THE RELATIONSHIPS BETWEEN SLEEP AND SELECTED WEIGHT GAIN-RELATED EATING BEHAVIORS

By

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ABSTRACT

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Many adults do not get enough sleep as previous studies noted that over 30% of adults in several developed countries reported less than the recommended 7 hours of sleep. Insufficient sleep increases the odds of obesity and death compared to people who have adequate sleep. Changes that promote weight gain after curtailed (shortened) sleep need to be identified. Strategies that might be able to overcome weight gain-related changes resulting from insufficient sleep should also be explored. In addition to sleep duration, a person's preferred time for activities and sleep cycle, the so-called chronotype, has been linked to certain eating behaviors which could promote weight gain. However, these relationships are poorly characterized among US adults. The overall objective of the research was to explore relationships between sleep and selected weight gain-related eating behaviors.

The effects of sleep curtailment on appetite, food cravings, food reward, and portion size selection were explored in women without obesity. A total of 24 participants underwent a habitual sleep night and a curtailed sleep night, during which sleep was reduced by 33%. Participants experienced greater hunger, food cravings, and food reward after one night of curtailed sleep. Larger portion sizes were selected after curtailed sleep, which led to an increase in the amount of energy plated for lunch. These undesirable responses that followed sleep curtailment could be contributors to weight gain (chapter 2).

Given that sleep curtailment led to changes in appetitive sensations and food cravings, which could lead to weight gain, it is imperative to explore possible strategies for these changes.

High protein intake has been shown to provide greater satiation than other macronutrients. For this reason, chapter 3 explored the effect of a high-protein breakfast on appetitive sensations, food cravings, and dietary intake after both habitual and curtailed sleep nights. A total of 27 non-obese women underwent habitual and curtailed sleep nights followed by a high protein breakfast or a high carbohydrate breakfast. The findings demonstrated that a high protein breakfast increased fullness after participants experienced habitual sleep, but this beneficial effect disappeared after a night of curtailed sleep. Food cravings decreased after participants consumed a high protein breakfast, regardless of sleep condition. Overall, the beneficial effects of high protein breakfast mainly occurred after participants had sufficient sleep.

The final chapter explored the relationships among chronotype, dietary behaviors, diet quality, and food cravings. Individuals identified as having evening-type chronotypes consumed snacks more frequently and consumed more energy-dense snacks than morning-types. However, chronotype was not related to sugar-sweetened beverage or alcohol consumption, energy and macronutrient intake, diet quality, or food cravings. The findings suggest that chronotype is negligibly related to specific behaviors associated with weight gain.

In summary, the work presented revealed the effects of insufficient sleep and explored a possible strategy to address the increased appetite and food cravings after sleep curtailment in women. It also identified the relationships between chronotype and eating behaviors in adults living in the United States.

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KEY TO ABBREVIATIONS

ANOVA: Analysis of Variance

AUC: Area Under the Curve

AUDIT-C: Alcohol Use Disorders Identification Test-Consumption

ASA24: Automated Self-Administered 24-Hour

AHA: American Heart Association

BEVQ-15: Beverage Intake Questionnaire-15

BMI: Body Mass Index

CN: Curtailed Night

CS: Curtailed Sleep

DGA: Dietary Guidelines for Americans

DHQ III: Diet History Questionnaire III

EEG: Electroencephalography

E-type: Evening-type

FDR: False Discovery Rate

FFQ: Food Frequency Questionnaire

G-FCQ-S: General Food Cravings Questionnaire-State

G-FCQ-T: General Food Cravings Questionnaire-Trait

HS: Habitual Sleep

HEI: Healthy Eating Index

HC: High Carbohydrate

HP: High Protein

HRPP: Human Research Protection Program

I-type: Intermediate-type

KSS: Karolinska Sleepiness Scale

MET: Metabolic Equivalents

MEQ: Morningness-Eveningness Questionnaire

M-type: Morning-type

NN: Normal Night

PSQI: Pittsburgh Sleep Quality Index

PSG: Polysomnography

REM: Rapid Eye Movement

RMANOVA: Repeated-Measures Analysis of Variance

SWS: Slow Wave Sleep

SSB: Sugar-Sweetened Beverage

TIB: Time in Bed

TSD: Total Sleep Deprivation

TST: Total Sleep Time

VAS: Visual Analog Scale

CHAPTER 1: INTRODUCTION

Obesity has become a global pandemic, as the prevalence of obesity doubled in over 70 countries around the world from 1980 to 2015 (Global Burden of Disease 2015 Obesity Collaborator, 2017). In the United States, the prevalence of obesity was 39.6% in adults in 2015-2016, with 37.9% of men and 41.1% of women classified as obese (Hales et al., 2018). By 2030, about 46-47% of U.S. adults are projected to be obese (Wang et al., 2020). It is problematic for a person to become obese since obesity increases the risk of several chronic diseases, including diabetes and cardiovascular disease (Sullivan et al., 2005), reduces the quality of life, and decreases life expectancy (Abdelaal et al., 2017).

Several studies have shown that short sleep duration is a risk factor for obesity (Cappuccio et al., 2008; Reutrakul & Van Cauter, 2018; Wu et al., 2014). The recommended sleep duration for adults is 7-9 hours per night (Hirshkowitz et al., 2015). The prevalence of short sleep duration in adults is cause for concern, as nearly 35% of American adults (Centers for Disease Control and Prevention, 2017) and half of Japanese adults sleep <7h (Furihata et al., 2015); 29% of Taiwanese (Lin et al., 2018), 11% of Canadian, and 10% of United Kingdom adults reported <6 h of sleep (Bin et al., 2013). A meta-analysis reported that individuals who experienced shorter sleep duration (≤6 h) had 1.45 times higher odds of obesity compared to people who experienced longer sleep duration (≥7 h) (Wu et al., 2014). Systematic reviews also suggest that lack of sleep is related to greater risk of weight gain (Beccuti & Pannain, 2011; Knutson, 2012). The main mechanism by which short sleep duration may contribute to weight gain is through increased food consumption (Chaput, 2014). Although, 24-hour energy expenditure increased by five percent after sleep insufficiency (Shechter et al., 2013), food consumption observed after lack of sleep was higher than the amount of energy needed to

maintain energy balance (Markwald et al., 2013). Overall, energy balance after insufficient sleep is positive due to excessive energy intake.

Undesirable changes in appetite occur when people experience insufficient sleep, which likely increases energy intake. First, hunger sensations increased after two nights of four hour sleep duration in 12 men (Spiegel et al., 2004). Also, one night of total sleep deprivation increased hunger among healthy men aged 20 to 40 the next morning (Schmid et al., 2008). One possible explanation for changes in appetitive sensations is the hormonal theory, where leptin decreases and ghrelin increases after short sleep (Spiegel et al., 2004). However, not all studies supported these findings (Pejovic et al., 2010; Simpson et al., 2010), and the study that supported the hormonal theory limited the generalizability of their findings, because the study did not allow participants to freely access foods, which could result in poor ecological validity (Spiegel et al., 2004). As a result, this laboratory-based study may not reflect a real-life situation (Chaput & St-Onge, 2014). Second, a person's craving for sugary, high-fat foods increases when their feelings of sleepiness increase (Lv et al., 2018). Since higher food cravings reflect a stronger desire to eat palatable foods (Nijs et al., 2007), the increase in sleepiness after insufficient sleep might result in increased food cravings and, as a result, increase energy intake (Hill, 2007; Liu et al., 2000). In addition, increased activation of certain brain regions related to food reward has been observed under conditions of sleep curtailment in normal-weight adults (St-Onge et al., 2014) and total sleep deprivation (Benedict et al., 2012b). Food reward refers to a person's willingness to work for access to food (Rogers & Hardman, 2015). Previous studies observed an increase in food reward in men after sleep deprivation (Rihm et al., 2019). An increase in susceptibility to food reward is related to greater food intake (Rogers & Hardman, 2015). Another factor that could contribute to food consumption is the self-selected amount of food, or portion size,

because 90% of people tend to consume all the food on their plate (Fay et al., 2011a). Insufficient sleep has been shown to reduce a person's capability to pay attention (Smith et al., 2002), and not focusing on the food they are eating can increase portion size and intake (Steenhuis & Poelman, 2017a). Whether portion size selection changes after insufficient sleep merits exploration. Overall, the effects of insufficient sleep on hunger sensations, food cravings, food reward, and portion size selection are poorly characterized. Exploring these effects could help researchers understand how insufficient sleep leads to increased dietary intake.

Given the negative effects of insufficient sleep on weight gain, finding strategies to overcome changes that promote intake after insufficient sleep is important. High protein meals have been shown to control appetite (Dhillon et al., 2016), food cravings (Hoertel et al., 2014), and energy intake (Halton & Hu, 2004) due to their high satiety properties. It is unknown whether the appetite-reducing effects of a high protein meal can overcome the appetite-promoting effects (Chaput, 2014; Yang et al., 2019) of insufficient sleep. Other studies have demonstrated that high protein food provided greater fullness and reduced hunger compared to carbohydrates and fats (Douglas et al., 2013; Halton & Hu, 2004; Paddon-Jones et al., 2008). Another study noted that a high protein breakfast reduced daily hunger sensations and daily energy intake in adolescents compared to breakfast with lower protein (Leidy et al., 2015). Therefore, a high protein meal might pose a solution for counteracting increased appetite and energy intake after insufficient sleep.

