The Relationship between Dietary Intake and Sleep Quality

by

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Abstract

Insufficient sleep is commonly associated with negative health outcomes, and healthy lifestyle recommendations often include suggestions for improving sleep hygiene. Similarly, poor diet habits are associated with a variety of health disorders, and a diet that follows the USDA's Dietary Guidelines for Americans promotes improved health. This thesis seeks to explore the intersection between sleep and diet and how they relate. To assess the correlation between diet quality and sleep quality, total Healthy Eating Index (HEI-2010) score and sleep efficiency were compared for 422 healthy men and women between the ages of 21 and 35 years from the Energy Balance Study (EBS) (1). Participants were predominantly Caucasian (66.8%) with four of more years of college education (83.7%) and had a mean BMI of 25.3 ± 3.8 kg/m^2. Participants spent an average of 7.99 ± 0.94 hours in bed with an average of 6.54 ± 0.89 hours of sleep time. Mean sleep efficiency across the sample was 82.12 ± 7.16 percent. The sample was split into two sleep efficiency groups (<85%, considered insufficient; and ≥85%, considered sufficient) for analysis. Significant differences were found between sleep groups for all sleep metrics except bedtime ($p = 0.0515$) and Pittsburg Sleep Quality Index (PSQI) latency score ($p = 0.0747$).

Mean HEI-2010 for the sleep efficiency groups of <85% and ≥85% were 58.09 ± 11.62 and 60.01 ± 12.7, respectively. After adjusting for covariates, no significant difference was found between groups ($p = 0.367$). Mean HEI-2010 whole grains to refined grains sub-scores were also analyzed as another way to explore diet quality. Ratios were 0.72 ± 0.76 for the >85% sleep efficiency group and 0.73 ± 0.81 for the ≥85% sleep efficiency group. No significant difference was found between groups ($p = 0.88$). The data suggest no relationship between diet quality and

sleep quality in participants of the EBS when measured by total HEI-2010 score, whole to refined grain sub-score ratios, and sleep efficiency.

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Chapter 1 Introduction

Insufficient sleep quality is correlated to poor health, including increased risk for chronic disease, obesity, and mortality (2, 3). Despite the known consequences of insufficient sleep, only 65.2% of the United States adult population report obtaining the recommended seven hours of sleep each night (2, 4). The fact that more than one third of Americans are struggling with poor sleep heightens the importance of quality sleep for American adults. Many factors influence sleep, and one lesser studied aspect is diet quality.

Considering the overall effect of dietary intake on sleep, it is important to examine the relationship between diet and sleep. Some research has been done in this area, with mixed findings. Poor perceived sleep quality was found in those who ate *ad libitum* versus those who were put on a calorie restricted diet (5). In another study, calorie restriction increased the deepest, most restorative stage of sleep (6).

Other studies have shown that increased consumption of certain food groups may improve sleep quality. Higher rice intake in Japanese factory workers was associated with improved scores on a self-rating sleep assessment (7), suggesting that eating more rice may increase sleep duration and quality. In the same study, noodle consumption was linked to more sleep disturbances and daytime problems associated with poor sleep, such as increased napping, difficulty with motivation, and increased feelings of tiredness (7). In another study, high sugar sweetened beverage and confectionary intake were associated with poor sleep quality (8). These varied findings contradict each other. Consuming some high Glycemic Index (GI) foods increased sleep quality, while others decreased sleep quality.

Other food groups may affect sleep as well. Considering the quality of carbohydrates and recommendations to make half of all grains whole grain choices (9), promoters of healthy eating would hypothesize sleep improvement with increases in whole grain consumption. There is much less research in this area, and while associations between simple carbohydrate consumption and sleep are known, links between complex carbohydrates and sleep have not been elucidated (10). Few studies looked at whole grain consumption alone, but there is some evidence that characteristics belonging to whole grains, such as high fiber content, may improve sleep quality. High fiber intake moved adults out of stage 1 sleep more quickly and also increased the time spent in deeper stages (11). Both findings suggest that improvements in the carbohydrate quality may improve overall sleep quality.

However, because eating habits and their effect on health is complex, it is misguided to look at individual nutrients or even components of the diet and their effect on sleep without considering the cumulative effects of food.

Due to this, one way to understand the compounded effects of all parts of the diet on sleep is by evaluating dietary patterns (12), as Campanini et al. did in a study of older adults and sleep quality. Those with a higher Mediterranean Diet Adherence Score (MEDAS) reported better sleep quality. Similarly, higher MEDAS showed a protective effect on indicators of poor sleep quality (12). Another method for evaluating overall diet quality is the Healthy Eating Index (HEI), which measures 10 dietary components and how closely a person's diet follows the USDA's recommendations for grains, vegetables, fruits, dairy, protein, sodium, fatty acids and overall diet quality (13). HEI scores derived from 24 hour diet recalls is a validated method for measuring diet and can provide a means of assessing both overall diet quality as well as individual components such as grain quality and fruit and vegetable consumption (13).

Many markers of diet quality were considered for this paper, including MEDAS score and each of the individual component scores that comprise the HEI. Total HEI score was chosen as an indicator of overall diet quality due to the ability of the HEI to show how well a person's diet aligns with the Dietary Guidelines for Americans, which serve as the recommendations nationally accepted and broadly recommended to those wishing to follow a healthy eating pattern in the United States. Ratio of whole grains to refined grains was chosen over other components of the HEI such as fruit, vegetable, dairy, or empty calorie intake due to findings that increased fiber and improvements in carbohydrate quality may increase sleep quality (11) and suggestions that higher quality carbohydrates contain nutrients that promote sleep such as melatonin and tryptophan and their precursors (7).

Sleep quality is no less complex than diet quality, with varied definitions and measurement strategies. For the purpose of this paper, the definition of sleep quality is considered a combination of sleep latency, total sleep duration, wake after sleep onset (WASO), sleep efficiency, and a person's opinions about their sleep experience. However, investigating each of these complex elements of sleep quality and their relationship with diet quality is beyond the scope of this thesis. Thus, sleep efficiency, or the ratio of total sleep time to time in bed, has been chosen for analysis. Sleep efficiency is a marker of sleep deemed an appropriate measure of sleep quality by the National Sleep Foundation's (NSF) panel of experts in 2017. Further, the measure of sleep efficiency incorporates not only total sleep time, but is altered by sleep latency and WASO, two other markers than were chosen as important indicators of sleep quality by the NSF (14).

Connections between sleep and diet are not fully understood. Thus far, data are mixed from epidemiological, observational, and clinical trials for the relationship between diet and sleep quality. While several studies have observationally examined the relationship between sleep quality and diet, further analysis is needed regarding the influence of diet on sleep quality.

Statement of Purpose

The purpose of this thesis is to explore correlations between diet quality and sleep quality in healthy men and women between the ages of 21 and 35 years.

