Energy Availability and Relative Energy Deficiency in Sport (RED-S) in Division I Athletes

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Authorization to Submit Thesis

This thesis of Katelyn Peterson, submitted for the degree of Master of Science with a Major in Movement & Leisure Sciences and titled, "Energy Availability and Relative Energy Deficiency in Sport (RED-S) in Division I Athletes," has been reviewed in final form. Permission, as indicated by signatures and dates below, is now granted to submit final copies to the College of Graduate Studies for approval.

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Abstract

Collegiate athletes practice year-round and must alter intake to compensate for changes in energy expenditure during high and low-volume training. Although adequate intake is needed to optimize performance, pressures in the sporting environment may lead to low energy availability (LEA). Therefore, the purpose of this study was to examine relationships between energy availability (EA) and eating disorder (ED) risk, body composition, and stress in Division I athletes. One hundred current student-athletes, 18-25 years of age, were recruited for the study. Dietary energy intake (DI) and exercise energy expenditure (ExEE) were assessed over three days (two weekdays and one weekend day) using accelerometer (ActiGraphGT3X+) and physical activity logs, while DI was recorded using a validated online dietary recall (ASA24®). Bone mineral density (BMD) and body composition (fat mass, FM; lean body mass, LBM) were assessed using dual-energy X-ray absorptiometry (DXA). EA was calculated using the following equation: (DI – ExEE) and categorized into low (<30 kcal/kg of LBM/day), reduced (30-45 kcal/kg of LBM/day), and adequate EA (>45 kcal/kg of LBM/day). Descriptive statistics were performed on dependent variables using measures of central tendency, variability, and frequencies. A Chi-square test of independence was performed to determine if EA category was dependent on sex. A Fisher's exact test was used to determine differences in ED risk by sex and independent t-tests were used to compare differences in EA, body composition, and stress by sex. Pearson correlations were performed to assess relationships between EA and ED risk, BMD, and stress in male and female athletes. Significance was accepted at $p<0.05$. Eighty-one participants (M: $n=38$, age 20.0±1.4 years; F: $n=43$, age 19.7±1.2 years) completed the study. Demographics were assessed by sex including height (M: 1.8±0.1 m; F: 1.7±0.1 m), weight (M: 94.2±25.3 kg; F:

65.0±10.7 kg), and body mass index (M: 27.5±6.8 kg/m^2; F: 22.3±2.7 kg/m^2). No differences were observed in EA by sex (p=0.995), however both fell into the reduced category on average (M: 41.1±13.7 kcal/kg of LBM/day; F: 41.1±12.6 kcal/kg of LBM/day). In addition, EA category was not dependent on sex (p=0.319). Males (10.5%) and females (9.3%) had similar occurrence of being classified as having increased ED risk (p=1.000). Differences were observed by sex in FM (M: 20.5±7.7%; F: 26.9±5.2%; p=0.001), LBM (M: 75.7±7.3%; F: 69.4±5.2%; p=0.001), BMD (M: 1.4±0.1 g/cm^2; F: 1.2±0.1 g/cm^2; p=0.001), and stress (M: 13.7±6.0; F: 16.9±6.2; p=0.021). Two participants (1 male, 1 female) had Z-scores between -1 and -2. EA was not significantly correlated with any of the dependent variables in males or females. In conclusion, although EA did not differ by sex, 68% of males and 58% of females had low or reduced EA (<45 kcal/kg of LBM/day), suggesting a greater need for EA assessment. Special attention should be dedicated to identifying, treating, and preventing LEA in college athletes.

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Chapter One: Introduction

Many athletes aspire to participate in their sport at the collegiate level and will go to great lengths to achieve this goal. To be successful, collegiate student-athletes must balance academic, athletic, and social responsibilities. While sports can produce positive effects, such as personal learning, character development, and teamwork, participation can also have negative consequences [1]. Sport-specific norms and societal pressures to achieve a more ideal appearance can contribute to poor body image and the development of eating disorders [2]. Maladaptive weight control behaviors can be intensified by pressures in the sport environment and lead to detriments in health and performance [2].

Eating disorders (ED) are prevalent in both female (14%) and male (3%) elite high school athletes (*n*=611) [3]. An ED is a diagnosed mental condition characterized by abnormal eating habits which threaten health [4]. Less severe irregular eating patterns used to improve body composition, known as disordered eating (DE), occur more often in sport than EDs [5]. EDs must meet diagnostic criteria, whereas DE occurs at the subclinical level. In 204 female collegiate athletes, 25% and 2% were classified as having DE and an ED, respectively, based on the 50-item Questionnaire for Eating Disorder Diagnosis (QEDD) [6]. Similar trends have been reported using the QEDD in males, where DE (16%) was more prevalent than EDs (1%) [7]. DE can be particularly difficult to identify in athletes, as overcompliance and commitment to training can be viewed as being a “good athlete” [8]. Although eating disturbances are common in sport, 18% (*n*=2,894) of NCAA coaches of female sports reported that they had never identified an athlete with an ED [9]. Moreover, 26% of coaches reported that they were aware of at least one athlete who was not identified as syptomatic while she was competing for them [9].

In some cases, athletes are unaware or misinformed of the energy cost of exercise, resulting in energy deficiency [10]. Ultimately, inadequate nutrition knowledge, weight control behaviors, and other attempts to achieve a more ideal appearance can result in low energy availability (LEA).

Energy availability (EA) [(dietary energy intake (DI) – exercise energy expenditure (ExEE) kcal/kg of lean body mass (LBM)/day] is the amount of energy remaining to support bodily functions after accounting for exercise [11]. EA is reduced by a decrease in DI, an increase in ExEE, or a combination of both. EA has mostly been studied in females in relation to the Female Athlete Triad, a syndrome of interrelated conditions including EA, bone mineral density (BMD) and menstrual function [12]. As a result, little is known about the impacts of LEA in males. LEA is defined as less than 30 kcal/kg of LBM/day [11] and can have detrimental effects on physiological function, health, and performance [13]. In previous research, reproductive function was impaired in regularly menstruating young females (*n*=29) at EAs lower than 20 kcal/kg of LBM/day [11]. Additional literature suggests that bone formation is disrupted at EAs lower than 30 kcal/kg of LBM/day [14]. Therefore, female athletes are recommended to follow a diet and exercise program that results in an EA of at least 45 kcal/kg of LBM/day to maintain energy balance, healthy menstrual function, and bone health [11, 15].

While males have been largely overlooked, research is beginning to investigate the impacts of LEA in males. Although the prevalence of DE and EDs are typically lower, research suggests that males experience similar weight pressures as females. Wilson et al. [16] found that 32% (*n*=138) of male collegiate athletes were attempting to lose weight, with caloric restriction and excess exercise being the most commonly used methods.

Attempts to achieve a more desirable body composition, shape, size, or weight can lead to LEA and negatively impact health [13]. Decreased BMD and hormonal imbalances in sex hormone binding globulin and testosterone have been observed in male professional horse jockeys (*n*=20; age 25.9 ± 3.3) using chronic weight control measures [17]. In addition, decreased leptin and insulin levels were associated with LEA in exercising men (n=6), regardless of whether LEA was reached with or without exercise [18]. However, further research is needed to understand other impacts of LEA in males.

In 2014, the International Olympic Committee (IOC) released an update to the Female Athlete Triad called Relative Energy Deficiency in Sport (RED-S) [13]. RED-S is inclusive to men, a group previously excluded under the Female Athlete Triad, and describes the potential physical, psychological, and performance consequences of LEA in both males and females [19]. Athletes with LEA may experience components of the Female Athlete Triad along with a wide range of other health outcomes which RED-S tries to capture. Although RED-S was developed predominantly from research conducted on female athletes, the new term provides a framework for future research on males as well as other possible health side effects [13].

Pressures to modify body weight and composition can lead to unhealthy weight control behaviors. Although the prevalence of clinical EDs are low, subclinical symptoms are common in male and female collegiate athletes [7, 20–22]. Previous research has focused mainly on the health outcomes of LEA in females. To date, few studies have investigated the impacts of LEA in males [17, 18, 23]. Therefore, more research is needed to accurately estimate the prevalence of LEA in male and female athletes from a variety of sports. Identifying factors related to LEA is crucial in preventing and treating LEA in collegiate athletes. A more well-rounded understanding would aid in improving both coach and athlete awareness in promoting healthy behaviors to achieve optimal health and sport performance.

Problem Statement

The purpose of this study is to determine EA of Division I athletes and its relationship to ED risk, BMD, and perceived stress.

Research Questions

1. To what extent does the prevalence of low, reduced and adequate EA differ by sex?
2. To what extent does ED risk, body composition, and perceived stress differ by sex?
3. To what extent does EA relate to ED risk, BMD, and perceived stress in males?
4. To what extent does EA relate to ED risk, BMD, and perceived stress in females?

Hypotheses

1. No difference exists in the prevalence of low, reduced, and adequate EA by sex.
2. Females will have a greater ED risk and FM, lower LBM and BMD and no difference in perceived stress compared to males.
3. No relationship exists between EA and ED risk, BMD, and perceived stress in males.
4. No relationship exists between EA and ED risk, BMD, and perceived stress in females.

Delimitations

1. Male and female student-athletes (age 18 – 25 years) at the University of Idaho will be recruited for this study. Males and females not enrolled at the University of Idaho will not be eligible to participate.
2. Individuals with contraindications to exercise based on the American College of Sports Medicine (ACSM) and American Heart Association (AHA) risk stratification including uncontrolled hypertension, currently taking blood pressure medications, or have been diagnosed with cardiovascular disease, stroke, diabetes, thyroid, or kidney dysfunction will not be eligible to participate.
3. Participants less than 6 months post-surgery or major injury will not be eligible to participate.
4. Data collection will place on two days (between 16:00-21:00 hours), with no more than seven days between visits. On the first visit, participants will complete an informed consent, medical history, Eating Attitudes Test (EAT-26), and Perceived Stress Scale (PSS). Participants will then be given accelerometers (ActiGraphGT3X+), physical activity (PA) logs, and a username and password to complete an online food recall (Automated Self-Administered 24-Hour Dietary Assessment Tool; ASA24®). EA will be assessed on two weekdays and one weekend day. On the second visit, dual-energy X-ray absorptiometry (DXA) will be used for body composition measures. Participants will be offered information on ED risk, perceived stress, DI, energy expenditure, and body composition following completion of the study.

Limitations

1. Training volume and intensity, nutritional behaviors, and stress levels may differ during between participants who are in season versus out of season.

Assumptions

1. Accelerometers and PA logs can be used to estimate ExEE.
2. ASA24® can be used to accurately assess DI.
3. DXA is an objective, reliable, and valid instrument for measuring body composition.
4. EAT-26 is a useful screening tool to assess ED risk in athletes.
5. The PSS is a valid tool for measuring the perception of stress in a student population.
6. Participants will be truthful in the information they provide.
7. Participants will understand instructions as intended and complete testing to the best of their ability.
8. The researchers are trained and capable of using data collection instruments.

Definition of Terms

1. **Appendicular Skeletal Mass Index (ASMI):** A measure of age-related muscle wasting (sarcopenia) and is the appendicular skeletal muscle mass (ASM)/height^2 (kg/m^2) [24].
2. **Body Composition**: Proportion of FM to LBM in the body. FM includes essential fats needed to support daily functioning and excess non-essential fats. LBM consists of blood, water, muscles, bones, ligaments, tendons, and organs [25].
3. **Bone Mineral Density (BMD):** The amount of mineral matter per square centimeter in bones which is used to assess bone health. Can be measured using DXA [12].
4. **Disordered Eating (DE):** A variety of irregular eating patterns which do not meet criteria for a clinical ED [5].
5. **Dual Energy X-Ray Absorptiometry (DXA):** A whole body X-ray scan using small amounts of radiation to measure areal BMD. DXA is capable of diagnosing osteopenia and osteoporosis in certain populations and can also be used to assess body composition [26].
6. **Eating Disorder (ED):** A mental disorder characterized by serious disturbances in eating patterns consisting of anorexia nervosa, bulimia nervosa, and binge-eating disorder [4].
7. **Energy Availability (EA):** The amount of energy remaining to support bodily functions and metabolic systems after accounting for exercise [12]. EA is the difference between dietary energy intake and exercise energy expenditure, relative to LBM [14].

8. **Energy Deficiency:** Energy intake less than total energy expenditure [27].
9. **Female Athlete Triad:** Triad of interrelated conditions including EA, menstrual function, and BMD [12].
10. **Relative Energy Deficiency:** Condition that results in LEA even in a state of energy balance [13].
11. **Relative Energy Deficiency in Sport (RED-S):** Impaired physiological function including, but not limited to, metabolic rate, menstrual function, bone health, immunity, protein synthesis, cardiovascular health caused by relative energy deficiency [19].
12. **Visceral Adipose Tissue (VAT):** Fat tissue deposited around internal organs of the trunk, abdomen, and pelvis [28].
13. **Weight-Sensitive Athlete:** Athlete competing in a sport which emphasizes body composition, shape, size, and/or weight [29].

Chapter 2: Review of Literature

Around the world, individuals of all ages and abilities participate in sport. Sports can aid in physical development, improve fitness, and control weight while teaching valuable life lessons such as hard work, discipline, and teamwork. In children and adolescents, there is a general consensus that sport participation is associated with positive psychological and social outcomes [30]. In collegiate sports, male and female athletes (n=163) have self-reported improved health, development, and opportunities to meet others as the core benefits of sport [31]. In the 2010 NCAA GOALS survey, collegiate athletes (n=12,000) most commonly reported the team (23%) and friends (17%) as the best part of the student-athlete experience [32]. Therefore, the rise in collegiate sport participation has likely resulted from a combination of physical, mental, and social factors.

In the United States, sport is believed to support and expand the educational experience. Sport became part of the college experience in 1852, when Yale and Harvard competed in the first collegiate rowing race [33]. Today, over 460,000 student-athletes participate across 24 sports in colleges and universities in the United States [34]. Although all collegiate sports are governed by the National Collegiate Athletic Association (NCAA), athletes compete in different divisions (Division I, II, III) depending on school size and sports offered. Multiple divisions allow individuals of differing skill levels the opportunity to continue their education while competing in a sport they love.