In addition to sleep duration, a person's natural rhythm of sleep and wake cycles could also influence their eating behavior. Individuals have different preferred times for activities and sleep, which influences their daytime behavior (Bakotic et al., 2017). These preferences are referred to as chronotype (Bakotic et al., 2017). Individuals with morning preferences, so-called

morning-types (M-types), have an early bedtime, an early wake up time, and function better in the early hours of the day. On the other hand, individuals with evening preferences, evening-types (E-types), go to bed late, get up late, and function better in the later afternoon or evening (Bakotic et al., 2017). Individuals who are neither morning-types nor evening-types are referred to as intermediate-types (I-types) (Rodríguez-Muñoz et al., 2020). Previous studies have linked an individual's chronotype with certain eating behaviors. For example, evening-type individuals tend to have problematic eating behaviors that could lead to weight gain, including frequent snacking, greater sugar-sweetened beverage (SSB) and alcohol consumption, and lower diet quality. One study observed that E-type chronotype was related to higher frequency of unhealthy snack (sugary or high in fat) consumption in adolescents (Arora & Taheri, 2015). Another study reported that E-type chronotype was associated with greater intake of SSB and alcohol in Chinese undergraduates (Zhang et al., 2018). In addition, among Finnish adults, E-type individuals had lower diet quality than the M-types and I-types (Maukonen et al., 2016). Chronotype appeared to have no relationship with food cravings among university students (Meule et al., 2012) and pregnant women (Teixeira et al., 2020), but these studies only focus on specific populations. Overall, previous studies that examine the relationship among chronotype, eating behaviors, and food cravings were conducted in certain populations or countries in Europe or Asia instead of the U.S. Given that the same relationships have not been fully characterized among U.S. adults, it is essential to reveal these relationships. This information can improve our understanding of how chronotype is related to a person's eating behavior and inform dietary recommendations based on their chronotype.

Based on the literature reviewed above, the first objective of this body of work was to examine the effects of insufficient sleep on appetitive sensations, food cravings, food reward,

and self-selected portion size. The second objective was to determine if, under conditions of insufficient sleep, a high protein breakfast reduces food cravings, improves appetitive sensations, and reduces dietary intake. The third objective was to examine the associations between chronotype, dietary intake, and food cravings. These objectives were tested in the following chapters.

CHAPTER 2: INCREASED HUNGER, FOOD CRAVINGS, FOOD REWARD, AND PORTION SIZE SELECTION AFTER SLEEP CURTAILMENT IN WOMEN WITHOUT OBESITY

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2.1 Abstract

This study examined the effects of one night of sleep curtailment on hunger, food cravings, food reward, and portion size selection. Women who reported habitually sleeping 7–9 h per night, were aged 18–55, were not obese, and had no sleep disorders were recruited. Sleep conditions in this randomized crossover study consisted of a normal night (NN) and a curtailed night (CN) where time in bed was reduced by 33%. Hunger, tiredness, sleep quality, sleepiness, and food cravings were measured. A progressive ratio task using chocolates assessed the food reward. Participants selected portions of various foods that reflected how much they wanted to eat at that time. The sleep duration was measured using a single-channel electroencephalograph. Twenty-four participants completed the study. The total sleep time was shorter during the CN ($p < 0.001$). Participants reported increased hunger ($p = 0.013$), tiredness ($p < 0.001$), sleepiness ($p < 0.001$), and food cravings ($p = 0.002$) after the CN. More chocolate was consumed after the CN ($p = 0.004$). Larger portion sizes selected after the CN resulted in increased energy plated for lunch ($p = 0.034$). In conclusion, the present study observed increased hunger, food cravings,

food reward, and portion sizes of food after a night of modest sleep curtailment. These maladaptive responses could lead to higher energy intake and, ultimately, weight gain.

2.2 Keywords

Sleep; hunger; food cravings; food reward; portion size

2.3 Introduction

Insufficient sleep is an independent risk factor for overweight and obesity (Gangwisch et al., 2005), and interventional studies demonstrate greater food intake after a night of curtailed sleep (Brondel et al., 2010) or total sleep deprivation (TSD) (Hogenkamp et al., 2013). Insufficient sleep, like obesity (Ng et al., 2014), is a global problem. Although the recommended sleep duration for adults is 7–9 h per night (Hirshkowitz et al., 2015), approximately 1 in 3 American adults report sleeping <7 h per night (Centers for Disease Control and Prevention, 2017), almost half of Japanese adults sleep <7 h (Furihata et al., 2015), and nearly 1 in 3 Taiwanese adults sleep <6 h (Lin et al., 2018). Given the large-scale public health implications, the mechanisms by which insufficient sleep increases obesity risk deserve further study.

There are a number of maladaptive changes that occur under conditions of insufficient sleep that could promote an excess intake leading to weight gain. For example, feelings of hunger increase after a night of TSD in males (Schmid et al., 2008). Increased ratings of self-reported sleepiness were associated with increased cravings for high-fat sweet foods (Lv et al., 2018). Food cravings reflect a strong desire to consume foods that are palatable; these cravings typically involve sugary, high-fat foods (Nijs et al., 2007). An increased susceptibility to food

reward under conditions of TSD has also been observed (Rihm et al., 2018). Food reward is a measure of the temporary value of food as it is being consumed (Rogers & Hardman, 2015), and an increased susceptibility to food reward has been associated with an increased intake (Rogers & Hardman, 2015).

In addition to the mechanisms promoting the excess intake described above, increases in self-selected portion size merit consideration. The amount of energy consumed at an eating occasion is largely determined by both the type of food and the amount of food selected (portion size) (Fay et al., 2011b). Importantly, when people serve themselves, over 90% of individuals consume the entire portion they self-select (Fay et al., 2011b). Portion size is influenced by expected satiety, which represents how filling the food is expected to be (Irvine et al., 2013). Expected satiety is dependent on the memory of previous experiences with specific foods (Brunstrom et al., 2008). Because insufficient sleep has been associated with poor performance on a variety of memory-related tasks (Smith et al., 2002), an exploration of the effects of insufficient sleep on self-selected portion size is warranted.

A considerable amount of work that has examined the physiological, psychological, and behavioral changes under conditions of insufficient sleep has relied on TSD, which does not reflect the real-world experiences of most individuals (Dinges et al., 1997). Another popular approach is to subject all participants to a prescribed amount of time in bed, for example, 4 h. Due to natural awakenings during the night, this means that the actual total sleep time will be less than the prescribed time in bed. The time in bed approach results in an uneven curtailment; longer sleepers receive a more severe curtailment than shorter sleepers, which could obscure findings if the study population was skewed towards shorter sleepers or inflate effects if the study population was comprised predominantly of longer sleepers. One way to address the

ecological validity issue of TSD and the uneven application of curtailment is to reduce the habitual sleep time by a percentage. Based on the work of others (Calvin et al., 2013; Dinges et al., 1997), a 33% reduction was selected, which was projected to translate into a 2–3 h reduction.

The purpose of the current study was to examine the effects of a more modest sleep curtailment, taken as a percentage reduction of habitual sleep time, on factors shown to promote increased intake. These factors included: hunger sensations, food cravings, susceptibility to food reward, and self-selected portion size of foods representing a variety of sweet, savory, healthy, and unhealthy attributes. We hypothesized that all dependent variables would increase under conditions of sleep curtailment.

2.4 Materials and methods

2.4.1 Participants

Participants included women without obesity (BMI < 30 kg/m2) between the ages of 18–55 who reported typically sleeping 7–9 h per night. The height and body weight were measured. The body fat was assessed using a bioelectrical impedance analysis (TBF-400, TANITA Corporation of America Inc., Arlington Heights, IL, USA). Potential participants were screened for possible sleep problems using the Pittsburgh Sleep Quality Index (PSQI) (Buysse et al., 1989). Participants had to score ≤5, suggesting no sleep problems (Buysse et al., 1989). Also, participants had to indicate that they enjoyed chocolate candy by rating their liking as 5 or more on a 10-point scale. Participants who indicated they did not have a usual bedtime were excluded. This was done to assist with the individualized sleep curtailment assignments. Given the fact that individuals with obesity can differ in terms of sleep architecture (Rao et al., 2009), sleep less

(Beccuti & Pannain, 2011) experience greater frequency of food craving (Chao et al., 2014), and differ in their responsivity to a food reward (Stice et al., 2009), participants were limited to individuals without obesity. The study was approved by the Human Research Protection Program (HRPP) at Michigan State University (East Lansing, MI, USA). All participants signed a consent form before testing.

2.4.2 Study design

This randomized crossover study consisted of two different sleep conditions lasting one night each. Visits occurred at least two weeks apart. During the normal night (NN), participants went to bed and woke at their usual time. The habitual sleep time was based on the self-reported habitual duration collected using the PSQI questionnaire. Sleep was curtailed by 33% during the curtailed night (CN). This reduction was selected based on previous work noting such a reduction was more ecologically valid than more extreme curtailment (Calvin et al., 2013; Dinges et al., 1997). The curtailment was split evenly between going to bed later and waking earlier to center the sleep and minimize circadian rhythm disruption due to curtailment (Brondel et al., 2010; Laposky et al., 2008). Individualized instructions were given to participants to achieve the 33% curtailment. For example, if the participant's usual sleep duration was from 10 p.m. – 7 a.m., the bed time was changed to 11:30 p.m. and wake time was changed to 5:30 a.m. Confirmation of compliance to the curtailment protocol was done using the Zmachine.

