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Relationship of Energy Balance and Body Composition in Elite Female Gymnasts

Taylor E. Blake
Georgia State University

ACCEPTANCE

This thesis, RELATIONSHIP OF ENERGY BALANCE AND BODY COMPOSITION IN ELITE FEMALE GYMNASTS, by Taylor Blake was prepared under the direction of the Master's Thesis Advisory Committee. It is accepted by the committee members in partial fulfillment of the requirements for the degree Master of Science in the Byrdine F. Lewis School of Nursing and Health Professions, Georgia State University. The Master's Thesis Advisory Committee, as representatives of the faculty, certify that this thesis has met all standards of excellence and scholarship as determined by the faculty.

Dan Benardot, PhD, RD, LD, FACSM
Committee Chair

Anita M. Nucci, PhD, RD, LD
Committee Member

Megan McCrory, PhD
Committee Member

Date

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Taylor Blake
1365 Morrow Drive
Bethlehem, GA 30620

The director of this thesis is:

Dan Benardot, PhD, RD, LD, FACSM
Professor
Department of Nutrition
Byrdine F. Lewis School of Nursing and Health Professions
Georgia State University
Atlanta, Georgia 30302

RESUME

Taylor E.M. Blake, DTR
1365 Morrow Drive
Bethlehem, GA 30620
Email: taylorb09@hotmail.com

EDUCATION

2014-2015	**Georgia State University Atlanta, GA** Masters of Science, Nutrition Coordinated Program, Dietetic Intern
2009-2012	**Georgia State University Atlanta, GA** Bachelor of Science, Nutrition Didactic Program in Dietetics (DPD) Verification
2007- 2009	**Georgia Perimeter College, Dunwoody, GA** Pre-requisite Coursework for DPD Program
2005-2006	**Le Cordon Bleu College of Culinary Arts, Tucker, GA** Associates of Occupational Science Degree

WORK HISTORY

2013 - 2014	**McDonald's, Akron Ohio** *Shift Supervisor*
2011 – 2013	**Atlanta Weightloss, LLC DBA Thin and Healthy's Total Solution, Stone Mountain, GA** *Owner-Operator*
2007 – 2009	**Dunwoody Country Club, Dunwoody, GA** *Cook- Banquets, Mixed Grille, Pool Snack Bar*
2006	**The Biltmore Estate, Asheville, NC** *Culinary Intern- Stable Café and Inn on Biltmore Estate*
2005-2006	**Starbucks Coffee Company, Kennesaw, GA** *Barista*
2004-2005	**Wendy's International, Woodstock, GA** *Shift Supervisor*

CERTIFICATIONS

- Dietetic Technician, Registered (2012-2018)
- ServSafe (2013 -2019)
- American Heart Association Basic Life Support

AWARDS

- AP Scholar (2003)
- Honor Roll (2005-2006)
- Dean's List (2010, 2011, 2012)
- President's List (2006-2010, 2011)

ORGANIZATIONS

- Academy of Nutrition and Dietetics Member
- Georgia Academy of Nutrition and Dietetics Member
- Sports, Cardiovascular and Wellness Nutrition (SCAN) DPG Member
- Collegiate and Professional Sports Dietitian Association (CPSDA) Member

ABSTRACT

Title: Relationship of Energy Balance and Body Composition in Elite Female Gymnasts

Background: Studies suggest that athletes participating in weight-specific and appearance-based sports, including gymnasts, are at risk for developing negative energy balance both during and at the end of the day. A prolonged state of negative energy balance has been associated with lower fat-free mass, higher fat mass, and lower bone mineral density. Energy balance is defined as energy in minus energy out, and has been viewed in the past as a static, 24-hour system that begins anew each day. This study examined the relationship of energy balance and body composition (lean body mass, fat mass, body fat percent) and bone mineral density. Studies evaluating the relationship between energy balance and body composition have been conducted in the past, but few have taken into consideration hourly energy balance and the effects of multiple time periods of energy deficit of < -400kcal.

Purpose: The purpose of this study was to assess the relationship between energy balance and body composition in female gymnasts.

Methods: This study utilized a secondary analysis of existing data, and included 23 female elite, nationally ranked, gymnasts. Participants were included in this analysis if they had completed three-day food and activity records and had full body DEXA scans. The food and activity records were analyzed using NutriTiming®, which predicts RMR via the Harris-Benedict equation, uses a MET-based relative intensity activity scale, and accesses the USDA Nutrient Database for Standard Reference, Release 26. NutriTiming provides both 24-hour and hourly energy balance values. Original data were collected as part of a study conducted at Georgia State University in 1993 that had received IRB-approval. The current study also received IRB approval.

Results: Subject characteristics (mean ± SD) were: age (15.1 ±1. 58 years), height (151.3 ±7.7cm), and weight (45.63 ±8. 31kg). Average energy intake during the three days examined was 1375 kcal (±405), and the average predicted energy expenditure was 2430 kcal (± 298), for an energy balance of -1053 (± -438). Subjects were in a negative energy balance state the majority of the days analyzed. Spearman rho analysis found significant negative correlations between kcal consumed per kg bodyweight and body fat percent (r= -0.603, p=0.002), bone mineral density (r= -0.577, p=0.004), fat mass (r= -0.556, p=0.006), lean body mass (r= -0.466, p=0.025), lean body to height ratio (r= -0.466, p=0.025), and weight (r=-0.633, p=0.001). A significant amount of variance (R^2= 0.435; SEE= ±0.05919, p=0.001) was explained in bone mineral density (dependent variable) with fat mass (independent variable).

Conclusion: The associations in this study are consistent with previous studies evaluating the relationships between energy balance deficits and body composition, indicating that poor energy balance is associated with lower lean and higher fat mass. Lean body mass, fat mass, and BMD were positively correlated with age, but 24-hour energy balance was negatively correlated with age (r= -0.484; p=0.019), suggesting that, although growing, subjects were consuming less energy with increasing age.

RELATIONSHIP OF ENERGY BALANCE AND BODY COMPOSITION IN ELITE FEMALE GYMNASTS

by
Taylor Blake

A Thesis

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THESIS COMMITTEE

Dan Benardot, PhD, RD, LD, FACSM (Chair)

Anita Nucci, PhD, MPH, RD, LD

Megan A. McCrory, PhD

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ABBREVIATIONS

ANOVA	Analysis of Variance
CHO	Carbohydrate
NHANES	National Health and Nutrition Examination Survey
RDA	Recommended Daily Allowance
BMI	Body Mass Index
LBM	Lean Body Mass
LBM/kg	Lean Body Mass per Kilogram Bodyweight
FFM	Fat Free Mass
FM/kg	Fat Mass per Kilogram Bodyweight
EDE-Q	Eating Disorder Examination-Questionnaire
BMD	Bone Mineral Density
BMD/kg	Bone Mineral Density per Kilogram Bodyweight
BMC	Bone Mineral Content
DEXA	Dual-Energy X-Ray Absorptiometry
SPSS	Statistical Package for the Social Science
FM	Fat Mass
BF	Body Fat Percent
EB	Energy Balance
PRO	Protein
Ca	Calcium
DT	Drive for Thinness
REE	Resting Energy Expenditure
RMR	Resting Metabolic Rate
ED	Eating Disorder
DE	Disordered Eating
MD	Menstrual Dysfunction
AN	Anorexia Nervosa
BN	Bulimia Nervosa
EDNOS	Eating Disorder Not Otherwise Specified
CLTEA	Computerized Time-Line Energy Analysis
EAT-26	Eating Attitudes Test
TFEQ	Three Factor Eating Questionnaire
RED-S	Relative Energy Deficiency in Sport

CHAPTER I

Introduction

Studies suggest that athletes participating in weight-specific and appearance-based sports, including gymnasts, are at risk for developing negative energy balance both during and at the end of the day. It is common for gymnasts to initiate their sport at a young age (between age 5 and 8 years), and they may be encouraged to sustain an artificially small physique for which they may not be genetically predisposed (Sundgot-Borgen et al. 2013; Sundgot-Borgen & Garthe, 2011). The consequences associated with a prolonged state of negative energy balance include developing a body composition with lower fat-free mass, higher fat mass, and attaining lower bone mineral density.

Energy balance is defined as energy in minus energy out and has been viewed in the past as a static, 24-hour system that begins anew each day. However, energy balance is more dynamic. Timing and frequency of meals becomes important due to the action of insulin on the body. Pre-prandial blood glucose levels can be seen within 2-3 hours after a meal (American Diabetes Association, 2001). Excess insulin production, which can occur when times between meals is delayed encourages fat synthesis (Benardot, 2007; Cohn, et al. 1968). By evaluating within-day intake and expenditure, the effects on body composition may be more apparent (Deutz, et al. 2000). Gymnasts with a history of negative energy balance satisfy one third of the criteria established for the Female Athlete Triad, which includes negative energy balance, amenorrhea, and low bone mineral density (Siatras & Mameletzi, 2014). The conditions of the Female Athlete Triad have recently been expanded to include the physiological and psychological effects around energy availability. This new framework is referred to as "Relative Energy Deficiency in Sports (RED-S) (Benardot, 2013; Javed et al. 2013; Mountjoy et al. 2014). This study examined the relationship of energy balance as a dynamic factor, assessing at within-day energy balance, which may influence body composition (lean body mass, fat mass, body fat percent) and bone mineral density.

