The Relationship between Dietary Intake and Sleep Quality in Endurance Athletes

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Dedication

This work is dedicated to my grandmother, Arnetha Clark and father, Theron Moss.

Chapter 1

Introduction

1.1 Characteristics of Sleep Quality

Several studies have sought to characterize sleep quality. Based on recent review studies among athletes, sleep quality may be determined by factors such as sleep duration (time spent asleep), sleep efficiency (time asleep relative to time in bed), sleep fragmentation index (restlessness during sleep relative to time in bed), sleep latency (time to fall asleep), day-time sleepiness or fatigue, disordered breathing while sleeping including snoring or sleep apnea, and awakenings during the night.[1,2] According to the National Sleep Foundation's, healthy adults should receive 7-9 hours of sleep per night,[3] and sleep latency should be between 10-20 minutes.[4]

1.2 Physiological Regulation of Sleep

Sleep is characterized as a state in which many physiological processes decrease, including responsiveness to the environment, reduced muscle tone, relaxed muscles, and decreased metabolic rate.[5,6] The sleep-wake cycle is regulated by circadian rhythms which are self-sustaining endogenous rhythms that recur on a cycle of nearly 24 h.[5–7] The circadian systems contain tissue-specific cellular clocks throughout the body that regulate the genetic expression of genes that affect the sleep-wake cycle.[8] These genes include the circadian locomotor output cycles kaput (CLOCK) and the brain and muscle aryl hydrocarbon receptor nuclear translocator-like protein 1 (BMAL-1).[8,9] The tissue-specific clocks are synchronized by a master circadian pacemaker, the suprachiasmatic nucleus (SCN).[9] The SCN is located in the anterior hypothalamus of the brain and is responsible for regulating high and low propensities for the need to fall asleep.[9] There are a number of factors that influence the regulation of the sleep-wake cycle by the suprachiasmatic nucleus including hormones (e.g., melatonin), environment (e.g., day or night), core body temperature, age, genetics, and behavioral factors.

Hormonal factors such as melatonin influence an individual’s ability to fall asleep.[10] Melatonin production is affected by the environment and core body temperature. When the SCN receives feedback such as light from the environment through the retinal ganglia cells in the eyes, the SCN firing increases.[11] As a result, the pineal gland decreases the production of melatonin which promotes increased wakefulness.[11] In contrast, when it becomes dark during the evening, the SCN firing decreases and melatonin production increases inducing sleep.[12,13] Similarly, when the core temperature of the body decreases, SCN firing is reduced and the pineal gland increases the production of melatonin resulting in increased sleepiness.[9] Therefore, sleeping in a dark room[14] and at a cool temperature near 65°F (18.3°C)[15] increases the production of melatonin which leads to better sleep quality.

Internal factors such as age and psychological stress have also been shown to influence sleep quality. As individuals age, several changes to sleep architecture occurs which leads to issues such as longer sleep latency[16], earlier bedtimes[17], earlier awakenings[17], increased awakenings[18], increased sleep fragmentation[19], and shorter sleep duration.[20] The increased sleep issues among older adults may be explained by neurophysiological changes. The number of cells in the SCN portion of the hypothalamus and retinal ganglia decreases with age.[21,22] Therefore, older adults are less sensitive to light and changes in light such as darkness which may lead to longer sleep latencies.[22] The age-related deterioration of the nuclei in the hypothalamic area and ascending brain stem which regulates the sleep-wake cycle[22,23] may explain earlier bedtimes, earlier awakenings, and increased awakenings during the night in this population. The thinning of the gray matter in the frontal and temporal cortex of the brain in older adults is related to reduced sleep time and increased sleep fragmentation.[22,24,25] These areas of the brain are responsible for regulating slow-wave sleep in which synaptic activity decreases and cellular restoration occurs.[25] Psychological stress due to competitions in sports as well as demands from training may also lead to disturbances in sleep quality.[26] For instance, prior to competition athletes experience hyperarousal (i.e., stress, nervousness, and anxiety) which has been shown to result in delayed sleep onset.[27–29] Additionally, athletes can experience psychological stress related to training. Specifically, many athletes worry about performing well during training which can lead to difficulty falling asleep and insomnia.[30]

Genes, another internal factor, may also influence sleep. Specific disorders such as delayed-sleep phase disorder have been linked to a mutation in the CLOCK genes that impact the circadian rhythms, which may lead to delays in sleep onset and awakening times.[31] Familial advanced sleep phase syndrome (FASPS) has been associated with mutations in the Period 2 (PER2) gene and Casein kinase 1 delta (CK1D).[31,32] CK1D, an enzyme, plays a role in regulating the phosphorylation of multiple proteins and the stability of PER2.[32] PER2 is responsible for coding proteins that determine the speed of the circadian clock .[32] If CK1D phosphorylation is disrupted, PER2 becomes unstable and mutates which leads to sleepiness in the early evening, falling asleep earlier, waking up earlier, and having increased circadian rhythm cycle speed.[32]

Behavioral factors such as the use of electronic devices, consuming alcohol, eating, or exercising heavily before bedtime may negatively affect sleep. Using electronic devices (e.g., cell phone, tablet, computer, television, etc.) within 1 hour of bedtime has been shown to increase the firing of the SCN and decrease the production of melatonin which inhibits an individual’s ability to fall asleep.[33] Consumption of alcohol right before bedtime has been linked to increased sleep- disordered breathing because it decreases upper airway capacity, and causes increased awakenings and gastrointestinal issues that may disrupt sleep.[34,35] Additionally, evening alcohol consumption may affect the synthesis of melatonin and result in difficulty falling asleep.[36,37] Further, eating a meal close to bedtime can result in gastro-esophageal reflux disease (GERD) related symptoms such as acid regurgitation, heartburn, and cause awakenings throughout the night.[38] Therefore, it is recommended to avoid consuming meals within 3 hours of going to bed to decrease instances of GERD symptoms during sleep.[38] High-intensity exercise (HIE) before bedtime may increase sleep latency.[39] The American Sleep Foundation recommends that individuals do not engage in high-intensity exercise within 3 hours of bedtime.[40] HIE prior to bedtime may increase sleep latency by elevating core body temperature and increasing physiological arousal which may lead to reductions in the production of melatonin.[39] Although heavy exercise prior to bedtime is not recommended, participating in regular exercise has been shown to improve sleep quality.[41] A proposed mechanism is that regular exercise improves thermoregulation by increasing peripheral blood flow which may allow the body to more efficiently decrease body temperature at night to promote sleep onset.[41]

Another behavioral factor, traveling, may also influence sleep. Jet lag as a result of frequent long-haul travel (across multiple time zones) has been shown to disrupt the circadian rhythm. One of the mechanisms that may explain the impact of jet lag on sleep is light-based phase shifting.[42] Specifically, individuals may be exposed to varying degrees of light when crossing time zones which impairs SCN firing and melatonin production.[42] To mitigate the effects of travel, it is recommended that individuals follow a new temporal schedule that is similar to their home environment until they are able to acclimate to the new time zone.[42]

However, this may be difficult to implement by athletes who may have limited flexibility in their schedule because of training and competition.

Although not commonly known, dietary intake may also affect sleep quality. This is reviewed in more detail in section 1.6 on dietary intake and sleep quality.

1.3 Sleep Quality among Athletes

Several studies have examined sleep quality among athletes. The studies show that many athletes in the U.S. and elsewhere have poor sleep quality. Poor sleep quality has been reported among over 38% of Brazilian athletes[43,44], 50% of Australian rugby and cricket players[45], 25% of Finnish ice hockey players[46], 35% of U.S. collegiate team sport athletes[47], 78% of Portuguese elite gymnasts[48], and 41% of Irish elite multi-sport athletes.[49] More specifically, sleeping less than <7 hours per night has been reported in 61% of U.S. collegiate team sport athletes[47], and the average sleep duration for Australian endurance cyclists is <7 hours before and during competitions.[50] In addition to this, nighttime awakenings have been reported in 55.6% of Brazilian athletes[43] and 24.5% of Norwegian ultramarathon runners[51], and sleep fragmentation was higher and sleep efficiency was lower among UK Olympic athletes compared to age-matched controls.[52] Daytime sleepiness was found in 28% of Australian rugby and cricket players[45], 37.6% of Norwegian ultramarathon runners[51], and 19% of U.S. collegiate team sport athletes.[47] Other sleep issues reported include 38% snoring and 8% sleep apnea in Australian rugby and cricket athletes[45] and 28% mild insomnia in U.S. collegiate team sport athletes.[47]

1.4 The Effects of Sleep Quality on Performance, Injury Risk, and Health among Athletes

Sleep quality may affect performance, risk for injury, and health among athletes. Several randomized studies have investigated the effect of partial or complete sleep loss on performance among athletes. Bulbulian and colleagues[53] examined the effects of 30 hours of sleep deprivation on knee strength among endurance exercise-trained men, and reported that muscular strength was lower following sleep deprivation versus their typical sleep duration.[53] Azboy et al.[54] investigated the effects of one full night of sleep deprivation on cardiorespiratory fitness in male distance runners and volleyball players and reported that it reduced time to exhaustion and minute ventilation (VE) (i.e., amount of air breathed per/min) compared to the usual sleep duration.[54] Similarly, Oliver et al.[55] reported higher ratings of perceived exertion (RPE) and less distance covered during a 30-min self-paced treadmill test among recreational endurance athletes following a full night of sleep deprivation compared to their usual amount of sleep. Additionally, Reyner and colleagues[56] found that serving accuracy among male and female tennis players was reduced by 53% when their sleep was limited to 5 hours/night.[56] The time during the night when sleep was deprived also affected performance. Souissi and colleagues[57] reported reduced anaerobic power and grip strength among male Judo athletes when they underwent partial sleep deprivation at the end of the night compared to the beginning of the night.[57] In addition to performance, sleep may also aid in stress recovery. In our own lab, we found that endurance athletes value sleep as a strategy to mitigate the effects of stress from training and to properly recover.[58]

Poor sleep quality may also increase the risk for injury. Milewski et al.[59] reported a 1.7 times greater risk for sustaining an injury among adolescent athletes who received <8 hours/night of sleep compared to those who slept longer. Von Rosen and colleagues[60] reported 61% decreased odds of sustaining an injury among adolescent athletes who received >8 hours of sleep per night in comparison to those who slept less. Moreover, Hayes et al.[61] examined risk factors for injuries among collegiate cross-country runners and reported that poor sleep quality increased the risk of sustaining a new injury or making an existing injury worse. Similarly, Johnston and colleagues[62] showed that a short sleep duration of <7 hours/night was linked to an increased risk of sustaining a new injury in endurance sport athletes. Further, Horgan et al.[63] investigated the relationship between sleep duration and injury among netball athletes and found that shorter sleep durations and poor sleep quality were associated with increased risk of injuries.

Health issues associated with poor sleep quality in athletes may include increased susceptibility to illness, impaired mood, and changes in pain modulation. Hausswirth and colleagues[64] reported that endurance athletes who have short sleep durations and lower sleep efficiency are at increased risk for developing an upper respiratory infection. Blumert et al.[65] examined health outcomes among athletes and showed that 24 hours of sleep loss led to negative changes in mood including increased confusion and fatigue in male collegiate athletes. In addition, Potter and colleagues[66] found that poor sleep quality among high school athletes was related to increased levels of anxiety, depression, fatigue, pain interference, and pain intensity. Similarly, Bascour-Sandoval et al.[67] reported that adolescent athletes experienced more pain at rest and during physical activity with lower levels of sleep quality. A recent review study concluded that poor sleep may lead to an increase in pain sensation among athletes.[68]

1.5 Dietary Intake among Athletes

Several studies have assessed the dietary intake of athletes and found that they do not meet many of the recommendations shown in the Dietary Guidelines for Americans developed to promote health and prevent chronic diseases.[69,70] More specifically, athletes have reported consuming inadequate amounts of fruit[69,71,72], vegetables[69,71,72], whole grains[71], and milk and dairy.[71] However, athletes are more likely to meet the recommendations for consumption of meats, eggs, and legumes.[69,71] In addition to these major food groups, athletes do not meet the recommendations for total water[73,74] obtained through consuming plain drinking water, beverages, and food.

Not meeting the Dietary Guidelines for Americans may lead to issues with energy and macronutrient intakes. Several cross-sectional studies have reported that the majority of athletes in the U.S. and elsewhere are not meeting the recommendations for their energy and some macronutrient needs. Studies have shown inadequate energy intakes in South Asian athletes[75], U.S. female collegiate cross-country and lacrosse athletes[76,77], and elite Brazilian athletes.[78] Additionally, many studies have found that endurance athletes, irrespective of country, have inadequate intakes of protein[79,80], carbohydrates[73,81–84], dietary fiber[83], and fatty acids (i.e., linoleic acid, alpha-linolenic acid (ALA), eicosapentaenoic acid (EPA), and docosahexaenoic acid (DHA)).[83,85] Furthermore, female athletes have an increased likelihood of consuming less than the recommended amount of dietary fiber compared to male athletes.[83] Athletes have been reported to consistently consume more total fat than the recommendations of 20-35% energy.[82,83,86]

Having an inadequate diet may also affect micronutrient intakes. Athletes have reported inadequate intakes of several micronutrients including vitamins A, C, D, E, and K, thiamine, riboflavin, niacin, vitamin B_6, vitamin B_{12}, pantothenic acid, biotin, folate, calcium, zinc, phosphorus, chromium, molybdenum, manganese, selenium, potassium, and magnesium.[73,80,83,86–93] Further, in multiple studies, female athletes have reported consuming less than the recommended amount of iron in comparison to male athletes.[73,80,83,89,94]

The literature on nutrient adequacy in athletes is limited by the fact that most studies have only examined macronutrient but not micronutrient adequacy.[76–78,82,84,85] In addition, studies that investigated micronutrient adequacy in athletes only focused on a few micronutrients.[73,80,83,86–94]

1.6 The Relationship between Dietary Intake and Sleep Quality

This section reviews the role of certain foods groups and water on sleep quality. It also examines the relationship between macronutrient and micronutrient intake and sleep quality. Most of the studies have been conducted in the general population and only a few among athletes.

Several studies in the general population have found that consuming more fruit, vegetables, and whole grain is associated with better sleep quality.[95,96] More specifically, higher fruit or vegetable intake is associated with increased sleep durations[97–99], fewer awakenings[100], increased sleep quality[100], and increased sleep efficiency,[100] and lower whole grain intake is associated with short sleep duration[101,102], evening chronotype.[103,104], increased sleep latency[100], poorer sleep quality.[105] There are several possible mechanisms by which fruit, vegetables, and whole grains may improve sleep quality. Polyphenols found in plant foods may increase the expression of gamma-aminobutyric acid (GABA), a neurotransmitter that promotes sleep duration and reduces sleep latency through inhibiting central nervous system (CNS) activity.[106,107] Additionally, beta-carotene in fruit is converted to retinoic acid (vitamin A) which may up-regulate CLOCK and BMAL genes that regulate the sleep-wake cycle.[108,109] Whole grains are a good source of tryptophan, an amino acid, which is a precursor to serotonin. Serotonin undergoes chemical changes such as acetylation and methylation to be converted into melatonin.[110,111]

Dairy milk is another food that may improve sleep quality. Studies in the general population have found that consuming more dairy milk is linked to better sleep quality.[95,96] Randomized controlled studies among athletes have found that higher dairy milk intake improved sleep latency in Japanese soccer players[112] and decreased poor sleep quality in female Japanese athletes but not male elite athletes.[113] A possible reason for increases in sleep quality with dairy milk may be related to the amino acid tryptophan, which increases the production of serotonin and melatonin.[114]

Another commonly included item in the diet that affects sleep quality is caffeinated beverages. Epidemiologic studies in the general population have found that higher caffeine intake impairs sleep quality.[95,96] Many endurance athletes consume caffeinated beverages or supplements prior to or during workouts.[115] Experimental studies conducted among athletes show that increased caffeine consumption increases awakenings[116], wakefulness[117], sleep latency[117,118], restlessness[117], and insomnia[119], and decrease sleep quality[117,120] and sleep efficiency among athletes.[118] Regularly consuming coffee throughout the day has been linked to reduced production of 6-sulfatoxymelatonin, a metabolite of melatonin resulting in decreased sleep quality and sleep duration.[121] Additionally, caffeinated products can reduce intracellular cyclic adenosine monophosphate (cAMP) signaling which regulates adenylyl cyclase activity.[122] When cAMP signaling is disrupted, lengthening of the circadian cycle occurs which can result in longer sleep latency.[122] It is recommended to avoid consuming caffeinated beverages or supplements at least 6 hours prior to bedtime.[123]

Intake of regular drinking water and total water from foods and other beverages may impact sleep quality. An epidemiological study by Grandner and colleagues[124] found that consuming less plain drinking water was linked to more non-restorative sleep and daytime sleepiness among U.S. adults. Parker et al.[125] showed that higher total water intake was related to earlier sleep midpoints (i.e., time between sleep onset and waking up) among U.S. college students. Therefore, students who consumed more total water fell asleep faster compared to those who consumed less total water.[125] Inadequate hydration is also associated with sleep disturbances among athletes.[126,127] Trabelsi and colleagues[127] conducted a review study that examined hydration status and sleep patterns among athletes during Ramadan and reported that fasting can lead to both dehydration and sleep loss. Dehydration increases core body temperature which will negatively affect sleep.[15]

Specific macronutrients from foods may also affect sleep quality. Shi and colleagues[128] showed that lower percent energy from carbohydrates was associated with <7 h or sleep among Chinese adults. Zhao et al.[129] found that a low versus a high carbohydrate diet (<50% vs ≥50% of total energy) was associated with difficulty maintaining sleep in middle-aged Japanese workers. Lindseth and Murray [130] compared diets of different composition on sleep quality in young adults and found that a high-carbohydrate diet resulted in shorter wake times than either high-protein, high-fat, or control diets. Afaghi et al.[131] reported that healthy adults experienced shortening of sleep latency following a carbohydrate-based high-glycemic meal compared to a carbohydrate-based low-glycemic meal given 4 hours before bedtime. Daniel et al.[132]

however, did not find a difference in sleep quality in pre-game nights among basketball adult male athletes given high-glycemic high-carbohydrate versus low-glycemic high-carbohydrate evening meals and snacks before bedtime. Although the relationship between carbohydrate intake and sleep is not entirely clear, a potential mechanism has been suggested. A high glycemic index or high-carbohydrate diet increases insulin levels. Insulin promotes the selective uptake of a number of amino acids except for tryptophan into the muscles.[129] This leaves tryptophan, a precursor of serotonin, more available for uptake into the brain leading to better sleep.[129]

In addition to carbohydrates, other macronutrients such as protein may affect sleep quality. Lindseth and colleagues[133] examined the effect of various diets on sleep quality among adults and showed that the high-protein diet resulted in fewer awakenings, higher sleep efficiency, and shorter sleep latency compared to the control diet.[133] Similarly, Zhou et al.[134] reported that high-protein diets among overweight and obese adults led to improvement in sleep quality. One proposed mechanism that can explain the results above is tryptophan, an amino acid in protein. Tryptophan is a precursor for serotonin which increases the uptake of melatonin thus increasing the drive to fall asleep.[106,110]

The relationship between dietary fat and sleep quality is controversial. Lindseth and colleagues[133] examined the effect of various diets on sleep quality among adults and showed that those on a high-fat diet had shorter sleep latency and higher sleep efficiency compared to the control diet. However, Grandner et al.[135] found an inverse relationship between fat intake and sleep duration among post-menopausal women. The conflicting findings may be partly related to the fact that dietary fat is made up of many different types of fatty acids that have different effects on health. Focusing on individual fatty acids may be more prudent. In a randomized controlled study, St-Onge et al.[136] found that increasing the intake of saturated fat led to more awakenings and lighter and shorter less restorative sleep among healthy individuals. In animal models, a diet deficient in DHA, an omega-3 fatty acid, was found to negatively impact the circadian rhythm resulting in poorer sleep.[137] Jansen and colleagues[138] reported that higher plasma DHA concentration was related to falling asleep earlier and sleeping longer on weekends among Mexican adolescents. A randomized study by Montgomery et al.[139] showed that higher levels of serum DHA through supplementation resulted in better sleep quality in children from the UK. A proposed mechanism by which omega-3 fatty acid affects sleep is that is a deficiency may disrupt endocannabinoid signaling within the SCN nucleus and decrease the release of melatonin.[140]

Micronutrients including vitamins and minerals may also influence sleep quality. Several studies have examined the relationship between micronutrient intakes and sleep quality in the general population, but none were conducted in athletes. Epidemiological studies in the U.S. and abroad have reported that inadequate amounts of calcium, iron, vitamins C, D, and K, thiamine, selenium, folic acid, vitamin B_{12}, magnesium, and water are associated with poor sleep quality.[124,141–143] Several randomized studies have investigated the effects of micronutrients on sleep quality. Drennan and colleagues[144] reported that potassium supplementation increased sleep efficiency and reduced awakenings in healthy young males. Majid and colleagues[143] showed that vitamin D supplementation in adults with sleep disorders improved sleep quality, reduced sleep latency, and raised sleep duration compared with placebo. Saito et al.[145] found that consuming a zinc enriched diet led to improved sleep onset and sleep efficiency compared to a diet without zinc enrichment in healthy individuals. Djokic et al.[146] reported that magnesium, melatonin, and vitamin B complex supplementation were beneficial in improving insomnia symptoms. There are a few mechanisms by which micronutrient intakes affect sleep quality. Iron deficiency has been reported to decrease the production of neurotransmitters such as serotonin which may result in poor sleep quality.[147,148] Retinoic acid, a metabolite of Vitamin A, up-regulates CLOCK and BMAL-1 gene expression and impacts circadian rhythm, sleep duration, and the sleep stages.[109] Zinc and copper inhibit N-methyl-D-aspartate (NMDA) excitatory receptors which are believed to affect sleep regulation.[149] Further, vitamin B_{12} and magnesium deficiencies have been reported to increase the risk of insomnia by decreasing the amount of melatonin produced at bedtime and subsequently making it difficult to fall asleep.[146]

There are several limitations in the literature on dietary intake and sleep quality. Most studies were conducted in the general population and very few studies included athletic populations.[124,128,130,131,133,135,141–143,145,150–154] To our knowledge, there are no studies that have investigated the effects of vegetable, fruit, and whole grain intake on sleep quality in endurance athletes. Further, studies among athletes did not use a comprehensive set of nutrients to investigate the relationship between nutrient intakes and sleep quality.[132,155–157] Studies examining the role of dietary intake on sleep quality among athletes are warranted especially given that poor sleep quality affects performance, risk for injury, and health among this population, and many athletes have been found to have a poor diet.

