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# Recreational Female CrossFit Athletes and Low Energy Availability

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# RECREATIONAL FEMALE CROSSFIT ATHLETES AND LOW ENERGY AVAILABILITY

BY

ALISON KUCH

A thesis submitted in partial fulfillment of the requirements for the

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# THESIS ACCEPTANCE PAGE

Alison Kuch

This thesis is approved as a creditable and independent investigation by a candidate for the master's degree and is acceptable for meeting the thesis requirements for this degree. Acceptance of this does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

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# TABLE OF CONTENTS

# ABBREVIATIONS

| | |
|---|---|
| ATP | adenosine triphosphate |
| BMD | bone mineral density |
| BMI | body mass index |
| BMR | basal metabolic rate |
| CP | phosphocreatine |
| EA | energy availability |
| EB | energy balance |
| EI | energy intake |
| ExEE | exercise induced energy expenditure |
| FFM | lean body mass |
| GH | growth hormone |
| HPA | hypothalamic-pituitary-adrenal |
| IGF-1 | insulin-like growth factor 1 |
| IOC | International Olympic Committee |
| ISSN | International Society of Sports Nutrition |
| kcal | kilocalorie |
| kg | kilogram |
| LH | luteinizing hormone |
| MET | metabolic equivalent of task |
| NEAT | non-exercise activity thermogenesis |
| RED-S | relative energy deficiency in sport |
| REE | resting energy expenditure |
| TDEE | total daily energy expenditure |

# LIST OF FIGURES AND TABLES

# ABSTRACT

# RECREATIONAL FEMALE CROSSFIT ATHLETES AND LOW ENERGY AVAILABILITY

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CrossFit is a demanding sport in which athletes perform constantly varied, functional movements at a high intensity, therefore requiring an adequate energy availability to avoid negative health and performance consequences. The purpose of this study was to assess risk of low energy availability (low EA) (phase 1) among recreational, female CrossFit athletes and measure and calculate energy availability using a 7-day dietary to measure energy intake (EI) and exercise energy expenditure (ExEE)

(phase 2). In phase 1, using the LEAF-Q (Low Energy Availability in Females Questionnaire), 49% of survey respondents (n=149) were found to be at risk of low EA. Of the 167 participants interested in phase 2 per the survey in phase 1, 83 completed at least one day of the EI and ExEE record, and 67 completed all 7 days. The athletes in phase 2 did not meet EI recommendations set forth by the International Society of Sports Nutrition (ISSN), 30% of participants were below 30 kcals.kgFFM$^{-1}$.d$^{-1}$, and the average energy availability among participants was 34.1 ± 12.3 kcals.kgFFM$^{-1}$.d$^{-1}$. EA was correlated to ExEE, EI, and carbohydrate and fat intake. Currently, CrossFit nutrition recommendations fall short when compared to those of the ISSN. CrossFit athletes and coaches should become familiar with the signs, symptoms, and implications of low EA and its resulting syndrome, RED-S (Relative Energy Deficiency in Sport).

# CHAPTER 1

# REVIEW OF LITERATURE

## *Current Knowledge of Low Energy Availability Risk and Prevalence*

Optimal energy intake can improve athletic performance and maintain general health in physically active individuals. Female athletes (along with some male athletes) may find it more difficult to achieve energy balance and requirements while maintaining low body weight and/or body fat.[1] Low EA (energy availability) has been reported among female athletes, primarily well-trained endurance athletes[2] (e.g. cyclists, runners, and triathletes[3]), along with recent research conducted among collegiate volleyball players[4] and female fitness physique competitors.[5] A study examining low EA risk in recreational athletes in New Zealand discovered that 45% of recreational athletes were at risk of low EA,[6] another reporting 63.2% of recreational athletes at risk of low EA.[7] This study also looked at more specific indicators of various self-reported data that could indicate variability in low EA risk. Those who were involved in individual sports had nearly double the risk of low EA compared to those who participated on a team.[6] For every extra hour of exercise performed per week, the odds of being at risk of low EA were 1.13 time greater (p=0.016).[6] The increased risk of low EA with increased exercise were also supported in a separate study, although not to as great of an extent (6% increase per extra hour; p=0.003).[8] Female athletes at all levels of any sport need to account for higher levels of ExEE (exercise energy expenditure) by considering the intensity, duration, and frequency of training. It is necessary to ensure all athletes have adequate EA to support their level of training and prevent the onset of health problems and disorders.[4]

### *Energy Metabolism*

There are important notes regarding the differences between energy availability and energy balance. EA acknowledges that dietary EI (energy intake) is expended via physiological processes, and that energy expended during these processes is not available for other things, creating metabolic demand.[9] EA is the amount of energy leftover for body processes once the demand of exercise is accounted for (energy expenditure of exercise is denoted as ExEE) and is equated as EA = EI-ExEE/FFM (kg).[10] This equation is divided by kilograms of FFM (fat free mass) to correct for differences in body composition.[11] In short, EA is an input into the body. EB (energy balance) is total energy intake minus TDEE (total daily energy expenditure). The EB equation is as follows: EB = EI – TDEE, or the net amount of dietary energy lost from or added to the energy stores of the body after all physiological processes have been completed for the day.[9] True EB is zero; energy intake matches energy expenditure. Energy intake larger than energy expenditure results in a positive energy balance, and energy intake smaller than energy expenditure results in a negative energy balance. In short, EB is energy output from the body. For healthy, young adults, EB is ±0 kcal when EA equates to 45 $\text{kcals.kgFFM}^{-1}.\text{d}^{-1}$ (kilocalories per kilogram of lean body mass per day).[9] An energy balance of zero indicates that body weight and body composition is stable. A positive energy balance over time may result in a gain in body mass, while a negative energy balance may result in a loss in body mass. Whether the gain or loss in body mass affects body fat stores or muscle mass would depend on the composition of the diet.[12] As mentioned above, energy availability is based on the balance of energy intake and ExEE. As ExEE increases the energy available for other body processes decreases if intake does not also increase.

