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The Role of Sleep Timing on Diet Quality and Physical Activity among College-Aged Women Participating in the University of Massachusetts Vitamin D Status Study

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THE ROLE OF SLEEP TIMING ON DIET QUALITY AND PHYSICAL ACTIVITY AMONG COLLEGE-AGED WOMEN PARTICIPATING IN THE UNIVERSITY OF MASSACHUSETTS VITAMIN D STATUS STUDY

A Thesis Presented

by

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DEDICATION

To my loving parents, to whom I owe everything good in my life.

And to Okhtay and Negar. I could not wish for better siblings.

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ABSTRACT

THE ROLE OF SLEEP TIMING ON DIET QUALITY AND PHYSICAL ACTIVITY AMONG COLLEGE-AGED WOMEN PARTICIPATING IN THE UNIVERSITY OF MASSACHUSETTS VITAMIN D STATUS STUDY

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Overweight and obesity are risk factors for chronic diseases such as cardiovascular disease and type-2 diabetes. Sleep has been associated with overweight and obesity. One potential mechanism by which sleep may lead to overweight and obesity is through positive energy balance, in which energy intake exceeds expenditure. There are few studies examining the impact of sleep timing (onset and wake time) on diet and exercise. In a cross sectional study, we examined associations between sleep timing (onset and wake time) and diet quality, as measured by the 2010 Dietary Guidelines for Americans Adherence Index (DGAI-2010), and in separate models, between sleep timing and meeting the 2008 Physical Activity Guidelines for Americans among the participants of the UMass Vitamin D Status Study. A total of 140 young women (aged 18 to 30 years) were grouped into four sleep timing categories based on the median of participants' sleep onset and wake time (Early sleep-Early wake, Early sleep-Late wake, Late sleep-Early wake, Late sleep-Late wake). Multivariable linear regression was used to model the associations between the four sleep timing categories and diet quality adjusting for BMI, sleep duration, current smoking status, total energy intake, alcohol intake, and sedentary behavior. Multivariable logistic regression was used to model the association between sleep timing and meeting the National Physical Activity Guidelines, adjusting for BMI, sleep duration, current smoking status, and being a member of a sports team. Participants in the Early sleep-Early wake (EE) group, had the highest diet quality scores and were more likely to meet the National Physical Activity Guidelines compared to the other sleep timing categories. The Early sleep-Late wake (EL) group had significantly lower diet quality scores and were less likely to meet the National Physical Activity Guidelines. To our knowledge, this was the first study in the U.S. examining sleep timing and diet quality and physical activity among young women. In conclusion, the old adage early to bed, early to rise appears to be related to higher diet quality and meeting physical activity guidelines.

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INTRODUCTION

Over the past three decades, overweight and obesity have reached epidemic proportions (Gonnissen et al., 2012). Approximately 69% of the adult population in the US is considered overweight (Body Mass Index [BMI] 25 – 29.9 kg/m^2) or obese (BMI ≥ 30 kg/m^2), with the prevalence of obesity at 34.9% in all adults and 30.3% among younger adults (aged 20 to 39 years) (Flegal et al., 2012). Obesity is one of the major contributors to preventable deaths in the US (Quatromoni et al., 2006) and is a risk factor for chronic diseases such as cardiovascular disease (CVD) and type 2 diabetes mellitus (T2DM) (Gonnissen et al., 2012). Obesity-related chronic diseases have a significant financial burden on society and are currently estimated to be about $200 billion/year in direct costs (Roberts et al., 2014). If obesity rates continue to increase at the same rate as they are now, the associated medical costs are expected to increase at a rate of $48 – 66 billion per year (Roberts et al., 2014).

Positive energy balance (i.e., energy intake > energy expenditure) often leads to overweight and obesity. Maintaining energy balance (i.e., energy intake from food equal to the energy expended through exercise and daily activities, resting metabolic rate and the thermic effect of food) is an important factor in preventing obesity (Sparling et al., 2013). Efforts to control energy balance through a low calorie diet and increased physical activity have been insufficient in controlling weight gain leading some researchers to focus on factors beyond diet and physical activity, such as sleep (Chaput et al., 2010). Sleep may potentially contribute to being overweight or obese by having an effect on either or both of these two factors. Because there has been a decrease in sleep duration and change in sleep habits over the same time period that obesity rates increased in the U.S., sleep habits, especially short sleep duration, have been suggested as one of the possible contributors to weight gain (Beccuti et al., 2011). The decrease in sleep duration over recent decades is possibly due to the modernization of the environment such as high use of computer before bed that can cause difficulty falling sleep and the increase in nighttime work and leisure activities (Beccuti et al., 2011; Bel et al., 2013; Chaput et al., 2011a; Seo & Li, 2010). Different aspects of sleep habits have been studied but the focus has been mostly on sleep duration. Short sleep duration, and to a lesser extent, *long* sleep duration have been associated with overweight and obesity (Chaput et al., 2011b). The association may be due to changes in physical activity, appetite, and metabolic regulation (Chaput et al., 2011b).

Existing literature suggests that poor sleeping behaviors, such as short sleep duration and later bedtimes, can lead to poor diet quality (Chaput, 2013). Poor diet quality has been shown to play a role in the development of obesity (Quatromoni et al., 2006). Although it lacks a standard definition, poor diet quality is characterized as low intakes of beneficial foods such as fruits, vegetables, low-fat dairy, and whole grains, and on the other hand, poor diet quality has been characterized as diets with high intakes of foods that have been associated with adverse health effects, including solid fats, saturated and *trans* fats, and added sugar (Hiza et al., 2013). The overall diet quality seems to be low among Americans. A study using data obtained from the National Health and Nutrition

Examination Survey (NHANES) 2003 – 2004 concluded that most Americans do not meet the recommendations for dietary guidelines and that more than 90% of women aged 19–30 years have usual intakes below recommendations for eight food groups, including total fruits, whole fruits, several vegetable subgroups, whole grains, and milk (Krebs-Smith et al., 2010). A recent study (Ervin, 2011) using the data from the NHANES 2003 – 2004, the participants (20 years of age and older), scored low on all diet quality components of the Healthy Eating Index-2005 (a diet quality measurement tool), except for total grains, meat, and beans.

Previous researchers have observed an association between sleep and physical activity (Awad et al., 2013). Physical activity has been associated with health-related conditions such as CVD and T2DM, partially through its role in preventing overweight and obesity (Seo & Li, 2010). Therefore, regular physical activity, which is defined as 150 minutes a week of moderate intensity activity plus resistance training two days a week, according to the 2008 Physical Activity Guidelines for Americans, has been labeled as an important factor in improving health (Lowry et al., 2013). According to the federal report for Healthy People 2020 (CDC, 2013; USDHHS, 2010), 80% of adults and adolescents do not meet the National Physical Activity Guidelines. Several studies have found that women are less likely to be physically active (Iannotti & Wang, 2013; Lowry et al., 2013; McArthur et al., 2009; Troiano et al., 2008; USDHHS, 2010). It has been observed that physical activity tends to decline during adolescence compared to earlier childhood and the rates are especially lower in older adolescents and young adults (Lowry et al., 2013; NCHARGR, 2006; Spriujt-Metz, 2011;

USDHHS, 2010). College-aged adults in the US have been shown to have inadequate physical activity (NCHARGR, 2006). McArthur et al. (2009), found that consistent with previous research, 50% of college-aged adults were active, 33% reported some activity, and 17% were mostly sedentary.

Sleep is regulated by circadian rhythms in the body (Ohlmann & O'Sullivan, 2009). Disruption in circadian rhythms can lead to different physical and mental changes, including sleep disturbances (Ohlmann & O'Sullivan, 2009) that appear to affect diet quality and physical activity, and may eventually lead to obesity (Seo & Li, 2010).

We conducted a cross-sectional study on the association between sleep timing, independent of sleep duration and BMI, and diet quality based on meeting the 2010 Dietary Guidelines for Americans (USDA, 2010), and physical activity based on meeting the 2008 Physical Activity Guidelines for Americans (USDHHS, 2008) among young, college-aged women in the US.

CHAPTER 1

LITERATURE REVIEW

Energy Balance

Obesity prevalence has increased drastically over the past three decades (Gonnissen et al., 2012). There are many environmental and genetic factors contributing to the increase in obesity (Chaput et al., 2011a; Hill et al., 2012). Environmental changes include easy access to food and especially energy-dense foods such as sugar sweetened beverages in large portions, and the decrease in physical activity with the increase in usage of cars and sedentary leisure time activities such as TV viewing (Chaput et al., 2011a). Genetic factors have been associated with prevalence of obesity and are responsible for increasing rates of weight gain in specific populations (Hill et al., 2012). Genetics can play a role in predisposing individuals to obesity by having an effect on energy balance components, such as a low metabolic rate (Hill et al., 2012). But one of the main factors proposed in increasing obesity rates is positive energy balance (Kim & Park, 2011; Mozaffarian et al., 2011).

Energy balance consists of intake (diet), expenditure, and storage (Hill et al., 2012). Energy expenditure has three components, consisting of: physical activity; resting metabolic rate, which is the energy used at rest to provide energy for body's basic metabolic needs; and the thermic effect of foods, which is the energy the body expends when digesting foods (Hill et al., 2012; Kim & Park, 2011). If the energy intake is more than expenditure, it will lead to positive energy balance, which over time may lead to weight gain (Hill et al., 2012; Kim & Park, 2011). To prevent obesity, energy balance needs to be restored. Negative energy balance (energy intake < energy expenditure) is needed for weight loss (Hill et al., 2012; Kim & Park, 2011). This simple formula (energy intake < energy expenditure) has been challenged in terms of preventing obesity. For example, adherence to low calorie diets alongside increasing physical activity has been insufficient in obesity prevention. Thus, the research focus has shifted towards other explanations and solutions in resolving this public health issue. Some suggest that preventing obesity is easier than reversing it as our bodies have adapted to preserving energy (Dubnov-Raz & Berry, 2010; Hall et al., 2012; Hill et al., 2012; Wells & Siervo, 2011). This is due to the shortage in food over the course of human existence that has made our bodies respond more readily to negative energy balance in order to preserve energy and store fat rather than responding to positive energy balance to prevent obesity (Dubnov-Raz & Berry, 2010; Hall et al., 2012; Hill et al., 2012; Wells & Siervo, 2011). Therefore, it is of importance to find the pathways contributing to maintaining the energy balance required to avoid obesity. In our study, among the three components of energy expenditure, we have focused on physical activity as it is the one component that we have the most control over among all components of the energy expenditure equation.

There are many other small factors that contribute to energy balance components and can change the course of energy storage. For example, while excessive energy content of the foods is one aspect leading to weight gain, the type of food may also play a role in developing obesity. Foods that contain high amounts of simple sugar (e.g., soft drinks) and processed foods have been deemed to contribute to weight gain compared to foods that are high in fiber (e.g., whole grains, fruits and vegetables) (Kim & Park, 2011).

Resting metabolic rate also is a significant contributor in keeping energy balance, and is positively related to the amount of fat free mass in the body (Hill et al., 2012). Fat free mass itself is related to physical activity. Individuals who are physically active tend to have more muscle mass, which expends more energy at rest compared to fat mass, which is a relatively inactive tissue that does not require a lot of energy to maintain and lowers the resting metabolic rate of the body (Hill et al., 2012). Low energy expenditure is a prominent feature of the current American lifestyle due mostly to the industrialization and advancement in technology over the past century (Hill et al., 2012). This type of lifestyle contributes to physical inactivity and eventually to a positive energy balance as well as a low fat free mass in the body. Also, at the same time that physical activity has declined, food accessibility has increased, making it more readily available to all populations, whereas in the past high food intake was exclusive to affluent groups in a population. Therefore, more individuals are now in positive energy balance.

Dietary Intake

Almost all researchers agree that positive energy balance (energy intake > energy expenditure) leads to weight gain. For many years the sole solution for weight loss has been to encourage negative energy balance through low energy intake and higher physical activity (Grafenauer et al., 2014; Manore et al., 2014). However, this simple formula has failed to prove effective in all attempts for weight loss. Mostly because the “one size fits all” approach used in interventions for weight loss does not consider the effect that the change in energy intake has on total energy expenditure (Manore et al., 2014), meaning that lower energy intake is usually concurrent with the body trying to preserve energy. Researchers have also failed to take into account that body weight is affected by various genetic, metabolic, environmental, social and behavioral components.

To address why restricted dietary intake and increased physical activity does not always result in weight loss, researchers have started to look at other explanations as to why a simple low dietary intake might not be the answer. The first approach was to look at certain micro- or macro-nutrients and their roles as to how they might affect body weight. For example, low-carbohydrate diets are among the most popular types of diets for weight loss. But studies show that although weight loss at 6 months on a low-carbohydrate diet is more than weight loss from a low-fat diet, the weight loss is similar for both at 12 months (Laddu et al., 2011; Hession et al., 2009). There are different hypotheses as to how a low-carbohydrate diet could lead to weight loss and one of them is that a low-carbohydrate intake is usually concurrent with a higher protein intake. High-protein intake is associated with satiety and suppressing appetite for a longer time, thus leading to a lower energy intake (Brehm & D’Alessio, 2008; Laddu et al., 2011). At least one study has shown lower weight gain with lower fat intake

(Hooper et al., 2012). However, results from several studies were inconsistent and were refuted as nutrients show their effects in conjunction with other dietary nutrients and because we do not consume foods as isolated nutrients (Bel et al., 2013; Haghighatdoost et al., 2012). In addition, some nutrients may have complicated interactions with other nutrients. This can show different effects on the body when they are consumed alongside other nutrients rather than alone (Bel et al., 2013).

Researchers started looking at diet quality when they noticed that weight loss interventions were most effective when poor diet quality was improved (Grafenauer et al., 2014). Some studies have shown that weight is affected by intake of foods like vegetables, fruits, whole grains, low fat dairy, legumes and nuts. These foods may facilitate weight loss or help maintain weight compared to foods that contain empty calories such as sugar-sweetened beverages, high fat meats (namely processed), high fat dairy, refined grains, and potato chips. High quality diets are characterized by having a high ratio of healthy fats, such as nuts & olive oil that are high in unsaturated fat, as opposed to unhealthy fats that are high in saturated fat and are primarily found in high fat animal sources (Grafenauer et al., 2014; Mozaffarian et al., 2011). To support this idea, studies have shown that a Mediterranean diet, which consists of mostly fruits, vegetables, olive oil, fish, and whole grains, is an effective diet for weight loss when on a hypocaloric diet (Laddu et al., 2011). The Mediterranean diet is recommended for prevention of chronic diseases, such as cardiovascular disease and cancer, and has long been considered as a “heart healthy” diet mostly because of its high ratio of unsaturated fats to saturated fats (Panico et al., 2014). One of the pathways through which high quality foods may help in weight loss and maintenance is suggested to be through the high fiber content of some of these foods such as fruits, vegetables and whole grains that provides longer duration of satiety (Mozaffarian et al., 2011). An indicator for the unhealthy outcome of having foods such as refined grains in the diet may be their high glycemic index and their ability to spike the blood sugar levels higher and faster that over time can lead to adverse metabolic conditions such as T2DM and central obesity, which are risk factors for CVD (Mozaffarian et al., 2011).