1.7 Significance

Participation in endurance sports is increasing at a rapid pace.[158] Additionally, endurance athletes are unique compared to other groups of athletes because their training sessions and competitions typically last for long durations.[159,160] Adequate sleep is essential in this population for performance, recovery, avoidance of injury, and health maintenance. Therefore, elucidating strategies to improve sleep in this population is paramount. Thus, having a better understanding of the role of diet on sleep quality may provide a framework for designing diets that promote healthy sleep. This will in turn allow coaches and dieticians to advise athletes on the best diets to optimize their performance, health, and overall well-being.

1.8 Summary of the Aims and Hypotheses

The aim of this dissertation was to examine the relationship between dietary intake and sleep quality among endurance athletes. More specifically, we examined nutrient adequacy among endurance athletes, and the relationship between consumption of specific foods, macronutrient, and micronutrient intakes and sleep quality.

In our first study, we examined whether endurance athletes (i.e., cyclists, triathletes, rowers, swimmers, and runners) are meeting their macronutrient and micronutrient requirements. We hypothesized that athletes will not meet many of their nutrient requirements, and that female athletes will be less likely to meet them compared to male athletes.

In our second study, we evaluated the relationship between dietary intake of foods such as fruit, vegetables, whole grains, dairy milk, and caffeinated beverages and sleep quality among endurance athletes. We hypothesized that participants who consume higher quantities of fruit, vegetables, whole grains, and dairy milk will have better sleep quality, whereas athletes who consumed larger amounts of caffeinated beverages will have poorer sleep quality.

In our third study, we assessed the relationship between macronutrient and micronutrient intakes and sleep quality among endurance athletes. We hypothesized that higher intakes of carbohydrates, protein, and several micronutrients will be related to better sleep quality.

In the conclusion of this dissertation, the findings from chapters 2-4 are summarized and discussed. More specifically, we discussed the contribution this dissertation has made to the current knowledge and implications for athletes and future studies.

Chapter 2

Nutrient Adequacy in Endurance Athletes

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Abstract

Proper nutrition is critical for optimal performance in endurance athletes. However, it is unclear if endurance athletes are meeting all their energy and nutrient needs. We examined if endurance athletes are meeting their nutritional requirements and any differences by gender. Forty-four endurance athletes (39.0±14.2 y) participated in the study. Dietary intake was evaluated using the 24-hour dietary recall method. Energy and nutrient intakes were calculated using the ESHA Food Processor Diet Analysis Software. Nutrient intakes were compared with nutrient standards developed by the Institute of Medicine, American College of Sports Medicine, American Heart Association, and the Dietary Guidelines for Americans. Fisher's Exact test was used to compare percentage of males and females who did not meet the nutrient requirements. More than 50% of male and female athletes did not consume enough protein, carbohydrates, linoleic acid, α-linolenic acid (ALA), eicosapentaenoic acid, docosahexaenoic acid, vitamins D and E, pantothenic acid, biotin, manganese, chromium, zinc, molybdenum, choline, and potassium. Vitamin K, magnesium, dietary fiber, and total water needs were not met by >50% of males, and vitamin B_{12} and thiamine needs by >50% of females. Majority of athletes, irrespective of gender, consumed more total fat, saturated fat, dietary cholesterol, and sodium than recommended. More males versus females did not meet the requirements for dietary fiber ($p \leq 0.001$), ALA ($p= 0.04$), and total water ($p = 0.03$). Many endurance athletes are not achieving their nutrient needs, with some differences by gender. These findings need to be confirmed by a larger study.

Keywords: nutrient intakes, endurance athletes, nutrient adequacy

2.1 Introduction

Nutrition is one of the key factors in achieving optimal training, performance, recovery, injury prevention, and health among endurance athletes.[79,161] More specifically, endurance athletes train at high volumes which may increase susceptibility to fatigue and muscle damage, negatively impacting performance.[162] To mitigate the effects of prolonged or rigorous training, athletes rely on nutrition to aid in recovery and maintaining health.[163] Studies have shown that prolonged inadequate energy and nutrient intakes can lead to increased risk for overtraining syndrome (i.e., when training exceeds the ability to recover), infectious diseases, and stress fractures.[85,164,165] Other health issues related to prolonged inadequate energy balance or relative energy deficiency in sport include physiological and medical complications impacting the gastrointestinal, endocrine, reproductive, skeletal, renal, cardiovascular, and central nervous systems.[166] Despite the importance of proper nutrition, previous studies have shown that many athletes do not achieve adequate energy, macronutrient, and micronutrient intakes.[73]

Cross-sectional studies have consistently found that a high percentage of athletes do not meet the recommendations for energy and some macronutrient intakes. Inadequate energy intake has been found in U.S. female collegiate cross-country and lacrosse athletes[76,77], elite Brazilian[78], and South Asian athletes.[75] In addition, several studies from different countries have shown that endurance athletes do not get enough carbohydrates[73,81–84], protein [7980], dietary fiber, and essential fatty acids such as linoleic acid, α-linolenic acid (ALA), eicosapentaenoic acid (EPA), and docosahexaenoic acid (DHA).[83,85] Moreover, female athletes are less likely to meet the recommended amount of dietary fiber.[83] In contrast to these findings multiple studies have found that many athletes consume more total fat than the recommended amount (20-35% energy).[82,83,86]

Besides inadequate consumption of several macronutrients, many athletes have been reported to have inadequate intakes of thiamin, riboflavin, niacin, vitamin B_6, vitamin B_{12}, pantothenic acid, biotin, folate, vitamins A, C, D, E, and K, potassium, calcium, zinc, phosphorus, manganese, chromium, molybdenum, selenium, and magnesium.[73,80,83,86–93] Further, female athletes are less likely to meet the recommendations for iron intake compared to male athletes.[73,80,83,89,94]

Although the importance of proper nutrition among athletes has been noted, there are some limitations in the current literature. The majority of the studies among endurance athletes have focused on macronutrient intakes.[76–78,82–85] Therefore, the primary aim of this study was to determine if endurance athletes are meeting their requirements for a comprehensive set of macronutrient and micronutrient intakes as compared to the recommended values by the Institute of Medicine (IOM)[167], American College of Sports Medicine (ACSM)[168], the Dietary Guidelines for Americans (DGA)[70], or the American Heart Association (AHA).[169] This is important to examine given that adequate nourishment is needed for optimizing training, performance, injury prevention, injury recovery, and health among endurance athletes.[163] The secondary aim of this study was to compare nutrient adequacy by gender. Based on previous literature, we hypothesized that the majority of endurance athletes will not meet the nutrient requirements and that fewer female athletes will meet the recommendations compared to male athletes.

2.2 Materials and Methods

2.2.1 Participants

Forty-four endurance athletes were recruited using fliers that were sent to endurance sports clubs via emails and their social media groups, posting flier on campus and sport stores in the metroplex, and by word of mouth. About 50% of the athletes lived in Texas and the remainder were from other states within the U.S. Inclusion criteria included individuals competing in and/or training for endurance-based sports (e.g., cycling, running, triathlon, swimming). The exclusion criteria included individuals under 18 years old and those who did not self-identify as an endurance athlete or participate in training activities for endurance-based sports.

This study was approved by the Institutional Review Board and each participant read and signed an approved informed consent form. Data collection began in January 2021 and ended in October 2021 and was during the COVID-19 pandemic.

2.2.2 Measurements

Demographics, Anthropometry, Type of Sport, and Health History

Demographic, anthropometric, type of sport, and health history were collected via questionnaire. Demographic information included age, sex (male and female), ethnicity (Hispanic and non-Hispanic), race (White and other including African American, Asian, American Indian, Native Hawaiian, and multiracial), education (high school diploma or lower, some college, college degree, and graduate degree or higher), and household income (US dollar) (<\$20,000, \$20,000-49,999, \$50,000-74,999, \$75,000-\$99,999, ≥\$100,000). Self-reported height (m) and weight (kg) were used to calculate body mass index (BMI). Type of sport included categories such as cycling, running, swimming, and triathlon. Health history included questions regarding the participant having any chronic health condition. Additionally, the participants were asked if they used any medications, supplements, were vegetarian, currently smoked/used tobacco products, or consumed alcohol.

Dietary Intake Assessment

Dietary recalls were collected via the United States Department of Agriculture (USDA) multiple-pass 24-hour recall method, a validated measure.[170,171] During the multiple-pass 24-hour recall, participants were asked to remember and report, in detail, the type and amount of all the foods and beverages that they had consumed on the previous day. The multiple-pass 24-hour recall method consisted of five steps.[171] In the first step, the participants provided a quick list of all of the foods and beverages they consumed. During the second step, participants were asked if they consumed any foods from the commonly forgotten list such as beverages, snacks, fruits, vegetables, and breads. In the third step, participants were asked about the time and occasion they consumed the foods. During the fourth step, participants provided details about the amounts food they consumed. Participants were asked to determine portion sizes using tablespoons, teaspoons, cups, pounds, ounces, grams, or slices. The participants were encouraged to provide brand names for processed food, restaurant names if they ate out, and recipes for the food they prepared at home. In the fifth step, the researcher asked additional questions about how the food was prepared and foods that the participant might have missed such as snacks or beverages. The 24-hour dietary recall was collected only after first verifying with the participant that the intake on the previous day was representative of their usual intake. The interview was re-scheduled for another day if the intake on the previous day was not similar to their usual intake.

Energy and nutrient intake were determined using ESHA's Food Processor Diet Analysis Software Version 11.1 (Salem, OR). The ESHA's Food Processor Diet Analysis software provides detailed reports on macronutrient and micronutrient intakes. The software database consisted of over 1,900 food sources from the Food and Nutrient Database for Dietary Studies (FNDDS), USDA Standard Reference database, USDA FoodData Central Brands, and manufacturer's data. Further, the software database had more than 129,000 ingredients, recipes, and restaurant food brands.

Dietary Nutritional Adequacy

The dietary nutritional adequacy was determined by calculating the percentages of participants who had nutrient intakes below the recommended standards set by the IOM, ACSM, DGA, or AHA. The ACSM recommendations for athletes, based on physical activity level, were used for assessing dietary fat, protein, and carbohydrate adequacy.[168] Estimated Average Requirements (EAR) a Dietary Reference Intake (DRI), set by the IOM were used to assess nutrient adequacy for omega 3 fat, omega 6 fat, vitamins A, C, D, E, B_6, and B_{12}, thiamin, riboflavin, niacin, folate, calcium, copper, iron, magnesium, phosphorus, selenium, molybdenum, and zinc.[172–177] Adequate intake (AI) which is another DRI was used for the nutrients that did not have an EAR to determine the number of participants who had inadequate intakes of linoleic acid, ALA, total dietary fiber, vitamin K, pantothenic acid, biotin, manganese, chromium, choline, potassium, sodium, and total water.[167,173,175,178] Estimated energy requirement (EER), a DRI, was used to determine energy needs.[179] Percent energy from saturated fat was calculated using the 2020-2025 DGA.[70] The AHA guidelines were used to determine the number of participants who do not meet the recommendations for EPA, DHA, dietary cholesterol, and percent energy from trans-fat.[169]

2.2.3 Procedures

Athletes who were eligible to participate were sent an electronic informed consent document which they signed and returned to the research team via email. Following this, a phone interview was scheduled with each participant to collect information on demographics, anthropometry, dietary intake, health information, medication and supplement use. Each member of the research team was trained by one the authors (KM) on how to collect the study data prior to conducting the interviews.

2.2.4 Statistical Analysis

Categorical variables were presented as percentages and continuous variables as median and 25th and 75th percentiles. Differences by gender for categorical variables (i.e., race, ethnicity, education, household income, endurance sport, smoking status, alcohol consumption, vegetarian status, chronic conditions, medication use, and supplement use) were determined using Fisher’s Exact test and continuous variables (age and BMI) by Wilcoxon Rank-Sum test. Since multiple nutrient variables had skewed distributions, the Wilcoxon Rank-Sum test was used to compare energy, macronutrient, and micronutrient intakes by gender. Fisher's Exact test was used to compare the proportion of female and male endurance athletes that did not meet the energy, macronutrient and micronutrient requirements. Data were analyzed using IBM SPSS version 26 (Armonk, NY, USA). Alpha level was set at 0.05.

2.3 Results

2.3.1 Participant Characteristics

Participant characteristics for the total sample are presented in **Table 2.1**. Median (25th and 75th percentile) age was 37.5 (28.3-45.6) y, BMI was 22.4 (20.4-24.0) kg/m^2, 54.5% were female, 93.2% were white, 88.7% were non-Hispanic, 59.1% had a graduate degree, 56.8% had a household income ≥ $100,000, 40.9% were triathletes, 18.2% were cyclists, 36.4% were runners, 4.5% were swimmers, none of the participants smoked or used tobacco, 75% consumed alcohol, 13.6% were vegetarian, 65.9% had a chronic condition, 34.1% were on medications, and 66.7% used supplements. None of the participant characteristics were significantly different by gender.

Table 2.1: Participant Characteristics of Endurance Athletes

Variables	**Total Sample (n=44)**	**Female (n=24)**	**Male (n=20)**	**P***
Age (y)	37.5 (28.3, 45.6)	37.5 (28.3, 42.0)	36.5 (28.5, 53.5)	0.21
BMI (kg/m^2)	22.4 (20.4, 24.0)	21.7 (20.0, 23.3)	23.1 (21.0, 25.0)	0.79
Race				
White	41 (93.2)	21 (87.5)	20 (100.0)	0.24
Other	3 (6.8)	3 (12.5)	0 (0.0)	
Ethnicity				
Hispanic	5 (11.4)	2 (8.3)	3 (15.0)	0.64
Non-Hispanic	39 (88.6)	22 (91.7)	17 (85.0)	
Education				
≤High school	2 (4.5)	0 (0.0)	2 (10.0)	0.36
Some college	5 (11.4)	2 (8.3)	3 (15.0)	
Bachelor’s degree	11 (25.0)	7 (29.2)	4 (20.0)	
Graduate degree	26 (59.1)	15 (62.5)	11 (55.0)	
Household Income				
<$20,000 USD	0 (0.0)	0 (0.0)	0 (0.0)	0.43
$20,000-$49,999 USD	1 (2.3)	1 (4.2)	0 (0.0)	
$50,000-$74,999 USD	1 (2.3)	1 (4.2)	0 (0.0)	
$75,000-$99,999 USD	7 (15.9)	2 (8.3)	5 (25.0)	
≥$100,000 USD	25 (56.8)	14 (58.3)	11 (55.0)	
No answer	10 (22.7)	6 (25.0)	4 (20.0)	
Endurance Sport				
Cycling	8 (18.2)	2 (8.3)	6 (30.0)	0.67
Running	16 (36.4)	9 (37.5)	7 (35.0)	
Triathlon	18 (40.9)	13 (54.2)	5 (25.0)	
Swimming	2 (4.5)	0 (0.0)	2 (10.0)	
Other	0 (0.0)	0 (0.0)	0 (0.0)	
Smoking				
Yes	0 (0.0)	0 (0.0)	0 (0.0)	1.0
No	44 (100.0)	24 (100.0)	20 (100.0)	
Alcohol Consumption				
Yes	33 (75.0)	19 (79.2)	14 (70.0)	0.74

No	11 (25.0)	5 (20.8)	6 (30.0)	
Vegetarian				
Yes	6 (13.6)	5 (20.8)	1 (5.0)	0.21
No	38 (86.4)	19 (79.2)	19 (95.0)	
Chronic Condition				
Yes	29 (65.9)	16 (66.7)	13 (65.0)	1.0
No	15 (34.1)	8 (33.3)	7 (35.0)	
Medication Use				
Yes	15 (34.1)	9 (37.5)	6 (30.0)	0.76
No	29 (65.9)	15 (62.5)	14 (70.0)	
Supplement Use				
Yes	30 (66.7)	15 (62.5)	14 (70.0)	0.76
No	15 (33.3)	9 (37.5)	6 (30.0)	

Abbreviations: BMI, Body mass index. Categorical variables are presented as number and percent of subjects and continuous variables as medians and 25th and 75th percentiles. *Fisher's Exact test was used to compare the categorical variables and a Wilcoxon Rank-Sum test was used to compare the continuous variables between the female and male participants.

2.3.2 Energy and Macronutrient and Micronutrient Intakes

Energy and dietary macronutrient intakes are presented in **Table 2.2** and micronutrients in **Table 2.3**. There were no significant differences between energy and dietary macronutrient intake by gender. Female endurance athletes consumed significantly less vitamin A (median difference: 451 µg/d; $p = 0.02$), vitamin B_{12} (1.4 µg/d; $p = 0.02$), and iron (7.5 mg/d; $p = 0.02$) compared to male endurance athletes.

