2023

IDEAL BODY WEIGHT AND BODY FAT PERCENTAGE PREDICT RELATIVE ENERGY DEFICIENCY IN SPORT (RED-S) SCORES IN COLLEGIATE ATHLETES

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Digital Object Identifier: https://doi.org/10.13023/etd.2023.116

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THESIS

A thesis submitted in partial fulfillment of the
requirements for the degree of Master of Science in Nutrition and Food Systems
in the College of Agriculture, Food and Environment
at the University of Kentucky

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2023

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ABSTRACT OF THESIS

IDEAL BODY WEIGHT AND BODY FAT PERCENTAGE PREDICT RELATIVE ENERGY DEFICIENCY IN SPORT (RED-S) SCORES IN COLLEGIATE ATHLETES

Background: Low energy availability (LEA) is the underlying cause of Relative Energy Deficiency in Sport (RED-S) which negatively affects athletes' physiological function, health, and performance. RED-S results from inadequate dietary intake to support energy expenditure for daily living, growth, and optimal performance. It occurs in both male and female athletes, with or without disordered eating. However, screening and diagnosis in athletes can be difficult. Objective: This study aims to identify strong predictors of RED-S and assess its prevalence in collegiate male and female athletes. Methods: A total of 270 NCAA athlete test points from mixed sports were evaluated for RED-S scores based on body fat percentage and difference between actual and ideal body weight. Athletes completed a physical health questionnaire and a body composition assessment (BodPod®). The RED-S Cumulative Risk Assessment Chart was created from the questionnaire. Results: Weight difference alone was not correlated with RED-S score, but when BF% was included, weight difference became a significant predictor ($p <$ 0.01). A lower weight difference below ideal body weight was predictive of RED-S only when body fat percentage was elevated. The study found a moderate RED-S risk in 30.1% of athletes. Conclusions: Weight difference was found to be an independent predictor of RED-S when controlling for BF%. Further research is needed to identify additional screening and prevention strategies for RED-S in collegiate athletes.

Keywords: relative energy deficiency in sport, low energy availability, collegiate athletes, female athlete triad, male athlete triad, body composition, ideal body weight

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March 8, 2023

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Chapter One: Introduction

Background

Energy status plays a key role in the health and sport performance of athletes. For an athlete to be healthy, energy intake must be adequate for the energetic demands of sport and physiological functions, allowing a balance between energy availability, bone metabolism, and proper menstrual functioning.[1] However, failure to consume sufficient energy to support exercise energy expenditure and daily living can lead to a state of Low Energy Availability (LEA).[2] Chronic LEA can limit training adaptation and increases risk of injury and illness in both male and female athletes.[3] Energy deficiency is the driving force behind both the Male and Female Athlete Triads. The Female Athlete Triad is defined as LEA, menstrual dysfunction, and changes in bone mineral density, while the Male Athlete Triad is defined as LEA, suppression of the hypothalamic-pituitary-gonadal axis, and impaired bone health.[1,4] The Female Athlete Triad, Male Athlete Triad, and Relative Energy Deficiency in Sport (RED-S) models conceptualize the responses of energy deficiency in athletes, with each model having their own strengths and limitations.[5]

Problem Statement

LEA can lead to the manifestation of RED-S, a condition that can result in irreversible health and performance impairments.[2] The underlying problem of RED-S is the inadequate intake of energy to support the range of body functions involved in optimal performance and health.[6] The International Olympic Committee (IOC) defines RED-S as "impaired physiological functioning caused by relative energy deficiency and includes, but is not limited to, impairments of metabolic rate, menstrual function, bone health, immunity, protein synthesis and cardiovascular health."[6] While the etiological factor of RED-S is LEA, the resultant can occur unknowingly with or without disordered eating or an eating disorder.[7]

Several challenges hinder the accurate diagnosis of RED-S. One challenge is the range of bodily dysfunctions that can be present, while different athletes may exhibit various subsets of dysfunctions.[8] Another challenge involves that the assessment of symptoms greatly relies on the accuracy of an individual's recall and self-report on questionnaires, food records and dietary behaviors to inform the professional's diagnosis.[8,9] The Female Athlete Triad Coalition developed screening questions along with a risk assessment scoring tool to help stratify female athletes at risk for the triad and RED-S. The National Collegiate Athletic Association (NCAA) recommends all athletes to be given a preparticipation physical examination prior to sport participation, which consists of questions related to nutritional concerns, menstrual and injury history.[10] The most relevant RED-S-associated diagnostic factor may consist of: oligo-amenorrhea (missing three of more menstrual cycles in six months), two or more bone stress injuries, low bone mineral density for age (Z-score < -1.0), chronic dietary restriction, substantial changes in body mass or composition in short time periods, prolonged fatigue, training irregularities, decreased libido, and factors related to a drive for thinness and extreme dieting.[6,11]

LEA has been shown to be prevalent, yet likely underreported, in athletes. The risk of LEA ranges from 20% to 60% in elite and collegiate athletes, with prevalence reported in volleyball players (20%), male and female distance runners (25%, 31%), soccer players (33.3%), and gymnasts (44.8%).[4,12,13] On the higher end of prevalence, when evaluating RED-S indicators in a mixed-sport cohort of female athletes (n = 112), 81% of athletes exhibited between one and three indicators.[14] By regularly reviewing the screening tools and instruments, the likelihood of identifying athletes at risk for LEA increases.[15] Early detection of such disorders is important to facilitate early treatment and reduce the risk of RED-S consequences.

