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Seasonal health tracking of Australian Football League Women’s athletes

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ABSTRACT

Background: Studies evaluating the dietary intake of Australian Football League Women’s (AFLW) athletes are few and limited to the preseason. This prospective observational study aims to evaluate seasonal changes in dietary intake and health parameters of professional AFLW athletes.

Methodology: Dietary intake (3-day weighed food records), body composition (bioelectrical impedance analysis, skinfolds), physical performance (global positioning system, GPS), and iron status (fasted blood sample) were assessed in 19 athletes (24 ± 5 years, 170 ± 6 cm, 22.8 ± 2.1 kg/m^2) at three timepoints: start of preseason, end of preseason, and end of competition season. Sociodemographic information, sports nutrition knowledge (SNK), and risk of low energy availability (LEA) questionnaires were completed at the start of preseason.

Results: Mean daily energy and carbohydrate (CHO) intakes were lower than recommendations across all seasons ($p < 0.05$). Mean daily CHO intake was highest at start of preseason (3.6 g/kg/day), decreased during preseason (3.1 g/day) and remained low during competition (3.2 g/day); >80% of players did not meet minimum recommendations at each timepoint (all, $p < 0.05$). The sum of seven skinfolds and fat mass (%) decreased during preseason (both, $p < 0.05$). Serum iron fell within recommended ranges for 95% of athletes at all timepoints. The total distance (m) and number of Very High Intensity (>21 km/h) efforts significantly increased across preseason and decreased during competition (all, $p < 0.05$). Nutrition knowledge was ‘poor’, and 42% of athletes were at risk of LEA.

Conclusions: AFLW athletes do not meet energy and carbohydrate requirements across the preseason and competition seasons, which may impact health and performance if deficits are sustained.

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KEYWORDS
Body composition; diet; global positioning system; team sport

Introduction

The establishment of a professional competition for female Australian Football (AF) players in 2016 (the Australian Football League Women’s, AFLW) has increased female participation across all levels and ages, from grassroots to elite (Willson et al. 2018). Up until 2022, the AFLW competition season was played during the Australian summer, consisting of nine rounds, with an additional 3–4 weeks for finals. Australian football requires high aerobic endurance as well as anaerobic power to accommodate for the frequent high-intensity efforts and long distances covered in a game (Thornton et al. 2020, 2020; Clarke et al. 2021). Athletes’ preparation, termed preseason, begins several months prior to competition. Typically, higher training volumes are recorded in preseason compared to competition (Moreira et al. 2015; Bilsborough et al. 2016; Thornton et al. 2020) when training volume is often tapered to allow for peak athletic performance on game days (Bilsborough et al. 2016; Thomas et al. 2016); however, data on AFLW athletes are limited.

Training volume and intensity, which vary across seasons, largely determines the energy and nutritional needs of athletes (Bilsborough et al. 2016; Thomas et al. 2016). Optimal nutrition ensures athletes consume sufficient energy and nutrients (carbohydrates and protein) to sustain exercise at higher intensities, facilitate recovery, and support general health and well-being (Mountjoy et al. 2018). The role of nutrition and its benefits for athletic performance have been acknowledged by various academic societies who have developed nutrition recommendations based on the intensity of activity (Thomas et al. 2016; Kerksick et al. 2018). However, the appropriateness of applying these intensity-based recommendations to sports such as AFLW, is yet to be determined, particularly because athlete requirements may vary depending on physical characteristics and role within that sport (e.g., ruck vs mid-fielder). Generally, macronutrient (carbohydrate, protein, and fat) recommendations are not sex-specific and instead are dependent on an athlete’s body weight (expressed in g/kg of body mass/day or as a percentage of total energy intake) (Thomas et al. 2016). However, certain micronutrients (e.g., iron, calcium, and vitamin B-12) require special consideration in females (Thomas et al. 2016) due to menstruation and potential favouring of dietary preferences that are lower in energy and devoid of animal foods (Cialdella-Kam et al. 2016; Rogerson 2017; Lis et al. 2019). Athletes favouring a low-energy diet for a sustained period of time may experience performance decrements due to

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The study was designed by all authors. CO collected the data. AMH and CO analysed the data. AMH, EM, and BS assisted with data interpretation. CO drafted the manuscript and all authors revised and approved the final manuscript.

the early onset of fatigue (Kerksick et al. 2018) particularly during prolonged and high-intensity activity. Furthermore, low energy diets may lead to decreases in body weight and fat-free mass, and accentuate complications related to pre-existing micronutrient concerns (iron, calcium), increasing the risk of developing symptoms related to Relative Energy Deficiency in Sports (Rogerson 2017; Mountjoy et al. 2018).