Research Questions

1. Is there a positively correlated relationship between diet quality as measured by the Healthy Eating Index and sleep quality as measured by sleep efficiency?
2. Is there a positively correlated relationship between diet quality assessed by the relative ratio of whole to refined grains using HEI sub scores and sleep quality as measured by sleep efficiency?

Chapter 2: Review of Literature

The Importance of Sleep Quality in Relation to Health

Sleep quality has an impact on health, ranging from physical to mental wellbeing (15, 16). Sleep quality is linked to weight gain (17) and obesity (18). Both weight gain and obesity are related to diet (19). Increased obesity prevalence is associated with decreased sleep quality (20). Therefore, there is a potential link between sleep quality and diet quality. Exploring the relationship between sleep and diet may reveal insight into underlying causes of obesity linked to inadequate sleep quality.

There are many ways to measure sleep quality, including time in bed, sleep duration, latency (the time it takes to fall asleep), movement, arousals, etc. While there is little universal agreement on which measurements are most appropriate, there is a consensus that reducing the number of latencies, arousals, and wake after sleep onset (WASO) episodes equates to better sleep quality (14). Further, a reduction of latency, arousals, and WASO will result in increased sleep efficiency, or the ratio of total time asleep to time in bed.

To improve sleep quality, sleep trends and sleep deterrents must be understood. The recommended healthy sleep duration is ≥7 hours (21), but an ever-increasing number of Americans report decreased sleep time due to the demands of modern society. In 2014, 11.8% of Americans reported a sleep duration ≤5 hours, and 23.0% reported sleeping at or around 6 hours (21). The American routine commonly includes many factors that inhibit sleep quality: work schedules, busy lifestyles, stress, poor eating habits, etc. We are sleeping worse now than ever before. The number of Americans sleeping ≤6 hours increased by 31% between 1985 and 2012 (4). Poor eating habits such as high sugar sweetened beverage and confectionary intake have been associated with poor sleep quality (8), suggesting that foods featured in the diet of many Americans may be active sleep deterrents.

Insufficient sleep quality is correlated to poor health, including increased risk for chronic disease, obesity, and mortality (2, 3). Despite the known consequences of insufficient sleep, only 65.2% of the United States adult population report obtaining the recommended 7 hours of sleep each night (2, 4). The fact that more than one third of Americans are struggling with poor sleep heightens the importance of quality sleep for American adults.

Further analysis is needed regarding the influence of diet on sleep quality. Thus far, data are mixed from epidemiological, observational, and clinical trials for the relationship between diet and sleep quality.

Sleep Quality

Definitions

To understand sleep quality, a few terms must be defined. Sleep is divided into five stages – stage 1, 2, 3, 4 and rapid eye movement (REM) (22). Stages 1 and 2 are the lightest sleep stages, where eye movements and brain waves slow (22). Time spent in these stages is considered less restorative (23). Stages 3 and 4 are deeper, more restorative stages of sleep. These stages are sometimes referred to as non-rapid eye movement sleep (NREM) or slow wave sleep (24). The final stage of sleep, REM, represents the portion of sleep where the brain is most active. Muscle activity is repressed, but the eyes move rapidly. This is the dreaming stage of sleep (22). All stages of sleep are important, but maximizing certain stages can improve sleep quality (23). Other key terms are sleep latency, arousals, wake after sleep onset (WASO), sleep duration, and sleep efficiency. Sleep latency is the length of time it takes a person to fall asleep.

Arousals are abrupt changes from a deep stage of sleep to a light stage. WASO is how much time is spent awake between falling asleep and waking in the morning. Sleep duration is the total number of minutes spent sleeping. Finally, sleep efficiency is a percentage derived by dividing total time spent asleep by the length of time spent in bed (22).

Sleep quality does not have a standard definition, but for the purposes of this paper, the measurement of sleep quality is considered a combination of latency, total sleep duration, WASO, number of awakenings, sleep efficiency, and a person's opinions about their sleep experience. The National Sleep Foundation has recommended four of these variables as appropriate measures of sleep quality: sleep efficiency, sleep latency, WASO, and number of awakenings (14). Of these variables, only sleep efficiency can reflect two of the other variables: sleep latency and WASO. Sleep efficiency has been chosen for the analysis portion of this thesis but review of sleep quality literature necessitates a broader look at the variables that make up sleep quality as defined above.

Recommendations for adequate sleep

Adults are recommended to obtain ≥7 hours of sleep per night (25) yet only 65.2% of the United States adult population report getting this amount (21). In addition, the number of adults sleeping ≤6 hours has increased by 31% since 1985 (4). Adult sleep adequacy is declining, and total sleep duration is the lowest in those with full time jobs. The number of full-time employed workers has increased every year for the last decade and total employment rates are near an all-time high (26) with 62.9% of the population was employed in 2018. This may explain the sharp increase of insufficient sleep in adults (4, 26). It is unlikely the circumstances of work and stress are going to change; therefore, other methods to improve sleep quality should be assessed. However, sleep duration is only one component of quality sleep.

Implications of quality sleep

Sleep quality and duration are related to health behaviors. Those with greater sleep duration and quality are less likely to be overweight (18), consume energy-dense foods, and consume calories through snacking (27). Short sleep duration is associated with weight gain, obesity, and dysregulation of appetite hormones (27). Moreover, reduction in total sleep time is associated with increases in dietary fat intake (28) as well as snacking and total carbohydrate consumption (27).

Sleep quality impacts more than weight status and diet composition. In college students, sleep quality was better related to improved mental health than average sleep quantity, suggesting that sleep quality is more important than hours of sleep (29). Even in adults, mental health and sleep are linked. A study by Banks et al. analyzed data from more than 1 million Americans and found that poor sleep quality was associated with poor mood (30). Additionally, depression and other mental health disorders are firmly linked to weight gain (31, 32). All these factors suggest a cycle of decreased sleep quality and a downturn in mental health status and diet that is linked to decreased sleep quality. An additional, opposite cycle may exist: trials that implemented increased sleep found a reduction in food intake as well as a decreased appetite for sweet and salty foods, characteristics which are associated with the lowest quality food choices (33, 34).

Measuring sleep quality

Sleep research has focused on self-reported sleep duration and quality (35). One of the most universally used sleep quality measurements is the Pittsburg Sleep Quality Index (PSQI). The PSQI is a survey that requires participants to self-rate 19 individual items. Responses target total sleep and sleep disturbances over a one month period (36). However, self-reported measures are biased and may lack accuracy (35).

There are options for more objective measurements. Validated measures of sleep quality include polysomnography (PSG) and Actigraph measurement. PSG uses electroencephalogram (EEG), electromyogram (EMG), and electroculogram (EOG) to measure sleep and sleep arousals and analyze both REM and NREM sleep (37, 38). Actigraph measurement uses a device worn on the hip or wrist and has proven valuable in the assessment of a variety of different sleep disorders (39). In addition, actigraphy is validated as a measurement in older adults for assessing circadian rhythm disorders and insomnia and in certain pediatric populations for assessing sleep patterns (39). The BodyMedia Senseware Armband (SWA) is similar to wrist actimeter (actigraphy), except that the SWA is worn over the arm and it utilizes a dual axis accelerometer. The SWA has been validated for total sleep time (TST), total wake time, and sleep efficiency(40). These objective measurements of sleep quality are highly desirable but subjective measures, such as the PSQI, can still provide valuable insight into sleep duration and quality.