Diet and Weight

Typically weight loss and maintenance are equated with dietary intake. To achieve energy balance, energy intake needs to be equivalent to energy expenditure (Drenowatz et al., 2014). Research focus has been mostly on diet as some studies have shown that excessive physical activity without having the right diet is not as effective as diet alone in losing weight (Swift et al., 2014). Researchers have come to realize that diet quality might be as important as the energy content of a diet as diets high in fruits, vegetables and whole grains as the foundation of a high quality diet are more effective than low quality diets high in saturated fat, refined grains, simple sugars and alcohol in maintaining weight (Drenowatz et al., 2014; Newby et al., 2004). The body of literature focusing on weight and dietary intake in terms of energy intake is extensive. As diet quality is a new area in research that needs further exploration, we focused on this aspect of diet and its relation with sleep and consequently with weight in our study.

Physical activity

Although some studies have suggested that physical activity is not as important as diet in achieving weight loss, it contributes to preventing metabolic complications attributed to obesity (even without weight loss) and numerous chronic diseases (e.g., T2DM and CVD) (Dubnov-Raz & Berry 2010).

As physical activity is the most variable component of total energy expenditure, there should be more focus on it to promote weight maintenance and weight loss (Dubnov-Raz & Berry, 2010). Physical activity itself, which is defined as bodily movements that lead to energy expenditure beyond resting metabolic rate and contributes to 15-30% of total energy expenditure, is broken down into two categories: non-recreational physical activity and recreational physical activity or exercise (De Feo, 2013; Psota & Chen, 2013). The latter is defined as planned and purposeful movements to improve physical fitness (De Feo, 2013) and it is the component the guidelines are directed at and is going to be the focus in our study.

In our study, we used the 2008 Physical Activity Guidelines for Americans (USDHHS, 2008), which is based on the evidence-based reports of the health-benefits of physical activity and designed by the Physical Activity Guidelines Advisory Committee. The unit used for the guidelines is a metabolic equivalent (MET), which shows the ratio of energy expended compared to the energy expended at rest that has a MET score of 1. To give an example, the MET score for walking at 3 miles per hour is 3.3 and it means that the energy expended through this particular activity is 3.3 times the energy expended at rest for the same period of time. Based on the committee's decision, the health benefits associated with physical activity translate to 500 to 1,000 MET minutes per week. They also specify the intensity for maximum benefit as moderate- or vigorous-intensity physical activity. Moderate-intensity activities are defined as 3.0 to 5.9 METs, such as walking at 3 miles per hour, and vigorous-intensity activities have a MET score of 6.0 or more, such as running at 6 miles per hour. Since MET-minutes are not useful for the public and there are few Americans who are familiar with this system, the committee decided to make the recommendations for general public in actual minutes per week. The committee indicated that 150 minutes of moderate intensity activity per week or at least 75 minutes of vigorous intensity activity is roughly equivalent to 500 MET-minutes per week. Highly fit individuals can exceed 1,000 MET-minutes per week of exercise, as there are no upper limits for vigorous-intensity activities. This committee also brought to attention studies that indicate the health benefits of 1,000 MET-minutes per week are higher than that of 500 MET-minutes per week.

In addition to 500 to 1,000 MET-minutes per week of aerobic exercise, they also recommended having 2 days a week of resistance training. The evidence for the benefits of incorporating resistance training in one's routine is substantial and growing (Trudelle-Jackson et al., 2011). Resistance training helps build muscle mass. Studies show that having higher levels of muscle mass in the body, independent of aerobic fitness level, may lead to lower rates of all-cause mortality in both men and women (Trudelle-Jackson et al., 2011). Higher muscle mass is also inversely associated with abdominal obesity and fat mass, both of which are related to lower incidence of various chronic diseases, such as CVD and T2DM (Trudelle-Jackson et al., 2011), as well as lower rates of metabolic syndrome (Williams et al., 2007). Higher muscle mass has also been associated with weight management (Williams et al., 2007). Researchers suggest that per 1 kg gain in muscle mass, resting metabolic rate increases by 21 Kcal/d (Williams et al., 2007). The unit of recommendation for resistance training is different than that of aerobic exercise, as the recommendations are in terms of "repetitions (reps) and sets" of movements (Williams et al., 2007). The American Heart Association has set the recommendation of each session of resistance training for healthy adults at 3 sets of 10 reps for 8-10 exercises (different exercise stations to engage different muscles in the body) (Williams et al., 2007). One set of 8-10 exercises can be achieved in about 15-20 minutes (Williams et al., 2007), thus making the complete resistance training session of 3 reps take about 45-60 minutes. There are no equivalents of time set for resistance training by the Physical Activity Guidelines Advisory Committee but based on the evidence mentioned above, we translated their recommendations of "2 times a week of resistance training that engages all muscles" to 1.5-2 hours of resistance training per week.

Physical activity and weight

Studies suggest that the decline in leisure time physical activity and occupational physical activity are among the main causes of increase in obesity rates over the past 3 decades (Swift et al., 2014). Lower levels of physical activity have been associated with increased risk of obesity in both men and women, with the risk being higher in women (Swift et al., 2014). Physical activity alone has shown moderate effects on weight loss but its rates have been lower compared to diet alone (Laddu et al., 2011; Jakicic 2012). However, when combined together, the effect of physical activity has been additive and has led to higher weight loss compared to either diet or physical activity alone (Jakicic, 2012). Also, physical activity has been associated to be most effective in maintaining weight after weight loss (Jakicic, 2009, 2012).

The current recommendation for physical activity to avoid weight gain, set by the American College of Sports Medicine, is approximately 150 to 250 minutes of moderate to vigorous physical activity (MVPA). This roughly translates to burning 1200 to 2000 calories per week (Swift et al., 2014). This recommendation is mostly to maintain weight. For the purpose of weight loss, other researchers have suggested much higher physical activity. One study suggests a minimum of 60 minutes a day of MVPA, which exceeds the 2000 calories per week of the previous study mentioned above (Laddu et al., 2011). The authors claim that the higher level of physical activity will not suffice if there is not a sufficient amount of dietary restriction. It should be noted that the main reason that most Americans do not meet the National College of Sports Medicine recommendation of 60 minutes of physical activity per day is because it may be intimidating for many people to follow given current physical activity habits as the length of time participating in physical activity is inversely associated with adherence (Laddu et al., 2011).

Although aerobic exercises are considered to be the most effective form of physical activity, resistance training has been proven effective in preserving muscle mass and increasing the resting metabolic rate through increasing fat free mass in the body (significantly more than aerobic) (De Feo, 2013), which is an active tissue and requires more energy to maintain and can contribute to a negative energy balance and eventually weight loss (Laddu et al., 2011; De Feo, 2013). This is especially important because resting metabolic rate makes up the largest proportion (about 60-80%) (Psota & Chen, 2013) of total energy expenditure compared to physical activity and thermic effect of food (Jakicic, 2012). Fat-free mass is the determinant causing the most variability among different individuals's resting metabolic rate (Psota & Chen, 2013). Many studies have found the beneficial effects of exercise to be 150 minutes of aerobic and three sessions of resistance training per week (De Feo, 2013). But in this study we focused on meeting the 2008 Physical Activity Guidelines for Americans (USDHHS, 2008).

Thermic effect of food, which makes up 8-12% of total energy expenditure, represents the energy expended to digest foods and is related to nutrient composition and energy content of food consumed. Therefore, quality of diet could also demonstrate its beneficial effects on the body, though minimal, through its effect on thermic effect of food (Hall et al., 2012).

Sleep domains

As mentioned earlier, the decrease in sleep duration over the past three decades, concurrent with the increasing rates in obesity, has prompted scientists to look at the possible association between short sleep duration and obesity (Horne, 2011). Researchers have been looking at sleep from 3 perspectives: total sleep deprivation (i.e., no sleep during 24 hours), sleep restriction (i.e., short sleep which in most cases was less than 7 hours), and sleep quality (St-Onge, 2013). Sleep deprivation has had the highest impact in increasing hunger levels (almost doubled) and sleep restriction has also increased hunger levels but to a lesser extent (St-Onge, 2013).

Studies looking at this association suggest having less than 7 hours of sleep in 24 hours as the cutoff for short sleep duration that could lead to its adverse effects on weight gain (Horne, 2011; St-Onge, 2013), compared to individuals whose sleep duration is in the recommended amount of 7-8 hours (St-Onge, 2013). Studies have revealed that the connection of short sleep with weight gain could be due to the disturbances it causes in the endocrine system involved in hunger and satiety, through changes in secretion of ghrelin and leptin (Bel et al., 2013;,Brondel et al., 2010; Kim et al., 2011; Magee & Hale, 2012; St-Onge, 2013). For example, leptin (the orexogenic hormone that sends the signal for satiety) is normally secreted more at nighttime (Gonnissen et al., 2013a) and ghrelin (the obesogenic hormone that sends the signal for hunger) has lower secretion at night (Gonnissen et al., 2013b). However, short sleep could disrupt the system of “normal” day and night cycle and lead to lower secretions of leptin and higher secretions of ghrelin at nighttime, which could lead to higher intakes around the very time that people are programmed to stop eating, thus naturally restricting daily energy intake (Gonnissen et al., 2013a, 2013b). Studies show that participants are usually involved in sedentary activities late at night (e.g., watching TV) and snacking on low quality snacks (e.g., potato chips) (Gonnissen et al., 2013a). The high hunger levels around the same time could contribute to higher intakes of high energy, low quality foods and lead to higher intakes of energy (Gonnissen et al., 2013a) and eventually to a positive energy balance. These effects were also seen in individuals who had normal sleep durations but not normal sleep quality (St-Onge, 2013). Therefore, more studies started looking at the effect of sleep quality on weight gain (St-Onge, 2013). In accordance with the discussion above, another study (Hursel et al., 2011) found that the group of participants who experience sleep fragmentation (waking up several times during the night that lowers the quality of sleep), have increased hunger rates, especially after dinner, compared to participants who get the same amount of sleep, though without fragmentation.

The results from studies suggest that there is no difference in hunger levels based on only one night but that it is the habitual short sleep that increases hunger (St-Onge, 2013). The increase in appetite has also been reported to lead to craving energy-dense and high-carbohydrate foods that could lead to lower diet quality (St-Onge, 2013). A study (Nedeltcheva et al., 2009) concurrent with the results for increase in appetite for carbohydrate-rich foods, showed an increase in intake of these foods after a night of sleep restriction. On the other hand, another study (Schmid et al., 2009) looking at sleep restriction and controlling for food intake, found that although energy intake remains the same, the proportion of fat intake (compared to total energy) increases after a night of sleep restriction. These results show the potential of sleep restriction in lowering diet quality and increasing cravings for high carbohydrate and high fat foods.

However, other studies have results that are different than the discussion above. In a study looking at normal weight men (Brondel et al., 2010), in participants who experienced only one night of sleep restriction there was an increase of about 600 calories the day following the night of sleep restriction. Another study looking at intake in a normal weight group who experience sleep restriction (St-Onge et al., 2011) found an increase in energy intake, and another study, looking only at women, found similar results (Bosy-Westphal, 2008).

Overall, there are a limited number of studies looking at the association of sleep and food intake, but most of them indicate a significant increase in food intake after sleep restriction. These studies have not controlled for sleep quality or sleep timing (which can contribute to sleep quality), and no studies have looked exclusively at the association of sleep timing and dietary intake. We chose to look at the association of sleep timing (the time of sleep and the time of waking up) with diet quality and physical activity, independent of sleep duration.

Physiologic/behavioral association between sleep and diet quality

Given the association between sleep and diet, we need to identify the possible mechanisms through which sleep may affect dietary intake so that we can improve diet by changing sleeping habits. A number of studies have looked at the mechanisms linking the two.

Short sleep duration (commonly defined as <6 hours/night) has been associated with poor diet quality (Bel et al., 2013; Brondel et al., 2010; Chaput, 2013; Magee & Hale, 2012; Seo & Li, 2010). Several explanations of why short sleep duration may lead to poor diet quality have been presented. For example, participants who sleep less have more time to eat (Bel et al., 2013; Brondel et al., 2010; Magee & Hale, 2012). Extended time for overconsumption may also be true for individuals who go to bed late or wake up early in terms of sleep timing, as well, especially as staying awake late at night has been associated with unhealthy snacking habits, which contributes to poor diet quality (Chaput et al., 2011a; Chaput, 2013). Another explanation is that people who sleep less usually have irregular food intake and snacking habits (Brondel et al., 2010; Haghighatdoost et al., 2012), potentially through the relationship between sleep and hormone levels that play a role in appetite. As mentioned above, levels of leptin have been shown to decrease in people who experience sleep deprivation (Bel et al., 2013; Brondel et al., 2010; Magee & Hale, 2012), and levels of ghrelin have been increased in sleep-deprived people (Bel et al., 2013; Brondel et al., 2010; Kim et al., 2011; Magee & Hale, 2012). One study (Patel et al., 2006) found that participants who slept less than 4 hours a night, had 18% lower levels of leptin and 28% higher levels of ghrelin compared to participants who slept 7 – 8 hours. The authors also observed that in response to their increased appetite, most of the participants preferred energy-dense high-carbohydrate foods such as sweets, salty snacks, and starchy food, with an increased intake of 33% to 45% (Patel et al., 2006).

The timing of sleep also may have an effect on hormonal levels and in turn influence diet quality. One study examined the effect of circadian rhythms on hunger (Wuorinen & Borer, 2013). The authors observed that hunger ratings were lower in the morning and in the evening compared to mid-day. Therefore, late sleep onset or late wake time may disrupt circadian rhythms and in turn, hunger levels during the day (Wuorinen & Borer, 2013). Another suggested explanation is that people with short sleep duration usually have less energy. Therefore, they seek to compensate for their tiredness by craving energy-dense foods, such as sweets (Brondel et al., 2010; Chaput, 2013; Magee & Hale, 2012; Patel et al., 2006). Sleep timing also may influence the feeling of tiredness. For example, going to bed late or waking up too early, may cause fatigue.] Lastly, one of the reasons for shorter sleep duration and going to bed late is media use. Having less energy due to sleep deprivation can lead to higher participation in sedentary activities, such as watching TV, which are usually concurrent with higher rates of snacking and eating unhealthy foods that in turn can increase the risk for developing overweight and obesity (Chaput et al., 2011a; Chaput, 2013). People who go to bed late are more likely to be involved in these activities compared to people who go to bed early. These findings suggest that high calorie consumption at night might be the link connecting short sleep as well as later bedtime to higher rates of obesity (Chaput, 2013). Some of the mechanisms mentioned above for short sleep duration involve the timing of sleep, as well.

Therefore, they can also be the possible mechanisms for the effect of sleep timing on diet quality.