Although playing sports provides clear benefits, the demanding nature can also contribute to a variety of health issues. Within collegiate sports, problems exist regarding athletes taking care of their bodies. Athletes have increased energy needs compared to non-athletes due to higher physical activity levels and must fuel their bodies to optimize performance and recovery. However, social pressures to be thin as well as unique pressures in the sport environment concerning body composition may challenge an athlete’s ability to meet nutritional requirements. Former female collegiate athletes (*n*=6) reported uniforms, teammates, appearance, fitness, and coaching attitudes as common factors influencing body image in the sport environment [35]. These sport-specific appearance and performance demands can result in detrimental health and performance consequences.

Energy Availability and Relative Energy Deficiency in Sport

Energy availability (EA) is the amount of energy the body has to support health and normal body functions after accounting for exercise [12]. EA is defined as the difference between dietary energy intake (DI) and exercise energy expenditure (ExEE) per kg of lean body mass (LBM) [11]. EA has primarily been studied in females in relation to the Female Athlete Triad, a syndrome consisting of EA, bone mineral density (BMD), and menstrual function [12]. However, the Female Athlete Triad excludes males and only considers two impacts of low energy availability (LEA). Therefore, in 2014, the International Olympic Committee introduced a new syndrome called Relative Energy Deficiency in Sport (RED-S) [13]. RED-S is inclusive to males and describes a wider range of health consequences resulting from LEA compared to the Female Athlete Triad [13].

RED-S is based on the concept of LEA and is impaired physiological function including, but not limited to, changes in metabolic rate, menstrual function, immunity, protein synthesis, endocrine pathways, and cardiovascular health [13, 27]. In addition, RED-S includes the psychological impacts that may precede or follow LEA, such as depression, irritability decreased concentration, and impaired judgement [13].

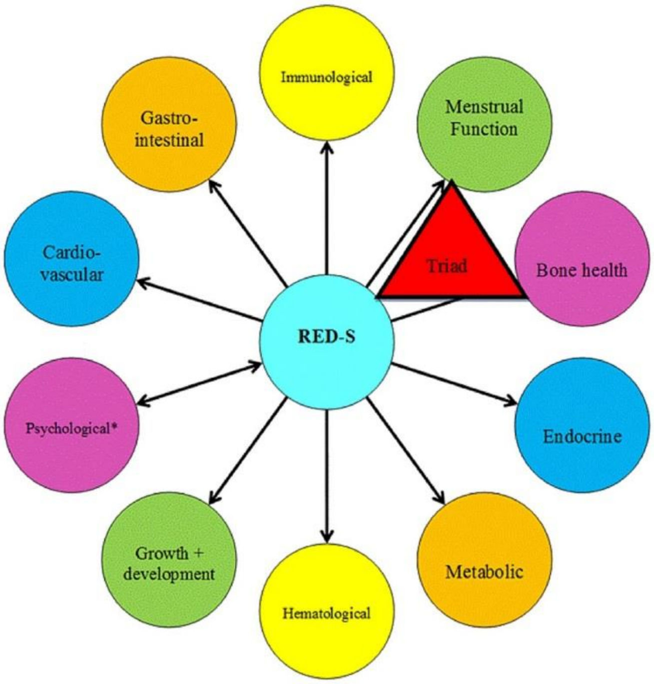

FIGURE 2.1 Potential Health Consequences of RED-S Comparison to Female Athlete Triad and a wide range of other consequences. Adapted from Mountjoy et al. [13].

Prevalence of Low Energy Availability

LEA is defined as less than 30 kcal/kg of LBM/day [11]. While optimum EA is unknown, 45 kcal/kg of LBM/day is suggested to maintain physiological function and energy balance [15]. LEA results from an increase in ExEE, a decrease in DI, or both.

Although energy requirements for health vary based on sex, body composition, and physical activity levels, average adult calorie needs range from 2,000-3,000 kcal/day for males and 1,600-2,400 kcal/day for females [36, 37]. However, training can increase and even quadruple energy requirements in athletes [10]. Noack et al. [38] found no significant difference in energy intake among female collegiate soccer players (*n*=11) and non-athlete controls (*n*=11). Soccer players in the previous study did not compensate for increased ExEE, resulting in energy deficiency (energy balance: -1281±514 kcal/day) [38]. Energy needs are complex and are dependent on individual and sport needs. Thus, it can be difficult for athletes to determine the correct intake for optimal performance. Therefore, it is possible that athletes may purposely (i.e. eating disorders) or inadvertently be in state of LEA [12].

Although differences in research methodology make it difficult to compare incidence of low (<30 kcal/kg of LBM/day), reduced (30-45 kcal/kg of LBM/day), and adequate (≥45 kcal/kg of LBM/day) EA, LEA has been reported to occur in both female and male athletes. Elite female synchronized swimmers (*n*=11; age 20.4±0.4) from the French national team were assessed during four weeks of intense training at three time points [39]. Schaal et al. [39] found that 100% of the swimmers fell below the threshold for LEA (<30 kcal/kg of LBM/day) at each time point. Similar findings have been observed in male (*n*=6) and female (*n*=4) competitive cyclists, with 90% of cyclists having LEA during at least one training period, and 70% having LEA across the entire season [23]. In addition, low and reduced EA has been reported as high as 92% in collegiate female track and field athletes (*n*=25) [40]. These findings indicate prevalence of LEA is high in both male and female competitive athletes and highlight a need for effective identification, prevention, and treatment of LEA.

Risk Factors for Low Energy Availability

Although energy deficiency can occur unintentionally, other purposeful, unhealthy weight control behaviors are common in sport and can place athletes at an increased risk for LEA. An eating disorder (ED) is a diagnosed mental condition characterized by abnormal eating habits which threaten health [4]. Individuals must meet specific criteria as outlined by the American Psychiatric Association (APA) to be diagnosed with one of the main EDs. The APA identifies anorexia nervosa, bulimia nervosa, and binge-eating disorder as the three main types [4]. Individuals with anorexia nervosa have an extreme fear of getting fat and use dieting to avoid weight gain [4]. Bulimia nervosa involves binge eating followed by compensatory actions such as vomiting. Individuals eat large amounts of food in a short time during a binge eating episode and often feel guilty or disgusted afterwards [4]. Binge eating disorder is classified as binge eating at least once per week for three consecutive months [4]. Disordered eating (DE) includes an array of abnormal eating behaviors which do not meet diagnostic criteria for an ED [12]. DE behaviors include binging, purging, vomiting, fasting, exercising to burn calories, and using diet pills, laxatives, or diuretics to control weight [4].

EDs and DE are concerns in athlete and non-athlete populations. Sundgot-Borgen & Torstveit [41] examined the prevalence of EDs and DE in Norwegian male and female elite athletes (n=1,620; F: n=660; M: n=960) and controls (n=1,696; F: n=780; M: n=916) using the Eating Disorder Inventory (EDI) and clinical interviews. Researchers found that more athletes (14%) than controls (5%; p<0.001) had DE or EDs [41]. In addition, DE and EDs were more prevalent in females (20%) when compared to males (8%; p<0.001) [41].

Martinsen & Sundgot-Borgen [3] conducted a similar study using the Eating Disorders Inventory-2 (EDI-2), the Hopkins Symptom Checklist (SCL-5), and a clinical interview to determine ED prevalence in female athletes (*n*=611) and controls (*n*=355). After the initial screening, a greater proportion of controls (51%) than athletes (25%, $p<0.001$) were identified as "at risk" for EDs, providing evidence of non-sport influences related to the development of weight control behaviors [3]. However, more athletes (7%) than controls (2%) were diagnosed with an ED after a clinical interview, suggesting that athletes may view dieting and other weight loss strategies as a normal part of sport [3].

Previous research on EDs differs in competitive level, sport type, and study methodology, making it difficult to directly compare findings. Still, there is general consensus that eating disturbances are more common in females than males [3, 21, 22, 41]. In addition, DE tends to occur more often than EDs. In female collegiate athletes (*n*=204), 1% (*n*=1) had a diagnosable ED but 25% (*n*=52) had DE according to responses on the 50-item Questionnaire for Eating Disordered Diagnosis (QEDD) [21]. In similar research on male collegiate athletes (*n*=203), 0% had an ED, but 19% (*n*=39) had DE [22]. While EDs are more severe than DE, DE occurs more frequently in sport. Therefore, special attention should be given to maladaptive weight control behaviors of all intensities to prevent health consequences associated with LEA [13].

Some research suggests that athletes competing in weight-sensitive sports are more likely to develop eating disturbances than those in non-weight sensitive sports [29, 42, 43]. Athletes competing in weight-sensitive sports have a greater emphasis placed on leanness and appearance which may contribute to additional pressure to reduce body weight than those competing in non-weight sensitive sports.

Weight-sensitive sports, such as dance, diving, long-distance running, and weight-lifting, place special attention on body composition, shape, size, and weight [29]. Whereas non-weight sensitive sports, such as basketball and golf, do not place as much pressure on appearance. Weight sensitive sports can be categorized into four main types: gravitational, weight-class, high body mass, and aesthetic [42]. Athletes in gravitational sports must move their body against gravity, as in jumping or sprinting. Smaller athletes with a greater strength-to-mass ratio have a competitive advantage over larger athletes with a lesser strength-to-mass ratio [42]. Sundgot-Borgen & Torstveit [41] found a greater prevalence of EDs among male athletes (n=960) in gravitational sports (22%) than those in endurance (9%) or ball game sports (5%; $p<0.05$). In weight class sports, such as wrestling and lightweight rowing, athletes are matched against others of the same size and are often required to lose mass quickly to compete in a specific weight class [44]. Extreme weight control and dieting have been reported as high as 94% in elite female (n=17) and 92% in elite male (n=24) athletes competing in lightweight rowing [45]. In high body mass sports, such as hockey and football, body weight is crucial for successful performance. Aesthetic sports, such as swimming, diving, and gymnastics, rely on the execution as well as beauty of the skills performed. In a study of female collegiate gymnasts (n=280) and swimmers/divers (n=134), 6% (n=26; gymnasts=6.1%; swimmers/divers= 7%) were classified with an ED and 26% (n=108; gymnasts = 29%; swimmers/divers = 21%) were classified as having DE [20]. Moreover, Sundgot-Borgen and Torstveit [41] reported that female athletes (n=660) in aesthetic sports (42%) had the highest prevalence of EDs when compared to endurance (24%), technical (17%) and ball game sports (16%).

To determine possible reasons for an increased incidence of EDs in weight sensitive sports, Petrie et. al. [6] investigated the amount of pressure female college athletes (*n*=442) experience from different sources regarding body size and/or weight. Athletes classified as having DE (*n*=81, 18%) reported significantly more pressure from teammates, judges, parents, friends, boyfriends/girlfriends, TV/movies, and magazines than those without DE ($p<0.05$). Consequently, special consideration should be given to female athletes in weight-sensitive sports who may be at an increased risk for ED and DE due to the nature of their sport.

Higher incidences of eating disturbances have also been observed in male athletes competing in weight-sensitive compared to non-weight sensitive sports. Chatterton & Petrie [7] found that 16% (*n*=117) of male collegiate athletes (*n*=732, aged 19.9±1.5) had DE. Of the male athletes with DE, those competing in weight-class sports (44%) were more likely to have DE compared to those in ball game (17%) or endurance (13%) sports [7]. However, no relationship between sport type and DE has also been reported in the male athlete population [22]. Although prevalence of ED and DE in males varies across the literature, males experience pressures related to body image and engage in weight control behaviors which can result in LEA.

Impacts of Low Energy Availability

RED-S refers to impaired physiological functioning caused by LEA in both males and females, which includes, but is not limited to menstrual function, bone health, metabolic rate, immunity, protein synthesis, and cardiovascular health [13, 27]. Although the wide range of consequences of LEA have not been fully investigated, detriments in hormonal, reproductive, and skeletal health have consistently been observed with LEA.

Menstrual Function

Eumenorrhea is defined as normal menstrual cycles occurring in females approximately every 28-days from puberty until menopause [12] and follows a pattern of follicular development, ovulation, development & regression of the corpus luteum, and menses [46]. A full cycle consists of the follicular phase (days 0-14), ovulation (day 14), and luteal phase (days 15-28) [46]. Gonadotrophic releasing hormone (GnRH) is released in pulses from the hypothalamus to regulate levels of follicle stimulating hormone (FSH) and lutenizing hormone (LH). FSH stimulates the growth of follicles and estrogen synthesis, while LH stimulates formation of the corpus luteum and release of the oocyte.

During the follicular phase, GnRH is released from the hypothalamus and signals the pituitary gland to increase concentrations of FSH and LH [46]. A surge in LH at the end of the follicular phase causes the release of the oocyte, known as ovulation. In the luteal phase, the corpus luteum secretes increasing amounts of progesterone and levels of FSH and LH decrease. Estrogen levels increase during the follicular phase, which helps grow the endometrium and prepare the uterus for a fertilized egg. If the egg is not fertilized, levels of progesterone and estrogen decrease and prepare for menses [46].

Each hormone plays a vital role in reproductive function and hormone imbalances associated with LEA can lead to an irregular or absent menstrual cycle [47]. Primary amenorrhea, secondary amenorrhea, and oligomenorrhea are all types of menstrual dysfunction [12]. Primary amenorrhea is no menarche by age 15 [48], secondary amenorrhea is the absence of three consecutive cycles post-menarche, and oligomenorrhea is a cycle length greater than 45 days [13].

Menstrual dysfunction has been estimated to be prevalent in 5% of women in the general population [49], but determining prevalence in college athletes is difficult due to methodological differences. Self-reported menstrual dysfunction was reported by 26% (*n*=29) of Division II athletes (*n*=112) from seven different sports [50]. Comparable rates of menstrual dysfunction (23%) have been observed in collegiate cross-country runners (*n*=300), with the majority having oligomenorrhea (18%) compared to amenorrhea (5%) [51]. In elite endurance athletes (*n*=40), 60% (*n*=24) had menstrual dysfunction based on gynecological assessment. Although athletes may ignore menstrual dysfunction or view it as a normal part of training, irregular or absent menses can indicate energy preservation resulting from LEA [5].