Energy metabolism is the process of generating energy in the form of ATP (adenosine triphosphate) from macronutrients. The metabolic pathways responsible for ATP production are influenced by hormones, substrates, the nervous system, and other cellular activity. The body attempts to maintain energy homeostasis through the regulation of energy intake and energy expenditure. Too few calories consumed can result in weight loss and affect energy metabolism, hormones, and cellular activity. Conversely, if too many calories are consumed in comparison to expenditure, the excess energy may be stored as body fat. For weight maintenance and proper function, energy intake must match energy expenditure, and this concept is referred to as energy balance.[4] Loucks and her extensive research estimates the optimal physiological balance is achieved at 45 kcals.kgFFM$^{-1}$.d$^{-1}$, and detrimental effects occur below 30 kcals.kgFFM$^{-1}$.d$^{-1}$;[13–17] although little research discusses the physiological effects between 30 – 45 kcals.kgFFM$^{-1.}$d$^{-1}$. However, one study reports a mean EA of 36.3 kcals.kgFFM$^{-1}$.d$^{-1}$ in athletes at risk of low EA.[7] When the threshold of 30 kcals.kgFFM$^{-1}$.d$^{-1}$ is not achieved, the body does not have enough energy to maintain homeostasis resulting in altered hormone secretions and receptor interactions that have more serious consequences than hormone imbalances.[18] These changes in hormone secretions and receptor interaction lead to both physiological adaptation to and perceptions of decreased endurance performance, increased injury risk, decreased training response, impaired judgement, decreased coordination, decreased concentration, irritability, depression, decreased glycogen stores, and decreased muscle strength.[19]

### *Effects of Low Energy Availability on Metabolism*

Metabolism is influenced by a number of hormones. The counter regulatory hormones, growth hormone, glucagon, epinephrine, and cortisol, are responsible for mobilization of free fatty acids and glucose for ATP production during periods of fasting, exercise, and other situations that limit glucose intake or deplete glucose stores, like a state of low EA. In low EA states, insulin is typically downregulated to allow for more substrate availability.[20] Significant decreases in insulin levels were demonstrated in low EA states (15 $\text{kcals.kgFFM}^{-1}.\text{d}^{-1}$) with and without exercise, with insulin decreasing by as much as 38%.[21] Loucks demonstrated a dramatic decrease in insulin while subjects consumed 10, 20, and 30 $\text{kcals.kgFFM}^{-1}.\text{d}^{-1}$,[14] however subject carbohydrate intake was reduced by 80%, 60%, and 40% respectively, so it cannot be determined if insulin reduction came from low EA alone, or by response to lower carbohydrate consumption. It should be noted that insulin concentrations were compared to balanced EA measurements (45 $\text{kcals.kgFFM}^{-1}.\text{d-}^{1}$), and the effects of low EA at 20 and 30 $\text{kcals.kgFFM}^{-1}.\text{d}^{-1}$ on insulin concentrations were 40% and 56% ($p < 0.05$ and $0 < 0.001$, respectively) smaller than the effect at 10 $\text{kcals.kgFFM}^{-1}.\text{d}^{-1}$. In response to the low energy intake of 30 $\text{kcals.kgFFM}^{-1}.\text{d}^{-1}$ basal growth hormone (GH) concentrations increased while insulin-like growth factor-1 (IGF-1) experienced a significant decline in basal concentrations. A further reduction in EA to 10 $\text{kcals.kgFFM}^{-1}.\text{d}^{-1}$ did not produce further changes in GH or IGF-1.[14] GH is an antagonist against the metabolic action of insulin, activates lipolysis and inhibits insulin secretion. Glucagon and insulin have opposite roles in metabolism; insulin increases in a fed state and glucagon increases in a fasted state. Glucagon has been shown to increase during increased exercise bouts,[22] however little research is available regarding measured glucagon during a period of low EA, a combined decrease in energy intake and increase in energy expenditure. A blunted catecholamine response (epinephrine and norepinephrine) response to high-intensity exercise was observed in certain amenorrhoeic athletes.[20] Catecholamines aide in the binding of cortisol and insulin alpha and beta receptors, and increase insulin resistance while inhibiting insulin secretion. Lastly, cortisol is important in prolonged exercise, starvation, glycogen depletion and stress.[20] Cortisol has a U-shaped relationship with BMI (body mass index) and body fat percentage. Both extremely underweight and overweight states can potentially active the HPA axis, resulting in higher cortisol levels.[20] Studies of severe caloric restriction and fasting have demonstrated increased circulating cortisol in humans.[20] In low EA states, cortisol levels rise, with incremental changes become more extreme as EA went from 45, 30, 20, and 10 kcals.kgFFM$^{-1}$.d$^{-1}$.[14] In summary, significant hormonal changes occur when EA is below 30 kcals.kgFFM$^{-1}$.d$^{-1}$. The changes in hormone secretion, sensitivity, and response results in changes in metabolism favoring an increase in lipid metabolism.

### *Effects on Energy Status and Energy Expenditure*

As the brain senses energy intake, the gastrointestinal tract will adjust and signal appetite inhibiting hormones such as cholecystokinin, peptide YY, and glucagon-like peptide-1 to signal satiety, or it will signal appetite stimulating hormones such as ghrelin, to signal remaining hunger.[23] Exercise also signals the gastrointestinal tract to adjust and release the necessary hormones to cue hunger or satiety. The influence of fat-free mass and fat mass on appetite expression are modulated by tonic appetite signals. Both fat-free mass and fat mass effect resting metabolic rate and either signal a metabolic demand for energy (consumption), or adipokines like leptin will release inhibitory appetite signals.[23] Ghrelin, an appetite stimulating hormone, is considered a marker of energy status – higher ghrelin levels indicate a lower energy state.[20] Some female athletes with decreased EA may have a psychological suppression of ghrelin's ability to stimulate appetite,[20] as the release of oxytocin is directly influenced by ghrelin.[24] Oxytocin is implicated in inhibiting reward-related eating behaviors, suppressing HPA (hypothalamic-pituitary-adrenal) axis activity, and modifying the glucoregulatory response to caloric consumption. Females with anorexia nervosa had lower overnight oxytocin secretion than controls[25] and reported a positive correlation of fasting oxytocin levels and surrogate measures of EA (body weight and BMI), REE (resting energy expenditure), and secretion of hormones involved in energy balance in young amenorrhoeic athletes.[20]

All components of TDEE and energy metabolism are in some way modulated by the thyroid hormone.[11] Even minimal changes in thyroid signaling can cause considerable perturbation in energy expenditure symptoms.[11] Thyroid-regulated pathways include nutrient feedback, androgenic stimulation, and cholesterol/cortisol/leptin feedback pathways.[26] There is a positive association between T3 (triiodothyronine, the active form of T4 (thyroxine)) and EA; T3 may be a helpful marker of low EA.[20] A secondary analysis of data collected by Yavuz et al. demonstrated that increases in REE/FFM correlated directly with an increase in free T4 and free T3 levels, and inversely with thyroid-stimulating hormone levels.[11]

### *Other Effects of Low Energy Availability*

The longer one is in a state of low EA, the greater its physiological impact.[27] Low EA is induced through a combination of both decreased energy intake and increased energy expenditure from physical activity and may lead to menstrual dysfunction,[1] and effects on LH (luteinizing hormone) pulsatility can be seen in as little as five days.[17] The body will also slow the production of estrogen (often measured as estradiol) which is required for regular menses. Although oral contraceptives provide the body with synthetic estrogen, there is no significant relationship between oral contraceptive use and risk of low EA or that it prevents health problems resulting from low EA.[6] In a Norwegian study, ten runners with regular menses were compared with ten runners with irregular menses with running status ranging from recreational to elite; results showed that the group with irregular menses failed to replenish ExEE, and were often in a negative energy balance.[28] However, menstruation status should not be the only sign used to determine female athlete health,[4] as the impact of various stressors on the reproductive systems tend to show a downward shift in occurrence as gynecological age increases.[29] It is imperative that physicians appropriately diagnose menstrual disorders, as 60% of athletes with other forms of menstrual disorders besides exercise induced menstrual dysfunction, like polycystic ovarian syndrome and functional hypothalamic amenorrhea, also had low EA and low bone mineral density (BMD).[2,30] The physical absence or irregularity of menses should not be the primary marker of female athlete health, considering the vast amount of hormonal contributions to both menses and changes in EA.