Study Purpose

The purpose of this study was to determine if relationships exist between within-day energy balance deficits and lean body mass, fat mass, body fat percent, and bone mineral density in elite female gymnasts. Prior studies exist examining the relationship between energy balance and body composition, however, this study sought to examine the relationship of within-day energy balance and body composition.

Hypotheses

Based on past studies, we hypothesized that there will be statistically significant relationships between within-day energy balance deficits and body composition and bone mineral density. Our specific hypotheses include:

1. Hypothesis 1: Time periods of 3 hours or more spent in energy balance deficit is associated with a lower lean body mass.
    a. Null Hypothesis: Time periods of 3 hours or more spent in energy balance deficit has no association with a lean body mass.
2. Hypothesis 2: Time periods of 3 hours or more spent in energy balance deficit is associated with higher fat mass.

   a. Null Hypothesis: Time periods of 3 hours or more spent in energy balance deficit has no association with fat mass.

3. Hypothesis 3: Time periods of 3 hours or more spent in energy balance deficit is associated with lower bone mineral density.
   a. Null Hypothesis: Time periods of 3 hours or more spent in energy balance deficit has no association with bone mineral density.
4. Hypothesis 4: 24-hour net energy deficits of more than 400 kcals will result in a statistical difference between highest and lowest lean body mass Z-scores.
   a. Null Hypothesis: 24-hour net energy deficits of more than 400 kcals has no association with lean body mass Z-scores.
5. Hypothesis 5: 24-hour net energy deficits of more than 400 kcals will result in a statistical difference between highest and lowest fat mass Z-scores.
   a. Null Hypothesis: 24-hour net energy deficits of more than 400 kcals has no association with fat mass Z-scores.

CHAPTER II

Literature Review

Introduction

Artistic gymnastics, a specific type of gymnastics, involves high-impact loading, acceleration, deceleration, pushing, pulling and acrobatics that are aesthetically pleasing. Usually, those who compete at an elite level in gymnastics initiated the sport at a young age (Siatras & Mameletzi, 2014). Gymnasts appear to be of high risk for energy inadequacies and decreased bone mineral density fueled by dieting and over-training strategies to achieve a thinner physique that would result in a reduced lean body mass and increased fat mass; which would is contraindicated for performance (Siatras & Mameletzi, 2014). Recommendations from coaches and judges to improve performance and reduce weight, in an attempt to improve performance, may exacerbate this problem (Sundgot-Borgen & Garthe, 2011). Female athletes, in general, demonstrate a higher incidence of satisfying the criteria for the Female Athlete Triad due to the high incidence of inadequate dietary intake (Gabel, 2006). This is, in part, fueled by weight-cutting to enhance performance that may jeopardize menstrual and skeletal health. Female athletes do not always compensate their energy expenditure by increasing dietary intake due to a post-exercise decrease in appetite (Blundell & King, 1998; Loucks et al. 2011). The purpose of this literature review is to examine factors regarding energy balance and energy availability and the effects on body composition and bone mineral density to provide key insights on how these factors relate to gymnasts' health and performance.

Relative and Daily Energy Balance

Many athletes struggle to maintain the delicate balance between energy intake and expenditure, and a failure to do so will result in suboptimal performance (Javed et al. 2013). Strength and performance are impaired when lean body mass is reduced due to a lack of energy, often the result of rapid weight loss with energy restriction (Sundgot-Borgen & Garthe, 2011). Performance can be enhanced with strategic food and fluid intake, thereby furthering the need to ensure that weight-sensitive athletes are maintaining proper energy balance (Benardot, 2007). Chronic instances of inadequate energy intake decreases the ability for muscle mass to increase and both lean and fat mass will decrease. Athletes should be educated on the importance of adhering to the recommendations for optimum health and physical activity. This includes a high amount of complex CHO (approximately 7-8g/kg per day), moderate protein intake (1.5-1.8g/kg per day) and a relatively low intake of dietary fat (2g/kg per day) (Benardot, 2007; Mountjoy, 2014).

A study assessing the dietary habits of the United States national women's artistic gymnastics team (n=29) (Jonnalagadda et al. 1998) found that the gymnasts were consuming less than was expected when compared to the NHANES III data for girls of the same age groups. All participants were actively training during the study. Their mean age was 15.1 ± 1.3 years (range 12-18 years), mean height was 151.4 ± 7.1cm, and mean weight was 48.8 ± 8.3kg. Daily baseline energy requirements for the gymnasts were estimated using the Harris-Benedict equation with an activity factor of 1.6 (moderate activity). Dietary intake was assessed by three-day food records that included two weekdays and one weekend day. Instructions on how to record foods and beverages consumed were given to each gymnast with pictures and common household measurements to determine portion size. They were also asked to record any medications or supplements they were taking. Nourish-Check®, a computerized database with access to the USDA Nutrient Database, was used as a standard for nutrient intake. For analysis, the gymnasts were divided into two groups based on age for RDA comparison (11-14 years and 15-18 years). It was determined that the gymnasts were consuming 34.4g/kg body weight, approximately 20% fewer calories than the recommended 40-47kcal/kg body weight for females age 11-18, which was a significant difference ($p=0.047$). Forty-eight percent of the participants reported that they were on self-prescribed diets, and their energy deficits were more severe (-635 kcal/d) than those who were non-dieters (-218 kcal/d). In addition, for those who were on self-prescribed diets, their energy intake from fat was less than non-dieters, (25g/day vs. 39g/day, $p<0.017$). As with other studies using self-reports of dietary intake, it is unclear if the estimated intakes were underreported.

A study involving rhythmic gymnasts recruited from athletic clubs across Greece in 2011 hypothesized that rhythmic female gymnasts (n=40) would exhibit negative energy balance during an 8-week preseason training period as compared to age-matched sedentary controls (n=40) (Michopoulou et al. 2011). Participants in the study were evaluated on age, anthropometrics, Tanner score, maximal oxygen consumption (VO2max) and x-rays of the hand/wrist (to determine skeletal age). The participants and their parents were taught how to complete the 6-day diet/physical activity record (Monday through Saturday only) needed for the study. Daily energy requirement and physical activity were calculated using the Harris-Benedict equation and activity intensity (rest, moderate, intense and very intense), respectively. Rhythmic gymnasts demonstrated lower body mass, BMI, body fat percent, and higher VO2max compared to controls ($p<0.05$). There was no significant difference in energy intake between the groups. However, the gymnasts had significantly higher CHO consumption ($p<0.05$) and lower fat intake ($p<0.05$). Estimated energy expenditure was higher in gymnasts ($p<0.05$). Overall, when age-matched, the gymnasts in the study demonstrated a 233 kcal daily deficit compared to controls, who demonstrated a 122 kcal daily energy surplus, which was a significant difference between the groups ($p<0.05$). Again, energy intake and expenditure can be underestimated or overestimated, a limitation of all studies that utilize self-reports for food and activity logs.

Eating Disorders in Athletics

Energy balance is crucial for weight loss or gain, and the basic laws of energy thermodynamics should be followed; meaning energy expenditure should exceed energy intake if weight loss is the goal, and vice versa if weight gain is the athlete's goal, provided that energy availability (dietary energy intake minus the energy expended) is not compromised (Mountjoy et al. 2015). The drive to remain thin can cause an energy deficit that leads to menstrual disturbances, as demonstrated by a study conducted using a large sample of exercising women, who exercised two or more hours per week (N=137) (Gibbs et al. 2011). In this study, the authors wanted to examine the association between high drive of thinness (DT) and energy deficiency and compare the menstrual status of exercising women with high vs. normal DT. A high DT was defined by the authors as a score of ≥ 7 on the Eating Disorder Index Inventory (EDI-2). Exercising women aged 22.9 ± 4.3 years with a BMI of 21.2 ± 2.2 were retrospectively grouped into high DT (n=27) or normal DT (n=90). Anthropometric data, age, menstrual status, psychometric measurements of eating attitudes and behavior, three-day nutritional logs and exercise regimen (2 or more hours per week) were evaluated. Energy status was defined using by measuring REE (laboratory-derived) and pREE to identify those who had experienced energetic adaptations to energy deficiency. REE was compared to the predicted REE (pREE) calculated using the Harris-Benedict equation. Chi-square analysis showed significantly more high DT women were energy deficient, defined as an REE:pREE less than 0.90, compared to those with normal DT (p=0.024). High DT was significantly associated with higher cognitive restraint to eating (p<0.001) and higher body dissatisfaction (p=0.009) compared to normal DT. Regarding menstrual status, 73.9% of women with high DT had either amenorrhea or oligomenorrhea compared to 38.0% of normal DT women (p=0.002). This study confirms that a high DT, as can also be seen within the gymnast population, is associated with cognitive dietary restraint, energy deficiency and menstrual disturbances.