Each visit occurred at the participant's usual lunchtime and at the same time for each visit. Participants were instructed to consume the same breakfast and snack(s) at the same time on each testing day. Researchers verified the food that participants had in the morning by asking them to recall their intake and to confirm their compliance. The researchers did not restrict these foods. If the participants did not follow the diet instructions, they were asked to reschedule the

visit. Participants were instructed not to eat or drink for at least one hour before the visit. Upon arrival at the lab, participants completed questionnaires and consumed 200 mL of water to minimize sensations of thirst contributing to hunger sensations

2.4.3 Sleep measurement

The night before each visit, participants wore a single-channel electroencephalography (EEG) device (Zmachine, General Sleep, Cleveland, OH). The Zmachine has been shown to substantially agree with polysomnography (PSG), the gold standard of sleep measurement (Kaplan et al., 2014). The Zmachine allows participants to sleep at home and is less invasive than PSG. For this study, the Zmachine recorded time in bed (TIB), total sleep time (TST), slow wave sleep (SWS), and rapid eye movement (REM) sleep and was used for sleep measurements in both the NN and CN conditions. The percentages of SWS and REM were calculated by dividing each stage's duration by TST.

2.4.4 Questionnaires – hunger, tiredness, sleep quality, and sleepiness measures

Visual analog scales (VAS) assessed hunger and tiredness (scored as 0 = not at all, 100 = extremely), as well as the quality of sleep for the previous night (0 = much worse than normal, 100 = much better than normal). Immediately prior to testing, current feelings of sleepiness were assessed using the validated Karolinska Sleepiness Scale (KSS) (Åkerstedt et al., 2014). The KSS asks about the degree of sleepiness during the previous 5 min. Scores range from 1 (extremely alert) to 9 (very sleepy).

2.4.5 Food cravings

The validated General Food Cravings Questionnaire-State (G-FCQ-S) was used to measure current cravings for general, rather than specific, foods (Nijs et al., 2007). The

questionnaire has five subscales: an intense desire to eat, anticipation of relief from negative states and feelings as a result of eating, anticipation of positive reinforcement that may result from eating, obsessive preoccupation with food or lack of control over time, and craving as a physiological state. Responses range from 1 to 5. The higher the score, the stronger the sensation of craving.

2.4.6 Portion size testing and liking of food

Chicken breast, white rice, salad, salad dressing, and soda were provided as meal options. Potato chips, mini chocolate sandwich cookies, green seedless grapes, and gummy candies were provided as snacks in order to provide a variety of food options. Participants were presented with large containers of food and were told “Based on your appetite right now, please prepare a meal using these meal options. Please select only the foods you wish to eat. You’re not actually going to eat what you select. This is just an exercise." Amounts plated rather than consumption were measured in order to eliminate the effects of palatability and post-ingestive experiences on portion size selection during the subsequent visit (Brunstrom, 2005; Yeomans et al., 2005). Participants indicated if they drank diet or regular soda. In addition, participants were told, "Please choose which of these snacks you would like to eat right now. You can choose more than one. Please put your snacks into separate bowls.” Participants were provided with two 26.5 cm (10.5 in) white plates, one 730 mL (24.7 oz) glass, one 118.3 mL (4 oz) plastic cup, and four 15.3 cm (6 in) white bowls to use. Researchers weighed all selected food items to a nearest 0.1 g. The manufacturer's information was used to analyze the energy and macronutrient content of the selections. Individual food liking was tested at the first visit to evaluate whether the test foods were liked by the participants or not. Participants were asked to indicate “How much do you like to eat (the food)?” on a VAS (0 = not at all, 100 = very much).

2.4.7 Food reward

Food reward can be quantified by asking participants their desire to eat, as well as measuring the amount of money they are willing to pay or work they perform to access a food (Rogers & Hardman, 2015). Therefore, food reward was assessed using two different methods. First, participants were asked to indicate the amount of money they were willing to pay for a standardized serving (pay-for-food) (Rogers & Hardman, 2015). Based on the MyPlate website (2015) and the manufacturer's information, one serving of each food was presented: 71 g white rice (0.5 cup), 83 g salad (2 cups), 28.5 g chicken breast (1 oz), 30 g salad dressing (2 tablespoons), 29 g mini chocolate sandwich cookies (9 pieces), 39 g gummy candies (17 pieces), 28 g potato chips (1 oz), and 147 g grapes (1 cup). Participants indicated their payment amount on a scale between 0–10 U.S. dollars and with the instruction of "Imagine you are having this food for lunch today. What is the maximum you would pay for this much food? (Brunstrom & Rogers, 2009)" The second method used to assess food reward utilized a progressive ratio task (Rogers & Hardman, 2015) where participants pressed a computer mouse button in exchange for chocolate candies (work-for-chocolate). The instructions said "You can earn a reward by clicking on the button on the next screen. Click as much or as little as you like. When you no longer want to continue, press the 'Quit' button to stop the session." Participants were instructed to eat each candy that was earned before continuing and could stop after eating the first candy or continue working for more. Food reward tasks were completed after the portion size testing.

2.4.8 Statistical analysis

A data analysis was conducted using IBM SPSS 25.0 statistical software (IBM Corporation, Armonk, NY, USA). Data are reported using means and standard deviations. Portion size information is presented using calories (kcals). Paired t-tests with bootstrapping

(Konietschke & Pauly, 2014) were used to test for differences between the normal and curtailed nights. A p-value under 0.05 was considered significant. Sleep staging is reported for 22 of the 24 participants due to Zmachine malfunction. Self-reported TIB was used for these participants.

2.5 Results

2.5.1 Participants

One-hundred and thirteen women were screened to identify 44 eligible participants. Of these participants, 14 were excluded due to an inability to follow the sleep or dietary protocol, three participants withdrew due to difficulties sleeping with the Zmachine, and three participants withdrew due to scheduling issues. Twenty-four participants completed the study. Participant characteristics are shown in Table 1.

Table 1. Characteristics of participants (n = 24)

Variable	Mean (SD)
Age (year)	24.4 (7.2)
BMI (kg/m^2)	22.1 (2.6)
Body fat (%)	25.8 (6.7)
PSQI	3.1 (1.1)
Race	n (%)
White	18 (75.0)
Asian	6 (25.0)
Ethnicity	n (%)
Non-Hispanic	23 (95.8)
Prefer not to answer	1 (4.2)

SD, standard deviation; BMI, body mass index; PSQI, Pittsburgh Sleep Quality Index.

2.5.2 Sleep time, hunger, tiredness, sleep quality and sleepiness

The sleep curtailment protocol was effective at significantly reducing the amount of sleep the participants obtained on the CN compared to the NN (4.60±0.72 vs. 7.03±0.96 h; $p<0.001$) (Table 2). TIB and TST were reduced by 33.5% and 34.6% during the CN, respectively ($p<0.001$, for both). SWS and REM sleep were lower during the CN compared to the NN ($p<0.001$, for both). The percentage of SWS was higher in CN compared to NN ($p=0.012$). Compared to the NN, participants reported increased sensations of hunger, tiredness, and sleepiness, and poorer sleep quality after the CN ($p<0.05$, for all) (Table 3).

Table 2. Sleep parameters from the Zmachine

Sleep Parameter	Normal Night	Curtailed Night	p-Value
TIB (hours)	8.19 (0.66)	5.45 (0.56)	<0.001
TST (hours)	7.03 (0.96)	4.60 (0.72)	<0.001
SWS (hours)	1.49 (0.41)	1.15 (0.41)	<0.001
REM sleep (hours)	2.03 (0.74)	1.30 (0.48)	<0.001
SWS (%)	21.19 (5.05)	24.67 (7.84)	0.012
REM sleep (%)	28.57 (8.91)	28.00 (9.10)	0.800

Data expressed as: mean (SD); TIB: time in bed; TST: total sleep time; SWS: slow wave sleep; REM: rapid eye movement.

Table 3. Effects of curtailed sleep on self-reported sleepiness, tiredness, quality of sleep and hunger

	Normal Night	Curtailed Night	p-Value
Sleepiness[1]	2.8 (1.3)	4.9 (1.9)	<0.001
Tiredness[2]	24.8 (16.2)	58.5 (15.3)	<0.001
Quality of sleep[2]	55.2 (17.2)	43.0 (17.0)	0.030
Hunger[2]	53.7 (16.9)	60.8 (15.7)	0.013

Data expressed as: Mean (SD); [1]Assessed by Karolinska Sleepiness Scale (score of 1-9); [2]Assessed by visual analog scales (mm).

2.5.3 Food cravings, food reward for test food

The total G-FCQ-S scores were significantly higher after the CN (Table 4). All subscales except "anticipation of positive reinforcement that may result from eating" were also significantly higher. For the work-for-chocolate task, significantly more chocolate candies were consumed after the CN (CN: 3.3±1.5 vs. NN: 2.6±0.9, p=0.004). There was no difference between NN and CN on the pay-for-food task.

