for intermittent, high intensity team sports.

To optimize performance capacity and recovery of elite athletes the periodization of energy and nutrients equivalent to daily training load EE is recommended. While limitations of indirect estimates of EI and EE exist, particularly during short periods such as several hours or individual days, new information from elite athlete cohorts is invaluable to better understand the demands of high-performance sport. Our sub-study provides a regression equation for high intensity running using an unobtrusive method which indicates the GeneActiv provides

acceptable precision during high intensity exercise and may provide reasonable estimates of EE that integrates daily (24 h) free living and training/competition periods in team sport athletes. However, further work is required to enhance the precision of estimates of energy expenditure.

Conclusion

The present study shows that when energy and nutrient intakes are quantified into daily proportions the highest daily energy demands necessitate greater EI. The present Australian Football athlete cohort appeared unable to meet their daily estimated energy requirements on days where training demands were high. The modest daily carbohydrate intake was below sports nutrition recommendations on most training days and carbohydrate contribution to total EI reported in the present study has potential to compromise team sport exercise capacity in training and competition.

Practical implications

- Specific dietary strategies appear to be required if team sport athletes are to consistently achieve an energy balance and appropriate macronutrient distribution, particularly on days with high training loads where athletes undertake multiple training sessions.
- The GeneActiv accelerometer can provide a reasonable estimate of energy expenditure during Australian Football training sessions or competition when additional calibration enhances precision at higher metabolic work rates, which is a useful tool for sports dietitians to provide feedback and dietary education to this athlete population.
- Professional Australian Football athletes may benefit from a greater focus on carbohydrate intake to meet energy expenditure, rather than merely increasing total food intake, when multiple daily training sessions are scheduled.

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387

388 Figure 1. Relationship between metabolic equivalents (METs) and GeneActiv accelerometer
 389 $\text{g}\cdot\text{min}^{-1}$ ($n=56$). METs were determined from oxygen consumption during a treadmill
 390 incremental exercise test of 3×5 min stages at 9, 12 and 15 km/h followed by a ramped
 391 increase 1 km/h every minute until volitional fatigue while wearing the GeneActiv. Data are
 392 plotted with line of identity and 95% confidence intervals.

393

394 Figure 2. Residuals ($n=56$) graphical representation of GeneActiv accelerometer $\text{g}\cdot\text{min}^{-1}$
 395 determined from a treadmill incremental exercise test of 3×5 min stages at 9, 12 and 15 km/h
 396 followed by a ramped increase 1 km/h every minute until volitional fatigue.

Figure 3. Estimated daily relative intake for (A) energy (EI) compared with daily relative energy expenditure (EE) and (B) estimated absolute daily kilojoule intake and contributions of macronutrients carbohydrate, protein, fat and other (fibre or alcohol), to daily energy intake during a 7 day experimental period in elite Australian Football athletes (n=14). Data for energy intake are mean $\pm$ standard deviation and were analysed using two-way analysis of variance with repeated measures. * significant difference vs. energy or macronutrient intake for the corresponding day ($p < 0.05$). CHO, carbohydrate; PRO, protein.

Figure 4. Estimated daily relative intake for (A) carbohydrate (CI), (B) protein (PI), and (C) fat (FI) compared with recommendations for carbohydrate (CR), protein (PR) and fat (FR) intake from the Academy of Nutrition and Dietetics, Dietitians of Canada, and the American College of Sports Medicine, during a 7 day experimental period in elite Australian Football athletes (n=14). Data are presented as mean $\pm$ standard deviation relative to body mass and were analysed using two-way analysis of variance with repeated measures. * significant difference vs. macronutrient intake for the corresponding day ($p < 0.05$).