The prevalence of disordered eating (DE) behavior and an eating disorder (ED) in the elite female athlete (n=186) compared to non-athlete controls in the same age group (n=145) from the general public was the aim of a study conducted in Norway (Torstveit et al. 2007). Athletes were further categorized as non-lean or lean-sport athlete. Leanness athletes were defined as those participating in sports where leanness and/or a specific body weight were considered important for performance. In this study, the investigators sought to determine characteristics of elite female athletes with EDs and test for predictability of risk, determine the percentage of female athletes and controls with DE behavior and EDs, and investigate what may characterize an athlete with EDs.

Participants were considered to have indication of DE behavior if they: self-reported as having and ED, were underweight (BMI <18.5kg/m2), the use of pathogenic weight control methods (PWCM), and had high scores on two subscales of the Eating Disorder Index Drive for Thinness (EDI-DT) and Body Dissatisfaction (EDI-BD). The scores that were used for DE in this study were an EDI-DT ≥15 and EDI-BD ≥14. Compared to controls, the prevalence of clinical EDs, determined by the Eating Disorder Examination (EDE) (Cooper et al. 1989) and DE was significantly higher in the leanness athlete groups by 46.7% (n=90, p<0.001). Three predictive models were used to determine risk for EDs. A total of 46.2% of athletes and 51.7% of the controls reported one or more of the criteria used for DE. Model 1 was based solely on the variable of self-reported EDs, one of the variables previously discussed to determine DE behavior, and raised the probability of an ED in all participating athletes, but not controls (n=186, p<0.01, OR=3.71, CI=1.44-9.55). Model 2 included pathogenic weight control measures, BMI, body dissatisfaction, and DT as predictive variables. The second model was determined to be a poor predictor in both athletes and controls. Model 3 expanded on the variables used in Model 2 by adding menstrual dysfunction (MD) and stress fractures. This raised the predictability and probability of EDs in leanness sports significantly (p<0.05). The author's determined that the addition of MD was an important predictor of the risk for ED in leanness sports despite stress fractures also having been added to Model 3.

Anderson and Pettie (2012) surveyed 400 NCAA Division I female athletes from 26 universities who participated in either gymnastics (n=280) or swimming/diving (n=134) to examine the prevalence of clinical and subclinical EDs as well as the extent of pathologic eating (binging) and weight control methods (purging, vomiting, dieting) amongst this population (Anderson & Petrie, 2012). They used the 50-item Questionnaire for Eating Disorder Diagnoses by Mintz et al. (1997) to determine which of the following categories would best fit each participant: Category 1 included EDs (AN, BN, EDNOS), Category 2 included subclinical EDs and Category 3 were asymptomatic. It was found that a greater number of gymnasts used dieting or fasting and exercise to lose weight. However, 65% of the gymnasts surveyed and 73% of the swimmers/divers were found to be asymptomatic of clinical or subclinical EDs (n=280). They found that 108 participants were classified as having a subclinical ED (28.9% gymnasts, 6.1% swimmers/divers) and 26 could be diagnosed with a clinical ED (6.1% gymnasts, 6.7% swimmers/divers). It is unclear if those who were diagnosable as clinical ED were among the 10 who indicated they were previously diagnosed as having an ED before the study was conducted.

The dynamic relationship between energy intake and expenditure should be considered to control optimally the hormones that influence anabolic and catabolic states. The timing of food intake, therefore, should also be considered as an important factor for helping athletes achieve the physiques that they desire, while reducing the risks of compromising performance (Benardot 2013; Mountjoy et al. 2014). Strategic eating habits, such as consuming meals with the appropriate amount of energy and substrates (carbohydrates, fats, and protein) every two to three hours, can help by providing adequate energy for improved performance, increased lean muscle mass, decreased body fat, and recovery from exercise. A lower weight on the scale may not be the answer that is needed for these athletes.

Within-Day Energy Balance

In the event an athlete desires to reduce body fat to emphasize leanness for aesthetic reasons, it should be ensured that adequate energy availability be taken into consideration as well (Mountjoy et al. 2014). This is important to gymnastics because higher body fat percentages are associated with energy balance deficits that exceed 300 kcal (Deutz et al. 2000). In this study, 42 gymnasts (mean age 15.5y) and 20 runners (mean age =26.6y) whom were either nationally ranked or on a national team, were evaluated on energy balance and body composition. Participants' energy intake and expenditure were analyzed by Computerized Timeline Energy Assessment (CTLEA), which simultaneously measures energy intake and expenditure, and has been validated for gymnasts (Benardot, 1996). Average energy deficit was 784kcal over 24 hours. The average amount of time spent in energy deficits larger than 300kcal was 7.60 ±6.36 hours. Body fat percentage measured by both DEXA ($r=0.484$, $p=0.01$) and skinfold ($r=0.508$, $p=0.00$) was significantly higher for artistic gymnasts in energy deficits ≥300kcal. A possible consequence of allowing the body to become energy deficient is that blood glucose decreases below homeostatic levels approximately 2-3 hours after the last meal was consumed. This can lead to a hyperinsulinemic response at the next meal, leading to increases in fat synthesis (Benardot, 2013).

Body Composition

Previous studies have shown that persistent negative energy balance will result in reduced lean body mass and proportionally increased fat mass (Benardot, 2007, 2013; Deutz et al. 2000). While it is important to improve the strength-to-weight ratio for performance enhancement, this does not mean that an athlete should reduce energy consumption to lose weight (Benardot, 2013).

In 2010 a study found that in professional ballet dancers, an energetic efficiency was associated with prolonged deficits in energy availability compared to age-matched controls (Doyle-Lucas et al. 2010). In this study, 15 professional, elite female ballet dancers, who were training for 27 or more hours per week, were age matched with 15 non-dancers who were sedentary or recreationally active (age 18-35 years). The purposes of the study were to describe the physical and behavior differences between the groups, RMR differences (observed and predicted) and to identify associations between the female athlete triad and energy efficiency based on the calculated RMR values. Researchers gathered data regarding self-reported four-day food records, physical activity logs, menstrual history, body composition, DEXA scans, RMR (using Cunningham, Mifflin St. Jeor, and Harris Benedict equations), and psychometric measures of eating behavior using the EAT-26 and the Three Factor Eating Questionnaire (TFEQ). Lab tests were performed during the follicular stage of ovulation (days 1-10). It should be noted, however, that 6 of the 15 dancers reported irregular menses. The ballet dancers were significantly lighter, had significantly lower body fat percentages, and were significantly more active as compared to controls. The dancers also showed a higher level of dietary restraint and higher EAT-26 scores and a higher prevalence of menstrual dysfunction (amenorrhea and oligomenorrhea), but the differences between groups were not significant. Dancers showed a significantly later age for onset of menses ($p \leq 0.01$). RMR for the dancers (1367±27) was significantly lower than the controls (1454±34; $p \leq 0.05$). Additionally, the dancers demonstrated a significantly lower energetic efficiency (30.9

±0.6 kcal/kg FFM/day) than controls (33.1 ±0.8 kcal/kg FFM/day; $p \leq 0.05$). FFM was higher in the group of dancers with menstrual dysfunction (n=6; 45.6 kg FFM) compared to eumenorrheic dancers (44.0 kg) and controls (43.4 kg), to which the authors attributed to their body's adaptation to use the fewest amount of calories to sustain a kilogram of bodyweight, thus they had the lowest calorie requirement despite having the greatest amount of FFM.

In a recent observational study involving young elite gymnasts from Brazil (Joao & Filho, 2015), 46 elite artistic gymnasts of both sexes were evaluated (males=21, females =25) for somatotype and body composition. Somatotype was determined by Heath and Carter's anthropometric somatotype model. Somatotyping describes the morphology of a subject. It is the quantification of form and composition of the body using ten anthropometric dimensions. Somatotype is expressed by three numbers, which represent endomorph (relative fatness), ectomorph (relative leanness) or mesomorph (relative skeletomuscular robustness). It is subject to change when a person's body changes due to growth, exercise, nutrition, and aging (Carter, 2002; Joao & Filho, 2015). Body composition was determined using bioelectrical impedance using an InBody R20 to measure skeletal muscle mass, fat mass, fat-free mass and body fat percent. Descriptive statistics were used to determine the dominant somatotypes. Thirty-three percent of the male gymnasts were balanced mesomorphs, meaning they were dominantly mesomorphic with similar degrees of endomorphy and ectomorphy. The authors determined this to be the dominant somatotype for the male gymnasts, despite a higher percentage (48%) falling into the category of ectomorph-mesomorph, meaning that they were very thin with visible musculature. Mean body fat percent for the males was 11.39% ± 5.78. For the females, 56% were considered to be “ectomorph-mesomorphs” with a mean body fat percentage of 15.84% ±3.79. Somatotype has been seen to associate with the gymnasts’ performance scores during competition, which is discussed below.