Table 4. Effects of curtailed sleep on food cravings and food reward

	Normal Night	Curtailed Night	*p*-Value
Food cravings			
Total G-FCQ-S	45.5 (8.4)	51.5 (7.4)	0.002 *
Factor I	9.5 (2.3)	11.0 (1.9)	0.009 *
Factor II	9.7 (2.3)	11.1 (2.1)	0.008 *
Factor III	9.9 (1.5)	11.2 (1.8)	0.009 *
Factor IV	6.3 (2.4)	7.7 (2.5)	0.022 *
Factor V	10.0 (2.2)	10.6 (1.9)	0.236
Food reward			
Chocolate count (each)	2.6 (0.9)	3.3 (1.5)	0.004 *

Data expressed as: Mean (SD); G-FCQ-S, General Food Cravings Questionnaire-State. Factor I: An intense desire to eat; Factor II: Anticipation of relief from negative states and feelings as a result of eating; Factor III: Craving as a physiological state. Factor IV: Obsessive preoccupation with food or lack of control over eating; Factor V: Anticipation of positive reinforcement that may result from eating. * $p < 0.05$.

2.5.4 Selected portion size of food and macronutrient content

Participants liked all foods (all scores > 50 (neutral)) except for the gummy candies and soda, which had a rating of 44.9 and 32.5, respectively. Apart from these two foods, all other foods were liked equally, with the exception that grapes were liked more than potato chips (p=0.034). Portion size was significantly larger after the CN than the NN for white rice (139.3±83.9 vs. 109.7±60.7 kcal, p=0.014) and potato chips (112.4±99.0 vs. 64.5±71.1 kcal, p=0.030) (Figure 1). The portions of all other foods, with the exception of gummy candies and soda, were larger after the CN, although not significantly.

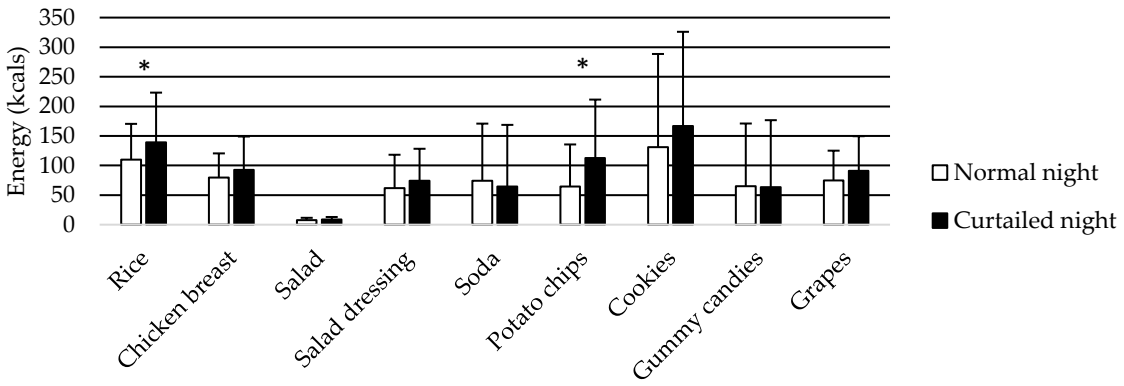


Figure 1. Means and standard deviations of selected portion sizes of meals and snacks after the normal night and curtailed night
The amount of energy selected from rice and potato chips was significantly higher after the curtailed night. * $p < 0.05$.

After the CN, participants chose more protein, fat, and total calories from the meal-associated foods compared to the NN (Table 5). Selections from snack-associated foods were higher in fat after the CN (Table 5). In terms of macronutrients from the total food selected (combining meals and snacks), protein, fat, and the percentage of total calories from fat were significantly higher after the CN than after the NN (Table 5).

Table 5. Energy and percentage of total energy by macronutrient for normal night sleep and curtailed night sleep

	Meal			Snack			Total		
Energy (kcal)	NN	CN	p-Value	NN	CN	p-Value	NN	CN	p-Value
Carbohydrate	179.4 (108.4)	194.7 (124.4)	0.295	239.0 (144.7)	294.2 (131.8)	0.106	418.4 (207.8)	488.9 (195.0)	0.068
Sugar	84.8 (95.4)	75.4 (102.6)	0.406	73.9 (61.6)	84.4 (70.0)	0.515	158.7 (128.3)	159.8 (143.4)	0.960
Protein	72.2 (32.0)	85.3 (44.2)	0.046*	10.4 (8.4)	13.7 (9.4)	0.144	82.7 (32.8)	99.0 (47.1)	0.035*
Fat	81.1 (53.0)	99.8 (55.4)	0.008*	85.8 (74.6)	126.3 (85.7)	0.036*	166.9 (114.6)	226.1 (115.2)	0.006*
Total kcal	332.7 (139.5)	379.8 (170.0)	0.034*	335.2 (212.5)	434.2 (206.8)	0.064	667.9 (302.7)	814.0 (321.3)	0.200
Carbohydrate (%)	50.5 (17.5)	48.2 (16.6)	0.339	71.8 (12.9)	70.4 (11.0)	0.516	61.9 (10.5)	60.5 (8.0)	0.312
Protein (%)	24.5 (12.7)	24.4 (14.1)	0.970	2.9 (1.2)	2.9 (1.0)	0.976	13.8 (5.4)	12.6 (5.7)	0.247
Fat (%)	24.9 (11.7)	27.3 (11.0)	0.096	25.3 (12.6)	26.7 (10.7)	0.500	24.2 (8.6)	26.9 (7.2)	0.014*

Values expressed as Mean (SD); NN: normal night; CN: curtailed night. *p<0.05.

2.6. Discussion

Insufficient sleep is associated with an increased energy intake (Brondel et al., 2010) and an increased risk of obesity (Gangwisch et al., 2005). This study evaluated the effect of modest sleep curtailment on hunger, food cravings, food reward, and portion size, all of which have been shown to contribute to excess intake and possible weight gain, but previous interventional studies have used more extreme curtailments (Brondel et al., 2010) or even total deprivation (Benedict et al., 2012a; Hogenkamp et al., 2013; Rihm et al., 2018). The modest curtailment in this study resulted in significantly reduced TIB, TST, SWS, and REM sleep durations as well as reduced subjective sleep quality. The percentage of REM and SWS ranged from ~21–~29% during both nights, which is consistent with healthy sleep (Carskadon & Dement, n.d.). The reduction in sleep duration resulted in participants feeling hungrier, reporting both increased food cravings and increased susceptibility to food reward, and selecting larger portions from meal items during lunch time, even though the same amount of breakfast foods and snacks were consumed at the same time on both days.

Despite the fact that participants consumed the same amount of food at the same time each day, hunger at lunchtime was increased as was the portion size of selected foods and the energy content of meal-associated foods after sleep curtailment. These findings are consistent with other research that reported that TSD led to higher hunger ratings after TSD compared to after a normal night's sleep in men (Hogenkamp et al., 2013; Schmid et al., 2008). These studies also observed that concentrations of the hunger hormone ghrelin increased, which could contribute to feelings of increased hunger. Others have also reported increased ghrelin as well as decreased leptin after a sleep restriction of four hours for four days (Broussard et al., 2016a). Not only is such a maladaptive change in hormones capable of influencing appetitive sensations, it can also affect food consumption as higher ghrelin and lower leptin levels are frequently associated with a higher energy intake (Broussard et al., 2016a). Unlike

a previous study in nine men where hunger did not differ between a night of longer (7 h) compared to a night of shorter sleep (4.5 h) (Schmid et al., 2008), we observed higher hunger ratings in our all-female sample. Whether insufficient sleep affects appetitive sensations differently by sex warrants further investigation. Taken together, these findings suggest that insufficient sleep results in increased hunger and the selection of more energy, in part due to an appetitive hormone dysregulation; however, it should be noted that the question of changes in appetitive hormones under conditions of insufficient sleep is not settled; others have observed that after five days of five-hour sleep curtailment, ghrelin concentrations decreased while leptin concentrations increased (Markwald et al., 2013). Clearly, further work is needed to resolve these discrepancies.

The total food craving scores on the G-FCQ-S were higher after the CN compared to after the NN, suggesting that participants had an increased urge to eat palatable foods. Higher food cravings have been associated with excessive energy intake and with obesity (Nijs et al., 2007), although people do not always give in to cravings (Hill, 2007). Previous work noted that sleepiness is related to food cravings for both savory and sugary high-fat foods (Lv et al., 2018), and individuals who reported a short sleep duration (<7 h) reported higher cravings for high-calorie foods (Lai & Say, 2013). Thus, evidence suggests that individuals who experience modest sleep curtailment may also experience increased food cravings, which could promote increased energy intake in susceptible individuals.

Food reward was higher after the sleep curtailment for the work-for-chocolate task, but no differences in the pay-for-food task were observed. It could be the case that a more severe curtailment is necessary to observe differences for both measures. Changes in the brain activity associated with the food reward have been noted after insufficient sleep (Benedict et al., 2012a). Previous research demonstrated that the TSD increased the willingness of men to pay more for food (Rihm et al., 2018). That study also observed

changes in the hypothalamus activity associated with food reward. A separate study noted that sleep deprivation increased activity in the right anterior cingulate cortex, which is associated with an increased appetite for energy-dense food (Benedict et al., 2012a). These findings suggest that insufficient sleep increases brain activity when individuals are exposed to food, which likely explains our findings of an increased willingness to engage in the work-for-chocolate task.