LEA has been shown to disrupt LH pulsatility in 29 young (19-23 years of age), sedentary, normally menstruating women [11]. This was tested by completing two treatments, once in balanced EA (45 kcal/kg of LBM/day) and one in one of three restricted EA treatments (10, 20, or 30 kcal/kg of LBM/day). Women at 10 and 20 kcal/kg of LBM/day had suppressed LH pulse frequency and increased LH pulse amplitude (all $p<0.04$;). However, LH pulse frequency and amplitude was not impacted at a slightly higher EA of 30 kcal/kg of LBM/day [11]. The authors concluded that 30 kcal/kg of LBM/day is sufficient to maintain normal reproductive function [11]. Similarly, Loucks, Verdun, & Heath [15] examined the effects of LEA on LH pulsatility in healthy, regularly menstruating women (*n*=9; aged 21±1.2). Participants each underwent a balanced (45 kcal/kg of LBM/day) and restricted (10 kcal/kg of LBM/day) EA treatment for four days while performing exercise at 70% of VO_2max [15].

Interestingly, LH pulse frequency was reduced to a lesser extent in the exercising women with LEA when compared to non-exercising women achieving LEA through dietary restriction ($p<0.03$) [15]. This finding indicated that the stress of exercise had no disruptive effects on LH pulsatility, apart from the energy cost on EA [15].

LEA can also impact regular functioning of the male reproductive system by changes in a variety of hormones. Hagmar, Berglund, Brismar, & Hirschberg [52] investigated hormone levels of Swedish male Olympic athletes (n=44) from weight-senstive (n=18) and non-weight sensistive (n=26) sports. Although all athletes fell within a normal range, athletes in weight-sensitive sports had significantly lower testosterone and leptin and higher concentrations of insulin-like growth factor (IGF-1; $p<0.05$) than non-weight sensitive athletes. In addition, Dolan et. al. [17] reported significantly lower concentrations of testosterone and higher concentrations of sex hormone binding globulin (SHBG), a hormone that decreases testosterone and estrogen availability, in male jockeys (n=20) when compared to age-matched controls (n=20). Changes in male endocrine markers suggest hormonal changes that parallel those seen in females, although more research is needed to confirm the impacts of LEA on the male reproductive system.

Bone Mineral Density

Bone is in a continuous process of remodeling, with osteoclast cells removing old bone and osteoblast cells forming new bone [53]. Remodeling repairs damage, prevents the accumulation of excess old bone, and supplies calcium and phosphorus when needed [54]. Mature bone cells, called osteocytes, control osteoblast and osteoclast activity to regulate homeostasis [54].

Osteocytes inhibit bone formation by secreting sclerostin, which inhibits osteoblast function. Furthermore, sclerostin stimulates the release of NFkb ligand (RANKL), stimulating osteoclast activity [55]. The process of bone turnover and the interaction between osteoclasts and osteocytes is shown in Figure 2.2. Osteocytes also communicate with calcium regulating hormones (parathyroid hormone, calcitriol, calcitonin), sex hormones (estrogen, testosterone), and other systemic hormones (growth hormone, thyroid hormone, cortisol) to regulate bone resorption and formation [53]. Absence or disruption of any of these hormones can impact bone mass and strength.

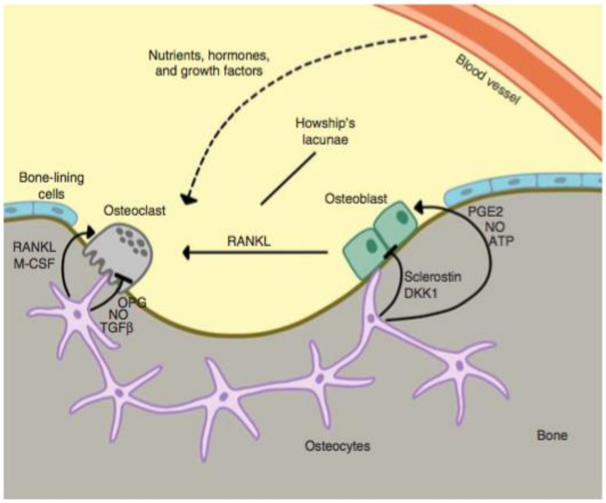

FIGURE 2.2 Bone Remodeling
Interaction of osteocytes, osteoblasts, and osteoclasts during bone remodeling. Adapted from Niedźwiedzki & Filipowska [55].

Dual-energy X-ray absorptiometry (DXA) is the gold standard for measuring BMD and is a useful tool in the diagnosis and treatment of bone loss. Z-scores are used in women prior to menopause and males under the age of 50 to compare BMD to people of the same age and size.

The International Society for Clinical Densitometry (ISCD) defines a Z-score above -2.0 as, "within the expected range for age," and score of -2.0 and lower as, "below the expected range for age" [56]. Weight-bearing sports, such as running, place greater loading on bones of the lower body and can increase BMD when paired with adequate intake. However, when mechanical stress is exerted on the body in sport and combined with LEA, impaired hormone function and increased bone turnover can occur [14]. Since athletes generally have 5-15% greater BMD than the general population due to the mechanical forces exerted on the skeleton during sport participation, even small decreases in BMD warrant further investigation in athletes [12]. Therefore, the American College of Sports Medicine defines low BMD in females as a Z-score between -1 and -2 and the presence of one or more secondary risk factors for fracture [12]. No defined cut-off has been established for male athletes [57]. Ihle & Loucks [14] used bone formation and resorption markers to examine the dose-response relationship between EA and bone turnover in healthy, menstrating women (n=29). Participants completed testing on two different occasions, once in a balanced EA treatment (45 kcal/kg of LBM/day) and one in one of the three restricted EA treatments (10, 20, or 30 kcal/kg of LBM/day) while diet and exercise were controlled. Restricted EA treatments at 10, 20, and 30 kcal/kg of LBM/day reduced bone formation marker concentrations (p<0.03;) and increased bone resorption marker concentrations at EA of 10 kcal/kg of LBM/day when compared to balanced EA [14]. Bone formation was impaired at much higher EAs (20 and 30 kcal/kg of LBM/day) than bone resorption (10 kcal/kg of LBM/day) [14]. Thus, an EA of at least 30 kcal/kg of LBM/day is needed to maintain normal bone remodeling processes.

Specific micronutrient deficiences can also lead to decreased BMD [49, 57].

Vitamin D, calcium, and phosphorus work together to keep bone formation and resorption tightly regulated. When Vitamin D levels fall below 30 ng/mL, parathyroid hormone levels increase and stimulate osteoclast activity [59]. In 223 male and female athletes, 33% (*n*=75) had low Vitamin D levels, with 31% (*n*=68) having insufficient (20-32 ng/mL) and 3% (*n*=7) being deficient (<20 ng/mL) [60]. Vitamin D is vital in calcium absorption as well as regulation of calcium and phosphorous levels [61]. Intakes below the reccommended dietary allowance (RDA) for calcium and phosphorus have also been reported using six-day food records in 10-12 year old female gymnasts (*n*=52) [62]. Researchers found that calcium (RDA: 1,300 mg/day; mean DI: 862.3 ± 164.8 mg/day) and phosphorus (RDA: 1,250 mg/day; mean DI intake; 976.7 ± 235.2) intakes were below RDAs by 34% and 22%, respectively [62]. Athletes are advised to perform sport activity with a balanced diet, meeting both macronutrient and micronutrient recommendations, to prevent low BMD and stress fractures.

Since bone remodeling activity is influenced by hormonal, mechanical, and nutritional, factors, deficiencies or imbalances in any of these areas can result in low BMD and stress fractures in athletes [12, 13, 55]. In females specifically, LEA has been shown to impact hormone balance and lead to menstrual irregularities [11]. Absent or irregular menstrual cycles have shown to impact bone resulting in decreased BMD [12]. In male professional horse jockeys (*n*=20) using chronic weight control measures, Dolan et al. [17] found that males athletes had significantly lower BMD than age-matched controls (n=20). Furthermore, jockeys had significantly higher concentrations of the bone resorption market urinary NTx/creatine than controls (athletes: 76.9 ± 29.5; controls: 55.9 ± 13.9 nmol mmoll^{-1}; $p<0.01$) [17].

Results from the previous study provide evidence of the serious bone implications of chronically low energy intake. Stress fractures, or microfractures in bone, are common in sport [54]. In a twelve-month prospective study of male (*n*=49) and female (*n*=46) track and field athletes, 10 males (21%) and 10 females (22%) sustained a total of 26 stress fractures, with the tibia (*n*=12, 46%) being the most commonly injured body part [63]. More recently, 32% (*n*=8) of female college track and field athletes (*n*=25) reported a history of one or more stress fractures while participating in their sport [40]. Athletes are reccommended to avoid bone injuries by practicing healthy exercise and eating behaviors [64].

Psychological Consequences

LEA can also have impacts on mental functioning such as depression, irritability, decreased concentration, and impaired judgement [13]. Stress is known to be particularly high in an athletic population, as individuals are expected to balance athletic, academic, and social demands [65]. Moreover, pressure from peers and coaches to achieve a more ideal body composition can add additional stress. Student-athletes have reported the college experience as a source of both eustress (positive stress) and distress (negative stress) [66]. Student-athletes may find it difficult to balance social activities with rigorous academic and athletic demands. In an interpretive study on stress and sport participation, student-athletes reported lack of social support and companionship when separated from their fellow athletes outside of the sport environment and feelings of isolation because non-athletes did not understand their life [66]. Social issues, such as feelings of isolation, contribute to pre-existing academic and athletic stress.

Stressors mentioned above can impact mental health, functioning, and worsen LEA. In turn, athletes may perceive life events and training as more difficult in a state of LEA [13].

A direct correlation was observed between change in cortisol levels and perceived fatigue (r= 0.76, *p*=0.02) in female synchronized swimmers (n=11) with LEA during 4 weeks of intense training [39]. In addition, male Olympic athletes (*n*=44) in weight-sensitive sports had higher scores for depression and anger than those in non-weight sensitive sports prior to competition [52]. While many factors contribute to LEA in athletes, it appears that psychological components such as perceived fatigue and stress are worsened by LEA [39, 52].

Conclusion

As the number of collegiate athletes continues to grow, governing officials, administrators, and coaches need to become informed on the health issues impacting student-athletes because they are a vulnerable population who have unique academic, athletic, and social challenges compared to regular college students [65]. Athletes must adequately fuel their bodies to support the demands of everyday life as well as athletic performance. Pressures in the sporting enviornment can make this especially challenging and too often results in the development of ED, DE, and LEA [41].

The Female Athlete Triad has contributed largely to the literature in regards to understanding EA, BMD, and menstrual function [12]. Moreover, controlled laboratory experiments have supported the detrimental consequences of LEA on reproductive and skeletal health [11, 15]. Yet, more research is needed to understand the diverse physiological and psychological consequences of LEA in both males and females. RED-S is a simple model that researchers can use as a framework to understand the more complex health issues resulting from LEA [13].

In order to better understand the various impacts of LEA, male and female Division I athletes will be recruited and measured for EA and examined for eating disorder risk, stress fractures, body compositon, stress, and menstrual function (females only). The present study will foster an increased understanding of the EA prevalence in free-living, collegiate student-athletes. Athletes will directly benefit by learning about their DI, ExEE, and current EA. Results will help all athletes, administrators, and coaches understand the dangers of LEA and direct attention to the importance of adequate nutrition for health and performance.

Chapter 3: Methods

Purpose

The primary purpose of this descriptive study is to determine the energy availability (EA) of male and female Division I athletes. Athletes will be classified as having low EA (<30 kcal/kg of lean body mass (LBM/day), reduced (30-45 kcal/kg of LBM/day), or adequate EA (>45 kcal/kg of LBM/day) [10, 66].

The secondary purpose is to determine to what extent eating disorder (ED) risk, body composition, and perceived stress differ by sex. The final purpose is to investigate the relationships between EA and ED risk, bone mineral density (BMD), and perceived stress in males and females.

Participants

Participants will be male and female Division I student-athletes at the University of Idaho (aged 18 – 25 years). Athletes will be convenience sample from track and field, football, volleyball, soccer, golf, basketball, and tennis. Student-athletes will be informed of the study’s purpose at team meetings and recruitment forms will be distributed to interested athletes. Participants will be asked to read and sign an informed consent prior to participation.

Individuals with contraindications to exercise based on the American College of Sports Medicine and American Heart Association (ACSM/AHA) risk stratification including uncontrolled hypertension, currently taking blood pressure medications, or have been diagnosed with cardiovascular disease, stroke, diabetes, thyroid, or kidney dysfunction will not be eligible to participate in the study. Participants will be a minimum of 6 months post injury prior to participation. The University of Idaho Institutional Review Board will approve the study prior to participant recruitment.

Instruments

Energy Availability

EA will be calculated using the following equation: dietary energy intake (DI) – exercise energy expenditure (ExEE) kcal/kg of LBM/day [11]. Information obtained from accelerometry, physical activity (PA) logs, dietary recall, and dual-energy X-ray absorptiometry (DXA) will be used to estimate EA.

DI will be measured on three days (two weekdays and one weekend day) using the Automated Self-Administered 24-Hour Dietary Assessment Tool (ASA24®). ASA24® is a web-based, self-administered, high quality dietary recall tool created by the National Cancer Institute (NCI). ASA24® was created using validated methods from the United States Department of Agriculture's Automated Multiple Pass Method (AMPM) [68]. AMPM is a 5-step process that uses cues, pictures, and icons to help participants remember and visualize food consumed over a 24-hr period. The convenience and accuracy of ASA24® will allow participants to complete dietary recall for without a researcher present and has been shown to perform well relative to true intakes [69].

Total daily and ExEE will be determined using accelerometers and PA logs. Participants will wear an accelerometer for three days total, two weekdays and one weekend day. Participants will also record waking daily activities in 15-minute intervals using PA logs. Accelerometers and PA logs will be used in combination to calculate ExEE of participants in free-living conditions. Although accelerometers will be worn for at least 600 minutes/day on the hip, only energy reported during exercise will be used to calculate ExEE and EA. Accelerometer use for activity counts has been validated using three to four days to achieve 80% reliability [70].

Eating Disorder Risk

The Eating Attitudes Test (EAT-26) will be used to determine ED risk. The EAT-26 is a screening tool to identify individuals who might need to seek clinical help, but does not provide ED diagnosis. The EAT-26 was used for the 1998 National Eating Disorder Screening Program (NEDSP) where over 35,000 people were screened, with over half of participants being college students. The instrument has shown to be a reliable, valid, and economical way to measure ED risk as well as an objective measure for symptoms of anorexia nervosa [71]. The EAT-26 has also been shown to be a useful tool for determining risk in athletes [72].