To date, only two studies have assessed the dietary intakes of AFLW athletes during a single preseason training week (Condo et al. 2019; Jenner et al. 2019). Both studies reported that AFLW athletes did not meet energy or nutrient requirements (carbohydrate, iron, and calcium) (Condo et al. 2019; Jenner et al. 2019). It is unknown whether these inadequacies continued during the competition season or if they resulted in detrimental health changes, such as iron deficiency anaemia. While some studies involving AFLW athletes have evaluated nutritional intake and Sports Nutrition Knowledge (SNK) (Condo et al. 2019), no study has evaluated additional health parameters (body composition, iron status) nor seasonal changes in these athletes.

Therefore, this study aimed to 1) assess the adequacy of energy and nutrient intakes across seasons by comparing to established recommendations (Schofield 1985; National Health and Medical Research Council 2006; Thomas et al. 2016) 2) evaluate changes in health parameters (iron status, anthropometry, and physical performance) across seasons, and 3) evaluate SNK and risk for low energy availability (LEA), in AFLW athletes.

Methods

A squad of 30 AFLW athletes contracted to one club for the 2020/21 season were approached for this cross-sectional observational study. Sociodemographic information, SNK, and risk of LEA were assessed at the beginning of preseason only. Iron status, anthropometry, GPS data, and dietary intake were assessed at three timepoints: start of preseason, end of preseason, and end of competition season. The study was approved by the University of South Australia Human Research Ethics Committee (203272) and the club's General Manager of Football Operation and included COVID-safe practices for data collection. However, due to the strict South Australian public health regulations in place at the time, the State had few active cases; training and game participation were generally consistent with those of previous seasons. Athletes provided informed consent to participate prior to data collection.

Age, employment status, living arrangements, diet preferences, and playing experience were self-reported in an online questionnaire. Sports nutrition knowledge was determined using the nutrition for sport knowledge questionnaire (NSKQ) (Trakman et al. 2017) which has been validated using Rasch analysis, which involved a combination of classical test theory and item response theory techniques. The NSKQ has strong construct validity ($p < 0.001$), excellent test–retest reliability ($p = 0.92$, $p < 0.001$), is quick to administer, easily accessible online and has been used previously with AFLW athletes (Jenner et al. 2020). Achievement was classified according to the following scoring system: <50% = poor, 50–65% = average, 66–75% = above average, and >75% = excellent. Risk of LEA was assessed using the low energy availability in female questionnaire (LEAF-Q) (Schofield 1985) and has previously been used to detect risk of LEA in AFLW athletes (Condo et al. 2019). The LEAF-Q is brief, easy to administer, and has acceptable sensitivity (78%) and specificity (90%) to enable early detection of LEA in female athletes at risk of RED-S (Melin et al. 2014). The LEAF-Q was scored using a scaling system which allocated a number (usually between 0–4) depending on the severity (or abnormality) of the athlete's response. A score of 8 or above indicates 'at risk' of LEA.

At each time point, athletes provided a fasting (minimum 8 h overnight) venous blood sample which was sent to Clinpath Pathology for iron status (serum iron, transferrin, transferrin saturation, and ferritin). Height was measured in duplicate to the nearest 0.1 cm using a Mobile Stadiometer (SECA-217, Hamburg, Germany). Body mass (kg) and percentage body fat were measured in duplicate using a portable Bioelectrical Impedance Analysis (BIA) scale post-void (Tanita Ultimate Scale 2000, Tokyo, Japan). A third measure was taken if values differed by more than 0.5 units. All measures were averaged. Skinfolds (biceps, triceps, subscapular, supraspinale, abdominal, thigh, and calf) were taken by an accredited anthropometrist (BS, Level 1) according to the International Society for the Advancement of Kinanthropometry guidelines as part of routine performance-based measurements using Baty International Harpenden Skinfold Calipers to the nearest 0.1 mm. Physical performance was captured using Global Positioning System (GPS) monitors. Global positioning system measures have become the most practical method used by most, if not all, AF clubs for tracking athlete training and game volumes (Walker et al. 2016). GPS monitors were worn in a small pocket inside athletes' playing guernseys, positioned on the upper back between the shoulder blades. As a protocol was already in place to capture physical performance using GPS monitors for all trainings and games, we used these data (analysed using Catapult Sports software, version 3.3) to reduce athlete burden. Total distance covered (m), distance covered during Very High-Intensity Running (>21 km/h, VHIR), and number of VHIR efforts were selected to reflect athlete's training volume.