Low EA has implications for musculoskeletal health. Even short-term diet- and exercise-induced low EA has been shown to negatively affect bone-turnover.[31] Even though GH has been shown to increase during periods of low EA,[14] BMD decreases. It appears that the effect GH has on bone formation are overridden.[31] Low BMD could also be attributed to nutrient deficiencies that come from extremely restricted caloric intake,[7] as those who exercise excessively and/or restrict certain food groups appear to be at higher risk of nutrient deficiencies.[32,33] In addition to caloric intake, it is important to consider macronutrient and micronutrient intake. Recreational athletes with low EA may have a greater percentage of energy intake from fat than competitive low EA athletes.[7] The higher consumption of fat in recreational athletes compared to competitive athletes could be attributed to internet advice to adhere to fad diets that tend to be higher in fat such as “paleo” or “keto.” Low-carb, high-fat diets are not suitable for maintaining intensive training, in part due to reduced exercise economy.[34] The Academy of Nutrition and Dietetics (formerly the American Dietetic Association), Dietitians of Canada, and the American College of Sports Medicine promote a high-carbohydrate/low-fat diet for performance, although these organizations also state there is no performance benefit below 15% of dietary intake from fat.[35] In the New Zealand survey of recreational athletes to determine risk of low EA, the athletes at risk of low EA had the lowest protein intake with 8.3% not even meeting minimum New Zealand general health guidelines.[7] Recreational athletes tend to avoid dairy products[36] and lack of dairy in the diet can lead to low calcium intake. Due to the relationship between bone health and low EA (bone acts as a primary calcium reservoir in the body), athletes at risk for low EA may especially benefit from a higher calcium intake.[7]

### *The Female Athlete Triad and Relative Energy Deficiency in Sport*

The Female Athlete Triad is comprised of disordered eating habits, menstrual dysfunction, and low BMD. The presence of two Triad components are currently present in 5.4-26.9% of competitive female athletes and 12.4-15.2% of recreational exercisers.[37] Currently, the Triad is understood to be more than just a triad of conditions. It consists of a myriad of issues at which low EA is the center, referred to as relative energy deficiency in sport (RED-S). These potential issues include overlapping issues from the Triad, as well as endocrine, metabolic, hematological, growth and development, psychological, cardiovascular, gastrointestinal, and immunological issues,[10] most of which were discussed in this review and still some lack research showing how detrimental low EA can be. It is important to note that the Triad and RED-S prevalence is like to be extremely underestimated as it is difficult to measure EA because of error associated with measuring/reporting energy intake and expenditure.[7] Although arm bands, watches, etc. report accurately at moderate, steady-intensity ExEE, they often underestimate at higher intensities.[4] Direct and indirect calorimetry are much more accurate, but they often have a high cost, require training for effective use, and are not as portable as other options.

### *Psychological Effects of Low Energy Availability*

Excessive exercisers are at greater risk for depression.[32] It is important to note that psychological effects of low EA can precede it, or be a result of low EA.[10] Low EA triggers the HPA axis, which is a natural response to stress; when the body is competing for energy sources within, it is in a state of stress. The HPA axis secretes glucocorticoids in response to higher levels of cortisol, which acts on multiple body systems to redirect energy to where it is needed. Female athletes suffering from anorexia, an instance of extreme low EA, show more psychological disturbances, depression, social insecurity, and fear of weight gain, than healthy individuals not suffering from anorexia.[10] In a survey study, those at risk of low EA were 4.3 times more likely to have impaired judgement, 1.6 times more likely to have decreased concentration, 1.6 times more irritable, and 2.3 more likely to suffer from depression.[19]

### *Perception of Athletic Performance Impairments and Injury*

A 113-question questionnaire (adapted from the International Olympic Committee's (IOC) position on RED-S[10]) was given to 1,000 active women who were classified as having low or adequate energy availability to assess potential negative outcomes of low EA; this study showed an increased likelihood of experiencing performance-decreasing detriments in those classified as low EA.[19] In addition to psychological detriments already mentioned, low EA athletes were 1.1 times more likely to be injured, 2.1 times more likely to have decreased training response, and 1.5 times more likely to have decreased endurance performance.[19] All of these findings were significant except the first, being more likely to become injured.[19] However, the likelihood to become injured presents a cyclical problem within the low EA when looked at as a whole alongside athlete behavior. Low EA can cause low BMD[7,14,31] which can cause stress fractures,[38] resulting in time off from training. In one study, 76.6% of women who reported a stress fracture that impacted training were also at risk of low EA.[8] Low EA can also lead to greater chance of illness, in fact women classified as at risk of low EA were likely to experience periods of illness affecting training three times more frequently than women classified as not at risk.[8] These absences from training create a recurring issue, as for every two days off from training due to injury or illness, risk of low EA has been shown to double (p=0.11),[6] and even triple (p=0.001).[8] This cyclical pattern presents an issue as the higher risk of low EA causes more days off due to injury/illness, and more days off creates higher risk of low EA.

### *Summary*

Energy deficiency is at the center of RED-S and the hormonal effects that accompany states of low EA. The Baltimore Longitudinal Study of Aging states, “If energy becomes deficient, adaptive behaviors develop aimed at conserving energy.” When energy balance is negative, the body is expending more energy than it is consuming, and physiological processes are downregulated to compensate for lack of energy. This negative energy balance poses a threat to healthy in every population of athlete, but considerably so to the recreational athlete population. Loucks has demonstrated that a sustainable EA threshold is 45 $\text{kcals.kgFFM}^{-1}.\text{d}^{-1}$, and a problematic threshold is <30 $\text{kcals.kgFFM}^{-1}.\text{d}^{-1}$.[9,13–15,39] Low EA facilitates negative outcomes in many areas of health in the active population including irregular menses,[13–17,40] various eating dysfunctions,[7,32,33,35] higher stress hormones,[7,9,11,18,20] changes in HPA axis activity,[20,25] low BMD,[14,31] lower resting metabolic rate,[20] and increased risk of psychological disturbances.[10,19] Low EA also affects athlete perception and likelihood of experiencing injury, decreased training response, and decreased endurance performance.[19] Reproductive health is a large indicator of metabolic health, although T3 and ghrelin are excellent markers of energy states as well.[11,20,41] As newer studies emerge, the use of menstrual health as the primary marker for low EA is becoming less and less popular.