Currently, the RED-S risk assessment scoring tool used for screening athletes at risk for RED-S consists of six health domains: low EA with or without disordered eating/eating disorder, delayed menarche, oligomenorrhea and or/amenorrhea, low bone mineral density, low body mass index (BMI), and stress reaction/fracture. These individual domains can be scored from a 0 (low risk) to a 2 (high risk) within a points system. Based on the total points per athlete, the individual will receive a cumulative RED-S score and be subject to low (0-1 points), moderate (2-5 points), or high-risk (≥ 6 points) category.[10] These tools can assist in screening athletes at risk for LEA, but additional scientifically validated and relevant methodology to identify athletes at risk for RED-S is needed within the athletic community.[6]

Purpose Statement

The objective of this study was to evaluate strong predictors of RED-S in order to help screen and identify at-risk athletes more accurately. The study aimed to investigate the prevalence of RED-S in this sample of collegiate athletes to better assess the population.

Research Questions

1) Are the categories of weight difference (based on body mass and ideal body weight) and body fat percentage together significant predictors of RED-S in both female and male collegiate athletes?
2) What percentage of athletes will be identified as at moderate risk for RED-S when screening 184 athletes from 13 different sports teams?

Hypothesis

We hypothesized that, when controlling for body fat percentage, weight difference (body mass (kg) – IBW) would be a significant predictor of RED-S score among male and female athletes. Specifically, a lower weight difference (below IBW/ more negative) will only be predictive of RED-S scores when elevated body fat percentage is also present. We also hypothesized that 25% of our athletes would be identified as moderate risk for RED-S when screening 184 athletes from 13 different sports teams.

Chapter Two: Review of the Literature

Energy status plays a vital role in the health of athletes, yet a considerable number of athletes consume an inadequate energy intake when performing at intensified levels of training. For optimal physiologic function to occur in athletes, adequate energy intake relative to energy expenditure is essential.[16] Since the protection of athlete health has become an area of increased priority within athletic organizations, the topic of low energy availability (LEA) has been brought to an elevated need for attention.[17] Negative health and performance outcomes can occur when an athlete is in a long-term energy deficit.

Low Energy Availability

LEA is correlated with deleterious physiological, psychological and performance effects.[18] Energy availability (EA) is defined as the difference between dietary intake and energy expenditure standardized to fat-free mass per day, which leads to the energy remaining for metabolic processes.[10] For an athlete, EA can be described as the consumed energy remaining for metabolic processes after the energy cost of training has been deducted. When persistent LEA occurs in the body, different mechanisms favor essential processes instead of secondary functions like development, reproduction, and growth.[1] The optimal EA for an athlete should support the basic functions that allow for adequate performance and a healthy condition of living, which has been studied to be > 45 kcal/kg of free fat mass/day for females and > 40 kcal/kg FMM/d for males.[10] EA < 30 kcal/kg FFM/day (for 5 days or greater) is typically defined as LEA in both male and female athletes.[19] Energy deficiency is the driving force behind the Female Athlete Triad, which is defined as LEA (with or without disordered eating or an eating disorder), menstrual dysfunction, and changes in bone mineral density.[1]

Female Athlete Triad

The Female Athlete Triad, Male Athlete Triad, and Relative Energy Deficiency in Sport (RED-S) models conceptualize the responses of energy deficiency in athletes, with each model having their own strengths and limitations.[5] In 1992, the American College of Sports Medicine (ACSM) defined the Female Athlete Triad (Triad) as the intertwined relationship between EA, bone health, and menstrual dysfunction that was being observed in physically active women.[20] In 1997, the first ACSM Female Athlete Triad position stand was published, and it emulated the most scientifically sound Triad research available with descriptions on how LEA disrupts the hypothalamic-pituitary-ovarian axis and suppresses menstruation. These effects in turn negatively reduce bone mineral density.[5] The Triad progresses as a continuum of severity, beginning with adequate EA, eumenorrhea and optimal bone health.[21] The Triad is currently described as a metabolic injury with a female athlete commonly having one or multiple of the components of the Triad, as the Triad is related to a continuous spectrum.

Relative Energy Deficiency in Sport

In 2014, the International Olympic Committee (IOC) published a consensus statement introducing new terminology "Relative Energy Deficiency in Sport" (RED-S).[5] RED-S is defined as "impaired physiological functioning caused by relative energy deficiency and includes, but is not limited to, impairments of metabolic rate, menstrual function, bone health, immunity, protein synthesis and cardiovascular health."[6] While the etiological factor of RED-S is LEA, the resultant can occur with or without disordered eating or an eating disorder.[7] The activity in the field of study behind the Triad stimulated an increase in advances towards RED-S awareness. The consensus statement on RED-S broadens the Triad statement to more vastly incorporate a diverse population and include other systems that could be negatively affected because of LEA.[15] According to the expanded RED-S model, LEA can affect at least 10 body systems. In a study conducted with 112 elite and pre-elite female athletes, 80% of participants demonstrated at least one symptom that is described within the RED- S model, with the most prevalent body systems affected were the hematological, psychological, gastrointestinal, and immunological systems.[22]

Male Athlete Triad

Low EA was traditionally associated with the female athlete triad, but with the introduction of RED-S terminology, the recognition that males are also negatively affected by low EA came to fruition.[23] An aspect of RED-S led to the further investigation of the effects of energy deficiency in males, which led to the resultant product of a two-part consensus statement on the Male Athlete Triad.[5] This statement, which was published in 2021, introduced the intertwined outcomes of low EA (with or without disordered eating) with osteoporosis (or low bone mineral density), and/or functional hypogonadotropic hypogonadism (FHH).[5] FHH in males is the reduction or absence of hormone secretion or other physiological activity of the testes.

Athletes at risk of or experiencing RED-S have an increased risk of injury, decreased athletic performance, and physiological performance disturbances. It has been found that higher exercise dependence has been positively associated with eating disorder symptoms, pronounced negative energy balance and higher cortisol levels, leading to potential negative effects on body composition and performance.[24] This current research looks at male athletes and the association between risk of injury and RED-S. Research involving RED-S in males has investigated low bone mineral density, stress injuries, and exercise dependence, with a smaller emphasis on body composition changes predicting RED-S.[25] An increase in studies specifically aimed at observing RED-S in males needs to be continually conducted in future studies.

