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The Relationship Between Nutrient Intake and Performance Recovery in NCAA Softball Athletes

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THE RELATIONSHIP BETWEEN NUTRIENT INTAKE AND PERFORMANCE RECOVERY IN NCAA SOFTBALL ATHLETES

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ABSTRACT

Collegiate athletes are faced with the challenge of maintaining optimal performance outcomes in spite of their demanding training schedules. As a result, athletes rely on recovery strategies such as nutrition and adequate sleep to optimize their recovery in these shortened windows. This study aimed to explore the relationship between dietary intake, sleep, and athletic performance in female collegiate athletes (N=27) using dietary recalls analyzed using the Nutrition Data System for Research, self-reported sleep data, and data collected using PERCH devices. Twenty-seven current members of a collegiate softball team participated in the data collection throughout their fall season (August – December). Results of the study showed that 77% of participants were categorized as having low energy availability and only one participant met their recommended carbohydrate intake, suggesting that athletes in this population are not following published recommendations for overall caloric or macronutrient intake. No statistically significant relationships were found between energy availability, sleep, and nutrient intake on performance. Further investigation is required to validate these results in female collegiate softball athletes.

LIST OF ABBREVIATIONS

BMI	Body Mass Index
CSCS	Certified Strength and Conditioning Specialist
CSSD	Certified Specialist in Sports Dietetics
DXA	Dual X-Ray Absorptiometry
EA	Energy Availability
FHA	Functional Hypothalmic Amennorhea
FOR	Functional Overreaching
HPA	Hypothalmic-pituitary-adrenal
LEA	Low Energy Availability
NCAA	National Collegiate Athletic Association
NDSR	Nutrition Data System for Research
NFOR	Non-Functional Overreaching
OTS	Overtraining Syndrome
PBT	Percentage-Based Training
RDA	Recommended Daily Allowance
REDS	Relative Energy Deficiency in Sport
RD	Registered Dietician
RPE	Rate of Perceived Exertion
TEE	Total Energy Expenditure
VBT	Velocity-Based Training

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CHAPTER I

INTRODUCTION

Elite athletes follow a rigorous schedule that requires them to perform frequent, high-intensity training sessions and competitions while maintaining or improving performance metrics. It is not uncommon for an elite level athlete to spend upwards of 30 hours/week engaging in high volume training with less than 24 hours to recover before the next training session or competition, though it has been documented that perceptual recovery can take over 96 hours in collegiate athletes (Robertson & Mountjoy, 2018; Fullagar et al., 2017). In addition to consecutive training days, some sports such as baseball and softball have as many as three consecutive competition days in their schedule, making it near impossible to fully recover in between competitions. With these physical demands, there is a need for methods to counter the effects of fatigue in the short periods of rest that athletes have before another training session or competition.

In a survey conducted by Murray et al. (2018), collegiate athletes report focusing on methods such as nutrition, sleep, and management of training load to decrease recovery time and improve athletic performance. Nutrition parameters such as adequate caloric intake, supplementation, and hydration were ranked among the most commonly practiced methods among the participants (Murray et al., 2018). These nutrition methods align with the recommendations published by the International Society of Sports Nutrition in 2018 to optimize performance and enhance recovery in athletes, however, some evidence used to formulate these recommendations are in non-athlete populations, thus some question their application in the athletic population (Hooper et al., 2021). Additionally, study designs typically do not account for practical considerations for athletics such as consecutive gamedays, limited access to high quality foods during travel to competition, and normal variation in training and competition schedules (Holway & Spriet, 2011).

Interestingly, 66% of athletes surveyed in Murray et al.'s 2018 study reported that they believed in sleep and nutrition as recovery strategies, but indicated that they did not incorporate them in their own routines. One potential explanation for this disconnect between belief and practice could be that while athletes have access to information from a wide range of sources such as the internet and various clinicians, their actual practice is largely influenced by coaches due to the amount of time spent together and the trust built in that relationship. Often, coaches recommend recovery practices based on their personal preferences or familiarity with a modality without having knowledge of the cost-benefit of the modality, and athletes may not be aware of the intended effects of the modality they use (Crowther et al., 2017). Fifty-nine percent of athletes surveyed indicated that they relied on subjective feel as opposed to objective metrics to determine whether or not they had recovered from their previous activity, while 25% relied on the outcome of their subsequent performance (Murray et al., 2018).

Another common topic in performance literature is training load. While acute fatigue is an expected result of training, inadequate recovery can result in a progression into states of fatigue ranging from Functional Overreaching (FOR) to full-blown Overtraining Syndrome (OTS), which results in long-term decreases in athletic performance (Stellingwerff et al., 2021). Objective training data is preferable to subjective data in the implementation and analysis of training methods. Recent studies have emerged using velocity-based training (VBT) data expressed as percent velocity loss as a measurement of fatigue in athletes as opposed to the traditional percentage-based methods for overload training. Velocity based training allows practitioners and athletes to objectively quantify changes in training load with decreased risk of injury and mechanical stress (Rauch et al., 2018)

The purpose of this study is to investigate the literature gap in the intake of collegiate women's softball players and compare results to general sports nutrition recommendations published by the International Olympic Committee (IOC) and International Society of Sport Nutrition (ISSN) (Mountjoy et al., 2024; Thomas et al., 2016). The secondary purpose of this study will investigate the potential relationships between fueling status, sleep, and performance in collegiate softball athletes.

CHAPTER II

LITERATURE REVIEW

Practical Considerations for College Athletes

College students face challenges such as financial struggles, lack of access to nutrient-dense foods, low nutrition knowledge, lack of access to kitchen facilities in on-campus living, high stress levels, and body image issues (Sogari et al., 2018). In most cases, college is the first time a young adult would be responsible for choosing and preparing their own meals, and it has been reported that college students generally have poor nutrition knowledge. In 2020, Werner & Betz found that while 91% of college students surveyed were aware that there were nutrition guidelines, only 23% of participants were able to correctly identify these recommendations. This, combined with a higher incidence of body image issues in this age range results in an increased prevalence of disordered eating in college students that has been well-documented (McLester, Hardin, & Hoppe, 2014).

In addition to these challenges, collegiate athletes must balance the physical and mental demands of training and competition. A combination of increased energy needs, misconceptions about proper nutrition practices, and a demanding training schedule put collegiate athletes at an increased risk of under-fueling, whether intentional or unintentional (Karpinski, 2012). In 2006, the National Collegiate Athletics Association introduced legislation that limited the amount of time that athletes could be mandated to spend training for their sport to 20 hours per week (NCAA, 2006). While this limit being placed is a step in the right direction, it should be noted that it does not account for out-of-season training sessions and voluntary training that athletes may engage in, which sometimes results in athletes training closer to 30 hours/week (Robertson & Mountjoy, 2016).

In order to balance these demands to achieve and maintain the most ideal training results, athletes should seek out reliable sources of information regarding training and nutrition. Multiple surveys of collegiate athletes have reported that the vast majority of athletes rely on friends, family, coaches, and the internet for nutrition recommendations, placing this group at high risk for obtaining misinformation (Karpinksi, 2012). According to Klein et al. (2021), 20% of athletes surveyed indicated that social media was their first source of nutrition information. While the internet and social media are readily available sources of information, athletes must understand that these are not always the most reliable sources of nutrition recommendations. Generally, these sources supply an abundance of information about weight loss, while finding information on recommendations for weight gain may be more difficult for athletes. Without reliable information on weight gain, athletes reported increasing caloric intake by increasing fat and supplement intake as opposed to carbohydrates or protein (Clark, 2005). Additionally, these online recommendations often are not appropriate for an elite athlete engaging in vigorous training sessions. Following these recommendations as opposed to recommendations from reliable peer-reviewed journals or qualified clinicians often results in under-fueling and can lead to a myriad of issues ranging from fatigue resulting in suboptimal performance outcomes to clinical low energy availability (LEA) which can result in a disruption of physiological functions (Parks, et al., 2016; Jenner et al., 2019).

Athletes should rely on nutrition professionals such as a sports Registered Dietitian (RD) for individual nutrition recommendations. Since a sports RD would have completed the necessary credentialing requirements to become a Board-Certified Specialist in Sports Dietetics (CSSD), this would be the clinician most qualified to evaluate the athlete's current nutrition status and performance goals to prescribe an appropriate fueling plan (Hull et al., 2016). Unfortunately, this type of nutrition counseling is inaccessible to many athletes. While the beginning of CSSD credentialing in 2006 was integral in increasing the number of collegiate athletic departments employing full-time RD's, it was reported in 2012 that only 10% of NCAA institutions employed a full-time registered dietitian (Karpinski, 2012). By 2019, this percentage had increased to 30%, but the majority of these schools only employed a single dietician to serve hundreds of athletes (CPSDA, 2019). Multiple surveys of collegiate athletes have reported that the vast majority of athletes rely on friends, family, coaches, and the internet for nutrition recommendations, placing this group at high risk for obtaining misinformation (Karpinksi, 2012).

Ideally, an athlete would work with a multidisciplinary performance team including a registered dietitian, sport coaches, and a strength and conditioning coach. This team would work together to develop a training and fueling plan that is individualized to reflect the needs of each athlete to avoid issues such as overtraining and under-fueling. While this would be the most ideal situation, it is not practical for most collegiate athletes. In team sports, sport specific training is planned by the coaching staff and assigned based on the position of the player. Strength and conditioning is programmed by a certified strength and conditioning coach based on the performance goals of the sport team or position. Both the sport coach and strength and conditioning coach consider individual factors when programming, but training for the team is very similar. These two coaching groups should work closely together to plan their training since it is typical that an athlete will have a strength and conditioning session and sport practice on the same day. From a performance standpoint, it would be important that there was communication regarding training and recovery goals to avoid overlap and/or overtraining. In addition to communicating among coaches, the training plan should be communicated to the athlete as well so that they are able to plan and fuel appropriately.