# CHAPTER 2

# INTRODUCTION

Energy availability (EA) is a concept important to elite and recreational athletes alike. Energy availability is the residual energy that is available to support an athlete's body functions once energy expenditure of exercise is deducted from energy intake.[9] Adequate EA allows the body to perform at its best, regarding both exercise and normal metabolic processes. When EA is neglected (low energy availability), detrimental consequences occur.[9,13,39] Such consequences are triggered by alterations in circulating hormones inherently resulting in negative effects like poor bone density, poor reproductive health, poor response to hunger cues, and impaired response to exercise.[5,7,20,31,39] According to the Baltimore Longitudinal Study of Aging, physiological changes occur as a result of the body trying to maintain homeostasis during periods of low EA, including changes in hormone secretions and receptor interactions to not only maintain homeostasis,[18] but to also minimize reproductive function and maximize survival efficiency[20] when underfed. Downregulating physiological functions as a survival tactic may be well-designed to maintain the existence of the human species; however, it is not optimal for an athlete's health and performance.[20] Research suggests there is a minimum energy intake of 30 kcals.kgFFM$^{-1}$.d$^{-1}$ (kilocalories per kilogram of lean body mass per day) required to avoid these consequences.[39] However, some research suggests that a threshold does not exist, and hormonal-induced menstrual disorders begin to increase linearly at 30 kcals.kgFFM-$^{1}$.d$^{-1}$, but are not necessarily associated with a threshold.[42]

The majority of research has investigated female endurance athletes who have experienced disordered eating, impaired menstrual function, and poor bone health; each of these a consequence of low EA, but together comprise the female athlete triad.[43] It is now understood that these three potential consequences of low EA are not just a triad of conditions, but an incredibly complex syndrome where energy availability is the center of a myriad of issues; this complex syndrome is often referred to as relative energy deficiency in sport (RED-S),[44] and affects both men and women. Low EA may not be common to only endurance athletes. About half of all female athletes are at risk of low EA[6] and are susceptible to its effects, as well as some sedentary females.[8] While low EA has been reported among professional endurance athletes and collegiate volleyball players, women who exercise recreationally, but regularly are also at risk for low EA.[2,4,6–8] Few studies have reported risk of low EA in recreational athletes, but it is speculated recreational athletes may be at a higher risk of low EA than professional athletes due to often limited access to nutritional advice and support,[6] as well as poor or incorrect advice that is readily available from the internet. A study recently done in New Zealand reports that 45% of its recreational female exercisers are at risk of low EA.[6]

Recreational exercise encompasses individual fitness endeavors as well as those in a group setting. High-intensity training is also gaining popularity among recreational exercises; CrossFit is a form of high-intensity functional training.  Training sessions/programs are designed to keep training intensity constantly varied and stress all three metabolic pathways (phosphagen (ATP-CP [adenosine triphosphate-phosphocreatine]), glycolytic, and oxidative).[45] The blueprint of a typical session allows for 3-5 sets of 3-5 reps of a fundamental lift (powerlift or Olympic lift) at a moderate pace, followed by 10 minutes of gymnastic or plyometric focus, ending with a 2-10 minute workout of the day (WOD).[46] The efficacy of a training program relies on adherence to both the program and diet. CrossFit is often associated with strict dieting behaviors. The CrossFit foundations course and many trainers recommend Paleo and Zone diets.[46,47] It should be noted that the recommendations of these diets do not parallel with those of the International Society of Sports Nutrition (ISSN).[48] In a recent study, the diet of 62 non-elite CrossFit athletes were compared to the ISSN recommendations. Both male and female athletes fell well below the recommended caloric and carbohydrate intake.[49]

## Statement of the Problem

Given the higher risk of low EA among recreational athletes[6] and the strenuous nature of CrossFit activities, it is possible that CrossFit athletes are at greater risk of low EA than other athletes. Accordingly, the general aim of this study is to assess both risk of low EA among female, recreational CrossFit athletes and determine prevalence in the same population.

**Specific Aim 1:** To assess the risk of low energy availability in the female recreational CrossFit athlete using the LEAF-Q questionnaire. We hypothesize that 20% of the respondents will be at risk for low EA. Furthermore, we believe that risk of low EA will be greater as participation level becomes more advanced (scaled, intermediate, Rx, elite).

**Specific Aim 2:** To determine the prevalence of low energy availability in the CrossFit community of the female recreational CrossFit athlete. We hypothesize energy availability will be low among CrossFit athletes ($< 30$ kcals.kgFFM$^{-1}$.day$^{-1}$).

# CHAPTER 3

# METHODS

## Phase 1: Risk of Low Energy Availability

### *Participants*

Participants were recruited through social media and online communication through a survey link via QuestionPro. Inclusion criteria stated participants must be 18 years of age or older, female and must be a current member of an affiliated CrossFit gym and have been for at least 3 months (90 days). If they met the criteria, participants clicked the survey link where they received the informed consent including a statement of purpose, the benefits and risks of the study, their right to privacy, their right to withdraw at any time, and contact information for the investigator. Implied consent was assumed when participants completed the survey. A power analysis indicated that 86 participants were required to achieve significant data using 80% power at a 0.05 alpha. An attempt was made recruit at least 100 participants to account for dropout and incomplete surveys.

The survey was first announced on March 9, 2021, via Instagram, and reached 1,641 accounts. A second announcement was posted on March 16, 2021 and reached 625 accounts. A last call was posted on March 24, 2021 and reached 923 accounts. The survey was open from March 9, 2021 through March 31, 2021.

### *Determination of Risk of Low Energy Availability*

The LEAF-Q is a 25-item questionnaire produced an acceptable sensitivity (78%) and specificity (90%) in order to correctly classify current EA and/or reproductive function and/or bone health.[50] Additional questions were added to assess participants involvement in CrossFit including length of participation, level of fitness (scaled, intermediate, Rx, elite), hours of training per week, number of classes per week, current body composition goals, access to a registered dietician, and activities done outside of CrossFit. A score equal to or greater than 8 indicates risk of low energy availability.

## Phase 2: Measurement of Energy Availability

This descriptive study includes a 7-day dietary and exercise record to calculate energy availability among recreational, female CrossFit athletes.