Dietary data were collected using 3-day weighed food records on non-consecutive days over 1 week, including two weekday trainings and one non-training weekend day. Athletes received written and verbal instructions on how to record their intake using the 'Easy Diet Diary' (EDD) smartphone application (Xyris Software) or a pen and paper template. Athletes took 'before' and 'after' photos of foods they found difficult to quantify or meals they had not prepared themselves (e.g., restaurant meals and takeaways) alongside a 3 × 3-inch personalised notecard using their smartphones. Diaries were reviewed for completeness during a one-to-one discussion with athletes. All dietary data were collected and transcribed for each athlete into FoodWorks nutritional software (Xyris Software, version 10, Highgate Hill, Australia). Food/fluid items not found in the FoodWorks database were substituted for products with similar nutritional composition. FoodWorks provided an estimate of daily energy, macronutrient, and micronutrient intakes.

Statistical analyses were conducted using Stata version 15.0 (StataCorp, 2017) with a significance set at $p < 0.05$. All data are presented as means and standard deviations for the different timepoints (beginning of preseason, end of preseason, and end of competition season). Pearson's Chi-Square and Fisher's exact tests were used to determine the proportion of athletes who met recommendations for dietary intake (energy, macronutrients, and micronutrients) and fell within suggested ranges for iron status (serum iron, transferrin, saturation, and ferritin) at each timepoint. One sample t-tests were used to compare athlete energy and nutrient intakes against their respective recommendations (Schofield 1985; National Health and Medical Research Council 2006; Thomas et al. 2016). Estimated energy requirements were determined using the Schofield equation (Schofield 1985) and multiplied by a physical activity level (PAL) of 1.6 and 2.0 based on females with a 'moderate' PAL from previous studies, and nutrient requirements were derived from nutrient reference values (NRV) (National Health and Medical Research Council 2006; Thomas et al. 2016). A linear mixed-effects model was used to assess changes in iron status, anthropometry, GPS data, and dietary intake over the season. Paired t-tests determined differences in energy intake on training and non-training days. Independent t-tests determined differences in energy intake between players with different levels of playing experience at the elite level (AFLW) (1–2 years vs. 3+ years), SNK (<50% = poor vs. ≥50% = average), and risk of LEA (≥8 'at risk' vs. <8 'not at risk'). A Pearson's correlation determined the relationship between total distance and energy intake on training days. Effect sizes (Cohen's *d*) were calculated to determine the magnitude of the difference between time points.

Results

Twenty-two athletes enrolled in the study. Three athletes withdrew prior to data collection, resulting in 19 athletes who participated in the study (24 ± 5 years, 170 ± 6 cm, 22.8 ± 2.1 kg/m^2). A further three athletes withdrew as detailed in Figure 1. Questionnaires completed at the start of preseason had a 100% completion rate ($n = 19$); however, other data were unable to be collected at various stages throughout the study (Figure 1).

Most athletes were living with others (inc. partner/parents/friends, 95%) and engaged in paid employment (95%). Several athletes ($n = 9$) had previously competed in semi-professional leagues for different teams or individual sports and had three or more years playing in the AFLW competition ($n = 12$). Ten athletes reported having a previous or current health condition (2: asthmatic, 3: gastro-intestinal (GI) disorder (e.g., Crohn's disease), 8: iron deficiency). Six athletes were taking dietary supplements (3: protein powder, 2: iron tablets, 1: probiotics). There were no vegan athletes and one athlete identified as vegetarian. Seven athletes (including the vegetarian) reported dietary modification within the last 3 years; of which three decreased their meat intake due to GI issues ($n = 1$), living situation ($n = 1$) and personal preference ($n = 1$), while others 'ate healthier' to match their energy intake with performance requirements ($n = 4$). The average SNK score was 39, classified as 'poor' knowledge. The highest average scores were achieved in the alcohol sub-section (6/8); the lowest scores were in the supplements (4/12) and micronutrients (4/12) sub-sections. The average score on the LEAF-Q was 7, with 42% of athletes scoring ≥8, indicating risk of LEA.

Transferrin saturation was the only blood-borne marker of iron status to change over time (Table 1). In most athletes (≥90%), serum concentrations of iron, transferrin, percent saturation, and ferritin fell within recommended ranges, yet athletes dietary iron intakes did not meet the recommended NRV (18 mg/day). Body mass and BIA assessed fat-free mass did not change across seasons. However, BIA assessed body fat and sum of seven skinfolds significantly decreased between the start and the end of preseason (both, $p < 0.05$) but returned to preseason start levels by the end of competition (both, $p < 0.05$) (Table 1).

As expected, GPS data varied across seasons. Intensity increased towards the end of preseason with a greater number of VHIR efforts and distance covered during each effort (both, $p < 0.05$). By the end of the competition season, athletes covered less distance and performed fewer VHIR efforts compared to the end of preseason (Table 1).