Signs and Symptoms of RED-S

Disordered Eating, Eating Disorder

There are frequent motivators that may influence an athlete's decision regarding specific dietary practices and habits. Common motivators may stem from cultural, familial, religious, social, or environmental concerns, which may lead to more sport-related influences like health, aesthetic requirements, weight-management, and/or weight-class restrictions.[26] Weight pressure and triggering factors such as pressure for performance, sudden increase in training volume, injury, and team weigh-ins can contribute to an athlete's concern towards eating.[6] These specific dietary preferences or restrictions may lead athletes to develop disordered eating habits or eating disorders. While the attributes of disordered eating behaviors and a clinical eating disorder differ, it is the energy restriction factor that may lead the athlete to a state of LEA.[27]

Compared to nonathletes, male and female athletes are at an increased risk of developing disordered eating, LEA, and the associated health outcomes.[27] With the use of multidimensional approaches and screening tools, Torres-McGehee et al. (2021) found that 76% of the observed female athletes and performing artists (dancers) were at risk for eating disorders when assessing traditional, comorbid, and pathogenic behavioral reasons.[28] The athletes who engaged in pathogenic behaviors (e.g., dieting, vomiting, using diet pills) demonstrated an increased risk for LEA.[29] Although it may seem obvious to evaluate leaner athletes for risk of an eating disorder, it is equally important to examine athletes who are not as commonly lean (e.g., soccer, softball players) since this population has been observed as the highest risk of athletes in some research findings.[29]

Melin et al., (2014) found that in a population of healthy male endurance athletes, greater exercise dependence scores positively correlated with eating disorder symptoms, a more negative energy balance, and greater cortisol levels.[30] There can be an overlap between LEA and eating disorders; Disordered eating can lead to LEA and LEA can result in eating disorders.[7] The energy imbalance results in a disturbance of several physiological functions and systems within the body.

Menstrual Dysfunction

When assessing the diagnostic tools of RED-S, the first manifestation of LEA in females results in dysregulation of the menstrual cycle or in amenorrhea.[1] A functional etiology must be considered in the existence of oligomenorrhea and/or amenorrhea for > 3 months. The energy-sparing adaptation of a female athlete experiencing impaired ovarian function appears to occur when EA decreases below 30 kcal/kg FFM.[31] When exercise training occurs simultaneously with ovarian suppression with evidence for energy conservation, poor sport performance has been shown to be associated.[32] Relatively current research by Schaal et al. (2021) showed that the chronic absence of menstruation may affect exercise performance, which complement similar studies' results. Menstrual dysfunction was observed in 60% of English elite middle- and long-distance runners.[31,33]

Comparable studies have shown that female athletes underreport menstrual cycle disorders, with a prevalence of up to 40%.[7] Menstrual dysfunction is often ignored and regarded as a casual or natural outcome of intense training, despite the alarming negative health consequences that can follow.[21] It can be difficult to assess menstrual cycle abnormalities as a factor of RED-S when female athletes often do not see an absence of the menstrual cycle as a problem, or they choose to prioritize sports performance over health.[7] Health concerns with functional hypothalamic amenorrhea include impaired bone health, reduced fertility, and increased cardiovascular risk factors.[5,6]

Impaired Bone Health

Low EA-related menstrual disturbances and dysfunction are associated with an increased risk of bone stress injury, as low bone mineral density (BMD) is an additional indicator of RED-S.[13] The IOC states that physically active female athletes with measured LEA or oligomenorrhoea/amenorrhea have demonstrated decreased BMD, decreased bone strength, and an increase for bone stress injuries compared with those who are not energy deficient.[6] For male athletes, Tenforde et al. (2018) demonstrated 43% of athletes had impaired bone health and proposed that factors related to RED-S (LEA and suppressed gonadal hormones) may increase risk for bone stress injury and lower BMD.[25] Athletes' Triad scores and RED-S criteria have been demonstrated to correlate positively with all-time fracture history, with amenorrheic athletes having a 4.5 times greater incidence of bone injuries compared to eumenorrheic female athletes and male athletes with normal testosterone levels.[12] These alarming results are in line with studies demonstrating endurance athletes with low EA and menstrual dysfunction being at a greater risk for low BMD. The findings discovered that females with elevated bone turnover consumed less than the recommended amounts of energy intake than those with normal bone turnover.[34] The prevalence of impaired bone health in groups of endurance athletes emphasizes the significance of early identification and prevention of athletes at risk for poor bone health.[21]

Effect on Sport Performance

All professional athletic staff, coaches, and their respected athletes desire collaboration in support of the athlete's optimal sport performance, yet this can only be achieved when the athlete's health and well-being are equally valued. The damaging physiological effects of LEA on an athlete's performance are important concerns for individuals to understand and investigate, as long-term LEA has been suggested to negatively affect sport performance through indirect mechanisms like impairment of muscle mass and function, along with a reduction in recovery.[6] In addition to the other consequences of RED-S, an increase in the risk of injury and illness is prevalent with LEA, so performance may be impaired due to the sequential loss of exercise and training.[19] A study conducted by Vanheest et al. (2014) demonstrated that sport performance declined by 9.8% in the energy deficiency, ovarian-suppressed group of female athletes, whereas performance improved by 8.2% in the cyclic group.[32] When an athlete is in a state of energy conservation, sport performance is most commonly not optimal. The potential negative consequences of LEA on sport performance indicate the need for increased research in this area, especially for male athletes.