Larger portions are associated with an increased food consumption (Rolls et al., 2004). Previous work reported that people establish appropriate meal sizes based on experience (Fay et al., 2011b). This experience plays an important role in determining portion size, more so than hunger (Brunstrom et al., 2011). Still, self-selected portion sizes are subject to variation (Broussard et al., 2016a; Brunstrom & Shakeshaft, 2009; Hogenkamp et al., 2013). Insufficient sleep is known to impair the ability to pay attention (Smith et al., 2002), and eating while distracted can lead to increased portion sizes and an increased intake (Steenhuis & Poelman, 2017b). This could be a mechanism by which sleep affects the portion size selection. In terms of lunch options, participants plated 12.4% more total calories after the CN. Given the high correlation between self-selected portion sizes and intake (Fay et al., 2011b), this result suggests that even modest sleep curtailment may result in an increased energy intake. The dietary intake for the rest of the day was not measured, so it is not known if dietary compensation occurs after a larger lunch. However, previous work demonstrated that while energy expenditure increases after insufficient sleep, energy intake overwhelms that increase, resulting in a net positive energy balance (Markwald et al., 2013).

Macronutrient content was significantly different for total food selected (combining meals and snacks) after the CN. Calories from fat and total percent calories from fat were significantly higher after the CN, which agrees with previous work demonstrating that sleep curtailment led to higher fat consumption in adolescents (Weiss et al., 2010). In addition to

fat content, the present study also observed that participants plated more protein from meal foods and from all foods after the CN than after the NN. Protein is considered to be the most satiating macronutrient and can postpone the feeling of hunger longer when compared to carbohydrate and fat (Dhillon et al., 2016). Whether changing the macronutrient content at meals counteracts the effects of a curtailed night of sleep warrants future testing.

This study did not observe significant differences between the two sleep conditions for energy selected from snacks. This finding is inconsistent with previous work that noted that after TSD or sleep curtailment, participants selected larger portions of snacks (Broussard et al., 2016a; Hogenkamp et al., 2013; Nedeltcheva et al., 2009). Since the present study asked participants to choose snack foods at lunchtime, if participants did not consider snack foods appropriate for lunch, differences might be less likely. However, the present study observed that participants took more chips after sleep curtailment which led to increased fat selected among the snack options. Potato chips are a high-fat, savory food, and previous work suggests that the intake of these foods is higher among adolescents who slept less than 8 h per night compared to those who slept more than 8 h per night (Garaulet et al., 2011). The fact that potato chips are often consumed during meals as well as during snacks could explain the increased selection. Regardless, these results suggest that sleep curtailment led individuals to choose a high fat, palatable food that resulted in increased energy coming from fat.

The strengths of this study included the randomized design to minimize order effects, use of objective sleep measurements rather than self-reporting, matching the time and content of breakfast to avoid confounding, centering the sleep curtailment to minimize circadian rhythm disruption, and conducting study visits at the same time two weeks apart to reduce the risk that participants would remember their responses between visits. There are several limitations to the present study. First, the actual food intake was not measured. However, self-selected portions resulted in more than 90% of participants cleaning their plates in a

previous study (Fay et al., 2011b). Habitual sleep patterns were obtained from self-reports, which can be unreliable, although others have reported moderate correlations between subjective and objective measures of sleep duration (r=0.45) (Lauderdale et al., 2008). Only one night's worth of sleep data for each sleep condition was obtained, which obscures the effects of a possible accumulation of sleep debt; however, we purposefully recruited "good" sleepers with habitual bedtimes in order to minimize night-to-night variability. While menstrual cycles were not measured, randomization should have minimized the effects of menstruation on the study outcomes. Our female-only sample limits generalizability as the effects of insufficient sleep may differ by sex (Bayon et al., 2014). While breakfast was not standardized, diet recalls were used to confirm that each day's breakfast was the same. It is possible that the additional time awake led to increased energy expenditure leading to increased hunger; however, the timing of meals did not differ between days, so this effect is likely minimal but warrants further exploration.

2.7 Conclusions

While previous studies utilized severe sleep curtailments or even complete deprivation, the present study observed increased hunger, food cravings, food reward, and larger selected portion sizes under a more modest 33% sleep reduction. Taken together, these responses and behaviors could contribute to an increased intake and, ultimately, weight gain. Future work should focus on how these maladaptive responses to sleep curtailment can be addressed to prevent excess intake and weight gain.

CHAPTER 3: BENEFICIAL EFFECTS OF A HIGH PROTEIN BREAKFAST ON FULLNESS DISAPPEAR AFTER A NIGHT OF SHORT SLEEP IN NONOBESE, PREMENOPAUSAL WOMEN

This chapter has been published at:

Yang, C.-L., & Tucker, R. M. (2021). Beneficial effects of a high protein breakfast on fullness disappear after a night of short sleep in nonobese, premenopausal women. Physiology & Behavior, 229, 113269. https://doi.org/10.1016/j.physbeh.2020.113269.

3.1 Abstract

As insufficient sleep and obesity become more widespread, finding strategies to overcome changes in appetite and food cravings after sleep reduction is imperative. This study examined the effects of a high-protein (HP) and high-carbohydrate (HC) breakfast on appetitive sensations, food cravings, and dietary intake after nights of habitual (HS) and curtailed sleep (CS). Twenty-seven non-obese, premenopausal women who reported routinely eating breakfast participated in this randomized crossover study. Participants completed 4 laboratory visits with different combinations of sleep and breakfast conditions. Sleep was reduced by 33% on curtailed nights. At each visit, appetitive sensations were measured before breakfast and every 30 minutes thereafter throughout the 4-hour visit; area under the curve (AUC) was calculated. Food cravings were assessed before and 3.5 h after breakfast. Intake of ad libitum lunch and daily dietary intake were measured. Regardless of the breakfast condition, CS increased hunger ($p=0.043$) and desire to eat ($p=0.044$) and decreased fullness ($p=0.035$). The HP breakfast increased fullness AUC after HS ($p=0.022$) but not CS. Regardless of the sleep condition, the changes in food cravings scores were

significantly different based on breakfast condition (p=0.009), with food cravings increased after the HC breakfast and decreased after the HP breakfast. However, breakfast condition did not influence hunger or desire to eat AUC after either sleep condition. Neither the breakfast condition nor the sleep condition influenced lunch and daily energy intake. In conclusion, it appears protein reduces food cravings regardless of sleep condition in this population but obtaining sufficient sleep is necessary to benefit from the effects of high protein intake on fullness.

3.2 Key words

Sleep curtailment, dietary protein, appetite, food cravings, dietary intake

3.3 Introduction

Obesity increases the risk of chronic diseases, reduces quality of life, and decreases life expectancy (Abdelaal et al., 2017) while insufficient sleep increases body weight and the risk of obesity (Markwald et al., 2013; St-Onge et al., 2011). These relationships suggest that ensuring sufficient sleep might aid in controlling body weight while also reducing negative health outcomes. Unfortunately, many adults fail to meet the recommendations of 7-9 h of sleep per night (Hirshkowitz et al., 2015) as several studies in developed countries report that more than 30% of adults are not sleeping at least 7 h per night (Centers for Disease Control and Prevention, 2017; Furihata et al., 2015; Lin et al., 2018). The global prevalence of insufficient sleep makes it a public health problem similar in scope to overweight and obesity (Chooi et al., 2019). Based on the research presented above, it appears that addressing insufficient sleep might also benefit obesity.

Energy expenditure has been found to increase after insufficient sleep; however, energy consumption increases more, leading to positive energy balance (Markwald et al., 2013). One study reported that 24-hour energy expenditure increased by 5% after two nights of sleep curtailment (Shechter et al., 2013). Another study also observed a similar increase in daily energy expenditure after five nights of sleep curtailment (Markwald et al., 2013). Thus, changes in dietary intake after insufficient sleep play an important role in the short sleep-weight gain relationship.

The changes in dietary intake that result after insufficient sleep stem from a number of maladaptive responses that promote food consumption (Schmid et al., 2008; St-Onge et al., 2011; Yang et al., 2019). Our previous work observed that one night of sleep curtailment increased hunger sensations, food cravings, food reward, and portion sizes (Yang et al., 2019). Since these changes could promote dietary intake and given the correlation between and the extent of obesity and inadequate sleep, finding strategies to combat these maladaptive responses after insufficient sleep is imperative.

Protein consumption provides greater satiation compared to carbohydrates and fat in many studies (Dhillon et al., 2016; Paddon-Jones et al., 2008). High protein meals have been shown to increase fullness (Dhillon et al., 2016) and reduce energy intake (Leidy et al., 2013). A breakfast high in protein also increased daily fullness (Douglas et al., 2019; Fallaize et al., 2013) and decreased daily dietary energy intake (Leidy et al., 2013) compared to a breakfast high in carbohydrate. Based on these studies, increasing protein intake at breakfast after insufficient sleep could help to counteract the maladaptive responses that promote increased dietary intake.