Epidemiology of sleep and diet quality

Prior epidemiologic studies of sleep and diet have mostly focused on the effect of sleep duration on the consumption of a specific nutrient or food (Baron et al., 2011; Grandner et al., 2013; Nishiura et al., 2010; Santana et al., 2012; Sato-Mito et al., 2011; St-Onge et al., 2011). As nutrients and foods are not consumed independently and might interact with each other (Haghighatdoost et al., 2012), it is advisable to look at overall diet quality and not just one nutrient or food in isolation. In a cross-sectional study (Grandner et al., 2013), looking at dietary patterns and sleep duration, normal sleepers (7 – 9 hours of sleep) had the greatest food variety, which is usually considered as a positive outcome in terms of diet quality but does not necessarily lead to high diet quality scores. One randomized crossover (Santana et al., 2012) and two cross-sectional studies (Grandner et al., 2010; St-Onge et al., 2011) found high intakes of fat with short sleep duration. In a longitudinal study (Nishiura et al., 2010), authors also found preference for fatty foods in people with short sleep durations. In another study (Schmid et al., 2009), the authors compared subjects' physical activity under acute sleep loss condition, they found that even though there were no significant differences in their subjects' energy intake levels when comparing 4 hours of sleep to 8 hours (3969 ± 258 vs. 4070 ± 285 Kcal/day, P = 0.70), the subjects in the 4 hours condition had a higher intake of fat compared to the 8 hour condition (394 ± 43 vs. 305 ± 46 kcal/day, P = 0.029). This could potentially lower the diet quality if it consists mostly of saturated fats. Two studies have looked at sleep timing as their exposure. In a cross-sectional study (Baron et al., 2011), late sleep onset was associated with high intakes of full-calorie soda and low intakes of fruit and vegetable, which can contribute to low diet quality. In a cross-sectional study (Sato-Mito et al., 2011) in Japan among young adult women, authors looked at the midpoint of sleep. They divided the sleep duration of each participant by two and they separated their study groups to late sleepers (midpoint of sleep ≥ 5:30 am) and normal sleepers (midpoint of sleep < 5:30 am). Late midpoint of sleep (which potentially shows late sleep onset) was found to be significantly positively associated with high intakes of fat, alcohol, and confections, all of which contribute to low diet quality. There is the possibility that participants, who went to bed late and woke up early, had approximately the same midpoint of sleep as participants, who went to bed early and woke up late. A recent study among obese adolescents (Adamo et al., 2013) observed associations between later bedtime and higher energy intake and higher screen time (e.g., TV viewing). However, this study was limited to obese adolescents and may not be generalized to people of other weight status and other age groups.

Few studies have examined the association between sleep and diet quality, using diet quality measurement tools (Bel et al., 2013; Golley et al., 2013; Haghighatdoost et al., 2012). The focus of the studies that we were able to find has been on sleep duration. The findings of the two studies looking at the association of sleep duration and diet quality (Bel et al., 2013; Haghighatdoost et al., 2012) suggest that participants with short sleep duration have lower diet quality scores.

Haghighatdoost et al. (2012) designed a cross-sectional study to be the first research group, to our knowledge, looking at diet quality as the possible mechanistic explanation in the association of sleep and weight gain. Dietary intake was measured via the Willett FFQ among 410 young women (aged 18 – 28 years). Diet quality was assessed using the Healthy Eating Index (HEI), developed in 1995 based on the Dietary Guidelines for Americans (Kennedy et al., 1995). Participants in the lowest tertile had lower diet quality indices (53.9 ± 15.1 versus 61.0 ± 17.0; P = 0.002), as well as higher BMI values (23.2 ± 3.2 versus 21.1 ± 2.0 kg/m^2; P = 0.0001) compared to the ones in the highest tertile. However, no significant difference was seen in terms of physical activity and socioeconomic status among these groups. One of the limitations of this study was that they compared the short sleepers to long sleepers instead of comparing them to participants who had normal length of sleep. Also, the authors used the HEI as their diet quality measurement tool, which is designed for Americans, and may not be applicable to Iranians because of the differences in lifestyle and dietary habits.

Another cross-sectional study, conducted by Bel et al. (2013), looked at the possible association of sleep duration and diet quality in 1522 European adolescents (aged 12.5 - 17.5 years). The authors used two non-consecutive 24-hour recalls to obtain dietary intake data and a self-reported questionnaire for sleep duration and the Dietary Quality Index for Adolescents with Meal Index to measure diet quality. They stratified sleep duration into three categories based on the definition of American National Sleep Foundation: insufficient sleep duration (< 8 h of sleep per night), borderline-insufficient sleep duration (between 8 and 9 h of sleep per night) and optimal sleep duration (≥ 9 h of sleep per night). Their findings indicated a positive relationship between sleep duration and diet quality. Participants in the two low sleep tertiles scored lower in diet quality (62.05 [SD 14.18] and 64.25 [SD 12.87] respectively) compared to the highest sleep tertile where they scored 64.57 [SD 12.39] ($P<0.001$; $P=0.018$). One of the strengths for this study was the use of a large sample size. However, the diet quality index they used was based on Flemish dietary guidelines and may not have accurately assessed diet quality in their study of adolescents from 8 European countries.

The only study looking at the effect of sleep timing, in addition to duration, on diet quality was conducted by Golley et al. (2013). This cross-sectional study was conducted among 2200 Australian children (aged 9 – 16). Dietary data was collected via two 24-hour recalls. Self-reported data was used to obtain both sleep duration and sleep timing (i.e., onset and wake time). Dietary Guidelines Index for Children and Adolescents (DGI-CA) was used to calculate the diet quality. The authors found that participants who went to bed early had significantly higher diet quality scores compared to both late sleepers who had early wake time (β = - 3.09, 95% CI – 5.32 to – 0.86, $P = 0.007$) and late sleepers who had late wake time (β = -3.99, 95% CI – 5.66 to – 2.32, $P < 0.001$), independent of physical activity and socioeconomic status. Their results were also independent of sleep duration, meaning that unlike the previous data, which indicated short sleep duration affecting diet quality levels, early sleepers had the highest diet quality compared to the late sleepers. However, the diet quality index they used was designed for British children and may not be generalized to other populations, including Australian children and adolescents. Since the dietary habits of children and adolescents are usually more variable compared to adults, the short period of study time may have led to misclassification. Additionally, the authors did not control for the pubertal stage of the children that has previously been associated with both dietary intake and sleep (Golley et al., 2013).

Overall, only one study has evaluated the association between sleep timing and diet quality in children and adolescents. Because the health effects of sleep, as well as sleep needs, are different among children and adolescents compared to adults (Bel et al., 2013), these results cannot be generalized to other age groups. To the best of our knowledge, there have been no studies published on sleep timing and diet quality in the US or among adults, including college-aged populations.

Physiologic/behavioral association between sleep and physical activity

While there have been many studies on the effects of physical activity on the improvement of sleep habits, including duration and quality (Uchida et al., 2012; Yang et al., 2012), few studies have looked at how sleep habits could affect physical activity (Ortega et al., 2011; Stone et al., 2013; Van den Bulck, 2004). Regular exercise may improve sleep onset time by improving depressive symptoms (Buman et al., 2011). Another suggested pathway is physical activity's effect on thermoregulation. Physical activity has been shown to help regulate body temperature and as circadian rhythms are affected by body temperature (Ohlmann & O'Sullivan 2009), physical activity can help improve sleep quality and duration (Buman et al., 2011).

Two studies have looked at how maintaining sleep duration can affect physical activity in children and adolescents (Ortega et al., 2011; Stone et al., 2013). One mechanism of the association of sleep duration with physical activity (Ortega et al., 2011; Van den Bulck, 2004) is involvement in sedentary activities, such as TV viewing, which can also lead to shorter sleep duration. Media use can also cause tiredness, which in turn could lower the physical activity (Van den Bulck, 2004), as well as lowering motivation to be active (Magee et al., 2014). It has been suggested that since short sleepers have less energy, they are less likely to participate in physical activity (Brondel et al., 2010; Magee & Hale, 2012; Patel et al., 2006).

Epidemiology of sleep and physical activity

Most studies on sleep and physical activity have focused on how physical activity can reduce sleep disturbances and increase sleep duration but few studies (Nielsen et al., 2011; Ortega et al., 2011; Stone et al., 2013) have looked at the possible effects that sleep habits could have on the physical activity (Awad et al., 2013) and we were only able to find one study looking at the effect of sleep timing on physical activity. Regular exercise may improve different aspects of sleep, including sleep onset time (Buman et al., 2011; Passos et al., 2010). The results on the association of sleep habits and physical activity have been inconsistent. One study showed an inverse association between short sleepers (4 hours of sleep compared to 8 hours) and high physical activity compared to normal sleep duration (Brondel et al., 2010), one observed no difference (Ortega et al., 2011), and one showed a positive association (Schmid et al., 2009). The difference in results may be due to differences in study populations (children versus adults), study design, and methodology (including objective measurement of sleep and physical activity compared to subjective measurements and methods of calculating sleep duration based on self-reports). One recent cross-sectional study on US high school students found that engaging in daily physical activity for more than 60 minutes and limiting screen time (e.g., watching TV) was positively associated with sleep duration (Foti et al., 2011). As causality and direction of association cannot be inferred in cross-sectional studies, it is possible that longer sleep duration can be the factor leading to higher physical activity. Children and adolescents who have less screen times are more likely to have longer sleep durations (Grandner et al., 2011). While most researchers have focused on the intensity of physical activity in their study of its effect on sleep duration, it seems that any amount of physical activity could be beneficial to improve sleep (Grandner et al., 2011). We are going to highlight 3 studies that had physical activity as an outcome, while having sleep as exposure.

In a cross-sectional study (Ortega et al., 2011) looking at the association of sleep and physical activity in Estonian and Swedish children and adolescents (aged 9 – 16 years), the authors found that participants sleeping more than 10 hours per day spent more time engaged in physical activity (Spearman coefficient: 0.208, $P<0.001$) and less time in sedentary activities than short sleepers (Spearman coefficient: -0.358, $P<0.001$). These associations were non-significant after adjustment for age but associations with sedentary time became borderline significant ($P=0.09$). Sleep duration was calculated based on self-reports of wake time and bedtime, but data on sleep timing was not presented. The strength of this study was using an objective measurement tool (accelerometers) to calculate both sleep duration and physical activity duration and intensity. The limitations of this study include its lack of generalizability to other populations due to differences in sleep and physical activity needs between children and other age groups. Also, as the authors mention, the daylight duration was positively effective on activity levels. Therefore, because of the difference between daylight duration in Nordic countries compared to many other countries, this could be another reason for limitation in generalizability.

In a recent study that has looked at the effect of sleep duration on physical activity in children in Canada (Stone et al., 2013), authors found that sleep duration was negatively associated with sedentary behavior (Pearson coefficient: -0.087, $P < 0.05$) and positively associated with physical activity (Pearson coefficient: 0.087, $P < 0.05$). Their results became non-significant after further adjustment for confounders. The main strength of their study was objective measurement of physical activity by accelerometry. On the other hand, the study was limited in terms of sleep duration measurement because sleep duration was reported by parents of the children, making the assessment of exposure unreliable to some extent. Also, the results cannot be generalized to other populations due to the difference in sleep needs in different age groups. Moreover, as daylight duration is different in Canada compared to many other countries, it could also limit generalizability to other populations.

In the only other study that had sleep as an exposure and physical activity as an outcome, Schmid et al. (2009) conducted a crossover, blinded experiment in healthy men where they looked at the effect of acute sleep loss on physical activity. The experiment included two consecutive nights of 4 hour sleep and two consecutive nights of 8 hour sleep. When comparing the results after 4 hours to results after 8 hours of sleep, they found that subjects were involved in a significantly higher proportion of low-intensity activities (57.6 ± 4.5% activity counts recorded by accelerometers after 2 days of 4 hour sleep vs. 52.3 ± 3.5% after 2 days of 8 hour sleep; P = 0.016) and a lower proportion of high-intensity activities (22.6 ± 3.5% activity counts recorded by accelerometers after 2 days of 4 hour sleep vs. 25.4 ± 3.4% after 2 days of 8 hour sleep; P = 0.044). Although the objective of this study was looking at sleep duration, since the authors controlled the sleep time, we can also consider their results based on sleep timing. In the 8 hour sleep condition, subjects went to bed at 22:45, whereas in the 4 hour sleep condition, they went to bed at 02:45. Based on this data, we can also infer that late sleepers (4-hour sleep) had lower physical activity compared to early sleepers (8-hour sleep). However, this interpretation of results cannot be completely accurate as it was an acute measurement (only 2 days) and did not represent the usual sleep timing of the participants. The main strength of this study was using objective measurement tools in assessing physical activity.

The only study (Olds et al., 2011) that we were able to find looking at the role of sleep timing on BMI and physical activity was conducted among Australian children and adolescents (aged 9 – 16 years). The researchers gathered information on sleep timing and physical activity by interview, using the Multimedia Activity Recall for Children and Adults. They also measured physical activity objectively by asking the participants to wear a pedometer for 7 days. Their results showed that compared to the early sleep/early wake group, the participants in the late sleep/late wake group were 1.77 times more likely to have low moderate to vigorous physical activity and they were also 2.92 times more likely to have high screen times ($P < 0.0001$). Overall, their results indicated that it was "late sleep" time that had a larger association with high screen time and that it was "early wake" time that had a larger association with higher moderate to vigorous intensity activity. Though because of high variability in sleep behavior especially in younger people their results may be limited for the use of a 4-day sample, it was unlikely to bias parameter estimates. Therefore, these results are fairly reliable.

Summary

Growing trends of obesity are concerning. Obesity is associated with adverse health outcomes such as cardiovascular disease and type 2 diabetes mellitus. These health conditions can be a burden on society because of their health costs, as well as lowering the quality of life in individuals who are afflicted with chronic diseases. A main contributor to obesity is positive energy balance (lower energy expenditure or physical activity relative to intake or diet) but efforts to control high energy balance through low energy diets and high physical activity alone have been insufficient in controlling weight gain, leading to a focus on other risk factors such as sleep. Short sleep duration and, to a lesser extent, long sleep duration have been positively associated with overweight and obesity. The mechanism through which sleep duration effects weight status is still unclear but there have been several theories examined and the evidence suggests a possible effect of sleep on energy balance. Recently, studies have started to look at the effect of sleep beyond its duration, such as sleep quality. There are few studies examining the association between sleep timing (onset and wake time) and weight-related risk factors such as diet quality and physical activity. Sleep may be an important factor affecting diet quality and physical activity. Prior studies show that decreased sleep duration was associated with increased risk of obesity. However, few studies have looked at the association of sleep timing with either or both diet quality and physical activity as outcomes. Young adulthood has been identified as a stage in life of women that puts them at a higher risk of gaining weight compared to other life stages (Hutchesson et al., 2013). Also, as studies have shown increased risk of developing chronic diseases in women who put on weight after the age of 18 (Hutchesson et al., 2013), looking at this specific population seems to be of importance. Therefore, we evaluated the association of sleep timing and diet quality and physical activity in young women.