Nutrition recommendations for athletes

There is no debate that proper nutrition practices are necessary for elite athletes to achieve and maintain optimal performance in their respective sport. While it is documented that Greek Olympic athletes used nutrition as a method to improve their performance as early in history as 500 B.C., specific nutrition recommendations for athletes were not published until more recent years (Maughan & Burke, 2011). These more recent studies hypothesize that a focus on performance nutrition could allow athletes to maintain their normal performance outcomes with less physical training by reducing the risk of injury and fatigue during training and competition. (Maughan & Burke, 2011). As a result of this increase in research on the topic of performance nutrition, various international organizations have published consensus statements including recommendations for nutrition practices in athletes, considering the level of competition, increased training demands, and practical considerations for this population. The general consensus in these recommendations is that overall adequate energy intake, along with adequate protein and carbohydrate intake is necessary for athletes to maintain optimal energy availability to support physiological functions such as muscle protein synthesis, glycogen stores, and menstrual function (Mountjoy, et al., 2018; Thomas et al., 2016). Dietary intake should be periodized to reflect training demands at the time, should rely heavily on the consumption of "whole foods" as opposed to supplements when possible, and timing of nutrient intake in relation to activity should be considered (Kerksick et al., 2018). In general, athletes' training is broken up into three "seasons"; a pre-season consisting of increased energy demands due to strength and conditioning and sport-specific training, a competition season that focuses on sport training and competition, and offseason which typically allows for a lighter training load. Nutrition recommendations should change to reflect the training goals and demands of each of these seasons. In the pre-season, recommendations call for an increase in intake to keep up with the energy demands of training. In the competition season, nutrition goals should shift toward recovery from competition while offseason intake should typically decrease to match the decrease in energy expenditure, unless the athlete has a goal to modify their body composition (Holway & Spriet, 2011).

A review conducted by Jenner et al. (2019) concluded that in general, athletes participating in team sports do not typically meet recommended guidelines for nutrient intake. These findings were corroborated by Jagim et al. (2019), who found that even when using the minimum recommendation for intake, athletes failed to meet the recommendations for overall energy intake as well as macronutrient intake. On average, athletes in this study consumed 500 calories less than the recommended energy intake for the athlete's activity level. Another study found that two thirds of athletes did not adjust their caloric intake based on an increase or decrease in energy expenditure, despite indicating that they were aware of the recommendation to match intake with expenditure to fuel and recover properly (Heikura et al., 2017). This lack of adherence to nutrition guidelines is well-documented in published literature, and more information is needed to determine if this lack of adherence to guidelines is a result of gaps in nutrition knowledge of athletes, inaccurate recommendations for intake, or other circumstances. Eck and Byrd-Bredbenner (2021) surveyed Division I athletes on the reasoning behind their food choices and found that while there were some gaps in nutrition knowledge, barriers such as lack of time, gastrointestinal issues, and access to quality food hindered athletes' ability to meet nutritional recommendations. Shriver et al. (2013) reported that athletes consumed most of their calories in the evening due to high volume training schedules, issues with access to food, and attempts to avoid gastrointestinal discomfort during training. However, Valliant et al. (2012) found that nutrition education sessions for athletes resulted in 66% of participants maintaining an increase in their intake, suggesting that lack of education is at least part of the problem.

It should be noted that many of the studies cited as evidence for these nutrition recommendations do not use collegiate athletes as participants, and interventions typically focus on a single activity type (endurance training vs resistance training). In the field, these conditions may not reflect the training demands of athletes in team sports. Team sports such as softball typically rely on both aerobic and anaerobic energy systems as there are intermittent bursts of high intensity activity followed by periods of rest or lower intensity (Holway & Spriet, 2011). Training and competition conditions are difficult to predict in team sports, thus posing a challenge in reproducing these conditions in studies. While some sports such as football only compete once per week during their competition season, other sports such as basketball or softball can compete as many as four days per week during their competition season with some of these days being consecutive, posing concerns for replenishing glycogen stores and recovery from the physical demands of their sport (Holway & Spriet, 2011).

Additionally, very few studies investigate the female population despite a dramatic increase in the number of female athletes competing in collegiate sports after the Title IX was introduced in 1972. This ruling, which states that federally funded programs could not deny participation on the basis of sex, resulted in the number of female collegiate athletes increasing from 32,000 in 1971 to over 230,000 in 2023 (NCAA, 2023). Despite this dramatic increase in the presence of female athletes, publications outlining nutrition recommendations for female team sport athletes are lacking. Along with a shortage of publications targeting female athletes, team sports, specifically batting sports, are largely ignored in nutrition studies due to the thought that they are less physically demanding than endurance sports. While batting sports may be less physically taxing, these competitions often last over 3-4 hours in outdoor conditions, requiring adequate glucose consumption to support attention span and decision making (Holway & Spriet, 2011).

While general nutrition recommendations promoting adequate nutrient intake, proper meal timing, and periodization of nutrition strategies to match energy demands are not typically challenged in the literature, there is concern that specific recommendations for recommended daily allowances for macronutrients in athletes may be inaccurate given the basis with which these recommendations were prescribed (Wohlgemuth et al., 2021). Professional organizations such as the Academy of Nutrition and Dietetics and the International Society of Sports Nutrition recommend that athletes measure their energy and macronutrient intakes in terms of grams per kilogram of body mass to normalize recommendations across a large range of body types in the athletic population (Thomas et al., 2016). Nonetheless, the general consensus among professional organizations is that athletes should consume enough kilocalories to support their daily bodily functions, along with replenishing the kilocalories burned during activity. For some elite athletes, the intense nature of their sport can push their energy needs upwards of 4,000 calories, about double the recommended intake for a member of the general public (Jagim et al., 2022; Stellingwerff et al., 2021). Factors such as time constraints, food availability, and gastrointestinal distress can deter athletes from consuming their recommended intake during intense training periods. In many cases, athletes are simply not aware of how many calories are burned during their training and the amount of food that should be consumed to replace the energy lost (Logue et al., 2021).

Energy Availability

Energy availability (EA) is defined by Loucks and Thuma (2003) as the difference between energy intake and energy expended during exercise relative to kilograms of lean body mass. Since this measurement is individualized, it is the preferred marker of energy status for athletes. The energy availability calculation accounts for normal variation in energy needs based on the amount of energy that is expended in a day, as well as changes in body composition. Generally, less than 30kcal/kg/day is considered the threshold for clinically low energy availability (LEA) that can lead to adverse effects over time. This threshold was established after numerous studies noted endocrine ad metabolic changes occurring, especially in females who maintained an energy availability status of less than 30 kcal/kg/day. Ideally, athletes should strive to maintain an energy availability of about 45kcal/kg/day to support normal bodily functions as well as the energy demands of their training (Loukes et al., 2011). It is of importance to note that energy availability can be affected by changes in nutrient intake as well as changes in exercise expenditure. Both of these variables should be assessed and manipulated to achieve favorable EA based on the individual needs of the athlete.

Adequate energy availability suggests there is a sufficient amount of energy present to support necessary biological functions along with the demands of physical activity. When dietary intake is restricted or exercise expenditure increases, an imbalance is created leading to LEA. In the IOC's 2023 concensus statement, the terms adaptable and problematic LEA were introduced.

In cases of adaptable LEA, mild physiological changes occur but are quickly resolved with an increase in energy availability. These changes typically do not pose a risk to long term health or performance. In more severe or chronic cases of LEA, physiological changes may be drastic enough to present with signs and symptoms such as fatigue, decreased training response, and reproductive system disruption. These cases are termed problematic LEA as these symptoms often cause decreased performance and may be detrimental to long-term health (Mountjoy et al., 2023).

Problematic LEA is a concern in the athletic population due to the risks of developing Relative Energy Deficiency in Sport (REDs) (Mountjoy et al., 2023). This syndrome is characterized by physiological changes including metabolic issues, endocrine changes, bone health, and menstrual dysfunction (Loukes et al., 2011). One of the most well-documented changes in athletes with LEA is a disruption of the hypothalamic-pituitary-adrenal (HPA) axis. When energy availability is low over an extended period of time, gonadotropin-releasing hormone (GnRH) is suppressed. This in turn suppresses the secretion of luteinizing hormone (LH) and follicle-stimulating hormone (FSH), resulting in functional hypothalamic amenorrhea (FHA) (Elliot-Sale, et al., 2018). Often, amenorrhea in female athletes is biggest “red flag” to indicate that energy availability or dietary intake may be insufficient, though many athletes with LEA do not exhibit this symptom (Mountjoy et al., 2018). Athletes with chronic menstrual disturbances often have decreased bone mineral density when compared to eumenorrheic athletes, placing athletes with LEA at a much higher risk for injuries such as stress factors. Ihle & Louke’s 2004 study found that even a short-term bout of LEA in eumenorrheic athletes resulted in a decrease in bone turnover markers, which could slow healing and place these athletes at higher risk for injury.

Literature on the Female Athlete Triad as well as REDs propose that LEA may result in a decreased resting metabolic rate. This reduction is explained as a result of adaptations the body makes to conserve energy for BMI maintenance and necessary bodily functions in times of inadequacy (Mountjoy et al., 2018). In addition to a low resting metabolic rate, there is an association with between LEA and a low ratio between actual and predicted resting metabolic rate. An RMR ratio less than 0.90 is recognized as a marker for LEA, though this is highly dependent on the predictive equation that is used to calculate RMR (Logue et al., 2020). The effects of LEA on the HPA axis function have also been investigated, revealing interesting effects on appetite-regulating hormones. It was found that in subjects with LEA, leptin was decreased while ghrelin was increased, resulting in a decrease in hunger and subsequent decrease in intake (Gould et al., 2022). Since ghrelin stimulates growth hormone secretion, a decrease in ghrelin results in a decrease in growth hormone secretion, potentially leading to issues with blood sugar regulation (Elliot-Sale et al., 2018). Insulin was downregulated in order to increase the availability of substrates to be metabolized for energy (Ackerman et al., 2012). Additionally, there was a decrease in oxytocin secretion, which is related to reward-related eating and T3 which is necessary for growth, reproduction, and metabolism. These changes in hormone functionality have both direct and indirect effects on most all of the physiological changes seen in REDs (Elliot-Sale et al., 2018).

There are many factors to take into consideration when discussing REDs in athletes. As stated previously, EA must be calculated in order to diagnose REDs. However, measuring EA, specifically EE, is more difficult in athletes since they train under conditions that can vary dependent on the training season and are not comparable to the laboratory conditions in which EA is calculated in studies (Kuikman et al., 2021). Without a standardized measurement to calculate energy availability in athletes, it is difficult to accurately estimate the prevalence of LEA in this population. Depending on the method used to calculate energy availability, it is estimated that between 22-58% of athletes could be categorized as having LEA (Logue et al., 2020). Screening athletes to identify potential symptoms of REDs has proven difficult as well since many symptoms appear over time and can be very subtle (Mountjoy et al., 2018). In order to treat REDs, an increase in dietary intake and/or decrease in physical activity is recommended. Athletes are often resistant to decreasing activity since their training is typically programmed by a coach to maximize performance outcomes. Instead, many athletes and practitioners treat and prevent LEA and REDs by increasing dietary intake in order to increase energy availability (Robertson & Mountjoy, 2018). There has been evidence that increasing energy intake alone was successful in reversing impaired physiological function such as amenorrhea in female athletes (Guebels et al., 2014).