Table 2.2: Energy and Dietary Macronutrient Intakes of Female and Male Endurance Athletes

Nutrient	Total Sample (n=44)	Female (n=24)	Male (n=20)	P*
Energy (kcal)	2,386 (1,639-2,766)	2,325 (1,594-2,613)	2,407 (1,935-3,278)	0.08
Protein (% energy)	16.4 (13.0-20.4)	16.0 (13.0-20.6)	17.8 (13.2-20.5)	0.72
Carbohydrate (% energy)	43.9 (39.8-53.5)	43.5 (39.1-50.0)	44.9 (36.4-54.9)	0.47
Total fat (% energy)§	36.4 (37.8-51.3)	35.2 (32.5-43.6)	34.9 (24.8-41.2)	0.21
SFA (% energy)	10.3 (7.75-15.0)	10.3 (7.3-13.8)	10.9 (8.7-15.0)	0.43
PUFA (% energy)	4.2 (3.0-7.0)	4.8 (3.2-8.9)	3.8 (2.2-5.6)	0.18
MUFA (% energy)	8.7 (7.1-13.7)	9.3 (7.1-13.7)	8.5 (6.6-13.4)	0.72
TFA (% energy)	0.00 (0.00-0.20)	0.00 (0.00-0.15)	0.10 (0.00-0.20)	0.20
LA (g)	7.61 (3.6-13.8)	11.0 (4.6-15.0)	6.7 (3.0-13.9)	0.25
ALA (g)	0.72 (0.44-1.39)	0.78 (0.49-1.6)	0.54 (0.37-1.3)	0.20
EPA (g)	0.00 (0.00-0.1)	0.00 (0.00-0.01)	0.00 (0.00-0.01)	0.70
DHA (g)	0.01 (0.00-0.06)	0.01 (0.00-0.06)	0.01 (0.00-0.08)	0.95
Cholesterol (mg)	262 (133-463)	170 (101-432)	336 (178-516)	0.09
Dietary fiber (g)	13.1 (8.1-21.6)	13.1 (6.7-19.2)	14.3 (9.3-23.3)	0.78

Abbreviations: SFA, saturated fatty acids; PUFA, polyunsaturated fatty acids; MUFA, monounsaturated fatty acids; TFA, trans fatty acids; LA, linoleic acid; ALA, α-linoleic acid; EPA, eicosapentaenoic acid, DHA, docosahexaenoic acid. Energy and macronutrient values are presented as medians and 25th and 75th percentiles. §Total fat includes SFA, PUFA, MUFA, TFA, and other unspecified fat. *Wilcoxon Rank-Sum test was used to compare energy and dietary macronutrients by gender.

Table 2.3: Dietary Micronutrient Intakes of Female and Male Endurance Athletes

Nutrient	**Total Sample (n=44)**	**Female (n=24)**	**Male (n=20)**	**P***
Vitamin A (µg)	632 (306-1169)	531 (220-765)	982 (463-1543)	**0.02**
Vitamin C (mg)	105 (39.3-179)	126 (60.9-202)	81.4 (38.2-165)	0.89
Vitamin D (µg)	2.1 (0.37-4.5)	1.8 (0.19-3.4)	2.9 (0.85-5.8)	0.12
Vitamin E (mg)	7.7 (5.1-12.1)	8.4 (6.1-12.4)	7.7 (3.8-12.0)	0.52
Vitamin K (µg)	91.0 (38.7-279.2)	150 (43.2-216)	75.5 (34.7-307)	0.72
Thiamine (mg)	1.0 (0.65-1.45)	1.0 (0.66-1.7)	1.0 (0.63-1.4)	0.49
Riboflavin (mg)	1.6 (1.1-2.3)	1.4 (1.2-2.1)	1.9 (1.0-2.7)	0.26
Niacin (mg)	22.5 (12.6-30.5)	22.2 (15.3-29.2)	25.2 (12.1-31.0)	0.65
Vitamin B_6 (mg)	1.5 (0.91-2.25)	1.5 (0.99-2.4)	1.5 (0.71-1.8)	0.67
Folate (µg)	289 (146-445)	343 (162-434)	254 (104-470)	0.66
Vitamin B_{12} (µg)	2.3 (1.2-4.0)	1.8 (0.87-3.5)	3.2 (1.8-6.2)	**0.02**
Pantothenic acid (mg)	3.1 (2.1-4.1)	3.1 (2.1-4.4)	3.0 (1.7-4.1)	0.82
Biotin (µg)	11.1 (4.0-20.0)	9.4 (3.9-22.2)	12.1 (3.9-18.4)	0.61
Calcium (mg)	810 (632-1277)	788 (605-1266)	856 (630-1501)	0.52
Copper (mg)	1.2 (0.77-1.7)	1.3 (0.94-1.9)	1.2 (0.56-1.6)	0.84
Manganese (mg)	1.7 (0.84-3.0)	1.6 (0.69-2.7)	1.9 (0.93-3.0)	0.56
Iron (mg)	15.9 (10.6-20.0)	11.8 (10.8-18.9)	19.3 (9.7-22.7)	**0.02**
Magnesium (mg)	281 (190-403)	296 (177-407)	254 (195-404)	0.80
Phosphorus (mg)	1027 (634-1246)	895 (670-1136)	1037 (556-1470)	0.52
Selenium (µg)	88.0 (41.4-116.0)	70.4 (36.8-125)	93.0 (42.2-114)	0.22
Chromium (µg)	0.93 (0.1-2.3)	1.3 (0.05-2.4)	0.6 (0.00-2.6)	0.94
Molybdenum (µg)	11.1 (3.6-21.9)	11.3 (4.4-18.9)	11.1 (0.00-22.5)	0.88

Choline (mg)	200 (130-337)	182 (117-358)	254 (153-334)	0.18
Zinc (mg)	7.0 (5.4-9.4)	6.4 (5.4-8.5)	8.6 (4.8-11.5)	0.07
Potassium (mg)	2645 (1431-3489)	2365 (1375-3433)	3104 (1491-4409)	0.17
Sodium (mg)	3510 (2607-4298)	3571 (2608-4569)	3510 (2367-4006)	0.96
β-carotene (μg)	1566 (410-7769)	1425 (564-7201)	2865 (250-12078)	0.98
Total water (L)	2.98 (2.27-3.90)	2.49 (1.81-3.90)	3.00 (2.33-3.96)	0.45

Micronutrient values are presented as medians and 25th and 75th percentiles. *Wilcoxon Rank-Sum test was used to compare micronutrient intakes by gender.

2.3.3 Proportion of Participants with Inadequate Nutrient Intakes

The proportion of participants that did not meet the energy, macronutrient and micronutrient requirements is presented in **Table 2.4**. More than 50% of male athletes did not consume enough protein, carbohydrates, linoleic acid, α-linolenic acid, EPA and DHA, vitamin D, vitamin E, pantothenic acid, manganese, biotin, chromium, zinc, molybdenum, choline, potassium, total water, dietary fiber, vitamin K, and magnesium and another 30-50% had insufficient vitamin C, thiamine, niacin, vitamin B_6, folate, calcium, and selenium. Among women, >50% did not consume enough protein, carbohydrates, linoleic acid, α-linolenic acid, EPA and DHA, vitamin D, vitamin E, pantothenic acid, manganese, biotin, chromium, zinc, molybdenum, choline, potassium, vitamin B_{12}, and thiamine, and 30-50% had insufficient vitamin A, vitamin K, folate, calcium, magnesium, and selenium. Over 50% of male and female athletes consumed more than the recommended amount of total fat, saturated fat, and sodium, and about 44-55% consumed too much cholesterol. Energy requirements were not met by 8% of women and 20% of men.

A significantly higher proportion of male compared to female athletes did not meet the requirements for ALA (90.0% and 60.0%, respectively; $p = 0.04$), dietary fiber (70.0% and 24.0%, respectively; $p \leq 0.001$) and total water (75.0% and 40.0%, respectively; $p = 0.03$).

Table 2.4: Proportion of Endurance Athletes with Inadequate Nutrient Intakes

	% who did not meet requirement			
Nutrient Requirement/d	**Total Sample (n=44)**	**Female (n=24)**	**Male (n=20)**	**P***
Energy[€] (kcal)	13.3	8.0	20.0	0.38
Protein[†] (M/F: 1.5 g/kg)	53.3	52.0	55.0	0.54
Carbohydrate [†] (M/F: 8 g/kg)	95.6	96.0	95.0	1.0
Total fat[†] (M/F: 20-35% energy)	55.6	60.0	50.0	0.56
Saturated fat[⁋] (M/F: <10% of total energy)	66.7	60.0	75.0	0.35
Trans fat[§] (M/F: < 1% energy)	11.1	8.0	15.0	0.64
Linoleic acid[‖] (M: 17 g (19-50 y); 14g (≥ 51 y)) (F: 12 g (19-50 y); 11g (≥ 51 y))	71.1	60.0	85.0	0.10
α-linolenic acid[‖] (M: 1.6 g; F: 1.1 g)	73.3	60.0	90.0	**0.04**
EPA+DHA[§] (M/F: 0.5 g)	100.0	100.0	100.0	1.0
Dietary cholesterol[§] (M/F <300 mg)	48.9	44.0	55.0	0.55
Dietary fiber[‖] (M: 38 g (19-50 y); 30 g (≥ 51 y)) (F: 25 g (19-50 y); 21 g (≥ 51 y))	44.4	24.0	70.0	**<0.001**
Vitamin A[⸸δ] (M: 625 µg; F: 500 µg)	33.3	40.0	25.0	0.35
Vitamin C[⸸] (M: 75 mg; F: 60 mg)	26.7	24.0	30.0	0.74
Vitamin D[⸸] (M/F: 10 µg)	95.6	96.0	95.0	1.0
Vitamin E[⸸δ] (M/F: 12 mg)	75.6	72.0	80.0	0.73
Vitamin K[‖] (M: 120 µg; F: 90 µg)	48.9	40.0	60.0	0.24

Thiamine[†] (M: 1.0 mg; F: 0.9 mg)	48.9	52.0	45.0	0.77
Riboflavin[†] (M: 1.1 mg; F: 0.9 mg)	20.0	16.0	25.0	0.48
Niacin[†,δ] (M: 12 mg; F: 11 mg)	26.7	24.0	30.0	0.74
Vitamin B_6[†] (M: 1.1 mg (19-50 y); 1.4 mg (≥ 51 y)) (F: 1.1 mg (19-50 y); 1.3 mg (≥ 51 y))	31.1	28.0	35.0	0.75
Folate[†,δ] (M/F: 320 µg)	48.9	48.0	50.0	1.0
Vitamin B_{12}[†] (M/F: 2 µg/d)	40.0	52.0	25.0	0.08
Pantothenic acid[‖] (M/F: 5 mg)	82.2	84.0	80.0	1.0
Biotin[‖] (M/F: 30 µg)	82.2	84.0	80.0	1.0
Calcium[†] (M: 800 mg (19-70 y); 1000 mg (> 70 y)) (F: 800 mg (19-50 y); 1000 mg (≥ 51 y))	42.2	48.0	35.0	0.55
Copper[†] (M/F: 700 µg)	20.0	20.0	20.0	1.0
Manganese[‖] (M: 2.3 mg; F: 1.8 mg)	57.8	60.0	55.0	0.77
Iron[†] (M: 6 mg) (F: 8.1 mg (19-50); 5 mg (≥ 51 y))	8.9	8.0	10.0	1.0
Magnesium[†] (M: 330 mg (19-30 y); 350 mg (≥ 31 y)) (F: 255 mg (19-30 y); 265 mg (≥ 31 y))	48.9	36.0	65.0	0.08
Phosphorus[†] (M/F: 580 mg)	22.2	20.0	25.0	0.73
Selenium[†] (M/F: 45 µg)	33.3	36.0	30.0	0.76
Chromium[‖] (M: 35 µg (19-50 y); 30 µg (≥ 51 y)) (F: 25 µg (19-50 y); 20 µg (≥ 51 y))	93.3	92.0	95.0	1.0
Molybdenum[†] (M/F: 34 µg)	91.1	92.0	90.0	1.0
Choline[‖] (M: 550 mg; F: 425 mg)	88.9	92.0	85.0	0.64
Zinc[†] (M: 9.4 mg; F: 6.8 mg)	57.8	56.0	60.0	1.0

Potassium‖ (M: 3,400 mg; F: 2,600 mg)	57.8	56.0	60.0	1.0
Sodium‖ (M/F: <1,500 mg)	95.6	92.0	100.0	1.0
Total water‖ (M: 3.7 L/d; F: 2.7 L/d)	55.6	40.0	75.0	**0.03**

Abbreviations: M, male; F, female *Fisher's Exact test was used to compare the portion of male and female endurance athletes that did not meet the requirements for macro- and micronutrient intakes. € Estimated energy requirement[179] †American College of Sports Medicine guidelines.[168] ⁋2020-2025 Dietary Guidelines for Americans guidelines.[70] §American Heart Association guidelines.[169] ‖Adequate Intakes.[167,173,175,177] ⸸Estimate Average Requirements.[173,175–177,180]

2.4 Discussion

This is one of the first studies to comprehensively examine the adequacy of macronutrient and micronutrient intakes among endurance athletes and differences by gender. The present study showed that both male and female endurance athletes are not meeting the requirements for several macronutrients and micronutrients with few differences by gender.

Energy needs were met by most athletes. This is unexpected given that several previous studies have reported that many athletes do not meet their energy needs.[75–78] The discrepancy may be partly explained by the fact that we used the multiple-pass 24-hour dietary recall method[171] which required probing the participants multiple times for forgotten foods resulting in more of a complete dietary recall compared to the use of dietary logs and dietary records without mention of probing by the other studies.[76,77]

The majority of the athletes in the present study consumed less than the recommended amount of carbohydrates and protein with no differences by gender. These results are corroborated by previous studies which have reported that many athletes, irrespective of gender, did not meet the recommendations for these nutrients.[78,79,81,83,84] Low carbohydrate intakes may lead to increased fatigue[181], negatively affect performance[182], and increase susceptibility to muscle damage[183] among athletes. Low carbohydrate intake may be especially detrimental to high-intensity exercise performance.[182] Adequate protein intake is also essential for recovery and performance among athletes.[184] For instance, previous research has shown that low consumption of protein may decrease time to fatigue, which decreases performance and post-exercise recovery.[185,186]

None of the endurance athletes met the recommendations for EPA and DHA, and many did not have enough linoleic acid and ALA in their diet and overconsumed dietary cholesterol. Moreover, over 55% of athletes consumed more total fat and saturated fat than recommended. Additionally, a significantly higher portion of male compared to female athletes did not meet the recommendation for α-linolenic acid. A possible explanation for this finding is that women engage in healthier eating practices compared to men.[187] Several studies have reported that a high proportion of athletes did not meet recommendations for linoleic acid, α-linolenic acid, EPA, and DHA.[83,85] Mielgo-Ayuso et al.[82] have found that 64% of female volleyball players consume greater amounts of fat than recommended. Another study showed that male athletes consumed more than the recommended amount of cholesterol, fat, and saturated fat.[79] Linoleic acid may decrease the uptake of lipids into adipocytes; therefore athletes who consume low amounts of linoleic acid might have difficulty maintaining a body weight conducive to optimal athletic performance.[188,189] Low consumption of α-linolenic acid may lead to increased exercise-induced inflammatory markers (e.g., interleukin 6, tumor necrosis factor, and c-reactive protein), which may impact the health and performance of athletes.[190] Other fatty acids such as EPA and DHA have been shown to improve athletic performance by reducing soreness and enhance recovery by increasing the structural integrity of muscles following exercise.[191] EPA and DHA may also reduce the risk of injury or illness due to their anti-inflammatory effects.[191] Further, high saturated fat intake may increase blood viscosity that could lead to poorer muscle oxidation and reduced athletic performance.[192]

A significantly higher portion of males compared to female athletes consumed less dietary fiber than recommended. This may be explained by a previous study which reported higher fruit intake among women.[187] Nevertheless, a previous study found a higher likelihood of low fiber intake among female compared to male athletes.[83] Low dietary fiber consumption may negatively impact gut microbiota composition and function[193], and this may cause increased inflammation and negatively affect athletic performance.[193]

Many athletes consumed less than the recommended amount of several water-soluble vitamins including pantothenic acid, biotin, thiamine, niacin, vitamin B_6, vitamin B_{12}, folate, and vitamin C. A number of previous studies have found that many athletes do not meet the recommendations for the aforementioned water-soluble vitamins.[90–92,94,194] In the present study, female athletes also had lower B_{12} intake compared to males. Janelle and Barr[195] have also reported a lower intake of vitamin B_{12} among female athletes, especially those who were vegetarian. Low intakes of pantothenic acid and biotin in athletes may influence an athlete’s ability to convert dietary protein, fat, and carbohydrates into energy during exercise, which may result in increased fatigue.[196] Athletes who do not consume enough vitamin C may have difficulty recovering from intense trainings and reduced performance because this vitamin plays an important role in collagen repair.[87] Chronic inadequate intake of thiamine may cause decreases in muscle tissue maintenance and repair and negatively impact performance.[197] Low intake of niacin is hypothesized to increase muscle glycogen depletion and lead to poor athletic performance.[198] Athletes who chronically under consume vitamin B_6 may have reduced performance possibly because this nutrient in needed for gluconeogenesis and glycogenolysis.[87] Both vitamin B_{12} and folate play a role in erythropoiesis.[87] Athletes who do not consume enough of these nutrients are at increased risk of developing megaloblastic anemia which may result in symptoms such as fatigue and decreased endurance during exercise.[87]

Numerous athletes did not meet the recommendations for the fat-soluble vitamins A, D, E, and K with no differences by gender. A number of studies have reported that these vitamins are under consumed by many male and female athletes.[79,80,86–88] However, these studies as well as the present study did not take into account the amount of vitamin D synthesized with exposure to sunlight. Low intake of vitamin D and calcium increases the risk for stress fractures among athletes.[165,196] Vitamin E, an antioxidant, plays a critical role in protecting the body from oxidative stress.[199] Athletes who do not consume enough vitamin E may experience increased muscle fatigue, muscle damage, and decreased immune function.[196,199] Low vitamin A intake may lead to increases in lactate levels resulting in decreased performance during strenuous exercise.[200] Moreover, athletes who consume lower than the recommended amount of vitamin K have been shown to have higher bone turnover and an increased risk for stress fractures.[88]

Many athletes did not consume the recommended amount of total water (obtained through plain drinking water, beverages, and food) and minerals including potassium, choline, magnesium, calcium, manganese, chromium, zinc, molybdenum, and selenium. Also, sodium intake was high among most participants. There were no significant differences by gender except for total water needs which were more likely to be met by females. This may be partly because of their greater intake of foods such as fruit that contain water. [187] Several studies have found that athletes do not meet the recommendations for potassium, total water, magnesium, calcium, manganese, chromium, zinc, [201]molybdenum, and selenium and consume too much sodium.[73,83,89,90,93,94,196,202–204] Water and electrolytes are needed for fluid balance and poor hydration can negatively affect training sessions and performance and lead to heat exhaustion.[196] Inadequate consumption of magnesium among athletes may decrease oxygen uptake during exercise, affect bone density, and increase the risk for stress fractures.[205] Athletes who do not consume adequate amounts of chromium and molybdenum may experience decreased glycogen stores, and increased fatigue during exercise.[206,207] Low zinc consumption among athletes may lead to deficits in muscle tissue repair, maintenance, growth, and energy production, and decreased immune functioning.[196] Athletes not consuming enough selenium or choline may have increased oxidative stress leading to poor recovery, fatigue, increased muscle soreness, and decreased performance.[208,209]

The present study had several limitations. Due to the nature of the study design causation may not be inferred. The 24-hour dietary recall method may be subject to under-recall. To minimize this, dietary intake was assessed using the validated USDA multiple-pass 24-hour recall method [171] where participants were probed several times for the most commonly missed foods. Another limitation is that we did not have objective data such as serum nutrient or metabolomics concentrations. This would limit our ability to assess certain nutrients such as vitamin D which is largely synthesized in the body.[210] Future studies should collect data on objective as well as subjective measures of nutrient intakes when assessing nutrient adequacy. The objective measures are seen as complementary rather than replacement for traditional validated dietary measures such as the one that we used in our study.[201] A strength of the study is that nutrient adequacy was assessed using a comprehensive set of nutrients not previously evaluated among athletes.

For most athletes in the present study, it is unlikely the number of calories consumed contributed to the nutrient inadequacies since most participants met their energy needs. Previous studies have shown that athletes tend to make poor food choices which may explain why many of our participants did not meet their nutrient needs.[211,212] The nutrient inadequacies may be addressed by consuming a diet that includes poultry without skin, fatty fish (e.g., salmon, trout, tuna, etc.), low-fat milk and dairy, whole grains (e.g., brown rice, whole-wheat pasta, etc.), green leafy vegetables, orange and yellow fruits and vegetables (e.g., carrots, sweet potatoes, mangoes, papaya, etc.), nuts, seeds, and legumes in the appropriate amounts. To maintain adequate water intake, male and female athletes should drink 3.0 and 2.2 L/d, respectively[167] in the form of water, coffee and tea without sugar or cream, and some low-fat milk and 100% fruit juice. Athletes should also follow the American College of Sports Medicine guidelines for water and electrolyte intake before, during, and after exercise.[196] A multi-vitamin and mineral supplement is also recommended for athletes but not as a substitute for a healthy diet. [196] A nourishing diet is rich in phytochemicals as well as nutrients known to promote health.[213]

In summary, the present study showed that many endurance athletes are not meeting the requirements for a number of macronutrients and micronutrients. There were few differences by gender, however. These results need to be confirmed with objective measures such as serum nutrient levels and metabolomics. Dietary counseling by a registered dietitian may be beneficial for athletes to achieve adequate nutrient intakes and for optimal performance, recovery, health, and prevention of injuries.