### *Participants*

Participants were recruited through the survey from phase 1 where information about phase 2 was given at the end of the survey. If interested, the participant submitted her email to be contacted with further information regarding phase 2. Participants completed informed consent and selected a start date to begin their dietary and exercise record between March 21, 2021 and April 18, 2021. New participants were not accepted after April 12, 2021.

### *Anthropometric and Body Composition Measurements*

All anthropometric and body composition measurements were self-reported. Body composition was measured using the MADE smartphone application and reported by the participant. The smartphone application is capable of measuring body fat percentage, fat mass and fat-free mass from a single digital image with acceptable accuracy and validity.[51,52] No images or personally identifiable information from the app were used as part of this study.

### *Energy Expenditure*

Assessment of energy expenditure was conducted by a 7-day exercise diary, where participants were instructed to keep record and report number of exercise minutes per day in specific categories (CrossFit, yoga, stretching, walking, weightlifting, dance, running (continuous), running (intervals), cycling, swimming, and rowing). Metabolic equivalents (METS) values associated with each exercise category as defined by the compendium of physical activity were used to calculate exercise induced energy expenditure for each day.[53] Basal metabolic rate (BMR) was calculated using the Harris-Benedict equation and total daily energy expenditure (TDEE) was calculated using an activity multiplier associated with the Harris-Benedict equation and the energy expenditure of non-exercise activity thermogenesis.[54–56]

### *Dietary Record*

Dietary intake was self-reported via MyFitnessPal for each of the 7 days as part of this study.[57,58] Participants were instructed to measure their food and beverages using a food scale or use the hand method.[59] Participants reported the number of total calories, grams of protein, grams of fat, grams of carbs, and percent recommended daily value of iron and calcium each day. Mean values of energy, macronutrient, and micronutrient intake were compared to ISSN and CrossFit recommendations.[46,48]

### *Calculation of Energy Availability*

Energy availability was calculated using the equation EA = [EI – ExEE] / kg FFM (energy availability equals energy intake minus exercise-induced energy expenditure divided by kilograms of fat-free mass). EI, ExEE, and FFM values were obtained via the measurements and calculations listed above.

### *Statistical Analysis*

This was a descriptive study, analyzing the energy intake and expenditure of recreational, female CrossFit athletes over 7-days. A one-way analysis of variance was used to determine if variables of interest varied day to day. Data are presented as means ± standard deviations. A multiple regression estimated which factors (kcals, protein, carbohydrates, fat, or ExEE) contributed most to energy availability.

# CHAPTER 4

# RESULTS

### *Phase 1: Risk of Low Energy Availability*

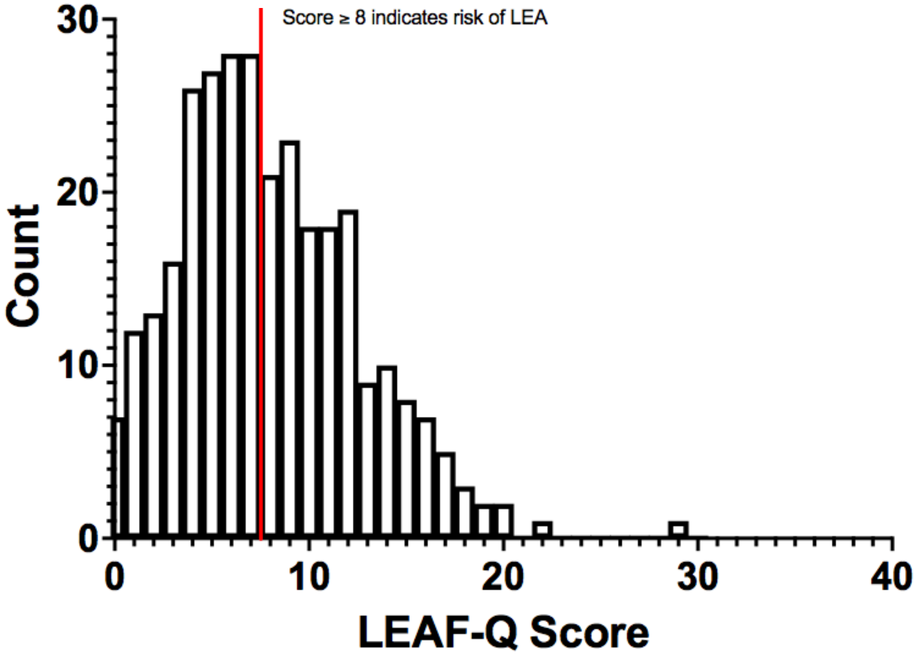
A total of 306 completed the LEAF-Q survey for phase 1 (75% completion rate). Of those entries, one entry was eliminated as the respondent was male, and one entry was discarded as the woman was in menopause for a total of 304 responses. Table 1 presents subject characteristics. Figure 1 describes the responses to the questionnaire. The mean LEAF-Q score was 8.1 (range 0-29), while the most common score was 6. A score greater than or equal to 8 indicated the respondent is at risk of low EA. The survey results indicated that 49% of survey respondents (n = 149) were assessed as at risk of low EA, while 51% of respondents were assessed as not at risk (n = 155). Figure 2 shows the distribution of LEAF-Q score by athlete skill level (scaled, intermediate, Rx, elite). Table 2 shows training goal and access to a registered dietitian. Average years of CrossFit training experience among respondents was 3.3 years.

*Table 1: Phase 1 Participant Characteristics*

| Age (years) | Height (cm) | Weight (kg) | BMI |
|---|---|---|---|
| 29.4 ± 7.4 | 164.9 ± 6.7 | 68.9 ± 12.6 | 25.3 ± 4.2 |

*Figure 1: LEAF-Q Scores*

*Figure 2: LEAF-Q Scores by Competition Level*



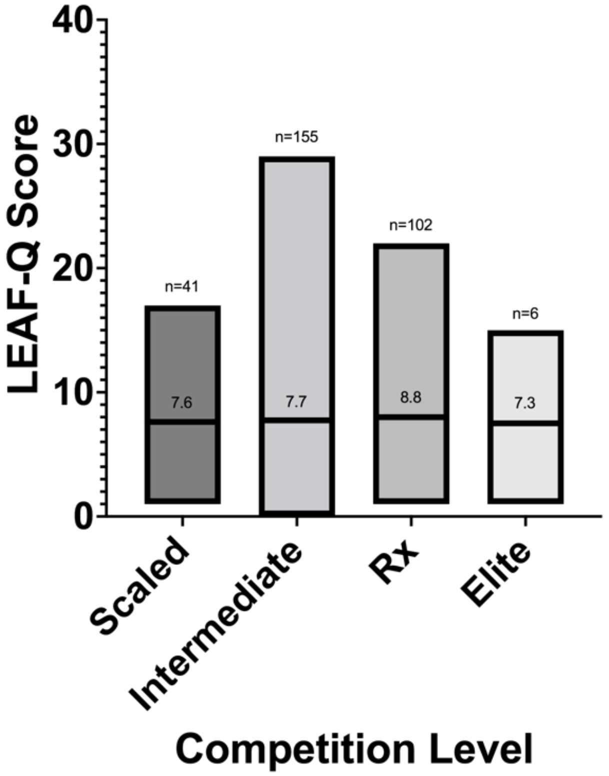


*Table 2: Current Diet and Training Goals, Access to Registered Dietitian*

| **Current Diet and Training Goals** | | | **Access to Registered Dietitian** | | |
|---|---|---|---|---|---|
| Improve general fitness | 47% | n = 143 | Yes | 43% | n = 130 |
| Weight loss | 21% | n = 63 | | | |
| Maintenance | 21% | n = 63 | No | 57% | n = 174 |
| Weight gain/increase muscle mass | 12% | n = 35 | | | |