In 2013, Reed, De Souza, and Williams conducted what is believed to be the first study to analyze changes in energy availability in athletes over the course of a competitive season. Their findings corroborated previous findings that female athletes often do not meet recommended guidelines for nutrient intake. In this study, 29% of the Division I soccer players participating in the study had LEA. Though this study did not explore factors contributing to this LEA, other studies have published similar findings that imply that team sport athletes, in general, do not consume adequate amounts of total calories, carbohydrates, and protein to achieve optimal energy availability relative to the amount of energy they expend during training and competition for their sports. Reported energy availability in eumenorrheic athletes ranges from 19 kcal/kg/day to 59 kcal/kg/day (Woodruff & Meloche, 2013). These studies varied widely in the level of competition, length of study, training period, and sport type (endurance vs intermittent team sport), which could explain the wide range of findings (Woodruff and Meloche, 2013). Potential explanations for the variation in findings can only be found by continuing to collect and publish data on energy availability in female athletes to fill this gap in research.

Since REDs is an emerging topic in the literature, there are not many longitudinal studies to document the long-term health effects of LEA, particularly in athletes (Hooper, et al., 2021). Without these studies, there has been much debate about the true causality of some of the symptoms related to this condition. However, it is hypothesized that many athletes are performance driven, and would be more likely to be concerned with the harm REDs and LEA could do to their performance than their long-term health. In a study with gymnasts, it was found that athletic performance negatively correlated with EA (Silvia & Pava, 2016). There was no significant change in $VO_{2\ max}$, however there was a decline in neuromuscular performance and reaction time in athletes with LEA. Other performance-related effects of REDs include decreased endurance performance and muscle strength as a result of decreased glycogen stores, increased injury risk, decreased training response, increased rating of perceived exertion (RPE) and psychological issues such as depression, irritability, and decreased concentration (Robertson et al, 2014).

While energy availability is considered the preferred method for athletes to measure energy status, there are some limitations that should be considered. Outside of a laboratory setting, there is no standardized measurement for energy availability. In order to calculate energy availability, several variables are necessary including energy intake, energy expenditure, and lean body mass (Gould et al., 2022). In a laboratory setting, energy intake is measured using doubly labeled water, expenditure is tracked using a wearable device, and lean body mass is measured using a DEXA scan. In the field, however, these techniques are not practical due to time and financial constraints. Instead of doubly labeled water, energy intake is typically calculated based on self-reported logs, which are often inaccurate due to over or underreporting of caloric intake. Wearable devices that track energy expenditure are fairly accessible, but may not give an accurate estimation of energy expenditure. Finally, a DEXA scan is considered the gold standard in measuring body composition, but these machines can be expensive and inaccessible. Other methods of measurement for body composition such as BOD POD, skinfold measurements, and bioelectrical impedance are often used due to their practicality, though these methods may not be as accurate as a DEXA scan (Mountjoy et al., 2018).

Macronutrients and Recovery

Recovery from physical activity is achieved by restoring muscle and liver glycogen to their pre-exercise levels. This is achieved by consuming adequate amounts of carbohydrates and protein to replenish glycogen that was used to fuel exercise, stimulate muscle protein synthesis repair muscle damage from training, and maintain body weight (Thomas et al., 2016). In addition to carbohydrates and protein, fat consumption is essential to absorb essential, fat soluble vitamins A, D, E, and K. These vitamins play essential roles in physiological processes effecting bone health, immune system support, reproductive function, and act as antioxidants (Thomas et al., 2016). While all three macronutrients play a vital role in the health and performance of athletes, this study will focus on carbohydrates and protein. In general, athletes consume adequate amounts of fat but struggle to abide by recommendations for carbohydrates and protein (Shriver et al., 2013).

Carbohydrates

The necessity of adequate carbohydrate intake to maintain muscle and liver glycogen stores is well-documented. Carbohydrate availability and fatigue have an inverse relationship where fatigue increases as carbohydrate stores are depleted during exercise (Alghannam et al., 2018). Before initiating exercise, carbohydrates must be ingested to be stored as muscle and liver glycogen. During exercise, this stored glycogen is converted to ATP to fuel the demands of the activity until the stores are depleted and fatigue sets in or more carbohydrates are consumed to replenish glycogen stores. After exercise, it is recommended that carbohydrates be consumed within 30-60 minutes of the completion of exercise since there is an increase in the rate of glycogen resynthesis during this time period (Alghannam et al., 2018).

Consumption of at least 5-7g/kg/day results in a decrease in reported fatigue, prevention of overtraining, and supports optimal energy availability (Heaton, et al., 2017). During prolonged exercise, fatigue coincides with low muscle glycogen, and carbohydrate supplementation results in an increase in time to exhaustion (Alghannam et al., 2018). Inadequate carbohydrate availability also limits performance in intermittent exercise lasting more than 90 minutes, which has implications for team sports such as basketball, softball, and soccer (Burke et al., 2011). While 5-7g/kg/day is generally recommended to prevent performance detriments, Burke et al., 2004 report that increases in glycogen storage continue until the upper limit of 10g/kg/day. Depending on the athlete's performance goals, training load, and type of exercise performed, this range of 5-10 g/kg/day is appropriate since the recommendations will fluctuate depending on the training period. The American College of Sports Medicine (2007) and International Olympic Committee (2003) statements recommend that athletes consume 30-60 grams/hour of exercise performed. Prescribing carbohydrate recommendations in relation to the duration of exercise may be easier to athletes to remember when refueling after a training session or competition, and aligns with the more recent recommendations of professional organizations indicating that nutrition recommendations should be individualized to each athlete's daily needs (Kersick et al., 2018). As an athlete's training may fluctuate on a daily or weekly basis to reflect performance goals, nutrition recommendations should mirror these changes.

In most instances, glycogen stores can be replenished within 24 hours when there is a sufficient period of rest and adequate carbohydrate intake at least equal to the carbohydrates used to fuel the training session (Burke et. al., 2011). When carbohydrate intake is below the threshold necessary to restore glycogen stores to pre-exercise levels, adjusting the timing of the intake and type of carbohydrate consumed can increase glycogen synthesis. After exercise, it is recommended that carbohydrates be consumed within 30 mins of the conclusion of exertion (Kersick et al., 2018). When carbohydrate intake is inadequate, co-ingesting carbohydrate with protein can increase glycogen storage. The type of carbohydrate (i.e. glucose vs fructose) should also be considered when replenishing stores. A study published by Jeukendrup (2010) found that while glucose was absorbed at a rate of 60g/hr when consumed alone, co-ingesting this same quantity of glucose with fructose, which uses a different transport mechanism, increased the absorption rate to 80-90g/hour. These findings sparked the commercial production of carbohydrate gels with a 2:1 ratio of glucose to fructose, which are marketed toward athletes to replenish carbohydrate stores during or immediately after exercise without gastrointestinal distress that is sometimes reported when large amounts of carbohydrates are consumed during activity (Burke et al., 2011).

According to a study by Reed et al. in 2014, as many as 73% of Division I soccer players who participated in this study consumed less carbohydrates than the recommendations published by the American College of Sports Medicine. Though this particular study did not explore the reasons behind this lack of compliance, these findings have been mirrored by similar studies focusing on athlete's ability to follow nutrition recommendations. More recently in 2019, Condo et al., found that only 3.7% of female athletes in their study consumed the recommended amount of carbohydrates for athletes engaging in moderate activity, and no participants met the recommended intake for athletes engaging in moderate to high intensity exercise. Various hypotheses have been introduced to explain this lack of adherence to carbohydrate intake recommendations including a lack of nutrition knowledge, appetite suppression caused by training, an increased popularity of low-carbohydrate diet trends, and the possibility that the current recommendations may be inaccurate for some sport types. For example, Condo et al. (2019) have suggested that since the general intake recommendations for macronutrients are based on the findings of studies that primarily included endurance athletes as subjects, these recommendations may not be the best fit for team sport athletes that use different primary energy systems. Glycogen depletion studies in team sports would be helpful to identify sport-specific or position-specific recommendations for intake, but are scarce due to practical considerations. Since there could be negative performance outcomes associated with participating in glycogen-depletion studies during a team sport's competition season, it is unlikely that athletes or coaches would consent to these conditions (Holway & Spriet, 2011). Without data that could prove that there should be separate recommendations for each sport type, best practice is to follow the general recommendations published by professional organizations such as the International Society of Sport Nutrition with the understanding that individual differences in performance and body composition goals should be taken into consideration.

Adequate carbohydrate intake also assists with fluid retention and rehydration. In athletes, hydration is important because exercise performance decreases when 2% of body weight is lost in fluids (Thomas et al., 2016). Similar to macronutrient recommendations, fluids should be consumed before, during, and after activity in quantities that vary based on the amount of sweat lost during exercise (Thomas et al., 2016).

In general, athletes show adequate knowledge of the relationship between hydration and performance, but few recognize the role of carbohydrates in hydration (Jagim et al., 2022). Adding carbohydrates and electrolytes to water allowed muscle glycogen restoration to begin immediately after the cessation of exercise, and stores were fully restored within 48 hours (Ott & Santos, 2019).

Recent literature has emphasized the role of carbohydrate intake in the development of REDs. In one of these studies, Hammond et al. (2019) found that in a small sample of male athletes, increased carbohydrate intake resulted in increases in biomarkers of bone metabolism, even when energy availability was not adequate. Another similar study reported that six days of carbohydrate restriction resulted in a greater impairment in bone resorption than low energy availability alone (Fensham et al., 2022). A consensus on the mechanism of these results has not been published to this date as research is ongoing. While a decrease in carbohydrates is typical in the case of overall energy restriction, these results suggest that carbohydrate intake is as important, if not more important than energy intake in the prevention of REDs (Mountjoy et al., 2023).

Protein

Adequate dietary protein intake stimulates muscle protein synthesis, increases satiety, and supports recovery. Total intake, as well as the timing in relation to exercise are important when considering recommendations for fueling (Bettonviel, et al., 2016). In fact, there should be more emphasis placed on the timing of protein intake throughout the day than the total quantity that is consumed (MacKenzie et al., 2015). Protein intake should fluctuate to match the athlete's training load and volume, as well as reflect body composition goals such as muscle hypertrophy or decreasing body fat (Egan, 2016). For example, it is recommended that protein should be consumed toward the end of the day, after training to increase muscle protein synthesis and overnight muscle recovery. Protein sources should also be considered when prescribing recommendations for athletes. Sources high in essential amino acids, specifically leucine, are recommended for their ability to stimulate muscle protein synthesis (Egan, 2016). Co-ingesting carbohydrates with protein is also recommended to increase the rate of muscle glycogen replenishment to recover from exercise bouts, especially when overall energy intake is suboptimal as is often the case in athletes (Egan, 2016).