Effect on Lean Body Mass

Research findings have been reported in both male and female athletes, with the hypothesis that a lowered RMR may be a protective mechanism to prevent weight reduction and changes in body composition.[35] A study analyzing male cyclists (n = 22) aimed to determine how a 4-week mesocycle of high-intensity endurance training would affect RED-S markers.[36] The researchers found that markers associated with LEA such as decreased RMR, lowered T_3, and increased cortisol were present at post-test, yet body composition (including FFM) remained unchanged.[36] A study experimenting with moderate, short-term energy restriction in physically fit men and women (n = 24) found that energy restriction did result in modest weight loss, with a majority coming from LBM.[37] A meta-regression looking at 59 articles indicated an energy deficient state impairs lean muscle mass gains as a result of resistance training, with the impairment of LBM gains correlating with the severity of energy deficit.[37,38] In a study evaluating 21 elite athletes, those receiving nutritional counseling following a meal plan with a surplus of 500 kcals/day had significantly greater, positive changes in body mass and LBM at the 12-month follow-up compared to the athletes who had ad libitum energy intake.[38] This suggests that LEA may inhibit the growth of lean body mass (LBM).[35,36]

The importance of LBM has been widely investigated, as studies have shown a positive relationship between an increase in muscle strength and power in correlation with an increase in LBM.[45] Lean tissue, especially in power sports, can lead to increased BMD, assist in power, and speed generation.[46] Strength training and nutritional advice are considerable elements when attempting to increase LBM in athletes. Regarding RED-S, it is ultimately less likely for an athlete to gain long-term LBM while in a state of LEA.

Prevalence of LEA and RED-S

Assessing Prevalence

Estimating the prevalence of RED-S within athletic populations is challenging due to the difficulties in diagnosing LEA and RED-S. Using the inferred surrogate measures that are commonly associated with LEA (such as the pervasiveness of injuries, physiological dysfunction, and physical signs of RED-S) can help to estimate the overall prevalence,[8] yet often nutritional data self-reported by athletes can fail to develop clear thresholds between EA and objective measures of RED-S.[13] Although precise differences are unknown between how LEA affects both females and males, females have been suggested to have a greater prevalence of LEA. The threshold and duration of LEA that leads to the induction of RED-S in males is still unknown.[6]

The increase of updated prevalence can only emerge with the increase of professional awareness; A recent cross-sectional survey investigated the knowledge among athletic trainers at NCAA member institutions and found that almost all of the athletic trainers (98.6%) were aware of the Triad, yet only one-third (33%) were aware of RED-S.[13,16] In a study with 108 athletes, a distressing 80% of participants were at some degree of risk of experiencing low EA.[23] When merging the clinical and subclinical Triad conditions in a study by Melin et al. (2015), 23% of the athletes displayed all three elements of the Triad (an even higher percentage than the 16% reported by Pollock et al. (2010), indicating that the coexistence of menstrual dysfunction, low EA, and impaired bone health are common among female elite endurance athletes.[21,33] With such a large, and often inconspicuous, number of athletes at risk for RED-S, the prevalence needs to be more promptly sought out.

Screening and Diagnosing

The gold standard for diagnosing RED-S has yet to be established, although similar questionnaires have been used in diagnosing the Triad.[8] Currently, the NCAA recommends screening for RED-S at the preparticipation physical examination (PPE), during annual health examinations, and when specific health problems are occurring for an athlete such as stress fractures, recurring injury or illness, severe weight loss or amenorrhea.[10,15] Screening for low EA within the PPE includes four parts related to nutritional concerns and three parts related to menstrual history.[10] As of current, the risk assessment scoring tool used for screening athletes at risk for RED-S consists of six health domains: low EA with or without disordered eating/eating disorder, delayed menarche, oligomenorrhea and or/amenorrhea, low bone mineral density, low body mass index (BMI), and stress reaction/fracture. These domains can be scored from a 0 (low risk) to a 2 (high risk) within a points system. Based on the total points per athlete, the individual will be subject to a low, moderate, or high-risk category.[10]

While the diagnosis of RED-S does not imply the presence of concrete clinical changes, its goal is to actively search for athletes at risk due to insufficient energy availability.[1] It has been found to be clinically important to ask athletes about their eating behaviors with various questions, framed in different ways, to detect disordered eating or an eating disorder.[26] Based on a detailed medical history and an individual's answers to questions about diet, weight fluctuations, stress, cycle menstruation, number of fractures and/or bone stress injuries, length of exercise and training hours, and sleep changes, a diagnosis or risk for RED-S can be determined.[1] With all of this said, it can be difficult to accurately measure LEA as it relies on the athlete's correct self-report of dietary intake and eating behaviors to inform the professional's subjective diagnosis.[9] It can be challenging to screen for LEA as EDs are commonly underreported by athletes. By regularly reviewing the screening tools and instruments, the likelihood of identifying athletes at risk for LEA increases.[15] Early detection of such disorders is highly important to facilitate early treatment and prevent the risk of RED-S consequences. The best practice for identifying individuals with RED-S should involve a multidisciplinary team that includes a medical physician, sports registered dietitian (RD), athletic training and strength and conditioning professionals, and a psychologist.[15]

Body Composition

An appropriate way to assess body composition in athletes is to use an air displacement plethysmography. Accurate measures of body composition within the athletic community are crucial to evaluate the health and performance of individuals. Body composition measures should be efficient, practical, and minimally invasive to maximize their usage, especially when dealing with collegiate athletes.[39] The specific BodPod® machine uses air displacement plethysmography to assess body composition, which is the utilized machine in this study. The BodPod® measures changes in pressure inside the machine to determine an athlete's total body volume. With the total body volume, the machine can calculate total body density, allowing an individual's percent body fat, percent fat free mass, fat mass (lbs.), and fat free mass (lbs.) to be calculated. Determining fat-free mass (FFM) for male and female athletes is important in evaluating for RED-s since an EA less than 30 kcal/kg of FFM is associated with a disruption of normal menstrual cycles and the other symptoms of RED-S.[40] Studies have shown air displacement plethysmography as a reliable method in estimating these measurements.[41] It is a strength when examining an athlete's health to have extremely accurate body composition measurements to better screen and evaluate for RED-S.