### *Phase 2: Measurement of Energy Availability*

Table 3 describes the participant characteristics of Phase 2.

Of the 167 participants interested in phase 2 per the survey in phase 1, 83 completed at least one day of the dietary record, and 67 completed all 7 days (81% completion rate). Table 4 describes daily average food and exercise records, including energy availability, the weekly average, and Table 5 are ISSN and CrossFit recommendations. The number of calories, protein, carbohydrates, and fat consumed were not different among the days of the week.

Although average EA is not below the unfavorable threshold, 30% of calculated EAs (n = 25) were below the threshold (< 30 kcals.kgFFM$^{-1}$.d$^{-1}$). Statistical analysis revealed that energy availability (EA) is significantly correlated to exercise-induced energy expenditure (p=0.0005, r= -0.39), energy intake (p<0.0001, r= 0.43), and intake of carbohydrates (p=0.0003, r= 0.40) and fat (p=0.0006, r= 0.38). Based on the regression analysis, the athletes in the present study who expend more 660 calories from exercise during the day were more than likely to experience EA below 30 kcals.kgFFM$^{-1}$.d$^{-1}$. Additionally, athletes in the present study who consumed less than 1715 calories per day, 170 grams of carbohydrates per day, or 53 grams of fat per day are more than likely to experience EA below 30 kcals.kgFFM$^{-1}$.d$^{-1}$. Protein intake was not significantly correlated to EA.

*Table 3: Phase 2 Subject Characteristics*

| **Age (years)** | **Height (cm)** | **Weight (kg)** | **Body Fat (%)** | **FFM (kg)** | **BMR (kcals)** |
|---|---|---|---|---|---|
| 29.6 ± 6.8 | 164.6 ± 6.2 | 67.7 ± 11.4 | 25.7 ± 6 | 50 ± 7.5 | 1455 ± 115 |

*Table 4: Daily and weekly average energy intake compared to ISSN and CrossFit dietary recommendations for athletes, exercise energy expenditure and energy availability among recreational, female CrossFit athletes*

| | **Day 1** | **Day 2** | **Day 3** | **Day 4** | **Day 5** | **Day 6** | **Day 7** | **Week Average** |
|---|---|---|---|---|---|---|---|---|
| **Energy Intake, Kcals** | 1934 ± 382 | 2012 ± 418 | 1985 ± 446 | 2049 ± 428 | 1937 ± 475 | 2056 ± 438 | 2019 ± 480 | 1983 ± 364 |
| **Protein, g** | 123 ± 39 | 130 ± 34 | 127 ± 33 | 127 ± 37 | 121 ± 37 | 127 ± 36 | 118 ± 39 | 124 ± 33 |
| **Protein, g/kg** | 1.86 ± 0.65 | 1.97 ± 0.58 | 1.95 ± 0.63 | 1.93 ± 0.65 | 1.86 ± 0.64 | 1.92 ± 0.63 | 1.79 ± 0.66 | 1.8 ± 0.6 |
| **Protein, % total kcals** | 25.6 ± 7.5 | 26.4 ± 7.4 | 26.1 ± 6.5 | 25.2 ± 7.7 | 25.6 ± 8.0 | 25.1 ± 7.8 | 23.9 ± 7.8 | 25.4 ± 6.5 |
| **Carbohydrate, g** | 197 ± 70 | 221 ± 68 | 217 ± 72 | 225 ± 65 | 213 ± 68 | 213 ± 69 | 221 ± 70 | 212 ± 58 |
| **Carbohydrate, g/kg** | 3.0 ± 1.16 | 3.33 ± 1.08 | 3.31 ± 1.22 | 3.41 ± 1.10 | 3.23 ± 1.09 | 3.24 ± 1.13 | 3.34 ± 1.13 | 3.2 ± 1.0 |
| **Carbohydrate, % total kcals** | 40.2 ± 9.8 | 43.6 ± 8.9 | 43.5 ± 9.9 | 43.6 ± 8.4 | 43.8 ± 8.2 | 41.1 ± 8.8 | 43.7 ± 9.5 | 42.5 ± 7.5 |
| **Fat, g** | 70 ± 30 | 69 ± 20 | 71 ± 26 | 67 ± 24 | 68 ± 33 | 76 ± 34 | 74 ± 30 | 71 ± 20 |
| **Fat, g/kg** | 1.06 ± 0.48 | 1.04 ± 0.30 | 1.06 ± 0.40 | 1.02 ± 0.38 | 1.03 ± 0.50 | 1.15 ± 0.56 | 1.11 ± 0.44 | 1.1 ± 0.3 |
| **Fat, % total kcals** | 32.7 ± 11.9 | 31.1 ± 6.7 | 31.9 ± 8.8 | 29.5 ± 8.4 | 31.3 ± 12.2 | 33.1 ± 10.9 | 32.3 ± 9.6 | 32 ± 6.7 |
| **Iron, % RDV** | 61 ± 41 | 65 ± 43 | 79 ± 70 | 65 ± 41 | 63 ± 43 | 65 ± 43 | 67 ± 57 | 67 ± 34 |
| **Calcium, % RDV** | 139 ± 174 | 126 ± 138 | 119 ± 126 | 146 ± 154 | 128 ± 141 | 125 ± 159 | 136 ± 147 | 131 ± 121 |
| **Exercise Energy Expenditure, kcals** | 495 ± 370 | 428 ± 252 | 458 ± 571 | 396 ± 248 | 407 ± 287 | 448 ± 540 | 460 ± 374 | 441 ± 264 |
| **Energy Availability, kcals.kgFFM$^{-1}$.d$^{-1}$** | 32.4 ± 13.9 | 35.2 ± 13.2 | 33.5 ± 14.7 | 35.9 ± 14.7 | 32.6 ± 12.5 | 34.7 ± 16.4 | 33.6 ± 12.7 | 34.1 ± 12.3 |

Kcals, kilocalories; kcals/kg, kilocalories per kilogram body weight; g, grams; g/kg, grams per kilogram of body weight; RDV, Recommended Daily Value.