Current recommendations suggest that athletes should aim to consume 1.2-2.2 g/kg/day, depending on their individual daily needs. At this time, there is no upper limit established for protein intake, and some studies indicate that athletes may benefit from doubling the RDA for protein to accommodate the amount of physical stress that is necessary to train at a high level (Egan, 2016; Lemon, et al., 1992). Inadequate protein consumption could result in increased recovery time due to decreased rates of muscle protein synthesis leading to fatigue, increased recovery times, decrease in lean body mass, and injuries during training (Kersick et al., 2018).

It is interesting to note that according to Jenner et al.'s 2019 review, athletes did not meet recommended intake levels for total energy or carbohydrates, but regularly exceeded the recommended intake for protein. This could have been intentional by the athletes in an attempt to maintain lean muscle mass while resistance training, but this conclusion was not investigated in the aforementioned study. Studies examining the nutrition knowledge of athletes commonly find that athletes are aware that adequate protein intake is vital to performance and recovery (Jenner et al., 2019; Logue et al., 2021). Another possible explanation for this finding is the use of protein supplements. Though it is recommended that the bulk of protein come from food sources, protein supplements are extremely popular amongst the athletic population. According to the NCAA's 2023 Student-Athlete Health and Wellness Study, protein supplement use in female collegiate athletes increased from 31% in 2017 to 41% in 2023.

Overtraining & REDs

Based on principles of progressive overload, some acute fatigue is necessary in elite training programs to achieve desired training adaptations and strength gains. Stimuli in training programs should progressively increase to allow for neuromuscular adaptations resulting in desired performance outcomes such as increases in strength. Initially, the response to the increased stimuli is acute fatigue, but with proper recovery the fatigue is overcome and improvements in performance are observed over time (ACSM, 2012). However, when there is inadequate time or to recover from this fatigue, or dietary intake to replenish energy expended in exercise, the athlete can experience suboptimal performance outcomes. If untreated for a period of time, these suboptimal training outcomes may progress into Functional Overreaching (FOR), Non-Functional Overreaching (NFOR), and ultimately, Overtraining Syndrome (OTS)

(Stellingwerff, et al., 2021). According to the 2012 Joint Consensus Statement of the European College of Sport Science and the American College of Sports Medicine, functional overreaching is a short-term deficit in performance as a result of increased training stress. This is a necessary component of training, since physiological processes typically compensate for the deficit resulting in improved performance in days or weeks. Should the training continue at this increased level without proper recovery, performance deficits may be observed for a period of weeks to months, resulting in Non-Functional Overreaching. NFOR is not a normal component of training, as these performance deficits may be easily observed by the athlete and coaches and could present with signs and symptoms of fatigue or physical injury. After a sufficient period of rest, the athlete is able to return to normal activity. Subjection to intense training without sufficient recovery for an extended period of time may result in Overtraining Syndrome in extreme cases. Overtraining syndrome is described by the American College of Sports Medicine (2012) as "a sport-specific decrease in performance together with disturbances in mood state." The differentiating characteristic of OTS from FOR and NFOR is that the observed performance deficits in OTS last weeks or months, and do not improve after a seemingly appropriate period of recovery. This differentiation is difficult since it can only be made retroactively, after an extended period of performance deficit has been noted without improvement even with weeks or months of rest. For an elite athlete, this could result in months of missed training to recover, and long periods of suboptimal performance in practice and competition. Since there is no diagnostic tool currently available, diagnosis of OTS is achieved by excluding other diagnoses that could produce similar symptoms of fatigue and suboptimal performance such as disease, LEA, insufficient carbohydrate and/or protein intake, and nutrient deficiency (ACSM, 2012). Though stress resulting from excessive training is typically identified as the causative factor for these symptoms, further evaluation is necessary to rule out the presence of disease or suboptimal nutrient status.

It should be noted that some symptoms of OTS are shared with REDs, including fatigue leading to a decline in performance outcomes, changes in mood, and LEA as a result of excessive energy expenditure or inadequate nutrient intake. These similarities are noted in the most recent IOC consensus statement, along with the shared involvement of the HPA axis and absence of diagnostic test for each syndrome (Mountjoy et al., 2023). Though these two conditions present with some of the same symptoms and under the same conditions, it is interesting that many studies do not connect the two. As stated previously, the underlying cause of REDs is inadequate energy availability, however, many studies on OTS do not mention energy availability or collect data regarding dietary intake. It is possible that many cases of OTS could actually be cases of REDs caused by LEA (ACSM, 2012). The IOC recommends that the presence of LEA should be excluded before an OTS diagnosis since its presence could indicate the presence of REDs as opposed to OTS (Mountjoy et al., 2023).

Velocity-Based Training

Since EA can be manipulated by adjusting dietary intake or exercise expenditure, more emphasis has been placed on optimizing training load to produce favorable performance outcomes. Literature comparing autoregulation has compared the effects of various subjective and objective methods to individualize training load by adjusting intensity, volume, and intensity (Larsen et al., 2021). Subjective methods of autoregulation such as rate of perceived exertion (RPE) and repetitions in reserve (RIR) have been studied and found to be effective in increasing strength, but these methods are less effective than objective autoregulation methods such as velocity-based training (VBT) (Shattock & Tee, 2020). While subjective data on perceived exertion is criticized by some for their reliability, these methods are widely used in team sports due to their practicality and ease of implementation, since there is no specialized equipment necessary (Helms et al., 2018). In team sports especially, athletes' self-reported RPE can be used to monitor day-to-day recovery for a large group without sacrificing training time and increasing training load to measure recovery using performance-based tests such as time trials, submaximal heart rate, or VO2max (Laurent et al., 2011).

VBT is a training load periodization method that allows athletes to train with less mechanical stress by manipulating the velocity at which a movement is performed as opposed to increasing the amount of weight that is lifted (Rodriguez-Rosell et al., 2019). Using linear position transducers and/or 3-D cameras, athletes are given instantaneous objective feedback on each repetition, allowing the strength and conditioning coach to individualize training loads on a daily basis while accounting for factors effecting performance such as neuromuscular fatigue, fueling status, or psychological factors (Banyard et al., 2021). In recent literature, VBT has been used as an indicator of fatigue by measuring the magnitude of velocity loss during movements (Jimenez-Reyes et al., 2021).

Three applications of VBT include estimating 1RM, prescribing volume and relative intensity, and providing instantaneous feedback (Weakley et al., 2021). Prediction equations using the mean velocity of the barbell are used to calculate an estimated 1RM for exercises such as squat and bench press. Use of a prediction equation as opposed to traditional measurement of 1RM can decrease the risk of injury and fatigue associated with training to failure and decrease the amount of time required to calculate 1RM for a large group. This decrease in mechanical stress and implementation time allows a strength coach to estimate 1RM more frequently, since fluctuations in 1RM can occur daily as a result of fatigue, sleep, nutrition status (Wlodarczyk et al., 2021). Development of an individual load velocity profile is necessary to identify normal variation in velocity as opposed to variation caused by fatigue or training adaptations (Weakley et al., 2021). This profile is created by calculating a regression of velocity at given loads and can be used to prescribe exercise loads based on velocity loss (VL) (Balsalobre-Fernandez et al., 2021 and Torres-Ronda et al., 2021). Using the velocity loss method, athletes are instructed to complete an exercise until their decrease in velocity reaches a pre-determined cut-off point, at which the set is terminated (Wlodarczyk et al., 2021). When comparing the effects of training at 10% velocity loss and 30% velocity loss, Rodriguez-Rosell et al. (2020) reported that both groups saw similar increases in strength even though the former group completed less than half the number of repetitions. This study also reported an increase in muscle damage in the 30% VL group, suggesting that training at a high velocity but lower volume and can produce the same neuromuscular adaptations as high-volume training while minimizing fatigue (Rodriquez-Rosell et al., 2020). Lastly, VBT's ability to provide instantaneous feedback on each repetition, often resulting in more effective training. Studies comparing exercise performance with and without immediate velocity feedback have reported greater improvements in velocity in groups that are provided feedback (Randell et al., 2011; Weakley et al., 2019).

Various velocity measurement devices are marketed for their use in implemented VBT including 3-D motion cameras, linear position transducers (LPT), and accelerometers. 3-D cameras are considered the gold standard for measuring velocity due to their accuracy and reliability when measuring exercises, but may not be practical choice due to the cost of equipment required for implementation (Guppy et al., 2023; Thompson et al., 2023). LPTs require a retractable tether to be attached to the barbell in order to measure the displacement of the bar during an exercise. While LPTs have shown similar validity and reliability to 3-D cameras, variation in the attachment site of the tether on the barbell can produce some measurement error (Appleby et al., 2020). Despite this risk of error, most practitioners surveyed in Thompson et al.'s 2023 study reported that they preferred to use LPTs over other measurement methods due to the ease of use, reliability, and validity. Similar to the implementation of 3-D cameras, the cost associated with the purchase of LPTs may not be feasible for some (Guppy et al., 2023). Accelerometer-based devices that can be attached to the body or barbell, depending on the exercise, have been introduced as lower-cost alternative to 3-D cameras and LPTs. However, literature reports high levels of measurement error, along with low sensitivity and poor validity (Guppy et al., 2023).

While velocity-based training is not necessarily a new topic, it has gained popularity in recent years in scientific studies and use in the field. Many published studies include exercise protocols using Smith machines with the intention of limiting horizontal movement (Larsen et al., 2021). While this practice is acceptable in research, it does lead some to wonder if this research is applicable in training protocols using free weights. Additionally, the majority of published VBT studies do not include female participants. According to Rissanen et al. (2022), of 70 articles published since 2010, only 16 included females in the study. Future research in this area is needed to validate velocity-based training devices in exercises using free weights, as well as expanding research to include female elite athletes.

Sleep

According to the American Academy of Sleep Medicine, adults require a minimum of 7-9 hours of sleep per night (Watson et al., 2023). However, recent literature has proposed that athletes may require up to 9-10 hours of sleep per night to account for the increased physical demands of sport (Bonnar et al., 2018; Reardon et al., 2019). College-aged adults are notorious for experiencing disruptions in sleep due to social and academic pressures causing psychological stress. A 2023 survey of over 24,000 college students revealed that 45% reported sleeping less than seven hours per night, on average. In this same study, only 8% of respondents reported that in the past week, they felt like they got enough sleep to feel rested more than five of those seven nights (American College Health Association, 2023).