The desire to remain small and light to improve performance is based on the theory that objects that are smaller and lighter move faster. However, the ability to remain small and light can prove difficult to maintain once the young female reaches puberty and her body begins to change from that of a child to a developing woman. These changes suggest that a higher percentage of fat mass will acquired as breasts develop, hips widen and the body prepares for adulthood; this results in a fear of puberty in some of these athletes (Blundell & King, 1998; Martin et al. 2008). In 1999, a study was conducted on 168 elite, female, artistic gymnasts (mean age 16.5 ± 1.8y) participating in the 1987 World Championships to identify anthropometric variables that correlate with performance scores (Claessens et al. 1999). Anthropometrics, skinfold, somatotype and skeletal maturity were examined. Performance scores were recorded for four events: balance beam, floor exercise, vault and uneven bars. Both individual event and composite event scores were recorded. Moderately high, negative correlations were found between skinfolds and the classification of endomorphy when compared to performance scores ($p<0.001$). Scores varied between -0.38 (biceps skin fold and balance beam score, $p\leq0.01$) and -0.60 (endomorphy and total score, $p\leq0.01$). A positive correlation +0.23 was seen between ectomorphy and score on uneven bars ($p \leq0.01$). Stepwise multiple regression analysis was used to explain variance. Upon analyzing the data, 32% - 46% of score variance could be explained by anthropometrics and age. Many correlations between degree of endomorphy and performance score were negative and significant.

Age was often correlated positively with performance scores, but was not strong enough to influence the effects of endomorphic somatotype on performance scores. This presents a problem for female gymnasts, as degree of fatness increases with age.

The scoring system for gymnastics can further promote, though inadvertently, this drive for thinness as studies have shown that the degree of fatness is negatively correlated with performance scores (Joao & Filho, 2015; Siatras & Mameletzi, 2014). It should also be noted that male gymnasts are not immune from the desire to maintain a low body weight. A case study about an injured 2012 Chinese Olympic gymnast (Chen et al. 2013) demonstrated the positive and successful effects of a more balanced diet. Over the course of six months, an intervention by an interdisciplinary team worked to help this gymnast heal from his injuries and correct energy deficits. The gymnast's original diet to intervention allowed for 30% CHO, 20% protein and 50% fat. He originally weighed 62.2kg with 5.845kg body fat. Dietary intervention changed his macronutrients to better suit an elite athlete: CHO was increased to 70%, Protein ranged from 20% to 23% total calories, and fat was decreased to 10%. He was also instructed to consume low Glycemic Index foods every 2-3 hours to achieve overall energy balance. Over the period of intervention, the gymnast was educated on the differences between total body weight and fat mass to help with the psychological stress that he encountered by being injured and the changes to his diet. Upon conclusion, and following the diet regimen, his weight decreased to 58.2kg (-4.0kg, -6.87%) and body fat decreased to 3.5kg (-2.3kg, -66.3%). He competed in the 2012 Olympic Games and "achieved world class results", which could be partially attributable to the change in his eating strategy, which helped him achieve an improved energy balance. This type of education should be explored and implemented within other teams in this sport.

Bone Density

Bone is composed primarily of type 1 collagen and contains 99% of the total calcium and phosphate in the body (Olyai & Thaker, 2009). It consists of cell types called osteoclasts, osteoblasts and osteocytes, which work together to form, mineralize and resorb bone. Under the presence of normal menses, mechanical loading brought on by exercise, can result in higher site-specific bone mass. However, studies have also determined that the effect of mechanical loading cannot offset the effects of hormonal deficiency caused by energy deficiency (Olyai & Thaker, 2009; Siatras & Mameletzi, 2014). Energy deficits that occur in an exercising gymnast may lead to bone demineralization due to a possible elevation in cortisol production that occurs from lack of carbohydrate consumption prior to exercise (Benardot, 2013). Risk of impaired bone health among female athletes rises when energy deficits begin to affect the menstrual cycle for a long enough period that estrogen and progesterone production becomes altered (Jürimäe & Jürimäe, 2008). Progesterone production is increased during the luteal phases of the menstrual cycle, and when this phase is shortened, progesterone production can be decreased, which may cause decreased cortical bone formation (Bennell et al. 1999). Typically, amenorrheic athletes who lack menses for a period of six months or more are suggested to undergo dual-energy X-ray absorptiometry (DEXA) to measure bone mineral density (Mountjoy et al. 2014). Low bone mineral density in this population is defined as a Z-score of -1.0 and -2.0 SD combined with fracture risks (nutritional deficiency, stress fractures, or hypoestrogenism) (Mountjoy et al. 2014). In addition, calcium becomes a concern when an energy deficit is encountered, as a lowered calcium intake can be a consequence of low energy intake. Low calcium intake is associated with an increased risk of stress fractures (Benardot, 2007). Hypoestrogenism causes calcium to be excreted from bone and impairs bone mineralization in the presence of energy deficits (Bennell et al. 1999).

Body composition is related to bone mineral density. However, bone mineral density may be site-specific in premenarcheal girls. A study conducted with 7-8 year old rhythmic gymnasts (n=46) and age-matched controls (n=43) sought to determine if there was a relationship between anthropometric variables, body composition and bone mineral density (Parm et al. 2011). The researchers measured body fat mass, lean mass and BMD and bone mineral content (BMC) using DEXA. Body fat percent was also measured by skinfold calipers. Using multiple stepwise regression, they found that height ($r=0.687$, $p<0.01$), body mass ($r=0.522$, $p<0.01$) and fat free mass ($r=0.568$, $p<0.01$) were significantly correlated with BMC in the L2-L4 spine in controls. However, in the gymnasts, the femoral neck BMC measurements were negatively correlated with body height ($r= -0.391$, $p<0.01$), body mass ($r= -0.306$, $p<0.05$), and fat free mass ($r= -0.399$, $p<0.01$). There were no significant correlations between BMD and BMC in the gymnasts. There were no differences between the gymnasts and controls in height, body mass, BMI or fat free mass. Possibly due to exercise-induced mechanical loading, significantly higher BMD and BMC in L2-L4 and femoral neck was observed in the gymnasts. The authors concluded that the ties between body composition and BMD status were weak for gymnasts in this study.

Similar results have been seen in other studies that have sought to examine compromised BMD in this population. In a study that was conducted by Robinson et al. (1990), 21 collegiate female gymnasts, 20 collegiate runners and 19 non-athletic college women controls were evaluated to determine if there was a relationship between BMD and menstrual status (Robinson et al. 1995). Gymnasts and runners were selected due to the different bone-loading mechanisms that are unique to both sports. Runners and gymnasts had similar body fat percent, and both groups were significantly leaner than the controls ($p<0.001$). Gymnasts had higher LBM/height2 than runners ($p=0.001$) and greater muscle strength ($p<0.05$), but significantly later age for time of menarche ($p<0.05$). Controls were eumenorrheic, while the 30% of the runners and 47% of the gymnasts exhibited menstrual dysfunction. Three runners were amenorrheic, and three were oligomenorrheic. Among the gymnasts, 6 were amenorrheic (4 were primary amenorrheic) and 4 were oligomenorrheic. Lumbar spine BMD was significantly lower in the runners than in the gymnasts in the femoral neck ($p=0.001$) and whole body ($p<0.01$). A significantly higher BMD was seen in gymnasts compared to controls even after the values were normalized for body weight. The authors concluded that the loading that occurs during the explosive movements of the gymnasts possibly aided in maintaining their BMD despite the higher incidence of MD compared to controls.

A study conducted by Barrack et al. (2008), aimed to determine if there was a link between dietary restraint using Eating Disorder Examination-Questionnaire (EDE-Q) sub scores to assess DE, pathologic behavior, MD and low BMD (Barrack, Rauh, Barkai, & Nichols, 2008). They recruited 93 female high school cross-country runners aged 13-18 years old. Menstrual history was obtained via medical history collected prior to engaging in high school sports. Those runners who demonstrated a higher dietary restraint (n=5) had a significantly lower BMD ($p<0.001$). It was also found that those runners with higher dietary restraint had lower lumbar spine and total body BMD than the runners who showed higher weight or shape concerns (n=13) ($p<0.05$). The authors discussed that in this study, BMD may have been compromised by low energy availability due to a possible elevation in urinary and salivary cortisol concentration, which has been demonstrated in other studies. Cortisol has catabolic effects on bone and is present with energy deficiency (McLean et al. 2001). This study did note that within this population of athletes examined, menstrual irregularity was not associated with low BMD.