Table 2 presents dietary intakes (energy, macronutrient, micronutrient) and their respective recommendations (Schofield 1985; National Health and Medical Research Council 2006; Thomas et al. 2016). Across the duration of the study, few athletes (31%) met their minimum estimated energy requirements (PAL 1.6). The average energy intake was lower on training days compared to non-training days, but this difference was not significant (8375 kJ vs 9405 kJ, $p = 0.06$). On average, carbohydrate intakes were significantly lower than minimum recommendations at each timepoint (all, $p < 0.05$); intake decreased between the start and the end of preseason ($p < 0.028$) and remained low across the competition season, as did the proportion of athletes meeting minimum recommendations (starting at 16% and dropping to 0%). Similarly, the proportion of athletes meeting protein, saturated fat and fibre recommendations decreased consistently over time. Across all timepoints, less than 40% of athletes met the recommended dietary intake (RDI) for calcium, less than 5% met the RDI for iron, and less than 30% met the suggested dietary target (SDT) for sodium. However, more than 90% met the RDI for vitamin B-12. The proportion of athletes meeting recommendations for these nutrients decreased over time.

There were no significant differences in energy intake between 'experienced' and 'inexperienced' athletes ($p = 0.079$), those with 'poor' and 'average' SNK ($p = 0.785$), and those 'at risk' and 'not at risk' of LEA ($p = 0.202$). There was a small, but non-significant positive correlation between total distance and energy intake on training days ($r = 0.28$, $p = 0.082$).

Discussion

This study profiled changes in dietary intake and health across different seasons of the AFLW competition, namely preseason, through to end of competition season. Athletes failed to meet daily energy and carbohydrate requirements at each of the three timepoints, with a progressive reduction in intake across the season. This was accompanied by changes in body composition, specifically a reduction in fat mass and skinfold thickness