CHAPTER 2

SPECIFIC AIMS AND HYPOTHESES

The objective of this cross-sectional study was to evaluate the association between sleep timing (onset and wake time) and diet quality and physical activity among participants in the UMass Vitamin D Status Study (UMVDS), independent of BMI and sleep duration.

Specific Aim 1: To test the hypothesis that sleep timing (onset and wake time) is associated with diet quality in young women, independent of BMI and sleep duration.

Hypothesis 1. Participants in the UMVDS with early sleep onset and early wake time will have higher diet qualities, compared to the participants with late sleep onset and late wake time, independent of BMI and sleep duration.

Specific Aim 2: To test the hypothesis that sleep timing (onset and wake time) is associated with physical activity in young women, independent of BMI and sleep duration.

Hypothesis 2. Participants in the UMVDS with early sleep onset and early wake time will be more likely to meet the 2008 Physical Activity Guidelines for Americans compared to the participants with late sleep onset and late wake time, independent of BMI and sleep duration.

CHAPTER 3

METHODS

Study Design

We assessed the cross-sectional association between sleep timing (sleep onset and wake time) and diet quality and physical activity, among college-aged (18 - 31 years) women participating in phase I (2006 – 2008) of the University of Massachusetts Vitamin D Status study (UMVDS). All measurements were completed in one clinical visit. Participants provided written informed consent. The study was approved by the Institutional Review Board of the University of Massachusetts Amherst (Appendix A).

Study Population

A total of 185 healthy, college-aged premenopausal women between the ages of 18 and 30 years, who were living in Amherst area in Massachusetts, participated in phase I of the UMVDS. Women were excluded from participating in the UMVDS if they reported: 1) being pregnant or not currently menstruating; 2) experiencing untreated depression; 3) a history of high blood pressure or elevated blood cholesterol levels, kidney or liver disease, bone disease, digestive disorders, rheumatologic disease, multiple sclerosis, thyroid disease, hyperparathyroidism, cancer, type 1 or type 2 diabetes mellitus, polycystic ovaries; or 4) taking corticosteroids, anabolic steroids, anticonvulsants, cimetidine, propranolol.

For the current study, we excluded participants who reported taking medications or conditions that may have influenced sleep timing. After exclusions, 140 participants were included in the analysis (see Table 1). For exclusion criteria, missing values were classified as a “no” response. Specifically, participants who did not respond to questions on wheezing (n=103) and being kept awake at night by an itchy rash (n=145) over the last 12 months were classified as not having the condition. We only excluded those who had specifically reported having experienced either or both of these conditions.

Table 1. Exclusion Criteria* for the Sleep Timing Study.

Exclusion Criteria	n (%)
Mild, moderate, severe insomnia as a PMS symptom over the last year	24 (12.9%)
Mild, moderate, severe insomnia as a PMS symptom the night before the clinical visit	17 (9.2%)
Sleep disrupted by wheezing one or more nights a week during the past 12 months	2 (1.1%)
Being kept awake at night by an itchy rash	2 (1.1%)
Taking Selective Serotonin Reuptake Inhibitors/SSRIs (e.g., Prozac), other antidepressants (e.g., MAOIs), and tranquilizers	13(7.0%)
Sleep duration <3 hours/night on an average weeknight	0 (0.0%)
Average weekday and/or weekend sleep duration missing	1 (0.5%)
Sleep duration for last night <3 or > 15 hr	3 (1.6%)
Missing data on diet quality	1 (0.5%)
Final Sample Size	**140 (75.5 %)**

* Participants may have one or more exclusion criteria.

Descriptions, classification, and considerations for analysis as well as validity are provided below for sleep timing (onset and wake time) as the exposure variable, diet quality and physical activity as outcome variables, and variables considered as covariates. Classification of study variables is presented in Table 2.

Exposure Assessment – Sleep Timing (onset and wake time)

The exposure of interest was sleep timing, measured by the UMVDS lifestyle questionnaire. Participants were asked two separate questions regarding the time they went to bed the night before the clinical visit and the time they woke up on the day of the visit. Specifically, "What time did you go to bed last night?" and "What time did you get out of bed this morning?" Responses were self-reported in hours and minutes.

Sleep timing was comprised of two components sleep onset (or the time participants went to bed) and sleep wake time (or the time participants woke up). Sleep timing was divided into four categories: 1) Early sleep onset, Early wake time (EE), 2) Early sleep onset, Late wake time (EL), 3) Late sleep onset, Early wake time (LE), and 4) Late sleep onset, Late wake time (LL).

We set the cutoff for early and late sleep onset based on the median time participants in our study reported going to bed (median = 12:15 am). Participants were categorized as having early sleep onset if they reported going to bed at or before 12:15 am (range 8:30 pm to 12:15 am) and categorized as having late sleep onset if they reported going to bed after 12:15 am (range 12:16 am to 4:07 am). We set the cutoff for early and late wake time based on the median of the time participants reported waking up (median = 7:30 am). Participants were categorized as having an early wake time if they reported waking at or before

7:30 am (range 4:00 am to 7:30 am) and categorized as having a late wake time if they reported waking up after 7:30 am (range 7:36 am to 9:35 am). Sleep timing was categorizes as a categorical variable in our primary analysis.

In secondary analysis, sleep onset and sleep wake time were analyzed separately in quintile categories. There may be inherent differences between participants who went to bed very early, for example 8:30 pm, and participants who went to bed at 12:15 am or even later that could confound our results. For instance, participants going to bed later at night might have unhealthier habits associated with increased late night calorie consumption, such as drinking more alcohol or snacking more (Chaput et al., 2011a; Chaput 2013). With regards to energy expenditure, they might be less physically active in general because of the potential fatigue caused by late sleep onset time. The difference between these two types of participants might be strikingly different with regards to characteristics, dietary habits and physical activity levels than when comparing participants whose sleep onsets are closer, for example 10:00 pm and 11:00 pm. Based on our initial categorization using median values in our study participants, we would not be able to detect an association between low diet quality and early sleep onset if such a difference in associations exist. To examine differences between extreme sleep onset and wake time values, we analyzed sleep onset and separately wake time in quintile categories. We also analyzed sleep onset (early onset versus late onset) and separately wake time (early wake time versus late wake time).

Sleep timing (onset and wake time) was analyzed as a categorical variable.

Validity of Exposure Assessment – Sleep Timing (onset and wake time)

Compared to objective measurements of sleep, such as actigraphy or polysomnography, self-reported sleep duration has been shown to be longer, especially in those who are at the lower end of sleep duration, possibly because they spend more time in bed than actually sleeping (Lauderdale et al., 2008; Magee & Hale 2012; Walsleben et al., 2004). Most of the studies on sleep have asked questions about sleep duration, such as "How many hours of sleep do you get on average a night?" but few have evaluated sleep timing and the ones that have examined sleep timing, have asked about the participants' sleep onset time and wake time but have used it to calculate sleep duration and usually the focus of their studies has been the average sleep duration over a long period of time (Lauderdale et al., 2008).

Lauderdale et al. (2008) compared self-reported sleep to actigraphic measurements among non-pregnant participants of the CARDIA study at year 15, whose age range at recruitment for CARDIA was 18 – 30 years old. Their results showed that self-reports were on average 50 minutes longer than objective measurements. Mean measured sleep explained 20 percent of the variation ($r^2 = 0.20$) in self-reported habitual sleep, a correlation of 0.45, which is considered a moderate correlation. Combining the effects of bias and calibration, participants who slept 5 hours, on average reported 6.29 hours of sleep and participants who slept 7 hours reported 7.31 hours. They also compared actigraphic measurements to the reports of sleep on single-night sleep. The bias for a single night was 0.63 hours (38 minutes), with subjective reports longer than measured sleep. For each additional hour of sleep recorded, the report of sleep duration increased by 35 minutes. Measured sleep explained 36% of the variation in the reported sleep for a single night, a correlation of 0.60.

On the other hand, one study (Knutson & Lauderdale, 2007) compared self-reported sleep to time diaries among a sample of 767 male and 779 female subjects between the ages of 10 and 19 years. Time diaries, which have been reported to be more accurate than sleep-reports (Juster et al., 2003; Magee & Hale, 2012) provide detailed information concerning all activities during a 24-hour period, where participants are asked to record the activity they were involved in and the duration of activity. Their findings showed that self-reports were about 60 minutes shorter than the length of sleep reported on sleep diaries. The modal response was 8 hours for self-reported sleep and an average of 9 hours for time-diary sleep. The Pearson's correlation coefficient between the 2 measures was 0.27 ($P < 0.001$). The β coefficient for time-diary sleep from the adjusted regression analyses that predicted self-reported sleep was 0.20 ($P = 0.002$), indicating that every additional hour of time-diary sleep was associated with 12 minutes of additional self-reported sleep.

Patel et al. (2004) validated their sleep duration question ("How many hours of actual sleep do you get in a 24-hour period"?) by comparing it to a 1 week sleep diary among 82,969 participants of the Nurses' Health Study, who were female nurses, aged 30 to 55 years. They found strong correlations between the question and the results from the diary. The Spearman correlation between average time spent sleeping by sleep diaries and time reported on the sleep duration question was 0.79 ($P < 0.0001$).

Overall, sleep questions seem to have a reasonable correlation with objective measurements, such as actigraphy, as well as subjective measures that are reliable, including sleep diaries. Single self-report of sleep has been shown to underestimate sleep duration by a small margin (Knutson & Lauderdale 2007; Meyer et al., 2012).

Outcome Assessment – Diet Quality

Using the dietary information obtained from the FFQ, diet quality was assessed by the 2010 Dietary Guidelines for Americans Adherence Index (DGAI-2010) originally developed by Fogli-Cawley et al. (2006). The tool was first developed assessing adherence to each of the key dietary recommendations from the 2005 Dietary Guidelines for Americans and it has been updated to measure adherence to the 2010 Dietary Guidelines for Americans (Troy & Jacques, 2012; Troy et al., 2013). DGAI-2010 is a continuous score and ranges from 0 (worst) to 100 (best) adherence to the 2010 Dietary Guidelines for Americans (USDA, 2010). Components of the DGAI-2010 are presented in Appendix D and described briefly below. The DGAI-2010 includes five main food groups (i.e., vegetables, fruit, protein, grains, and dairy) with subgroups of some food groups that have been shown to have different beneficial or non-beneficial effects on the body. It should be noted that total grains are made up of two subgroups called refined grains that includes white bread, as well as sweetened refined grains such as cookies and cakes and whole grains that includes whole grain cereals and breads. The DGAI-2010 includes items that are nutrients such as eating less than 10 percent of calories from saturated fat and foods such as eating low fat and non-fat dairy. There is also a category for variety based on protein sources and vegetable and fruit intakes. For protein, there are 3 subgroups called “seafood, meats and poultry and eggs”, “nuts, seeds”, and “soy products”. For vegetables there are dark green, orange/red, beans and peas, starchy vegetables, and other vegetables. DGAI-2010 is a continuous score and the score for each category ranges from 0-1 as a proportion of the target and the total score for all the components have a possible range of 0 to 100. For non-energy dense foods, if intake is over the recommendation, the score is set to a maximum of 1. For energy dense foods such as starchy vegetables, there is an overconsumption penalty; that is, if the intake exceeds the recommended amount, the score decreases proportionally by the amount over the target that is consumed with the lowest possible value set to zero.

Since no other study had looked at the diet quality using DGAI-2010 in the age range of our population and there was no record of high and low levels of diet quality in young women, we used the median DGAI-2010 score in our population to determine the cutoff for high versus low diet quality. The median DGAI-2010 score was 69.30; we rounded up to set the cutoff for diet quality at DGAI-2010 = 70. Participants with DGAI-2010 scores equal to or above 70 were categorized as high diet quality and participants with DGAI-2010 below 70 were categorized as having a low diet quality.

Diet quality was analyzed a continuous variable and as a categorical variable.

Validity of Outcome Assessment – Diet Quality

The authors who developed DGAI used face validity; that is, the ability of an instrument to relate with factors in ways that are expected based on prior experience, to validate the DGAI. The DGAI score relates to many participant characteristics and to nutrient intake as expected. Participants in the highest DGAI quintile category were more likely to be women (77 vs. 26%, $P<0.001$), older (57 vs. 51 y, $P<0.001$), multivitamin supplement users (40 vs. 23%, $P<0.001$), and have lower BMI (26.4 vs. 28.3 kg/m^2, $P<0.001$), and were less likely to be current smokers (8 vs. 35%, $P<0.001$). Based on previous studies, women, older individuals, nonsmokers, leaner individuals, and those who used vitamin supplements, consume a higher quality diet, which was seen with DGAI (Fogli-Cawley et al., 2006). These results are consistent with the finding of previous studies using other indices, such as HEI. Therefore, the authors concluded that DGAI demonstrates face validity (Fogli-Cawley et al., 2006).

Dietary data obtained in the UMVDS was collected by the Willett FFQ that has previously been validated (Willett et al., 1985; Rimm et al., 1992; Subar et al., 2001). In a validation study for Willett FFQ, participants were recruited from the Nurses' Health Study to compare the results to series of four week diet records that is a reliable index, previously validated (Subar et al., 2001). Overall, only three percent were misclassified into extreme quintiles, making this questionnaire valid and reliable. The Willett FFQ has been shown to overestimate intake in women but when compared to two other food-record instruments, it has shown validity after adjustment for energy intake (correlation coefficient = 0.58 for the Willett FFQ) (Subar et al., 2001).

For the purposes of this study, DGAI-2010 and the Willett FFQ have the validity to show us acceptable results that have high correlations with the true diet quality and intake of participants (Fogli-Cawley et al., 2006; Rimm et al., 1992; Subar et al., 2001; Willett et al., 1985).

Outcome Assessment – Physical Activity

Physical activity was measured by four sections included in the UMVDS lifestyle questionnaire. For section 1, participants were asked to report the time spent in ten different types of recreational activities (e.g., “During the past month, what was your average time per week spent at each of the following recreational activities?”). In the second and third sections, participants were asked to report their outdoor activities in the daily life (e.g., “What is your usual walking pace outdoors?” and “How many flights of stairs [not individual steps] do you climb daily?”). Section 4, focused on hours per week spent on non-recreational activities, such as watching TV and using computer that would contribute to their sedentary activities (see Appendix B).

Activities were assigned Metabolic Equivalent of Task (MET) values based on different intensity levels associated with an appropriate activity category, such as sleeping (1.0 MET), walking indoors (4.0 MET), mixed standing/walking at home/work (2.5 MET), sitting at home/work (1.0 MET) (Ainsworth et al., 2011) (see Appendix C).