*Table 5: Dietary Recommendations by the International Society of Sports Nutrition (ISSN) and CrossFit, Inc.*

| | **ISSN Recommendations**[48] | **CrossFit Recommendations ("athletic, well-muscled female")**[46] |
|---|---|---|
| **Energy Intake, Kcals** | 40-75 kcals/kg/day<br>2000-7000 kcals/day for 50-150kg athlete | 1275 kcals/day |
| **Protein, g** | | 98 g/day |
| **Protein, g/kg** | 1.4-2.0 g/kg/day | |
| **Protein, % total kcals** | | 30% |
| **Carbohydrate, g** | 150-1200 g/day for 50-150kg athlete | 126 g/day |
| **Carbohydrate, g/kg** | 5-8 g/kg/day | |
| **Carbohydrate, % total kcals** | | 40% |
| **Fat, g** | | 42 g/day |
| **Fat, g/kg** | | |
| **Fat, % total kcals** | 30% | 30% |
| **Iron, % RDV** | 18 mg/d (females)<br>18 mg/d (USDA)[60] | N/A |
| **Calcium, % RDV** | 1000 mg/d<br>1000 mg/d (USDA)[60] | N/A |

# CHAPTER 5

# DISCUSSION

The general aim of this study was to assess the risk of low EA among female, recreational CrossFit athletes and determine prevalence in the same population utilizing the LEAF-Q. In addition, we enrolled a subset of individuals who completed the LEAF-Q questionnaire to track physical activity and energy intake to calculate energy availability over a 7-day period. To our knowledge, this is the first study to assess risk and prevalence of low EA among CrossFit athletes, although a 2020 study observed the dietary intake and energy expenditure of 62 CrossFit athletes.[49] We report 49% of women surveyed were at risk of low EA. This proportion falls within reports of other recreational athlete studies,[6–8] although this study assessed a much larger number of participants. Previous studies surveyed recreational athletic women who met physical activity guidelines (150 minutes of moderate-intensity exercise or 75 minutes of vigorous-intensity exercise),[6–8] while the present study was focused within a single fitness niche, CrossFit.

Low energy availability (low EA) occurs when an imbalance occurs between energy consumption and exercise energy expenditure resulting in a negative energy balance and leaving inadequate energy available for normal physiological processes. It is the center of a complex energy deficiency syndrome, RED-S (Relative Energy Deficiency in Sport),[10] and stems from knowledge of the Female Athlete Triad (disordered eating habits, low bone mineral density, and amenorrhea). Consequences of low EA are triggered by alterations in circulating hormones inherently resulting in negative effects like poor bone density, poor reproductive health, poor response to hunger cues, and impaired response to exercise.[5,7,20,31,39]

While risk does not immediately mean an athlete will experience all, if any, of these consequences, it is important to minimize the risk of the potentially detrimental consequences of low EA. Coaches and athletes may find using the LEAF-Q more feasible than measure EA, as it requires minimal equipment, knowledge, cost, time, and can be used with multiple athletes simultaneously. The LEAF-Q affords a point of reference to identify potential risk and recognize individuals who would benefit from educational and counseling to avoid potential low EA consequences.

It is important to note that while an athlete may not experience menstrual issues (or perhaps they are masked by contraceptive measures), they may experience decreases in performance and motivation, and increased risk for illness and injury, because of low energy availability. On the contrary, an athlete may experience gastrointestinal or menstrual issues resulting in a high LEAF-Q score but does not necessarily indicate low EA is the root cause. Several physiological and psychological factors may impact the GI system and the menstrual cycle. The LEAF-Q does not allow for exact determination of cause, but rather existence of symptoms.

The second phase of this study found the average energy availability (EA) among participants was about 34 $\text{kcal.kgFFM}^{-1}.\text{d}^{-1}$, lower than the EA found among recreational exercisers in a 2018 study,[7] vocational dance students,[61] endurance athletes,[2] and collegiate volleyball players,[4] but more than CrossFit athletes,[49] German football players,[62] collegiate basketball players,[63] and lacrosse players[64] observed in other studies. The EA observed among athletes in this study was much lower than the recommended 45

$kcal.kgFFM^{-1}.d^{-1}$ but not below the threshold of 30 $kcal.kgFFM^{-1}.d^{-1}$ suggested of Loucks' and the IOC working group.[10,13–17]

The low EA is most likely attributed to insufficient carbohydrate consumption resulting in inadequate energy consumption. Average energy and carbohydrate intake did not meet ISSN recommendations.[48] However, protein intake was within ISSN recommendations,[48] and fat intake fell in line with both ISSN and CrossFit recommendations (30% of daily intake).[46,48] Additionally, participants were deficient in iron intake, consuming about 65% of the DRI, but consumed more than 100% of the DRI for calcium. Deficiencies in any category can cause implications for the athlete. Not meeting energy recommendations can cause low energy availability, which is the center of a complex energy deficiency syndrome, RED-S.

The energy requirement for athletes is higher than that of the average, sedentary person due to the higher energy demand of exercise, and energy needed for recovery. As CrossFit contains both strength-building activities and high-intensity functional training, athletes should consume an appropriate number of calories and protein each day for proper muscle protein synthesis and repair and glycogen resynthesis.

A result of prolonged inadequate energy intake is the loss of muscle mass and strength, a decline in bone mineral density, and may make an athlete more susceptible to illness and injury as disturbances occur among the immune, endocrine, and reproductive system function.[10] Although energy deficiency occurs in both men and women, female athletes may be at a particularly increased risk due to competitive and aesthetic pressure placed upon them by both sport and society. Average daily energy intake did not meet the minimum recommendations per the ISSN (40-75 $g.kg^{-1}.d^{-1}$) nor did EA meet 45 kcal.kgFFM$^{-1}$.d$^{-1}$, which is associated with energy balance and optimal health.[10,13–17] However, the average daily intake surpassed that recommended by CrossFit.[46] Not surprisingly, caloric intake is positively correlated with energy availability. It can be assumed that if an athlete is not meeting an adequate caloric intake, at least one macronutrient will be deficient. In the present study, athletes were deficient in carbohydrate and total energy intake.