Practical Application

Many endurance athletes are not meeting their nutrient requirements. Therefore, it is necessary for athletes to consult with a registered dietitian to ensure that they are receiving the necessary nutrients for optimal health and performance. Dietitians and coaches should encourage athletes to consume a well-balanced diet that is rich in whole grains, green leafy vegetables, orange and red fruits and vegetables, lean meats, and low-fat milk and dairy.

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Chapter 3

The Relationship between Dietary Intake and Sleep Quality in Endurance Athletes

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Abstract

Many endurance athletes have poor sleep quality which may affect performance and health. It is unclear how dietary intake affects sleep quality among athletes. We examined if sleep quality in endurance athletes is associated with consumption of fruit, vegetables, whole grains, dairy milk, and caffeinated beverages. Two hundred thirty-four endurance athletes (39.5±14.1 y) participated in a survey. Participants provided information on demographics, anthropometry, sleep behavior and quality, and dietary intake via questionnaires. Sleep quality was assessed using the Athlete Sleep Screening Questionnaire (ASSQ) with a global score (ASSQ-global) and subscales including sleep difficulty (ASSQ-SD), chronotype (ASSQ-C), and disordered breathing while sleeping (ASSQ-SDB). A general linear model (GLM), adjusted for age, body mass index, sleep discomfort, sleep behavior, gender, race, and ethnicity, showed that higher caffeinated beverage intake was related to poorer global sleep quality (p=0.01) and increased risk for disordered breathing while sleeping (p=0.03). Higher whole grain intake was associated with a morning chronotype and lower risk for sleep issues (p=0.01). The GLM did not reveal a relationship between sleep quality and dairy milk, fruit, and vegetable intake. In conclusion, caffeinated beverages and whole grain intake may influence sleep quality. This relationship needs to be confirmed by further research.

Keywords: dietary intake, sleep quality, endurance athletes, chronotype, sleep behavior

3.1 Introduction

Sleep inadequacy, characterized as having insufficient sleep duration (<7 h), decreased subjective sleep satisfaction, increased sleep latency or time to fall asleep, unrestful sleep, day-time sleepiness, and/or feeling fatigued during the day, is common among athletes with 50-78% suffering from one or more of these issues.[2,214,215] Inadequate sleep among athletes has been found to negatively affect physical performance[106], impair immune responses (i.e. increased susceptibility to illness)[216], and increase risk for injury.[59] Inadequate sleep also lowers psychomotor performance such as attention, concentration, speed processing and decisive tasks in athletes.[217] These variables are vital for optimal performance in this population. In addition to psychomotor problems, inadequate sleep causes or modulates pain and increases physical and psychological stress in this group.[106] Both pain and stress have been found to negatively affect athletic performance.[218,219]

Possible causes for poor sleep quality and/or quantity among athletes include the low priority of sleep relative to training demands, lack of awareness of the role of sleep in performance, and scheduling constraints.[220] Because of the high susceptibility for poor sleep quality among athletes and the negative effects of sleep inadequacy on performance and health, exploring strategies that could improve sleep outcomes among athletes is warranted. More specifically, there has been increased interest in recent years in the role of dietary intake on sleep quality. Possible dietary factors related to sleep quality may be intake of fruit, vegetables, dairy milk, whole grains, and caffeine.

According to a recent systematic review of studies in the general population, most but not all studies have found a protective association of healthy foods such as fruit, vegetables, whole grain, and dairy milk, and sleep quality, and many have shown a detrimental relationship between caffeine consumption and sleep health.[95] Moreover, consumption of a Mediterranean type of diet (high in plant based foods) may have a protective role on sleep quality.[96] Higher fruit or vegetable consumption has been linked to longer sleep duration [97,98,221], fewer sleep disturbances[222], better sleep quality[222], and improved efficiency or total time asleep relative to time in bed.[222] Studies on specific fruit found that kiwifruit and tart cherry juice increase sleep duration and efficiency.[223,224] Kiwifruit also reduces sleep latency and awakenings[223], and tart cherry juice increases sleep satisfaction.[225] Lower whole grain consumption is associated with less sleep[101,226], more sleep latency[100], and impaired sleep quality.[105] Further, individuals that have less whole grain, vegetable, and fruit intake have more of an evening chronotype, i.e. they prefer to conduct activities in the evening which increases risk for sleep issues.[103,104] Moreover, milk and dairy foods has been linked to better sleep quality possibly because dairy foods contain the amino acid tryptophan a precursor for melatonin.[227]

There are no studies to our knowledge that have assessed the role of fruit, vegetable, and whole grain intake on sleep among endurance athletes. However, several randomized studies have evaluated the effect of dairy milk and caffeine intake on sleep quality among athletes. Consuming dairy milk at breakfast decreased sleep latency among Japanese soccer athletes.[112] More frequent dairy milk consumption decreased the risk for poor sleep quality among female but not male Japanese athletes.[113] As with dairy milk, a number of randomized controlled studies have assessed the role of caffeine intake on sleep outcomes among athletes. Higher caffeine consumption caused increased trouble sleeping (e.g. difficulty falling asleep and increased awakenings during the night)[116], sleep latency[117,118], restlessness[117], wakefulness[117], likelihood for insomnia[119], decreased sleep quality[117,120] and sleep efficiency[118] among athletes.

A major limitation of the current literature is that the relationship between fruit, vegetable, and whole grain intake and sleep quality has not been examined among athletes despite the fact that significant sleep issues have been reported in this population.[97,98,100,101,103,105,221,222,226]. It is important to examine this relationship given that poor sleep quality is linked to lower psychomotor[217] and physical performance[53], increased risk for injury[62], and impaired health[228] among endurance athletes. Moreover, participation in endurance sports is rapidly increasing[158] further underscoring the significance of examining potential dietary factors that may mitigate the risk for poor sleep quality. Therefore, the purpose of this study was to examine if sleep quality in endurance athletes such as cyclists, runners, and triathletes is related to the consumption of fruit, vegetables, whole grains, dairy milk, and caffeinated beverages. Based on previous research, we hypothesized that participants who consume higher quantities of fruit, vegetables, whole grains, or dairy milk will have better sleep quality, while athletes who consume larger amounts of caffeinated beverages will have poorer sleep quality.

3.2 Materials and Methods

3.2.1 Recruitment and Participants

Endurance athletes were recruited via email and social media groups using a digital flier. They were also recruited by sending the flyer to online organizations that channel communications between endurance athletes and their teams and coaches, and by word of mouth.

Two hundred thirty-four participants (95.2% from North America and 4.8% from elsewhere), who self-identified as an endurance athlete (i.e., engaging in sports that are fueled by aerobic energy production which can last for hours to days)[159,160] based on competitive sport or training style, were included in the study. Individuals under the age of 18 y, those who did not self-identify as an endurance athlete and compete in training activities for endurance-based sports were excluded. The Institutional Review Board approved the study and each participant read and signed an approved informed consent document. Data was collected during the COVID-19 pandemic from June 2020 to February 2021.

3.2.2 Measurements

Demographics

All anthropometric and demographic measures were obtained via a self-reported questionnaire. Height was reported in inches and weight was reported in pounds. Body mass index (BMI) was calculated by dividing body weight (kg) by height (meter) squared. BMI was used to categorize participants as underweight (<18.5 kg/m^2), normal weight (18.5-24.9 kg/m^2), overweight (25.0-29.9 kg/m^2), or obese (≥ 30.0 kg/m^2).

Demographic information collected included age, sex (male and female), ethnicity (Hispanic and non-Hispanic), race (White, African American, Asian, American Indian, Native Hawaiian, multiracial, and other), education (high school diploma or lower, vocational training, some college, college degree, and graduate degree or higher), and household income (<\$20,000, \$20,000-34,999, \$35,000-49,999, \$50,000-99,999, and >\$100,000 USD).

Type of Sport

Self-reported information on the type of endurance sport and competitive level was collected via questionnaire. The endurance sport categories included cycling, running, triathlon, and other (e.g., para-cycling, race walking, rowing, swimming, and wheelchair racing).

Sleep Behavior

Sleep behavior was assessed using the Athlete Sleep Behavior Questionnaire (ASBQ), an 18-item validated questionnaire (Cronbach's alpha = 0.63) designed to identify sleep behaviors among athletes.[229] The ASBQ measures maladaptive sleep behaviors and is utilized to provide recommendations on sleep hygiene in athletic populations.[229] The ASBQ asks athletes questions such as taking prolonged naps (≥ 2 h) during the day, training in the evening, getting up in the night to use the restroom, worrying, using light emitting devices, drinking alcohol (<4 h) before bedtime, room temperature in the bedroom, and bed and pillow comfort.[229] Participants answered the ASBQ questions by selecting the 5-point Likert scale choices including never, rarely, sometimes, frequently, or always. ASBQ global scores were calculated by adding up each item, and a higher score indicates poorer sleep behavior. An ASBQ global score of ≤36 indicates good, 37-41 neither good nor poor, and ≥42 poor sleep behavior.[229]

Sleep Difficulty Due to Discomfort

The participants provided a self-reported response to a question on whether or not they have had trouble sleeping due to muscle pain, numbness, aching, soreness, or twitching in the survey.

Sleep Quality

Sleep quality was assessed using the Athlete Sleep Screening Questionnaire (ASSQ). The ASSQ is a 16-item validated screening tool (Cronbach's alpha = 0.74) to assess sleep quality over the last month among athletic populations.[230,231] The ASSQ provides validated cut off points to detect clinically significant sleep difficulties among athletes. A higher score indicates poorer sleep quality.[230,231] The ASSQ subscales include sleep difficulty (SD), chronotype (C), and sleep disordered breathing (SDB).[231] ASSQ-SD was categorized as having none (0-4), mild (5-7), moderate (8-10), or severe (11-17) SD.[231] ASSQ-C was categorized as morning (>4) or evening (≤4) type.[231] Chronotype indicates the time of day that an individual prefers to conduct their daily activities.[232] Those with an evening chronotype are at increased risk for poor sleep quality.[232] ASSQ-SDB was categorized as difficulty breathing (≥1) or no difficulty breathing (<1) during sleep.[231] ASSQ-SDB indicates if the participant reported either snoring loudly or had sleep apnea (choking, gasping, and/or stop breathing while sleeping) or both.[231]

Dietary Intake

Information on usual intake of fruit (fresh, frozen, canned, or dried), vegetables (raw, cooked, canned, or frozen; excluding white potatoes), dairy milk (whole, 2%, 1%, ½%, or non-fat skim), whole grains (bread, tortillas, oatmeal, cereal, rice, pasta, or popcorn), and caffeinated beverages (coffee, tea, soda, energy drinks) was collected over the last month. Fruit quantities were categorized as consuming <1, 1-2, 3-4, 5-6, 7-8 and > 8 servings/d, vegetable as <1, 1-2, 3-4, 5-6, 7-8 and >8 servings/d, whole grain quantities were categorized by consuming <1, 1-2, 3-4, 5-6, 7-8, 9-10,11-12, >12 servings/d, dairy milk as <1, 1-2, 3-4, 5-6, 7-8 and >8 cups/d, and caffeinated beverages as <1, 1-1.5, >1.5-2, >2-2.5 and >2.5 cups/d.

Serving sizes for each food group assessed were defined according to standards set by the Dietary Guidelines for Americans.[70]

3.2.3 Procedures

Eligible subjects provided information on demographics, anthropometry, dietary intake, and sleep habits via questionnaires on Qualtrics using their own computer, cell phone, or another electronic device. The Qualtrics link was available to the participants in the recruitment flyer. Participants completed the questionnaires once based on their usual dietary intake and sleep habits over the last month.

3.2.4 Statistical Analysis

After a preliminary assessment of the sample, the demographic and dietary variable categories with less than 5% of the sample distribution were regrouped within each variable, and the final categories are shown in the results and tables.

Participant characteristics are presented as percentages. Sleep quality (ASSQ global score) by participant characteristics is presented as mean ± standard deviation (SD). The bivariate relationships between sleep quality (ASSQ global scores) and participant characteristics were assessed using a one-way ANOVA for characteristics with more than two categories (age, education, household income, type of sport, BMI, and sleep behavior) and an independent samples t-test for variables with two categories (race, ethnicity, gender, and sleep discomfort).

The bivariate relationships between sleep quality (ASSQ global scores) and participants' fruit, vegetable, whole grain, dairy milk, and caffeinated beverage intakes were assessed using a one-way ANOVA. The same test was also used to examine the relationship between each ASSQ subscale (SD, C, and SDB) and dietary intake. Follow-up analyses were conducted to identify significant differences in ASSQ global and subscale scores by dietary categories.

A general linear model (GLM) was performed to further examine the multivariate relationship between the intake of fruit, vegetables, whole grains, dairy milk, and caffeinated beverages and sleep quality (ASSQ global and subscales scores), while controlling for age, BMI, sleep discomfort, sleep behavior, gender, race, and ethnicity. Age, BMI, and sleep behavior were included as covariates (continuous variables) and gender, race, sleep discomfort, and ethnicity were included as fixed factors (dichotomous variables) in the GLM.

Data were analyzed using IBM SPSS version 26 (Armonk, NY, USA).

3.3 Results

3.3.1 Demographic Characteristics

Mean (SD) age was 39.5 ± 14.1 y. Participant characteristics for the total sample are presented in **Table 3.1**. Slightly more than 50% of the participants were 18-39 y, female, and had a household income of ≥ $100,000. More than 80% of the participants were white, non-Hispanic, and had a college or graduate degree. More participants identified themselves as runners (37.6%) and triathletes (33.8%) than cyclists (20.5%). About one-third of the participants were overweight or obese, had poor sleep behavior, and felt discomfort while sleeping due to pain, numbness, aching, soreness, or twitching.

Table 3.1. Sleep Quality (ASSQ Global Score) by Participant Characteristics

Participant Characteristics	**Total Sample (n=234)** *n* (%)	**ASSQ Global (n=234)**
Age (y)		
18-39	121 (51.7)	19.8 ± 4.13
40-59	88 (37.6)	22.0 ± 4.27[a]**
≥60	24 (10.3)	22.1 ± 4.50[a]*
NR	1 (0.4)	
Gender		
Male	104 (44.4)	21.0 ± 4.49
Female	121 (51.7)	20.6 ± 4.30
NR	9 (3.8)	
Race		
White	208 (88.9)	21.0 ± 4.36
Non-White	23 (9.8)	20.0 ± 4.21
NR	3 (1.3)	
Ethnicity		
Hispanic or Latino	23 (9.8)	20.3 ± 4.18
Non-Hispanic or Latino	196 (83.8)	21.0 ± 4.47
NR	15 (6.4)	
Education		
High School Diploma/ Vocational Training or lower	11 (4.7)	19.6 ± 4.88
Some college	33 (14.1)	20.4 ± 4.76
College degree	75 (32.1)	20.5 ± 4.31
Graduate degree or higher	115 (49.1)	21.3 ± 4.26
NR	0 (0.0)	
Household income		
<$20,000 USD	13 (5.6)	19.8 ± 3.79
$20,000-$49,999 USD	19 (8.1)	20.8 ± 5.52
$50,000-$74,999 USD	27 (11.5)	21.3 ± 4.94
$75,000-$99,999	23 (9.8)	20.2 ± 4.49
≥$100,000 USD	124 (53.0)	21.2 ± 3.98
NR	28 (12.0)	
Endurance Sport		
Cycling	48 (20.5)	21.9 ± 4.48
Running	88 (37.6)	20.9 ± 4.06
Triathlon	79 (33.8)	19.9 ± 4.52
Other	19 (8.1)	21.9 ± 4.37
NR	0 (0.0)	
Body Mass Index (kg/m^2)		
Underweight	8 (3.4)	19.8 ± 2.77
Normal	139 (59.4)	20.7 ± 4.48
Overweight	44 (18.8)	20.8 ± 4.47
Obese	28 (12.0)	21.7 ± 4.19
Height and/or weight NR	15 (6.4)	

Athlete Sleep Behavior global score		
Good Sleep Behavior	74 (31.6)	19.6 ± 3.93[b]**
Neither Good nor Poor Sleep Behavior	73 (31.2)	20.5 ± 4.45
Poor Sleep Behavior	83 (35.5)	22.1 ± 4.33
NR	4 (1.7)	
Discomfort during sleep due to (pain, numbness, aching, soreness, or twitching)		
Yes	81 (34.6)	21.8 ± 4.15
No	153 (65.4)	20.3 ± 4.41[c]**
NR	0 (0.0)	

Abbreviations: ASSQ, Athlete Sleep Screening Questionnaire; NR, not reported; BMI, body mass index.
ASSQ global scores are presented as mean ± standard deviation.
One-way analysis of variance was used to compare the relationship between sleep quality (ASSQ global score) and age, education, income, endurance sport type, BMI categories and sleep behavior.
Independent t-test was used compare sleep quality (ASSQ global score) by gender, race, ethnicity, and sleep discomfort.
[a] compared to 18-39 y
[b] compared to poor sleep behavior
[c] compared to yes
*p < 0.05, **p < 0.01

3.3.2 ASSQ Global Scores by Participant Characteristics

ASSQ global scores (sleep quality) were significantly different by age groups ($F(2, 228) = 8.36$, $p < 0.001$, partial $\eta^2 = .068$), sleep behavior levels ($F(2, 225) = 7.06$, $p = 0.001$, partial $\eta^2 = .059$) (**Table 3.1**), and sleep discomfort ($t\ (172.59) = 2.62$, $p = 0.01$, $r = .20$). Participants who were 18-39 years old had better sleep quality (lower scores) compared to those who were 40-59 years ($p = 0.01$) and ≥60 years ($p = 0.04$) old. Participants with good sleep behavior had significantly better sleep quality (lower scores) versus those with poor sleep behavior ($p = 0.01$). Presence of sleep discomfort due to pain, numbness, aching, soreness, or twitching was related to poorer sleep quality (higher scores) compared to no sleep discomfort. There were no significant differences in sleep quality (ASSQ global scores) by gender, race, ethnicity, education, household income, type of sport, or BMI categories.

3.3.3 Bivariate analysis of Sleep Quality (ASSQ Global) and Subscale Scores by Dietary Intake

Bivariate relationships between dietary intake and ASSQ global and subscale scores are presented in **Table 3.2**. There was a significant relationship between ASSQ global scores (sleep quality) and caffeinated beverage ($F(4, 189) = 8.87$, $p < 0.001$, partial $\eta^2 = .158$) but not fruit, vegetable, dairy milk, or whole grain consumption. *Post hoc* tests revealed that those who consumed 1.5 cups/d or less of caffeinated beverages had significantly better sleep quality (lower scores) compared to those who consumed more caffeinated beverages ($p < 0.05$).

There was a significant relationship between ASSQ-SD (sleep difficulty) and caffeinated beverage consumption ($F(4, 189) = 3.54$, $p = 0.01$, partial $\eta^2 = .070$). Participants who consumed 1.5 or fewer cups/d of caffeinated beverages had significantly lower sleep difficulty compared to those who consumed >2-2.5 cups/d ($p < 0.05$). Fruit, vegetable, whole grain, or dairy milk consumption was not related to sleep difficulty.

There was a significant relationship between ASSQ-C (chronotype) and whole grain consumption ($F(3, 229) = 3.67$, $p = 0.02$, partial $\eta^2 = .046$) but not fruit, vegetable, dairy milk, or caffeinated beverage intake. Participants who consumed <1 serving/d of whole grains had lower ASSQ-C scores, associated with a more evening chronotype, compared to those who consumed 3-4 servings/d ($p = 0.03$).