To set the criteria for participants meeting and not meeting the 2008 Physical Activity Guidelines for Americans (USDHHS, 2008), we chose the minimum requirement for meeting the guidelines and specified having at least aerobic score of 500 MET-minutes per week plus resistance training of 1-1.5 hours per week. Failure to meet any of the two criteria resulted in participants being categorized as not meeting the 2008 Physical Activity Guidelines. The reason for choosing 1-1.5 hours of resistance training is based on the nature of the questions asked for physical activity on the UMVDS lifestyle questionnaire. The participants were asked to report their average physical activity per week in 10 categories of time. An example follows: “Recreational activity: Time per week spent doing weight training or resistance exercise” and the multiple choices that they were given to choose from were “zero, 1-4 minutes, 5-19 minutes, 20-59 minutes, one hour, 1-1.5 hours, 2-3 hours, …”. The closest choice to meeting the minimum recommendations for resistance training was 1-1.5 hours and we decided not to get an average of 1-1.5 and 2-3 hours category, so as not to manipulate data in a way that had the possibility of making it inaccurate. The aerobic activities were a combination of moderate and vigorous intensity activities that were available on the questionnaire, which included “walking or hiking, jogging, running, bicycling, aerobics/dance/rowing, tennis/squash/racket sports, lap swimming, martial arts or law mowing, and yoga or pilates".

Physical activity questions from the UMVDS lifestyle questionnaire are provided in Appendix B. The MET values used in the UMVDS for type of physical activity are provided in Appendix C.

Physical activity was analyzed as a continuous variable and as a categorical variable.

Validity of Outcome Assessment – Physical Activity

The questions on physical activity were adapted from a questionnaire on physical activity and inactivity used for the Nurses' Health Study II, which has been previously validated (Wolf et al., 1994) by comparing the scores of the developed questionnaire to the data obtained from four past-week activity recalls and four 1-week activity diaries collected over a year, as reference methods. These questionnaires were mailed to the participants every 3 months over the course of a year. Another questionnaire was mailed to the participants by the end of the year, asking about the activities over the past year. The 2-year test-retest correlation was 0.59 (CI: 0.48 – 0.69). Correlations between the recalls and diaries with the questionnaire were 0.79 (CI: 0.64 – 0.88) and 0.62 (CI: 0.44 – 0.75), respectively. The physical activity questionnaire used in this study has a relatively high correlation with other reliable measures of physical activity (Wolf et al., 1994).

Covariate Assessment

Covariates were selected based on their potential to act as a confounder. Linear regression was used to test the associations of covariates that, based on previous literature, were expected to have strong associations with sleep timing, diet quality and/or physical activity. Age, race/ethnicity (Li & Wen, 2013), BMI, energy intake, cigarette smoking (McNamara et al., 2014), alcohol consumption (Popovic & French, 2013), caffeine intake (Lodato et al., 2013; Lohsoonthown et al., 2013; Roehers & Roth, 2008), average sleep duration, and belonging to a sports team were considered as covariates (Bel et al., 2013; Erlacher et al., 2011; Golley et al., 2013; Gregersen et al., 2011; Haghighatdoost et al., 2012; St-Onge et al., 2010).

Among girls, African-Americans have been shown to have the lowest level of physical activity (Gregersen et al., 2011; St-Onge et al., 2010). There have been correlations between energy intakes with diet quality (Haghighatdoost et al., 2012). Smokers have been shown to have both lower physical activity and diet quality levels (Gregersen et al., 2011; McNamara et al., 2014). Alcohol consumption has been associated with lower diet quality levels (Lodato et al., 2013) and increase in sleep disturbances (Popovici & French, 2013). Caffeine affects sleep and can also affect physical activity (Lohsoonthown et al., 2013; Roehrs & Roth 2008). Sleep duration has been associated with physical activity and diet quality as previously stated (Haghighatdoost et al., 2012; Stone et al., 2013). Being a member of a sports team would positively affect physical activity (Erlacher et al., 2011).

The cutoff for sedentary behavior was considered to be at least six hours a day based on previous data (Hutchesson et al., 2013; Patel et al., 2010) and was based on their answer for 3 questions on the UMVDS questionnaire: 1) how many hours a week they spent sitting at the computer, at work, at school, or while driving; 2) how many hours a week they spent sitting reading, eating, or talking; 3) how many hours a week they spent sitting watching TV.

For covariates, missing values were classified as a “no” response. Specifically, participants that did not respond to the question on being a member of a sports team (n=150 or 81.08% prior to exclusions) were categorized as “not being a member of a sports team”. After the exclusion, the number of participants who were members of a sports team was six (4.29%).

The covariates that we considered in our models looking at diet quality and physical activity when looking at diet quality as a continuous outcome were age, BMI, sleep duration from the night before the clinical visit, current smoking status, total energy intake, alcohol intake, total physical activity (aerobic plus weight resistance training), and sedentary behavior. We used forward selection in choosing the final covariates to be included in our model. We added the covariates that had the potential of having an association with our exposure or either one of our outcomes one by one to the initial model and looked at the change in trends among different sleep categories, as well as P-values to detect the strength of the contribution of that covariate, to decide to either keep or eliminate the covariate in the model. We looked at the P-value of the association of covariate and smaller values (less than 0.5), were considered to be included in the final model, as long as their association remained strong when entering other covariates in the model. We also looked at the beta for our outcomes across the sleep timing categories and if a covariate made the association of exposure with outcome stronger (P-value < 0.05), we considered keeping that covariate in our final model. Based on the strength of the associations, covariates included in the model examining the association between sleep timing and diet quality were energy intake, alcohol intake, current smoking status, and sedentary behavior. Because we wanted to examine associations between sleep timing and diet quality independent of BMI and sleep duration, we included BMI and sleep duration in final models. The covariates included in the model examining the association between sleep timing and meeting the National Physical Activity Guidelines were age, race, smoking status, BMI, sleep duration, and being a member of a sports team. Adjustments for final models are listed in the results and tables.

After considering relationships between different covariates, the only significant interactions found were between sleep duration and energy intake, and smoking and energy intake. As energy intake is incorporated in one of our exposures (diet quality), we decided not to include the interactions in our final model.

Table 2. Classification of Study Variables: UMass Vitamin D Status Study, Phase I, 2006 - 2008.

Name	Description	Type
Exposure Variables		
Sleep timing	Sleep timing	Categorical
	0 = Early sleep/Early Wake	
	1 = Early sleep/Late Wake	
	2 = Late sleep/Early Wake	
	3 = Late sleep/Late Wake	
Sleep timing extremes	Sleep timing in quintiles	Categorical
Outcome Variables		
Physical Activity	Level of activity	Dichotomous
	0 = Does not meet national guidelines*	
	1 = Meets national guidelines**	
Physical Activity	Level of activity	Continuous
Diet quality, measured by DGAI-2010	0 = Low Diet Quality, DGAI-2010 < 70	Dichotomous
	1 = High Diet Quality, DGAI-2010 ≥ 70	
Diet quality, measured by DGAI-2010	Diet quality	Continuous
Potential Covariates		
Age (years)	Subject's Age	Continuous
Race	Subject's race	Categorical
	1 = white	
	2 = other	
BMI (kg/m^2)	Subject's BMI	Continuous
Energy intake (kcal/d)	Subject's energy intake based on FFQ	Continuous
Current smoking status	Currently smokes	Dichotomous
	0 = No	
	1 = Yes	
Alcohol intake (gm/d)	Average alcohol intake based on FFQ	Continuous
Caffeine (mg/d)	Subject's caffeine intake based on FFQ	Continuous
Sleep duration (hours)	Sleep duration the night before clinic exam	Continuous
Member of sports team	Are you a member of an organized sports team or group?	Dichotomous
	0 = No	
	1 = Yes	
Sedentary behavior	Sedentary behavior	Dichotomous
	0 = Low, Sitting time < 6 h/d	
	1 = High, Sitting time ≥ 6h/d	

* <500 MET-min/week of aerobic exercise and/or <1.5 hours/week of resistance training
** ≥ 500 MET-min/week of aerobic exercise plus ≥ 1.5 hours/week of resistance training

CHAPTER 4

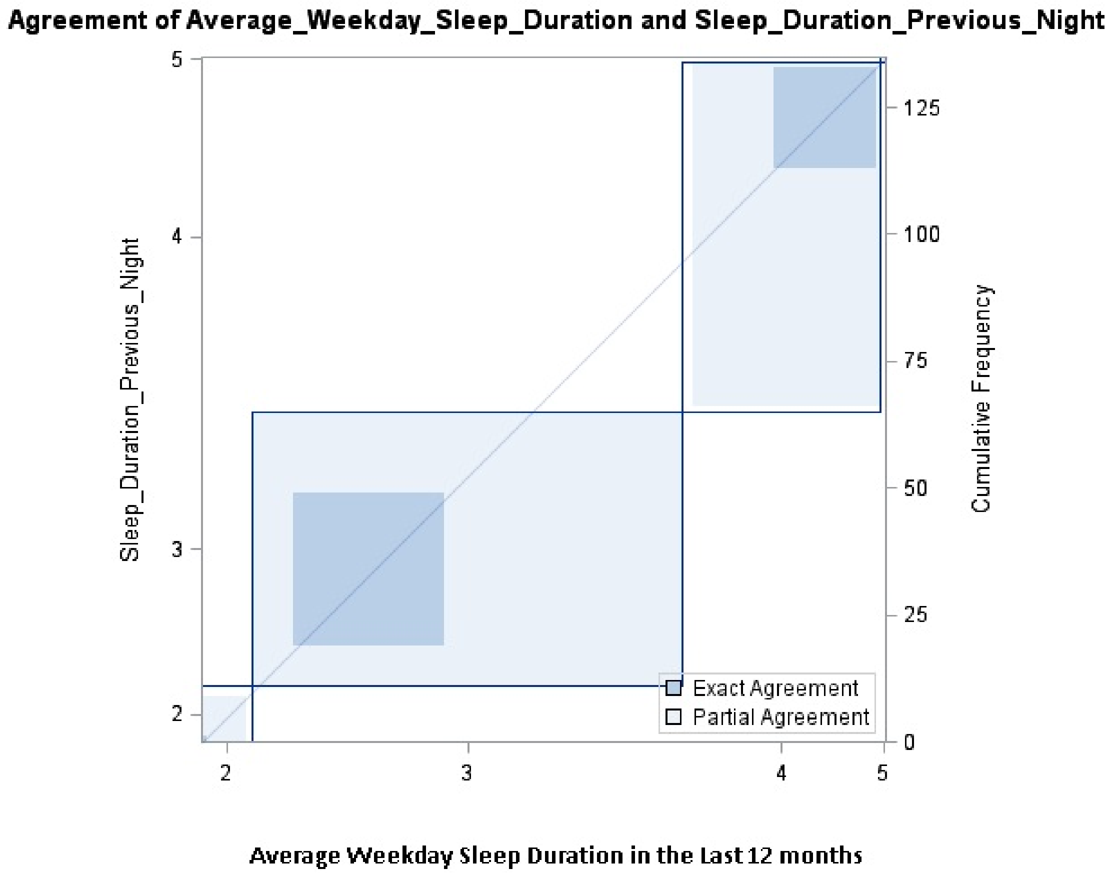
STUDY LIMITATIONS

Non-Differential Misclassification

a. Non-Differential Misclassification of Exposure

Prior studies have found that individuals with short sleep durations tend to over-report their sleep duration as compared to individuals with longer sleep duration (Lauderdale et al, 2008; Xiao et al, 2013). However, while the previous studies looked at the sleep duration over the past month, our study asks about sleep timing the night prior to the clinical visit which may reduce the likelihood of non-differential misclassification. There is a chance of over-reporting sleep duration if the time participants reported for sleep onset was the time they went to bed and not the actual time that they fell asleep. Self-reported sleep and objective sleep have been moderately correlated and the mean difference between objective and subjective sleep duration was only 0.3 hours (or 20 minutes) further reducing concerns regarding non-differential misclassification of the exposure (Knutson & Lauderdale, 2007). If this type of misclassification has occurred, it would bias our results towards the null. Comparing two different sleep reports (the night before the study and usual sleep) has minimized the possibility of non-differential misclassification of the exposure.

Sleep timing, sleep onset and sleep wake times, is a variable behavior. To examine misclassification of sleep timing, we compared the sleep duration of the night before the clinical visit (based on self-reported sleep onset and wake time) to the participants' usual sleep duration, which is asked separately on the questionnaire, to assess if the reported sleep timing for the prior night was representative of their usual sleep onset and wake time. Usual sleep duration was assessed by a question on the UMVDS lifestyle questionnaire and the participants were given different choices to choose from (<3 hours, 3-4 hours, 5-6 hours, 7-8 hours, 9-10 hours, >10 hours) and we categorized the sleep duration from the previous night to check the concordance. This might explain some of the discordance seen in the graph below because categorizing sleep duration into categories only gives a range and not the exact time for sleep onset and wake time. We only used the report for "weekday sleep" average sleep duration as the clinical visits had taken place on a weekday and even if the clinic visit was on a Monday, we decided that a Sunday night sleep is more similar to a "weekday" sleep than a "weekend" sleep duration. Although we found a high concordance between night before and average sleep duration, it is possible that the sleep onset time in some cases might not have been their usual sleep onset time. A prospective study design will result in having more confident results in terms of sleep timing.



b. Non-Differential Misclassification of Outcome – Diet Quality

Diet quality was assessed using the DGAI-2010 by analyzing the data gathered from the Willett FFQ. Self-report of diet may be inaccurate due to under-reporting of specific foods and some macronutrients such as protein especially in women (Freisling et al., 2012; Murakami et al., 2012) and over-reporting foods that are perceived as being beneficial, such as fruits and vegetables (Freisling et al., 2012; Michels et al., 2005). In addition, both obese and non-obese women tend to under-report their consumption of carbohydrates and sweets (Poppitt et al., 1998). If participants over- or under-reported their macronutrient or food intakes, participants could be misclassified into the incorrect category for dietary quality and bias the results of the study towards the null. The current study uses a validated FFQ (Willett et al., 1988) and measure of diet quality (Fogli-Cawley 2006) reducing non-differential misclassification in diet quality.

c. Non-differential Misclassification of Outcome – Physical Activity

Physical activity is measured by self-reported questionnaire designed for the UMVDS. A study conducted by Hagstromer et al. (2010), showed significant but moderate to low correlation between objective and subjective measurements of physical activity. Participants tended to over-report their vigorous physical activity, as well as their sitting time. Given that higher physical activity is perceived as a beneficial lifestyle habit and participants might tend to over report their activity levels, physical activity may have been misclassified, which would bias the results of the study towards the null. The current study assessed physical activity from questions that were adapted from a previously validated physical activity questionnaire (Wolf et al., 1994), reducing non-differential misclassification in physical activity.

Bias

a. Information Bias

The information on our exposure, sleep timing (i.e., sleep onset and wake time), and both our outcomes, diet quality and physical activity, are based on self-report. As many individuals are limited in recalling information, recall bias is the primary type of information bias that may have occurred in our study.

Participants' recall of information is subject to error because of their retrospective nature (Magee & Hale, 2012; Nielsen et al., 2011). If this is the case for our exposure, some of the participants may have been incorrectly classified into sleep timing categories. Recall bias may have occurred if participants, who report an earlier sleep onset, were possibly also the ones who would have wanted to report more healthy behaviors in general including more desirable dietary intake, such as higher vegetable and fruit consumption. This may lead to an overestimation of the association between early sleep and higher diet quality.