Diet Quality

Quality diet and implications

Bowman et al. found 18% of Americans have a poor diet quality, while only 12% of Americans have a good diet quality (41). There is a clear need for improvement as diet quality influences many aspects of health, sleep notwithstanding. Poor diet is linked to diabetes, hypertension, obesity and other co-morbidities (19, 42, 43). Obesity alone is a major detractor of quality sleep and is linked to insomnia and other negative sleep conditions (44, 45).

Measuring diet

Measuring diet quality is subjective, thus finding a reliable tool to minimize error is crucial. Nearly every method of dietary assessment relies on self-reported intake, and some measures, such as food frequency questionnaires (FFQ), rely solely on participants' memory of perceived intake over weeks or months at a time (46). Other similar dietary measures include 24-hour dietary recall (47) and the 7-day food diary (48). By using the 24-hour recall method, error from memory is lessened and capturing multiple 24-hour recalls randomly over a set period heightens chances of capturing days that are indicative of an individual's normal diet (47). Once diet data are collected, they can be quantified using the HEI. The HEI can be obtained from analysis of any of the above-mentioned methods of recall. The HEI is based on the Dietary Guidelines for Americans and is updated every 5 years. For this project HEI-2010 was used. HEI-2010 provides a validated measure through assessing 12 dietary components with a maximum score of 100 (41). The components measure how closely a person's diet follows the USDA's recommendations for grains, vegetables, fruits, milk, meat, overall fat, saturated fat, cholesterol, sodium, and overall diet variety (13).

Research Outcomes Linking Diet and Sleep

Energy balance and sleep

Considering the overall effect of dietary intake on sleep, it is important to examine the relationship between diet and sleep. Poor perceived sleep quality was found in those who ate *ad* *libitum* during observation versus those were put on a calorie restricted diet (5). In another study, calorie restriction increased the deepest, most restorative stage of sleep, stage 4 sleep (6).

Not only does calorie restriction improve sleep, but decreased sleep is also linked to higher calorie consumption. Women sleeping <6 hours per night had a greater average calorie consumption when compared to those sleeping 7 hours per night (49). Similarly, a positive energy balance, specifically found in obese individuals, was associated with increased REM and decreased slow wave sleep (50).

The reason the body responds to calorie restriction with better sleep follows a logical progression. The deepest stages of sleep allow for the greatest conservation of energy, allowing the energy starved body to use the least number of calories. Less restorative sleep stages, such as REM, burn more calories, which may be why the body favors this type of sleep during positive energy balance (6, 50). This supports the evidence that those who consume excess calories have poorer sleep quality.

Calorie needs vary greatly by individual and the HEI-2010 is not a measure of the number of calories consumed or the appropriateness of that number, rather it is a measure of servings of various food groups with portion sizes adjusted based on total caloric consumption (13). This necessitates exploration of diet quality and its effect on sleep quality beyond simple calorie intake.

Carbohydrates and sleep

The macronutrient content of diet may affect sleep and relationships exist between the consumption of carbohydrates and sleep quality. In addition to overall amount of carbohydrates consumed, the glycemic index (GI) and fiber content all influence sleep quality and duration (7, 10, 11). In Japanese factory workers, higher rice intake was associated with a lower PSQI-J score (a version of the PSQI adapted for the Japanese population) (7), suggesting that eating more rice may increase sleep duration and quality. Low carbohydrate consumption is also linked to high sleep fragmentation (10, 28).

Conclusions about overall carbohydrate consumption cannot be universally assumed. Looking again at Japanese factory workers, not all carbohydrate consumption was associated with improved PSQI-J scores. Noodle consumption was linked to more sleep disturbances and daytime problems associated with poor sleep, such as increased napping, difficulty with motivation, and increased feelings of tiredness (7). Additionally, another study found that high carbohydrate intake is associated with increased REM sleep (51).

These varied findings contradicted each other. Consuming more high GI foods increased sleep quality in some studies, while lowering consumption of simple carbohydrates (which tend have a high GI index) decreased sleep quality. One hypothesis for this conundrum is that rice and other high GI foods contain greater amounts of melatonin and tryptophan, hormones whose increased levels are associated with improved sleep. Eating foods high in these nutrients in the latter half of the day may improve sleep more than the effect of high GI foods that are associated with poor sleep quality (7).

Other food groups may affect sleep as well. Considering the quality of carbohydrates and recommendations to make half of all grains whole grain choices (9), promoters of healthy eating would hypothesize sleep improvement with increases in whole grain consumption. There is much less research in this area, and while some associations between simple carbohydrate consumption and sleep are known, links between complex carbohydrates and sleep have not been elucidated (10). Few studies looked at whole grain consumption alone, but there is some evidence that characteristics belonging to whole grains, such as high fiber and nutrient content, may improve sleep quality. High fiber intake moved adults out of stage 1 sleep more quickly and also increased the time spent in deeper stages of sleep (28). Both findings suggest that improvements in the carbohydrate quality improve overall sleep quality.

Comprehensive Diet Measures

Because eating habits and their effect on health is complex, it is misguided to look at individual nutrients or even components of the diet and their effect on sleep without considering the cumulative effects of food. All foods and their macro- and micronutrients work interactively in intricate pathways.

Due to this, the way to understand the compounded effects of all parts of the diet on sleep may be by evaluating dietary patterns (12), as Campanini et al. did in a study of older adults and sleep quality. Those with a higher Mediterranean Diet Adherence Score (MEDAS) reported better sleep quality. Similarly, higher MEDAS showed a protective effect on indicators of poor sleep quality (12). However, the results of this study are complicated by the limitations of self-reported measures of sleep quality and duration. Despite these less than ideal measures, Campanini et al. findings were corroborated by another study. That study found that the Mediterranean Diet prevented multiple insomnia factors in a French population of older adults (52). However, both studies focused only on older populations and further research is needed to generalize claims.

While higher diet quality like that of the Mediterranean Diet may increase sleep quality, many of the foods contained in the Mediterranean Diet, such as olives and grapes, are rich in melatonin (53). Like the study concerning rice consumption by Yoneyama et al., results are confounded by the composition of nutrients in the foods that are consumed. These facts point back to the need to examine complete eating patterns as well as individual components.

Conclusion

Connections between sleep and diet are not fully understood. Several studies have observationally examined the relationship between sleep quality and diet, but more research is needed to substantiate claims.

Even within the existing body of literature, there are many limitations. Much of the current research relied on subjective measures of diet and/or sleep quality. Diet quality is difficult to accurately measure without great financial investment. Furthermore, measuring the diet outside of a lab setting is not feasible without relying on participant report. The measurement of sleep quality and duration may be simpler, with some researchers already using actigraphy and PSG, but additional studies that pair these objective measures of sleep quality with dietary assessments are needed.