While protein intake has been shown to increase satiety (Dhillon et al., 2016), it is important to note that the distribution of protein throughout the day needs to be considered (Layman, 2009). Increased protein at breakfast was found to produce the highest sensation of

short-term and longer-term fullness compared to increased protein at lunch or dinner (Leidy et al., 2008). It is common for American adults to consume less than 10 grams of protein for breakfast and consume significantly more protein later in the day (Layman, 2009), which suggests increasing protein intake at breakfast is an underutilized strategy to improve satiety. However, it is unknown whether the appetite-suppressing effects of a high protein breakfast can overcome the appetite-promoting effects (Chaput, 2014; Yang et al., 2019) and increased food cravings that result from insufficient sleep (Yang et al., 2019).

The purpose of this study was to determine if a high-protein breakfast resulted in better control of appetitive sensations and food cravings and reduced dietary intake after both habitual and curtailed sleep. We hypothesized that a high protein breakfast would decrease energy intake both at lunch and over the course of the day by reducing hunger, increasing fullness, reducing desire to eat, and decreasing food cravings more than a high carbohydrate breakfast after both habitual sleep and curtailed sleep nights.

3.4 Materials and methods

3.4.1 Participants

Women between the ages of 18 to 55 years old, who were not underweight or obese (body mass index between 18.5 and 30.0 kg/m^2), were generally healthy and nonsmoking, and reported routinely eating breakfast were recruited. This population is consistent with our previous work that demonstrated increased hunger and food cravings after sleep curtailment (Yang et al., 2019). Further, this study excluded men because there are gender differences in sleep duration and quality (Mallampalli & Carter, 2014), and women are more prone to be influenced by insufficient sleep (Krishnan & Collop, 2006). Underweight and obese populations were excluded because these populations are known to have more sleep problems

(Palm et al., 2015). To ensure participants liked the test foods, they had to score ≥ 50 liking for test foods on a 100 mm Visual Analog Scale (VAS) that measured liking (Gregersen et al., 2008); participants who scored < 50 were ineligible to participate. Participants had to report regularly sleeping 7-9 h per night and adhering to a regular bedtime to assist with the establishment of a sleep curtailment schedule. Participants with self-reported sleep problems, diagnosed sleep conditions, or poor quality sleep based on a Pittsburgh Sleep Quality Index (PSQI) score > 5, which indicates sleep problems (Buysse et al., 1989), were excluded. Due to possible effects of caffeine on appetitive sensations and dietary intake, participants with self-reported caffeine consumption > 300 mg per day were excluded (Schubert et al., 2017). Because restrained eaters react differently to food cues compared to non-restrained eaters (Fedoroff et al., 2003), participants who reported a high level of dietary restraint (restrained eating score >13) (Cassady et al., 2009) as determined by the Three-Factor Eating Questionnaire were also excluded (Stunkard & Messick, 1985). Informed consent was collected before testing. The Human Research Protection Program (HRPP) at Michigan State University (East Lansing, MI) approved the study (MSU Study ID: STUDY00002437).

3.4.2 Study design

Before the visits, participants were told that the purpose of the study was to investigate the effects of sleep and breakfast on feelings of hunger and food cravings. Participants were aware that there were two different sleep conditions, but participants were not aware of the differences in breakfast conditions.

Using a randomized crossover design, participants attended 4 laboratory visits during weekdays, which took place at least one week apart (Figure 2). Before two of the visits, the participants were instructed to follow their habitual sleep pattern, which was based on self-reported sleep data in the PSQI. One visit involved a high-protein breakfast; the other

involved a high-carbohydrate breakfast. Before the other two visits, participants followed a sleep curtailment protocol where their habitual sleep duration was reduced by 33% (Szczygiel, Cho, & Tucker, 2019; Yang et al., 2019) and the breakfast was either high in protein or carbohydrate. The curtailment was split equally between going to bed later and waking up earlier to center the sleep period and minimize disruption of circadian rhythm (Laposky et al., 2008).

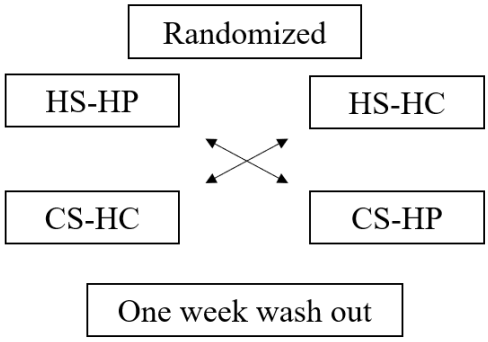


Figure 2. Study design for laboratory visits.
Four laboratory visits with different combinations of sleep and breakfast conditions were assigned to participants in a randomized order with one-week wash-out periods between visits. HS: habitual sleep; CS: curtailed sleep; HP: high protein; HC: high carbohydrate.

Each laboratory visit took place at the same time of day, with participants fasting for at least 8 hours. After participants consumed the breakfast that was provided by the researchers, they stayed in the laboratory and filled out several questionnaires. Participants were given eight fluid ounces of water and allowed to read and use cellphones and laptops in a sitting position in the laboratory. An ad libitum lunch was provided 4 hours after breakfast, in which participants were presented with a large bowl of macaroni and cheese and instructed to eat until they were comfortably full. The large bowl of macaroni and cheese was made with six packages of Easy Mac Original Flavor Macaroni & Cheese (Kraft). This serving contained 1380 kcal, 24 g total fat, 246 g carbohydrate, and 48 g protein. The amount

consumed was measured after the participant finished eating. Participants could leave the laboratory once 30 minutes had elapsed after lunchtime.

3.4.3 Measurement of anthropometric data and sleep

Body weight and body fat percentage were measured using a body composition analyzer with scale function and bioelectrical impedance analysis technology (TBF-400, Tanita, Arlington Heights, IL). Participants' height was measured using a stadiometer, and body mass index (BMI) was calculated based on height and weight.

The Zmachine (Zmachine® Insight & Insight+, DT-200, General Sleep Corporation, Euclid, OH) is a single-channel electroencephalography (EEG) device that measures sleep duration in 30 second epochs (Kaplan et al., 2014; Keenan, 2005). Data were stored on the device and downloaded in the laboratory. The Zmachine has been demonstrated to highly agree with polysomnography (PSG) (Kaplan et al., 2014), which is identified as the gold standard for measuring sleep (Keenan, 2005). The Zmachine is less invasive than PSG and also allows an individual to sleep at their home (Kaplan et al., 2014). The Zmachine was used to assess total sleep time (TST), which served to confirm that participants followed the assigned sleep protocol (Kaplan et al., 2014). In this study, participants used the Zmachine before each visit.

3.4.4 Breakfast content

The two breakfast conditions consisted of a high protein (HP) and high carbohydrate (HC) meal (Table 6) in random order. Both breakfasts included yogurt and granola bars. HP strawberry yogurt was made with Greek yogurt, milk powder, and skim milk. HC strawberry yogurt was made with whole milk yogurt and maltodextrin. The high protein meal consisted of 30 g of protein (30% of energy from protein, 44% from carbohydrate), which was considered high in protein (Symons et al., 2009; Westerterp-Plantenga et al., 2012); the high

carbohydrate meal consisted of 8 g of protein (8% of energy coming from protein, 65% coming from carbohydrate), which was considered high in carbohydrate (Hopkins et al., 2016). Fat was matched for each meal. Participants finished the breakfast in its entirety within 20 minutes. Participants were allowed to choose what to drink for breakfast; choices included water, tea, and coffee. Drink choice and amount was consistent across all visits.

Table 6. Breakfast content and characteristics

	High protein (HP)	High carbohydrate (HC)
Strawberry yogurt[1]		
Yogurt (g)[2]	180	190
Milk powder (g)[3]	14	-
Skim milk (g)[4]	10	-
Maltodextrin (g)[5]	-	6
Granola bar(s) (g)[6]	40	48
Total amount (g)	244	244
Energy (kcals)	402.7	401.3
Protein (g)	30.3	7.9
Fat (g)	12.0	11.9
Carbohydrate (g)	44.2	65.8
Fiber (g)	6.9	2.0
Sugar (g)	31.7	34.3
Meal liking (mm)[7]	63 ± 21	64 ± 21
Meal sweetness (mm)[7]	64 ± 13	64 ± 17
Meal healthiness (mm)[7]	53 ± 22	54 ± 26

[1]HP strawberry yogurt was made with yogurt, milk powder, and skim milk. HC strawberry yogurt was made with yogurt and maltodextrin.
[2]HP yogurt was Greek yogurt (Chobani, strawberry). HC yogurt was whole milk yogurt (Dannon, strawberry).
[3]Milk powder was non-fat dry milk (Kroger).
[4]Skim milk was fat-free milk (Meijer).
[5]Maltodextrin was maltodextrin powder (Nutricost).
[6]HP granola bars were peanut butter dark chocolate protein chewy bars (Nature Valley). HC granola bars were chewy chocolate chip granola bars (Kroger).
[7]Data assessed using 100 mm Visual Analog Scales (Gregersen et al., 2008); data expressed as: mean ± standard deviation.