Participants who are more health conscious and have a set schedule for their sleep time, meals (affecting their diet) and physical activity, are more likely to remember their exact sleep time and also, their dietary intake and physical activity, as compared to participant who are not concerned about healthy lifestyle choices as much. If this has occurred, it might have caused an overestimation of the relative risk between early sleep and diet quality and meeting National Physical Activity Guidelines. The use of a validated FFQ, diet quality tool, and physical activity questionnaire has minimized recall bias.

b. Selection Bias

It is possible that women who go to bed early and have higher diet quality and meet physical activity guidelines are more concerned about their health and consequently may be more likely to take part in studies concerning their health. This could bias our results away from the null. However, as we have used the UMVDS study, where the primary objective was to look at the association of premenstrual syndrome and vitamin D status in the participants, it was less likely that selection bias would occur in our study. Although in the consent form it is stated that among the benefits of the study is that the participants will learn about the strengths and weaknesses of their diet, as this was not the main objective of the overall UMVDS study, any selection bias that has occurred is likely to be minimal.

c. Temporal Bias

Given the limitation cross-sectional studies have in establishing temporal relationships between exposures and outcomes, we cannot infer etiologic causality based on our study. Our results indicated that subjects, who have earlier sleep onset and earlier wake time, were more physically active or had better diet quality. However, as physical activity has been shown to be positively associated with better sleep quality, the results may have occurred if participants who exercised more went to bed earlier or woke up early to exercise. Similarly, better diet quality may contribute to sleep habits. Because cross-sectional studies can only capture events at the same time, we cannot be sure if sleep timing is affecting physical activity and diet quality or that physical activity and diet quality are affecting sleep timing. Aside from this fact, there is a possibility of correlation rather than a causal effect; that is individuals with more favorable sleep timing habits are the same individuals who pay attention to their dietary intakes and physical activity.

Confounding

Confounders recognized in the literature and available in the dataset were evaluated in the final statistical models. Although we controlled our results for numerous covariates, there is the possibility for residual confounding by poorly measured covariates. In addition, there is the concern of unmeasured confounders.

Several aspects of sleep habits may influence sleep onset and wake times including use of sleep aids or napping. Sleeping medication or other types of sleep aids may have altered participants' natural sleep timing habits. Napping has been shown to affect circadian rhythms and possibly shift sleep onset (Drewnowski, 2012), more likely to a later time. A previous study by Grandner et al. (2010) showed that napping was related to higher fat intake that adversely affects diet quality. This may lead to an overestimation of relative risk between sleep timing and diet quality. We did not have data on participants' sleep aid use or napping habits and therefore could not control for these variables in our analysis.

We did not assess the activities the participants were involved in the night before they filled out the questionnaire, immediately prior to the time period that they were asked to report their sleep onset and wake time. Some of the possible activities the participants could have been involved in that might have affected their sleep timing include being awake late at night to study for an exam, having coffee or alcohol before sleep time, or attending a party. Our inability to control for sleep disturbing behavior, if it is a confounder, could have resulted in underestimation of relative risk. In addition, the UMVDS study may have manipulated the participants' usual sleep timing behavior. The participants in the UMVDS were supposed to have their clinical visit in the morning in a fasting state that may have altered their usual sleep timings, as they may have had to wake up earlier than usual or have gone to bed earlier than usual to be able to wake up on time in the morning.

Previous studies have shown "preference" for later sleep onset to be associated with poor health behaviors such as higher alcohol intake and smoking (Baron et al., 2011; Giannotti et al., 2002; Wittmann et al., 2006). However, we do not have the information to assess preference versus a sleep disturbing behavior.

Another confounder that we were not able to control for, as we did not have the data for it, was income. Individuals with lower incomes are more likely to have poorer diet quality (Drewnowski, 2012). At the same time, low socioeconomic status, including poverty, has been associated with sleep disturbances such as difficulty falling sleep or staying sleep (Grandner et al, 2013).

Seasonality may influence both sleep and physical activity. A recent study has shown seasonal variation among adults in terms of sleep, physical activity, and sedentary behavior (O'Connell et al., 2014). Based on the findings of this study, sedentary behavior and total time in bed, sleep duration, were increased during wintertime. We did not include time of year that the participants completed their visit for this study but it may be possible that some of the participants in the EL group had completed their visit during wintertime. Similarly, season will likely influence physical activity type and duration in some participants and recent activity may affect self-reporting of physical activity levels which were intended to reflect physical activity over the past year. Therefore, if our theory of EL participants joining the study in wintertime might be true, it may have also affected their report on their physical activity; that is individuals tend to report their recent behavior and had their physical activity reduced due to the weather, they were less likely to report their true average of physical activity that may have been higher.

CHAPTER 5

SIGNIFICANCE

If sleep timing is associated with better diet quality and higher physical activity, then sleep timing recommendations may contribute to improve these outcomes and potentially improve BMI status. Helping women reach optimal sleep targets may lower the rates of overweight and obesity and prevent obesity-related diseases such as CVD and T2DM.

CHAPTER 6

STATISTICAL ANALYSIS

All the statistical analyses in this study were conducted using SAS statistical software (version 9.3; SAS Institute, Cary, NC). P-values less than 0.05 were considered as statistically significant unless otherwise stated.

SAS PROC UNIVARIATE with histogram was used to assess the normality of data for diet quality and physical activity as continuous variables. Diet quality was normally distributed. The distribution of physical activity values was skewed to the left and log transformation was used to improve normality of the data.

Subject characteristics were assessed across sleep timing categories. Differences between continuous variables were assessed by SAS PROC GLM and categorical variables were assessed by SAS PROC LOGISTIC.

As described earlier in the Methods section, median values of corresponding variables and national guidelines when available were used to determine categories for sleep timing, diet quality and physical activity. Briefly, the cutoff for early versus late sleep onset was set to 12:15 am and the cutoff for early versus late wake time was set to 7:30 am. We present the number and percent of participants within each category of sleep timing (see Table 5).

High diet quality was set to DGAI-2010 scores equal to or above 70 and low diet quality was set to DGAI-2010 scores below 70. For physical activity, meeting the 2008 Physical Activity Guidelines for Americans was defined by at least 500 MET minutes per week of aerobic exercise plus 1.5 hours per week of resistance training. We present the mean (SD) for DGAI-2010 and total physical activity and the number and percent of participants in high versus low diet quality and meeting versus not meeting National Physical Activity Guidelines in Table 6.

We collapsed race/ethnicity into White and other, as most participants (85.4%) were Caucasian and few participants were in other racial/ethnic groups (1.0% black/African American, 5.9 Asian, and 7.5% other).

To examine the differences in the distribution of diet quality and total METs of physical activity as continuous variables across the four sleep timing categories (EE, EL, LE and LL), one-way analysis of variance test for linear trend was used. Unadjusted and multivariable adjusted models were run and diet quality was adjusted for BMI, sleep duration, current smoking status, total energy intake, alcohol intake, and sedentary behavior and separately for sleep timing and total physical activity was adjusted for BMI, sleep duration, current smoking status, total energy intake, and being a member of a sports team.

Chi-square test was used to examine the association between sleep timing categories and high and low diet quality and meeting National Physical Activity Guidelines. If the expected cell counts were less than 5, Fisher's exact test was conducted instead of Chi-square analysis for the 2 by 2 tables. The Fisher's exact test was used in the association of sleep timing with physical activity as a categorical outcome, race, smoking status, and being a member of a sports team. P-values are shown to present the differences in distributions for all covariates. P-values less than 0.05 were considered as statistically significant results. Based on the analysis, categories were collapsed if needed. Multivariable adjusted models were run for sleep timing and diet quality adjusted for BMI, sleep duration, current smoking status, and total energy intake and separately sleep timing and physical activity adjusted for BMI, sleep duration, current smoking status, and being a member of a sports team. The results are presented as unadjusted and multivariable adjusted odds ratio (OR) with the corresponding 95% confidence interval (CI).

Linear regression test was used to examine the association between sleep timing categories (EE, EL, LE and LL) and diet quality and physical activity as continuous variables in the unadjusted model (Table 8). The results are presented with standard errors (SE) and p-values. Logistic regression test was used to examine the association between sleep categories and diet quality and physical activity as categorical variables (Table 9). The results are presented as odds ratio (OR) with the corresponding 95% confidence interval (CI).

The association between the independent variable (sleep timing) and dependent variables (diet quality and physical activity as continuous variables) was examined using multivariable linear regression. Multivariable logistic regression was used to model the association of sleep timing with diet quality and physical activity as categorical variables. Both linear and logistic models were controlled for covariates. Multivariable adjusted standard errors (SE) are presented with the corresponding p-values for the association of sleep timing and diet quality and physical activity as continuous variables in Table 8 and the multivariable adjusted OR with the corresponding 95% CI for the association of sleep timing and diet quality and physical activity as categorical variables are presented in Table 9 and Table 10, respectively.

All the covariates listed in Table 1 were examined in each model separately. The final covariates included in each model are listed in the Results Section.

We further analyzed our data based on different categorization of sleep timing. To examine the extreme ends of the sleep timing, we categorized participants into quintile categories based on sleep onset, and in separate models, categorized them into quintile categories based on wake time.

To examine the association of wake time regardless of sleep onset, and to examine the association of sleep onset time regardless of wake time, we analyzed data in two additional models. In one model, we categorized participants into early sleep onset versus late sleep onset and examined the association of sleep onset time with diet quality and separately physical activity. In separate models, we categorized participants into early wake versus late wake time and examined the association of wake time with diet quality and separately physical activity.

Sensitivity Analysis

Almost a third of our final sample had reported having dry cough at night for one or more nights a week over the past year. Dry cough might have had an effect on their sleep and the ability to fall sleep or stay sleep but not only did we not know the severity or the frequency of the dry cough. By excluding participants with affirmative responses to having a dry cough, we would have lost a significant number of our sample size. Therefore, we conducted a separate analysis to excluded participants who reported experiencing dry cough for one or more nights per week over the last 12 months. To examine the potential influence of dry cough on results, we compared our associations and trends before and after exclusion of participants with dry cough.

To assess a possible effect modification by BMI, we entered interaction terms for sleep timing by BMI categories (underweight <18.5 kg/m^2, normal range18.5 - 25 kg/m^2, and overweight/obese >25 kg/m^2) into multivariable linear models for dietary quality and separately for physical activity. We further stratified our multivariable regression models for diet quality and physical activity by BMI categories.

Power Analysis

Previous research shows that approximately 80% of US adults do not meet the recommendations for overall physical activity (CDC, 2013). Also, it has been shown that 90% of American women aged 19 – 30 years do not meet the federal guidelines for diet intake (Krebs-Smith et al., 2010). Sleep timing was analyzed using 4 categories, and therefore we expected equal numbers to be in each category. This resulted in a ratio of approximately 1:1 in the exposed quartile and the unexposed quartile. Table 3 presents the power of a two-group t test with a 0.05 two-sided significance level to detect the clinically meaningful mean difference assuming a standard deviation of 1.7. For the multivariable logistic regression modeling the association between sleep timing and physical activity levels, given a sample size of 140 women, we have a power of 80% to detect a relative risk of approximately 4.3 or larger, with 95% confidence (Table 4).

Table 3. Power to Detect the Effect of Sleep Timing on Diet Quality with a 0.05 Two-Sided Significance Level: UMVDS, 2006 – 2008.

EE vs. LL	Diet Quality
Standard Deviation	1.7
Mean Difference	3.6
Two Sample Size	90
Alpha	0.05
Power	>.999

Table 4. Power to Detect the Effect of Sleep Timing on Not Meeting the Physical Activity Guidelines for an Odds Ratio with 95% Confidence: UMVDS, 2006 – 2008.

OR	Power
3.2	60%
3.7	70%
4.3	80%
5.3	90%

CHAPTER 7

RESULTS

More than one-third of our participants fell into the EE group, with 15.0% in the EL group, 19.2% in the LE group, and 30% in the LL group (see Table 5). Nearly half of participants, 48.5% had high diet quality score that is DGAI-2010 score of 70 or above, and 32.9% participants met the National Physical Activity Guidelines (see Table 6). The number and percent of participants with high versus low diet quality scores and meeting or not meeting the National Physical Activity Guidelines are presented in Table 6.

The majority of participants (73.5%) fell in the normal BMI category (18.5 – 24.9 kg/m^2), with a mean BMI of 22.8 kg/m^2 (SD = 3.0 kg/m^2). Mean age was 21.5 years (SD = 3.2 years). Mean energy intake was 2122.5 Kcal (SD = 675.3 Kcal). The mean diet quality score was 68.9 (SD = 6.5) and mean total physical activity was 3544.4 MET-minutes per week (SD = 3329.5 MET-minutes per week) was relatively high for this age group. Mean sleep duration from the night before of 7.0 hours (SD = 1.1 hours) and falls within the recommended sleep duration of 7-8 hours per night (Krueger et al., 2009). Mean caffeine intake was 86.0 mg/day (SD = 86.7 mg). Mean alcohol intake was 5.9 gm/day (SD = 8.7 gms). There were a total of 5.7% current smokers. Most participants (86.4%) were Caucasian. Only 4.3% participants reported being a member of a sports team. Subject characteristics across sleep timing categories are presented in Table 7.

In the unadjusted model, compared to the referent group (EE), participants in the EL category had the lowest diet quality, though not statistically significant (β = -2.7, P = 0.1) (see Figure 1).

In the assessment of covariates, age, race and BMI were not significant in multivariable linear regression models and did not alter the results and across the sleep timing categories in terms of diet quality, possibly because age, race, and BMI were relatively homogenous. In other words, participants were almost of the same age, most of them fell in the Caucasian category for race and almost all of them fell in the normal BMI category. Energy intake was significantly and negatively associated with low diet quality across sleep categories. Smoking was negatively associated with diet quality, with the lowest in the EL group. Caffeine, sleep duration, and sports team participation were also negatively associated with diet quality, though not significantly.

Unadjusted and multivariable adjusted models for sleep timing and diet quality as a continuous variable are presented in Table 8. Final models were adjusted for BMI, sleep duration the night before the clinical visit, current smoking status, total energy intake, alcohol intake, and sedentary behavior. After adjusting for the above covariates, both the LE (β = -0.77, P = 0.6) and LL (β = -0.85, P = 0.5) groups remained non-significant; however, the EL group had a statistically significant lower diet quality score 3.62 points compared with the EE group (β = -3.62, P=0.03).

We collapsed the four exposure categories into two groups based on wake time (early wake and late wake) or based on sleep onset time (early sleep and late sleep) and analyzed diet quality as a continuous variable. In multivariable models, the late wake group had a lower diet quality score (β = -1.3, P = 0.2) compared to the early wake group and participants, who fell in the late sleep onset category, had slightly lower diet quality scores compared to the early sleep onset group (β = - 0.3, P = 0.7) but the results were not significant.