CrossFit, Inc. endorses the Zone Diet recommendations. Based on these guidelines, a small female athlete is allotted 10 blocks, while a “well-muscled” female athlete is allotted 14 blocks, 1 block is equivalent to 7 grams protein, 9 grams carbohydrate, or 3 grams fat, ranging from 910-1275 calories.[46] The blocks do not account for “hidden calories” (other macronutrients present in a food classified by a single macronutrient). Thus, the actual caloric intake should surpass the value associated with the recommended blocks, however it is uncertain by how much. Additionally, an athlete or coach with limited nutrition knowledge may view the recommended blocks as a macronutrient recommendation and strict adherence to those values will result in chronic low energy availability. CrossFit recommendations do not match those of the ISSN, and CrossFit recommendations appear to not recommend enough energy intake to support the demands of CrossFit activities and may explain the high prevalence of low EA among the participants.

Protein intake is associated with loss of fat mass and increase of fat free mass.[65,66] Increased in protein intake (through diet and supplements) appear to have some advantage in developing strength and muscle to individuals following a strength training program when the athlete is also consuming adequate calories.[65,66] Inadequate protein intake may lead to loss of muscle mass, but at the very least will not facilitate muscle protein synthesis, making an increase in strength and/or muscle mass extremely difficult. The athletes in this study consumed adequate protein when compared to ISSN recommendations, but fell below CrossFit recommendations,[46,48] furthermore, protein intake was not correlated with EA in the present study. Athletes interested in reducing weight may require a higher protein intake (2.3-3.1 $g.kg^{-1}.d^{-1}$) which is associated with retention of lean body mass of resistance-trained individuals during a caloric deficit.[65]

Carbohydrate intake is extremely important when considering the diet of an athlete. Carbohydrate intake supplies and replenishes muscle glycogen stores required for muscle work. CrossFit is demanding among all energy systems, and absolute intensity only increases as an athlete progresses. Carbohydrate intake throughout the day, prior to, during, and after exercise can provide direct support to athletic performance. Additionally, carbohydrate has been studied as an ergogenic aid.[48] Inadequate carbohydrate intake can result in deficient glycogen stores, hindering athletic performance.[34] The present study demonstrated that recreational, female CrossFit athletes do not consume an adequate amount of carbohydrates when compared to the ISSN recommendations. However, athletes did consume more carbohydrates per day than recommended by CrossFit. In addition to caloric intake, carbohydrate intake was positively correlated with energy availability.

Fat intake for athletes parallels recommendations of the general public. A high fat diet is not recommended for athletes.[34,67] The athletes in this study demonstrated a fat intake in accordance with both the ISSN and CrossFit recommendations. In the present study, fat intake was positively correlated with energy availability.

This study measured calcium and iron, which are associated with bone metabolism and aerobic capacity, respectively. Adequate iron intake is needed to attenuate iron losses during exercise training and suboptimal iron stores, or marginal deficiencies will impair performance. Calcium plays a crucial role in bone metabolism but is not effectively absorbed without Vitamin D,[68] which the current study did not measure. The athletes in this study exceeded the RDI for calcium, but not iron. Over time, inadequate iron intake during intense training will result in iron deficiency and affect performance.[69,70] Supplementation may attenuate effects of iron depletion and should be considered by athletes not meeting the RDI.[71]

Lastly, the ISSN states those who follow a general fitness program may follow the recommendations of a normal diet, while specifying the energy expenditure of this group as 200-400 calories per session (30-40 mins, 3-4 times per week).[48] . The athletes in the present study expended ~495 calories per day during structured activity, with an estimated TDEE of 2750 kcals. The TDEE and the EE associated with exercise is similar to the TDEE measured in other CrossFit athletes[49] NCAA DII lacrosse athletes,[64] and the average across-season energy expenditure of collegiate basketball players.[63] The CrossFit athletes in the present study expended more energy than vocational dance students[61] and German football players,[62] but less than that reported of endurance athletes[2] and collegiate volleyball players.[4]

The athletes in phase one of the current study reported a similar number of active hours per week as another study of recreational athletes.[6] A CrossFit athlete, specifically a recreational CrossFit athlete, may place themselves in the “general fitness” category, but based on average daily caloric expenditure from exercise, should likely follow the recommendations of an athlete. It is also important to note that depending on the training session, exercise stimulus may require different energy demands. The number of calories, protein, carbohydrates, and fat consumed were not different among the days of the week for the athletes in this study. This could lead to within-day energy deficiencies for athletes. In female athletes, within-day energy deficiency is associated with higher cortisol levels, menstrual dysfunction, lower estradiol, and a lower RMR ratio (ratio between measured and predicted resting metabolic rate, a predictor of low EA).[72,73]

Future research should investigate biological and performance markers of various energy availabilities (low, adequate, optimal) among CrossFit athletes. A 2020 descriptive study examined the dietary intake and energy expenditure of a small sample of CrossFit athletes, but did not measure specific WOD performance or biological markers.[49] Any intervention that manipulates EA and promotes low EA for an extended period of time results in a greater risk to the participant and a question of beneficence.

It is important for coaches and athletes to become aware of low energy availability, RED-S, and their signs and consequences. It has been documented that CrossFit coaches do not have adequate knowledge of sports nutrition, especially surrounding macronutrients.[47] There is no data reporting knowledge of low EA and RED-S among CrossFit coaches, but knowledge of the Female Athlete Triad (disordered eating habits, low bone mineral density, and amenorrhea), low EA, and RED-S is limited among physicians, physiotherapists, athletic trainers, and coaches.[37,74–77] The CrossFit training seminars and guide should consider discussing the implications of under-fueling and low energy availability, and athletes should be screened periodically for low energy availability.

This study has limitations. All data was self-reported and may result in error, and it cannot be ruled out that some diet records, weight, and fat free mass measurements were inaccurate and therefore resulted in incorrect calculations of energy availability values. To reduce the potential sources of error, the investigators of this study provided information regarding how to appropriately measure and record food in the diary and measure body composition.

Additionally, this study was conducted during the COVID-19 pandemic (March-April 2021). Nearly all gyms experienced obstacles to normal operation, and the type and intensity of training that the gym was able to deliver may have changed during this time. It is unknown if all the athletes in this study had resumed to “normal” training at the time of the study. If intensity of and time dedicated to training lowered during the pandemic, the prevalence of low energy availability during “normal” training may be much higher than reported in this study.

### *Conclusion*

This study demonstrated that about half of recreational, female CrossFit athletes are at risk of low energy availability, which if unaddressed can lead to negative consequences among several body systems. This study also showed that the energy and carbohydrate intake of recreational, female CrossFit athletes do not meet the recommendations set forth by the ISSN. CrossFit is a demanding sport that stresses multiple energy pathways and requires the athlete to be well-versed in several areas (weightlifting, Olympic lifting, running, gymnastics, calisthenics, and high-intensity bursts). Energy intake must meet the energy demands of the sport. CrossFit athletes and coaches should become more familiar with low EA, RED-S, and proper nutrition for athletes. CrossFit, Inc. should consider updating its recommendations to match those of governing bodies among sports nutrition.

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