3.4.5 Questionnaires

Information about menstrual cycle duration and the first day of the last period was collected. Menstrual cycles have been shown to influence women's dietary intake (Barr et al., 1995; Pliner & Fleming, 1983), especially in the luteal phase (Barr et al., 1995, p. 13; Bryant et al., 2006). Because the luteal phase consistently lasts for 14 days (Reed & Carr, 2000), the follicular phase was determined by deducting 14 days from the expected menstruation day (Pliner & Fleming, 1983).

Once participants arrived at the laboratory, sleepiness, tiredness, and subjective sleep quality were measured at the baseline before breakfast. The Karolinska Sleepiness Scale (KSS) was used to assess participants' momentary sleepiness (Åkerstedt et al., 2014). The KSS is a validated questionnaire; scoring ranges from 1 to 9 with 1 indicating extremely alert and 9 indicating very sleepy (Åkerstedt et al., 2014). Visual Analog Scales (VAS) (Gregersen et al., 2008) measured tiredness (0 score = not at all, 100 score = extremely) and subjective sleep quality (0 score = much worse than normal, 100 score = much better than normal).

Appetitive sensations were measured before starting breakfast and every 30 minutes after breakfast until participants finished lunch. These sensations included hunger, fullness, and general desire to eat, and were measured with 100 mm VAS (Gregersen et al., 2008). The participants were asked "how strong is your feeling of hunger/fullness" and "how strong is your desire to eat" with anchors of "not at all" and "extremely" (Greenberg & Geliebter, 2012). The responses for each appetitive sensation (from the baseline to 4 h after breakfast) were used to calculate area under the curve (AUC).

The General Food Craving Questionnaire (State) is a validated questionnaire that assesses state-dependent food cravings (Nijs et al., 2007). This questionnaire contains 15 questions, which are answered on a five-point Likert scale with a total possible score of 75 points. The questionnaire was completed at baseline before breakfast as well as 30 minutes and 3.5 h after consuming breakfast. Changes in food craving total scores between 3.5 h after breakfast and baseline (score at 3.5 h minus the baseline) were calculated to examine the effects of breakfast on state-related food cravings.

Thirty minutes after participants started breakfast, a 100 mm VAS was used to assess participants' liking for breakfast and how sweet/healthy they thought breakfast was. Again, anchors of "not at all" and "extremely" were used (Greenberg & Geliebter, 2012). The same questionnaire was used to assess participants' liking for lunch after they consumed it.

After participants left the laboratory, they completed the Automated Self-Administered 24-Hour (ASA24®) Dietary Assessment Tool (Subar et al., 2016). The ASA24 is a validated online recall tool that collects dietary information for the past 24-hour period. To analyze daily dietary intake, participants entered all foods and beverages consumed on the testing day after the provided lunch. Participants were asked to complete the recall before they went to bed.

3.4.6 Statistical analyses

To check the effectiveness of sleep curtailment, one-way repeated-measures analysis of variance (RMANOVA) with Greenhouse-Geisser correction was used to analyze sleep parameters, sleepiness, tiredness, and subjective sleep quality in different sleep conditions and breakfast contents. When differences in groups were detected, a groups comparison with Bonferroni's correction for multiple comparisons was performed. A RMANOVA was used to assess order effects of consuming breakfast and lunch throughout four laboratory visits. Order effects were not controlled for because none were observed for breakfast liking ($p=0.355$) or macaroni and cheese intake ($p=0.447$). To determine whether liking for lunch differed between visits, RMANOVA analysis was conducted.

The differences in appetitive sensations were assessed using area under the curve calculated using the trapezoidal rule (Allison et al., 1995). Two-way repeated measures ANOVA was used to examine the main effects of sleep, breakfast, and sleep x breakfast interaction on outcomes, including appetitive sensations, food cravings, lunch intake, intake after lunch, and daily dietary intake. To identify confounding factors that could affect ingestive and post-ingestive effects, a paired t-test was used to assess the differences in meal liking, sweetness, and healthiness for the two types of breakfasts. A chi-square test of

independence was used to examine the distribution of follicular and luteal phases of menstrual cycles in each sleep and breakfast condition.

Assuming a medium effect of 0.25 and α=0.05, a sample size of 24 provides 80% power to detect the differences between sleep conditions and between breakfast contents. All data were collected after specifying all the hypotheses and determining the statistical analyses that would be conducted. Data were analyzed using SPSS version 25 (IBM Corp., Armonk, NY). All values are displayed as mean and standard deviation.

3.5 Results

3.5.1 Participants

Of the 72 participants who completed the screening survey, 33 met the eligibility criteria and were available for testing. A total of 27 participants successfully completed all testing procedures. Of those who did not complete the study, three withdrew due to scheduling issues, and three were excluded due to non-compliance. The characteristics of participants are displayed in Table 7. In total, 26 participants provided self-reported menstrual cycle information with one participant not reporting and coded as missing. In the 4 laboratory visits, the distribution of participants who were assigned in each sleep and breakfast condition did not differ by menstrual phase, $X^2(3)=1.538$, p=0.673.

Table 7. Participant characteristics (n = 27)

Variable	Mean ± SD
Age (year)	27.5 ± 7.5
Height (cm)	164.9 ± 7.2
Weight (kg)	63.1 ± 10.3
Body fat (%)	28.2 ± 7.0
Body mass index (kg/m^2)	23.2 ± 3.2
Cognitive restraint score[1]	6.5 ± 3.0
Global PSQI score[2]	2.5 ± 1.6
Race	n (%)
Asian	7 (25.9)
Black	3 (11.1)
White	16 (59.3)
More than one	1 (3.7)
Ethnicity	n (%)
Non-Hispanic	26 (96.3)
Prefer not to answer	1 (3.7)

SD: standard deviation. [1]Assessed using the Three-Factor Eating Questionnaire (Stunkard & Messick, 1985). [2]Assessed using the Pittsburgh Sleep Quality Index (PSQI) (Buysse et al., 1989).

3.5.2 Sleep duration, sleepiness, tiredness, and subjective sleep quality

Participants followed the sleep protocol and successfully reduced their total sleep time (TST) on the curtailed sleep (CS) nights compared to habitual sleep (HS) nights before having HP breakfasts (4.5 ± 0.6 vs. 7.0 ± 0.7 h, $p<0.001$) and HC breakfasts (4.6 ± 0.6 vs. 7.0 ± 0.8 h, $p<0.001$) (Table 8). The reduction of TST was 35.7% for HP and 34.3% for HC breakfast on the CS nights. Participants experienced more sleepiness and greater tiredness after CS nights than HS nights. Subjective sleep quality did not differ between different sleep conditions.

Table 8. Total sleep time, subjective feelings, and sleep quality

	CS		HS	
	HC	HP	HC	HP
TST (hr) [1]	4.6 ± 0.6 [a]	4.5 ± 0.6 [a]	7.0 ± 0.8 [b]	7.0 ± 0.7 [b]
Sleepiness[2]	6.1 ± 1.8 [a]	5.1 ± 1.9 [b]	3.4 ± 1.4 [c]	3.6 ± 1.4 [c]
Tiredness[3]	57 ± 19 [a]	51 ± 17 [a]	20 ± 14 [b]	24 ± 17 [b]
Sleep quality[3]	50 ± 20 [a]	48 ± 17 [a]	54 ± 25 [a]	54 ± 17 [a]

Data expressed as: mean ± SD.
Different letters denote significant differences between each other ($p<0.05$).
[1]Total sleep time (TST) was assessed using the Zmachine (Zmachine® Insight & Insight+, DT-200, General Sleep Corporation, Euclid, OH). [2]Score was measured by Karolinska Sleepiness Scale (Åkerstedt et al., 2014). [3]Data obtained by Visual Analog Scales (mm) (Gregersen et al., 2008).
CS: curtailed sleep; HS: habitual sleep; HC: high carbohydrate; HP: high protein.

3.5.3 Liking and appetitive sensations

Because cognitive factors were previously shown to affect appetite and subsequent dietary intake (Crum et al., 2011; Jayasinghe et al., 2017), we confirmed that these did not differ between the breakfasts. Participants liked the HP and HC breakfasts equally ($p=0.700$). Both breakfasts were considered to have the same sweetness ($p=0.878$) and were rated as equally healthy ($p=0.953$) (Table 6).

There was a significant main effect of sleep ($F(1,26)=4.522$, $p=0.043$) on hunger (Figure 2). Participants' area under the curve (AUC) of hunger was higher when they experienced CS (7913 ± 3628 min*mm) when compared to HS (6805 ± 3348 min*mm). There was no significant main effect of protein ($F(1,26)=1.171$, $p=0.289$) or the interaction between sleep and breakfast ($F(1,26)=2.205$, $p=0.150$) on hunger.

With regard to fullness, a significant main effect of sleep ($F(1,26)=4.935$, $p=0.035$) on fullness was noted (Figure 3). Participants' fullness AUC was lower after CS nights (10291 ± 4533 min*mm) compared to HS nights (11538 ± 4405 min*mm). There was no significant main effect of protein on fullness ($F(1,26)=1.326$, $p=0.260$). Sleep x breakfast interactions were observed on fullness ($F(1,26)=4.833$, $p=0.037$), in which the HP breakfast resulted in

greater fullness under the condition of HS (p=0.022) but not under CS (p=0.795). Also, sleep curtailment reduced fullness under the condition of having HP breakfast (p=0.003) but not under the condition of having HC food (p=0.463).