There was a significant relationship between ASSQ-SDB (sleep disordered breathing) and fruit ($F(3, 226) = 3.36$, $p = 0.02$, partial $\eta^2 = .043$), whole grain ($F(3, 229) = 3.24$, $p = 0.02$, partial $\eta^2 = .041$), dairy milk ($F(2, 230) = 4.63$, $p = 0.01$, partial $\eta^2 = .039$), and caffeinated beverage ($F(4, 189) = 2.78$, $p = 0.03$, partial $\eta^2 = .056$) but not vegetable intake. Those who consumed 3-4 servings/d of fruits had lower scores, indicating less difficulty breathing while sleeping, compared to those who consumed <1 serving/d ($p = 0.03$). Participants who consumed < 1 servings/d of whole grains had higher scores than those who consumed 3-4 servings/d ($p = 0.04$). Those who consumed ≥ 3 cups/d of dairy milk had higher scores compared to those consumed less milk ($p < 0.05$). Although there was an overall significant relationship between caffeinated beverage intake and ASSQ-SDB, there were no individual differences among the groups.

Table 3.2. Sleep Quality (ASSQ Global) and Subscale Scores by Dietary Intake

Dietary Intake	**Total Sample** (n=234) *n* (%)	**ASSQ Global** (n=234)	**ASSQ-SD** (n=234)	**ASSQ-C** (n=234)	**ASSQ-SDB** (n=234)
Fruits					
<1 serving/d	42 (17.9)	20.1 ± 4.10	6.02 ± 2.82	8.67 ± 2.74	0.50 ± 0.77
1-2 servings/d	112 (47.9)	21.0 ± 4.01	6.05 ± 3.01	9.64 ± 2.70	0.30± 0.64
3-4 servings/d	61 (26.1)	20.8 ± 4.97	6.08 ± 3.65	9.33 ± 2.82	0.11 ± 0.41[a]*
≥ 5 servings/d	15 (6.4)	20.9 ± 5.02	6.47 ± 3.07	9.73 ± 2.74	0.40 ± 0.74
Not reported	4 (1.7)				
Vegetables					
<1 serving/d	17 (7.3)	21.0 ± 4.91	7.06 ± 3.27	8.88 ± 1.97	0.18 ± 0.53
1-2 servings/d	98 (41.9)	20.4 ± 4.27	5.84 ± 2.93	9.26 ± 2.63	0.32 ± 0.67
3-4 servings/d	81 (34.6)	21.2 ± 4.26	6.27 ± 3.33	9.53 ± 2.98	0.28 ± 0.64
≥5 servings/d	36 (15.4)	20.8 ± 4.75	5.86 ± 3.32	9.75 ± 2.75	0.25 ± 0.50
Not reported	2 (0.9)				
Whole Grains					
<1 serving/d	25 (10.7)	20.4 ± 4.99	6.96 ± 3.59	8.24 ± 2.88	0.44 ± 0.77
1-2 servings/d	115 (49.1)	20.9 ± 4.02	6.13 ± 2.89	9.26 ± 2.93	0.37 ± 0.68
3-4 servings/d	68 (29.1)	20.8 ± 4.56	5.56 ± 3.13	10.2 ± 2.28[b]*	0.10 ± 0.39[b]*
≥5 servings/d	25 (10.7)	20.8 ± 5.06	6.60 ± 3.91	9.00 ± 2.29	0.28 ± 0.68
Not reported	1 (0.4)				
Dairy Milk					
<1 cup/d	170 (72.6)	20.9 ± 4.35	6.15 ± 3.16	9.45 ± 2.71	0.28 ± 0.62 [c]*
1-2 cups/d	46 (19.7)	20.1 ± 4.39	5.87 ± 3.12	8.98 ± 3.00	0.17 ± 0.49 [c]*
≥3 cups/d	17 (7.3)	22.0 ± 4.64	6.29 ± 3.53	9.82 ± 2.16	0.71 ± 0.92
Not reported	1 (0.4)				
Caffeinated Beverages					
<1 cup/d	20 (8.5)	18.1 ± 2.75	4.75 ± 2.61[f]*	9.05 ± 2.28	0.20 ± 0.52
1-1.5 cups/d	58 (24.8)	19.2 ± 3.78	5.38 ± 2.77[f]*	9.31 ± 2.49	0.10 ± 0.41
>1.5-2 cups/d	48 (20.5)	21.6 ± 3.96[d]*, [e]*	5.98 ± 2.85	10.1 ± 2.40	0.40 ± 0.74
>2-2.5 cup/d	36 (15.4)	22.5 ± 4.64[d]*, [e]*	7.19 ± 3.58	9.06 ± 2.84	0.44 ± 0.77
>2.5 cups/d	32 (13.7)	23.0 ± 4.56[d]*, [e]*	6.78 ± 2.93	9.09 ± 3.34	0.47 ± 0.72
Not reported	40 (17.1)				

Abbreviations: ASSQ, Athlete Sleep Screening Questionnaire; ASSQ-SD, Athlete Sleep Screening Questionnaire - sleep difficulty; ASSQ-C, Athlete Sleep Screening Questionnaire - chronotype; ASSQ-SBD, Athlete Sleep Screening Questionnaire - sleep disordered breathing.

Data are presented as mean ± standard deviation unless otherwise specified.

One-way analysis was used to analyze the relationship between global sleep scores and sleep subscales and fruit, vegetable, whole grain, dairy milk, and caffeinated beverage intake.

[a] compared to <1 serving/d of fruit

[b] compared to <1 serving/d of whole grains

[c] compared to ≥3 cups/d of dairy milk

[d] compared to <1 of cup/d of caffeinated beverages

[e] compared to 1-1.5 cups/d of caffeinated beverages

[f] compared to >2-2.5 cups/d of caffeinated beverages

*p < 0.05

GLM: Relationship Between ASSQ Global and Subscale Scores and Dietary Intake

The GLM assessing the relationship between dietary predictors (caffeinated beverages, dairy milk, whole grain, fruit, and vegetables) and ASSQ global and subscales (ASSQ-SD, ASSQ-C and ASSQ-SDB), controlling for age, gender, race, ethnicity, BMI, sleep behavior, and sleep discomfort, showed a significant positive relationship between sleep quality (ASSQ global scores) and caffeinated beverage consumption (*F*(4, 139) = 3.60, p = 0.01, partial η^2 = .094) (**Table 3.3**). As caffeinated beverage consumption increased, ASSQ global scores increased, indicating worse sleep quality. There was also a significant positive relationship between ASSQ-SDB and caffeinated beverage intake (*F*(4, 139) = 2.73, p = 0.03, partial η^2 = .073). As caffeinated beverage intake increased, ASSQ-SDB increased, indicating increased difficulty breathing while sleeping. There was a significant positive relationship between ASSQ-C and whole grain consumption (*F*(3, 139) = 3.88, p = 0.01, partial η^2 = .077). Higher whole grain intake was associated with increased ASSQ-C scores (more of a morning chronotype), indicating decreased risk for sleep issues. The remaining dietary variables were not related to sleep quality in the GLM analysis.

Table 3.3. GLM: Relationship Between ASSQ Global and Subscale Scores and Dietary Intake

Predictor	**ASSQ Global**^{a}			**ASSQ-SD**^{b}			**ASSQ-C**^{c}			**ASSQ-SDB**^{d}		
	SS	df	F	SS	df	F	SS	df	F	SS	df	F
Fruits	23.20	3	.504	7.46	3	.329	4.54	3	.247	1.02	3	1.05
Vegetables	20.94	3	.455	16.68	3	.736	2.57	3	.140	2.02	3	2.09
Whole Grains	28.53	3	.619	19.30	3	.852	71.36	3	3.88**	1.78	3	1.84
Dairy Milk	10.70	2	.348	21.04	2	1.39	11.06	2	.902	.568	2	.879
Caffeinated Beverages	220.98	4	3.60**	20.16	4	.667	16.33	4	.666	3.53	4	2.73*
Residual	2135.14	139		1049.98	139		851.93	139		44.88	139	

Abbreviations: SS, sum of squares; df, degrees of freedom
[a] ASSQ Global R squared = .294 (Adjusted R squared = .177)
[b] ASSQ-SD R squared = .255 (Adjusted R squared =.131)
[c] ASSQ-C R squared = .271 (Adjusted R squared = .150)
[d] ASSQ-SDB R squared = .254 (Adjusted R squared = .130)
GLM was used to analyze the relationship between global sleep scores and sleep subscales and fruit, vegetable, whole grain, dairy milk, and caffeinated beverage intake controlling for age, gender, race, ethnicity, BMI, sleep behavior and sleep discomfort.
*p < 0.05, **p < 0.01

3.4 Discussion

This is the first study that examined how consumption of fruit, vegetables, and whole grains affect sleep quality in endurance athletes, and found that lower whole grain intake is related to increased evening sleep chronotype. The present study also showed that increased caffeinated beverage intake is associated with poor sleep quality and increased disordered breathing while sleeping.

Consuming > 1.5 cups of caffeinated beverages per day was related to lower sleep quality than consuming a lower amount. This would be equal to > 150 mg of caffeine in brewed coffee. Salinero et al.[119] reported higher rates of insomnia in endurance athletes when they were given an energy drink containing 3 mg of caffeine per kg body weight versus placebo prior to exercise. Based on their average weight, male and female subjects in the study by Salinero et al.[119] received 228 mg and 189 mg of caffeine, respectively. The results from this study as well as our study suggest that limiting coffee to 1.5 cups per day may be prudent in athletes with sleep inadequacy.

Lower whole grain consumption was linked to a better chronotype score in both the bivariate and GLM analyses. Bivariate analysis also showed that lower whole grain intake was related to a higher score for disordered breathing. Based on the ASSQ questionnaire, the prevalence of disordered breathing was 19.7% in our participants. Our results on whole grain consumption and sleep quality are corroborated by several cross-sectional studies among non-athletes. Reid et al.[233] reported that obstructive sleep apnea, a type of disordered breathing, was associated with lower intake of whole grains in a multi-ethnic population from the U.S. Kanerva et al.[104] found that adults in Finland who consumed fewer whole grains had a chronotype towards eveningness. Lower whole grain intake was also associated with shorter sleep duration and more sleep latency[100] in women, and less sleep in the general US population.[226] Moreover, sleep quality was found to be higher among medical students in Pakistan who consumed more whole grains.[105] The results on whole grain intake and sleep quality need to be confirmed by laboratory-controlled polysomnography studies that specifically manipulate whole grain intake while controlling for all other variables potentially influencing sleep.

Higher dairy milk intake was related to increased disordered breathing while sleeping but only in the bivariate analysis where the other predictors were not controlled for. Our results are not consistent with the previous literature. For instance, Kawada et al.[112] reported that consuming dairy milk for 20 days versus no dairy milk resulted in decreased sleep latency among male soccer athletes. Further, Yasuda et al.[113] found that consuming dairy milk ≤ 2 versus 3 or more days/week was associated with increased risk for poor sleep quality in female but not male Japanese elite Olympic athletes. The inconsistent results between our study and the previous studies may be due to the fact that there was not much variability in dairy milk consumption in the present study with 72.6% consuming less than 1 serving of dairy milk. Moreover, the previous studies did not control for intake of whole grains and caffeine which we found to be related to sleep in the GLM analysis.

Bivariate analysis showed that lower fruit consumption was associated with increased disordered breathing while sleeping in the present study. Stamatakis et al.[98] and Noorwali et al.[221] reported shorter sleep duration among Japanese factory workers and British women who consumed less fruit. Moreover, Zuraikat et al.[222] reported fewer sleep disturbances among American women who ate more fruit.

The mechanisms by which dietary intake influences sleep quality is not fully understood. An important circadian hormone which regulates sleep is melatonin.[110] Melatonin production occurs in the pineal gland at night which results in sleepiness.[106,110] One of the proposed mechanisms is that caffeine consumption during the day reduces the production of melatonin leading to sleep disruptions at night.[121] Consumption of carbohydrate rich foods such as whole grains may promote sleep by increasing tryptophan which is a precursor for serotonin.[106,110] Serotonin is converted into melatonin.[110,111] Additionally, butyric acid made when dietary fiber from whole grains is fermented by bacteria in the gut and polyphenols (plant based chemicals) in plant foods such as grains and fruit may lead to increased production of a neurotransmitter, gamma-aminobutyric acid (GABA).[105–107] GABA inhibits neural activity in the central nervous system resulting in decreased sleep latency and increased sleep duration.[106,107] Retinoic acid (vitamin A) synthesized from beta-carotene in fruit has been shown to regulate the circadian sleep cycle, sleep stages, and sleep duration.[108,109] Further, studies have shown that diets rich in grains, fruit, and vegetables increase gut microbial diversity[234] which has been positively correlated with increased sleep efficiency and duration.[235]

Our study is limited by the cross-sectional design in which causation may not be inferred. Also, there may be reverse causality, i.e., inadequate sleep quality may lead to poor dietary intake. Another limitation is that the study was conducted using a convenience sample which may limit the generalizability of the results. The data was self-reported, and the participants may have reported their dietary intake and/or sleep behavior to be better than what it is. The data on dietary intake was collected over the last month, and this may not have captured seasonal variations in food consumption. Cycling or running on a hilly versus a flat terrain may lead to higher energy expenditure (38,39). In our sample, 81.3% of cyclists, 76.1% of runners, and 94.9% of triathletes were road cyclists, road runners, and road triathletes, respectively. Global sleep scores were not different by type of cyclists, runners, or triathletes. We did not limit the study to a specific level of endurance athlete. Majority (80.8%) of our athletes identified themselves as recreational athletes, and there was no difference in sleep quality by level of athlete when controlling for age. In addition, sleep quality was not assessed using objective measures such as polysomnography or actigraphy. Further, the majority of the participants were non-Hispanic white which decreases the ability to generalize the sample to all endurance athletes. We had a wide age range which affected sleep quality. We addressed this by adjusting for age in the GLM analysis on diet and sleep quality. Our sample was not large enough to run the analysis by age sub-groups. The study results may have been affected by the COVID-19 pandemic. Trabelsi et al.[236] reported that the COVID-19 lockdown was associated with lower sleep quality and total physical activity energy expenditure in adults > 55 years. Many (10.3%) of our participants were older adults. We did not assess water intake of the participants which could affect their sleep quality. Sleep disturbances have been reported by Chamari et al.[237] in athletes who avoid any food or fluid from dawn to sunset during Ramadan. The average BMI of our sample was 23.4±3.4 and 22.4±2.8 kg/m^2 in male and female athletes, respectively, and is lower than that shown among runners in the Running USA report.[238] Nevertheless, the prevalence of overweight or obesity in our sample may be overestimated because BMI does not distinguish lean mass from fat mass. Witt and Bush[239] have reported that many athletes are misclassified as overweight based on BMI classification. Assessment of body fat is needed to classify athletes as normal or overweight.

The study has several strengths. To our knowledge, this is the first study to examine the relationship between sleep quality and fruit, vegetable, and whole grain intake in endurance athletes. The study utilized validated questionnaires which were designed to assess sleep quality and behavior in athletes. The sleep issues in our participants were similar to that among athletes in previous studies. We found that 30.7% of athletes had clinically significant moderate or severe sleep difficulty. These results are consistent with a clinical validation study in which 25.1% of athletes were reported to have clinically significant sleep difficulty.[231] The majority of our participants had a morning chronotype and low prevalence of disordered breathing which is similar to that reported by other studies among athletes.[240,241]

To infer causation, randomized controlled studies examining the effect of a healthy diet rich in plant foods versus a standard diet on sleep quality in athletes are needed. These studies should also assess melatonin levels, psychomotor and physical performance since melatonin affects sleep which in turn affects performance. Moreover, melatonin levels are influenced by diet as noted earlier, and melatonin supplementation in sleep deprived collegiate student athletes improves psychomotor and physical performance.[242]

In summary, the present study revealed that increased caffeinated beverage intake and decreased intake of whole grains were associated with poor sleep quality in endurance athletes. The findings of this study suggest that dietary intake may influence sleep quality. To improve sleep quality among athletes, dieticians and coaches should promote more whole grains and restrict caffeinated beverage consumption especially close to bedtime, in addition to encouraging healthy sleep behaviors. Randomized controlled studies examining the effect of more nourishing diets on sleep outcomes are needed. Moreover, sleep outcomes need to be assessed using both subjective and objective instruments.

Contribution to the Field Statement

Endurance athletes have a high prevalence of poor sleep quality which may affect performance and health. Not much is known about how dietary intake affects sleep quality among athletes. We examined if dietary intake is associated with sleep quality in endurance athletes. A general linear model (GLM) analysis found that higher caffeinated beverage and lower whole grain consumption were associated with poor sleep quality. Fruit, vegetable, and dairy milk intake were not related to sleep quality in the GLM. Coaches and dieticians working with athletes should promote more whole grain intake, restrict caffeinated beverage intake, and encourage healthy sleep behaviors. More research is needed to confirm the relationship between dietary intake and sleep quality.

Conflict of Interest

None

Author Contributions

Kamiah Moss: Conceptualization, Writing- Original Draft Preparation, Project Administration, Methodology, Formal Analysis, Investigation. **Yan Zhang**: Methodology, Formal Analysis, Investigation, Writing – Review & Editing. **Andreas Kreutzer:** Conceptualization, Project Administration, Investigation, Writing – Review & Editing. **Austin J. Graybeal**: Conceptualization, Project Administration, Investigation, Writing – Review & Editing. **Ryan R. Porter**: Investigation, Writing – Review & Editing, **Robyn Braun-**

Trocchio: Conceptualization, Writing – Review & Editing. **Meena Shah**: Conceptualization, Methodology, Writing – Review & Editing, Supervision, Funding Acquisition.

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Chapter 4

Nutrient Intakes and Sleep Quality in Endurance Athletes

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Abstract

Many athletes report poor sleep quality which can have detrimental effects on performance, recovery, and health. Specific nutrient intakes may predict sleep. However, there is limited data on how nutrient intakes affect sleep in endurance athletes. We examined if macronutrients and micronutrients are associated with sleep quality in endurance athletes. Seventy-five endurance athletes (35.5 ± 14.0 years) participated in the study. Dietary intake data was collected using the 24-hour dietary recall method. The ESHA Food Processor Diet Analysis software was used to calculate nutrient intakes. Sleep quality was assessed using the Athletes Sleep Screening Questionnaire (ASSQ). A multiple linear regression was used to assess if specific groups of macronutrients, fatty acids, vitamins, and minerals and water predict sleep quality, while controlling for age, gender, and sleep behavior. Fatty acid intakes significantly predicted sleep quality ($p < 0.001$). More specifically, increased intake of α-linolenic acid (ALA) ($p = 0.04$) and eicosapentaenoic acid (EPA) ($p = 0.001$) were related to better sleep quality. No other nutrients were related to sleep quality. In conclusion, ALA and EPA intakes may improve sleep quality. These findings need to be confirmed by further research.

Keywords: nutrient intakes, sleep quality, endurance athletes

4.1 Introduction

Many athletes have poor sleep quality which is characterized as increased time to fall asleep or sleep latency, less than 7 hours of sleep, more awakenings during the night, unrestful sleep, lower subjective sleep satisfaction, and day-time sleepiness and fatigue.[2,214,243,244] Inadequate sleep has been reported to impair training, performance, and mood, increase risk for injury and susceptibility to illness, and enhance pain perception in athletes.[30,46,59,126,155,215,245–248] The numerous issues associated with poor sleep justify exploring strategies that may improve sleep quality. One potential approach may be related to dietary intake, specifically understanding how macronutrients and micronutrients affect sleep.

Several studies have examined the relationship between macronutrient intakes and sleep quality, and only a few studies were conducted in athletes. Carbohydrate intake may improve sleep. Shi et al.[128] reported that lower percent energy from carbohydrates was associated with < 7 hours/night of sleep among Chinese adults. In a study among Japanese workers by Tanaka and colleagues,[249] a low carbohydrate diet (< 50% vs. ≥ 50% of total energy) was associated with difficulty maintaining sleep. Lindseth and Murray[130] have reported shorter wake incidences with a high-carbohydrate diet compared to a high-protein, high-fat, or control diet in young adults. Daniel et al.[132] found no difference in sleep quality among athletes on high-carbohydrate meals and snacks that varied in glycemic index. Other macronutrients besides carbohydrates may also affect sleep quality. Lindseth and colleagues[133] observed fewer awakenings, higher sleep efficiency, and shorter sleep latency with a high protein versus a control diet in young adults. Similarly, Zhou et al.[134] reported that high-protein diets led to improved sleep quality in overweight adults.