Growth

Energy balance is critical for a young person during times of growth, particularly puberty. A series of studies published between 2001 and 2005 sought to obtain information on the impact gymnastics training and competition had on height velocity information and skeletal maturation in rhythmic gymnasts (Georgopoulos et al. 2001) and growth (Georgopoulos et al. 2002) and pubertal development (Theodoropoulou et al. 2005) in rhythmic and artistic gymnasts. Height, growth and pubertal development can be altered by the stresses incurred by the intense physical training necessary. Georgopoulos et al. (2001) focused on height velocity included 104 elite, rhythmic gymnasts aged 12-23 years. They were evaluated twice over a span of one year (±3 months). Eighteen were evaluated yearly for a 2-year period, and 9 were reevaluated over a period of 3 years. Anthropometric data were collected by a physician, and skeletal maturation was evaluated via x-ray of the left hand and wrist. Body composition was predicted by Futrex 500, a portable apparatus that measures body fat percent and total body water using infrared analysis. Training intensity, number of competitions and family data regarding parental and maternal heights data were self-reported by questionnaire completed by the gymnasts. Target height for the gymnasts was calculated based on the equation TH= (father's height (cm) -13 + mother's height (cm))/2. For the group of gymnasts who had at least one annual reevaluation (n=72), there was a delay in skeletal maturation compared with chronological age of 1.8 year, which was statistically significant (r= 0.730, P <0.001). Rhythmic gymnasts were taller than average height for age, but lighter. Height velocity SD score was higher for each age group, and was higher than 50th percentile for all age groups. Actual height was positively correlated with target height SD score (p= 0.02). Regression analysis demonstrated that weight SD score and number of competitions positively influenced actual height (p<0.001 and p=0.018, respectively). However, weight SD score was negatively influenced by BMI and body fat (p<0.001 and p= 0.029, respectively). Predicted height SD score was positively correlated to the difference between chronological age and bone age (P=0.05). The data suggest that catch-up growth is possible, but is a slow and late process as it is coupled with a delay in puberty. However, the authors concluded that there was sufficient time for skeletal bone to mature. The positive correlations in this study denoted that careful monitoring of energy balance and adequate nutritional intake were part of the training for the gymnasts who were studied.

In a similar study by Georgopoulos et al. (2002), 129 rhythmic gymnasts and 142 artistic gymnasts were evaluated to compare somatometric data to determine if the impact of gymnastics training on growth (Georgopoulos et al. 2002). Data collection methods and protocols were the same as for the study performed by Georgopoulos et al. in 2001.

The age distribution was 11-23yr both the rhythmic gymnasts and artistic gymnasts. As in the previous study, rhythmic gymnasts were taller and leaner than average for age. The artistic gymnasts were below the 50th percentile for height, but also below the 50th percentile for target height SD score, the same as the rhythmic gymnasts. Both groups of gymnasts followed the same pubertal growth pattern, however, artistic gymnasts presented pubarche later than rhythmic gymnasts. As in the previous study, regression analysis demonstrated that actual height SD score was influenced positively by weight SD for rhythmic gymnasts ($p < 0.001$) and for artistic gymnasts ($p < 0.001$). BMI negatively influenced target height for artistic gymnasts ($b = -0.81$, $t = -12.38$, $p < 0.001$). This study found that the intensive training for rhythmic gymnasts preserved, and in some cases exceeded, the genetic predispositions for growth. However, they observed a deterioration of growth potential in artistic gymnasts; which is possibly due to the selection criteria for artistic gymnasts (short-limbed for mechanical advantage and lower degree of fatness for performance scores).

The final study in the series evaluating rhythmic and artistic gymnasts aimed to evaluate differences, if any, existed between the pubertal development of either type of gymnast (Theodoropoulou et al. 2005). This study was cross-sectional and included 423 elite rhythmic gymnasts and 427 elite artistic gymnasts; aged 11-23. The clinical evaluation was the same protocol as the prior two studies discussed by Georgopoulos, et al. (2001; 2002). A significant delay in skeletal maturation was found in both groups, but it was more pronounced for artistic gymnasts than rhythmic gymnasts ($p = 0.01$). Breast development was the same for both groups according to Tanner stages according to bone age. Menarche was significantly delayed for both groups as compared to the reported onset of both maternal and untrained-sisters' menarche. In artistic gymnasts, menarche was influenced by pubic hair development, bone age, and body fat; in rhythmic gymnasts menarche was influenced by onset of pubic hair and bone age; as determined by multiple regression analysis. The authors did note, however, that despite the delay in pubertal progression, both rhythmic and artistic gymnasts did achieve puberty. Pubertal development was shifted to a later age, and was noted to be mainly influenced by low body weight. Breast development and menarche are related to estrogen, as opposed to pubarche, which is influenced by adrenal androgen production. These hormones are both heavily influenced by female adipose tissue, as it serves as an extragonadal source of estrogens and converting androgens to estrogens (Perel & Killinger, 1979). It should be noted that the mothers of the artistic gymnasts had significantly later menarche than those mothers of the rhythmic gymnasts. Therefore, genetics in combination with negative energy balance may have contributed to delayed menarche in the artistic gymnasts in this study.

Summary and Conclusion

Energy balance and availability is a growing area of the research and has been shown to have implications in a sort of "trickle-down" manner. The flow appears to be low energy availability leads to disruptions in body composition and menstrual function, possibly simultaneously. The alterations in available energy stores then affects bone health in time due to both increases in cortisol production due to low energy stores (Barrack et al. 2008), which is highly catabolic to bone mass. Additionally, the decrease in available energy alters luteinizing hormone, follicle stimulating hormone, estradiol and progesterone, which alters menstrual status in women.

Many of the studies examined reported using DE and EDs as part of their determining criteria. It would make sense that most of the subjects who exhibited signs of DE and clinical EDs would have disruptions in menstrual status and energy availability. The IOC has recently emphasized the importance of energy balance with their published additions to the RED-S consensus that it is important to look at energy intake within athletes as real-time availability, rather than a 24-hour energy balance (Margo Mountjoy et al. 2015).

Body composition has been shown to be altered by low energy availability. If energy is not adequate within the athlete, alternate sources of fuel from body tissues will be accessed. Additionally, if more than three hours passes between meals, blood glucose levels will decrease, leading to a hyperinsulinemia at the next eating opportunity. This excess amount of insulin will result in higher fat storage. Fat oxidation for energy occurs during normal, aerobic activity. Amino acids, when used for fuel in the presence of inadequate energy availability, is the result of the breakdown of muscle. This breakdown will, mathematically speaking, decrease the ratio of lean body mass (muscle) to fat mass, thus creating a body composition that is higher in fat mass and lower in lean body mass. Lean body mass is required for performance in sport and should be spared. By having adequate energy availability, particularly with carbohydrate intake, the body will spare muscle, leaving it to do the work associated with the sport.

This loading on the skeleton puts gravitational force on bone, forcing the body to reinforce the areas where decreases in density would normally be seen (in the lumbar spine and femoral neck). Of the articles reviewed, only the runners exhibited by Barrack, et al. (2008) were shown to have a negative effect on BMD as a possible side-effect of documented low energy availability.

The differing conclusions from the studies reviewed, demonstrates the need for additional studies specifically evaluating effects of within-day low energy availability on body composition and bone mineral density. Possibly assessing RED-S criteria as well, at-risk athletes could be identified earlier and intervention given, as not all athletes who are energy deficient are also amenorrheic and compromised BMD. As demonstrated by the study conducted by Parm, et al. (2011) body composition did not relate significantly with BMD or BMC. However, they did not evaluate the effect of energy availability as a possible influence. It is unknown if the gymnasts in the study were of elite status, and only mentioned that they practiced for 6-12 hours per week compared to controls who were compulsory in exercise, amounting to approximately 45 minutes of activity per week. Studies that provide more concrete and reliable results were those who were able to look at the relationship between energy availability, body composition, bone mineral density and menstrual history. Hormone levels (ghrelin, cortisol and insulin-like growth factor-1) would be appropriate to include in future studies as male athletes, particularly those in weight-specific sports, are not immune from the effects of low energy availability. Findings from future research in this area could lead to a greater proportion of well-fueled and healthier athletes.

CHAPTER III

Methods

Subjects

This study included 23 female elite, nationally ranked, gymnasts who were actively training at the time of data collection in 1993. The accessed data were collected as part of a previous IRB-approved study conducted at Georgia State University in 1993. Participants were included in this analysis if they had complete three-day, 24-hour food intake and activity records and DEXA scans.

Study design

This was a cross-sectional study approved by Georgia State University's Institutional Review Board. This secondary analysis assessed the association between energy intake, substrate intake (CHO, PRO, and fat), and time spent in periods of energy deficit and lean body mass, fat mass, body fat percent and BMD.