The results for the logistic regression model to detect a possible association between sleep timing and diet quality as a categorical outcome (high versus low diet quality) are presented in Table 9. In unadjusted models, the EL group, was approximately 3 times more likely to have low diet quality (OR = 2.93, CI = 0.98 – 8.8) compared to the EE group, though results were not statistically significant. After controlling for BMI, sleep duration, current smoking status and total energy results became statistically significant with participants in the EL group nearly 5 times more likely to be in the low diet quality category (OR = 4.75, 95% CI = 1.35 – 16.61) compared to the EE group. The other two categories also had a higher OR of being categorized as low diet quality but the results were not statistically significant.

We collapsed the sleep timing categories into two groups based on sleep onset (early onset and late onset) and wake time (early wake and late wake) and analyzed diet quality as a categorical variable. Participants with late wake time were more likely to have low diet quality (OR = 1.9, 95% CI = 0.9 – 4.1). The results were not significant when collapsing the sleep categories based on sleep onset. Participants in the late sleep group had an OR = 0.8 for being in the low diet quality group (95% CI = 0.3 – 1.9).

We ran linear regression models to detect the possible association of sleep timing with total physical activity as a continuous outcome and results are presented in Table 8. The results were not significant in the unadjusted model but the EE group had the highest total physical activity and the LL group had the lowest (β= - 0.19, P = 0.4). After adjusting for BMI, sleep duration, total energy intake, and being a member of a sports team the results remained not significant (Table 8).

The results were slightly stronger when collapsing the sleep categories based on sleep onset time (early sleep versus late sleep). The late sleep group had lower physical activity compared to the early sleep onset group (β = -0.28, P = 0.19). The results did not change after collapsing the exposure groups into two groups based on wake time (early wake versus late wake). Late wake group had lower physical activity (β = - 0.06, P = 0.7) compared to the early wake group.

We used logistic regression to evaluate the association between sleep timing and physical activity as a categorical outcome. Compared to participants in the EE category of sleep timing, the OR for not meeting the National Physical Activity Guidelines in the EL category was 3.34 (95% CI = 0.9 – 11.3), LE was1.57 (95% CI = 0.6 – 4.1), and LL was 2.21 (95% CI = 0.9 – 5.3) presented in Table 10. After conducting the forward regression models to determine covariate selection, our final model included age, race, BMI, sleep duration, current smoking status, and being a member of a sports team. In multivariable models adjusted for covariates listed above, results for EL group became significant (OR = 4.03, 95% CI = 1.01 – 16.04), but the results for the LE group (OR = 1.5, 95% CI = 0.4 – 5.4) and the LL group (OR = 2.3, 95% CI = 0.9 – 6.2) remained roughly the same and not statistically significant. As mentioned earlier, participants were in the similar age and racial groups. Therefore, we decided to run our model without these two covariates. The results did not change substantially from adjusted models including race and age; the risk of not meeting the National Physical Activity Guidelines in the EL group (OR = 3.97, 95% CI = 1.03 – 15.2) remained statistically significant (Table 10).

After collapsing the sleep categories based on wake time (early wake versus late wake, regardless of sleep onset time), the OR for not meeting the National Physical Activity Guidelines in the adjusted model among participants with late wake time was 2.2 (95% CI = 1.01 – 4.8) and was statistically significant. Collapsing categories based on sleep onset (early onset and late onset) the OR was 1.5 (95% CI = 0.6 – 3.6) and remained not statistically significant.

After categorizing sleep onset time and wake time into quintiles to look at the most extreme ends of sleep timing on diet quality and meeting National Physical Activity Guidelines, there were no significant results found for diet quality. But in terms of meeting the physical activity guidelines, the participants in the fourth quintile for wake time were less likely to meet the National Physical Activity Guidelines (OR = 4.3, 95% CI = 1.4 – 13.4), compared to the first quintile.

Meaning that late wake time has a stronger correlation with not meeting the National Physical Activity Guidelines, compared to early wake time. The results remained significant after adjusting for BMI, sleep duration, current smoking status, and being a member of a sports team (OR = 4.3, 95% CI = 1.3 – 13.9). There were no significant results in terms of meeting the National Physical Activity Guidelines, according to the sleep onset time quintile categories. Looking at physical activity as a continuous outcome, there were no significant results across sleep onset time quintile categories. But the participants in the third wake time quintile had significantly lower physical activity ($\beta = -0.95$, $P = 0.005$).

After conducting the sensitivity analysis based on excluding participants, who reported having experienced dry cough at night over the past year, we did not see any difference in results.

CHAPTER 8

DISCUSSION

We observed that sleep timing was associated with diet quality as measured by the DGAI-2010 and meeting the 2008 National Physical Activity Guidelines for Americans. Four sleep timing categories were created based on sleep onset and wake time: early sleep onset, early wake time (EE); early sleep onset, late wake time (EL); late sleep onset, early wake time (LE); and late sleep onset, late wake time (LL). Participants in the EE category had the highest diet quality score and were most likely to meet the National Physical Activity Guidelines compared to the other sleep timing categories. Participants in the EL category had the lowest diet quality score ($\beta = -3.6$, $P = 0.03$) and were almost 4 times less likely to meet National Physical Activity Guidelines (OR = 3.97, 95% CI = 1.03 – 15.23) compared to the EE group.

Our findings that the EE group had the best outcome in terms of diet quality are similar to previous studies looking at sleep timing (Golley et al., 2013; Baron et al., 2011). Baron et al. (2011) reported high intake of calories and lower diet quality (less fruits and vegetables intake) in late sleep onset (mean=3:45 am, SD=1:13). Lower diet quality was also correlated with intake after 8:00 pm. Golley et al. (2013) reported lower diet quality scores in children 9 to 16 years of age who had late sleep onset time, regardless of wake time. However, similarities between our findings and the findings of the two studies above are interpreted with caution since children have different sleep requirements and different sleep timings than other age groups, such as young adults. The discrepancy between our results for the EL category with the results from previous studies (Baron et al., 2011; Golley et al., 2013) could also stem from the fact that diets and sleep timing of children and adolescents are mostly controlled by their parents or guardians and it may be that children whose parents are more concerned about their healthy behavior, would be more strict about the time their children go to bed and also about their dietary intake. Indeed, poor parental control has been shown to be associated with later bedtime and higher BMI (Garasky et al., 2009; Olds et al., 2011). However, in case of college-aged students, most of them live away from home and have the independence to be in charge of their own sleeping and dietary habits. Therefore, in this case too, it is likely that the participants who are more health-conscious would pay closer attention to their sleeping habits and diet quality, whereas students who go to bed early and wake up late, might be the ones who have lower diet quality and a behavior that results in their diet qualities being lower, such as skipping breakfast. Skipping breakfast has been correlated positively with higher BMI and unhealthy behaviors such as smoking, alcohol use, infrequent exercise, and importantly less sleep, (Keski-Rahkonen et al., 2003; Wong & Mullan, 2009). This might partially explain the lower diet quality score and the lower likelihood of meeting National Physical Activity Guidelines among the participants in the EL group in our study.

On the other hand, the participants in the EE group met most of the criteria for healthy habits that have been identified by previous studies. Never smoking, low alcoholic consumption, sleeping 7-8 hours a night, exercising, avoiding snacks and eating breakfast are among the habits that specify healthy behavior (Wong & Mullan, 2009). Compared to the other sleep timing categories, the EE category had the lowest alcohol intake, the highest total physical activity, and aside from the LE group, they had the least number of current smokers (4% vs. 4.7% in the EL group and 13.5% in the LL group). They were also the only group whose sleep duration fell in the recommended 7 - 8 hours per night duration (7.3 hours, SD = 0.8) (St-Onge, 2013). Laska et al. (2009) examined patterns of risk behaviors among American college students and found that specific wellness and lifestyle habits among female college students may cluster together. For example, for female students, the highest probabilities of not exercising, having poor diets, and having poor sleep habits are often concurrent in one person and they were labeled as the “poor lifestyle” group in the mentioned study. The authors also identified classes of wellness and lifestyle characteristics that are considered more favorable and labeled the participants falling in this group as the “health conscious group” (Laska et al., 2009). The students belonging to this class yielded the most favorable diet and physical activity characteristics and were less likely to smoke or binge drink. Comparing this study to ours, we can pair the EE group with the “health conscious” group, as both had favorable outcomes in terms of dietary intakes and physical activity whereas the participants in the LE group in our study that had the lowest sleep duration and relatively low diet quality and physical activity are comparable to the “poor lifestyle” group.

Our observation that participants in the LE category had the lowest average for sleep duration (5.7 hours, SD = 0.9) and lower dietary quality scores compared to the EE or the LL group (though not statistically significant) is consistent with the results from previous studies that suggest an association between short sleep duration and low diet quality (Bel et al., 2013; Haghighatdoost et al., 2012). Being awake late at night may be associated with poor behavioral factors that can contribute to poor diet quality, such as increase in opportunities to consume calories (Baron et al., 2011) and poor availability of healthy foods at night (Baron et al., 2011). One study (Kim et al., 2011) showed an association between short sleep duration (<6 hours) and long sleep duration (>10 hours) with higher snacking, which has been associated with lower diet quality. Short sleep duration has been associated with lower diet quality in several studies (Baron et al., 2011; Brondel et al., 2010; Chaput et al., 2011a; Chaput, 2013; Haghighatdoost et al., 2012; Ma et al., 2003). The shortest average sleep duration was seen in our LE category (5.7 hours, SD = 0.9) and the longest in the EL category (8.5 hours, SD = 0.7), and both these groups had the lowest diet quality scores among the four sleep timing categories. The LE group also had the highest energy intake, which could contribute to low diet quality (Gonnissen et al., 2013a). Though not significant, they also had lower diet quality scores, second to the EL group. This suggests that relatively short or long sleep duration is associated with relatively poorer diet quality compared to those in the EE and the LL groups that had similar sleep durations (7.3 hours, SD = 0.8 vs. 6.8 hours, SD=0.8). Another contributor to the LE group's low diet quality scores could be their late sleep onset, as going to bed late is associated with intake of energy-dense foods, especially after dinner (Chaput et al., 2011a; Chaput, 2013; Ma et al., 2003).

We did not have the variability of sleep duration for individuals. Participants may sleep longer on weekends versus weeknights, which may affect their circadian rhythms and consequently their diet quality through changes in hunger and satiety hormones. Sleep duration variability may be associated with high consumption of sugar-sweetened beverages and lower diet quality scores (Kjeldsen et al., 2014). Variability in sleep timing might also be a contributor to sleep duration and consequently diet quality scores. It may be that the EL group in our study had the most variability in their sleep onset time that may have contributed to their poor diet quality scores.

Contrary to our hypothesis, the LL group had the second best outcome in terms of diet quality. The average age for this group was the lowest among the 4 sleep timing categories (20.6 years, SD = 2.2). It is mandatory for freshmen and sophomores attending UMass to be on “meal plans” and almost all of them eat at the UMass dining commons and have access to high quality foods compared to other students that may be purchasing their own food by eating prepared foods at home or eating away from home, both known to have lower dietary quality or cooking at home, which may or may not be lower dietary quality. Therefore, it may be that the LL category consists mostly of freshmen and sophomores and the fact that they are on “meal plans” may contribute to their high diet quality. Similarly, the higher diet quality in the EE group that had the highest age average

(22.4 years, SD = 3.4). It is possible that the participants in this sleep category are working professionals, post-graduation, who do not have the stress of college life and may have access to better quality foods through higher incomes. The possible higher rate of access to the dining commons might also in part explain why the LL group may be less likely to skip breakfast compared to the EL group, although they both have later wake times.

The LE group had the lowest average for total physical activity compared to the EE group. However, in terms of meeting or not meeting the National Physical Activity Guidelines, consistent with our results for diet quality, it was the EL group that had the highest OR of not meeting these guidelines. The participants in the EL group and the LL group were less likely to meet the guidelines. These results indicate a possible negative association between late wake time and physical activity. We were able to find one study (Olds et al., 2011) that has looked at the association of sleep timing with physical activity among children and adolescents. Based on their results, participants with early wake time, particularly in their EE group, were more physically active and this is consistent with our findings. The authors reported that the participants with late sleep time, accrued more screen time in the evening. Our findings for sedentary activity across sleep timing categories also match their observations. The participants with the late sleep time (LE and LL categories) in our study, spent more time in sedentary activity than the EE or the EL group. The authors reported more moderate to vigorous physical activity among the participants who woke up early and the participants in our study with early wake time were also the ones with higher moderate to vigorous physical activity.

Olds et al. (2011) justified their findings partially based on what they called “activity patterns controlled by parental authority”, which meant strict parents may encourage early sleep onset and early wake time in their children. However, the same reasoning cannot be used for our study as our study population consisted of young adults who are mostly independent individuals, as opposed to the participants in the Olds et al. study that consisted of children and adolescents. One possibility for our results is that participants who have earlier wake times, may incorporate physical activity into their daily schedules easier compared to the participants with late wake time. This might particularly be true about our population that consists mostly of college students, who spend most of their time after waking up in class and the fatigue might prevent them from being engaged in physical activity later in the day. The reason for the unlikelihood of the EL group meeting the National Physical Activity Guidelines could be the fact that they have longer sleep duration and thus, less time during the day to spend on physical activity.

Summary of Strengths and Limitations

The strengths of the current study include use of validated instruments including FFQ, diet quality, and physical activity questionnaire. Nevertheless, the information on our exposure, sleep timing (i.e., sleep onset and wake time), and both our outcomes, diet quality and physical activity, were based on self-reported information and self-report is subject to recall bias and social desirability bias.

Recall bias was minimized by using validated measures of sleep timing, diet quality, and physical activity.

The participants in the UMVDS were a relatively "healthy" population as evidenced by their high diet quality scores, physical activity levels, and BMI values. The cutoff for the high versus low diet quality scores were based on the median in this population that may exceed scores of other populations, especially as mentioned before 80% of the U.S. population does not meet the dietary guidelines. Therefore, to make our results more comparable to the general population in possible future studies, we may choose lower cutoff value for high versus low diet quality and repeat the analysis. BMI has been associated with diet quality and physical activity and it is possible that we would have observed different results in terms of the association of sleep timing with either of our outcomes had we had participants with more variability in BMI among participants, over 73% of our participants had BMIs in the normal range (18.5 to 25 kg/m^2).

The current study is cross-sectional and therefore can only capture events at the same time. We cannot be sure if sleep timing is affecting diet quality or physical activity or if diet quality and physical activity are affecting sleep timing.

Generalizability

The association between sleep timing and diet quality and physical activity from our study may be generalized to women in the U.S., who are in the same age group. It would be difficult to generalize beyond the demographic of young women primarily because sleep requirements vary by age and gender and may affect sleep onset and wake times. Also, dietary and physical activity requirements and habits are different in younger and older age groups and men and women. Nonetheless, our study provides a foundation for future examination of sleep timing and diet and physical activity in different demographic groups.

CHAPTER 9

CONCLUSION

In conclusion, our findings suggest that there is an association between sleep timing and diet quality and physical activity in young women in the U.S.. Specifically, participants with both early sleep onset and early wake time had higher diet quality scores and were more likely to meet National Physical Activity Guidelines. Further analysis of sleep timing in quintile categories showed that wake time may be more influential in meeting physical activity guidelines than time of sleep onset.