The role of dietary fat in sleep is unclear. Lindseth and Murray[130] reported shorter sleep latency and higher sleep efficiency on a high-fat diet compared to a control diet. However, Grandner et al.[135] found an inverse relationship between fat intake and sleep duration among post-menopausal women. The conflicting results may be because fatty acids were not evaluated, and they may have differing effects on sleep quality. St-Onge and colleagues.[136] showed that increasing the intake of saturated fat led to more awakenings and lighter and shorter restorative sleep among healthy individuals. Omega-3 fatty acids, on the other hand, improved sleep quality. Murphy and colleagues[250] reported that higher alpha-linolenic acid (ALA) blood concentrations were associated with lower risk for increased sleep latency. Similarly, ALA supplementation was found to improve sleep quality among Alzheimer's patients[251] and overweight adults.[252] Murphy et al.[253] reported shorter sleep duration in adults with lower serum levels of eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) and Jansen et al.[138] found reduced sleep latency with higher plasma DHA levels among Mexican adolescents. Increasing EPA intake through consumption of EPA-rich oils increased sleep efficiency in healthy adults[254] and supplementation with DHA resulted in improved sleep quality in children.[139]

A number of studies have explored the relationship between micronutrient and water intakes and sleep quality but none of them were in athletes. Epidemiological studies in the general population have shown that higher intake of selenium, calcium, magnesium, vitamin C, D, and K, thiamin, folic acid, vitamin B_{12}, iron, and water were associated with better sleep quality.[124,141,142] In addition, randomized controlled studies have found that supplementation with vitamin D[143], magnesium, melatonin, and vitamin B complex[146], potassium supplementation[144], and consuming zinc enriched foods improves sleep quality.[145]

One of the major limitations in the current literature is that few studies have examined the relationship between nutrient intakes and sleep quality in athletes.[124,128,130,131,133,135,138,141–146,150–154,250–252,254,255] Additionally, the studies among athletes were focused on a limited number of macronutrients and micronutrients.[132,155,156,256] The purpose of this study was to evaluate whether certain nutrients were associated with better sleep quality in endurance athletes. Based on the previous literature, we hypothesized that higher intakes of carbohydrates, protein, ALA, EPA, DHA, selenium, calcium, magnesium, vitamin $B_{12,}$ C, D, and K, thiamin, folic acid, iron, potassium, zinc, and water will be related to better sleep quality.

4.2 Materials and Methods

4.2.1 Study Design

Our study was a convenience survey sample.

4.2.2 Participants

Seventy-five endurance athletes living in the U.S. participated in this study. The athletes were recruited by word of mouth and via a flyer that was disseminated through email and social media groups and posted at sports stores. Additionally, athletes were recruited in the recreational center on campus. The inclusion criteria included individuals who were 18 y or older and those who train for or compete in endurance-based sporting events such as running, triathlon, swimming, and cycling. Individuals under 18 y and those who did not identify as an endurance athlete based on training or competition were excluded from the study.

This study was approved by the Institutional Review Board. Prior to participating in the study, participants read and signed an approved consent form. Data was collected during the COVID-19 pandemic from January 2021 through March 2022.

4.2.3 Measurement

Demographic, Anthropometric, Behavior, and Health History Information

The participants reported their demographic, anthropometric, behavior, and health history information via a questionnaire. Demographics included information such as age (18-39, 40-59, ≥ 60 y), sex (male and female), ethnicity (Hispanic and non-Hispanic), race (White and other combining African American, Asian, American Indian, Native Hawaiian, and multiracial), education (high school diploma or lower, some college, college degree, and graduate degree or higher), household income (USD) (<\$20,000, \$20,000-49,999, \$50,000-74,999, \$75,000-\$99,999, ≥\$100,000), and type of endurance sport (running, cycling, swimming, and triathlon). Self-reported weight (kg) divided by height^2 (m) were used to calculate body mass index (BMI). BMI was categorized as underweight (<18.5 kg/m^2), normal weight (18.5-24.9 kg/m^2), overweight (25.0-29.9 kg/m^2), or obese (≥30.0 kg/m^2). Behavior information was collected on following a specific diet (i.e., vegetarian), tobacco, alcohol, supplement use, and sleep behavior categories (good, neither good nor bad, or bad). Health information was collected on presence of any chronic conditions and medication use.

Sleep Behavior

The Athlete Sleep Behavior Questionnaire (ASBQ) was used to assess sleep behavior. The ASBQ is an 18-item validated questionnaire (Cronbach's alpha = 0.63) which was designed to identify maladaptive sleep behaviors and to provide recommendations for sleep hygiene among athletes.[229] A global score was computed by adding the points attributed to the response to each question. The total score was also categorized as good (≤ 36), neither good nor bad (37-41), or bad (≥ 42).[229]

Sleep Quality

The validated Athlete Sleep Screening Questionnaire (ASSQ) was used to assess sleep quality. The ASSQ is a 16-item tool (Cronbach's alpha = 0.74) which was designed to assess sleep quality among athletes and contains questions regarding sleep duration, sleep latency, difficulty staying asleep, and alertness after awakening.[230,231] A global score can be calculated by adding the total for each question and a higher ASSQ score indicates poorer sleep quality.[230,231]

Dietary Intake Assessment

The validated United States Department of Agriculture (USDA) multiple-pass 24-hour recall method was used to collect dietary recall.[170,171] It was only collected on a day that represented the participant's usual intake. The multiple-pass 24-hour recall method consisted of five steps in which the participants were asked to remember and report specific details about the amount of all foods and beverages they consumed on the previous day.[171] First, the participants reported a quick list of every food and beverage they consumed. Next, the participants were presented with a list of foods that are often forgotten including snacks, fruits, vegetables, breads, and beverages. The participants then were asked about the time and occasion (e.g., breakfast, lunch, dinner) in which the food was consumed. Then, the participants were asked to provide the specific amount using tablespoons, teaspoons, cups, pounds, ounces, grams, or slices of foods they ate. Brand names were obtained for processed food, recipes for foods prepared at home, and restaurant names for foods eaten away from home. Finally, the participants were asked how the food was prepared and participants were asked again if they missed any foods including snacks, beverages, and breads.

The ESHA's Food Processor Diet Analysis Software Version 11.1 (Salem, OR) was used to determine energy and nutrient intakes from the 24-hour recalls. The software provides information on 1,900 food sources from databases including the USDA Standard Reference database, Food and Nutrient Database for Dietary Studies (FNDDS), and USDA FoodData Central Brands. Further, the ESHA software contains manufacturer's data, more than 129,000 ingredients, recipes, and restaurant food brands.

4.2.4 Procedures

A telephone interview was set up for all participants who were eligible and had signed the informed consent. The interview was set at a time that was convenient for the participants. Data on demographics, anthropometry, health, sleep behavior, sleep quality, and dietary intake were collected by the study investigators via Qualtrics during the telephone interviews. Each interview took 45-60 minutes to complete. The investigators who collected the data were trained by one of the lead investigators (KM). Following completion of the study, the participants were entered into a random drawing to win one of thirty $50.00 gift cards.

4.2.5 Statistical Analysis

An independent samples t-test was used to examine the relationships between sleep quality and binary participant characteristics such as sex (female and male), race (white and other races), ethnicity (Hispanic and non-Hispanic), alcohol use (yes and no), tobacco use (yes and no), vegetarian status (yes and no), supplement use (yes and no), medication use (yes and no), and presence of chronic conditions (yes and no). One-way analysis of variance was used to assess the association between sleep quality and participant characteristics with 3 or more categories such as age (18-39, 40-59, ≥60 years), BMI (underweight, normal weight, overweight, and obese), education (high school or less, some college, bachelor's degree, and graduate degree), household income (<$20,000, $35,000-$49,999, $50,000-$74,999, $75,000-$99,999, and ≥$100,000) endurance sport (cycling, running, swimming, triathlon, and rowing), and sleep behavior categories (good, neither good nor bad, and bad).

A multiple linear regression analysis was run to examine if specific groups of macronutrients, fatty acids, vitamins, and minerals and water predict sleep quality, while controlling for age, gender, and sleep behavior. The nutrients within each group were selected based on relationships between nutrient intakes and sleep quality observed in previously published studies.[124,128,133,141,142,144,145,226,250,253] The nutrient groups were macronutrients (percent energy from carbohydrates, total fat, protein, and dietary fiber), fatty acids (polyunsaturated (PUFA), monounsaturated (MUFA), linoleic acid (LA), ALA, EPA, and

DHA), vitamins (A, C, D, K, thiamine, B_{12}, and folate), and minerals (calcium, selenium, magnesium, potassium, iron, and zinc) and water. The nutrient intakes were log transformed prior to analysis due to skewed distributions. The results were not reported separately by gender because of the limited sample size. The data were analyzed using IBM SPSS statistical package (version 26; Armonk, New York).

4.3 Results

4.3.1 Flow Diagram

The flow diagram is show in **Figure 4.1**. One hundred and forty-two individuals were approached to participate or inquired about the study. Sixty individuals did not meet the inclusion criteria and seven were lost to follow-up. Seventy-five participants were enrolled in the study and included in the final analysis.

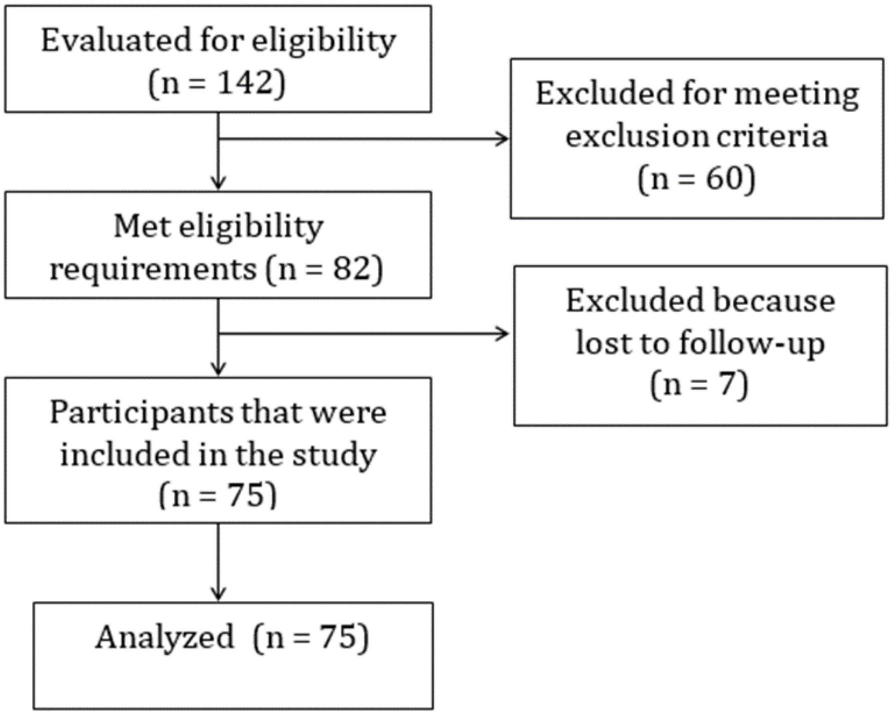

Figure 4.1 Flow diagram shows the number of participants screened and included in the analysis

4.3.2 Participant Characteristics and Sleep Quality

Participant characteristics and sleep quality are presented in **Table 4.1**. Sixty-four percent of the participants were 18-39 y with a mean age of 35.5 ± 14.0 y for the total sample. Slightly more than half of the participants (50.7%) were female, 93.3% were white, 82.7% were non-Hispanic, 73.3% had a college or graduate degree, 40.0% had a household income of ≥ $100,000, 17.3% were cyclist, 49.3% were runners, 26.7% were triathletes, 28% had good sleep behavior, 26.7% had neither good nor bad sleep behavior, 45.3% had bad sleep behavior, 0% smoked, 66.7% consumed alcohol, 86.7% were non-vegetarian, 65.3% had a chronic condition, 32.0% used medications, and 58.7% used supplements. Majority (70.7%) of the participants were normal weight and the average BMI for the total sample was 23.5 ± 4.0.

There were no significant differences in sleep quality by any of the participant characteristics except age and sleep behavior. There was a significant difference between age and sleep quality scores ($F(2,72) = 4.07$, $p = 0.021$, partial $\eta^2 = .102$). *Post hoc* tests revealed that those who were 60 years or older had significantly better sleep quality (lower scores) (13.7 ± 3.08) compared to those who were 18-39 (17.7 ± 4.05; $p = 0.044$) or 40-59 (19.5 ± 5.68; $p = 0.01$) years old. There were significant differences between sleep behavior categories and sleep quality ($F(2,74) = 14.3$, $p < 0.001$, partial $\eta^2 = .284$). *Post hoc* test revealed that those who had bad sleep behavior had significantly worse sleep quality (higher scores) (20.6 ± 4.81) than those with good sleep behavior (15.9 ± 3.44; $p < 0.001$) and neither good nor bad sleep behavior (15.4 ± 2.94; $p < 0.001$).

Table 4.1: Sleep Quality (ASSQ-global) by Participant Characteristics

Variables	**Total Sample (n=75)** *n* (%)	**ASSQ global scores (n=75)**	**P***
Age (y)			
18-39	48 (64.0)	17.7 ± 4.05 [a*]	**0.021**
40-59	21 (28.0)	19.5 ± 5.68	
≥60	6 (8.0)	13.7 ± 3.08 [b**]	
Sex			
Male	37 (49.3)	18.3 ± 4.62	0.462
Female	38 (50.7)	17.5 ± 4.79	
Race			
White	70 (93.3)	17.9 ± 4.80	0.654
Other	5 (6.7)	17.2 ± 3.11	
Ethnicity			
Hispanic or Latino	62 (82.7)	17.8 ± 4.75	0.712
Non-Hispanic or Latino	13 (17.3)	18.3 ± 4.53	
BMI (kg/m^2)			
Underweight	1 (1.3)	14.0 ± 0.00	0.547
Normal	53 (70.7)	18.1 ± 4.94	
Overweight	18 (24.0)	16.9 ± 4.19	
Obese	3 (4.0)	20.0 ± 4.65	
Education			
≤High school	2 (2.7)	15.5 ± 2.12	0.605
Some college	18 (24.0)	18.7 ± 4.55	
Bachelor’s degree	21 (28.0)	18.4 ± 5.39	
Graduate degree	34 (45.3)	17.3 ± 4.44	
Household income			
<$20,000 USD	1 (1.3)	15.0 ± 0.00	0.855
$35,000-$49,999 USD	4 (5.3)	16.8 ± 2.22	
$50,000-$74,999 USD	7 (9.3)	19.6 ± 5.88	
$75,000-$99,999 USD	10 (13.3)	18.6 ± 6.02	
≥$100,000 USD	30 (40.0)	17.4 ± 4.48	
Prefer not to answer	23 (30.7)	17.9 ± 4.54	
Endurance sport			
Cycling	13 (17.3)	17.9 ± 4.73	0.253
Running	37 (49.3)	17.2 ± 4.42	
Swimming	2 (2.7)	14.5 ± 0.70	
Triathlon	20 (26.7)	18.8 ± 5.12	
Rowing	3 (4.0)	23.3 ± 4.51	
Tobacco use			
Yes	0 (0.0)	0.00 ± 0.00	--

No	75 (100.0)	17.9 ± 4.69	
Alcohol consumption			
Yes	50 (66.7)	17.2 ± 4.21	0.09
No	25 (33.3)	19.3 ± 5.35	
Vegetarian			
Yes	7 (13.3)	16.9 ± 4.38	0.554
No	68 (86.7)	18.0 ± 4.74	
Chronic condition			
Yes	49 (65.3)	18.3 ± 4.74	0.222
No	26 (34.7)	17.0 ± 4.55	
Medication use			
Yes	24 (32.0)	18.7 ± 6.15	0.372
No	51 (68.0)	17.5 ± 3.83	
Supplement use			
Yes	44 (58.7)	18.7 ± 5.05	0.058
No	31 (41.3)	16.6 ± 3.89	
Sleep Behavior			
Good	21 (28.0)	15.9 ± 3.44 ^{c***}	**<0.001**
Neither Good nor Bad	20 (26.7)	15.4 ± 2.94 ^{d***}	
Bad	34 (45.3)	20.6 ± 4.81	

Abbreviations: ASSQ, Athlete Sleep Screening Questionnaire; BMI, body mass index
ASSQ global scores are presented as mean ± standard deviation.
*One-way analysis of variance was used to compare the relationship between sleep quality (ASSQ global score) and age, BMI, education, household income, endurance sport and sleep behavior categories. Independent t-test was used compare sleep quality (ASSQ global score) by sex, race, ethnicity, tobacco use, alcohol consumption, vegetation status, medication use, and supplement use, and chronic conditions.
[a] compared to ≥60 years
[b] compared to 18-39 years
[c, d] compared to bad sleep behavior
*p = < 0.05, **p = < 0.01, ***p=<0.001

4.3.3 Multiple Linear Regression Analysis: Nutrient Predictors of Sleep Quality (ASSQ Global)

A multiple linear regression test was run to examine if intakes of macronutrients, fatty acids, vitamins, and water and minerals predicted sleep quality (ASSQ Global), while controlling for age, gender, and sleep behavior (**Table 4.2).** Fatty acids intakes significantly predicted sleep quality $R^2 = 0.397$, $F(9,73) = 6.10$, $p < 0.001$, adjusted $R^2 = 0.386$. Increased ALA intake was associated with decreased sleep quality scores and increased EPA intake was related to decreased sleep quality scores, indicating better sleep quality. This would amount to an approximate improvement in sleep score of 2.5 units for ALA and 2.2 units for EPA if the participants had met their requirements for these nutrients compared to their actual intakes. None of the other nutrient intakes significantly predicted sleep quality.

Table 4.2: Macronutrient and Micronutrient Predictors of Sleep Quality (ASSQ-global)

Predictor	***b*** **(SE)**	**B**	***t***	***p***	R^2
Major Macronutrients					
Percent energy from Carbohydrates	8.64 (5.64)	.282	1.53	.130	.329
Percent energy from Total Fat	2.75 (2.64)	6.22	.442	.660	
Percent energy from Protein	7.66 (4.37)	.246	1.75	.084	
Fiber	.278 (2.22)	0.13	.125	.901	
Fatty Acids					
PUFA	-1.75 (2.42)	-.152	-.725	.471	.397
MUFA	-1.77 (1.67)	-.200	-1.06	.293	
LA	4.13 (2.45)	.452	1.69	.097	
ALA	-4.88 (2.27)	-.393	-2.15	**.035**	
EPA	-2.08 (.583)	-.391	-3.57	**.001**	
DHA	.695 (.606)	.124	1.15	.256	
Vitamins					
Vitamin A	-.121 (1.11)	-.017	-.110	.913	.322
Vitamin C	2.39 (1.24)	.276	1.92	.059	
Vitamin D	-.294 (.985)	-.035	-.299	.766	
Vitamin K	-1.12 (1.27)	-.141	-.883	.380	
Thiamin	-1.97 (2.42)	-.140	-.811	.420	
Vitamin B_{12}	1.48 (1.14)	.163	1.29	.200	
Folate	.302 (1.67)	.031	.180	.858	

Minerals and Water					
Calcium	2.69 (2.37)	.143	1.14	.260	.310
Selenium	-.591 (1.87)	-.065	-3.16	.753	
Magnesium	1.64 (3.38)	.102	.485	.629	
Potassium	-1.44 (2.7)	-.087	-.517	.607	
Iron	1.70 (2.92)	.061	.400	.690	
Zinc	.776 (3.38)	.061	.230	.819	
Water	-2.16 (2.44)	-.115	-.883	.381	

Abbreviations: ASSQ global, Athlete Sleep Screening Questionnaire global scores; PUFA, polyunsaturated fatty acids; MUFA, monounsaturated LA, linoleic acid; ALA, α-linoleic acid; *B*, Unstandardized Regression Coefficient; *b* (SE), Standard Error of the Coefficient; Β, Standardized Coefficient; *t*, T-Statistic calculated by dividing estimated regression coefficient by standard error; R^2, Coefficient of determination. Age, gender, and sleep behavior were controlled for in the analysis. *p = 0.05,* *p = 0.01, ***p = 0.001

4.4 Discussion

To our knowledge, this is the first study that has examined the relationship between a number of macronutrient and micronutrient intakes and sleep quality among endurance athletes. In the present study, we found that increased intakes of omega-3 fatty acids, including ALA and EPA, were associated with better sleep quality. None of the other nutrients predicted sleep quality.