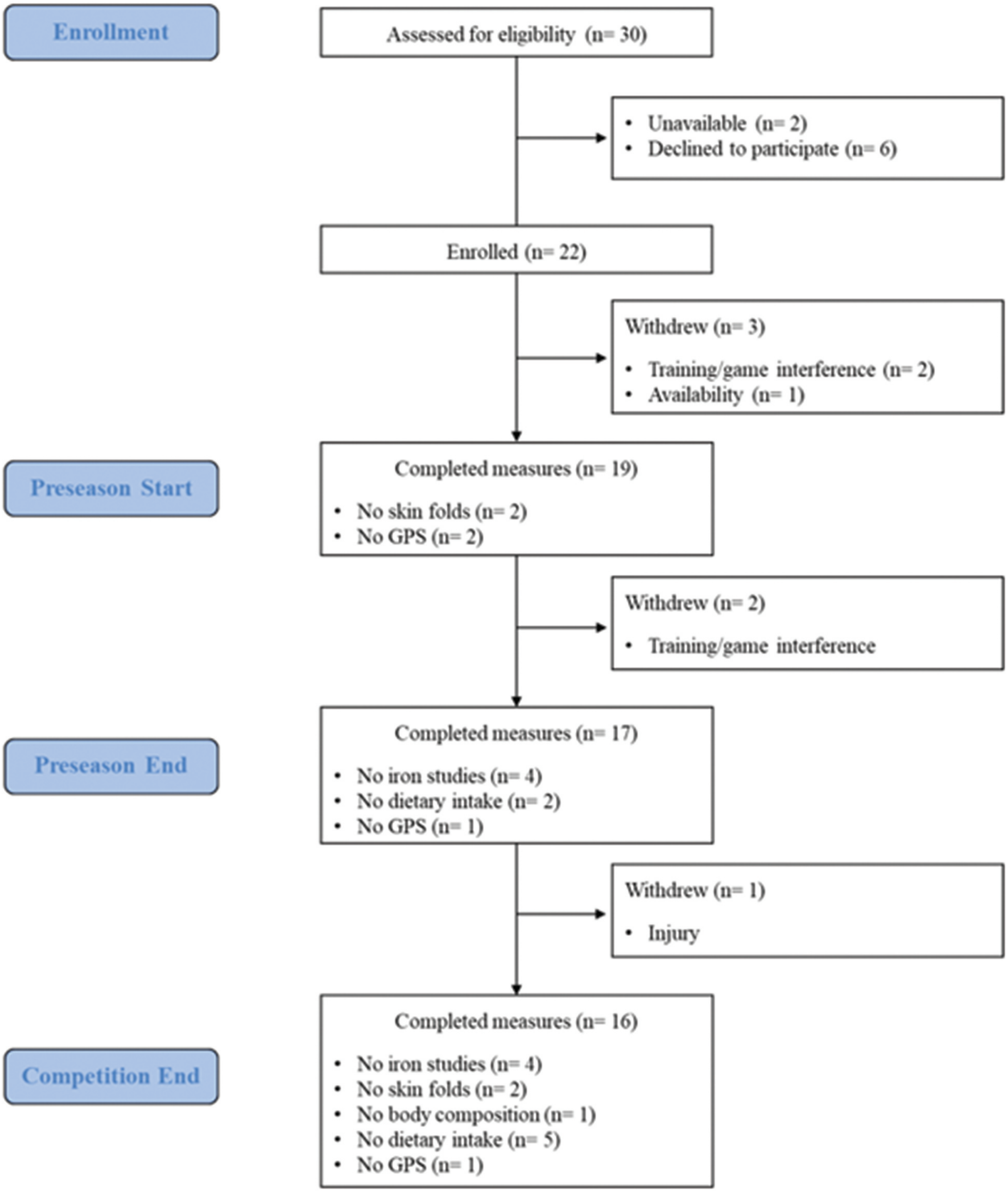

Figure 1. Flow of athlete participation through the study. Figure 1 presents the total number of athletes recruited, and those that withdrew at various stages, with reasoning for withdrawal.

by end of preseason. While athletes' daily protein intake met recommendations at all timepoints, their intakes of key micronutrients (iron and calcium) were below the NRV, which is consistent with previous research on AFLW athletes (Condo et al. 2019; Jenner et al. 2019). Furthermore, 42% of athletes reported sufficient physiological symptoms to be identified as at risk for LEA, causing concern due to its link with RED-S and the negative impacts this has on an athlete's health and performance (Mountjoy et al. 2018). Nutrition knowledge was 'poor' to 'average', which, along with other sociodemographic factors (i.e., high employment status potentially causing athletes to be time poor), likely contributes to the inability of athletes in this study to meet nutritional requirements.

Using GPS technology, athletes were observed to cover greater distances and at higher intensities during preseason compared to the competition season, suggesting seasonal

Table 1. Iron status, anthropometry, and GPS data of ALW athletes across seasons (mean ± SD).

				Preseason Start vs Preseason End		Preseason Start vs Competition End		Preseason End vs Competition End	
Variable (recommended range)	Preseason Start (n = 19)	Preseason End (n = 17)	Competition End (n = 16)	*p*-value	Cohen's *d* [95% CI]	*p*-value	Cohen's *d* [95% CI]	*p*-value	Cohen's *d* [95% CI]
Iron Status	**n = 19**	**n = 13**	**n = 12**						
Serum iron (10 – 30 umol/L)[a]	15±7	18±7	19±7	0.129	-0.4 [-0.9, 7.0]	0.241	-0.6 [-1.6, 6.4]	0.783	-0.1 [-5.0, 3.8]
Transferrin (2.1 – 3.8 umol/L)[a]	2.7±0.4	2.6±0.4	2.8±0.5	0.926	0.3 [-0.2, 0.2]	0.520	-0.2 [-0.1, 0.3]	0.612	-0.5 [-0.2, 0.3]
Transferrin saturation (15 – 45 %)[a]	24±10	32±13	31±12	0.017	**-0.7 [1.5, 15.1]**	0.064	-0.7 [-0.4, 13.6]	0.671	0.1 [-9.3, 6.0]
Ferritin (30 – 220 umol/L)[a]	55±29	57±48	70±41	0.895	-0.1 [-21.0, 24.0]	0.245	-0.4 [-9.4, 36.9]	0.343	-0.3 [-13.0, 37.5]
Anthropometry	**n = 19**	**n = 17**	**n = 15**						
Body mass, kg	66.1±7.0	65.4±6.8	66.4±7.0	0.940	0.1 [-0.6, 0.5]	0.065	0.0 [-0.0, 1.1]	0.061	-0.1 [-0.0, 1.1]
Body fat, %	28.5±3.9	27.4±3.4	28.5±4.0	0.018	**0.3 [-1.5, -0.1]**	0.524	0.0 [-0.5, 0.9]	**0.004**	**-0.3 [0.3, 1.7]**
Fat free mass, kg	47.1±3.1	47.3±3.5	47.3±3.4	0.070	-0.1 [-0.0, 1.0]	0.462	-0.1 [-0.3, 0.7]	0.311	0.0 [-0.8, 0.3]
Sum of 7, mm	69.6±13.6	61.2±15.1	67.1±17.3	**<0.001**	0.6 [-12.2, -4.1]	0.268	0.2 [-6.7, 1.9]	**0.009**	**-0.4 [1.4, 10.0]**
GPS	**n = 17**	**n = 16**	**n = 15**						
Total distance, m	6416±1208	6548±1195	4775±602	0.506	-0.1 [-364.2, 738.1]	**<0.001**	**1.6 [-2245.5, -1169.6]**	**<0.001**	**1.8 [-2462.1, -1326.9]**
VHIR distance, m	290±133	351±108	240±105	**0.045**	**-0.5 [1.3, 111.7]**	**0.038**	**0.4 [-110.7, -3.0]**	**<0.001**	**1.0 [-170.2, -56.5]**
VHIR, no. of efforts	8±4	12±4	9±4	**<0.001**	**-1.0 [2.4, 5.7]**	0.234	-0.3 [-0.6, 2.5]	**<0.001**	**0.8 [-4.8, -1.4]**

[a] *Sourced from Australian Clinical Labs 2022.*

GPS, global positioning system; VHIR, very high intensity running.