The EAT-26 consists of 26 questions based on three subscales; dieting, bulimia and food preoccupation, and oral control. A score of 20 or higher indicates a need for additional screening by a mental health professional. In addition, the EAT-26 includes five behavioral questions to identify more extreme weight control behaviors [71]. Individuals who have a positive score on any of the behavioral questions are recommended to seek further evaluation. In the present study, participants with a behavioral risk factor or score of 20 or higher were classified as being at increased risk for an ED.

Body Composition

BMD, fat mass (FM), lean body mass (LBM), appendicular skeletal muscle mass index (ASMI), and visceral adipose tissue (VAT) will be measured using DXA.

DXA is an accurate tool for measuring BMD in the lumbar spine, proximal femur, forearm, and whole body as well as whole-body composition [71–73].

The International Society for Clinical Densitometry (ISCD) definition will be used to identify male participants with low BMD. The ISCD defines a Z-score of -2 or lower as “below expected range for age” and a Z-score of greater than -2 as “within the expected range for age” [56]. The American College of Sports Medicine (ACSM) defines low BMD in females as a Z-score between -1 and -2 together with one or more secondary clinical risk factors for fracture [12]. Secondary risk factors include, but are not limited to, previous stress fracture, history of nutrient deficiencies, and hypoestrogenism [12]. Females with a Z-score between -1 and -2 along with one or more secondary risk factors for fracture will be classified as having low BMD.

Perceived Stress

The Perceived Stress Scale (PSS) is the most widely used psychological scale and will be used to measure the degree to which respondents appraise life events as stressful. Cohen et al. [76] developed the instrument as a global tool and therefore, the scale does not contain questions specific to any population group. The scale has been shown to possess substantial validity and reliability [77]. Participants in the present study will complete the PSS-10, which is a reliable and valid instrument for measuring perceived stress in college students [78]. The PSS classifies respondents as having low (0-13), moderate (14-26), or high (27-40) perceived stress.

Medical History Questionnaire

Medical history will be collected for all athletes to obtain health information including major injuries (i.e. stress fractures). Females will complete a separate section on menstrual function including age of menarche, regularity of menses, and use of contraceptive medications. Females with self-reported irregular or absent menstrual cycles will be classified as having primary amenorrhea, secondary amenorrhea, or oligomenorrhea.

Procedures

During the Spring and Fall 2017 semesters, the researchers will hold meetings with interested University of Idaho sports teams to inform student-athletes of the study. The researchers will collect contact information from interested student-athletes at the meeting and notify participants via text message to schedule a first visit. Participants will be informed to meet the researcher in the Physical Education Building in the Human Performance Laboratory (HPL), room 116. Data collection will take place on two separate days (between 16:00 – 21:00 hrs.), with no more than seven days between visits.

First Visit

Participants will be informed of the study's purpose and of their privacy and rights concerning participation in this study. Participants will be given an informed consent and be informed of their right to terminate the study at any time. After reading and signing the informed consent, participants will complete a medical history, EAT-26, and PSS.

Following completion of the questionnaires, participants will be instructed on how to properly wear the accelerometer and be given PA logs to record daily activities. Participants will be instructed to wear accelerometers on the hip for two week days and one weekend day during all waking activities. Participants will be given a username and password to complete two week days and one weekend day of ASA24®.

Researchers will then briefly explain procedures for the second visit, which will be scheduled before the first visit is completed. A reminder text will be sent one day prior to the second visit to inform participants of proper clothing need for the DXA scan.

Second Visit

Participants will return to the HPL (between 16:00 – 21:00 hrs.) with their accelerometer and three days of PA logs. After confirming wear time and completion of ASA24®, females will complete a DXA consent form to confirm absence of pregnancy. All participants must wear clothing free of metal and/or plastic (buttons, zippers, snaps, etc.). Participants will complete one non-invasive whole body DXA scan in the supine position using the Hologic DXA Scanner (Hologic Horizon™; Marlborough, MA). The scan will last approximately 5-7 minutes.

Athletes will be thanked for their participation and notified via text when results are complete. Participants will be given detailed explanations of DI, energy expenditure, ExEE, ED risk, perceived stress, and body composition.

Statistical Analysis

EA will be calculated using the following equation: (DI – ExEE) kcal/kg LBM/day and categorized into low (<30 kcal/kg LBM/day), reduced (30-45 kcal/kg of LBM/day), and adequate EA (>45 kcal/kg of LBM/day) [10, 66]. Descriptive analysis will be performed on dependent variables using measures of central tendency, variability and frequencies. A Chi-square test of independence will be performed to determine if EA category is dependent on sex. A Fisher's exact test will be used to determine differences in ED risk by sex. Independent group t-tests will be performed to compare differences in all variables by sex. Pearson correlations will be used to determine the relationship between EA and ED risk, BMD, and perceived stress in males and females. Significance will be accepted at $p<0.05$.

Chapter 4: Results

Description of Subjects

Table 4.1 shows participant demographics for those who completed the study (N=81, M=38, F=43). Males and females were similar in age, with males being significantly taller (p=0.001) and weighing more than females (p=0.001). On average, males were in the overweight category (25-30 kg/m^2) and females were in the normal weight category (18.5-25 kg/m^2) based on body mass index (BMI). Regarding race, the male sample was 73.6% white, 21.1% African American, and 5.3% Pacific Islander. The racial distribution of females was 81.4% white, 9.3% Asian, 2.3% African American, 2.3% Hispanic/Latino, and 4.7% fell into other categories. Most males (89.5% total population) were football and track & field athletes, whereas females were more evenly distributed across various sports, apart from track & field (39.5% total population).

TABLE 4.1 Participant Characteristics by Sex[1]

	Male (*n*=38)	**Female** (*n*=43)
Age	20.0±1.4	19.7±1.2
Height (m)	1.9±0.1*	1.7±0.1
Weight (kg)	94.2±25.3*	65.0±10.7
BMI (kg/m^2)	27.5±6.8*	22.3±2.7
Grade		
Freshman	31.6	32.6
Sophomore	36.8	32.6
Junior	13.2	16.3
Senior	5.3	14.0
5th Year Senior	13.2	4.7
Sport (%)		
Track & Field	50.0	39.5
Football	39.5	NA
Volleyball	NA	7.0
Soccer	NA	11.6
Golf	7.9	18.6
Basketball	NA	11.6
Tennis	2.6	11.6

[1] Mean ± SD (all such values)

BMI, body mass index; kg, kilograms; m, meters

* Indicates significant difference ($p < 0.05$) between males and females

Menstrual Function

Menstrual dysfunction was self-reported in 20.9% of females (*n*=9) based on the menstrual history questionnaire. Menstrual irregularities included oligomenorrhea (*n*=5; 11.6%), primary amenorrhea (*n*=3; 7.0%), and secondary amenorrhea (*n*=1, 2.3%). Contraceptive use was not controlled for, however almost half of the female participants reported current birth control use (*n*=21, 48.8%).

Energy Availability

Energy availability (EA), dietary energy intake (DI) and exercise energy expenditure (ExEE) are shown in Table 4.2. No differences were observed in EA by sex (*p*=0.995), however, on average both males and females fell into the reduced category (M: 41.1±13.7 kcal/kg of LBM/day; F: 41.1±12.6 kcal/kg of LBM/day). Males had significantly greater DI (M: 3190±1033 kcal; F: 2016±517 kcal; *p*=0.001) and ExEE (M: 372±183 kcal; F: 200±158; *p*=0.001) compared to females.

Figure 4.1 shows the distribution of low, reduced, and adequate EA by sex. The majority of the population (M: *n*=26, 68.4%; F: *n*=25; 58.1%) were in the low or reduced EA categories. More males (*n*=9; 23.7%) than females (*n*=5; 11.6%) were in the low EA category, although the difference was not statistically significant (*p*=0.205). The Chi-square test of independence revealed that none of the EA categories were dependent on sex (*p*=0.319).

All participants completed the online dietary food record for three days and macronutrient data can be found in Table 4.3. Males had significantly greater DI (M: 3190±1033 kcal; F: 2016±517 kcal; *p*=0.001), carbohydrate (M: 1332±412 kcal; F: 950±296 kcal; *p*=0.001), fat (M: 1209±513 kcal; F: 719±218 kcal; *p*=0.001), and protein (M: 651±309 kcal; F: 375±97 kcal; *p*=0.001) intake compared to females. However, when expressed as percent of total calorie consumption, males had significantly lower carbohydrate intake compared to females (M: 42.8±7.9%; F: 46.9±6.8%; *p*=0.010), and fell below the acceptable macronutrient distribution range (AMDR; 45-65%) for the average adult [79]. Males and females did not differ in carbohydrate consumption relative to body weight (M: 3.8±1.4 g/kg; F: 3.7±1.3 g/kg; *p*=0.930), but were both below the 6-10 g/kg/day recommendation for athletes [79]. Both males and females were above the AMDR for fat (M: 37.3±5.2%; F: 35.5±5.5%; AMDR: 20-35%) and within the AMDR for protein (M: 20.2±5.2%; F: 18.9±3.7%: AMDR: 10-35%). Males had significantly greater protein intake relative to body weight than females (M: 1.8±0.8 g/kg; F: 1.5±0.4 g/kg; *p*=0.024), and exceeded the 1.2-1.7 g/kg/day recommendation for aerobic and resistance-trained athletes [79].

TABLE 4.2 Energy Availability by Sex[1]

	Male (*n*=38)	**Female** (*n*=43)
EA (kcal/kg of LBM/day)	41.1±13.7	41.1±12.6
DI (kcal)	3190±1033*	2016±517
ExEE (kcal)	372±183*	200±158

[1] Mean ± SD (all such values)
DI, dietary energy intake; EA, energy availability; ExEE, exercise energy expenditure; kcal, kilocalorie; kg, kilogram; LBM, lean body mass
* Indicates significant difference ($p < 0.05$) between males and females

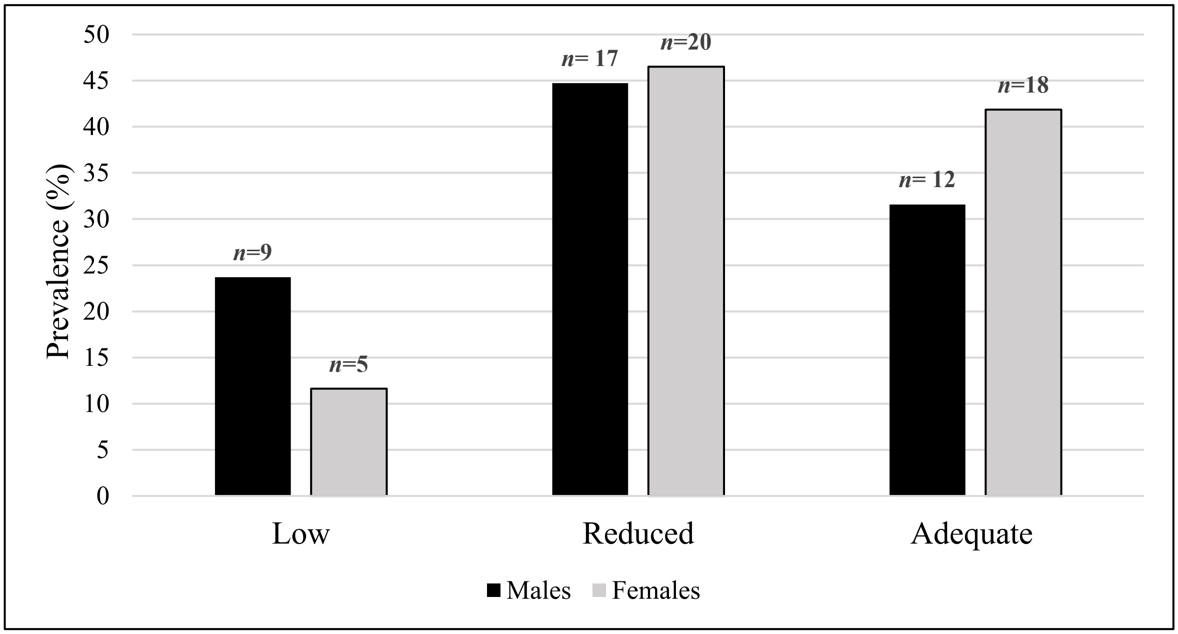

FIGURE 4.1 Energy Availability Categories by Sex[1]
Prevalence of low (<30 kcal/kg of LBM/day), reduced (30-45 kcal/kg of LBM/day), and adequate EA (≥45 kcal/kg of LBM/day)

TABLE 4.3 Dietary Characteristics by Sex[1]

	Male (*n*=38)	**Female** (*n*=43)
Dietary Energy Intake (kcal)	3190 ± 1033*	2016 ± 517
Carbohydrate (kcal)	1332 ± 412 *	950 ± 296
Carbohydrate (% of total intake)	43 ± 8*	46 ± 7
Carbohydrate (g/kg)	3.8 ± 1.4	3.7 ± 1.3
Fat (kcal)	1209 ± 513*	719 ± 218
Fat (% of total intake)	37 ± 5	36 ± 6
Protein (kcal)	651 ± 309*	375 ± 97
Protein (% of total intake)	20 ± 5	19 ± 4
Protein (g/kg)	1.8 ± 0.8*	1.5 ± 0.4

[1] Mean ± SD (all such values)
g, gram; kcal, kilocalorie; kg, kilogram;
* Indicates significant difference ($p < 0.05$) between males and females

EAT-26

The average EAT-26 score was 4.7±4.6 for males and 4.6±0.8 for females (*p*=0.905). A total of four males (10.5%) and four females (9.3%) were classified as having increased ED risk. Athletes with scores ≥20 and/or positive responses to behavioral questions were identified as having an increased ED risk. All male participants scored <20 on the EAT-26 assessment, however four were identified as having increased ED risk based on affirmative responses to behavioral questions. Males self-reported binge eating (*n*=1), laxative, diet pill, and/or diuretic use (*n*=1), exercising more than 60 minutes/day to control weight (*n*=1), and losing more than 20 pounds in the past six months (*n*=1). Of the four females identified as having increased ED risk, two females scored ≥20 and two answered affirmatively to one or more of the behavioral questions reflective of disordered eating. Females identified as having increased ED risk based on behavioral questions reported binge eating (*n*=2) and the use of laxatives, diet pills and/or diuretics to control weight (*n*=1).