Our findings on ALA and EPA and sleep quality were confirmed by several previous studies. However, none of the earlier studies were conducted among athletes. Murphy et al.[250] found that increased ALA blood concentrations were associated with lower risk for increased sleep latency among healthy adults. Yehuda and colleagues.[251] reported improved sleep quality among Alzheimer's patients resulting from a supplement containing both ALA and linoleic acid. Similarly, Cavina and colleagues[252] showed that ALA supplementation led to improved sleep quality in overweight adults. An epidemiological study found lower intake of EPA in individuals with very short sleep duration (< 5 hours/night) versus those with normal sleep duration (7-9 hours/night) in adults.[253] Moreover, a study in adults with cardiovascular disease reported that lower EPA concentration was related to sleep apnea.[257] In a randomized controlled study conducted among young adults, EPA rich oil improved sleep quality and sleep efficiency compared to the placebo.[254]

None of the other macronutrient intakes or any of the micronutrient intakes predicted sleep quality. This is inconsistent with previous studies in the general population and athletes which found that increased carbohydrate[128,131,132,136,154,156] and protein[130] consumption was related to better sleep quality. Moreover, studies among the general population have found a positive relationship between many micronutrient intakes and sleep quality.[124,141–146] The discrepancy between the results from these studies and our findings may be related to the fact that majority of the previous studies were conducted in general population whereas our study was conducted in athletes. Athletes have unique demands that differ from the general population which may play a bigger role on their sleep quality than nutrient intakes. Athletes undergo many hours of training (our participants were training on average for 10 hours per week) and competition which may negatively affect sleep through increased psychological stress and maladaptive sleep behaviors.[26] During training and competition, athletes can experience hyperarousal resulting in nervousness and anxiety which may delay sleep onset and increase insomnia symptoms.[27–29] Additionally, athletes may be more susceptible to maladaptive sleep behaviors that occur due to jetlag from travel, late night trainings, and exposure to light in the late evening which negatively affect sleep.[39,258,259]

Another explanation for the conflicting results may be due the fact that the studies assessed nutrient intakes without looking at the whole diet. Consuming a healthy diet may be just as impactful as nutrient intakes on sleep quality.[260] In our own lab, we found that increased consumption of whole grains and decreased consumption of caffeine was related to better sleep quality among endurance athletes.[261] Consuming a Mediterranean diet which is rich in whole grains, fruit, vegetables, legumes, nuts, and olive oil is also linked to better sleep quality.[96] Plant foods contain phytochemicals which have been shown to improve sleep quality.[262] Moreover, the interactions of the various nutrients as well as phytochemicals within foods may also have some association with sleep.[224,262] Limiting the assessment to only nutrient intakes may not capture the influence of plant-based chemicals as well as the interactions of the various components of food on sleep.

The mechanisms by which omega-3 fatty acids influence sleep quality are not yet clearly understood.[250] However, one of the proposed biological mechanisms is that fatty acids help to regulate the sleep-wake cycle. More specifically, deficiencies in omega-3 fatty acids may disrupt signaling in the suprachiasmatic nucleus (SCN) in the anterior hypothalamus and lead to decreases in melatonin, a hormone which promotes sleep.[140] Another mechanism that may affect sleep quality is heart rate variability (HRV) which is the variation in the amount of time between heart beats.[263] For instance, if your body is in flight-or-flight mode you will have less variability between heart beats or low HRV whereas if you are in a relaxed state your HRV will have more variablity.[264] Therefore, increased HRV during sleep is important because it indicates that your body is more adaptable and less stressed.[265] Increased EPA intake may help in regulating the sleep-wake cycle by increasing HRV through control of the sympathetic and parasympathetic autonomic nervous system activity.[266,267] Moreover, consumption of fatty fish, rich in EPA and DHA, is thought to increase HRV during sleep resulting in better sleep quality.[266,267] An additional mechanism that explains the role of omega-3 fatty acids and sleep is the effect of EPA has on sleep mediators such as prostaglandin D2 (PGD2).[255] Increased EPA consumption may up-regulate PGD2 production which stimulates the hypothalamus to produce adenosine which is a sleep-promoting molecule.[268]

A limitation of this study is that causation may not be inferred. In addition, our results may not be generalized to more diverse athletic populations. The 24-hour dietary recall method to assess diet may be subject to under-recalling of foods eaten. To mitigate this, we used the five step USDA multiple pass 24-hour recall in which the participants were prompted on multiple occasions for commonly forgotten foods.[171] Another limitation was that we did not have an objective measure for nutrients such as serum nutrient values or nutritional metabolomics (focuses on active metabolites, nutrients or non-nutrients, among the thousands of components in the metabolome that are related to the effects of different diets on health).[269] These need to be included in future studies in addition to using the validated dietary assessment method we used in our study. Furthermore, the whole diet should be evaluated in addition to nutrient intakes when evaluating the predictors of sleep. Although sleep quality was self-reported, we assessed it using a questionnaire that was validated in the athletic population. Nevertheless, sleep quality needs to be assessed by objective measures such as accelerometry or sleep studies in addition to using validated questionnaires.[2] A strength of this study is that we evaluated multiple nutrients that have not been previously examined among endurance athletes. Further, we are also one of the first studies to take sleep behavior into account since it may strongly influence sleep quality especially among athletes.

In summary, the present study found that increased ALA and EPA intake predicted better sleep quality in endurance athletes. To promote optimal sleep quality, coaches and dieticians should encourage athletes to consume a well-balanced diet that is rich in ALA containing foods such as flaxseeds, canola oil, pumpkin seed, tofu, and walnuts, and EPA sources such as salmon, tuna, and sardines. Randomized controlled studies examining the effects of increasing the intake of omega-3 fatty acids, through dietary changes or supplementation, on sleep quality are needed to confirm our findings among athletes.

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Chapter 5

Discussion

5.1 Summary

The objective of this dissertation was to assess the relationship between dietary intake and sleep quality in endurance athletes. To accomplish this goal, we first examined nutrient adequacy among endurance athletes. This was followed by examining the role of specific foods on sleep quality. Lastly, we studied the relationship between macronutrients and micronutrients and sleep quality in this population.

In our first study, we found that the majority of endurance athletes are not meeting their requirements for several nutrients. More specifically both males and females reported not consuming enough protein, carbohydrates, dietary fiber, linoleic acid, ALA, EPA, DHA, vitamins D and E, pantothenic acid, biotin, manganese, chromium, zinc, molybdenum, choline, potassium, and magnesium. In addition, a majority of male athletes did not meet their requirements for vitamin K, magnesium, and water and more than 50% of female athletes did not consume enough vitamin B12 and thiamine. Additionally, both male and female athletes consumed more than the recommended amount of total fat, saturated fat, dietary cholesterol, and sodium. There were very few differences in nutrient adequacy by gender.

In our second study we evaluated the relationship between specific foods including whole grains, fruit, vegetables, dairy milk and caffeinated beverages and sleep quality among endurance athletes. Higher whole grain intake was related to a morning chronotype which has a reduced risk for sleep issues. We also found higher caffeinated beverage intake was associated with poorer sleep quality and increased risk for disordered breathing. No relationships were found between dairy milk, fruit, and vegetable consumption and sleep quality.

In the third study, we examined the role of macronutrients and micronutrients in predicting sleep quality. We found that consumption of omega-3 fatty acids such as α-linolenic acid ALA and EPA significantly predicted sleep quality in endurance athletes. More specifically, as ALA and EPA intakes increased sleep quality improved. Further, this study revealed that no other macronutrients or micronutrients significantly predicted sleep quality.

5.2 Contribution to Knowledge Base, Gaps, and Future Research

In this section, we will describe our contribution to the knowledge base regarding nutrient adequacy among endurance athletes and how their dietary and nutrients intakes affect sleep quality. We will then identify any further gaps in the literature and propose future studies based on the limitations.

Nutrient Adequacy among Endurance Athletes

A literature search on dietary adequacy among athletes shows that many do not meet their nutrient needs.[75–79,81–85] However, most of studies limited their evaluation to just a few nutrients. [75–79,81,84,85] This makes it more difficult to comprehensively evaluate the nutritional status of athletes. To address this limitation, we examined whether endurance athletes are meeting their requirements for a comprehensive set of nutrients as compared to the recommended values. To evaluate this, we assessed the intake of all the macronutrients and micronutrients. Our results on most macronutrients were corroborated by previous studies that showed that many athletes do not consume enough carbohydrates[78,79,81,83,84], protein[78,79,81,83,84], dietary fiber[83], and certain fatty acids (linoleic acid, ALA, EPA, and DHA)[79,85], and ingest too much total fat, saturated fat, and dietary cholesterol.[79] For micronutrients, our findings were similar to previous investigations which found that many athletes are not meeting their needs for vitamin A, D, E, and K, potassium, magnesium, calcium, manganese, chromium, zinc, molybdenum, selenium, and consume more than the recommended amount of sodium.[73,80,83,86–90,93,94,196,197,202–204] Our study had inconsistent findings for energy intake in comparison to previous studies.[75–78] We found that most athletes met their energy needs whereas the previous studies found that many athletes do not consume enough energy. These dissimilar results could be due to the methods used to obtain dietary intake information. We used the multiple-pass 24-hour dietary recall method[171] that involves probing for foods that are often not reported and thus capturing missing caloric intake whereas the previous studies did not use that technique.[76,77]

Although our findings were consistent with the majority of studies, further research is needed to address additional gaps in the literature. A major gap in the literature is that the nutrient adequacy has been determined using subjective measures of dietary intake. Objective measures such as assessment of serum nutrient levels and metabolomics (i.e., includes active metabolites, nutrients and non-nutrients, that contain thousands of components in the metabolome that are related to the effects of different diets on health)[269] are needed along with the subjective measures of dietary intake for several reasons.

One reason for not limiting dietary intake assessment to just subjective measures is that the gut microbiota plays a role in how nutrients are absorbed and processed.[270] Only objective measures of nutritional status would capture this. Additionally, serum nutrient levels are especially important for vitamin D because it is mostly synthesized by the body from exposure to sunlight.[210] Therefore, just examining vitamin D through diet may only assess a fraction of vitamin D sources.

Another justification for using objective measures is that the nutrient standards used to determine nutrient adequacy are largely based on recommendations for non-athletes of the same age and gender. This is because very few nutrient requirements have been determined for athletes specifically. This is concerning because athletes have higher physiological demands and metabolic activity than non-athletes and their requirements for many nutrients may be higher.[271] Objective measures of nutrient adequacy would provide a more comprehensive picture of their nutritional status.

An additional issue with just using subjective measures is that the database used to calculate nutrient intakes is limited. Software programs that analyze nutrient intakes utilize the database from the United States Department of Agriculture (USDA).[272,273] However, the database only contains a comprehensive set of nutrient information for generic foods but not brand name foods or fast foods. The information on brand name or fast foods is based on what is provided by the manufacturers of these foods and limited to very few nutrients. This limitation may lead to substantial undercounting of nutrient intakes in individuals who consume a lot of brand name or fast foods. Moreover, athletes consume many sports specific foods and dietary supplements, and the USDA database may not have all the nutrient information on these foods.[274]

Using an objective measure to estimate energy needs of athletes is also warranted. Future studies should employ the doubly labeled water method (DLW) which is considered to be the gold standard for calculating estimated energy requirements among athletes.[275] This method also assesses energy needs in a free-living situation over several weeks.[275] It is important to assess long-term energy intake in athletes because prolonged inadequate energy balance or relative energy deficiency in sport may increase the risk for overtraining syndrome (i.e., when training exceeds the ability to recover), infectious diseases, stress fractures, and complications related to multiple organ systems.[85,164,165]

The primary limitation of the objective measures of dietary intake is that they are costly. Because of the expense, future studies using objective measures could be done in sub-set of the participants. Subjective measures should also be included in the assessment of nutrient intakes because objective measures alone would not capture all the information. For example, eating frequency, different patterns of eating during weekdays compared to weekends, or foods consumed during training or competition may not be adequately captured.[201]

Intake of Specific Foods and Sleep Quality among Endurance Athletes

Many studies have reported that dietary intake such as fruit, vegetables, whole grains, milk and dairy, and caffeinated beverages affect sleep quality. However, the vast majority of the studies explored this relationship in the general population and not among athletes. It is important to examine this relationship in endurance athletes because not only is this sport participation rapidly increasing[158], but they have also been shown to have significant sleep issues.[97–101,103,105,138,222] In addition, poor sleep among endurance athletes has been linked to several consequences including increased poor stress-recovery balance[58], risk of injury[62], impaired health[228], and poor athletic performance.[53] We addressed this gap by conducting a study to examine the role of dietary intake and sleep quality among endurance athletes.

Another limitation of the previous studies among athletes is that they used questionnaires that were only validated to be used in the general population which may not capture the unique factors that impact sleep quality among athletes.[112,113,116,117] One of the unique factors that influence sleep quality in athletes include experiencing sleep disturbances when traveling for training or competitions.[231] To address this issue, we employed a validated questionnaire that was specifically designed to assess sleep quality among athletes.[231]

An additional constraint is that many studies on diet and sleep did not control for other factors that may influence sleep quality. This is a major limitation because sleep quality is affected by a multitude of factors.[2] For instance, as individuals age, they undergo physiological changes in the brain that may impact sleep including reduction in the number of cells in the suprachiasmatic nucleus[21], degradation of the hypothalamic area of the ascending brain stem[23], and thinning of the gray matter in the temporal and frontal cortexes.[24] As a result, older adults may go to bed and awaken earlier and experience increased sleep fragmentation.[22–25] Increased BMI[276,277] and sleep discomfort due to physical pain are also associated with poor sleep quality.[278] Additionally, sleep behaviors including using an electronic device[33], consuming alcohol[34], and engaging in high-intensity exercise shortly before bedtime[39] has been shown to negatively impact sleep quality. Previous studies have also found disparities in sleep quality by gender, ethnicity, and race.[279–281] Therefore, in our study, we adjusted for variables that may affect sleep quality such as age, BMI, sleep discomfort, sleep behavior, gender, race, and ethnicity.

In our study, we found that endurance athletes with higher caffeinated beverage intake had poorer sleep quality, and lower whole grain intake was associated with evening chronotype, which is related to increased risk for sleep issues. Additionally, in our bivariate analyses we showed that lower whole grain, higher dairy milk, higher caffeinated beverage, and lower fruit intakes were related to higher risk of disordered breathing while sleeping. Previous research assessing the relationship between dietary intake of caffeine[95,116–120], whole grains[95,101,103–105,138,222], and fruit[95,97–100,103,222] and sleep quality were consistent with our findings. However, our results on dairy milk intake were not corroborated by another study[112] possibly because most of our participants (72.6%) consumed <1 serving/day of dairy milk.

Majority of the studies evaluating the relationship between dietary intake and sleep quality have been cross-sectional or prospective cohort studies and limited to the general population. Our study was one of the few studies that examined the role of dietary intake on sleep among athletes. Causation may not be inferred from these studies, however. Thus, randomized controlled studies among endurance athletes are highly warranted to determine whether consuming a healthy diet improves sleep quality. Based on the findings from our study and other similar investigations reviewed earlier, randomized controlled studies are needed to determine whether a diet rich in fruit, vegetables, and whole grains enhances sleep quality compared to the typical American diet that is not rich in plant foods. Examples of diets that could be tested against a typical American diet or the DASH diet and the Mediterranean diet. Both diets are high in plant-based foods. The DASH diet is very effective in lowering hypertension[282] and the Mediterranean diet in reducing the risk for cardiovascular disease.[283] Both diets have been shown to improve sleep quality in the general population[96,284] but warrant further study among athletes.

Also important to study is how plant-based diets, proposed above, affect the physiological markers of sleep. Well known physiological indicators of sleep include serotonin and melatonin.[285] Plant foods such as whole grains contain tryptophan which is a precursor to serotonin and the latter is needed to synthesize melatonin.[106] Additionally, inflammatory markers should be considered a physiological marker of sleep since they have been shown to predict sleep quality and are inversely related to plant food consumption.[286] For instance, high concentrations of pro-inflammatory markers such as serum c-reactive protein (CRP), interleukin-6 (IL-6), and tumor necrosis factor-α (TNF-α) have been linked to poor sleep quality.[287] Increased pro-inflammatory markers negatively affect sleep by reducing melatonin production in the hypothalamus making it difficult to fall asleep.[288] Thus, physiological markers should be measured in randomized controlled studies that evaluate the role of plant based versus the typical American diet on sleep outcomes. This would allow the researchers to comprehensively evaluate the effects of diet on sleep quality.

Further, randomized controlled studies that utilize objective measures of sleep such as actigraphy and polysomnography studies are needed. Actigraphy devices are a cost-effective alternative to using polysomnography and can examine sleep over time in a free-living setting. However, there are several disadvantages to using actigraphy. Actigraphy do not measure sleep stages, insomnia, sleep efficiency, and sleep duration as accurately as polysomnography.[2] Moreover, our own experience using actigraphs show that the device may fall off while asleep. Additionally, some manufacturers of actigraphy devices do not provide the algorithms used to calculate sleep quality variables and as a result, expertise is required to properly analyze actigraphy sleep data.[2] Because of these issues, actigraphy should be used in conjunction with validated sleep questionnaires.

Polysomnography is the gold standard for objective sleep assessment and is highly effective in evaluating sleep disorders.[2] Polysomnography sleep studies include assessments of eye movement, brain activity, muscle activity, body movement, oxygen saturation, heart rate, and breathing rate.[289] These physiological assessments are used to calculate sleep latency, sleep duration, awakenings, sleep efficiency, and the various stages of sleep including REM (rapid eye movement) and non-REM stages.[289,290]Although considered the gold standard measure of sleep quality, there are several limitations. Polysomnography assessments are expensive and are typically performed in a laboratory setting.[2] Moreover, extensive training and expertise is required to conduct a polysomnography test and interpret the results.[2] Despite the disadvantages, studies using objective measures are needed to receive more comprehensive insight on the effects of diet on sleep architecture.

Macronutrient and Micronutrient Intakes and Sleep Quality Among Endurance Athletes

Our study on dietary intake and sleep quality in endurance athletes showed that certain foods groups are associated with better sleep quality. To further advance this line of inquiry, we wanted to understand if there were specific nutrients within foods that were driving these results. This is especially important since we found that athletes do not meet the requirements for many nutrients.

Several studies have assessed the relationship between macronutrient and micronutrient intakes and sleep quality. However, most studies were conducted in the general population.[124,128,130,131,133,135,138,141–146,150–154,250–252,254,255] In addition, the small number of studies that were conducted in athletes only examined a few nutrients.[132,155–157] Therefore, we addressed these limitations by examining the relationship between nutrient intakes and sleep quality among endurance athletes. Similar to previous studies, we showed that increased consumption of omega-3 fatty acids such as ALA and EPA predicted better sleep quality.[250–

[253,257] However, the major macronutrient intakes including carbohydrates, and protein did not significantly predict sleep quality. This was unexpected because other studies have found these nutrients to be related to better sleep quality.[128,130–132,136,154,156] Moreover, we also found that none of the micronutrients significantly predicted sleep quality. This was inconsistent with previous research which showed that several micronutrients were related to better sleep quality.[124,141–143,145]

Our findings may differ from that of the previous studies because the present study was performed in endurance athletes whereas most of the earlier research was conducted in the general population. Endurance athletes are a unique population with higher physical demands compared to the general population, and the effect of this on sleep may supersede that of nutrient intakes. The increased physical demands are in the form of intense trainings and competitions. This may cause hyperarousal, stress, worry, and nervousness that can lead to sleep issues.[27–29] Moreover, competitions may require travel, and this could result in jetlag, late-night trainings, and exposure to blue light.[258,259] All of these are known to negatively affect sleep.[258] We adjusted for sleep hygiene in our study. However, there may have been factors related to training, competition, or travel that may not have been captured when assessing sleep hygiene and therefore not adjusted for in the analyses.

