Original Article

The relationship between hourly energy balance and fat mass in female collegiate soccer players

CHRISTIAN E. BEHRENS[1] ✉, ASHLEY DELK-LICATA[1], DAN BENARDOT[2,3], BRENDA M. BERTRAND[1], PAULA C. CHANDLER-LANEY[1], ERIC P. PLAISANCE[1,4], JOSÉ R. FERNÁNDEZ[1]

[1]Department of Nutrition Sciences, University of Alabama at Birmingham, Birmingham, United States of America
[2]Department of Nutrition, Georgia State University, Atlanta, United States of America
[3]Center for the Study of Human Health, Emory University, Atlanta, United States of America
[4]Department of Human Studies, University of Alabama at Birmingham, Birmingham, United States of America

ABSTRACT

Introduction: Soccer athletes have better performance if they maintain low fat mass (FM) relative to fat-free mass. Recent evidence suggests that maintenance of energy balance (EB) is associated with lower FM in athletes. Prior studies have used daily EB rather than hourly, but this approach does not consider duration of time athletes spend in EB versus surplus or deficit. Objective: Test the hypotheses that (1) time spent in EB is inversely associated with FM, and (2) athletes with mean hourly EB in the deficit range have lower FM than those in balance or surplus. Methods: Collegiate female soccer players (n = 20) were enrolled in this cross-sectional study. A 3-day diet/activity record was obtained and analysed to estimate EB in hourly increments. Hourly EB was categorized as: Surplus, > 400 kcal EB; Balance, between ± 400 kcal EB; Deficit, < -400 kcal EB. Total hours spent in each category and mean EB (kcals) was calculated from the 3-day period. Bioelectrical Impedance Analysis was used to derive indices of FM (total FM in kg, % fat, fat mass index). Pearson correlations evaluated associations between FM measures and time spent in each EB category. One-way ANOVA with Tukey post-hoc testing was used to assess differences in FM among athletes stratified into surplus, balance, or deficit based on mean hourly EB. Results: Hourly energy deficit was associated with higher FM compared to energy surplus or balance. Conclusion: Female collegiate soccer players who sustain EB during the day, and limit time spent in energy deficit, had lower FM measures.
Keywords: Body composition; Sports nutrition; Athlete; Sport performance; Diet.

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✉ **Corresponding author.** *Department of Nutrition Sciences, University of Alabama at Birmingham, 1675 University Boulevard, Webb 512. Birmingham, AL 35294-3360, United States of America.*
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INTRODUCTION

According to the American College of Sport Medicine, body composition is an important component of physical fitness and functional performance among most aerobic athletes (Devlin, Kingsley, Leveritt, & Belski, 2017; Mountjoy et al., 2018; Nevill, Holder, & Watts, 2009). Athletes with higher body mass index (BMI) and body mass, due to increased fat mass (FM), have reduced functional performance measures than those with lower BMI and FM (Nicolozakes, Schneider, Rower, Borchers, & Hewett, 2017). Consequently, it is important to identify strategies to optimize body composition in order to improve performance among competitive athletes.

Appropriately structured nutritional intake is a key ingredient for success in competitive athletics. Adequate energy intake meeting energy balance (EB), optimizes performance, assists in macro and micronutrient storage and delivery, and allows for the manipulation of body composition as determined by sport- and position-specific demand. The energy requirements of an athlete are dependent on age, conditioning, athletic goals, and training/competition schedule. These factors can vary greatly from day to day and throughout the macrocycle as changes in training volume occur. Chronic EB deficits may negatively impact BC, performance, and increase health risks due to impaired bone health, menstrual, hematologic, metabolic, or hormonal dysfunction, cardiovascular complications, and psychological distress (Keay, Francis, & Hind, 2018; Mountjoy et al., 2018; Mountjoy et al., 2014, 2015; Rodriguez, Di Marco, & Langley, 2009).

There is an established and growing body of evidence highlighting the importance of sustaining EB during the day to optimize body composition in athletes (Deutz, Benardot, Martin, & Cody, 2000; Hall et al., 2012; Manore, 2013). EB is traditionally thought to be achieved when energy (kcal) consumed is equal to energy (kcal) expended in 24-hour units. Chronic energy surplus over time results in an increase in body weight and fat. Conversely, chronic energy deficit results in a net loss of body mass, with a disproportionately high loss of lean (metabolic) mass as an adaptation to inadequate energy provision (D. Benardot, 1996). Since body tissues steadily expend energy throughout the day, maintaining a state of EB is best achieved when energy from the diet is consumed with sufficient frequency to avoid a catabolic state. In addition to activities of daily living, athletes have sport-related activities occurring at different times during the day, illustrating the need to know when and how to eat before, during, and following training and competition to optimize performance, recovery, and body composition (Mountjoy et al., 2014).