Body Composition

Bone mineral density (BMD), Z-scores, fat mass (FM), visceral adipose tissue (VAT), lean body mass (LBM), and appendicular skeletal muscle mass index (ASMI) are shown in Table 4.4. Males had significantly greater BMD than females (*p*=0.001). All male participants were within the expected BMD range for age as defined by the International Society for Clinical Densitometry [56] definition of a Z-score above -2.0. One female was identified as being at risk for low BMD based on ACSM guidelines, and had a Z-score between -1 and -2 [12]. However, the female identified had no previous stress fractures or secondary risk factors, and therefore was not classified as having low BMD [12]. A total of 11 stress fractures were self-reported by seven athletes (M: *n*=2; F: *n*=5). Previous stress fractures were reported in the foot (*n*=6), wrist (*n*=3), arm (*n*=1), and back (*n*=1). Males had significantly lower FM (M: 20.5±7.7%; F: 26.9±5.2%; *p*=0.001) and greater LBM (M: 75.7±7.3%; F: 69.4±5.2%; *p*=0.001) compared to females. Males had significantly greater VAT compared to females (M: 79.3±38.6 cm^2; F: 45.0±18.8 cm^2; *p*=0.001), but both males and females had low cardiovascular disease (CVD) risk on average, based on previously established cutoffs (low risk: <105 cm^2; moderate risk: 106-109 cm^2; high risk: >140 cm^2) established by Nicklas et al. [80]. Three males and zero females were identified as having high risk for CVD based on VAT estimates. In addition, males had significantly greater ASMI (M: 9.7±1.7 kg/m^2; F: 6.9±0.7 kg/m^2; *p*=0.001) compared to females. However, males and females were above ASMI cutoffs (M: <7.40 kg/m^2; F: <5.14 kg/m^2) established for healthy maintenance of skeletal muscle for a person's height [81].

TABLE 4.4 Body Composition Variables by Sex[1]

	Male (*n*=38)	**Female** (*n*=43)
BMD (g/cm^2)	1.4±0.1*	1.2±0.1
Z-score	1.4±1.1	1.0±1.2
FM (%)	20.5±7.7*	26.9±5.2
FM (kg)	21.0±13.7	17.7± 5.7
VAT (cm^2)	79.3±38.6*	45.0±18.8
LBM (%)	75.7±7.3*	69.4±5.2
LBM (kg)	69.7±12.2*	44.8±6.4
ASMI (kg/m^2)	9.7±1.7*	6.9±0.7

[1] Mean ± SD (all such values)
ASMI, appendicular skeletal muscle mass index; BMD, bone mineral density; cm, centimeter; FM, fat mass; g, grams; kg, kilogram; LBM, lean body mass; m, meter; VAT, visceral adipose tissue
* Indicates significant difference (*p* < 0.05) between males and females

Perceived Stress

Figure 4.2 shows the prevalence of low (0-13), moderate (14-26) and high (27-40) perceived stress by sex. Females had significantly higher perceived stress (16.9±6.2) compared to males (13.7±6.0; *p*=0.021). On average, females had moderate perceived stress whereas males had low perceived stress.

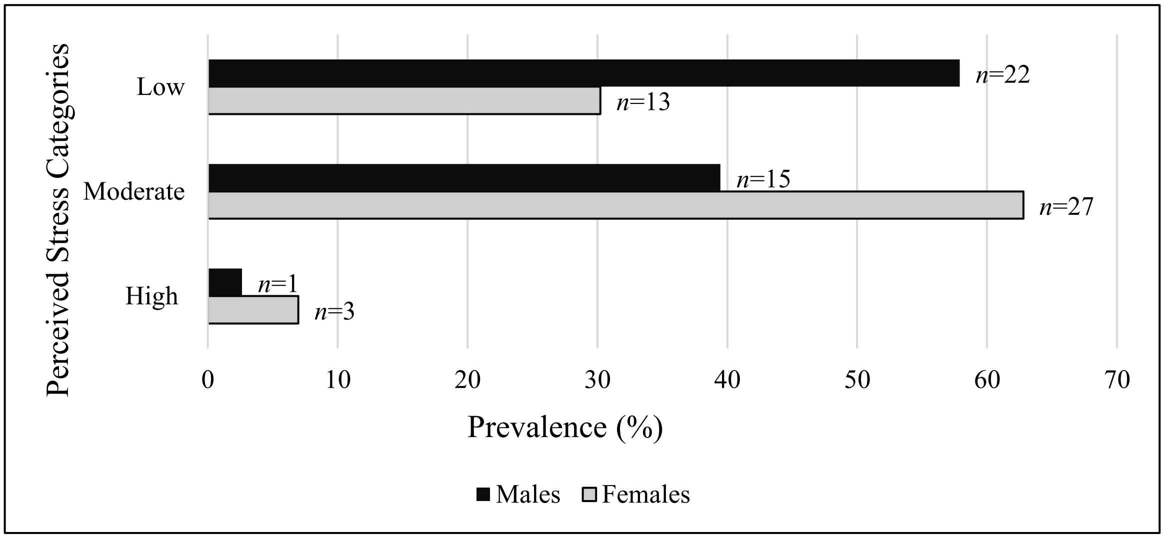

FIGURE 4.2 Perceived Stress Classification by Sex[1]

Prevalence of low (0-13), moderate (14-26) and high (27-40) perceived stress

Relationship Between Energy Availability and Dependent Variables

In males (*n*=38), EA was not significantly related to ED risk (r=-0.212, *p*=0.202, r^2=4.5%), BMD (r=-0.283, *p*=0.085, r^2=8.0%), or perceived stress (r=-0.137, *p*=0.412, r^2=1.9%). Figures 4.3 and 4.4 show Pearson correlations between EA and BMD as well as EA and perceived stress in males. In females (*n*=43), EA was not significantly related to ED risk (r=-0.225, *p*=0.147, r^2=5.1%), BMD (r=-0.047, *p*=0.764, r^2=0.2%), or perceived stress (r=-0.205, *p*=0.187, r^2=4.2%). Figures 4.5 and 4.6 show the relationships between EA and dependent variables in females.

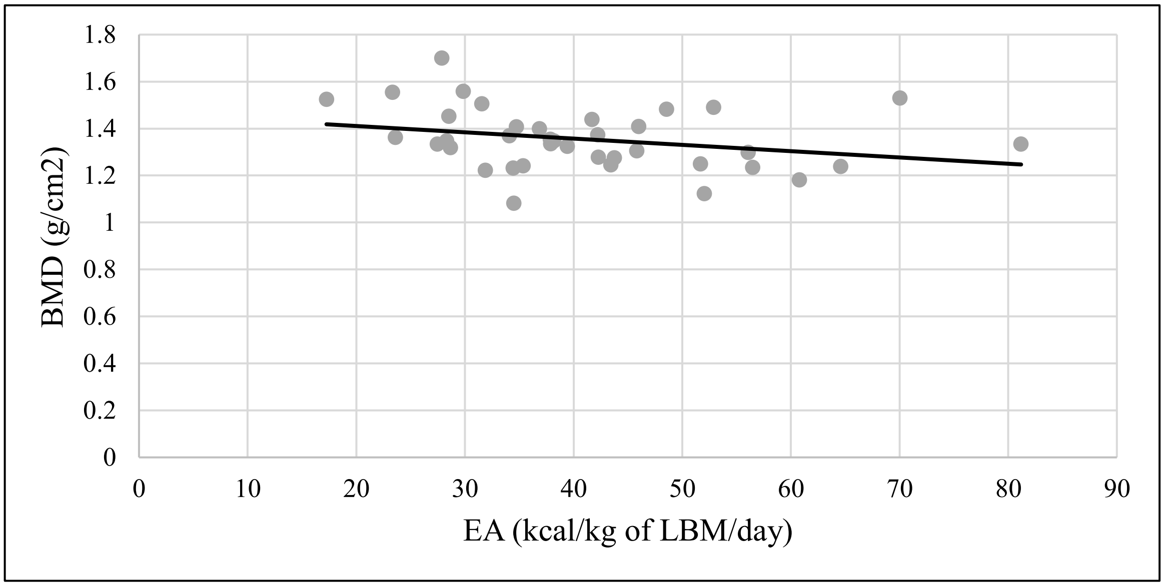

FIGURE 4.3 Energy Availability and Bone Mineral Density in Males

No significant relationship was observed between BMD and EA (r=-0.283, *p*=0.085, r^2=8.0%)

Cm, centimeter; BMD, bone mineral density; EA, energy availability; g, gram; kcal, kilocalorie; kg, kilogram; LBM, lean body mass

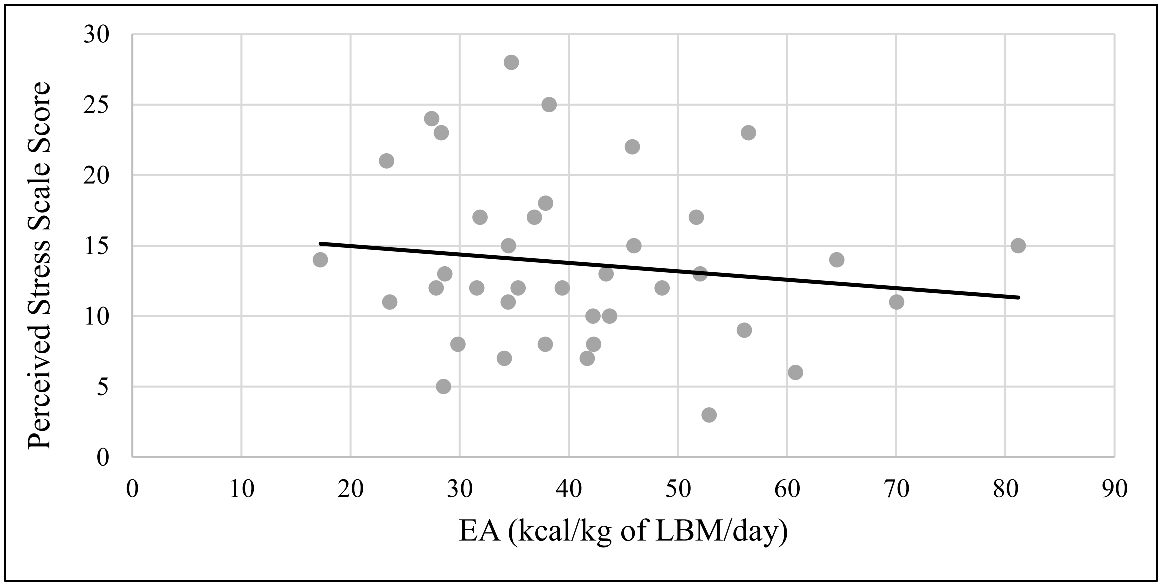

FIGURE 4.4 Energy Availability and Perceived Stress in Males

No significant relationship was observed between PSS and EA (r=-0.137, *p*=0.412, r^2=1.9%)

EA, energy availability; BMD, bone mineral density; kcal, kilocalorie; kg, kilogram; LBM, lean body mass

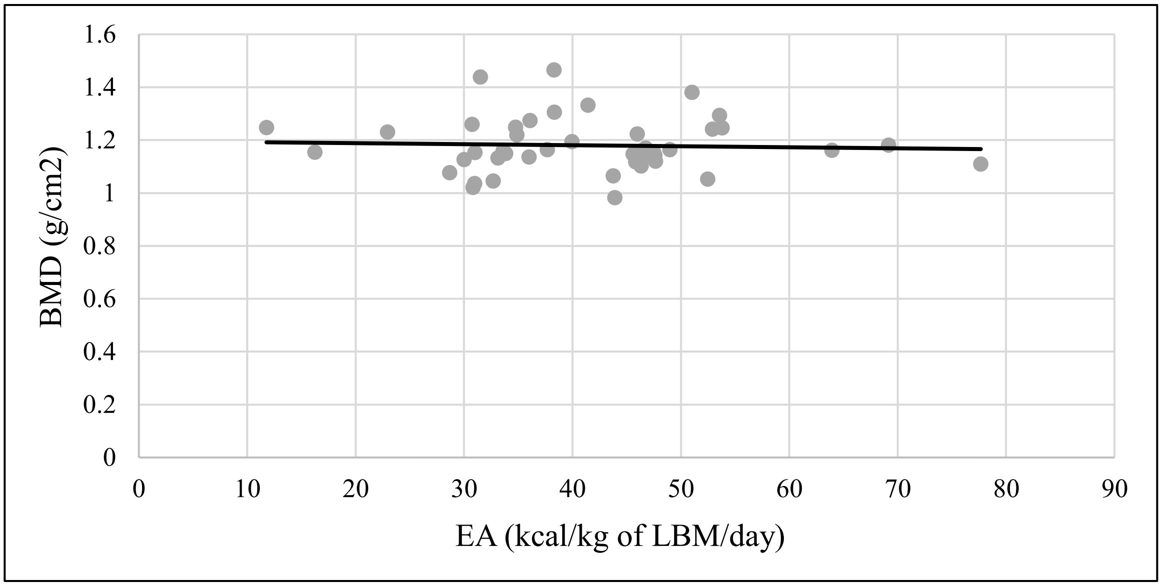

FIGURE 4.5 Energy Availability and Bone Mineral Density in Females

No significant relationship was observed between BMD and EA (r=-0.047, *p*=0.764, r^2=0.2%)

Cm, centimeter; BMD, bone mineral density; EA, energy availability; g, gram; kcal, kilocalorie; kg, kilogram; LBM, lean body mass