At this stage, the research is inconclusive due a lack of objective measurements as well as the focus on individual dietary components. It will be important in the future to improve measurement techniques and to examine a combination of individual diet components as well as overall diet quality.

Chapter 3: Methods

Overview

The purpose of this thesis is to explore correlations between diet quality and sleep quality in healthy men and women between the ages of 21 and 35. Data are provided from the Energy Balance Study (EBS)(1). The EBS was a study designed to demonstrate interactions of caloric intake and energy expenditure on changes in body weight and composition over a 12-month period. The EBS study took place at the University of South Carolina and was published in Research Quarterly for Exercise and Sport in 2013.

Inclusion and Exclusion Criteria

Participants in the EBS were healthy women and men aged 21 to 35 years old with a Body Mass Index (BMI) between 20-35 kg/m^2. Recruitment was stratified to four target groups: females aged 21 to 28 years, males aged 21 to 28 years, females aged 28 to 35, and males aged 28 to 35. Participants were also required to have telephone access for interviews and dietary recalls and plan to remain in the area for the next 15 months.

To recruit a range of healthy individuals without acute or chronic disease, health and behavior exclusion criteria were constructed. Participants were excluded who had made any large changes to health behaviors in the last 6 months such as the use of medications labeled for weight-loss, a change in smoking status in the past 6 months, or planned weight loss surgery. Also excluded were those with a resting blood pressure >150 mmHg systolic and/or >90 mmHg diastolic, an ambulatory blood glucose level ≥145 mg/dl as measured by a finger-stick blood sample and glucose meter, or those taking medications for chronic health conditions. Individuals were excluded if they had a history of major depression, anxiety disorder, or panic disorder, or were taking selective serotonin inhibitors. Women were excluded if they were pregnant or had given birth in the previous 12 months. Lastly, concerns existed over transient and cyclical body water and appetite changes associated with contraceptive medications. However, because of contraceptive usage prevalence in the target population, only women planning to begin or to stop birth control during the 12month observational period were excluded with a temporary exclusion applied to women who had changed their birth control regimen in the last 3 months (1).

Procedures

The EBS was an observational study that followed 430 individuals for 12 months. All measurements were obtained by research staff that were trained, demonstrated competency, and were certified in each specific measurement technique. An extensive baseline assessment was completed and was repeated quarterly. Before entering the study, all eligible participants attended an orientation session that included a 25-min presentation describing the study protocols and all associated expectations for the participant. Height and weight were also taken to verify BMI. Following the orientation, 3 additional baseline visits occurred in the following 3 weeks to gather further measurements.

The purpose of the first of these visits (baseline 1) was to complete a variety of questionnaires for each participant, including demographics questionnaires and Pittsburg Sleep Quality Index (PSQI). Partial PSQI scoring will be presented in the results section of this thesis.

At baseline 1, participants also received training in how to estimate portion sizes to prepare them for 24-hour dietary recall interviews. Baseline 2 included measurement of resting blood pressure, height, weight, waist and hip circumference, body composition via dual x-ray absorptiometry, and a maximal fitness test using a modified Bruce protocol (54) with 12-lead electrocardiogram (ECG). Visit 3 consisted of a blood draw and measurement of height, weight, and resting metabolic rate while the participant was 12 hours fasted and had abstained from physical activity during the past 24 hours.

After baseline measurements, follow up visits were completed every three months for a total of one year. Complete description of measurements included in these visits is described elsewhere and follow up data were not used for this analysis. It is worth mentioning that the dietary, sleep, and activity data were collected at each 3 month time point (1).

Energy Expenditure and Sleep Measurement

Participants were then given a SenseWear mini Armband (SWA) (BodyMedia Inc., Pittsburg, PA) and an ActivPal (PAL Technologies Ltd., Glasgow, UK) physical activity monitor to wear for 10 days.

The SWA is a portable, multi-sensor device that is worn on the upper arm. It activates when sensors contact the skin and incorporates tri-axial accelerometry, heat flux, galvanic skin response, skin temperature, and near-body ambient temperature. These data are used along with demographic information and entered into an algorithm to estimate energy expenditure, physical activity, and sleep (55). The SWA has been validated for measurement of energy expenditure, activity, and sleep (56-58). Participants were given approximately 20 min of training on care and use of the SWA and began wearing the monitor immediately. They were asked to abstain from removing the monitor during the 10-day wear time, except during periods were the monitor might get wet – typically during showering or bathing. Participants were asked to record their activities during any periods of non-wear by recording the time removed, the time replaced, and details about the reason removed on a paper log. These periods of non-wear time were filled based on matching the details provided in the non-wear log with corresponding MET values according to the 2011 Compendium of Physical Activities (59) and then added to the SWA recorded estimates to allow for full 24-hr estimate of energy expenditure. Participants were also asked to record their bedtime as the time they began trying to fall asleep (1). Compliance with minimal wear time was defined as 7 days of total wear time (including 2 weekend days) with ≥21 hours of verifiable time for each of the 7 days.

All SWA data were analyzed by computer-based software (SenseWear Professional software, version 7.0; BodyMedia Inc.) using demographic information (i.e. handedness, gender, age, height, and weight) and applied to proprietary algorithms. Only participants with ≥4 days of sleep data were eligible for this analysis.   Sleep metrics were derived from the SWA minute-by minute sleep epochs with sleep efficiency equaling total sleep time divided by the length of the time in bed. Sleep onset was considered the first of 3 consecutive minutes spent asleep, sleep latency was the time from lying down to sleep onset, WASO was the sum of all ≥2minute episodes spent awake between sleep onset and wake time. Wake time was the first of 90 consecutive minutes spent awake after sleep onset.

Additional sleep measurements included administration of the PSQI. The PSQI is a self-report questionnaire that consists of 19 questions that create 7 components. These components are added together to create one global score that assesses sleep quality for the past month (36). The PSQI has been validated for the assessment of sleep, but is vulnerable to influence of depression and pessimistic thinking (60). In one large validation study, the component scores for total sleep time and sleep efficiency were found to have the strongest correlation to actigraph measure (60). For this analysis, only the component scores for sleep latency and sleep efficiency were used. The questions that comprise the sleep latency component score are “how long (in minutes) has it taken you to fall asleep [during the past month]?” and “how often have you had trouble sleeping because you cannot get to sleep within 30 minutes [during the past month]?” The first question is assigned a score as follows: ≤15min = 0, 16-30min = 1, 31-60min = 2, >60min = 3. The second question is assigned a score that corresponds with the following answers: not at all during the past month = 0, less than once a week = 1, once or twice a week = 2, three or more times per week = 3. Both scores are totaled, and a final score for the component is assigned based on the following ranges: 0=0; 1-2=1; 3-4=2; 5-6=3. The PSQI component score for sleep efficiency also has two parts: “During the past month, how many hours of actual sleep did you get at night *and* how many hours were you in bed?” To obtain the score for this component, the following equation is used: *(total # of hours asleep) / (total # of hours in bed) x 100*, then a numerical value of 0-3 is assigned as follows: >85%=0, 75%-84%=1, 65%-74%=2, <65%=3 (36).