Collegiate athletes experience these same stressors, along with a demanding competition and training schedule which can negatively affect sleep (Yang et al., 2019). Temporary sleep disturbances are common in this population due to factors such as late scheduled competitions, early morning training sessions, and travel to and from competitions, and physical pain (Bonnar et al., 2018). In 2019, collegiate athletes reported an average of 6 hours 15 minutes of sleep during their competition season, falling short of the general recommendations for adults as well as the proposed recommendations for athletes (NCAA, 2020). Similar to nutrition recommendations, collegiate athlete's sleep duration seems to fluctuate depending on the training season and its required training load (Mah et al., 2011). Athletes report less sleep during periods of increased training load when training sessions are typically longer in duration when compared to off-season training where sessions are less frequent and intense, resulting in more time to sleep (Mah et al., 2011).

Murray et al.'s 2018 study revealed that though collegiate athletes indicated that they recognized sleep as a recovery modality, they often did not understand how it affected recovery and did not obtain recommended amounts of sleep for recovery. While sleep is widely recognized as beneficial for health in general, many are unaware of the effects proper sleep can have on metabolism of glucose and lipids, nutrient intake, and hormone secretion (Datillo et al., 2019). A four-hour reduction in sleep for six consecutive days may decrease glucose tolerance, disrupt growth hormone patterns, and create a more catabolic state (Rae et al., 2017). Sleep deprivation also has negative effects on autonomic nervous system function, ultimately resulting in overtraining syndrome (Yang et al., 2019). Rae et al. (2017) found that there was a reduction in peak power after a single night of reduced sleep. Additionally, sleep deprivation results in decreased muscle glycogen stores, even with adequate carbohydrate intake (Bonnar et al., 2018). In cases where objective measures of athletic performance are not affected by diminished sleep, athletes have reported an increase in the rate of perceived exertion after a decrease in sleep (Kroshus et al., 2019). In addition to these metabolic changes, sleep duration has been identified as a predictor in injury risk and overall mood. In a sample of collegiate volleyball players, athletes who slept less than seven hours the previous night had a significantly increased risk of injury when compared to those who slept more than seven hours (Haraldsdottir et al., 2021).

Recent publications by the IOC and the NCAA have addressed the prevalence of insufficient sleep in elite athletes and the potential detrimental effects of sleep loss on performance and general health (Kroshus et al., 2019). As a result, recommendations for sleep hygiene have been published. Among these recommendations are establishing a consistent sleep routine, seeking light during daylight hours and avoiding bright light at night, avoiding stimulants in the evening hours, and avoiding the use of electronics during the bedtime routine (Kroshus et al., 2019). In addition to individual changes in sleep routines, the IOC recommends a team-level approach to promote optimal sleep including educating athletes on the role of adequate sleep on performance, encouraging coaches to avoid scheduling training in early morning or late evening to maximize sleep, and implementing protocols to track sleep and screen for clinical sleep disorders (Reardon et al., 2019). Literature also supports the practice of napping to combat the detrimental effects of inadequate sleep (Mah et al., 2011).

Various measurement tools are available to quantify sleep duration as well as the quality of sleep. The gold standard in monitoring sleep duration and sleep quality is polysomnography (PSG), but this method can be impractical as a screening method due to the financial cost and duration of time required to conduct the test (Nedelec et al., 2018). PSG testing is conducted using specialized equipment and requires participants to spend the night in a laboratory, potentially resulting in atypical sleep conditions due to an unfamiliar setting (Kroshus et al., 2019). Actigraphy allows for objective measurement of sleep duration in the home over long study periods, but accuracy relies on the compliance of the athlete to wear the tracker during sleep. This, along with inconsistencies in tracking sleep during naps or periods of extended sitting, require actigraphy to be combined with a sleep diary (Nedelec et al., 2018). Commercially available wearable sleep trackers have been used in studies including elite athletes, however inconsistencies in software algorithms across brands has made validation of these instruments difficult (Claudino et al., 2019). Questionnaires such as the Pittsburgh Sleep Quality Index and Epstein Sleepiness Scale are often used in large populations due to the lack of required equipment and low cost, but are not validated in athletes (Claudino et al., 2019). Collection of self-reported data on sleep quality is a common practice due to ease of implementation and low cost, but risks the subject over or underestimating data. However, Caia et al. (2018), found a significant positive correlation with self-reported sleep duration and sleep duration measured via actigraphy ($r = 0.85$) suggesting that self-reported sleep data can be as accurate as data collected using actigraphy.

Treatment conditions in studies on the relationship between sleep and athletic performance often consist of total sleep deprivation, however, collegiate athletes typically experience partial sleep deprivation or acute sleep restriction over consecutive nights as opposed to total deprivation (Bonnar et al., 2018). Chase et al. (2017), describes acute sleep restriction as the delayed onset of sleep, intermittent waking, or early rising. Thus, results of studies including total sleep deprivation for a period of time may not be valid in the collegiate athletic population since collegiate athletes more often experience acute sleep restriction as opposed to full sleep deprivation. To this point, Mah et al. (2011) studied the effect of an increase in sleep duration on athletic performance in collegiate athletes during their competition season. Over a period of 5-7 weeks, participants increased their nightly sleep from a baseline of 6.67 hours/night to a goal of 10 hours/night. This increase in sleep resulted in significant improvements in reaction time, basketball shooting accuracy, and sprint time, suggesting that extending sleep duration during high-volume training periods is possible and may result in improved performance (Mah et al., 2011).

Circadian rhythm, or the body's internal clock, drives the natural sleep-wake cycle and has an impact on nutrient metabolism and other physiological functions (Reardon et al., 2019). External factors such as light exposure, travel across time zones, and exercise can have a direct impact on circadian rhythms, and as a result, sleep duration (Kroshus et al., 2019). Collegiate athletes, in particular, are at risk for circadian rhythm disruptions resulting from frequent travel across time zones for athletic competition, unfamiliar sleep conditions in hotels during travel, and the common practice of competitions being held at night, delaying their normal bedtime (Thun et al., 2015). Individual differences in circadian rhythm can result in a preference in the time of day that activities are performed (Laborde, et al., 2015). This preference, or chronotype, is classified as morning-type, evening-type, or intermediate which shows no preference (Lastella et al., 2016). Literature on the relationship between chronotype and athletic performance suggest that an individual's chronotype may identify a peak period of athletic performance for them. In elite swimmers, Rae et al. (2015), found that those with a morning-type chronotype who habitually trained in the morning recorded faster times than those with intermediate or evening types when training at 6:30AM. Findings such as these have led to the suggestion that athletic performance may be optimized by scheduling training sessions during athlete's peak performance window described by their chronotype (Nedelec et al., 2018; Reardon et al., 2019).

Summary and Purpose of Study

The purpose of this study is to investigate the literature gap in the intake of collegiate women's softball players. Research is lacking in developing nutrition recommendations for team sport athletes, specifically female team sport athletes. Currently, there are no published recommendations for performance nutrition for collegiate softball players. In this study, dietary intake of collegiate softball players will be compared to general sports nutrition recommendations published by the International Olympic Committee (IOC) and International Society of Sport Nutrition (ISSN) (Mountjoy et al., 2024; Thomas et al., 2016). The secondary purpose of this study will investigate the potential relationships between fueling status, sleep, and performance in collegiate softball athletes. As mentioned previously, there is a lack of evidence involving collegiate athletes as subjects in studies on the relationship between sleep and athletic performance/recovery. This study will aim to fill the literature gap in exercise performance and sleep in collegiate athletics.

Hypotheses

H_{01}: Fueling status will have no effect on power output in female collegiate softball athletes.

H_{A1}: Fueling status will have an effect on power output in female collegiate softball athletes.

H_{02}: Energy availability will have no effect on power output in female collegiate softball athletes.

H_{A2}: Energy availability will have an effect on power output in female collegiate softball athletes.

H_{03}: Protein intake will have no effect on power output in female collegiate softball athletes.

H_{A3}: Protein intake will have an effect on power output in female collegiate softball athletes.

H_{04}: Carbohydrate intake will have no effect on power output in female collegiate softball athletes.

H_{A4}: Carbohydrate intake will have an effect on power output in female collegiate softball athletes.

H_{05}: Sleep duration will have no effect on power output in female collegiate softball athletes.

H_{A5}: Sleep duration will have an effect on power output in female collegiate softball athletes.

CHAPTER III

METHODS

Recruitment and Study Design

Current members of a NCAA Division I softball team at a southeastern public university were recruited for this study. Participation was voluntary, and participants were not compensated for their participation. A total of 27 females aged 18-23 were eligible to complete the study. Inclusion criteria consisted of current participation in fall competition and strength training for the softball team. Exclusion criteria included injury or illness that caused the participant to miss more than half of the scheduled training sessions and/or competitions in their season, or failure to complete their dietary recall during the study period.

The study followed a prospective observational design. Subjects participated normally in team training including morning workouts prescribed by their strength and conditioning coach, afternoon softball practices facilitated by the coaching staff, and scheduled competitions. Workouts were held at 7:00 am, two to three days per week, depending on the scheduling of competitions. The observation period was four days, though this data was compared to data collected during training sessions over the course of the entire fall season (August-December).

Variables and Measurement

Body composition was measured using Air Displacement Plethysmography (BOD POD®, COSMED USA, Concord, CA, USA) analysis for each athlete. Baseline measurements were collected at the beginning of the fall training season (August). Testing was conducted between 6:00am and 7:00am to ensure that measurement was completed before any training sessions. Participants were instructed not to consume any food or drink for at least 4 hours prior to the test, and to empty their bladder prior to reporting. Participants were instructed to wear form-fitting clothing such as compression shorts and a sports bra and remove any jewelry. Each participant covered their hair using a swim cap, which was worn for the duration of the measurement. Height was measured using a wall-mounted stadiometer and rounded to the nearest cm. Calibration of the scale and BOD POD® cabin was completed before each participant was tested. Participants completed two 50-second trials, and were instructed to stay as still as possible during each trial and to breathe normally. Resting Metabolic Rate (kcal/day) for each participant was estimated using the Nelson equation and multiplied by an activity factor of 2.07 (Very Active) to predict total energy expenditure (TEE) for each individual. This information was also used to estimate energy availability (EA) using the formula below.

$$EA = \frac{Daily\ Intake\ (kcal) - \ Exercise\ Expenditure\ (kcal)}{Fat - Free\ Mass\ (kg)}$$

Fueling status was determined by collecting a 24-hour diet recall from each athlete. This recall was collected on an off day after a three-game series to gain insight into fueling behaviors for athletes when their schedule does not include practice or strength and conditioning. After receiving education regarding recording intake, participants reported all food and drink consumed along with portion sizes, where the consumption occurred (e.g., home, restaurant, cafeteria, etc.), and information about preparation methods that could alter the nutrient content of the food/drink consumed. Participants also reported any use of dietary supplements during this time period. All intake was analyzed using the Nutrient Data System for Research (NDSR) software in order to determine total daily energy intake along with carbohydrate and protein intake. Actual total intake for each day was compared to the estimated TEE that was calculated for each athlete, placing them one of two categories regarding fueling status ("adequately fueled" or "under-fueled"). In addition to determining fueling status, intake was analyzed to assess the carbohydrate and protein intake for each participant in absolute (g) and relative (g/kg/day) terms and compare to the recommended intake for athletes. A daily protein intake recommendation of 1.7g/kg FFM was used, as this is a median in the recommended range of 1.2-2.2g/kg/day published by the International Society of Sports Nutrition (2018). Actual carbohydrate intake was compared to a recommended carbohydrate intake of 8g/kg/day. This value satisfies the recommended intake for both moderate (5-8g/kg/day) and high (8-10g/kg/day) activity (Kersick et al., 2018; Sims et al., 2023).