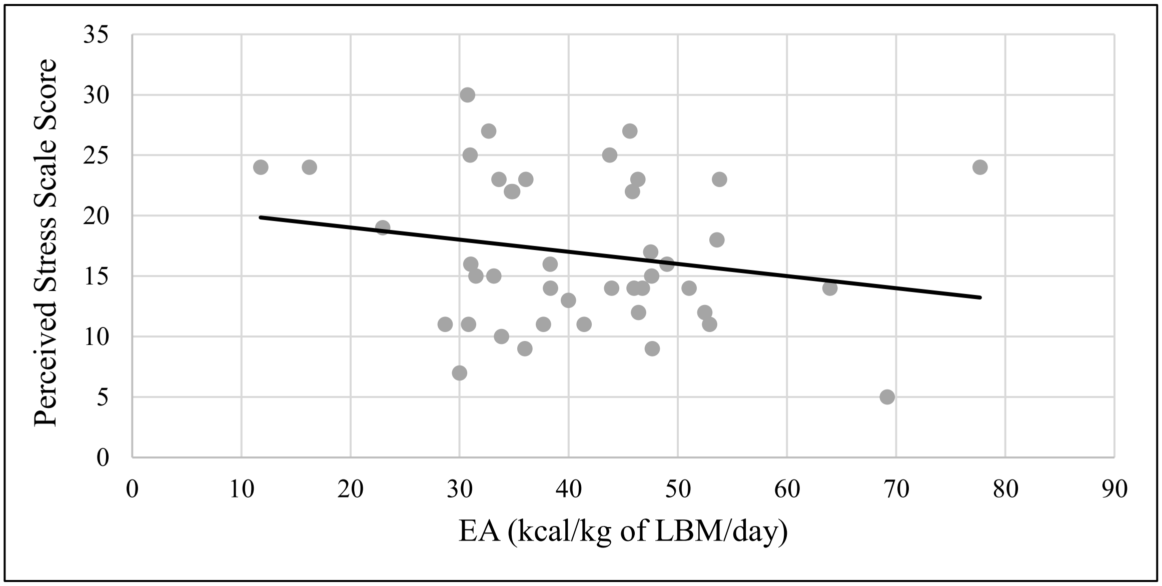

FIGURE 4.6 Energy Availability and Perceived Stress in Females

No significant relationship was observed between PSS and EA (r=-0.205, *p*=0.187, r^2=4.2%)

EA, energy availability; BMD, bone mineral density; kcal, kilocalorie; kg, kilogram; LBM, lean body mass

Chapter 5: Discussion

Pressure to meet performance and aesthetic demands can lead to body image issues, unhealthy weight control behaviors, and low energy availability (LEA) in sport. Although prior research has focused primarily on females, LEA has been shown to negatively impact physiological functioning in males and females [11, 14, 15, 23, 39, 77]. Consequently, a new condition, called Relative Energy Deficiency in Sport (RED-S), was proposed to encompass the wide range of physical and psychological consequences thought to result from LEA in both males and females [13]. To our knowledge, this is the first study to investigate the energy availability (EA) of male and female collegiate athletes and associations with eating disorder (ED) risk, BMD, and stress. The primary findings show a high prevalence of males (68%) and females (58%) with EA <45 kcal/kg of LBM/day and a need for further EA assessment, prevention, and treatment in both male and female collegiate athletes.

Energy Availability

The findings of the present study confirm the hypothesis that no difference exists in the prevalence of low, reduced, and adequate EA by sex. While males and females had similar EA, both had reduced EA on average. LEA was observed in 24% of males and 12% of females, at which increased bone turnover and impaired hormonal functioning has been shown to occur [11, 14, 39]. The prevalence of LEA observed in the present study is lower than reported by Viner et al. [23], who examined adult male (*n*=6) and female (*n*=4) cyclists (29-49 years) throughout an entire season and found 70%, 90%, and 80% had LEA during precompetition, competition, and off-season, respectively. Fluctuations in EA have also been observed in Division I female soccer players (*n*=19, 18-21 years) across the season, with EA lowest during midseason [82]. Within season variations in EA among cyclists and soccer players suggest that training phase, and therefore training demands, influence EA. Participants in the present study were recruited from a variety of sports, with the inclusion of in-season and out-of-season athletes, and weight-sensitive and non-weight sensitive athletes. It is possible that LEA prevalence in this study was lower than previously reported due to differences in training phase as well as sport type. Since weight-sensitive athletes face additional pressures to achieve a more ideal body composition [42], a higher prevalence of LEA may have been observed if athletes were selected from weight sensitive sports only. Although it is likely that sport type and training phase influenced EA, the majority of males (68%) and females (58%) fell below the 45 kcal/kg of LBM/day recommended to maintain adequate energy for physiological functions [12]. The incidence of low and reduced EA (<45 kcal/kg of LBM/day) in this study was higher than the 36% prevalence previously reported in high school female athletes [83] and similar to the 63% prevalence observed in female exercising women [67]. Inconsistencies in EA prevalence rates across the literature can be attributed to sport type as well as methodological differences in EA assessment.

While indirect calorimetry has been consistently used to verify total energy expenditure in the laboratory [11, 14, 15], no standardized method exists for quantifying exercise energy expenditure (ExEE) and EA in free-living individuals. The Compendium of Physical Activities, accelerometers, heart rate monitors, and physical activity (PA) logs have been used alone or in combination to estimate energy expenditure in the real world. However, differing definitions of ‘exercise’ make methodological comparisons increasingly difficult, even when the same instruments are used to determine ExEE. When EA was measured with four different methods, estimates varied by 30% [84].

Although the literature is unclear as to what activities should be included as exercise, all planned, structured, repetitive PA aimed at improving or maintaining fitness was included as ExEE [85]. In the current study, accelerometer counts were converted to kcals using ActiGraph regression equations, which have all been reported to underestimate vigorous activity compared to indirect calorimetry [86]. Thus, the Freedson Combination ('98) equation was used, which has been shown to give close energy expenditure estimates for low and moderate activity when compared to indirect calorimetry [86]. PA measurements using accelerometers for seven consecutive days have shown minimal time in vigorous PA (vigorous= >5725 counts per minute; 3.3±6.56 minutes/day) in a college population [87]. Even though vigorous PA accounts for a small percentage of waking hours, it is likely that collegiate athletes spend more time in vigorous exercise when compared to normal university students. Since only ExEE is considered when calculating EA, underestimation of vigorous PA could have a greater impact than when considering total daily energy expenditure. Average ExEE was only 372 kcal/day for males and 200 kcal/day for females, which appears low, as Division I athletes can train as much as 4 hours/day. It is possible that a larger percentage of athletes in this study had low or reduced EA than were reported due to the unexpectedly low ExEE reported by the accelerometers. Low reported ExEE may also be explained by the time of year for data collection, with some athletes being out-of-season and others nearing conference championships.

Dietary energy intake (DI) is another key component in EA, and our analysis showed that males had a significantly greater DI (M: 3190±1033 kcal; F: 2016±517 kcal; p=0.001) compared to females.

Although energy requirements vary greatly by sport, DI in males in the present study were similar to those reported by Cole et al. [88] in Division I football players (*n*=28) using three-day diet records (DI: 3288±92 kcal). In addition, DI in females was comparable to those observed in collegiate female track and field athletes (DI: 2211±582 kcal) using ASA-24® [40]. In regards to macronutrients, males were below (42.8±7.9%) and females were within (46.9±6.8%) the acceptable macronutrient distribution range (AMDR) for carbohydrate intake (45-65%) suggested for the average adult [79]. However, both males and females (M:3.8±1.4 g/kg; F: 3.7±1.3 g/kg) were substantially below the 6-10 g/kg/day recommendation for athletes [79]. Insufficient intake can be particularly detrimental to endurance athletes, who have increased carbohydrate needs [89]. Moreover, it is unknown if athletes were knowingly restricting carbohydrate intake, or if nutrition education is needed to inform athletes of carbohydrate demands. In sports, particularly those which are weight-sensitive, athletes with a greater strength-to-mass ratio tend to have a competitive advantage [42]. Therefore, nutrition strategies aimed at losing fat mass (FM) while maintaining lean body mass (LBM) may be beneficial for athletes seeking a leaner body composition. Lower carbohydrate and higher protein intakes have been shown to decrease FM and preserve LBM during periods of DI restriction [90]. Aerobic and resistance trained athletes are recommended to consume 1.2-1.7 g/kg/day of protein [79], but recommendations can be as high as 2.0 g/kg/day during caloric deficit [91]. In this study, males (20.2±5.2%) and females (18.9±3.7%) were both within the AMDR for protein (10-25%) however when adjusted for body weight, females were within (1.5±0.4 g/kg/day) and males exceeded (1.8±0.8 g/kg/day) the recommendation defined by the American College of Sports Medicine, American Dietetic Association, and Dietitians of Canada joint position stand statement [79].

In the case of DI deficit and LBM attenuation, males and females were under the 2.0 g/kg/day recommendation [91]. Although 68% of males and 58% of females had low or reduced EA in the present study, it is unclear whether lower carbohydrate intake and higher protein intakes had a significant impact on sport performance and/or body composition because dietary characteristics were only collected at one time point. Both males and females had fat intakes (M: 37.3±5.2%; F: 35.5±5.5%) above the AMDR for fat (10-35%) [79]. This could pose a potential issue as it has been previously suggested by Burke et al. [89] that athletes should consume less than 30% of total DI from fat in order to maintain adequate carbohydrate and protein consumption. It is possible that high fat intake observed in the present study contributed to low carbohydrate consumption. Low carbohydrate, possible adequate protein, and high fat intakes suggest that collegiate athletes, coaches, and trainers could all benefit from nutrition education within athletics [92].

EAT-26

Clinical EDs and subclinical DE can be particularly detrimental for collegiate athletes due to their rigorous training schedules and increased ExEE. Responses to the EAT-26 identified a total of eight athletes (M: *n*=4, 10.5%; F: *n*=4, 9.3%) with increased ED risk. Males and females had similar ED risk, which does not support the hypothesis that females would have greater ED risk when compared to males. However, ED and DE prevalence has been previously shown to vary by sport type and sex, occurring in 6-45% of females and 0-19% of males [93]. Our findings are similar to those of Beals & Manore [94], who identified 15% of female collegiate athletes (*n*=425) as being at increased risk for an ED. Contrary to the current study, Day et al. [40] identified no females as having increased ED risk in a sample of collegiate track & field athletes (*n*=25) when using the EAT-26.

Our results agree with those of Rosendahl et al. [95], who reported 10.4% (*n*=38) of male adolescent elite athletes (*n*=366; 15.7±1.2 years) having increased ED risk based on the EAT-26. The Questionnaire for Eating Disorder Diagnosis (QEDD) has also been used to determine ED prevalence among collegiate athletes. Petrie et al. [22] observed DE in 20% of male collegiate athletes (*n*=203), which is similar to the DE in 16% of male collegiate athletes (*n*=732) reported by Chatterton & Petrie [7] when using the QEDD. Variations in ED and DE prevalence may be partly due to the fact that no screening tool has been established specifically for an athletic population. While the development of a new assessment tool could be beneficial in identifying maladaptive eating behaviors, it is also possible that ED or DE is not a reliable indicator of LEA [67].

In the present study, there was a relatively low incidence of increased ED risk (M: *n*=4, 10.5%; F: *n*=4, 9.3%) especially when considering the high prevalence of low or reduced EA that was observed (M: 68.4%; F: 58.1%). Similarly, data from Melin et al. [67] observed that only 28% (*n*=7) of female endurance athletes (*n*=25) with low or reduced EA were identified with an ED or DE. It may be that ED or DE alone cannot accurately identify individuals with energy deficiency [67]. Many athletes in the present study had low or reduced EA, despite self-reported normal eating patterns. These findings suggest that athletes may be unaware of increased energy needs and unintentionally be in an energy deficit. In addition, these findings support the RED-S framework that EA cannot be described completely by one or two components, it is the combination of many factors that aid in the ability to identify LEA.

Body Composition

A significant difference was observed by sex in bone mineral density (BMD) which supports the hypothesis that males would have significantly greater BMD when compared to females (*p*=0.001). All male athletes in the present study had healthy BMD and were within the expected range for age as defined by a Z-score above -2 [56]. One female had a Z-score between -1 and -2, but was not classified as having low BMD due to the absence of a secondary risk factor for fracture [12]. EA was not significantly related to BMD in males (*p*=0.085) or females (*p*=0.764). These results are meaningful because even though athletes were classified with normal BMD, many were still in the low or reduced EA category. Similarly, LEA has been shown to occur without dramatically impacting BMD in the Female Athlete Triad [12]. Although physiological and psychological consequences resulting from LEA are interrelated [13], conditions are not always present simultaneously.

In a healthy adult, osteocytes and osteoblasts work together to recycle and form new bone tissue, resulting in little to no change in BMD [55]. However, when EA is <30 kcal/kg of LBM/day, altered hormonal concentrations of bone formation and resorption markers have been shown to occur [14]. Changes in bone turnover markers have been observed in young women (*n*=29, 21±1 years) following five days of restricted EA treatments (10, 20, and 30 kcal/kg of LBM/day) [14]. In addition, significantly higher bone resorptive activity and low bone mass has been reported in male professional horse jockeys (*n*=20) compared to age-matched controls (*n*=20) [17]. Although EA was not measured in the previous study [17], professional horse jockeys (*n*=21) have been shown to engage in chronic dieting measures, including sauna use (*n*=18; 86%), exercise to induce sweating (*n*=17, 81%), and restriction of energy intake (*n*=15, 71%) [96]. Therefore, decreased BMD observed in professional horse jockeys is likely the result of years of inadequate DI and LEA. Normal bone health despite LEA in this study may be partly due to the fact that bone deterioration is a slow process, and detectable decreases in BMD only occur after chronic energy deficiency. Therefore, it is possible that collegiate athletes in this study were not in LEA for a long enough period to induce detectable changes in BMD. Research by Viner et al [23] found no significant differences in spine or hip BMD among competitive cyclists (*n*=10; M: *n*=6; F: *n*=4) across a 10-month season, despite consistent LEA and inadequate micronutrient intake. Thus, the time frame required to observe decreased BMD may partially explain why EA was not related to BMD (M: *p*=0.085; F: *p*=0.764) in our study. These findings further support the notion that other factors in addition to BMD should be considered when assessing EA. In females, irregular or absent menstrual function, known as amenorrhea, has long been used to identify individuals needing further medical assessment [5]. Prolonged, absent menstrual cycles are associated with hypoestrogenism, which results in increased bone turnover [5]. Although most participants in the present study had normal menstrual function, dysfunction was self-reported in 21% of females in the form of primary amenorrhea (*n*=3), secondary amenorrhea (*n*=1), and oligomenorrhea (*n*=5). Ultimately, early prevention, identification, and treatment are important in proper growth and development as well as maintenance of optimal BMD [97].