Diet measurement

HEI-210 scores were derived from information collected using the 3 random 24-hour dietary recalls administered during the 10-day SWA wear period (1). These 24-hour recalls are a self-report measure that is considered an imperfect “gold standard” for estimating dietary intake and the quality of data collected relies on the capacity of a subject to recall foods consumed and the proficiency of the interviewer in eliciting comprehensive information (61). The 24-hour recalls in the EBS were collected by a team of registered dietitians, with experience using a protocol developed by the Nutrition Coordinating Center (NCC) at the University of Minnesota as well as experience (>6 years) entering dietary recall data into the Nutrient Data System for

Research software (NDSR Version 2012) (1). NDSR has a food database that includes 19,000+ foods that are updated annually, providing nutrition composition information for >120 nutrients. NCC's protocol for collecting 24-hour recall data uses the multi-pass approach which includes prompting to reduce omissions. This protocol also standardizes the interview methodology across interviewers (62). Portion estimation was taught to participants during baseline 1 visits. This training lasted about 10-15 minutes and utilized a 2-dimentional, validated, food portion visual (FPV) (63). The training also incorporated life-size dishes (plates, cups, utensils) and food models (64). 24-hour recalls were randomly assigned to non-consecutive days and were administered via cold calls to minimize preparation/rehearsing that could contribute to recall bias (1, 65).

Once 24-hour recall data were collected and entered into NDSR, the resulting output was used to calculate HEI-2010 score. To calculate HEI-2010 using the simple method, intake from multiple days must first be summed per person (66) and translated from NSDR servings to HEI-2010 servings (e.g. fruit and vegetables in NDSR are ½ cup servings; HEI-2010 calculates 1 cup servings per 1,000 calories of intake) (67). Then the ratios of dietary component servings to energy (per 1,000 calories) is constructed and scored according to scoring standards, resulting in 12 sub scores for the HEI-2010. Sub-scores are summed to compute total HEI-2010 (66).

Ethics

The University of South Carolina Institutional Review Board approved all study protocols. Participants received $500 for study completion and received a report with their collected information along with a one-on-one counseling session with a member of the research staff to review the report at study completion (1).

Analysis of Data

Secondary data analysis performed for this thesis project used SAS software version 9.4 (SAS Institute, Inc). The dependent variable, sleep efficiency, was split into two categories, <85% and ≥85%. Sleep efficiency <85% is considered insufficient while sleep efficiency ≥85% is considered sufficient by the NSF's expert panel (14). Demographic data is provided for age, sex, race, education, income, employment status and number of children <18 years in the household by counts and percentages for total n as well as by sleep efficiency group. Using simple means and standard deviations, anthropometric data are provided for height, weight, BMI, body fat percentage, resting energy expenditure (REE), energy intake, energy expenditure, steps, moderate to vigorous physical activity (MVPA), and alcohol consumption. The number of "on body hours" (wear time) for SWA and number of recalls is also provided using simple mean and standard deviation. Potential covariates included age, sex, race, education, income, employment status, alcohol consumption, number of children in the household, and minutes of MVPA.

Covariate selections started as a series of bivariate analyses where covariates with a p-value less than or equal to .20 were added to a "full" model. Backward elimination procedures were used to develop "final" models that included all covariates that are statistically significant ($p < .05$). For example, when looking at total HEI-2010 score, the p-values for covariance were age (0.0094), sex (0.0788), education (0.0003), income (0.4959), employment (0.0079), race (0.4425), alcohol consumption (0.0354), number of children (0.0056), MVPA (0.1899). Age, sex, education, employment, alcohol consumption, number of children, and MVPA were all added to the full model. The new p values for covariance were (0.3662, 0.0163, 0.028, 0.0771, 0.0749, 0.0027, 0.0048), respectively. Income, employment, and alcohol consumption were removed, leaving a final model with covariates (*p*-value) of age (0.0009), sex (0.0497), education (0.0317), number of children (0.0014), and MVPA (0.0053). Covariates were tested in the same manner for whole and refined grains HEI-2010 sub-scores as well as ratio of whole to refined grain HEI-2010 sub-scores.

Mean HEI-2010, whole grain HEI-2010 sub-score, refined grains HEI-2010 sub-score and ratio of whole grains to refined grains using HEI-2010 sub-scores were calculated for level of sleep efficiency (<85% and ≥85%). Ratio of whole grain to refined grain grams was not analyzed as originally proposed due to missing data for refined grain grams from the data set. Results from analysis of HEI-2010 whole and refined grain sub-scores indicate that analyzing whole and refined grain consumption in terms of grams would not have impacted results.

Chapter 4: Results

The hypothesis states that there will be a positive correlation between diet quality and sleep quality for subjects of the EBS. High HEI-2010 scores and consumption of nutrient dense whole grains over refined grains will correlate to increased sleep efficiency. Diets with low HEI-2010 scores or ratios of complex over refined grains will show decreased sleep efficiency (7, 10, 11).

<u>Demographics and Anthropometrics</u>

422 participants in the EBS qualified for analysis based on the requirement of ≥4 days of available baseline sleep data. The mean age for the sample was 27.6 ± 3.8 years and about half were female (51.4%) with a racial/ethnic makeup of predominately white/Caucasian (66.8%). Most participants had four or more years of college education (83.7%) and an income $10,000-$50,000 (57.85%). Nearly the entire sample was employed for wages (52.6%) or students (44.8%), and most did not have children in the home (85.3%). All demographic data are presented in Table 1.

Mean height and weight resulted in an average BMI of 25.34 ± 3.8 m/kg^2, and mean body fat was 28.26 ± 9%. Daily average resting energy expenditure (REE), energy intake, and energy expenditure were 1521.92 ± 257.75, 2084.45 ± 679.24, and 2737.61 ± 508.22 kcals, respectively. Mean steps were 7663.37 ± 2749.18 per day and participants averaged 77.96 ± 64.24 minutes of MVPA daily. Mean alcohol consumption was 10.11 ± 18.86 grams daily. Means ± SD for these anthropometrics and other descriptive statistics are presented by sleep efficiency group (<85%, n = 261; and ≥85%, n = 161) in Table 2. Groups were similar for all variables except BMI (p = 0.0281) and minutes of MVPA (p = 0.036).