Table 2. Dietary intake of AFLW athletes across seasons (mean ± SD).

	Preseason Start (n = 19)		Preseason End (n = 15)		Competition End (n = 11)		Preseason Start vs Preseason End		Preseason Start vs Competition End		Preseason End vs Competition End	
Daily intake (recommendations)	Intake	% met min. rec.	Intake	% met min. rec.	Intake	% met min. rec.	*p*-value	Cohen's *d* [95% CI]	*p*-value	Cohen's *d* [95% CI]	*p*-value	Cohen's *d* [95% CI]
Energy, kJ (9654–12068 kJ/day)[a]	8879 ± 1652*	32	8520 ± 1251*	20	8316 ± 1196*	18	0.360	0.2 [−1088.6, 395.8]	0.166	0.4 [−1417.4, 243.1]	0.579	0.2 [−1417.4, 243.1]
CHO, g/kg (%) (5–10 g/kg/day)[b]	3.6 ± 1.0^ (44%)	16	3.1 ± 1.0^ (42%)	0	3.2 ± 0.5^ (43%)	0	**0.028**	**0.5 [−1.0, −0.1]**	0.062	0.5 [−1.1, 0.0]	0.991	−0.1 [−0.6, 0.1]
PRO, g/kg (%) (1.4–2.0 g/kg/day)[b]	1.9 ± 0.5 (24%)	90	1.6 ± 0.3 (22%)	64	1.4 ± 0.3 (19%)	46	**0.006**	**0.7 [−0.4, −0.1]**	**<0.001**	**1.1 [−0.6, −0.2]**	0.106	0.7 [−0.4, 0.0]
FAT, g/kg (%) (20–35%TEI)[c]	1.0 ± 0.2 (28%)	100	1.1 ± 0.5 (34%)	100	1.2 ± 0.3 (36%)	100	**<0.001**	**-1.1 [2.3, 7.8]**	**<0.001**	**-1.6 [3.3, 9.4]**	0.408	−0.4 [−1.8, 4.5]
SFA, g/kg (%) (<10%TEI)[c]	0.3 ± 0.1(9%)	68	0.4 ± 0.1 (11%)^^	29	0.5 ± 0.2 (14%)^^	9	**<0.001**	**-1.0 [1.1, 3.3]**	**<0.001**	**-2.1 [3.1, 5.6]**	**0.001**	**-1.2 [0.9, 3.5]**
Fibre, g (25 g/day)[c]	29 ± 7	63	24 ± 4	33	21 ± 5**	18	**0.013**	**0.9 [−7.4, −0.9]**	**<0.001**	**1.3 [−10.8, −3.6]**	0.106	0.7 [−6.8, 0.7]
Alcohol, g (20 g/day)[c]	0 ± 1	100	0 ± 0	100	3 ± 5	100	0.610	0.0 [−2.0, 1.2]	**0.007**	**-1.0 [0.7, 4.1]**	**0.002**	**-0.9 [1.0, 4.6]**
Calcium, mg (1000 mg/day)[c]	991 ± 397	37	843 ± 253**	33	804 ± 243**	9	0.058	0.4 [−251.6, 4.2]	0.097	0.5 [−265.4, 22.1]	0.978	0.2 [−143.7, 147.8]
Iron, mg (18 mg/day)[c]	12 ± 3**	5	10 ± 2**	0	10 ± 2**	0	0.051	0.8 [−3.2, 0.0]	**0.006**	**0.7 [−4.3, −0.7]**	0.333	0.0 [−2.7, 0.9]
Sodium, mg (<2000 mg/day)[c]	2516 ± 882^^	32	2412 ± 809^^	33	2567 ± 606^^	0	0.757	0.1 [−410.8, 298.9]	0.975	−0.1 [−392.1, 404.7]	0.763	−0.2 [−343.2, 467.7]
Vitamin B-12, ug (2.4 ug/day)[c]	5 ± 3	95	4 ± 1	93	4 ± 2	91	0.370	0.4 [−1.6, 0.6]	0.769	0.4 [−1.4, 1.1]	0.620	0.0 [−1.0, 1.6]