Prevention and Treatment

Prevention

The first step towards prevention must be an increase in awareness and improved educational strategies. Educational initiatives aimed at emphasizing the positive aspects of energy must be developed for athletes to understand that food is fuel, and fuel is ultimately needed for optimal performance.[11] Educational materials should include the signs/symptoms related to RED-S, healthy practices pertaining to weight assessment and body composition, open communication around eating patterns, menstrual cycles, and body image. Having accurate tools that can sensitively and safely identify athletes at risk for LEA and the associated health consequences is crucial for getting help towards the prevention of RED-S and for creating appropriate recommendations.[10]

Treatment

The recommended treatment of LEA includes an increase in energy intake, a reduction or decrease in energy exercise expenditure or a merger of the two components.[24] The absolute goal for athletes with LEA or disordered eating is to improve their dietary habits and overall nutritional status by improving eating behaviors and increasing healthy eating patterns. To achieve improved dietary habits, it may involve complex methods towards modifying behavioral change, challenging thoughts related to food, and treating any underlying psychological issues.[15] It must be assured that athletes have the proper access to a specific referral network of sports experts, including physicians, registered dietitians, athletic trainers, and sports psychologists, to better navigate guidance towards the goal of an increase in energy intake.[11]

Gaps in the Research

The measurement of EA, through dietary and exercise recordings, is difficult and lacks sensitivity as the main diagnostic tool for the presence of LEA. Despite ongoing investigation and advances in RED-S research, gaps in the understanding of the pathophysiology and physiology of athletes with LEA remain; These need to be filled to progress screening, treatment, and return-to-play recommendations.[42] An increase in multicentered research will be required to validate a diagnostic tool more accurately applied for RED-S.[11] Comparatively, an insufficient number of studies have investigated the impact LEA has on sport performance, specifically in collegiate-level athletics.[19] Most of the research investigating the signs, symptoms, and consequences of RED-S has been conducted in female athletes.[30] Few studies have observed the relationship between LEA and disordered eating in male athletes. The number of male-based studies on LEA is limited. For that reason, this current research will include findings from both male and female athletes. This research will evaluate a large sample size of athletes and attempt to determine significant predictors of RED-S score while considering body mass index (BMI), BF%, and IBW as potential predictors in both male and female sports considering RED-S signs and symptoms. The need for future research in this area is evident by the portrayal of poor understanding of athletes and coaches of the potential health and performance consequences of RED-S.

Conclusion

The Female Athlete Triad, Male Athlete Triad, and RED-S models conceptualize the responses of energy deficiency in athletes, with each model having their own strengths and limitations.[5] The findings of a multitude of studies substantiate the importance of further monitoring and understanding LEA and RED-S in female and male athletes undergoing intense physical activity regimens. Research has significantly shown the body-wide consequences of having low energy availability as an active athlete. There needs to be an increased awareness and education of RED-S among all athletes, coaches, and appropriate professionals within the athletic community, especially at the collegiate level. The development and expansion of sports nutrition programs that focus on the diagnosis, prevention and treatment for RED-S is needed to improve knowledge of EA and help athletes maintain an optimal health status. The aim of this research is to evaluate strong predictors of RED-S and investigate the prevalence of RED-S in collegiate student-athletes in hopes of increasing the awareness of this syndrome.

Chapter Three: Methodology

Research Design

For this primary data analysis study, participant data was analyzed from 13 University of Kentucky National Collegiate Athletic Association Division 1 (NCAA D1) male and female collegiate teams. The aim was to analyze the physiological and behavioral attributes of athletes as related to sport-specific performance, injury, and student-athlete wellness. The athlete data was obtained from two fall athletic seasons, August 2021, and August 2022. The University of Kentucky's Office of Research Integrity Institutional Review Board approved all procedures and questionnaires for this study.

Participants

The study investigated the prevalence of relative energy deficiency in sport (RED-S) in the athletic community from a sample of NCAA Division 1 male and female athlete test points (N = 270) in the disciplines of softball (n = 38), gymnastics (n = 31), volleyball (n =9), baseball (n = 35), men's tennis (n = 2), women's tennis (n =10), men's soccer (n = 33), women's soccer (n = 44), men's swim (n = 18), women's swim (n = 40), men's cross country (n = 5), women's cross country (n = 3), and women's track (n = 2). Both male (n = 93) and female (n = 177) athlete test points were used in the study with the range of ages being 17 to 25 years (average age, 20 ± 1.45 years). A convenience sample of athletes varying from freshmen to graduate-level students from a variety of sports teams was chosen to evaluate the potential range of RED-S scores among differing physical activity requirements. There was a total of 184 individual athletes evaluated with 86 of those athletes having repeated assessments. In total, 270 athlete test points were included in the primary analysis. The inclusion criteria for this study were for an athlete to have fully completed a physical health questionnaire, a BodPod® assessment, and provided written informed consent. The exclusion criterion was if an athlete had an incomplete physical questionnaire or had not completed a BodPod® assessment. All participants provided written informed consent after being told the specificities of the research.

Measurements

Physical Health Questionnaire

The annual pre-participation physical evaluations (PPE) were conducted in both August of 2021 and 2022 by the sports medicine physicians where the athletes completed the mandatory, back-to-school physical health questionnaire (seen in Table 1). The questionnaire was electronically accessed by the athletes via a link sent from their team's corresponding athletic trainers and physicians. The athletes could also access the questionnaire by scanning a QR code from the athletic training room that would electronically connect them to the link. Both the questionnaire and RED-S policy in place at the University of Kentucky were consistent with the IOC Consensus Statement: Beyond the Female Athlete Triad – Relative Energy Deficiency in Sport (RED-S) as well as the 2014 Female Athlete Triad Coalition Consensus Statement which is endorsed by the American College of Sports Medicine and American Medical Society for Sports Medicine. The questionnaire had been used for several preceding years, yet 2021 was the first year the questionnaires had been completed electronically due to an update in the technology and due to the COVID-19 pandemic.