A significant difference was found in FM and LBM by sex (all *p*=0.001). Males had significantly lower FM (M: 20.5±7.7%; F: 26.9±5.2%) and greater LBM (M: 75.7±7.3%; F: 69.4±5.2%) compared to females, which supports our hypotheses and previous research [98–100]. However, athletes in the present study had a greater FM% on average, and therefore lower LBM%, than the reference values observed by Santos et al. [101] in male (*n*=339; FM: 13.9%) and female (*n*=143; FM: 23.5%) athletes (16-45 years) from 21 sports. Body composition is known to vary by sex, sport, and position, so it is not surprising that our results differ from reference values previously reported.

Carbuhn et al. [102] examined the body composition of female collegiate athletes (*n*=67) from five sports (softball: *n*=17; basketball: *n*=10; volleyball: *n*=7; swimming: *n*=16; track jumpers and sprinters: *n*=17) using dual-energy X-ray absorptiometry (DXA). Differences were observed in LBM (g) and total mass (g), with volleyball and basketball athletes having the highest values [102]. In addition, track jumpers and sprinters had significantly lower total mass (kg), FM (g) and FM (%) compared to all other athletes (all $p<0.05$) [102]. Variations in body composition reflect both sport-specific demands as well as the somatotype advantageous to be successful in a particular sport [102]. Therefore, "optimal body composition" varies depending on sport type as well as position within the sport. In a sample of collegiate track and field athletes (M: *n*=31; W: *n*=29), separated by event groups, Hirsch et al. [103] reported significantly greater total body mass (kg), FM (kg) and percent fat in throwers compared to all other event groups (all $p<0.05$). Moreover, further differences were seen between multis and sprinters, with sprinters having a lower body mass (kg) [103]. Differences in body composition by position type have also been observed in male collegiate football players (n=44; age: 19±1 year) [104]. Therefore, a lean and muscular body composition may be ideal for sprinters and jumpers who need to propel their bodies against gravity, but not optimal for throwers and football players who need greater mass in order to exert strength and power [105].

Perceived Stress

Although unique athletic, academic, and social pressures have all been shown to contribute to perceived stress in student-athletes [66], females in this study had significantly greater perceived stress than males ($p=0.021$). Men and women have been shown to react differently to stress, both psychologically and biologically [106].

Women are more likely to report symptoms associated with stress [107], which may have contributed to higher stress scores in female athletes. Females were in the moderate perceived stress category (score: 16.9±6.2) whereas males were in the low perceived stress category (score: 13.7±6.0) on average. Scores in this sample of collegiate athletes are comparable to established norm groups from the L. Harris Poll (*n*=2,387) [77], which show that males tend to have lower perceived stress (score: 12.1±5.9) than females (score: 13.7±6.6) [77]. Low-moderate stress levels indicate that athletes in this study felt confident in their abilities to manage stress and overcome challenges associated with being a student-athlete.

Stress was not related to EA and our results did not offer support for the consideration of psychological factors proposed to contribute and/or result from LEA [13]. However, Schaal et al. [39] found that perceived fatigue was inversely related to EA in a sample of female elite synchronized swimmers (*n*=11), providing support that energy deficiency has psychological consequences that can directly impact training. Athletes in a state of energy deficiency may not be able to optimally perform, which can in turn increase stress, and lead to further detriments in performance. In-season and out-of-season athletes were included in our sample, which make it unclear if pressures directly related to athletic performance significantly impacted stress. In addition, stressors other than those related to athletic performance may have had a greater impact on in-season versus out-of-season athletes. For example, in-season athletes are required to travel for competitions, resulting in missed classes and less time for academic responsibilities, potentially increasing perceived stress. Therefore, it is possible that significant relationships between overall stress may have been found if athletes were separated by in-season versus out-of-season. Further research is needed to determine if psychological indicators can be used to successfully identify athletes “at-risk” for LEA or if stress is a byproduct of LEA.

Limitations & Strengths

Energy intake was assessed using ASA24®, a self-report online dietary recall tool. Although ASA24® is a validated, multiple pass method that has been shown to perform well relative to true intakes [69], adults have been shown to underestimate energy intake by approximately 15% [108]. However, participants were instructed on how to correctly use ASA24® and to maintain normal dietary habits. Another limitation was the use of self-report methods to identify athletes with increased ED risk. Although clinical interviews are the preferred method for identifying ED and DE [10], they were not feasible in this study. Since the EAT-26 is not capable of diagnosing an ED, the results should be compared to other research using self-report questionnaires. In addition, contraceptive use was not controlled for and approximately 50% of females reported current birth control use. It is possible that contraceptive use masked menstrual irregularities resulting from LEA. Our findings may be limited to other Division I universities without a sports dietician, as athletes in the present study did not have access to nutrition services through the athletic department. Moreover, it is unknown how much low or reduced EA is based on other factors such as nutrition knowledge, access to food, and ability to cook.

Strengths include a relatively large sample size (*n*=81), representative of multiple sports from a single Division I university. Our study had a low drop-out rate, with 81/100 recruited student-athletes who completed the study. In addition, all testing procedures took place at a specific time of day between 16:00-21:00 hours and the gold-standard for bone mineral density was used for body composition assessment (DXA). Participants were given detailed reports including DI, energy expenditure, EA, ED risk, body composition, and perceived stress following completion of the study.

Implications

Student-athletes have higher athletic and academic expectations to remain eligible for active student-athlete status compared to requirements of an average college student. Rigorous training demands coupled with inadequate dietary intake can be particularly detrimental to performance, but more importantly long term health. The sample of student-athletes recruited for this study was from a small, Division I university that does not have access to sports nutrition services, which differs from larger university athletic programs who employ sports dieticians and offer healthy food options in athletic dining halls. In the current study, dietary analysis revealed that males and females did not meet carbohydrate recommendations for an athletic population and exceeded fat recommendations. Therefore, it seems that athletes would greatly benefit from basic nutrition education and support in order to optimize overall health and performance. Aside from diet, athletes are not being screened for other health parameters, such as ED risk, body composition, and stress. More screening would be beneficial in preventing, identifying, and treating health problems in this population. Screening would also help to direct the athlete's attention to the importance of adequate nutrition to optimize health, performance, and recovery.

Conclusion

In conclusion, this is the first study to seek out a better understanding of the physical and psychological impacts of LEA in male and female Division I collegiate athletes. Males and females on average fell into the reduced EA category, and a large portion of males (68%) and females (58%) were in either the low or reduced EA category. Moreover, no differences were observed in EA or ED risk by sex. This is an equally important finding, as it supports the notion that LEA is prevalent in the male athlete population similarly to the female athlete population. However, further research is needed to develop a standardized method of measuring EA in free-living individuals to allow for comparisons between studies. Even though athletes were within a normal BMD range, chronic energy deficiency over time could result in both short and long term health consequences if left untreated. Although perceived stress was not related to EA in this study, these findings show that the collegiate athlete population in the present study did not experience high levels of psychological stress. Additional research is needed to determine the wide range of health and performance consequences proposed to relate to LEA in both male and female collegiate athletes and to determine if the low, reduced, and adequate cut-offs for EA are appropriate to apply to a male population. Increased understanding of LEA consequences could aid in improving methodologies to prevent, identify, and treat LEA as well as benefit the health and performance of male and female collegiate athletes.

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Appendix A

Informed Consent Form for Research Involving Human Subjects

University of Idaho

Department of Movement Sciences

Title: Relative Energy Deficiency in Sport (RED-S) among University of Idaho Student-Athletes
Primary Investigator: Ann Brown, Ph.D., CISSN
Other Investigators: Katelyn Peterson
Participant's Printed Name: ____

You are being asked to take part voluntarily in the research project described below. Please take your time in deciding. Before agreeing to take part in this research study, it is important that you read the consent form. Please ask the researcher to explain any words or information that you do not understand.

VOLUNTARY CONSENT

I voluntarily and without element of force or coercion, consent to be a participant in the research project titled, "Relative Energy Deficiency in Sport (RED-S) among University of Idaho Student-Athletes." This study is being conducted by Ms. Katelyn Peterson and Dr. Ann Brown, of the College of Education at the University of Idaho.

PURPOSE

The primary purpose of this study is to assess the risk of Relative Energy Deficiency in Sport (RED-S) in student-athletes. The secondary purpose is to describe differences in energy availability, eating disorder risk, body composition, and stress levels by gender.

I must meet the following criteria to be included in the study: (1) current student-athlete between ages of 18-25, (2) have no contraindications to exercise based on the American College of Sports Medicine and American Heart Association (ACSM/AHA) risk stratification criteria including uncontrolled hypertension, currently taking blood pressure medications, or have been diagnosed with cardiovascular disease, stroke, diabetes, thyroid, or kidney dysfunction, (3) have no risk factors for cardiovascular disease as determined by ACSM guidelines, and (4) have no significant musculoskeletal injuries or other medical conditions over the past 6 months.

PROCEDURES

If you agree to take part in this study, the research team will ask you to attend 2 visits between 4:00-8:00 PM in the Human Performance Laboratory (HPL) within two weeks. The 2 visits will take approximately 2 hours total and all measurements and assessments are described in detail below. You will record physical activity for 3 days (two week days & one weekend day) and recall dietary intake for 3 days (two week days & one weekend day) which will take approximately 90 minutes. The total time for this study is 3 ½ hours over 2 weeks. Measurements include: (1) survey information on medical history, eating disorder risk, and perceived stress; (2) dietary recall; (3) physical activity and; (4) body composition.

FIRST VISIT

Upon arrival to the HPL, the written informed consent and medical history questionnaire will be signed. I will then complete the Eating Attitudes Test (EAT-26) to assess eating disorder risk and Perceived Stress Scale (PSS) to measure current stress levels. The physical activity monitor (accelerometer) and physical activity logs will be distributed and explained by the researcher. The ASA-24 login and password information will be given to me to complete the online dietary recall.

Survey Information: Surveys will be used to gather information about medical history (including history of stress fractures and menstrual function in females), eating disorder risk, and perceived stress. This private information will be held in the utmost confidence. Surveys will not include your name and will be coded by a subject number to which only the researchers have access.

Activity Monitor: You will be asked to wear an activity monitor for 3 days (2 week days & 1 weekend day) to record your daily physical activity. We will ask that you maintain usual activity habits during this time period. You will also be asked to maintain a physical activity log of your daily activity during these 3 days. The log will indicate any physical activity that you did each day lasting 15 minutes or longer (e.g., walked for 30 minutes).

Dietary Recall: Dietary intake will be measured using ASA-24, an online 24-hour dietary recall program for a total of 3 days (2 week days & 1 weekend day). You will be asked to maintain normal eating patterns and habits throughout the study.

SECOND VISIT

Upon arrival to the HPL, I will return the accelerometer and physical activity logs to the researcher. Height and weight will be measured with a wall-mounted SECA stadiometer and digital scale (SECA, Hamburg, Germany) before completing a DXA scan.

Height and weight: A measurement of your height and weight, without shoes, will be taken.

Body composition with DXA: My body composition will be assessed via DXA scan. I will be asked to change into clothing that is free of metal and/or hard plastic (buttons, zippers, snaps, etc.) and asked to remove all metal from the body (jewelry, eyeglasses, etc.). The body composition of my total body will be measured noninvasively via the use of the Hologic DXA Scanner (Hologic Horizon™; Danbury, CT), with one scan; anteroposterior (AP) view of the total body lying supine. Very low doses of radiation are used; however, this test is non-invasive. Testing will be completed according to the manufacturer's instructions and specifications by a certified X-ray technician. My hands and feet will be secured in place to avoid unwanted movements during the body scan. The scan will take approximately 10 minutes to complete. From the scan, my lean mass (kg), fat free mass (kg), percent fat, and bone density will be determined.

DISCOMFORTS AND RISKS

I understand there is a minimal level of risk involved if I agree to participate in this study. Body composition will be evaluated by Dual-Energy X-ray Absorptiometry (DXA). This involves low exposure to radiation less than 5 mREMs per DXA scan. Doses received from DXA examinations are small in comparison to other common radiation sources and are believed to represent no significant health risk. No risk of adverse health conditions has been established for lower exposures of 5000 mREM or less. By comparison, natural background radiation is about 300 mREM/year, an x-ray of the spine is 70 mREM, a mammogram is 45 mREM, and a round trip transcontinental plane flight is 6 mREM. The measurement of body composition using DXA is non-invasive. For your safety, a research team member will be with you at all times during test procedures. If I am identified to be at risk in any of the variables being tested I will be referred to the appropriate medical provider (i.e. campus dietician and/or counseling center).

POSSIBLE BENEFITS

You can gain knowledge of your body mass index, body composition, and my bone mineral density (BMD). You may benefit by learning your RED-S risk and if you should seek nutritional counseling. The benefit to society relates to a better understanding of the risk of RED-S in student-athletes.

STATEMENT OF CONFIDENTIALITY

The results of this study may be published but my name or identity will not be revealed. Information obtained during the course of the study will remain confidential, to the extent allowed by law. My name will not appear on any of the results. No individual responses will be reported. Only group responses will be reported in the publications. Confidentiality will be maintained by assigning each subject a code number and recording all data by code number. The only record with my name and code number will be kept by the principal investigator, Dr. Ann Brown, in a locked drawer in her office. Data will be kept for 10 years and then destroyed.

CONTACT INFORMATION FOR QUESTIONS OR CONCERNS

You may ask any questions you have now. If you have questions later, you may call Katelyn Peterson or Ann Brown at the number or email listed below.

Katelyn Peterson
Ph. (208) 766-3106
pete3249@vandals.uidaho.edu

Dr. Ann Brown
Ph. (208) 885-7986
afbrown@uidaho.edu

If you have questions or concerns about your participation as a research subject, please contact the University of Idaho Institutional Review Board (IRB) at (208) 885-6340.

SIGNATURE AND CONSENT TO PARTICIPATE IN RESEARCH

The nature, demands, benefits and risks of the study have been explained to me. I knowingly assume any minimal risk involved. I have read the above informed consent form. I understand that I may withdraw my consent and discontinue participation at any time without penalty or loss of the benefits to which I may otherwise be entitled. In signing this consent form, I am not waiving my legal claims, rights or remedies. A copy of this consent form will be given to me.

Participant Name: _______________ **Date:** __________ **Time:** ___________

Participant Signature: ____________ **Date:** __________ **Time:** ___________

I have discussed this research study with the subject and his or her authorized representative, using language that is understandable and appropriate. I believe I have fully informed the subject of the possible risks and benefits, and I believe the subject understands this explanation. I have given a copy of this form to the subject.