The majority of investigations examining meal frequency and/or EB have obtained and reported data in 24-hour time blocks (Bingham et al., 1994; Ortega, Perez-Rodrigo, & Lopez-Sobaler, 2015). This methodology provides information on daily EB but fails to account for the real-time shifts in EB that lead to inevitable endocrine responses involving hormones known to impact body composition, namely insulin, cortisol, leptin, and ghrelin (Dan Benardot, 2007; Elliott-Sale, Tenforde, Parziale, Holtzman, & Ackerman, 2018; Mountjoy et al., 2018). For example, a pattern of delayed eating followed by a large meal can cause hyperinsulinemia, resulting in increased fat synthesis, and therefore increased FM (Dan Benardot, 2007). It is for this reason that the examination of within-day, hourly EB is important to assure an optimally distributed and customized provision of energy required by each athlete.

The purpose of this study was to examine the association between measures of FM and duration of time spent in energy deficit, EB, and energy surplus in Division I female collegiate soccer players. We hypothesized that athletes who spent more time at or above EB would be associated with lower measures of FM. EB was defined as ± 400 kcals which is roughly in line with the predicted amount of liver glycogen storage and is based on similar previously conducted studies (Deutz et al., 2000; Fahrenholtz et al., 2018;

Melzer, 2011). As a secondary objective, we stratified the cohort into those with mean hourly EB (kcals) in surplus vs. balance vs. deficit and tested the hypothesis that those in deficit would have greater measures of FM than those in balance or surplus.

MATERIALS AND METHODS

Participants

This cross-sectional study was approved by the Institutional Review Board. Participants in the study were given full explanation of the study protocol by study investigators, and each signed an approved written informed consent prior to participation. All participants were NCAA Division I student athletes between the ages of 18 and 21 years and members of a women's soccer team at a university in the Southeast United States. Participants were recruited during the offseason before beginning standard of care nutrition assessments. Participants were healthy and cleared for athletic participation from the Sports Medicine Department. Athletes who were not cleared for active sport participation were excluded from the study. A total of 21 eligible participants were recruited for the study with 20 completing the study protocol.

Study Protocol

At this institution, all student athletes go through an individual nutrition assessment protocol during their respective offseason. For this study, cross-sectional data from an hourly 3-day diet and activity record, and body composition analysis using multi-current, segmental bioelectrical impedance analysis (BIA) were collected from each participant. Eligible participants arrived at the UAB Athletic Training Facility for Visit 1 where they were asked to complete a detailed 3-day hourly diet and activity log. The logs requested extensive detail regarding time of food consumption, food preparation method (e.g., grilled, baked, fried, sauté), quantity consumed, and type and intensity of activity at rest and during exercise. Explicit instructions about completing the daily logs were provided to each athlete by a single licensed Registered Dietitian Nutritionist (RDN). The three collection days included two weekdays and one weekend day. Participants returned to the Sports Medicine Facility for Visit 2 approximately one week after Visit 1. Participants brought completed food/activity records which were reviewed by the RDN for accuracy, completion, and clarity. Participants providing insufficient detail on food intake and/or activity intensity were asked follow-up questions to enhance clarity. Height was measured, without shoes or socks, using a wall-mounted stadiometer with participants in the Frankfurt position(Yuan, Wee Kheng, & Thiam Chye, 2012) and body composition was assessed via BIA for each participant. At the end of Visit 2, participants completed a nutrition and health history questionnaire that contained questions regarding demographics, medical history, athletic-related injury history, and nutrition and health goals.