The athletes were first presented educational material made by the NCAA regarding energy availability and the female athlete triad. They were then asked to complete the questionnaire to assess for health outcomes included within the LEAF-Q (low energy availability in females questionnaire): history of stress reactions/fractures, history of critical comments about eating or weight from parent, coach, or teammate, history of depression, history of dieting, pressure to lose weight and/or frequent weight cycling, recurrent and non-healing injuries, and low body mass index or recent weight loss. Specific questions regarding history of menstrual irregularities, amenorrhea, and age of menarche were only applicable for the females to answer. The completed forms were reviewed by the athletic training staff and team physician. The data from the questionnaires was assessed and used to answer the RED-S Cumulative Risk Assessment Chart explained below.

Table 1: University of Kentucky Female Athlete Health Questionnaire

Name: ____________ Sport: ____________ Date: ____________

1. How old were you when you had your first menstrual period? ______
2. When was your most recent menstrual period? ____________
3. How many menstrual periods have you had in the past 12 months? ______
4. Have you ever missed 3 or more consecutive months of your menstrual period? ______
5. Are you on any form of estrogen/birth control? ________
   If yes, what form? ____________
   How long have you been taking it? ____________
   Why? (heavy/painful periods, pregnancy prevention, other) _
   If it has been recommended and you are not taking it, why? ____________________
6. Do you worry about your weight? ____________
7. Are you trying to gain or lose weight? __________
8. Has anyone recommended that you gain or lose weight? ____________
9. Have you ever used excessive exercise, laxatives, diuretics, or vomiting to help control your weight?
   If yes, which of the above apply? ______________________________
10. Are you on a special diet (vegetarian, gluten free, diabetic, etc.) or do you avoid certain types of foods or food groups? ________________________
11. How many meals and snacks do you eat per day?
    Breakfast ______
    Lunch ________
    Dinner ________
    Snacks ________
12. Have you ever had an eating disorder? __________
    If yes, are you in a treatment program or involved in a treatment plan? ______________
13. During your participation in your sport, how often do you feel the following:

	None		Sometimes		Often
Extreme Happiness	1	2	3	4	5
Depression	1	2	3	4	5
Anxiety	1	2	3	4	5
Anger/short temper	1	2	3	4	5
Feelings of isolation	1	2	3	4	5
Fatigue	1	2	3	4	5
Low self-esteem	1	2	3	4	5

14. Have you ever had a stress fracture or a bone stress reaction? ________
    If yes, where was it located? ________________________
15. Have you ever had a bone scan or bone density test?__________

BodPod®

The BODPOD® Body Composition System (Cosmed, Chicago, IL) was used in this study. Body composition (percent body fat, body mass) was analyzed and directed by a certified technician at the Sports Medicine Research Institute on campus in the adjacent building to the athletes' training facilities. The student-athletes were instructed to wear compression clothing and a swim cap inside the BodPod® and to not drink or eat anything two hours prior to the assessment. The BodPod® test took approximately three minutes to complete. BMI was calculated by using the ratio of weight to height (kg/ m^2). IBW was calculated using the Devine formula[43] (for men: 50 kg + 2.3 kg/each inch over 5 feet, for women: 45.5 kg + 2.3 kg/each inch over 5 feet). Weight difference was calculated using actual body mass (kg) minus calculated IBW. The athletes were each scheduled to attend a BodPod® assessment at one time in the month of August. The body composition data was condensed and organized by data scientists and trained graduate students.

RED-S

The following management policy to evaluate athletes for RED-S is based on the current recommendations from the NCAA, International Olympic Committee (IOC), Female Athlete Triad Coalition, American College of Sports Medicine, and American Medical Society for Sports Medicine. The policy represents a multi-faceted approach to treating RED-S, with the inclusion of clinical guidelines for risk stratification and management of athletes with the syndrome. The RED-S Cumulative Risk Assessment Chart (Table 2) was used to serve as an objective method of risk stratification built on evidence-based risk factors, which was completed using the athlete's answers from the physical health questionnaire. The following seven factors were scored for female athletes: (1) low EA with or without DE/ED, (2) low body fat, (3) delayed menarche, (4) oligomenorrhea and/or amenorrhea, (5) low BMD, (6) stress reaction/fracture, and (7) physical complications. The male athletes were scored for all the same factors except for delayed menarche and oligomenorrhea/amenorrhea. Each factor had indications for low risk (0 points), moderate risk (1 point), and high risk (2 points). The cumulative risk score was the total sum score from each category's points.

Table 2: RED-S Cumulative Risk Assessment Chart

RED-S CUMULATIVE RISK ASSESSMENT

RISK FACTORS	MAGNITUDE OF RISK		
	Low Risk = 0 points each	**Moderate Risk = 1 point each**	**High Risk = 2 points each**
Low EA with or without DE/ED	☐ No dietary restriction	☐ Some dietary restriction; current/past history of DE	☐ Meets DSM-V criteria for ED
Low Body Fat	☐ BMI >18.5 or >90% EW or weight stable	☐ BMI 17.5 – 18.5 or <90% EW or 5-10% weight loss/month	☐ BMI <17.5 or <85% EW or >10% weight loss/month
Delayed Menarche	☐ Menarche <15 years	☐ Menarche 15-16 years	☐ Menarche >/=16 years
Oligomenorrhea and/or Amenorrhea	☐ >9 menses in 12 months	☐ 6-9 menses in 12 months	☐ <6 menses in 12 months
Low BMD	☐ Z-score >/= -1.0	☐ Z-score -1.0 <-2.0	☐ Z-score </= -2.0
Stress Reaction/Fracture	☐ None	☐ 1	☐ >2; >/= 1 high risk or of trabecular bone sites
Physical Complications	☐ None	☐ Lab abnormalities ☐ ECG abnormalities	☐ Extreme weight loss techniques leading to dehydration-induced hemodynamic instability
CUMULATIVE RISK	________ **points +**	________ **points +**	_______ **points =** _______ **total score**