Another explanation for why we did not see a relationship between most nutrients and sleep maybe because dietary intake may be more important than individual nutrients in predicting sleep. Our own study in athletes found that higher consumption of whole grains is linked to better sleep quality.[261] Other studies among athletes showed that consuming healthy foods such as kiwifruit or tart cherry juice improves sleep.[223–225] Plant foods contain phytochemicals which are associated with better sleep quality and this is not assessed when examining nutrients.[262] In addition, the interactions of the various nutrients as well as phytochemicals within foods may also improve sleep.[224,262]

Although we addressed some gaps in the literature, there are still several unanswered questions that must be explored. The majority of the studies that have examined the relationship between nutrient intakes and sleep quality were epidemiologic studies. As a result, causation may not be inferred based on the study design. Randomized controlled studies are needed in endurance athletes to assess if consumption of certain nutrients improve sleep quality. Specifically, randomized studies are needed to determine whether the consumption of omega 3 fatty acids such as EPA, DHA, and ALA enhance sleep quality. This could be done by randomly assigning athletes to a diet rich in fatty fish or a standard American diet. Alternately, randomizing subjects into a supplement group containing omega-3 fatty acids or a placebo group would allow assessment of a mega dose of omega-3 fatty acids which would not be possible with diet alone. Using supplements would also allow researchers to evaluate the dose response effect of omega-3 supplements on sleep quality. Because sleep is dependent on many factors, potential confounding variables such as sleep hygiene should be carefully measured and controlled for in these studies. Moreover, other confounding factors such as age and gender could be addressed by stratifying the randomization by these characteristics.

Sleep outcomes in the randomized controlled studies should be assessed using objective as well as subjective measures. Assessing sleep objectively by polysomnography would provide a comprehensive set of data.[2]Use of polysomnography is especially warranted in studies that examine the effects of omega-3 fatty acid rich diets or supplementation since this measure includes assessments such as heart rate and breathing rate.[216] EPA and DHA intakes has been shown to positively influence heart rate variability (i.e., the variation in the amount of time between heart beats) which may lead to better sleep quality.[266,267] Therefore, future randomized studies should employ polysomnography to examine the effects of omega-3 fatty acids on sleep quality.

5.3 Conclusions

Many endurance athletes are not meeting their macronutrient and micronutrient requirements and are overconsuming sodium, dietary cholesterol, total fat, and saturated fat. Due to these results, we recommend that athletes seek dietary counseling from a registered dietician to achieve adequate nutrient intakes. More research is needed to confirm these findings employing serum nutrient levels and metabolomics.

Endurance athletes had better sleep quality with higher consumption of whole grains and lower intake of caffeinated beverages. Dieticians and coaches should encourage endurance athletes to restrict intake of caffeinated beverages several hours prior to bedtime and consume more plant-based foods such as whole grains, fruit, and vegetables. Randomized studies are needed to confirm the effects of plant-based diets such as the Mediterranean or DASH diet on sleep quality in this population.

Finally, increased consumption of fatty acids including ALA and EPA significantly predicted better sleep quality among endurance athletes. Therefore, we recommend that coaches and dieticians promote the consumption of diets rich in omega-3 fatty acids including flaxseeds, canola oil, walnuts, and fatty fish such as salmon, tuna, and sardines. The effects of omega-3 fatty acids on sleep quality need to be substantiated by randomized controlled studies using objective measures of sleep quality.

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Kamiah Moss

EDUCATION

2019- Present	**Texas Christian University** Ph.D. Candidate Health Sciences Mentor: Meena Shah, Ph.D. Dissertation: The Relationship between Dietary Intake and Sleep Quality in Endurance Athletes Expected Graduation Date: May 2022
2014	**University of Texas at Arlington** M.S., Exercise Physiology Advisor: Christopher T. Ray, Ph.D.
2012	**University of Texas at Arlington** B.S., Exercise Science Minor: Psychology

RESEARCH EXPERIENCE

August 2019 - Present	**Graduate Research Assistant & Adjunct Instructor**, Texas Christian University
January 2015 - August 2019	**Research Assistant**, University of North Texas Health Sciences Center ***Clinical Trial Coordinator*** for NIH's National Institute of Aging project Therapeutic Effects of Exercise in Adults with Amnestic Mild Cognitive Impairment. ***Neuropsychological Rater*** for projects including, The Alzheimer's disease Research and Care Consortium, The Health and Aging Brain Study Health Disparities, and Alzheimer's Disease in Primary Care.
January 2013 - December 2014	**Graduate Research Assistant**, University of Texas at Arlington Implemented exercise interventions for older adults, analyzed research data presented finding.
January 2014 - December 2014	**The Center for Healthy Living and Longevity Internship Supervisor,** The University of Texas at Arlington Assigned research tasks to undergraduate students and taught students data collection protocol.

August 2013 – December 2014	**Graduate Teaching Assistant/Assistant Instructor** The University of Texas at Arlington

CLINICAL EXPERIENCE

August 2012 - December 2012	**Cardiac/Pulmonary Rehabilitation Intern**, Baylor All Saints, Fort Worth, TX Performed ECG testing on Phase II Cardiac patients, created/implemented exercise interventions for patients, wellness counseling, and monitor/obtained vital signs during exercise sessions.
August 2013 - December 2014	**Maverick Fit program**, University of Texas at Arlington, Department of Kinesiology Provided weight loss consulting and performed (ECG, DXA scans, blood lactate, VO2 Max testing)

PROFESSIONAL MEMBERSHIPS

Society of Kinesiology Scholars
The American College of Sports Medicine
Sigma Alpha Phi
Golden Key International Honour Society
American Society for Nutrition

PUBLICATIONS

JOURNAL ARTICLES

Completed/Published

Moss K, Zhang Y, Kreutzer A, Graybeal AJ, Porter RR, Braun-Trocchio R and Shah M (2022) The Relationship Between Dietary Intake and Sleep Quality in Endurance Athletes. *Front. Sports Act. Living* 4:810402. doi: 10.3389/fspor.2022.810402

Kreutzer A, Graybeal AJ, **Moss K**, Braun-Trocchio R and Shah M (2022) Caffeine Supplementation Strategies Among Endurance Athletes. *Front. Sports Act. Living* 4:821750. doi: 10.3389/fspor.2022.821750

Graybeal AJ, Kreutzer A, Willis JL, **Moss K**, Braun-Trocchio R, Shah M. Age Drives the Differences in Dietary Supplement Use in Endurance Athletes: A Cross-Sectional Analysis of Cyclists, Runners, and Triathletes. *J Diet Suppl*. 2022;1-19. doi:10.1080/19390211.2022.2056670

Braun-Trocchio R, Graybeal AJ, Kreutzer A, Warfield E, Renteria J, Harrison K, Williams A, **Moss K**, Shah M. Recovery Strategies in Endurance Athletes. *Journal of Functional Morphology and Kinesiology*. 2022; 7(1):22. https://doi.org/10.3390/jfmk7010022

Graybeal, A.J., Kreutzer, A., Rack, P., **Moss, K.,** Augsburger, G., Willis, J.L., Braun-Trocchio, R., Shah, M. (2021) "Perceptions of appetite do not match hormonal measures of appetite in trained competitive cyclists and triathletes following a ketogenic diet compared to a high-carbohydrate or habitual diet: a randomized crossover trial." *Nutrition Research*. S0271-5317(21)00050-6 https://doi.org/10.1016/j.nutres.2021.07.008.

Biggan, J. R., Taylor, W. E., **Moss, K.,** Adumatioge, L., Shannon, V., Gatchel, R. J., Ray, C. T. (2017) "Role of ApoE-ε4 Genotype in Gait and Balance in Older Adults: A Pilot Study." *Journal of Applied*

Biobehavioral Research. 22:n/a, e12061.

Preprint

Kreutzer, A., Graybeal, A.J., Rack, P.P., **Moss, K.,** Ausgburger, G.R., Willis, J.L., Braun-Trocchio, R., Shah, M. (2021) “Ketogenic and High-Carbohydrate Diets in Cyclists and Triathletes.” *Sportxiv*. https://doi.org/10.51224/SRXIV.19

Submitted/Under Review

Moss, K, Kreutzer, A, Graybeal, AJ, Zhang, Y, Braun-Trocchio, Porter, RR, Shah, M. (n.d.) “Nutrient Adequacy in Endurance Athletes.”

Kreutzer, A., Graybeal, A.J., Rack, P.P., **Moss, K.,** Ausgburger, G.R., Willis, J.L., Braun-Trocchio, R., Shah, M. (n.d.) “Ketogenic and High-Carbohydrate Diets in Cyclists and Triathletes.”

PUBLISHED ABSTRACTS

Moss, K, Kreutzer, A, Graybeal, A.J., Braun-Trocchio, R, Zhang, Y, Porter, R.R., and Shah, M. (2022) "Nutrient Adequacy in Endurance Athletes," *International Journal of Exercise Science: Conference Proceedings*: Vol. 2 : Iss. 14 , Article 28.
Available at: https://digitalcommons.wku.edu/ijesab/vol2/iss14/28

Nijjar, B, Shah, M, **Moss, K**, Kreutzer, A, Graybeal, A.J, Braun-Trocchio, R, Zhang, Y, and Porter, R.R. (2022) "Training Modifications in Endurance Athletes due to COVID-19 Restrictions," *International Journal of Exercise Science: Conference Proceedings*: Vol. 2 : Iss. 14 , Article 144. Available at: https://digitalcommons.wku.edu/ijesab/vol2/iss14/144

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Available at: https://digitalcommons.wku.edu/ijesab/vol2/iss13/43

Kreutzer, A., Graybeal, A.J., **Moss, K.,** Braun-Trocchio, R., and Shah, M. (2021) "Caffeine Supplementation Strategies Among Endurance Athletes," *International Journal of Exercise Science: Conference Proceedings*: Vol. 2 : Iss. 13 , Article 19.

Graybeal, A.J., Kreutzer, A., Rack, P., **Moss, K.,** Augsburger, G., Willis, J.L., Braun-Trocchio, R., and Shah, M. (2021) "Appetite Alterations in Endurance Athletes Following the Ketogenic Diet," *International Journal of Exercise Science: Conference Proceedings*: Vol. 2 : Iss. 13 , Article 47. Available at: https://digitalcommons.wku.edu/ijesab/vol2/iss13/47

Renteria, J., Warfield, E., Kreutzer, A., Graybeal, A.J., **Moss, K.,** Williams, A., Harrison, K., Shah, M., and Braun-Trocchio, R. (2021) "Recovery Strategies in Endurance Athletes," *International Journal of Exercise Science: Conference Proceedings*: Vol. 2 : Iss. 13 , Article 46. Available at: https://digitalcommons.wku.edu/ijesab/vol2/iss13/46

Graybeal, A.J., Willis J.L., Kreutzer A., **Moss K.**, Braun-Trocchio R., Shah M. Nutrition Beliefs and Practices Among Endurance Athletes. Journal of the Academy of Nutrition and Dietetics, Volume 121, Supplement, 2021.

Large, S.E., Johnson, L.A., O'Jile, J., **Moss, K.**, Hall, J.R. and O'Bryant, S. (2019), P4-373: Impact of Physical Activity on Cognition in Older Mexican Americans With Diabetes. Alzheimer's & Dementia, 15: P1443-P1443. doi:10.1016/j.jalz.2019.06.4044

Moss, K., Large, S, O'Bryant, S., & Johnson, L.A. (2018) Impact of Physical Activity on Cognition in Older Mexican Americans: 409 Board #250 May 30 11. Medicine & Science in Sports & Exercise. 50. 92.

10.1249/01.mss.0000535389.95056.e0.

Moss, K., Adumatioge, O., Biggan, J., Taylor, W., Shannon, V., Ray, C. (2014, November). ApoE-ε4 Genotype and Gait Cadence in Older Adults. The Gerontologist, Volume 54, Issue Suppl_2, 1 November 2014, Pages NP, https://doi.org/10.1093/geront/gnu106

Moss, K. (2014) "The Relationship Between Family and Friend Social Support on Balance in Older Adults," International Journal of Exercise Science: Conference Proceedings: Vol.2: Issue. 6, Article 56.

Moss, K. and Ray, C.T. (2014). The Relationship Between Family and Friend Social Support on Balance in Older Adults. Symposium Handbook, [online] p.80 https://www.uta.edu/aces/docs/ACES2014AbstractsName.pdf

POSTERS PRESENTATIONS

Moss, K, Kreutzer, A, Graybeal, A.J., Braun-Trocchio, R, Zhang, Y, Porter, R.R., and Shah, M. (2022) "Nutrient Adequacy in Endurance Athletes," Texas ACSM Annual Meeting.

Nijjar, B, Shah, M, **Moss, K,** Kreutzer, A, Graybeal, A.J, Braun-Trocchio, R, Zhang, Y, and Porter, R.R. (2022) "Training Modifications in Endurance Athletes due to COVID-19 Restrictions," Texas ACSM Annual Meeting.

Moss, K., Kreutzer, A., Graybeal, A.J., Zhang, Y., Braun-Trocchio, R., Porter, R.R., and Shah, M. (2021) "The Relationship between Dietary Intake and Sleep Quality in Endurance Athletes," Texas ACSM Annual Meeting.

Kreutzer, A., Graybeal, A.J., **Moss, K.,** Braun-Trocchio, R., and Shah, M. (2021) "Caffeine Supplementation Strategies Among Endurance Athletes," Texas ACSM Annual Meeting.

Graybeal, A.J., Kreutzer, A., Rack, P., **Moss, K.,** Augsburger, G., Willis, J.L., Braun-Trocchio, R., and Shah, M. (2021) "Appetite Alterations in Endurance Athletes Following the Ketogenic Diet," Texas ACSM Annual Meeting.

Renteria, J., Warfield, E., Kreutzer, A., Graybeal, A.J., **Moss, K.,** Williams, A., Harrison, K., Shah, M., and Braun-Trocchio, R. (2021) "Recovery Strategies in Endurance Athletes,"

Graybeal, A.J., Willis J.L., Kreutzer A., **Moss K.,** Braun-Trocchio R., Shah M. (2021) Nutrition Beliefs and Practices Among Endurance Athletes. Food & Nutrition Conference and Expo.

Large, S.E., Johnson, L.A., O'Jile, J., **Moss, K.**, Hall, J.R. and O'Bryant, S. (2019), P4-373: Impact of Physical Activity on Cognition in Older Mexican Americans With Diabetes. Alzheimer's & Dementia, 15: P1443-P1443. July 1, 2019 Los, Angeles, CA.

Moss, K., Large, S, O'Bryant, S., & Johnson, L.A. (2018) Impact of Physical Activity on Cognition in Older Mexican Americans: 409 Board #250 May 30 18 Minneapolis, MN.

Moss, K., Adumatioge, O., Biggan, J., Taylor, W., Shannon, V., Ray, C. (2014) "Role of ApoE-ε4 Genotype in Cadence and Velocity: A Holistic Assessment of Gait in Older Adults." Society of Kinesiology Scholars Research Day, Arlington, TX.

Moss, K., Adumatioge, O., Biggan, J., Taylor, W., Shannon, V., Ray, C. (2014, November). ApoE-ε4 Genotype and Gait Cadence in Older Adults. Poster presented at the 67th Annual Meeting of the Gerontological Society of America (GSA), Washington, D.C.

Moss, K. (2014) "The Relationship Between Family and Friend Social Support on Balance in Older Adults," Texas ACSM Annual Meeting, Fort Worth, TX.

Moss, K., Ray C.T. (2014) "The Relationship Between Family and Friend Social Support on Balance in Older Adults," ACES Research Symposium, Arlington, TX.

Hernandez, B., Hill, D., Masters N., **Moss, K.** (2011) "Competitive Anxiety Could Not Get You Down?" Society of Kinesiology Scholars Research Day Arlington, TX.

MANUSCRIPTS IN PREPARATION (data collection compete)

Moss, K., Kreutzer, A., Graybeal, A.J., Zhang, Y., Braun-Trocchio, R., Porter, R.R., Shah, M. Nutrient Adequacy in Highly Trained Endurance Athletes.

MANUSCRIPTS IN PREPARATION (data collection)

Moss, K., Kreutzer, A., Graybeal, A.J., Zhang, Y., Braun-Trocchio, R., Porter, R.R., Shah, M. Nutrient Intakes and Sleep Quality in Endurance Athletes.

GRANTS

Harris College Student Research Grant (February 15, 2021) ($500.00)

TEACHING EXPERIENCE/MENTORING

TEACHING ASSISTANTSHIPS

Fall 2013-2014	**Intro to Kinesiology Lab (KINE 1400),** University of Texas at Fall Arlington
Spring 2014-2014	**Intro to Kinesiology Lecture (KINE 1400),** University of Texas Fall at Arlington
Fall 2014	**Physiology of Exercise Lecture (KINE 3315),** University of Texas at Arlington
Fall 2014	**Fitness Assessment and Programming (KINE 4330),** University of Texas at Arlington

TEACHING PRACTICUM

Spring 2020	**Neuromuscular Pathophysiology (KINE 30843),** Texas Christian University

TEACHING

Fall 2020-Spring 2021	**Anatomical Kinesiology (KINE 10603),** Texas Christian University
Fall 2021	**Exercise Assessment and Prescription (KINE 30523),** Texas Christ Christian University
Spring 2022	**Human Disease Pathology (HLTH 40203),** Texas Christian University

MENTORING UNDERGRADUATE RESEARCH

Fall 2020-Spring 2021	**Senior Research Project:** Nutrient Intakes in Highly-Trained Endurance Athletes (Annie Obereiner, Desiree Tadwilliams, Chris Rivas, Tatum Johnston, Ally Lunich)
Fall 2021-Spring 2022	**Senior Research Project:** Sleep Quality and Behavior among Trained Endurance Athletes (Ashlyn Fisher, Abby Sheets, Maddie Tanklage, Ryan Williams)

Abstract

Many endurance athletes have reported experiencing poor sleep quality. Adequate sleep is critical for optimal performance and recovery. It is also needed to reduce the susceptibility for injury, illness, impaired mood, and enhanced pain perception in this population. One potential strategy to mitigate sleep issues is proper nutrition. More specifically, dietary intakes of certain foods, macronutrients, and micronutrients may improve sleep quality. However, much of the previous research has been performed in non-athletes. In this dissertation, we examined nutrient adequacy and the relationship between consumption of specific foods and nutrient intakes and sleep quality in endurance athletes.

Adequate nutrition is a key factor for performance, recovery, and health and wellbeing among endurance athletes. A majority of the previous studies on nutrient adequacy among endurance athletes only examined a handful of nutrients. The goal of our first study was to examine if endurance athletes are meeting their needs for a comprehensive set of nutrients. We also assessed if there were any differences by gender. We found that many endurance athletes reported consuming less than the required amount for protein, carbohydrates, linoleic acid, ALA, EPA, DHA, vitamins D and E, pantothenic acid, biotin, manganese, chromium, zinc, molybdenum, choline, and potassium. Vitamin K, magnesium, dietary fiber, and total water were not met by more than 50% of males, and vitamin B_{12} and thiamine needs by more than 50% of females. Additionally, they also reported overconsuming total fat, saturated fat, dietary cholesterol, and sodium. There were very few differences in nutrient adequacy by gender.

It is unclear how dietary intake affects sleep quality in endurance athletes. Therefore, in our second study we evaluated if sleep quality in endurance athletes is influenced by consumption of fruit, vegetables, whole grains, dairy milk, and caffeinated beverages. We

found that higher whole grain intake was related to more morning chronotype which indicates a reduced risk for sleep issues. In addition, higher caffeinated beverage intake was associated with poorer sleep quality and increased risk for disordered breathing while sleeping. There were no relationships between dairy milk, fruit, and vegetable consumption and sleep quality.

In our final study, we further advanced our line of inquiry on how diet affects sleep by examining the relationship between many macronutrient and micronutrient intakes and sleep quality among endurance athletes. The results revealed that increased intakes of omega-3 fatty acids such as ALA and EPA were associated with better sleep quality. However, no other nutrients predicted sleep quality.

In conclusion, endurance athletes do not meet the needs for many nutrients and their dietary intake has some influence on sleep quality. Whole grain intake is related to better sleep quality whereas caffeinated beverage intake worsens it. Higher intakes of ALA and EPA also predict better sleep quality in this population. Endurance athletes should seek help from dieticians to achieve adequate nutrient intakes and to include more plant-based foods and omega-3 fats rich sources in their diet. Our results on how diet affects sleep quality in endurance athletes need to be confirmed by randomized controlled studies with objective measures of sleep.