Signature of Investigator: _________ **Date:** __________ **Time:** ___________

Appendix B

Medical History Questionnaire

Human Performance Laboratory
University of Idaho
Department of Movement Sciences
Exercise Science & Health

HEALTH AND FITNESS HISTORY QUESTIONNAIRE

The following questions are designed to obtain a thorough preliminary medical history. The information you provide will help us to make the best determination about your eligibility for this study. Please answer all questions and provide as much information as possible. This questionnaire, as well as any other medical information you provide will be kept confidential and will not be shared with any unauthorized person or organization unless you specifically request us to do so.

Name: ______________________________ Email address: _________________________

Address: ____________________________ City: ______ State: ____ Zip code: ______

Date of Birth (mm/dd/yy): _____________ Phone: (___) ___________________________

Age: _______ Sex: M____ F____ Race: ___________

Height: ________

Weight: ________

Years of sport involvement: ____________

Personal Physician: ____________________ Phone: (___) ___________________________

Address: _____________________________ City: ______ State: ____ Zip code: ______

Signature: ___________________________ **Date:** _________________________

PERSONAL HEALTH HISTORY

Have you ever been hospitalized or had surgery? Yes _______ No _______

Please list all hospitalizations and surgeries to the best of your recollection.

Reason for hospitalization, disease, or injury	Duration	Age

List any disease or illness you have had not listed above (e.g., pneumonia, strep, etc.)

List any history of stress fractures

HEALTH CONCERNS

Are you currently seeing a doctor or other health care provider for any reason (depression, anxiety, sleeping difficulties, acupuncture, etc.)? Yes______ No______

If yes, please explain:

FEMALES ONLY

MENSTRUAL HISTORY

At what age did you first begin your menstrual cycle? __________

Do you still have a monthly menstrual period (*circle one*)?

Yes

No

What was the first day of your last menstrual cycle? ___________

Is your menstrual cycle regular (*circle one*)?

Yes

No

If no, please explain ____

Have you had prolonged, absent periods for > 3 months?

Yes

No

Are you currently taking any form of birth control (*circle one*)?

Yes

No

If yes, what kind? ____

MEDICAL HISTORY

Have you ever been diagnosed as having any of the following and if yes, how are you currently treating the condition?

Y N High Blood Pressure
Last known blood pressure reading _______/_______

Y N High Cholesterol or High Triglycerides
Please indicate last known reading
Cholesterol: _______
Triglycerides: ______

Y N Diabetes (circle one) Type 1 Type 2
Note: Type 1 diabetes is insulin-dependent diabetes mellitus. It is typically diagnosed at an early age and requires insulin shots or an insulin pump immediately upon diagnosis. Type 2 diabetes is often diagnosed at an older age (past age 20) and is usually treated with changes in diet and/or medication.

Y N Hypoglycemia (low blood sugar)

Y N Asthma (circle one) Regular or exercise induced

Have you ever had the following tests?

Y N Glucose tolerance test
If yes, what were the results?________________________________

Y N Fasting blood sugar test
If yes, what were the results? ________________________________

Does anyone in your immediate family (including your grandparents) have a history of cardiovascular disease (heart attacks, stroke, etc.)?

Y N If yes, please explain ______________________________________

Do you have any neurological problems including fainting, dizziness, headaches or seizures?

Y N If yes, please explain ___________________________________

Please list past injuries that may impact your ability to perform exercise.

____

Do you smoke or use smokeless tobacco?

Y N If yes, how many cigarettes per day? ______

Please list all vitamins, minerals, and other nutritional (performance) supplements as well as medications you are currently taking. Please include how long you have been taking them and how often.

____

____

____

Do you exercise regularly outside of your sport?

Y N

How often do you have required practice or training? Please be detailed in the description of an average week of training.

____

Please list the 3 most current competitions you have participated in and when they occurred:

1. ___________________________________

2. ______________________________________

3. ______________________________________

How does your current exercise and physical activity compare to 6 months ago? 1 year ago?

____

Have you had a physical exam in the past 2 years?

Y N

Please describe your assessment of your overall health: _______________

Appendix C

Physical Activity Logs

Name: ____________________ **Date**: ______________ **Day of the Week**: ________

Please record your activities throughout the day. This record will be used to verify the information from the accelerometer. We especially need details about the exercise/training that you do on the days that you are recording your food intake. For example, instead of putting “Swim Meet, 2 hours, high intensity”, record how long you are warming up, what events you are competing in, as well as the duration and intensity of those events. Please provide detailed information about any and all training (lifting, practices, etc.), any other physical activities (yoga class, ultimate Frisbee with friends, etc.), as well as any significant lifestyle physical activity (e.g., riding your bike to school, walking to the grocery store, etc.)

Time	**Type of Exercise/Activity**	**Duration**	**Intensity**
12:00am (midnight)			
12:15am			
12:30am			
12:45am			
1:00am			
1:15am			
1:30am			
1:45am			
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11:00am			
11:15am			
11:30am			

11:45am			
12:00pm (Noon)			
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11:00pm			
11:15pm			
11:30pm			
11:45pm			
12:00am (Midnight)			

Appendix D

DXA Consent for Women

DXA: X-Ray Consent for Women of Childbearing Age

1. Date of last menstrual period: ________________

2. Date today: ________________

3. Are you pregnant (*circle one*)?

    a. Yes

    b. No

4. A pregnancy test is highly recommended if I have not had a menstrual cycle in the past 28 days or if I am not using a reliable form of birth control. I recognize that if I am pregnant and have a radiation to the abdomen, there is a possibility of injury to the fetus. However, I understand that the likelihood of such injury is slight. I, therefore, wish to have this x-ray examination performed now.

____ ____________________

Name of Patient *Date*

____ ____________________

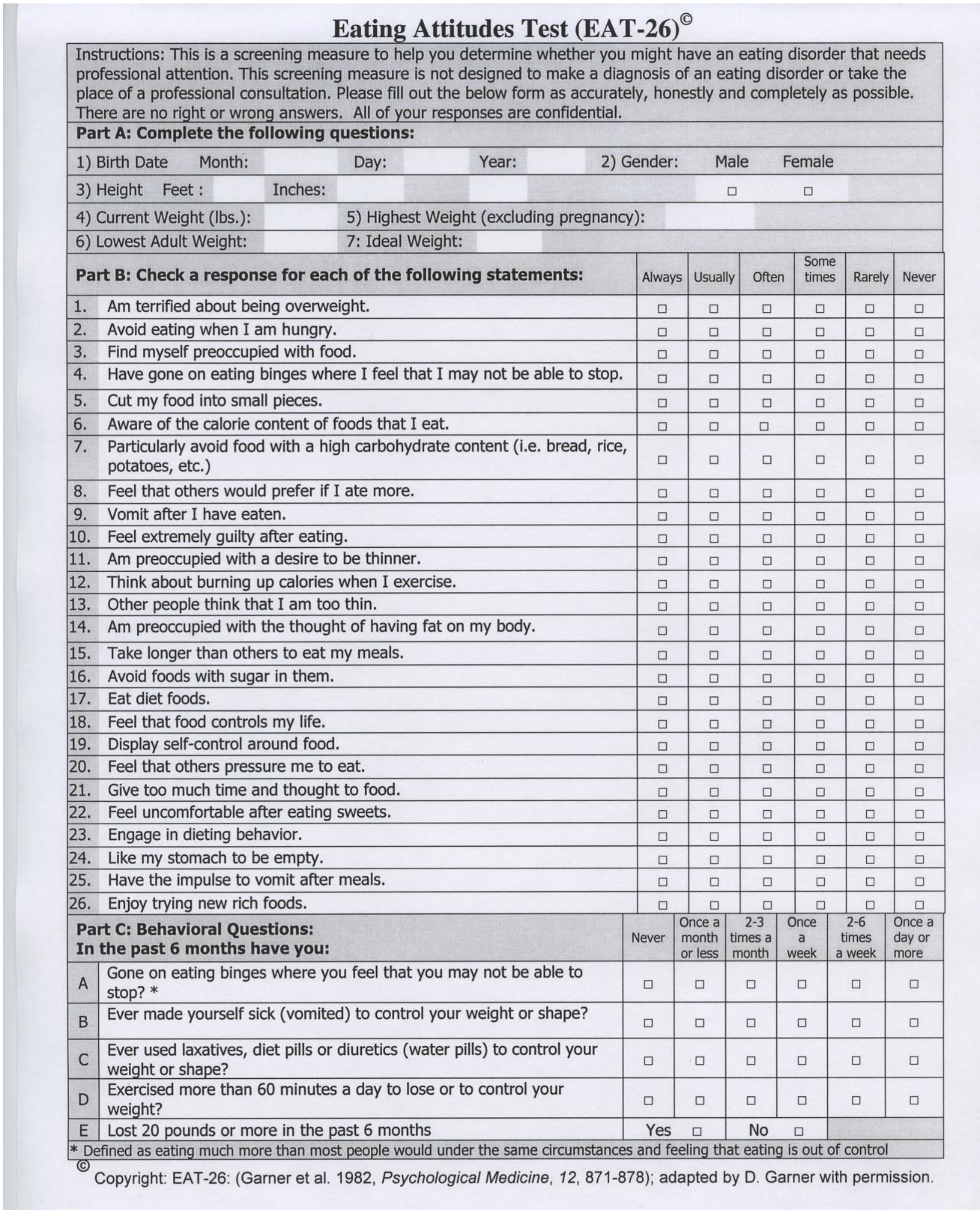
Signature of Patient *Date*

____ ____________________

Signature of Witness *Date*

Appendix E

EAT-26



Eating Attitudes Test (EAT-26)©

Instructions: This is a screening measure to help you determine whether you might have an eating disorder that needs professional attention. This screening measure is not designed to make a diagnosis of an eating disorder or take the place of a professional consultation. Please fill out the below form as accurately, honestly and completely as possible. There are no right or wrong answers. All of your responses are confidential.

Part A: Complete the following questions:

1) Birth Date Month: Day: Year: 2) Gender: Male Female
3) Height Feet : Inches: ☐ ☐
4) Current Weight (lbs.): 5) Highest Weight (excluding pregnancy):
6) Lowest Adult Weight: 7: Ideal Weight:

Part B: Check a response for each of the following statements:		Always	Usually	Often	Some times	Rarely	Never
1.	Am terrified about being overweight.	☐	☐	☐	☐	☐	☐
2.	Avoid eating when I am hungry.	☐	☐	☐	☐	☐	☐
3.	Find myself preoccupied with food.	☐	☐	☐	☐	☐	☐
4.	Have gone on eating binges where I feel that I may not be able to stop.	☐	☐	☐	☐	☐	☐
5.	Cut my food into small pieces.	☐	☐	☐	☐	☐	☐
6.	Aware of the calorie content of foods that I eat.	☐	☐	☐	☐	☐	☐
7.	Particularly avoid food with a high carbohydrate content (i.e. bread, rice, potatoes, etc.)	☐	☐	☐	☐	☐	☐
8.	Feel that others would prefer if I ate more.	☐	☐	☐	☐	☐	☐
9.	Vomit after I have eaten.	☐	☐	☐	☐	☐	☐
10.	Feel extremely guilty after eating.	☐	☐	☐	☐	☐	☐
11.	Am preoccupied with a desire to be thinner.	☐	☐	☐	☐	☐	☐
12.	Think about burning up calories when I exercise.	☐	☐	☐	☐	☐	☐
13.	Other people think that I am too thin.	☐	☐	☐	☐	☐	☐
14.	Am preoccupied with the thought of having fat on my body.	☐	☐	☐	☐	☐	☐
15.	Take longer than others to eat my meals.	☐	☐	☐	☐	☐	☐
16.	Avoid foods with sugar in them.	☐	☐	☐	☐	☐	☐
17.	Eat diet foods.	☐	☐	☐	☐	☐	☐
18.	Feel that food controls my life.	☐	☐	☐	☐	☐	☐
19.	Display self-control around food.	☐	☐	☐	☐	☐	☐
20.	Feel that others pressure me to eat.	☐	☐	☐	☐	☐	☐
21.	Give too much time and thought to food.	☐	☐	☐	☐	☐	☐
22.	Feel uncomfortable after eating sweets.	☐	☐	☐	☐	☐	☐
23.	Engage in dieting behavior.	☐	☐	☐	☐	☐	☐
24.	Like my stomach to be empty.	☐	☐	☐	☐	☐	☐
25.	Have the impulse to vomit after meals.	☐	☐	☐	☐	☐	☐
26.	Enjoy trying new rich foods.	☐	☐	☐	☐	☐	☐

Part C: Behavioral Questions: **In the past 6 months have you:**		Never	Once a month or less	2-3 times a month	Once a week	2-6 times a week	Once a day or more
A	Gone on eating binges where you feel that you may not be able to stop? *	☐	☐	☐	☐	☐	☐
B	Ever made yourself sick (vomited) to control your weight or shape?	☐	☐	☐	☐	☐	☐
C	Ever used laxatives, diet pills or diuretics (water pills) to control your weight or shape?	☐	☐	☐	☐	☐	☐
D	Exercised more than 60 minutes a day to lose or to control your weight?	☐	☐	☐	☐	☐	☐
E	Lost 20 pounds or more in the past 6 months	Yes ☐		No ☐			

* Defined as eating much more than most people would under the same circumstances and feeling that eating is out of control

Appendix F

Perceived Stress Scale

The questions in this scale ask you about your feelings and thoughts during the last month. In each case, you will be asked to indicate by circling how often you felt or thought a certain way.

0 = Never 1 = Almost Never 2 = Sometimes 3 = Fairly Often

1. In the last month, how often have you been upset because of something that happened unexpectedly?

   0 1 2 3

2. In the last month, how often have you felt that you were unable to control the important things in your life?

   0 1 2 3

3. In the last month, how often have you felt nervous and “stressed”?

   0 1 2 3

4. In the last month, how often have you felt confident about your ability to handle your personal problems?

   0 1 2 3

5. In the last month, how often have you felt that things were going your way?

   0 1 2 3

6. In the last month, how often have you found that you could not cope with all the things that you had to do?

   0 1 2 3

7. In the last month, how often have you been able to control irritations in your life?

   0 1 2 3

8. In the last month, how often have you felt that you were on top of things?

   0 1 2 3

9. In the last month, how often have you been angered because of things that were outside of your control?

0 1 2 3

10. In the last month, how often have you felt difficulties were piling up so high that you could not overcome them?

0 1 2 3