Student-athletes participating in a sport who screened positive for multiple risk factors for RED-S or disordered eating after completing the physical health questionnaire underwent a Cumulative Risk Assessment. The RED-S Clearance and Return to Play Policy (Table 3) was dependent on the total score from the risk assessment. The three recommendations were as followed: (1) full clearance was permitted with 0-1 points and denoted with the green light for full participation, (2) provisional or limited clearance was recommended with 2-5 points and denoted with the yellow light, and (3) restricted from training and competition was recommended with $\geq$ 6 points and denoted with the red light. Pre-participation medical clearance and return to play recommendations were determined by risk stratification and assessment of the athlete by the team physician and the Management Team, including the athletic training staff, sports dietitian, and mental health professional, if needed. An athlete with 2 points or greater (yellow to red light) had to follow up with the requested multi-disciplinary team members as determined by the team physician and had to have necessary tests within a defined time.

Table 3: RED-S Clearance and Return to Play Chart

RED-S CLEARANCE AND RETURN TO PLAY RECOMMENDATIONS BY RISK STRATIFICATION

	Cumulative Risk Score	Green Light	Yellow Light	Red Light
Full Clearance	0-1 point	☐ Full Participation		
Provisional/Limited Clearance	2-5 points		☐ Provisional Clearance ☐ Limited Clearance	
Restricted from Training and Competition	>/= 6 points			☐ Provisional Restriction ☐ Disqualified

Statistical Analysis

Only fully completed questionnaires and BodPod® tests were included in the analysis. Statistical analyses were performed using IBM SPSS Version 28.0 (IBM Corporation, Armonk, New York). Linear regression was used to determine significant predictors of RED-S occurrence while considering body mass index (BMI), BF%, and weight difference (actual body mass (kg) - IBW) as potential predictors in both male and female sports. This allowed the researchers to determine the best predictor in RED-S occurrence while controlling for other variables. The linear regression was first performed with the total sample size together, then was split between males and females. Descriptive statistics were used to analyze the frequency of RED-S scores ranging from 1-5 points. Statistical significance level was defined as $P < 0.05$.

Chapter 4: Results

The demographic, anthropometric, and mean RED-S score of all athletes is presented in Table 4. The mean age, BMI, and weight were greater in the male population, while mean body fat percentage, RED-S score, and sample size were greater in the female population.

Table 4: Athlete Demographics

	Males	Females
Mean Age (yrs)	20 ± 1.44	19.73 ± 1.06
Mean BMI (kg/m^2)	23.87 ± 2.46	22.68 ± 2.3
Mean Weight (kg)†	80.34 ± 10.31	64.99 ± 8.73
Mean Body Fat (%)†	11.97 ± 4.68	20.20 ± 5.40
Mean RED-S Score	0 ± 0.70	1.39 ± 1.35
Number of participants	N = 93	N = 177
Percentage of participants	34%	66%

N = 270 athlete test points
Data are mean ± SD;
†measured by BodPod; BMI, body mass index; RED-S, relative energy deficiency in sport

Table 5 demonstrates the athletes separated into their respective sports teams. There were 13 total teams analyzed. The highest frequency of athletes studied were baseball players for the male teams and soccer players for the female teams.

Table 5: Sports Teams

Gender	**Teams (13)**	**# of Athletes**
Male Teams	Baseball	35
	Soccer	33
	Swim	18
	Cross Country	5
	Tennis	2
Female Teams	Soccer	44
	Swim	40
	Softball	38
	Gymnastics	31
	Tennis	10
	Volleyball	9
	Cross Country	3
	Track	2

N = 270 athlete tests

The prevalence of RED-S scores is presented in Table 6 among all 270 athlete test points. Tables 6a and 6b are total RED-S scores split by sex. There were no significant changes in total RED-S score from August 2021 to August 2022. RED-S scores did not change overtime when analyzing repeated athletes with multiple time points.

Table 6: Total RED-S Scores

Score	Frequency	%
0	134	49.6
1	55	20.4
2	45	16.7
3	20	7.4
4	11	4.1
5	5	1.9

N = 270 total athlete tests
RED-S, relative energy deficiency in sport

Table 6a: Male RED-S Scores

Score	Frequency	%
0	74	79.6
1	13	14.0
2	1	4.3
3	1	1.1
4	1	1.1
5	0	0

N = 93 total male athlete tests
RED-S, relative energy deficiency in sport

Table 6b: Female RED-S Scores

Score	Frequency	%
0	60	33.9
1	42	23.7
2	41	23.2
3	19	10.7
4	10	5.6
5	5	2.8

N = 177 total female athlete tests
RED-S, relative energy deficiency in sport

As seen in Table 7, weight difference (under or over IBW) alone was not correlated with RED-S ($p = 0.521$). Although when controlling for BF%, weight difference became a significant, independent predictor of RED-S ($p = 0.010$). Body fat percentage was also an independent predictor in this model, ($p < 0.001$). Weight difference was a negative predictor, indicating greater reductions in weight difference (below ideal body weight) promoted greater RED-S scores, while BF% was a positive predictor, indicating greater body fat percentages predicted greater RED-S scores.

Table 7: Model of RED-S Predictors

Effect	β	SE	*P*
Model of weight difference alone as a predictor			
Weight difference[1]	-0.039	-0.642	0.521
Model of weight difference and % body fat as predictors			
Weight difference	-0.175	-2.587	0.010
% Body fat[2]	0.282	4.176	<0.001

a. Dependent Variable: RED-S
[1]Weight difference: Difference in weight between IBW (ideal body weight) and actual body weight
[2]% Body fat: calculated from the BodPod data

When the data was separated by sex, we found that weight difference and BF% were no longer significant in the female population. The trends were only significant in the male population as seen in Table 8.