Sleep Metrics

Participants spent an average of 7.99 ± 0.94 hours in bed with an average of 6.54 ± 0.89 hours of sleep time. Average wake time was just before 8 AM (7:49 AM) and bedtime was just after midnight (12:05 AM). Average WASO was 54.34 ± 30.82 min, and mean latency was 13.02 ± 6.75 min with an average PSQI latency score of 0.96 ± 0.84. Mean sleep efficiency across the sample was 82.12 ± 7.16 percent, and mean PSQI sleep efficiency was reported as 0.18 ± 0.49 (a score of 0 corresponds to >85% efficiency where sleep efficiency = *total number of hours asleep*/*total number of hours in bed*). Significant differences were found between sleep groups for all sleep metrics except bedtime (p = 0.0515) and PSQI latency score (p = 0.0747). Sleep efficiency had a nearly normal distribution, with the majority of participant's sleep efficiency at or near the cut point of 85%, as seen in Figure 1.

HEI-2010

Mean unadjusted total HEI-2010 for all participants was 58.82 ± 12.07 with mean HEI-2010 for the sleep efficiency groups (<85% and ≥85%) being 58.09 ± 11.62 and 60.01 ± 12.7, respectively. No significant difference was found between groups (p = 0.1135). After adjusting for covariates, groups became even more similar (p = 0.367).

Grains Ratio

Mean HEI-2010 whole grains to refined grains sub-scores was 0.73 ± 0.78 across the sample, with little difference seen between sleep efficiency groups. This number was not adjusted for covariates, as none of the examined potential covariates exerted any statistically significant impact.

Tables and Figures

Table 1. Subject demographics of the sample

	All Participants *n = 422*	<85% sleep efficiency *n = 261*	≥85% sleep efficiency *n = 161*
Age, *mean* ± *SD*	27.63 ± 3.78	27.70 ± 3.87	27.51 ± 3.65
Gender, n (%)			
Male	205 (48.58)	134 (31.75)	71 (16.82)
Female	217 (51.42)	127 (30.09)	90 (21.33)
Race, n (%)			
White/Caucasian	282 (66.82)	154 (59)	128 (79.5)
Black/African American	53 (12.56)	42 (16.09)	11 (6.83)
Hispanic/Latino	12 (2.84)	11 (4.21)	1 (0.62)
Asian	44 (10.43)	28 (10.73)	16 (9.94)
Other	15 (3.55)	13 (4.98)	2 (1.24)
Mixed	16 (3.79)	13 (4.98)	3 (1.86)
Education, n (%)			
HS Graduate/GED	4 (0.95)	2 (0.77)	2 (1.24)
Some College	65 (15.4)	46 (17.62)	19 (11.8)
College (4+ years)	353 (83.65)	213 (81.61)	140 (86.96)
Income ($), n (%)*			
0-9,999	24 (5.71)	18 (6.9)	6 (3.77)
10,000-19,999	46 (10.95)	25 (9.58)	21 (13.21)
20,000-29,999	74 (17.62)	48 (18.39)	26 (16.35)
30,000-39,999	72 (17.14)	53 (20.31)	19 (11.95)
40,000-49,999	51 (12.14)	31 (11.88)	20 (12.58)
50,000-59,999	32 (7.62)	20 (7.66)	12 (7.55)
60,000-69,999	34 (8.1)	19 (7.28)	15 (9.43)
70,000-79,999	19 (4.52)	7 (2.68)	12 (7.55)
80,000+	68 (16.19)	40 (15.33)	28 (17.61)
Employment Status, n (%)			
Employed for wages	222 (52.61)	136 (52.11)	86 (53.42)
Self-employed	9 (2.13)	7 (2.68)	2 (1.24)
Out of work for < 1 year	2 (0.47)	1 (0.38)	1 (0.62)
Homemaker	2 (0.47)	1 (0.38)	1 (0.62)
Student	186 (44.08)	115 (44.06)	71 (44.1)
Unable to work	1 (0.24)	1 (0.38)	-
Number of Children <18y, n (%)			
0	359 (85.27)	217 (83.46)	142 (88.2)
1	35 (8.31)	25 (9.62)	10 (6.21)
2	19 (4.51)	11 (4.23)	8 (4.97)
3	4 (0.95)	4 (1.54)	-
4+	4 (0.95)	3 (1.15)	1 (0.62)

*missing income data for 2 participants, both are from ≥85% sleep efficiency group

Table 2. Subject anthropometrics and other characteristics (n=422)

	All Participants *n = 422* *mean ± SD*	<85% sleep efficiency *n = 261* *mean ± SD*	≥85% sleep efficiency *n = 161* *mean ± SD*	*p*-value
Height (cm)	171.56 ± 9.51	171.64 ± 9.33	171.42 ± 9.83	0.8173
Weight (kg)	74.78 ± 13.62	75.76 ± 13.63	73.19 ± 13.49	0.0596
BMI (kg/m^2)	25.34 ± 3.8	25.66 ± 3.87	24.83 ± 3.63	0.0281
Body Fat (%)	28.26 ± 9	28.38 ± 8.97	28.08 ± 9.06	0.74
REE (kcal)	1521.92 ± 257.75	1539.23 ± 255.3	1493.88 ± 260.02	0.0791
Energy Intake (kcal)	2084.45 ± 679.24	2052.58 ± 664.36	2136.12 ± 701.69	0.2201
Energy expenditure (kcal)	2737.61 ± 508.22	2743.2 ± 513.1	2728.54 ± 501.68	0.7738
Steps (#/day)	7663.37 ± 2749.18	7550.04 ± 2522.94	7847.09 ± 3080.34	0.2815
MVPA (min/day)	77.96 ± 64.24	72.82 ± 60.53	86.31 ± 69.21	0.036
Alcohol (grams/day)	10.11 ± 18.86	10.38 ± 21.26	9.69 ± 14.19	0.7172
On Body Hours	23.26 ± 0.69	23.23 ± 0.71	23.3 ± 0.65	0.2918
Number of Recalls	2.78 ± 0.48	2.78 ± 0.47	2.77 ± 0.48	0.8108

Table 3. Mean baseline sleep metrics using SWA

	All Participants *n = 422* *mean ± SD*	<85% sleep efficiency *n = 261* *mean ± SD*	≥85% sleep efficiency *n = 161* *mean ± SD*	*p*-value
Total sleep (hours)	6.54 ± 0.89	6.32 ± 0.91	6.88 ± 0.71	<.0001
Bedtime (HH:MM)	00:05 ± 00:01	00:11 ± 00:01	23:55 ± 00:01	0.0515
Wake time (HH:MM)	07:49 ± 00:01	08:01 ± 00:01	07:29 ± 00:01	<.0001
Time-in-bed (hours)	7.99 ± 0.94	8.11 ± 0.99	7.79 ± 0.80	0.0005
Latency (min)	13.02 ± 6.75	14.85 ± 7.21	10.06 ± 4.62	<.0001
Latency PSQI (score) *	0.96 ± 0.84	1.02 ± 0.87	0.87 ± 0.78	0.0747
WASO (min)	54.34 ± 30.82	70.29 ± 28.2	28.49 ± 10.91	<.0001
Sleep efficiency (%)	82.12 ± 7.16	78.14 ± 6.13	88.57 ± 2.49	<.0001
Sleep efficiency PSQI (score) †	0.18 ± 0.49	0.24 ± 0.56	0.1 ± 0.32	0.0045