Significantly lower than minimum EER based on the [a]Schofield equation[15] multiplied by PAL of 1.6–2.0, $p<0.05$; ^significantly lower than the [b]American College of Sport Medicine recommendations[7], $p<0.05$;significantly lower than [c]Nutrient Reference Values[16] (NRV), $p<0.05$; ^^significantly higher than NRV, $p<0.05$.*

CHO, Carbohydrate; EER, Estimated Energy Requirement; PAL, Physical Activity Level; PRO, Protein; SFA, Saturated fat; % met min. rec., proportion of athletes who met the minimum recommendations.

periodisation in workload. Therefore, adjusting energy intake to meet energy expenditure during different seasons, and more specifically on training and game days, is important for meeting nutritional needs and body composition goals (Bilsborough et al. 2016; Thomas et al. 2016; Jenner et al. 2018). However, we did not observe a significant relationship between energy intake on training days and total distance covered during training which suggests that athletes did not adjust their energy intake to meet their changing energy requirements, a finding that has been reported in several other studies involving AF and other team sport athletes (Bilsborough et al. 2016; Heydenreich et al. 2017; Renard et al. 2021; Salagaras et al. 2021). Salagaras and colleagues observed a significant increase in carbohydrate intake across days with increased carbohydrate availability ; however, this did not coincide with periods of greatest workloads (Salagaras et al. 2021). To the best of our knowledge, few studies involving professional team sport athletes, from AF (Routledge 2019; Routledge et al. 2020) rugby league (Bradley et al. 2015) rugby union (Bradley et al. 2015) and soccer (Anderson et al. 2017) have reported adjustments in energy and nutrient intakes in accordance with upcoming workloads. Anderson et al. (2017) suggests that increased scientific research over the years may have contributed to an increase in athlete (and coach) awareness of sports nutrition requirements (Anderson et al. 2017). Indeed, more recent studies show that male AF athletes practice elements of carbohydrate periodisation alongside fluctuations in training load (Routledge 2019; Routledge et al. 2020) and upcoming match days (Routledge 2019). However, Routledge et al. (2020) argues that improvements in carbohydrate periodisation may be an unconscious decision rather than a deliberate choice by the athlete to meet sports nutrition requirements (Routledge et al. 2020).

Energy periodisation, matching energy intake with training volume, across different seasons of the AFLW competition is important for favourable changes in body composition (Bilsborough et al. 2017). Typically, preseason aims to reduce fat mass whilst promoting and maintaining lean mass into the competition season (Thomas et al. 2016; Bilsborough et al. 2017; Kerksick et al. 2018). In the current study, fat mass (assessed via skinfolds and BIA) was lowest at the end of preseason but increased during the competition season. This trend has been observed in male AF athletes (Bilsborough et al. 2017) and other professional team sports athletes (Carling and Orhant 2010; Harley et al. 2011). In the current study, energy and carbohydrate intake remained stable (and below requirements) throughout the seasons. This, coupled with the higher training volume (total distance, VHIR-distance, and number of VHIR efforts) at the end of preseason, likely explains the observed reduction in fat mass. Comparatively, there was a significant reduction in total distance covered during the competition season to prepare for peak athletic performance on game days (Bilsborough et al. 2016; Thomas et al. 2016) and facilitate recovery, with no changes in energy and carbohydrate intakes, likely causing the observed increases in body fat. It may be argued that athletes consumed sufficient, if not more than enough, energy across seasons as evidenced by relatively consistent levels of fat and fat-free mass. Given that energy and carbohydrate recommendations are consistently unmet by female AF (Condo et al. 2019; Jenner et al. 2019) male AF (Anderson et al. 2017; Jenner et al. 2018; Lohman et al. 2019; Salagaras et al. 2021) and other team sport athletes (Jenner et al. 2019) it is possible that these recommendations are set too high.

It is important to recognise that although lower body fat may be desirable in some sporting contexts, it should not be at the expense of other physiological systems (Thomas et al. 2016). While it is difficult to compare our findings to other studies due to differences in sport-based requirements, or reporting of intake at a single time-point only, the literature to date shows female athletes participating in individual and team-based sports (including AF) consistently fail to meet their requirements for energy or carbohydrate (Melin et al. 2014). In addition to potential physical and cognitive performance decrements, such as more rapid onset of fatigue during trainings/games or slower reaction times (Thomas et al. 2016; Kerksick et al. 2018) this can also lead to health consequences associated with LEA.