Table 8: Model of RED-S Predictors Split by Sex

Sex	Effect	β	SE	*P*
Male	Weight difference[1]	-0.297	-2.488	0.015
	% Body fat[2]	0.230	1.923	0.058
Female	Weight difference	-0.044	-0.501	0.617
	% Body fat	-0.074	-0.844	0.400

a. Dependent Variable: RED-S
[1]Weight difference: Difference in weight between actual body weight and IBW (ideal body weight)
[2]% Body fat: Calculated from the BodPod data

Chapter 5: Discussion

The purpose of this study was to evaluate strong predictors of RED-S in order to help screen and identify athletes at-risk for RED-S more accurately. The study aimed to investigate the prevalence of RED-S in this sample of collegiate athletes to better assess the population. Overall results indicated that an athlete's weight difference alone (under or over IBW) was not independently related to RED-S until BF% was added. When controlling for BF%, weight difference was an independent predictor of RED-S. Weight difference was a negative predictor, indicating that greater reductions in weight difference (below ideal body weight) promoted greater RED-S scores, while BF% was a positive predictor, indicating greater body fat percentages predicted greater RED-S scores.

Our results indicate greater moderate RED-S scores among the athletes than was hypothesized (25%), with 30.1% of athletes from a variety of sports teams with differing physical activity requirements scoring 2-5 points on the RED-S Cumulative Risk Assessment Chart. Scoring 2-5 points classifies under the category of Provisional/Limited Clearance. This prevalence rate is similar to other studies investigating total RED-S scores among collegiate volleyball (20%) [44] and D1 women soccer players (26-33%).[45] However, prevalence rates of over 60% have been reported in collegiate athletes, indicating that there is a large range of athletes being identified with RED-S indicators.[46] To acknowledge the prevalence of RED-S among all of the athletes in our study, 50.4% scored at least 1 point and greater for RED-S criteria.

To our knowledge, this is one of the first studies to analyze elevated BF% and IBW as predictors of RED-S for athletes. BMI is currently used as a predictor for RED-S in assessing BF%, yet the IOC states that low BMI is an imperfect surrogate marker for LEA.[6] A study analyzing BMI to BF% found both under- and overfat athletes having self-reported numerous RED-S indicators, indicating that BMI was not a valid measure for assessing body composition in female elite athletes.[47] Among 40 female elite athletes, 63% had low/reduced EA, 25% ED, 60% MD, 45% impaired bone health, and 23% had all three Triad conditions despite all athletes being within a normal BMI range. [21] There is a need to start investigating additional body composition components beyond BMI, such as body fat or fat free mass, when attempting to identify and prevent RED-S in athletes.

It is important to note that 269 out of the 270 athletes' test points had normal BMIs (BMI > 18.5). An athlete will earn one point on the RED-S Cumulative Risk Assessment Chart for having a BMI of 17.5-18.5 and earn two points for having a BMI < 17.5 under the category of 'Low Body Fat'. Our results show that the athletes who did score for RED-S would not have received a point for their BMI in the risk assessment, yet several would have fallen under the categories of these newer predictors (elevated BF%, under IBW). With this information, we do not know how these trends would correlate for underweight athletes (BMI < 18.4). Suggestions for future research could include examining larger ranges of BMI categories.

After splitting up the data by sex, we found that when controlling for BF%, weight difference was a significant independent predictor of RED-S only among males, and not among females, suggesting this relationship was stronger in males. In contrast to our study, most of the research concerning RED-S has been conducted in female populations. Both the female and male athlete triads have been researched more frequently than RED-S, partially because RED-S is a newer term and condition.[6] Our research will help to expand the relationships surrounding what is known about RED-S and collegiate athletes, especially in males. These findings will increase the research on prevalence of RED-S among collegiate team sports. By analyzing new predictors of RED-S, this research may help to increase the potential components of body composition for professionals who are screening athletes for the syndrome to further investigate.

The concerns surrounding RED-S and LEA for athletes need increased research, especially in the collegiate and elite male athlete populations. Our findings indicate an opportunity for education directed at student-athletes about the importance of maintaining adequate food intake and understanding energy availability. As suggested by the IOC Consensus Statement, prevention, early detection, and treatment of RED-S are crucial for limiting health consequences, injuries, and optimizing sports performance and proper recovery.

Strengths and Limitations

A strength of this research was the relatively large number of participants and the variety of sports teams including both male and female athletes. An increase in the research associated with RED-S findings among male athletes is a strength. With the research data obtained during the athletes' normal routines, the Hawthorne effect was avoided. Obtaining body composition assessments with a single BodPod® machine used for each individual athlete resulted in consistency and reliability among the varied sports teams.

Several limitations must be considered in this study. Self-reporting bias from the physical questionnaire is a primary concern and is dependent on the honesty of completion by the individuals and their comprehension of the questions. This may lead to underreporting of nutrition concerns and eating behaviors. Secondly, retrospective recall of injury, menstruation, and nutrition could have resulted in recall bias. It has been studied that many of the questions related to eating and nutrition from the PPE may not be sensitive enough to identify athletes at-risk for RED-S[10]. We acknowledge that RED-S has been and still is a complex field of research, and the results demonstrated in this study should be interpreted with care. Third, female athletes on birth control may be a limitation since the researchers do not have the information of each brand of birth control relative to how many periods are safe or appropriate for the individual female to be having, which could have affected their RED-S score. In addition, LEA, defined as energy intake minus energy expenditure relative to fat-free mass < 30kcal/kg of FFM/d, was not measured in this study. Our sample was limited to one NCAA Division 1 institution and a small age range which may limit generalizing findings to a full population of athletes. Despite these limitations, our research was able to apply the RED-S Cumulative Risk Assessment Chart in conjunction with reliable body composition data points that have not previously been analyzed.

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