Performance was measured using velocity-based training data recorded using Perch Camera devices (Catalyft Labs, Cambridge, MA), which have been previously validated to monitor velocity in back squat and bench press (Weakley et al., 2022). Perch devices were mounted to each lifting rack, and connected to a Samsung Galaxy tablet (Samsung Electronics, Suigen, South Korea) used to display velocity data after each rep via the Perch app ensure compliance with target velocity range. (version 2.1.4). Participants were given a target velocity range of 0.5-0.75 m/s to achieve the goal of gaining accelerative strength for this exercise (Gonzalez-Badillo et al., 2014). Average power (watts) was recorded for back squat exercise. All training sessions were completed at the same time of day (7:00am) on designated training days programmed by the team strength and conditioning coach. The average session power calculated for back squat was compared to an average power of calculated during back squat over the entire fall season.

Sleep duration was self-reported by participants. Each participant recorded the number of hours they slept the night before each training session, rounded to the nearest hour. Participants were instructed to record hours actually slept at night, and did not include daytime naps. Actual sleep reported was compared to the minimum recommendation of 7 hours of sleep for the general population and 9 hours of sleep that is recommended for athletes (Bonnar et al., 2018).

Statistical Analysis

Data was analyzed using SPSS (version 29; IBM Corp) with significance set at a=.05. Independent samples *t*-tests were used to determine the significance of any effect that dietary intake and sleep may have on power over the observation period.

CHAPTER IV

RESULTS

Participants

Of the 27 participants who were eligible for the study, 26 met all of the inclusion criteria. One participant was excluded due to failure to complete a training session during the observation period. These participants completed a four-day dietary intake record before a normal scheduled weight training session where PERCH data was collected for back squat.

Table 1. Descriptive Statistics (N=26)

	Min	Max	M	SD
Actual - Recommended Intake (kcal)	-1964.00	1327.41	-404.46	830.01
Calculated EA (kcal/kg/day)	26	-6.93	54.47	20.26
Actual - Recommended Protein Intake (g)	-95.07	66.30	-13.01	38.39
Actual - Recommended Carbohydrate Intake (g)	-549.0	81.0	-292.66	143.78
Sleep	26	5	12	7.46

Caloric Intake

Of the 26 participants who completed the study, 19 failed to meet their intake recommendations (under-fueled) while seven met their recommended caloric intake (adequately fueled). On average, participants consumed 404 calories less than the recommended intake that was calculated based on their body composition and activity level (See Table 1). Participants who were under-fueled recorded mean difference in power output of -23.26 watts (SD=27.01), while those who were adequately fueled recorded a mean difference in power output of -18.86 watts (SD=32.77) during the observation period (See Table 2 and Figure 1). An independent samples *t*-test was conducted to explore the effect of nutrition status on average power during back squat. This test was not found to be statistically significant, t(24)= -0.35, $p > 0.05$; d = -0.15.

Table 2. Group Statistics – Fueling Status

		N	M	SD
Difference in Power (w)	Adequately Fueled	19	-23.26	27.01
	Underfueled	7	-18.86	32.77

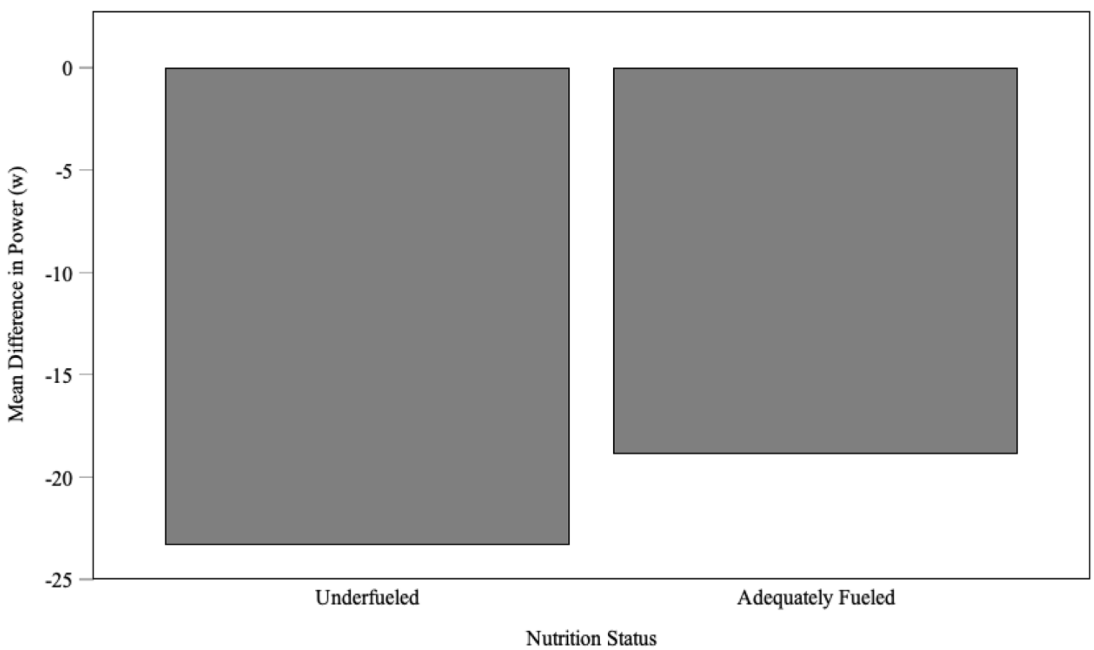

Figure 1. Comparison of the mean difference in power output grouped by participants who consumed the recommended number of calories (Adequately Fueled) and participants who consumed less than the recommended number of calories (Underfueled).

Energy Availability

Of the 26 participants who completed the study, 20 were considered as having LEA using the threshold of clinical LEA established in the literature by Loukes et al. (2011). Six participants had a calculated EA above 30 kcal/kg/day, and were considered to be adequately fueled. The mean value for energy availability for all participants in this study was 20 kcal/kg/day. Participants in the LEA group recorded mean difference in power output of -22.65 watts (SD= 26.43), while those who had adequate energy availability recorded mean difference in power output of -20.17 watts (SD= 35.70) (See Table 3 and Figure 2). An independent samples *t*-test was performed to assess the difference between the groups. However, no statistically significant differences were found, t(24) = -0.33, $p > .05$, d= -0.09.

Table 3. Group Statistics – Energy Availability

		N	M	SD
Difference in Power (w)	LEA	20	-22.65	26.43
	Adequate EA	6	-20.17	35.70

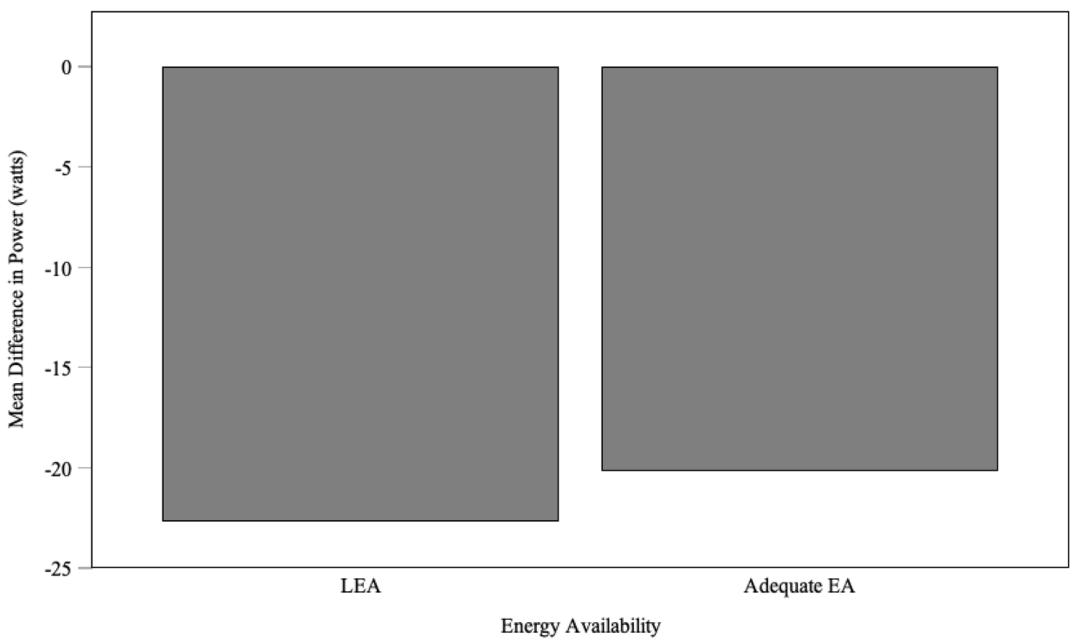

Figure 2. Comparison of mean difference in power output (w) grouped by energy availability status. Low energy availability is defined as < 30g/kg/day.

Protein Intake

Individual protein recommendations were met by 12 participants. The remaining 14 participants failed to consume the recommended amount of protein based on their body composition and activity level. Participants who did not consume the recommended amount of protein recorded mean difference in power output of -18.21 watts (SD=31.62), while those who consumed the recommended amount of protein recorded mean difference in power output of -26.58 watts (SD=23.79) (See Table 4 and Figure 3). An independent samples *t*-test conducted to test the effect of protein intake on average power during back squat was not statistically significant, $t(24)= 0.75$, $p > 0.05$; $d = 0.29$.