Diet and Physical Activity Analysis

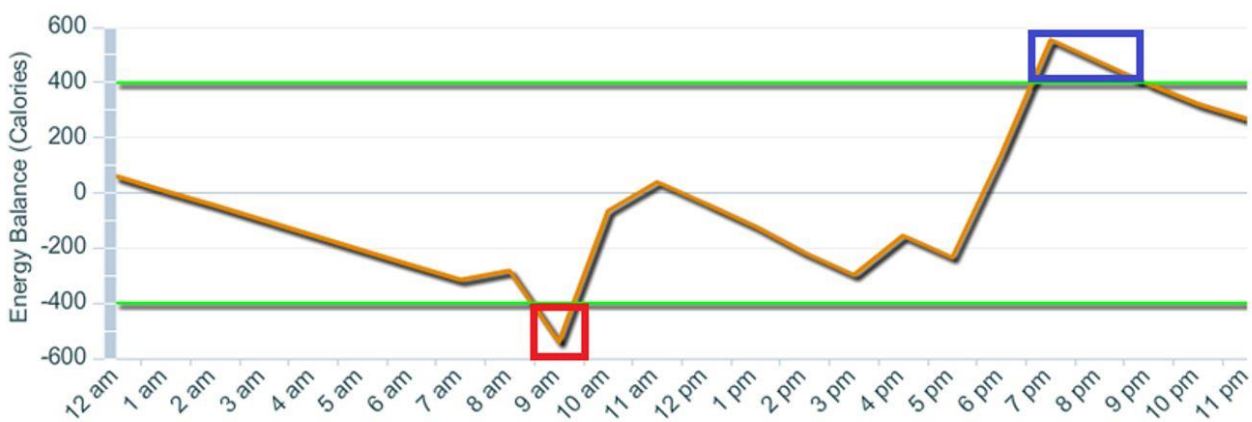
Food and beverage items and physical activity recorded on each completed diet record were entered into the diet analysis software, NutriTiming® (NutriTiming® LLC, Atlanta, GA, USA), an online energy analysis database. NutriTiming® predicts individual resting metabolic rate via the Harris-Benedict equation, accesses the United States Department of Agriculture Nutrient Database for Standard Reference (US Department of Agriculture, 2015) to provide nutritional data for food items, and uses MET-activity descriptions derived from the National Research Council Subcommittee to predict energy expenditure from the physical activity data reported (National Research Council Subcommittee on the Tenth Edition of the Recommended Dietary, 1989). Items not listed under the USDA database were added as new food/beverage items using information obtained from the manufacturer and/or nutrition labels. NutriTiming® provides both 24-hour and hourly energy balance values. Energy expenditure data for NutriTiming® is determined by the Physical Activity Guidelines Advisory Committee of 2008 ("Physical Activity Guidelines Advisory Committee report, 2008. To the Secretary of Health and Human Services. Part A: executive summary," 2009) and the National Research Council Activity of 1989 (National Research Council Subcommittee on the Tenth Edition of the Recommended Dietary, 1989). Hourly energy expenditure is also assessed. Reported activity factors range from "1" (resting) to "7" (exhaustive), using 0.5 incremental increases. Output from NutriTiming® provided data for total energy (kcal) consumed, 24-hour energy balance (ending energy balance), 24-hour energy balance net (calories in less calories out), hours in deficit (EB < -400 kcal), hours in EB (between ± 400 kcal), hours in surplus (EB > +400 kcal), and relative amount of time spent in deficit and surplus.

Body Composition Analysis

Weight was measured and body composition predicted using Tanita MC-780U (Tanita Corp of America, Inc. Arlington Heights, Illinois, USA), a multi-current 8-mode bioelectrical impedance device. This system estimates whole body and segmental body composition (right leg, left leg, right arm, left arm and trunk) and provides body weight, percent body fat, fat mass (kg), fat-free mass (kg), muscle mass (kg) and total body water. All measures were taken with participants in light clothing without socks or shoes.

Outcomes

Several variables were created to describe energy balance and body composition based on food/activity records and BIA. Continuous variables were created to quantify the total number of hours each participant spent in energy surplus (hours > +400 kcals), energy balance (hours between ± 400 kcals), and energy deficit (hours < -400 kcals). An example of hourly EB, which includes energy surplus, balance, and deficit, is illustrated below in Figure 1. An average value for hourly EB in kcals across the collection period was also calculated for each athlete and used to stratify athletes into categories (i.e., energy surplus, balance, and deficit).



Orange line representing energy (Kcal in – Kcal out) at each hour. Green boundaries at ± 400 Kcals representing a state of energy balance. Area in red representing 1 hour in energy deficit (< -400 Kcals). Area in blue representing 2 hours in energy surplus (> +400 Kcals).

Figure 1. Sample output of energy average of three days.