Data Analysis

NutriTiming® (NutriTiming® LLC, Atlanta, GA), a computerized timeline energy analysis software program, was used to analyze the three day average dietary intake and energy expenditure for each gymnast. NutriTiming® predicts RMR via the Harris-Benedict equation, uses a MET-based relative intensity activity scale, and accesses the USDA Nutrient Database for Standard Reference, Release 26. NutriTiming® provides both 24-hour and hourly energy balance values. The data were collected in the early 1990s, therefore, some products listed in the records have since been discontinued. Nutrient composition of those foods was estimated by substituting the information from a modern-day product in appropriate serving sizes to match the caloric value of the original item, if available, or approximated using the USDA Nutrient Database and were manually entered. Energy expenditure data for NutriTiming® is determined by the Physical Activity Guidelines Advisory Committee of 2008 and the National Research Council Activity of 1989. Hourly energy expenditure is assessed in this program. Activity factors range from “1” (resting, reclining) to “7” (exhaustive, to the point of collapse), increasing in increments of 0.5. A NutriTiming® Activity Factor Scale of “4.0” (Moderate activity; comfortable but sweating and faster heart rate) was assigned for all training activities, in lieu of a daily activity factor. This value was assigned due to the adaptation of the gymnasts to the nature of a typical gymnastics training session, which includes rest periods between bouts of explosive movement. Output from NutriTiming® provided the calculations for total calories consumed, 24-hour energy balance (Ending Energy Balance), 24-hour energy balance Net (calories in less calories out), Hours Catabolic, and relative amount of time spent in energy deficits totaling 400kcal or more (EB Deficit Hours >400kcal).

Statistical analysis

Descriptive statistics were performed to determine mean and standard deviation (SD) on body fat percentage, bone mineral density, fat mass, lean body mass, intake of carbohydrate, fat, and protein, and energy balance variables listed above.

Hypotheses Testing

ANOVA tests were performed on total and relative time spent in a negative energy balance of 400kcal and greater, body composition and bone mineral density in order to address the hypotheses. Z-scores were obtained for age, body composition variables (FM, BF, LBM, weight, weight for height (WH) and BMD) to segment the subjects into subgroups for analysis to determine any significant differences between energy balance variables (kcal consumed, kcal per kg bodyweight, energy expenditure, 24-hour energy balance, 24-hour energy balance net, energy balance deficit hours ≥-400 kcal, EB surplus hours ≥+400 kcal, Energy Balance hours per day, hours catabolic and hours anabolic) and the standardized values for BF, LBM, Weight, WH, and BMD. Independent samples T-tests were also performed to test each hypothesis.

Spearman Rho correlations were conducted to evaluate any significant relationships between the energy balance variables and body composition variables listed previously.

Additional Statistical Tests

As an additional step, correlation tests on the daily intake amounts of specific energy substrates (CHO, PRO, fat and calcium), body composition, bone mineral density, energy balance, and menstrual status were performed. Students t-tests were used to determine if a significant difference existed between the standard recommended protein intake for athletes (1.2-1.7g/kg), standard recommended carbohydrate intake (5g/kg) and fat (30% of daily calories) and what was actually ingested of those substrates. Regression analysis was used to predict if a significant amount of variance is explained in lean body mass (dependent variable) from total time spent in energy deficit greater than 400 kcal per 24 hour period; fat mass and total time spent in energy deficit greater than 400 kcal per 24 hour period; as well as body fat percentage and total time spent in energy deficit greater than 400 kcal per 24 hour period. We also used a regression analysis to determine the amount of variance explained in BMD (dependent variable) when fat mass and weight were used as a variable. All statistical analyses were performed using SPSS (version 20.0, SPSS, Inc., Chicago, IL). A p-value of <0.05 were considered statistically significant.

CHAPTER IV

Results

Subjects

All 23 subjects were included in this analysis. Table 1 shows the means and standard deviations for the subjects. All the gymnasts included in the study were teenagers, except one who was aged 12 years. They were all relatively small in stature and lean. Bone mineral density varied amongst subjects; mean total BMD was 1.1g/cm^2 ±0.07.

Table 1: Descriptive Statistics of Elite Female Gymnasts (N=23)

	Mean	Std. Deviation	95% Confidence Interval Lower	95% Confidence Interval Upper
Age (yr)	15.1	1.6	14.4	15.8
Height (cm)	151.3	7.7	148.0	154.6
Weight (kg)	45.6	8.3	42.0	49.2
Body Fat %	12.9	2.9	11.6	14.1
BMD (g/cm^2)	1.1	0.07	1.1	1.2
LBM (kg)	40.9	12.2	35.6	46.2
Fat Mass (kg)	6.1	2.3	5.1	7.1

Energy Balance Descriptive Statistics

For all subjects, the average energy intake during the three days examined was 1375 kcal (±405). Energy expenditure averaged 2430 kcal (±298). All subjects were found to be in a catabolic state the majority of the time (Table 2). Only one gymnast had an energy balance surplus of >400kcal totaling 1 hour over the three day average.

Table 2: Energy Balance Descriptive Statistics of Elite Female Gymnasts (N=23)

	Mean	Std. Deviation	95% Confidence Interval Lower	95% Confidence Interval Upper
Energy Consumed (kcal)	1375	405	1200	1800
Energy Consumed per Kg Bodyweight (kcal/kg)	31	10	26.7	35.4
Energy Expenditure (kcal)	2430	298	2301	2559
Hours spent +/-400 kcal	13	3.4	11.5	14.4
24-Hour Energy Balance Net (kcal)	-1053	438	-1242	-864
EB Deficit Hours <-400 (kcal)	11	3.5	9.4	12.5
EB Surplus Hours >+400 (kcal)	0.04	0.21	-0.05	0.13
Hours Catabolic	20.8	2.6	19.8	22.0
Hours Anabolic	3.1	2.6	2.0	4.2
Largest EB Deficit (kcal)	-1024	572	-1272	-777
Largest EB Surplus (kcal)	148	104	103	193

A significant difference was observed between kcal/kg and z-score category ($p=0.030$). Bonferroni post hoc analysis (Table 3) revealed that this difference was between group 1 (< -1 SD) and group 3 (> +1 SD) ($p=0.030$). Independent samples t-test revealed a significant difference between kcal per kg and weight ($p=0.018$) and energy expenditure and weight ($p=0.023$). A significant difference was also found between age Z-score and weight ($p=0.014$) and energy expenditure ($p=0.032$). Weight was significantly correlated with 24-hour energy balance ($r= -0.442$, $p=0.035$), energy expenditure (r= 0.656, p=0.001), 24-hour energy balance net (r= -0.430, p=0.041), age (r= 0.637; p=0.001), and kcal/kg (r= -0.633, p=0.001), as shown in Table 9.

Table 3 ANOVA and Bonferroni Post Hoc Test Results of Z-score Weight (kg) and Kcal per Kg Body Weight

	Mean (SD)	Mean Difference		Sig.
Group 1 (< -1.0 SD)*	39.8 (3.5)	Group 2	9.4	.167
		Group 3	15.9	.030**
Group 2 (-1 to +1 SD)*	30.4 (10.5)	Group 1	-9.4	.167
		Group 3	6.5	.536
Group 3 (> +1.0 SD)*	24.0 (6.5)	Group 1	-15.9	.030**
		Group 2	-6.5	.536

*Groups were based on Z-scores for weight (kg) for analysis. **Significance set p<0.05

Hypothesis 1

Our first hypothesis was time periods of 3 hours or more spent in an energy balance deficit is associated with lower lean body mass. A significant, negative correlation was found between lean body mass and kcal consumed per kg (r= -0.430, p=0.041), as seen in Table 9. Negative correlation was found between LBM and energy deficit hours < -400 kcal, but it was not significant (r= -0.278, p=0.198).

A positive significant correlation was found between lean body mass per kg (LBM/kg) and 24-hour energy balance (r= 0.432; p=0.040) and kcal per kg (r= 0.505; p=0.014). Bonferroni post hoc (Table 4) revealed group 1 (< -0.5 SD) and 3 (> +0.5 SD) had the largest amount of variance. Independent samples t-test showed a significant difference between age Z-score and lean body mass (p=0.050), kcal per kg and Z-score lean body mass (p=0.046), and energy expenditure and lean body mass (p=0.036). Age was also found to be negatively correlated with LBM/kg (r= -0.573; p= 0.004).

Table 4 ANOVA and Bonferroni Post Hoc Test Results of Z-score Lean Body Mass (kg) and Kcal per Kg Body Weight

	Mean (SD)	Mean Difference		Sig.
Group 1 (< -1.0 SD)*	37.2 (5.4)	Group 2	8.2	.255
		Group 3	10.7	.258
Group 2 (-1 to +1 SD)*	29.0 (12.0)	Group 1	-8.2	.255
		Group 3	2.6	1.000
Group 3 (> +1.0 SD)*	26.5 (3.9)	Group 1	-10.7	.258
		Group 2	-2.6	1.000

*Groups were based on Z-scores for lean body mass (kg) for analysis.

ANOVA analysis showed no significant difference between lean body mass for height (LBMH) and energy expenditure. Spearman rho correlation (Table 9) was significant for LBMH and kcal per kg consumed (r= -0.466, p=0.025) between group 1 and group 3.