Forty-two percent of athletes in the present study was at risk of LEA. Low energy availability, the underpinning concept of Relative Energy Deficiency in Sport, is a state of insufficient energy due to over-training or under-fuelling, leaving the body in a negative energy balance, unable to support the range of bodily functions required for optimal health and performance (Mountjoy et al. 2018). Athletes at risk of LEA are of concern due to the range of negative biological, physiological, and psychological effects which can coincide with performance decrements (Mountjoy et al. 2018). Health and performance consequences of LEA are further exacerbated by inadequate intakes of key nutrients supporting bone healths, such as protein, calcium, and vitamin D (Mountjoy et al. 2018). While protein recommendations were met in this study, more than 60% of athletes failed to meet the NRV for calcium from the start of preseason to the end of competition, consistent with proportions reported in previous studies of AFLW athletes (61–66%) (Condo et al. 2019; Jenner et al. 2019). Australian football is considered high-impact physical activity due to the number of collisions during the game (Bilsborough et al. 2016). In combination with low levels of estrogen, common among women suffering from LEA, this may disrupt post-collision bone remodelling processes, resulting in weakened bones and increased susceptibility to injury (Mountjoy et al. 2018). Therefore, compared to their nonathletic counterparts, female athletes should ensure that their intake of calcium meets the NRV to support higher bone density and reduce the risk of bone stress injuries (Mountjoy et al. 2018).

Iron deficiency can contribute directly and indirectly to energy deficiency (Mountjoy et al. 2018). This condition is common among female athletes, typically triggered by a combination of poor iron intake in the diet, menstruation, exercise-induced mechanisms, such as foot strike haemolysis, and/or LEA (Mountjoy et al. 2018). This can lead to fatigue, depression, irritability, and performance detriments including increased injury risk, decreased coordination, muscle strength, and concentration (Thomas et al. 2016). The ACSM recommends female athletes consume more iron than the general population and thus should aim to meet the RDI (18 mg/day) (Thomas et al. 2016). More than 95% of athletes failed to meet the RDI for iron at each timepoint, despite these most athletes (69–100%) fell within the recommended ranges for serum iron, transferrin saturation, transferrin, and ferritin. Similar haematological effects are also caused by vitamin B-12 deficiency (Mountjoy et al. 2018) yet intake for this micronutrient was above recommendations across all timepoints. It is important that athletes are monitored regularly to ensure levels are optimal.

There are many possible reasons why athletes under-consume energy and carbohydrate during training and competitive seasons. Jenner and colleagues found that appetite was suppressed with greater training volume and intensities (Jenner et al. 2021) and other studies have determined gut discomfort influences food choice (Pelly and Thurecht 2019; Thurecht and Pelly 2020). Ninety-five percent of athletes in the present study worked and/or studied, and as they are required to train at night (e.g., during dinner), this leaves little time to prepare and eat meals (Jenner et al. 2021). Consequently, these athletes may choose more convenient foods that are less nutritious (Jenner et al. 2019). AFLW athletes also have less access to professional nutritional support due to their shorter pre- and competition season lengths. The majority (79%) of athletes in this study had ‘poor’ SNK, with the remaining athletes only just meeting the cut-off for ‘average’ SNK. Access to nutrition support and subsequent nutrition education may improve AFLW athletes’ nutrition knowledge (Hull et al. 2016) and their ability to meet energy and nutrient requirements in the future.

To address previously reported limitations in capturing food intake in athletes, we encouraged participants to photograph their meals alongside a standard-sized notecard, which provided a quick, feasible, and reliable method to better quantify serving sizes (Pelly and Thurecht 2019). Although athletes were provided verbal instructions on how to weigh their foods/fluids, athletes were not provided with scales and did not receive written instructions, which may have limited the accuracy of the self-reported dietary information. Access to GPS data increased our understanding of athletes' training volume; however, future studies should consider quantifying metabolic power (and hence estimate energy expenditure). To reduce player burden we used a combination of BIA and skinfolds to assess body composition, however, more sensitive methods may be required to capture small changes in lean mass. While BIA measures were consistently conducted pre-training to account for the expected fluid loss during training, the inclusion of fluid protocols would have assisted in standardising hydration prior to assessment. Although we were limited to a small sample recruited from one AF club, it is similar to that of other studies and reflective of the fact that this was the only professional AFLW team in the state at the time of data collection. Additionally, we did not explore the reasons behind deficits in energy and nutrient intakes, therefore future studies should capture these through qualitative measures.

In conclusion, the present study highlights the importance of regular monitoring of players throughout seasons to identify suboptimal dietary intakes and associated physiological impacts. Practitioners working with AFLW athletes should prioritise access to nutrition support, and subsequent nutrition education to improve athletes’ nutrition knowledge and ability to meet energy and nutrient requirements. The data from this study will contribute to the limited research on elite female athletes and the development of future nutritional interventions.

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