Table 4. Group Statistics – Protein Intake

		N	M	SD
Difference in Power (w)	Recommendation Not Met	14	-18.21	31.62
	Recommendation Met	12	-26.58	23.79

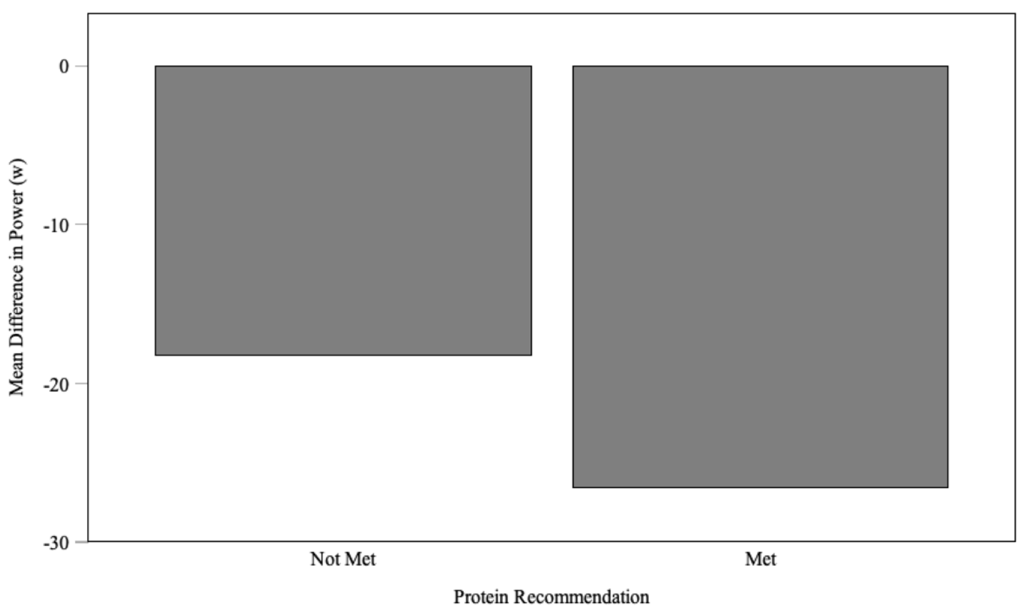

Figure 3. Comparison of the mean difference in power output grouped by participants who consumed their recommended amount of protein (Met) and those who consumed less than the recommended amount of protein (Not Met).

Carbohydrate Intake

Individual carbohydrate recommendations were not met by 25 of the 26 participants. The average difference in recommended – actual intake for carbohydrates was -292 grams (See Table 1). Since only one participant met their carbohydrate recommendations, the data was grossly skewed and resulted in invalid outputs in statistical tests (See Table 5 and Figure 4). There were no statistical tests conducted to form a relationship between carbohydrate intake and power, therefore, this was not included in the results of this study.

Table 5. Group Statistics – Carbohydrate Intake

		N	M	SD
Difference in Power (w)	Recommendation Not Met	25	-22.24	28.62
	Recommendation Met	1	-18.00	*

**Statistic unable to be calculated due to skewed data*

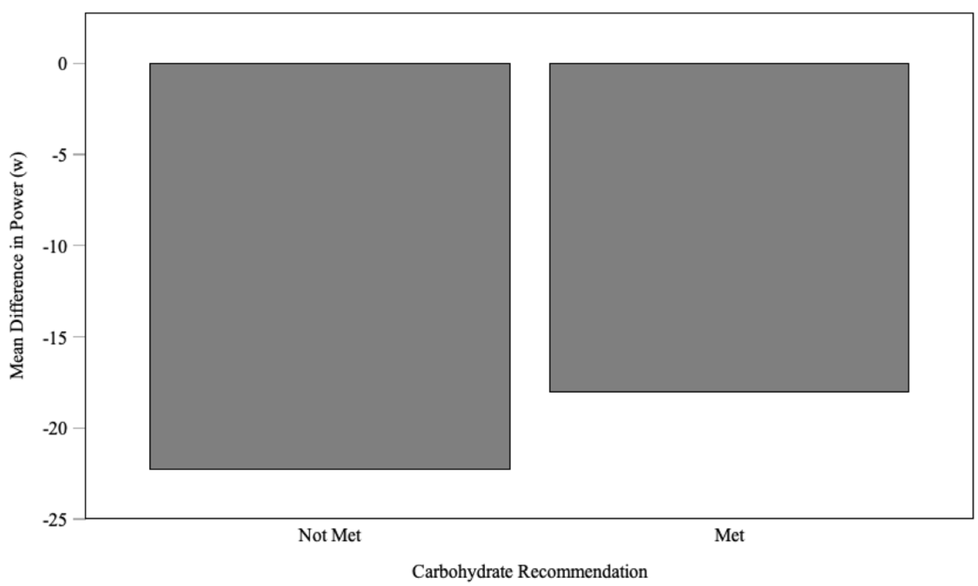

Figure 4. Comparison of the mean difference in power output grouped by participants who consumed their recommended amount of carbohydrates (Met) and those who consumed less than the recommended amount of carbohydrates (Not Met).

Sleep

Using the minimum sleep recommendation of seven hours per night, 21 participants received an adequate amount of sleep, while five participants did not. Participants who slept at least seven hours recorded a mean difference in power output of -22.86 watts (SD= 28.72), while the participants who slept less than seven hours the night before data collection recorded mean difference in power output of -18.80 watts (SD= 27.90) (See Table 6 and Figure 5). An independent samples *t*-test was performed to assess the difference between these groups. However, no statistically significant differences were found, t(24)= -0.34, $p > 0.05$; d= 0.14.

Using the recommendation of nine hours per night, 23 participants did not receive the recommended amount of sleep while three participants did follow the recommendation. Participants who slept over nine hours recorded a mean difference in power output of -31.67 watts (SD= 31.79), while participants who slept less than nine hours recorded mean difference in power output of -20.83 watts (SD= 28.07) (See Table 7 and Figure 6). An independent samples *t*-test was performed to assess the difference between the groups. However, no statistically significant differences were found, t(24)= 0.03, $p > 0.05$, d= 0.38.

Table 6. Group Statistics - 7 Hour Sleep Recommendation

		N	M	SD
Difference in Power (w)	Recommendation Not Met	5	-18.80	27.90
	Recommendation Met	21	-22.86	28.72

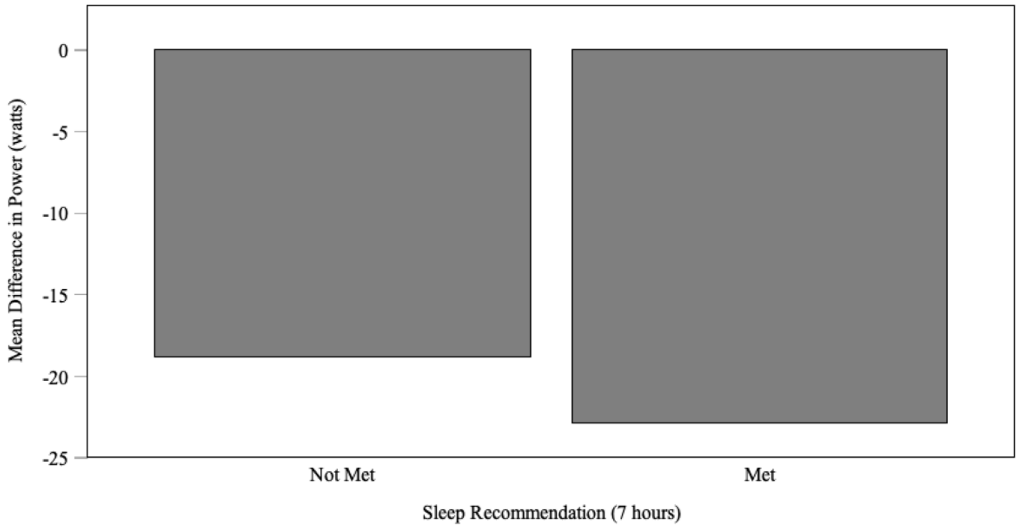

Figure 5. Comparison of mean difference in power output (w) grouped by participants who slept a minimum of 7 hours and participants who slept less than 7 hours.

Table 7. Group Statistics – 9 Hour Sleep Recommendation

		N	M	SD
Difference in Power (w)	Recommendation Not Met	23	-20.83	28.07
	Recommendation Met	3	-31.67	31.79

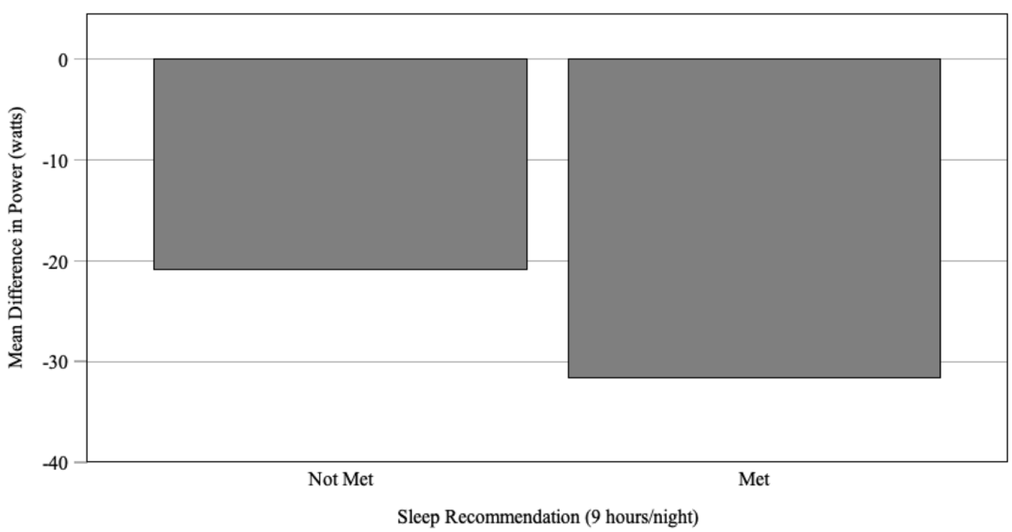

Figure 6. Comparison of mean difference in power output (w) grouped by participants who slept a minimum of 9 hours and participants who slept more than 9 hours.