Table 5. ANOVA and Bonferroni Post Hoc Test Results of Z-score Lean Body Mass/Height and Kcal per Kg Body Weight

	Mean (SD)	Mean Difference		Sig.
Group 1 (< -0.25 SD)*	36.0 (6.00)	Group 2	4.6	1.000
		Group 3	10.1	.133
Group 2 (- 0.25 to +0.25 SD)*	31.4 (14.2)	Group 1	-4.6	1.000
		Group 3	5.5	.818
Group 3 (>+ 0.25 SD)*	25.9 (6.7)	Group 1	-10.1	.133
		Group 2	-5.5	.818

*Groups were based on Z-scores for lean body mass/height for analysis.

Hypothesis 2

Our second hypothesis was time periods of 3 hours or more spent in energy balance deficit is associated with higher fat mass. Fat mass was negatively associated with energy balance deficits of < -400kcal, but it was not significant (r= -0.156; p=0.476), as shown in Table 9. Age was positively correlated with fat mass (r= 0.439, p= 0.036). Fat mass was significantly correlated with kcal consumed per kg (r= -0.556, p=0.006). There was a significant difference between kcal per kg body weight and fat mass (p=0.21). Bonferroni post hoc test (Table 6) revealed the significant difference was between Group 1 (< -1 SD) and 3 (> +1 SD). Independent sample t-test also revealed a significant difference between kcal per kg bodyweight and fat mass (p=0.009).

Table 6. ANOVA and Bonferroni Post Hoc Test Results of Z-score Fat Mass(kg) and Kcal per Kg Body Weight

	Mean (SD)	Mean Difference		Sig.
Group 1 (< -0.5 SD)*	38.7 (4.5)	Group 2	8.9	.148
		Group 3	14.5	.021**
Group 2 (-0.5 to +0.5 SD)*	29.8 (10.6)	Group 1	-8.9	.148
		Group 3	5.5	.685
Group 3 (> +0.5 SD)*	24.2 (8.6)	Group 1	-14.5	.021**
		Group 2	-5.5	.685

*Groups were based on Z-scores for fat mass (kg) for analysis.
**Significance set p<0.05

Table 7 shows results from ANOVA and Bonferroni post hoc used to determine if a significant difference exists between body fat percent z-score and energy balance variables. Categories body fat percent showed a near significant difference for kcal consumed per kg body weight (p=0.60). Independent samples t-test was also performed, no significance was found between energy balance and body fat percent. Spearman rho analysis revealed a negative, significant correlation between body fat percent and kcal consumed per kg bodyweight (r= -0.603, p=0.002). Age was positively correlated with body fat percent (r=0.570; p=0.005).

Table 7 ANOVA and Bonferroni Post Hoc Test Results of Z-score Body Fat Percent and Kcal per Kg Body Weight

	Mean (SD)	Mean Difference		Sig.
Group 1 (< -0.5 SD)*	35.0 (9.7)	Group 2	4.4	1.000
		Group 3	5.3	.075
Group 2 (-0.5 to +0.5 SD)*	32.6 (9.3)	Group 1	4.4	1.000
		Group 3	4.9	1.000
Group 3 (> +0.5 SD)*	22.1 (7.5)	Group 1	5.3	.075
		Group 2	4.9	1.000

*Groups were based on Z-scores for body fat percent for analysis.

Hypothesis 3

Our third hypothesis was time periods of 3 hours or more spent in energy balance deficit is associated with lower bone mineral density. BMD was significantly correlated with: age (r= 0.672; p<0.001), kcal consumed per kg (r= -0.613, p=0.002), 24-hour energy balance (r= -0.578; p=0.004), 24-hour energy balance net (r= -0.589; p=0.003), weight (r= 0.707; p <0.001), LBM (r= 0.507, p=0.013), LBMH (r= 0.512; p=0.012), LBM/kg (r= -0.557; p=0.006), FM (r= 0.626; p=0.001), FM/kg (r= 0.551, p=0.006), and body fat percent (r= 0.761, p <0.001). There were no statistically significant differences between BMD Z-score and kcal/kg as seen in Table 8. Calories per kilogram bodyweight showed near significant difference between group 1 (-0.5 SD) and 3 (+0.5 SD) (p=0.080). Independent Samples t-test revealed a significant difference between BMD and Kcal consumed per kg bodyweight (p=0.032). Age Z-score was also significantly different from BMD by independent t-test (p=0.008). Linear regression analysis did show a significant amount of variance in BMD for these subjects could be explained based on their fat mass and weight, but not lean body mass. The equations are as follows:

$$BMD g/cm^2 = \text{Fat Mass(kg)}(0.22) + 0.973$$
$$SEE = \pm 0.0591862;\ R^2 = 0.435;\ p=0.001$$

$$BMD g/cm^2 = \text{Weight(kg)}(0.007) + 0.810$$
$$SEE = \pm 0.068059;\ R^2 = 0.423;\ p=0.001.$$

Table 8. ANOVA and Bonferroni Post Hoc Test Results of Z-score Bone Mineral Density (g/cm^2) and Kcal per Kg Body Weight

	Mean (SD)	Mean Difference		Sig.
Group 1 (< -1 SD)*	36.0 (5.5)	Group 2	5.7	.613
		Group 3	12.2	.080
Group 2 (-1 to +1 SD)*	30.3 (12.8)	Group 1	-5.1	.613
		Group 3	6.6	.644
Group 3 (> +1 SD)*	23.7 (6.3)	Group 1	-12.3	.080
		Group 2	-6.6	.644

*Groups were based on Z-scores for bone mineral density (g/cm^2).

Hypothesis 4

Our fourth hypothesis was 24-hour net energy deficits < -400 kcals will result in a statistical difference between the highest and lowest Z-scores lean body mass. No statistical difference was found between 24-hour net energy deficit < -400kcal and lean body mass. We fail to reject the null hypothesis.

Hypothesis 5

Our final hypothesis was to determine if 24-hour energy deficits < -400 kcals will result in a statistical difference between highest and lowest Z-scores fat mass. No statistical difference was found between 24-hour net energy deficit < -400 kcals and fat mass. We fail to reject the null hypothesis.

Table 9 Spearman Rho Correlations Hypothesis Testing Energy Balance and Body Composition for Elite Female Gymnasts (N=23)
(Note: **. Correlation is significant at the 0.01 level (2-tailed).*. Correlation is significant at the 0.05 level (2-tailed)

		Weight (kg)	Body Fat %	BMD (g/cm2)	Lean Body Mass (kg)	Lean Body Mass/ Ht Ratio	Fat Mass (kg)	Lean Body Mass/ Kg	Fat Mass/ Kg
Age (yr)	Correlation Coefficient	**.637****	**.570***	**.672****	**.423***	.393	**.439***	**-.573***	.322
	Sig. (2-tailed)	**.001**	**.005**	**.000**	**.044**	.064	**.036**	**.004**	.134
Energy Consumed	Correlation Coefficient	.010	-.211	-.227	.141	.066	-.019	.155	-.146
	Sig. (2-tailed)	.964	.334	.297	.520	.766	.930	.481	.505
Kcal/kg	Correlation Coefficient	**-.633****	**-.603****	**-.613****	**-.430***	**-.466***	**-.556****	**.505***	**-.516***
	Sig. (2-tailed)	**.001**	**.002**	**.002**	**.041**	**.025**	**.006**	**.014**	**.012**
Energy Expenditure	Correlation Coefficient	**.656****	.340	**.577***	.407	.368	.327	-.355	.085
	Sig. (2-tailed)	**.001**	.113	**.004**	.054	.084	.128	.097	.700
24-Hour Energy Balance	Correlation Coefficient	**-.442***	-.387	**-.578***	-.122	-.165	-.244	**.432***	-.165
	Sig. (2-tailed)	**.035**	.068	**.004**	.581	.452	.263	**.040**	.452
24-Hour Energy Balance Net	Correlation Coefficient	**-.430***	-.375	**-.589***	-.129	-.181	-.235	.399	-.163
	Sig. (2-tailed)	**.041**	.077	**.003**	.556	.409	.280	.059	.457
EB Deficit Hours <-400	Correlation Coefficient	.030	.052	.107	-.278	-.259	-.156	-.208	-.151
	Sig. (2-tailed)	.892	.814	.628	.198	.232	.476	.342	.493
EB Surplus Hours >+400	Correlation Coefficient	.096	.032	.032	.064	.032	.032	.032	.000
	Sig. (2-tailed)	.662	.884	.884	.771	.884	.884	.884	1.000
EB Hours Per Day (+/- 400kcal)	Correlation Coefficient	-.030	-.052	-.107	.278	.259	.156	.208	.151
	Sig. (2-tailed)	.892	.814	.628	.198	.232	.476	.342	.493
Hours Catabolic	Correlation Coefficient	.351	.216	.372	.078	.102	.178	-.314	.090
	Sig. (2-tailed)	.101	.321	.081	.725	.642	.417	.144	.685
Hours Anabolic	Correlation Coefficient	-.351	-.216	-.372	-.078	-.102	-.178	.314	-.090
	Sig. (2-tailed)	.101	.321	.081	.725	.642	.417	.144	.685

Energy Balance and Carbohydrates, Protein, and Fat

Average intake of energy substrates and calcium were also examined. Table 8 shows the descriptive statistics for carbohydrates (CHO), protein (PRO), fat and calcium.