Future studies with stronger study designs, larger sample sizes, and objective measurements of sleep and physical activity in different age groups and in diverse populations are important to better understand the influence of sleep timing on obesity as acting through diet and physical activity.

APPENDIX A

HUMAN SUBJECT PROTECTION

This study was approved by the Institutional Review Board of the University of Massachusetts Amherst. All participants signed an informed consent form stating that they understood that they were under no obligation to participate in the study and that they were free to withdraw from participation at any time.

All the information collected is kept confidential and will not be sold or shared with anyone not associated with the study. To further ensure the privacy of the participants, the information collected is coded. Also, to prevent inadvertent breech in confidentiality, the identifying information is stored in locked file cabinets and kept separate from the study data at the University of Massachusetts Amherst.

The risks to participants in this study are minimal. The risks to participating in this study are those associated with having blood pressure taken, blood drawn, urine collected, undergoing studies of genetic factors, and undergoing a DXA scan. For having blood pressure taken, the procedure may cause some mild discomfort as the blood pressure cuff is inflated. For having blood drawn, risks include pain at the site of needle entry, occasional bruising at the site, and rarely, fainting. Risk of infection is minimal since only sterile one-time-use equipment will be used. There are minimal risks associated with providing a urine sample. The collection of a drop of blood with a lancet may cause minimal pain and bleeding. For the genetic studies, some people involved in these studies have felt anxious about the possibility of carrying an altered gene that they could possibly pass on to their children or which might put them at high risk for developing a disease. The genetic factors included in the UMVDS (polymorphisms) are different types of genes that are normal and common in human populations and are generally not associated with specific diseases. For the DXA scan, the risk from exposure to low-dose radiation is very small and is about the same as would occur in a flight between Boston and Los Angeles.

Participants received information about their dietary intake and their body compositions by filling out the FFQ and getting dual X-ray absorptiometry (DXA) scans.

APPENDIX B

PHYSICAL ACTIVITY QUESTIONS ON THE UMVDS LIFESTYLE QUESTIONNAIRE

1. During the past year, what was your average time per week spent at each of the following recreational activities?
Walking or hiking outdoors (include walking to work)
Jogging (slower than 10 minutes/mile)
Running (10 minutes/mile or faster)
Bicycling (include stationary machine)
Calisthenics/aerobics/aerobic dance/rowing machine
Tennis, squash, or racquetball
Lap swimming
Other aerobic recreation (e.g., lawn mowing)

2. On average, how many hours per week do you spend:
Standing or walking around at work?
Standing or walking around at home?
Sitting at work or while at the computer, in class, at work or driving?
Sitting while reading, talking, or eating?
Sitting watching TV?

3. **What is your usual walking pace outdoors?**
4. **How many flights of stairs do you climb every day?**

APPENDIX C

METABOLIC EQUIVALENT OF TASK (MET) VALUES FOR TYPE OF PHYSICAL ACTIVITY ON THE UMVDS QUESTIONNAIRE

Type of Physical Activity	MET Score
Walking/hiking outdoors or on a treadmill	3.5
Jogging outdoors or on a treadmill	7.0
Running outdoors or on a treadmill	10.0
Bicycling/using a stationary bike	8.0
Aerobics/Dance/Rowing machine	6.0
Tennis/Squash/Racket sports	7.0
Lap swimming	8.0
Other aerobic activities (i.e., martial arts/lawn mowing)	6.0
Yoga/Pilates	4.0
Weight training or resistance exercises	4.0

APPENDIX D

THE 2010 DIETARY GUIDELINES FOR AMERICANS ADHERENCE INDEX

(DGAI-2010) COMPONENTS

Food Intake Sub-score	Healthy Choices Sub-score
Fruit	**Choose whole fruit over fruit juice**
Vegetable (5 subgroups) Dark green vegetables Orange and red vegetables Legumes Other vegetables Starchy vegetables	**Sodium intake <2300 mg/d** **20 %≤ Total fat ≤ 30 % of total energy** **Saturated fat <10% of total energy** ***Trans* fat <1% of total energy**
Fruit and Vegetable Variety: based on fruit and vegetable subgroups	
Grains	**At least 50% grains as whole grains** **Fiber intake 14 grams/1000 calories**
Dairy	**Choose low or non-fat dairy products** (percent of total dairy that is low- or non-fat)
Protein (3 subgroups): Seafood Meat, poultry, eggs Nuts, seeds, soy	**Choose lean meat** (percent of total meat that is lean meat)
Protein Variety: based on protein subgroups	
Empty Calories: % total energy from added sugar	**Alcohol intake:** ≤1 drink/d women and ≤ 2 drinks/d men

Figure 1. Distribution of Diet Quality across Sleep Timing (Onset and Wake Time) Categories

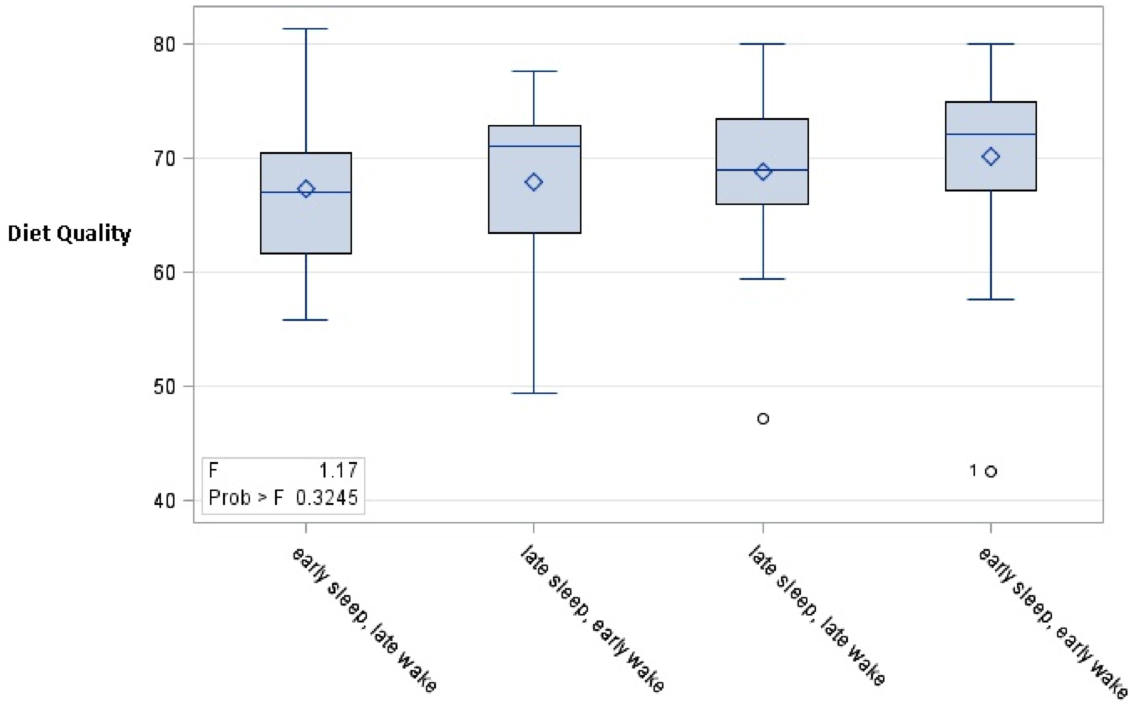


Table 5. Distribution of Sleep Timing (Sleep Onset and Wake Time) Categories*.

Sleep timing category	n (%)
Early sleep onset - Early wake (EE)	50 (35.7)
Early sleep onset - Late wake (EL)	21 (15.0)
Late sleep onset - Early wake (LE)	27(19.3)
Late sleep onset - Late wake (LL)	42 (30.0)

* Sleep Timing refers to the sleep onset time and wake time. For the purpose of this study we categorized participants into four sleep timing groups: “Early sleep onset, Early wake time” (EE), “Early sleep onset, Late wake time” (EL), “Late sleep onset, Early wake time” (LE), “Late sleep onset, Late wake time” (LL).

Table 6. Distribution of Diet Quality and Physical Activity Variables.

	n (%)	M (SD)
Total Diet Quality Scores	-	68.9 (6.5)
High Diet Quality Scores (≥70)	68 (48.5)	-
Low Diet Quality Scores (<70)	72 (51.4)	-
Total Physical Activity (MET-minutes/week)	-	3544.5 (3329.5)
Met Physical Activity Guidelines *	46 (32.8)	-
Did Not Meet Physical Activity Guidelines**	74 (67.1)	-

* ≥ 500 MET-min/week of aerobic exercise plus ≥ 1.5 hours/week of resistance training
** <500 MET-min/week of aerobic exercise and/or <1.5 hours/week of resistance training

Table 7. Subject Characteristics by Sleep Timing (Sleep Onset and Wake Time) Categories*

		Sleep timing categories n (%)				
		EE 50 (35.7)	**EL** 21 (15.0)	**LE** 27(19.3)	**LL** 42 (30.0)	**P-value**
Subject Characteristics		**Mean (SD)**	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**	
Age (y)		22.4 (3.3)	21.6 (3.8)	21.4 (3.4)	20.6 (2.2)	0.05
BMI (kg/m^2)		22.6 (2.9)	21.7 (3)	24 (2.7)	22.9 (3)	0.04
Energy Intake (Kcal/d)		2162 (689)	2007 (553)	2232 (755)	2062 (673)	0.6
Caffeine Intake (mg/d)		97 (101)	79.3 (84.7)	78.4 (59.4)	81 (85)	0.7
Alcohol Intake (gm/d)		5 (7)	5.4 (5.7)	7 (14.3)	6.5 (6.7)	0.76
Sleep duration the night before (hours/d)		7.3 (0.8)	8.5 (0.7)	5.7 (0.9)	6.9 (0.8)	<.0001
DGAI-2010 (range 0 - 100)		70 (6.8)	67.3 (6.5)	68 (6.5)	69 (6.3)	0.3
Physical Activity (MET Min/wk)		4113 (4025)	2946 (2191)	3490 (2890)	3201 (3143)	0.5
		n (%)	**n (%)**	**n (%)**	**n (%)**	
Race	**White**	45 (32)	17 (12)	20 (14.3)	39 (27.8)	0.1
	Other	5 (3.5)	4 (2.8)	7 (5)	3 (2)	
Smoking	**Current smoker**	2 (1.4)	1 (0.7)	0 (0)	5 (3.5)	0.2
	Not current smoker	48 (34.3)	20 (14.3)	27 (19.3)	37 (26.4)	
Member of Sports Team	**Yes**	1 (0.7)	1 (0.7)	3 (2)	1 (0.7)	0.24
	No	49 (35)	20 (14.3)	24 (17)	41 (29.3)	
Sedentary behavior	**High ****	38 (27.1)	15 (10.7)	23 (16.4)	34 (24.3)	0.64
	Low	12 (8.6)	6 (4.3)	4 (2.8)	8 (5.7)	

* Sleep Timing refers to the sleep onset time and wake time. For the purpose of this study we categorized participants into four sleep timing groups: “Early sleep onset, Early wake time” (EE), “Early sleep onset, Late wake time” (EL), “Late sleep onset, Early wake time” (LE), “Late sleep onset, Late wake time” (LL).

** More than six hours of sitting time per day.

Table 8. Diet Quality and Physical Activity as Continuous Variables by Sleep Timing (Sleep Onset and Wake Time) Categories *

Unadjusted and multivariable adjusted regression coefficients (Beta), standard errors (SE) and P-values.

Unadjusted								
	Diet Quality				**Physical Activity**			
	EE	**EL**	**LE**	**LL**	**EE**	**EL**	**LE**	**LL**
Beta	Referent	-2.79	-2.15	-1.24	Referent	- 0.17	- 0.15	- 0.19
(SE)		(1.70)	(1.56)	(1.36)		(0.28)	(0.26)	(0.23)
P-value	-	0.10	0.17	0.36	-	0.53	0.56	0.40

Adjusted								
	Diet Quality **				**Physical Activity *****			
	EE	**EL**	**LE**	**LL**	**EE**	**EL**	**LE**	**LL**
Beta	Referent	-3.62	-0.77	-0.85	Referent	0.04	- 0.47	- 0.20
(SE)		(1.7)	(1.75)	(1.27)		(0.31)	(0.31)	(0.23)
P-value	-	0.03	0.65	0.50	-	0.88	0.13	0.37

* Sleep Timing refers to the sleep onset time and wake time. For the purpose of this study we categorized participants into four sleep timing groups: “Early sleep onset, Early wake time” (EE), “Early sleep onset, Late wake time” (EL), “Late sleep onset, Early wake time” (LE), “Late sleep onset, Late wake time” (LL).

** Diet Quality adjusted for BMI, sleep duration, current smoking status, total energy intake, alcohol intake, and sedentary behavior.

*** Physical activity adjusted for BMI, sleep duration, current smoking status, total energy intake, and being a member of a sports team.

Table 9. Diet Quality as Categorized into High and Low Diet Quality by Sleep Timing (Sleep Onset and Wake Time) Categories *

Unadjusted and multivariable adjusted odds ratio and 95% confidence intervals.

		EE	EL	LE	LL
Unadjusted					
High diet quality	Crude OR	1	2.93	0.94	1.29
	(95% CI)	Referent	(0.98 – 8.8)	(0.36 – 2.4)	(0.56 – 2.94)
Adjusted **					
High diet quality	OR	1	4.75	0.56	1.27
	(95% CI)	Referent	(1.35 – 16.61)	(0.16 – 1.91)	(0.52 – 3.06)

* Sleep Timing refers to the sleep onset time and wake time. For the purpose of this study we categorized participants into four sleep timing groups: “Early sleep onset, Early wake time” (EE), “Early sleep onset, Late wake time” (EL), “Late sleep onset, Early wake time” (LE), “Late sleep onset, Late wake time” (LL).

** Adjusted for BMI, sleep duration, current smoking status, and total energy intake.

Table 10. Meeting the 2008 Physical Activity Guidelines for Americans by Sleep Timing (Onset and Wake Time) Categories

Unadjusted and multivariable adjusted odds ratio and 95% confidence intervals.

		EE	EL	LE	LL
Unadjusted					
Physical activity met	Crude OR	1	3.34	1.57	2.21
National guidelines	(95% CI)	Referent	(0.98 – 11.35)	(0.59 – 4.17)	(0.91 – 5.37)
Adjusted**					
Physical activity met	OR	1	3.97	1.32	1.95
National Guidelines	(95% CI)	Referent	(1.03 – 15.23)	(0.39 – 4.43)	(0.78 – 4.87)

* Sleep Timing refers to the sleep onset time and wake time. For the purpose of this study we categorized participants into four sleep timing groups: “Early sleep onset, Early wake time” (EE), “Early sleep onset, Late wake time” (EL), “Late sleep onset, Early wake time” (LE), “Late sleep onset, Late wake time” (LL).

** Adjusted for BMI, sleep duration, current smoking status, and being a member of a sports team.

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