Outcomes from the BIA included body weight and BMI, total fat mass (FM), percent fat, and fat mass index (FMI). FMI was calculated as fat mass divided by height squared (VanItallie, Yang, Heymsfield, Funk, & Boileau, 1990) and was included to account for differences overall body size.

Statistical Analysis

Descriptive statistics, including mean, standard deviation, minimum and maximum, were calculated for all quantitative variables including demographic and anthropometric information, and diet/activity information from 3-day diet and activity recall (calories in/calories out, macronutrient intake) for the 3-day collection period. Pearson correlations were used to evaluate the association between indices of FM and total time spent in energy deficit, balance, and surplus. A one-way ANOVA with Tukey post-hoc testing was performed to evaluate differences in FM across participants stratified into surplus, balance, or deficit groups, based on their mean hourly EB (kcals) across the 3-day period. Significance was set a priori at .05. Data were analysed using SPSS (IBM® SPSS® Statistics, Version 23).

RESULTS

Participant Characteristics: Twenty female collegiate soccer players completed the study. The mean age of athletes in this study was 19 ± 1 years. Athletes were predominately Caucasian (n = 18), with one African-American participant and one Asian-American participant. Descriptive characteristics of the sample are shown in Table 1.

Table 1. Demographic Characteristics of Cohort of NCAA Division 1 Female Soccer Players (n = 20).

Characteristic	Minimum	Maximum	$\bar{x}$ ± SD
Age	18.0	21.0	18.9 ± 1.0
Height (cm)	152.4	185.4	163.9 ± 6.9
Weight (kg)	47.0	81.8	59.0 ± 7.9
BMI (kg/m^2)	18.8	26.4	21.9 ± 2.2
Fat Mass (kg)	5.2	21.6	12.0 ± 4.6
Fat %	10.1	30.1	19.8 ± 5.3
FMI (kg/m^2)	2.0	7.9	4.4 ± 1.6

Energy Balance: Table 2 provides results for energy intake and expenditure. Mean energy intake for the three observation days was 2112.4 ± 504.7 kcals. Mean energy expenditure for the three observation days was 2240.2 ± 271.3 kcals, leaving a mean difference between intake and expenditure of -127.8 ± 504.6 kcals. On average, participants spent 7.0 ± 4.8 hours in energy deficit, 13.9 ± 3.4 hours in energy balance, and 3.1 ± 2.9 hours in energy surplus. Across the entire cohort, the mean hourly EB for the 3-day period was -15.5 kcals ± 545.0. When stratified into EB group, n = 6, 9, and 5, for the deficit, balance, and surplus, respectively. Mean hourly EB for each group were -728.7 ± 229.5, 127.9 ± 155.6, and 582.0 ± 203.5 kcals, respectively.

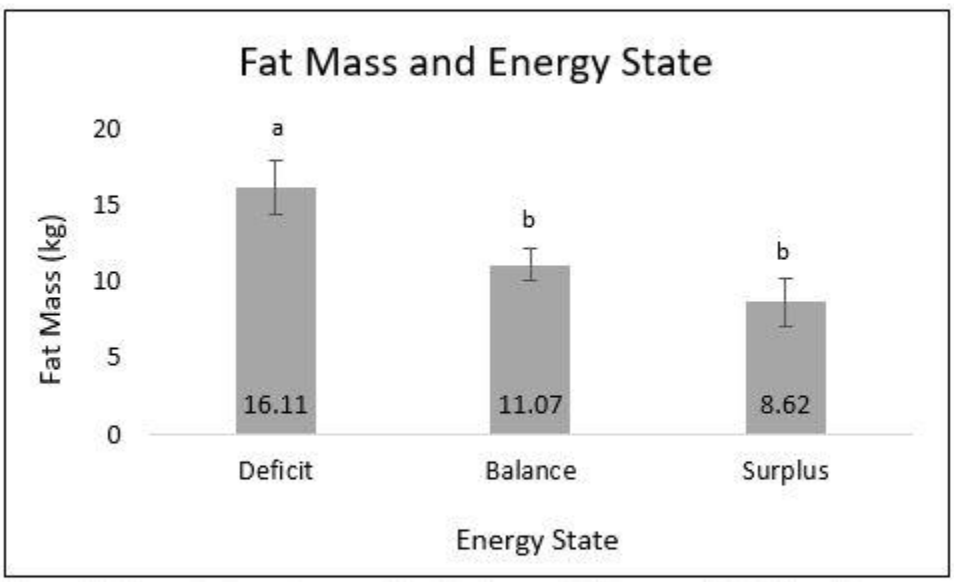
Table 2. Measured Dietary Intake of Cohort of NCAA Division 1 Female Soccer Players (n = 20).