*Score 0-3, calculated by answer to “how long (in minutes) has it taken you to fall asleep [during the past month]?” (≤15min = 0, 16-30min = 1, 31-60min = 2, >60min = 3) + answer to “during the past month how often have you had trouble sleeping because you cannot get to sleep within 30 minutes?” (not at all during the past month = 0, less than once a week = 1, once or twice a week = 2, three or more times per week = 3). If sum is equal 0=0; 1-2=1; 3-4=2; 5-6=3

†Score 0-3, calculated by answer to “during the past month, (a) how many hours of actual sleep did you get at night? and (b) how many hours were you in bed? (total # of hours asleep) / (total # of hours in bed) x 100, >85%=0, 75%-84%=1, 65%-74%=2, <65%=3

Table 4. Adjusted HEI-2010 total score and sub-scores

	<85% sleep efficiency *n = 261* *mean ± SEM*	≥85% sleep efficiency *n = 161* *mean ± SEM*	*p*-value
Total HEI-2010*	58.41 ± 0.72	59.48 ± 0.92	0.367
HEI-2010 whole grain sub-score†	3.93 ± 0.20	4.25 ± 0.26	0.3282
HEI-2010 refined grain sub-score‡	5.92 ± 0.20	6.27 ± 0.25	0.2812
Ratio of HEI-2010 whole grain to refined grains sub-score §	0.72 ± 0.05	0.73 ± 0.07	0.8812

*adjusted for age, gender, education, children, total MVPA
†adjusted for gender, income
‡adjusted for age, alcohol, MVPA
§45 records were dropped from the analysis due to sub-scores of zero, 30 records from the <85% sleep efficiency group, 15 records from the ≥85% sleep efficiency

Table 5. Spearman Correlation Coefficient, n = 422, prob > |r| under H0: Rho=0

		Total HEI-2010	Sleep efficiency
Spearman's Rho	Total HEI-2010	1.0000	0.0808
	Sig.		0.0974
	Sleep efficiency	0.0808	1.0000
	Sig.	0.0974	
		HEI-2010 whole grains	Sleep efficiency
	HEI-2010 whole grains	1.0000	0.04962
	Sig.		0.3092
	Sleep efficiency	0.04962	1.0000
	Sig.	0.3092	
		HEI-2010 refined grains	Sleep efficiency
	HEI-2010 refined grains	1.0000	0.04232
	Sig.		0.3858
	Sleep efficiency	0.04232	1.0000
	Sig.	0.3858	

Figure 1. Sleep efficiency distribution

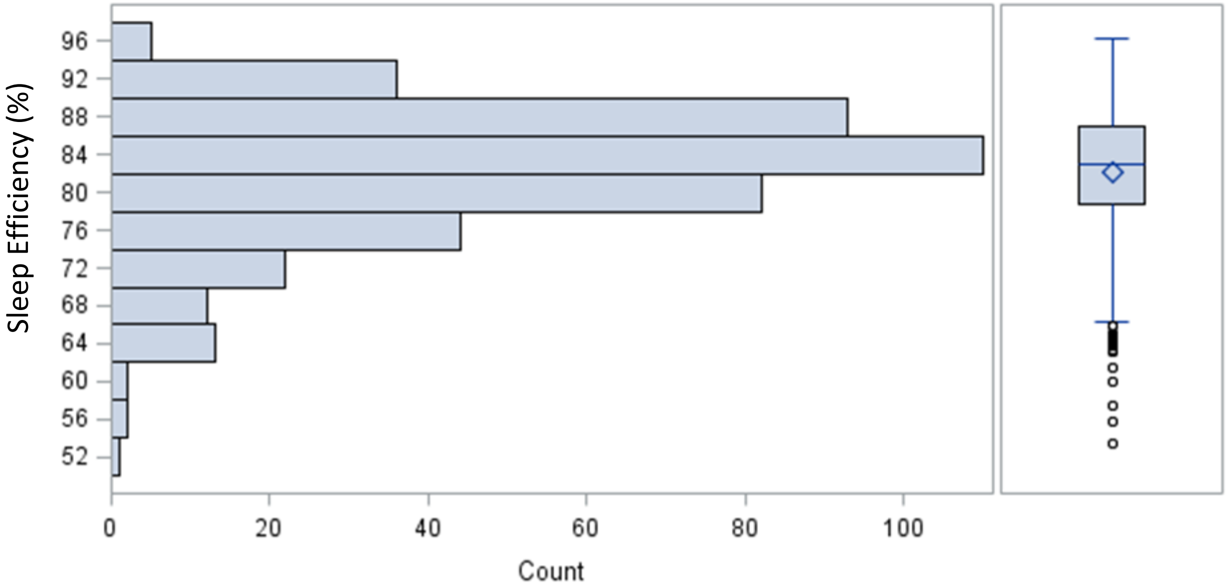
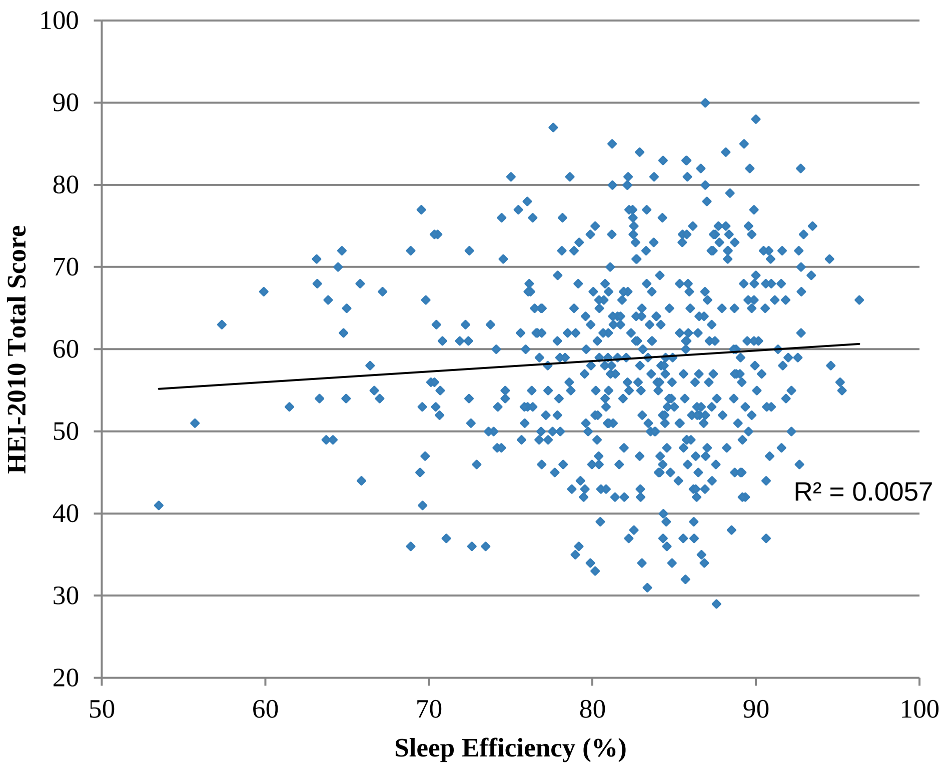


Figure 2. Linear regression and scatter plot of sleep efficiency vs HEI-2010 total score



Additional Tests

Spearman's correlation analysis was run for total HEI-2010, HEI-2010 whole grain sub-score, and HEI-2010 refined grains sub-score. Results were ρ = .0808, ρ = 0.04962, ρ = 0.04232, respectively [Table 5]. All values fail to reject the null hypothesis.