Table 10: Carbohydrate, Protein, Fat Descriptive Statistics of Elite Female Gymnasts (N=23)

	Minimum	Maximum	Mean	Std. Deviation
Carbohydrate (gm)	112	456	235	73
Protein (gm)	27	98	59	18
Fat (gm)	10	47	24	10

Correlations between the amount of CHO, PRO, fat and calcium and energy balance variables were assessed. Table 11 shows these associations.

Table 11: Correlation Energy Balance Variables Carbohydrate, Protein, Fat

		Hours Catabolic	24-Hour Energy Balance (End Day)	24-Hour Energy Balance Net	EB Deficit Hours <-400	Hours Anabolic	Largest EB Deficit (kcal)
Carb (gm)	Pearson Correlation	**-.638****	**.750****	**.724****	**-.743****	**.638****	**.558****
	Sig. (2-tailed)	**.001**	**.000**	**.000**	**.000**	**.001**	**.006**
Protein (gm)	Pearson Correlation	**-.420***	**.626****	**.583****	**-.599****	**.420***	**.711****
	Sig. (2-tailed)	**.046**	**.001**	**.004**	**.003**	**.046**	**.000**
Fat (gm)	Pearson Correlation	**-.573****	**.646****	**.632****	**-.640****	**.573****	**.517***
	Sig. (2-tailed)	**.004**	**.001**	**.001**	**.001**	**.004**	**.012**

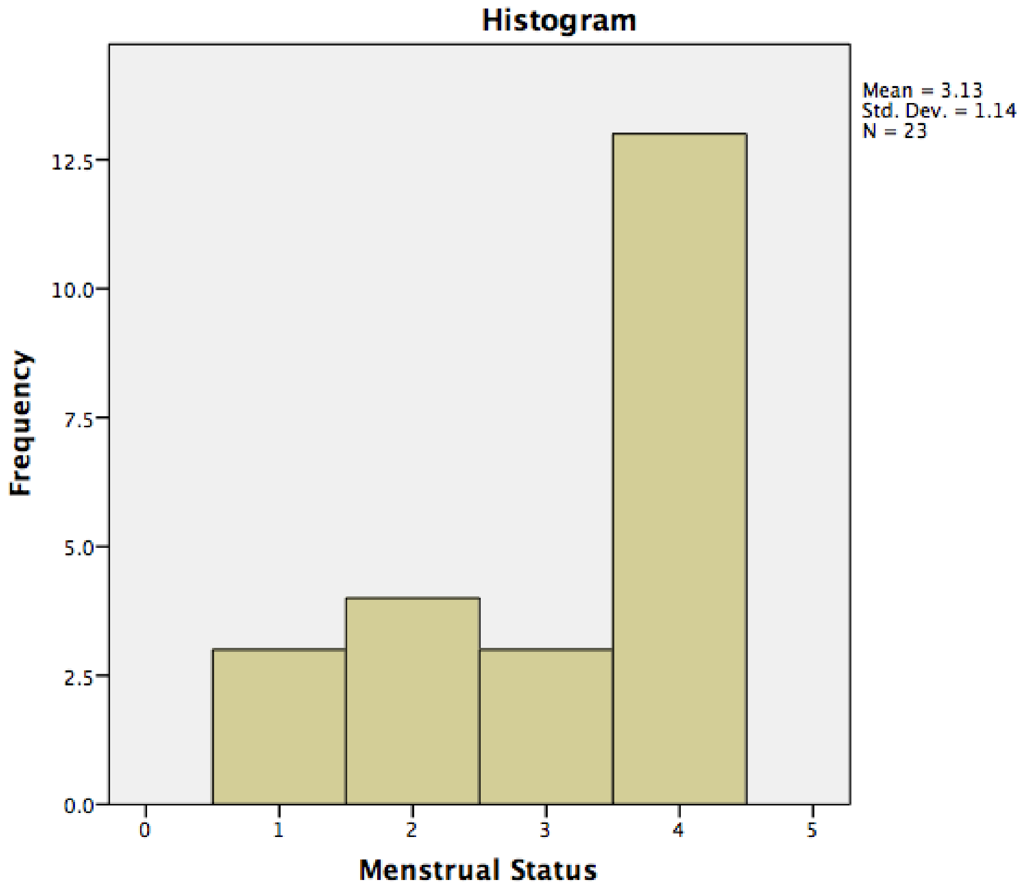
**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

A one-sample student t-test was performed on each macronutrient to determine if there was a significant difference between what was consumed and the standard recommendations for an athlete (Benardot, 2007). The recommended amount of CHO for an athlete is 5g/kg, student t-test did not reveal a significant difference (p=0.404). Student t-test for PRO was set against the recommendations of 1.2g/kg and 1.7g/kg. When tested, protein gm/kg was significant for the maximum recommended intake of 1.7g/kg (p <0.001); the minimum recommended intake of 1.2g/kg protein was not significantly different (p=0.141). When analyzed using the RDA for fat (30% total calories), there was a significant difference (p <0.001) for fat consumed among the subjects. The RDA for calcium was used in a t-test to determine that a significant difference existed between average intake over the three days and the recommended value of 1300mg/day (p <0.001).

Menstrual Status

Of the 23 subjects, 13% were eumenorrheic according to self-reported monthly menstrual patterns. The remaining 87% were considered to have an irregular (oligomenorrheic, secondary amenorrheic or primary amenorrheic) menstrual cycle. Menstrual status was not significantly correlated with energy balance, bone mineral density, or intake of CHO, PRO, or fat. Age was negatively correlated with menstrual status, but it was not significant (r= -0.374, p=0.079). A negative correlation was shown between catabolic hours, but it was not significant (r= -0.218, p=0.318). A near-significant correlation between menstrual status and BMD was found with Spearman Rho (r= -0.381; p=0.073). Menstrual status was significantly correlated with LBM/kg (r= 0.430; p=0.041).

Graph 1: Menstrual Status of Elite Female Gymnasts (N=23)



CHAPTER V

Discussion and Conclusions

We sought to determine the relationship of energy deficiency with body composition and bone mineral density in elite gymnasts. The participants highly homogenous, making it necessary to divide the data into subgroups by Z-score for analysis. These athletes spent greater time periods in an energy balance deficit than surplus. All subjects, except for one, were catabolic over the three days assessed. A substantial amount of the day was spent in energy balance deficits greater -400kcals, which has been shown to be associated with increased body fat percent (Deutz et al. 2000). Menstrual status was compromised for the majority of the subjects, making a clear correlation between energy balance and menstrual status difficult to assess. The associations in this study are consistent with previous studies evaluating the effects of energy balance deficits and body composition.

The number of calories consumed per kilogram body weight is a standard reference for athletes. Many researchers have suggested that 30kcal/kg-1FFM/d-1 be the minimum calorie requirement for athletes to preserve lean muscle mass for optimum performance (American College of Sports Medicine, American Dietetic Association, & Dietitians of Canada, 2000). By normalizing parts of total body mass (LBM/kg and FM/kg) we were able to demonstrate that the pieces of the whole, in regards to weight, are as important when considering the effects of energy balance on body composition by segmenting the data into parts that make logical sense. Significant differences and correlations were seen when kilocalories per kilogram body weight were analyzed with body composition. Significant differences were found using nonparametric testing, which tend to be weaker compared to data that is analyzed with parametric testing techniques.

In regards to the hypotheses tested, data analysis revealed no significant relationships or differences between time spent in energy balance deficit > 3 hours or 24-hour energy balance <-400 kcals and lean body mass, fat mass, body fat percent or bone mineral density. As energy balance increased so did lean body mass, which is expected and has been reported by previous studies. The wide age range in the study sample made it necessary to categorize subjects by Z-score and use age as a covariate As the gymnasts increased in age, their fat mass, lean body mass, body fat percent, weight and bone mineral density increased with growth. However, a negative correlation between 24-hour energy balance and age, suggests that they were consuming less energy as they aged.

Bone mineral density, when analyzed, was found to have many significant correlations to energy balance and body composition. A negative correlation found between bone mineral density and 24-hour energy balance and 24-hour energy balance net, demonstrates that despite growth and increases in weight, height, lean body mass and fat mass, bone mineral density values decreased as energy balance decreased. This association between decreased energy availability and a decrease in bone mineral density has been reported in previous studies. In our study, we found that a significant amount of variance in bone mineral density can be explained by fat mass.

Conclusions

We observed significant correlations between within-day energy balance, lean mass, fat mass, and bone mineral density. Lean body mass, fat mass, and BMD were positively correlated with age, but 24-hour energy balance was negatively correlated with age, suggesting that these growing, subjects were consuming less energy with increasing age. Future investigators may consider comparing athletes to active, age-matched control subjects in order to further elucidate the effects of within-day energy balance on body composition. Medical professionals and staff who are responsible for athletes of all ages should be educated on the importance of maintaining energy balance to maximize the health of their athletes.

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