Characteristic	$\bar{x}$ ± SD
Caloric Intake (kcal/d)	2112.4 ± 504.7
Calories Expended (kcal/d)	2240.2 ± 271.3
24 Hour Net (kcal/d)	-127.8 ± 504.6
Protein (g)	100.4 ± 33.9
Carbohydrates (g)	256.4 ± 61.4
Fat (g)	77.1 ± 27.8
% of calories from protein	18.6% ± 4.2
% of calories from carbohydrate	49.3% ± 6.4
% of calories from fat	32.1% ± 4.9

Energy Balance and Body Composition: In this sample, time spent in energy balance and surplus were each inversely associated with BMI and each FM indices (FM, % Fat, FMI). Conversely, time spent in energy deficit was positively associated with all indices of FM (Table 3). When the cohort was stratified into those with a mean EB in surplus, balance, or deficit, some indices of FM differed by group. Specifically, FM (kg) was lower in both the surplus (p = .010) and balance (p = .048) groups compared to the deficit group. Percent fat, FMI, and BMI were significantly lower in the surplus group than in the deficit group (p = .021, .015, and .010, respectively) (Figures 2-5).

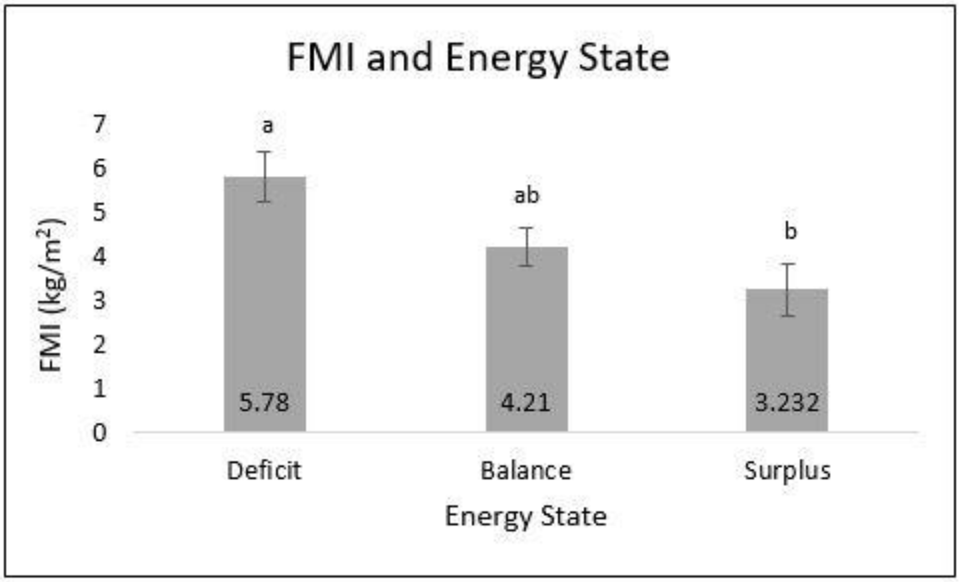
Table 3. Pearson Correlations for time spent in each energy state and body composition in a cohort of NCAA Division 1 Female Soccer Players (n=20).

	Hours in Deficit	Hours in Balance	Hours in Surplus
Fat Mass (kg)	r = .71	r = -.49	r = -.61
	p = < .01	p = .03	p = < .01
Percent Fat	r = .67	r = -.46	r = -.58
	p = < .01	p = .04	p = < .01
BMI (kg/m^2)	r = .61	r = -.38	r = -.56
	p = < .01	p = .10	p = .01
FMI (Fatkg/m^2)	r = .66	r = -.44	r = -.59
	p = < .01	p = .05	p = < .01