CHAPTER V

DISCUSSION

The first purpose of this study was to explore the relationship between nutrient intake and athletic performance in collegiate softball players. No statistically significant difference in power was found in athletes based on their fueling status. However, the results showed that 73% of participants did not consume the recommended number of calories to support their body composition and activity level (See Table 2). These findings corroborate those of previous studies suggesting that athletes typically do not follow recommendations for caloric intake (Holtzman & Ackerman, 2019; Jagim et al., 2019; Jenner et al., 2019). While professional organizations have published nutrition recommendations for athletes, female athletes and team sport athletes are often not participants in the studies cited as evidence for developing these recommendations (Mountjoy et al., 2024; Sims et al., 2023). When compared to individual sports, team sports often have a wider variation in energy expenditure due to variation in individual playing time, the position that is played, weather conditions, and duration of competition (Ferraris et al., 2019). Additionally, there are very few studies including softball athletes as participants. This is largely due to the thought that nutrient intake is less important in softball since the sport is less physically taxing than other sports (Holway & Spriet, 2011). In reality, softball requires athletes to depend on the aerobic energy system for short bursts of energy and the anaerobic energy system for endurance to perform in competitions that can last upward of 3 hours in outdoor conditions. Proper fueling practices are necessary in this population to provide sufficient energy to withstand the demands of the sport (Ferraris et al., 2019).

An independent samples *t*-test found no statistically significant effect of energy availability on power, though interesting data was collected regarding the prevalence of low energy availability in collegiate softball players. In this study, 77% of participants were identified as having clinically low energy availability (See Table 1). These results are alarming, but findings are similar to data collected by Torres-McGehee et al. (2020) who found that 100% of softball players in their study had low energy availability. Though no literature to date has identified softball as a “high risk” sport for the development of REDs, these findings suggest that further studies in this area are warranted. If this is not addressed, these athletes are at an increased risk of complications including metabolic issues, injuries, menstrual changes, and decreased performance (Loukes et al., 2011). Literature suggests that athletes should aim to maintain an energy availability above 45g/kg/day to adverse effects, but only two participants in this study met this threshold.

This study did not include data on the factors that influence food choices in female collegiate athletes, but literature suggests that there is a discrepancy in the actual versus perceived amount of nutrients in food (Jagim et al., 2019). Many athletes have the perception that they are consuming an appropriate amount, but either under-estimate their exercise expenditure or over-estimate their intake, causing them to inadvertently underfuel (Eck & Byrd-Bredbenner, 2021). Other factors such as a lack of nutrition knowledge, issues with access to high quality food sources, and time constraints could be the cause of the discrepancy between recommendations and practice (Eck & Byrd-Bredbenner, 2021). In a survey of 23,000 current student athletes, only 22% of softball athletes reported that they felt that they had enough time to eat healthy meals each day, 37% indicated that they could afford healthy meals, and 22% stated that healthy food options were readily available to them after practices and/or competitions (NCAA, 2024). These reported statistics indicate that an audit of athletic departments' policies and procedures is necessary to ensure that healthy meals are accessible to athletes, and adequate time is given to consume them between training and academic engagements.

This study found no statistically significant effect of protein intake on average power output. Though dietary protein's role in stimulating muscle protein synthesis is well documented, literature on the direct relationship between protein intake and power in resistance trained athletes report conflicting results (Jager et al., 2017). For example, Hoffmann et al. (2007) reported a 22% strength increase in squat for collegiate football players consuming above of 2.0g/kg/day when compared to those consuming a minimum of 1.6g/kg/day. However, literature investigating the protein intake in female athletes failed to find a significant effect on athletic performance (Hida et al., 2012). These discrepancies in findings may be the cause of improper timing of protein intake in relation to exercise, or athletes consuming the recommended amount of protein but suboptimal caloric intake (Jenner et al., 2019). This is evident in our study where nearly all of the participants failed to consume the recommended number of calories, but 46% of the participants were able to meet their recommended protein intake. This study did not explore the reasoning behind the participants' dietary choices, but it is possible that athletes are more cognizant of the importance of protein intake on the maintenance of lean muscle mass and muscle recovery after exercise, leading them to prioritize protein intake in their food choices. Future studies are necessary to determine the accuracy of this suggestion.

Due to grossly skewed data in our sample, statistical testing was not possible using carbohydrate intake. In similar studies exploring the intake of collegiate athletes, a failure to meet carbohydrate recommendations has been well-documented (Danh et al., 2021; Shriver et al., 2013). This study corroborated those findings with 96% of participants failing to consume recommended amounts of carbohydrates. On average, participants consumed 292 grams of carbohydrates less than the recommendations for their activity level and body composition. Literature on nutrition knowledge in athletes suggest that this population may be unaware of the role of carbohydrate intake in athletic performance (Shriver & Wollenberg, 2013). Additionally, there is evidence that collegiate aged-females and female athletes feel pressure to fit into societal norms to be thin and are susceptible to being influenced by diet trends such as low carbohydrate diets (Sogari et al., 2018).

The second purpose of this study was to assess the relationship between sleep and performance in female collegiate athletes. Independent samples *t*-test investigating the effect of sleep duration on power were run using the recommendations of seven hours for the general population as well as the recommend nine hours for athletes (Bonnar et al., 2018; Reardon et al., 2019; Watson et al., 2023). Sleep was not determined to have a statistically significant effect on power using either threshold. Though the results of these analyses were not statistically significant, a small-to medium effect size was calculated for this t-test. This could indicate that the sample size is too small to properly evaluate this relationship. Using the recommendations for the general population, 80% of participants did receive the minimum recommended amount of sleep. In a collegiate population, this is encouraging since literature suggests that collegiate athletes are at a higher risk of sleep interruptions due to the time demands of academic responsibilities along with training and competition (Yang et al., 2019). Using the recommendation of nine hours, 88% of participants did not get an adequate amount of sleep the night before training. Findings regarding reported sleep duration in this study are similar to findings of other studies in elite athletes, indicating that sleep duration is not adequate in collegiate athletes in other sports as well (Fullagar et al., 2017). Future studies should be conducted in a larger sample to validate these findings, and to determine whether there should be separate sleep recommendations in the collegiate athletic population.

Limitations

There were limitations present in this study. The first is associated with the small sample size of participants. Access to current collegiate female softball athletes was limited, though future studies should be proposed in this population to collect further data. This small sample size may have been responsible for homogenous data in some variables, preventing statistical testing. There are also potential limitations in the collection of self-reported nutrition data, as there is a tendency for participants to under-report or restrict intake during the study period when asked to track dietary intake (Ferraris et al., 2019). Nutrition data was collected on an off-day, which may not represent typical fueling behaviors on a day including training and academic responsibilities. Sleep data collected in this study was also self-reported, and focused on nighttime sleep duration. Naps were not included in this data, and may have resulted in underreporting in sleep duration.

Practical Applications

The results of this study indicate that nutrient intake and sleep had no statistically significant effect on power in collegiate softball athletes. Though no statistically significant findings were found, this study contributes to the lack of data involving this population and corroborates the findings of previous studies reporting that athletes often do not meet recommendations for overall intake, protein intake, or carbohydrate intake. As stated previously, studies on fueling practices in female collegiate athletes and softball athletes, specifically, are scarce compared to those including male athletes. An increase in data regarding nutrition practices in this population could allow future assessment of the accuracy of nutrition recommendations for female team softball athletes and highlights the need for more studies exploring the variables driving fueling practices in female athletes. Additionally, this study contributes to data involving sleep duration in collegiate athletes. Future studies in this population are necessary, and should focus on objective measures to monitor sleep duration in collegiate athletes.

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VITA

Name: Derionne Brooks, MS, ATC, LAT

Current Position: Assistant Director of Administration, University of Mississippi

Academic Preparation

a. *Prospective Degrees*
University of Mississippi, University, Mississippi
Doctor of Philosophy, 2024; Field of Study: Nutrition and Hospitality Management
Concentration: Sport Nutrition

b. *Degrees Completed*
University of Mississippi, University, Mississippi
Master of Science, 2017; Field of Study: Food and Nutrition Services
Emphasis Area: Nutrition

Louisiana State University, Baton Rouge, Louisiana
Bachelor of Science, 2014; Field of Study: Kinesiology
Major: Athletic Training

Professional Credentials and Experience

Licenses/Credentials
Licensed Athletic Trainer (LAT), Mississippi State Department of Health, Jackson, Mississippi (AT0742), 2015-Present.
Licensed Athletic Trainer (LAT), Louisiana State Board of Medical Examiners, Baton Rouge, Louisiana (ATH.200366), 2014-2015
Certified Athletic Trainer (ATC), Board of Certification, Omaha, Nebraska (BOC271705), 2014-present

Certifications
Dry Needling Level-1, Total Motion Physical Therapy (2018)
CPR BLS Instructor, American Heart Association (2018)
CPR BLS Instructor, American Red Cross (2022)
Graston M-1 Technique, Graston Technique (2012)

Professional Positions

Assistant Director of Administration; The University of Mississippi, Athletics Department, University, Mississippi; (2022-Present)
Adjunct Professor; The University of Mississippi, Department of Health, Exercise Science, and Recreation Management, University, Mississippi; (2022-Present)
Assistant Athletic Trainer; The University of Mississippi, Athletics Department, University, Mississippi; (2017-Present)
Graduate Assistant Athletic Trainer; The University of Mississippi, Athletics Department, University, Mississippi; 2 years (2015-2017)
Assistant Athletic Trainer; University of Louisiana at Lafayette, Athletics Department, Lafayette, Louisiana; 11 months (2014-2015)
Athletic Training Intern; Pittsburgh Steelers Football Club, Pittsburgh, PA 2 months (2013)

Instruction and Advisement

a. Courses Taught
University of Mississippi, Spring 2024
NHM 319 – Sport Nutrition (46 students) (sole instructor)

University of Mississippi, Fall 2022, Spring, 2023, Fall 2023, Spring 2024
Public Health 203 – CPR and First Aid (20 students) (sole instructor)

University of Mississippi, Fall 2022
Exercise Science 396 – Allied Health Terminology (42 students) (sole instructor)

Scholarly and Creative Activities/Accomplishments

Theses
Derionne Brooks, (Fall 2015-Spring 2017), The Effect of Body Image Awareness Program on Weight Satisfaction in Division I Female Athletes.

Professional Association Memberships and Service

Mississippi Athletic Trainers' Association (MATA) (2015-present)
National Athletic Trainers' Association (NATA) (2011-present)
Southeast Athletic Trainers' Association (SEATA) (2011-present)
Louisiana Athletic Trainers' Association (LATA) (2011-2015)

Community Memberships and Service

The Geauxlden Kause, Board Member (2020-present)
Project Neaux Limits, Board Member (2019-present)
University Service (The University of Mississippi)

University Committees
Diversity Liaison (2022-present)

School of Applied Sciences Committees
Clinical Instructor/Lecturer of Athletic Training Search Committee (2021, Member)

Departmental Committees
Diversity Planning Committee (2022-present, Member)
Disordered Eating Treatment Team (2017-present, Member)
Athletics Counselor Search Committee (2021, Member)
Sports Registered Dietician Search Committee (2020, Member)
Athletics Counselor Search Committee (2019, Member)