Simple linear regression was run and a scatter plot of sleep efficiency versus HEI-2010 total score was created [Figure 2]. Resulting R and R^2 values were 0.0758 and 0.0057, respectively.

Chapter 5: Discussion

The aim of this study was to examine correlations between the effect of diet quality as measured by HEI-2010 and sleep quality as measured by sleep efficiency. No significant differences were found between sleep efficiency groups (<85% and ≥85%) for total HEI-2010, HEI-2010 whole grains sub-score, HEI-2010 refined grains sub-score, or ratio of HEI-2010 sub-scores of whole grains to refined grains, despite the hypothesis that higher HEI-2010 scores and higher whole grain consumption ratios would be found in the ≥85% sleep efficiency group.

Sleep Metrics

In this study, sleep efficiency was the main outcome selected, which incorporates total sleep time and time in bed (22). Data were also presented for sleep duration, WASO, and latency. Studies have shown that certain foods (i.e. kiwifruit) and food groups (i.e. carbohydrates) can increase sleep efficiency and duration (68, 69). Other studies have focused on associations between sleep architecture and diet, finding links between calorie restriction and the deepest, most restorative stages of sleep (6) and associations between reduced carbohydrate consumption and deep, slow-wave sleep (70). None of these studies used the HEI-2010 or examined whole grain consumption.

Diet Quality Measurement

Studies designed to examine the relationship between typical dietary intake (using multiple 24-hour recalls) and typical sleep qualities (using PSQI) were in agreement with this analysis and found no associations between main food groups or macronutrient composition and sleep quality, though one study found increased beverage intake (in several categories: non-alcoholic beverages, carbonated beverages, water, and coffee/black tea) in short duration sleepers

(71, 72). In contrast, one literary view from the University of Helsinki confirmed a link between diet and its impact on sleep, sighting that sleep is improved by foods that impact the availability of tryptophan as well as the synthesis of sleep promoting serotonin and melatonin (73). Research indicating this link was the rationale for examining whole and refined grains in this project. However, evidence surrounding foods that may promote sleep hormones is only just emerging, mostly from small trials, and clinical relevance must be studied further (73). Still, these findings were supported in a randomized cross-over study of American adults which found that increased fiber consumption was associated with increased sleep depth. This may be attributed to high fiber foods reducing the intake of sugars and other non-fiber carbohydrates (which are lower in melatonin and tryptophan) (11).

Timing

Dietary data collected as part of the EBS was gathered by 3 random recalls. This process results in an overview of typical diet in an individual rather than a single day's intake, which may or may not represent typical diet behaviors. Similarly, the sleep data collected were analyzed as an average across all available days of data per person. Further, the 24-hour recalls collected in the EBS may or may not have corresponded with the days that sleep data were collected, if participants did not have all 10-days of sleep time available. The PSQI is another tool designed to elucidate average or typical sleep habits, by asking all sleep questions in terms of "during the past month" (36). Averaging multiple days of measurement is a useful way to look at eating patterns and typical diet in individuals (74), just as averaging multiple days of sleep data seeks to examine typical sleep duration, efficiency, and other metrics.

However, many studies that found correlations between diet and sleep quality were designed to examine the relationship between a day's dietary intake and immediate nighttime sleep response (6, 11, 75). One study that looked at carbohydrate consumption timing and effect on circadian rhythms and sleep found that a carbohydrate-rich meal in the evening delayed the circadian rhythm of core body temperature and reduced night-time melatonin secretion (76).

Limitations

Many limitations to this study exist. The lack of diversity of the sample (predominately white, with similar socio-economic status and no children) may affect generalizability. Average time in bed was near 8 hours, with average sleep time of 6.5 hours, which is higher than national averages (21). Further, sleep efficiency, while normally distributed across the sample, was concentrated around the cut point of 85%. This value was chosen based on information from the NSF (14), but may have been inappropriate for this sample. To investigate this potential limitation, further analysis of HEI-2010 mean total score was done by comparing top and bottom tertiles as well as quartiles. Still, no significant difference between groups was found (Table 4).

There are many other ways to measure sleep quality apart from sleep efficiency, including examining sleep stages and measuring length of light and deep stages of sleep (22). This requires PSG, which must be measured in a laboratory setting (37). This type of measurement has been used in carbohydrate effect on sleep quality (70) but was not part of the EBS.

Using self-report for diet measures is problematic and may undermine the quality of data collected (77). While validity studies have shown that 24-hour recalls have improved accuracy over other self-report dietary measures such as food frequency questionnaires (FFQs), underreporting still averages 15% when compared to doubly-labeled water (DLW) (78). Underreporting is higher in obese and overweight individuals (79).

As mentioned, the methods used in the EBS study and in this secondary data analysis did not allow for examination of timing of intake (e.g. does consumption of whole grains during the day affect that night's sleep quality?). Matching diet record dates with sleep data dates may influence outcomes.

Future Research

Inconsistent findings in the literature and a paucity of evidence point to the need for further research in this area (80). The creation of a validated, gold standard for measuring diet intake in free-living adults has potential to improve all research that examines dietary intake. Some researchers have attempted innovations in this area, including the use of photographic diet diaries (81). Preliminary results indicate that adding photographs to dietary intake collection techniques may enhance validity and reliability of recalls.

The collection of data that can be linked to show a dose/response relationship between food intake and sleep is an area to be further explored, along with granularity of diet composition. Examining intake of food sub-groups such as whole grains and refined grains restricts ability to look at total dietary micronutrients that may play a role in melatonin and serotonin production, or other sleep promotors in the body. Research examining dietary intake in terms of an array of specific micronutrients is limited to populations with sleep disorders (82). More reliable data collection measures of diet, delineation of intake and sleep timing, and other novel ways to look at diet quality may help to illuminate the influence of diet quality on sleep quality.

Conclusion

Many studies have found that changes in diet quality, composition, and energy intake influence sleep, in terms of duration, architecture, and efficiency. Other studies have failed to find these connections. This study did not find any relationship between sleep efficiency and diet quality as measured by HEI-2010 total score or ratio of HEI-2010 whole grain to refined grain sub-scores. This could be due the limitations of the study, specifically the inability to look at timing of intake, or a relationship between diet and sleep quality simply may not exist in this sample. Further research in this area is needed to determine if diet quality has the ability to improve sleep quality.

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