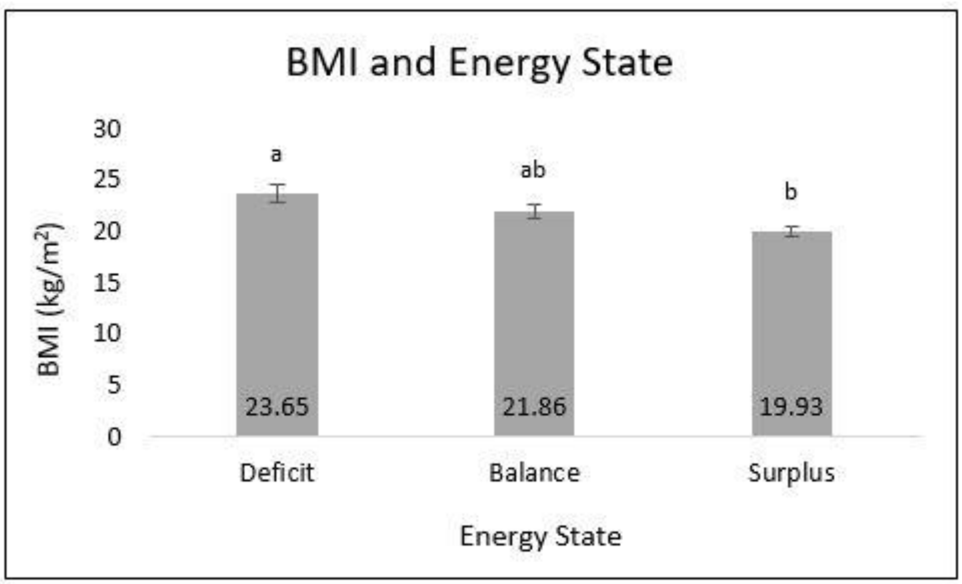
Significant difference in FM between Deficit and Surplus group (p = .010), and Deficit and Balance (p = .048).

Figure 2. Fat mass in Kg and energy state (Surplus, n = 5. Balance, n = 9. Deficit, n = 6).



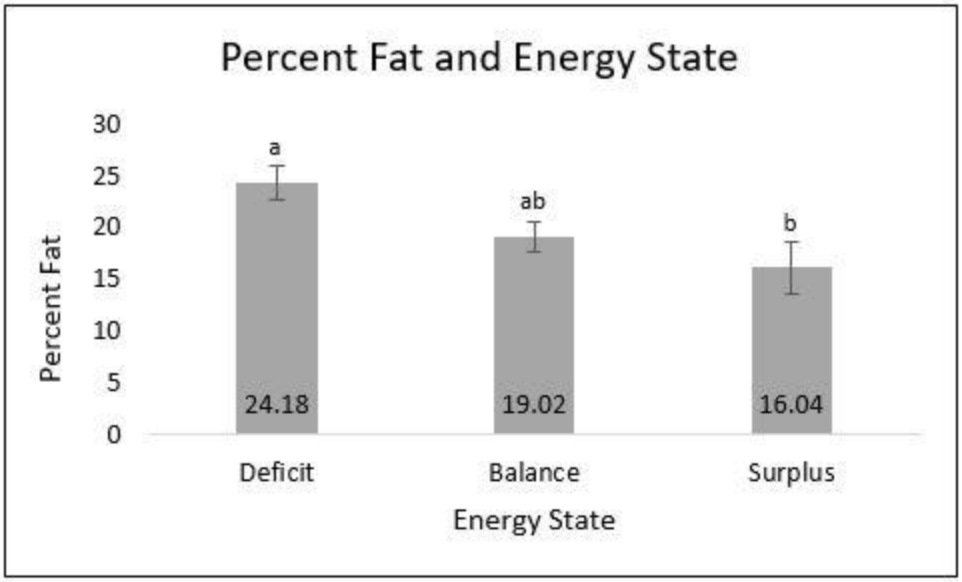
Significant difference in FMI between Deficit and Surplus groups (p = .015).

Figure 3. Fat mass controlled for height, and energy state (Surplus, n = 5. Balance, n = 9. Deficit, n = 6).



Significant difference in FMI between the Deficit and Surplus groups (p = .010).

Figure 4. Body Mass Index (BMI) and energy state (Surplus, n = 5. Balance, n = 9. Deficit, n = 6).



Significant difference in FMI between the Deficit and Surplus groups (p = .021).

Figure 5. Percent fat and energy state (Surplus, n = 5. Balance, n = 8. Deficit, n = 6).

DISCUSSION

The primary purpose of this study was to explore the association between time spent at or above EB and indices of FM for collegiate female soccer players. Results showed that time spent in EB and time spent in energy surplus were each associated with lower measures of FM, whereas time spent in energy deficit was associated with greater measures of FM. Further, when the group was stratified based on the mean hourly EB (kcals rather than time), those with a mean EB in the balanced or surplus range had lower measures of FM than those in the deficit range. To our knowledge, this is the first study to report hourly, rather than daily EB in female collegiate athletes, this is important because hourly reporting provides greater insight toward the pattern of EB across the day. Further, by investigating the duration of time spent in surplus, balance, or deficit, rather than the mean EB, we reduce the risk that the data will be unduly influenced by an unusually large or small meal. Ultimately, assessment of hourly, rather than daily EB will inform the development of tailored interventions to address sub-optimal EB in order to improve performance, recovery, body composition, and the overall health of collegiate athletes.

The majority of studies conducted to date measure energy balance across a 24-hour time period (Bingham et al., 1994; Ortega et al., 2015). The benefit of using this method of assessment lies in what is currently available for reference population recommendations (RDAs, WHO Standards, based on a 24-hour period of intake. Unfortunately, when energy intake is only measured over a 24-hour period, within-day variations in energy balance go unaccounted, which then diminishes opportunities to tailor interventions toward each athletes dietary and activity schedule. Previous studies employing a similar method of hourly EB have focused on the effects of EB on professional athletes and utilized the 24-hour recall technique as a means for diet and activity information collection. The 24-hour recall is a well-established method for collecting data about energy intake (Basiotis, Welsh, Cronin, Kelsay, & Mertz, 1987; Bingham & Day, 1997; Ma et al., 2009), but may be inadequate to capture daily variations in schedule and training, particularly for collegiate athletes who have competing demands from class schedules. Three-day diet/activity records, as used for this study, result in higher quality data collection because participants are instructed to record energy intake shortly after consumption (Schroder et al., 2001; Yang et al., 2010), and to record time periods during which activity took place. With this additional layer of information, comparisons can be made between intake/expenditure at each hour of the day yielding hourly values for energy deficit, balance, and surplus.

Our results show that athletes spending more time in energy balance and surplus had lower measures of FM than those in energy deficit. This finding was also confirmed by secondary analysis, showing athletes with a mean hourly EB in surplus or balance had less FM than those in the deficit. The association of hourly EB with FM in this study is consistent with results of several other studies in non-athletic populations that have illustrated the relationship between energy restriction and/or acute starvation on reduction in metabolic rate and increased fat storage (Deutz et al., 2000; Mulligan & Butterfield, 1990; Saltzman & Roberts, 1995; Schoenfeld, Aragon, & Krieger, 2015; Thompson, Manore, & Skinner, 1993). Additionally, following extended periods of energy restriction, larger amounts of insulin are released in response to energy intake, compared to a fed state resulting in higher fat storage for the same amount of energy consumed (Dan Benardot, 2007; Elliott-Sale et al., 2018; Mountjoy et al., 2015). Consequently, these findings extend the existing literature by showing that both the time spent in energy balance or surplus, and the magnitude of the energy surplus, are associated with measures of FM.

This study was limited by the use of self-report methods to assess energy intake and expenditure. As with other self-report methods, there may be a bias toward underreporting energy intake (Basiotis et al., 1987; Bingham & Day, 1997; Ma et al., 2009; Schroder et al., 2001; Yang et al., 2010). A strength of this study was that participants reported intake on two weekdays and one weekend day, thereby providing better representation of EB across days when schedules differ. Further limitations to this study were participant homogeneity and a small sample, limiting generalizability of these findings. However, to ensure scientific rigor and to account for potential deviations in normality that may arise due to a small sample size, non-parametric correlation and ANOVA analysis were also performed in our statistical analysis producing the same results reported (data not shown).

CONCLUSIONS

Results of this study highlight the importance of considering EB within discrete periods of time that are less than a full 24-hour day to optimize body composition and potentially impact sports performance. Based on outcomes from this study, calorie restriction and increased time spent in energy deficit should be avoided in collegiate female soccer athletes. Current recommendations to athletes are limited by energy requirement calculations that only provide information on whole day needs. The assessment of EB on an hourly basis can assist in overcoming this limitation. Future research should identify methods to more tightly control for intake and activity while incorporating hourly assessment of EB to confirm results collected from this study. Further, incorporating performance measures could serve to determine if EB may have an effect on other metrics of athletic performance. Nutrition counselling for collegiate athletes should focus on hourly instead of whole-day dietary recommendations to assist with a more logical provision of energy and achievement of body composition goals.

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Plaisance. All authors approved the final version of the paper. The authors have no conflicts of interest in this study.

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