Sleep also had a main effect (F(1,26)=4.488, p=0.044) on desire to eat (Figure 3). Participants' AUC of desire to eat was higher when they had CS (8250 ± 3845 min*mm) compared to HS (7068 ± 4014 min*mm). There were no significant main effects of breakfast on desire to eat (F(1,26)=0.565, p=0.459) and no interaction between sleep and breakfast (F(1,26)=3.374, p=0.078) on desire to eat.

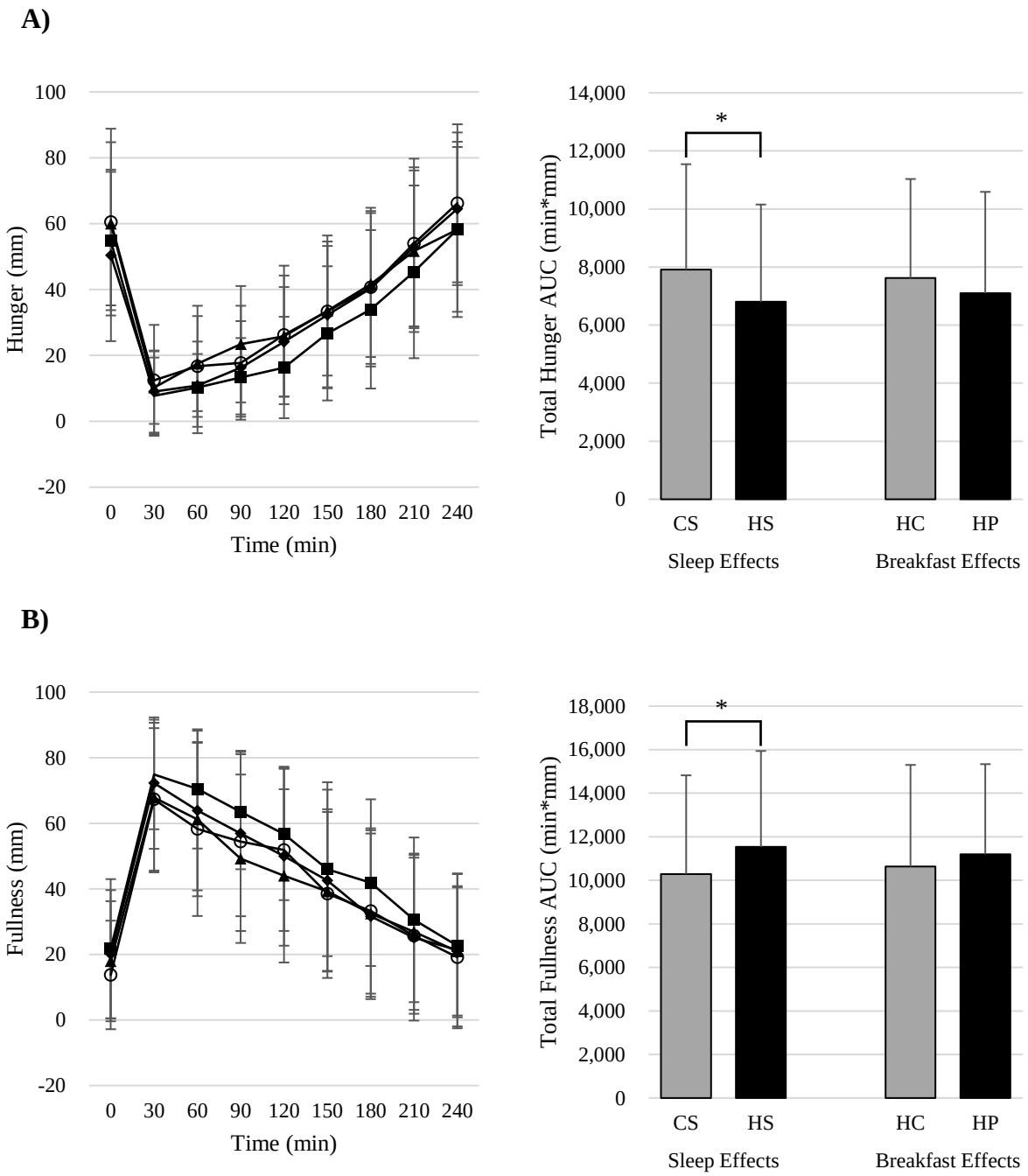
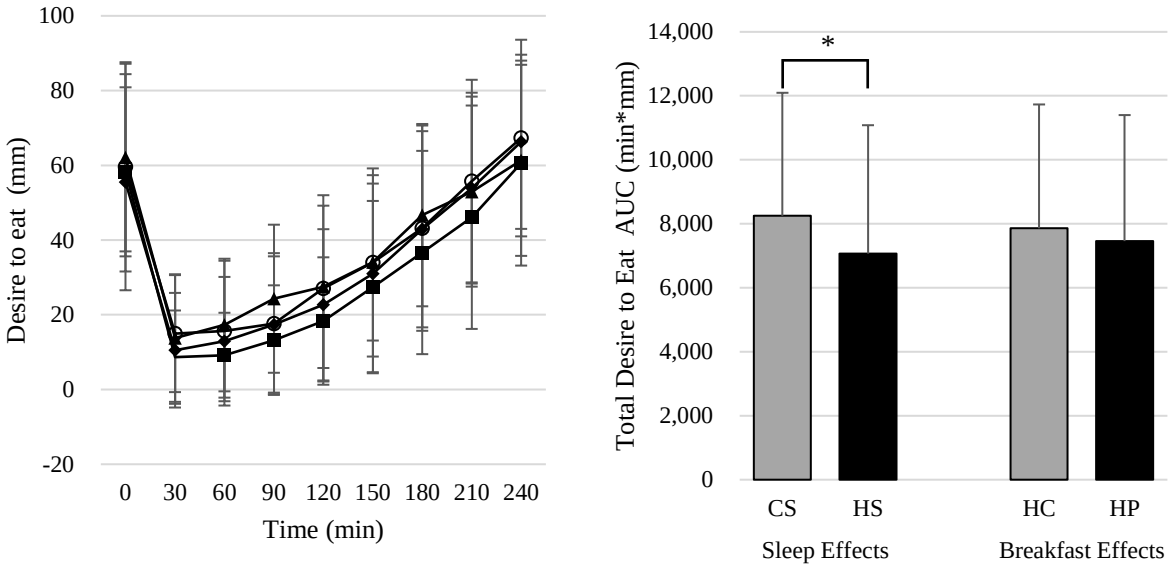


Figure 3. Perceived hunger (A), fullness (B), and desire to eat (C) responses over 4 hours on the testing days

Values are mean and standard deviation. The line graphs represent the responses during 4 hours after consuming the breakfasts. The bar graphs represent the area under the curve (AUC) for the responses. *denotes significance between different sleep conditions ($p<0.05$). CS: curtailed sleep; HS: habitual sleep; HC: high carbohydrate; HP: high protein. CSHC (○), CSHP (▲), HSHC (♦), HSHP (■).

Figure 3 (cont'd)
C)



3.5.4 Food cravings

There was a significant main effect of breakfast on food cravings between 3.5 hours after consuming breakfast and baseline ($F(1, 26)=8.1$, $p=0.009$) (Figure 4). After consuming the HP breakfast, participants' food cravings were reduced by 2.3 points; whereas, after consuming HC breakfast, participants' food cravings were increased by 1.3 points. Thus, compared to baseline, food cravings increased more after participants consumed the HC breakfast than the HP breakfast. There was no significant main effect of sleep ($F(1, 26)=0.034$, $p=0.855$) or sleep x breakfast interaction ($F(1, 26)=0.001$, $p=0.980$) on changes in food cravings. There was also no significant main effect of sleep ($F(1, 26)=2.378$, $p=0.135$) on food cravings at baseline.

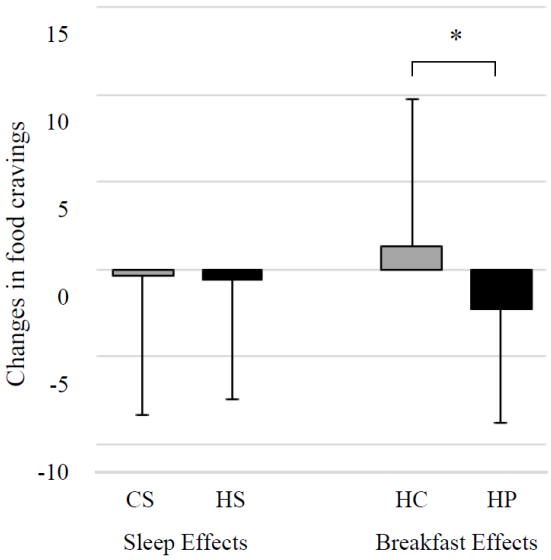


Figure 4. Changes in food cravings between 3.5 hours after breakfast and baseline
Values are mean ± standard deviation. *denotes significance between different breakfasts ($p<0.05$). CS: curtailed sleep; HS: habitual sleep; HC: high carbohydrate; HP: high protein.

3.5.5 Total dietary intake and ad libitum lunch

No main effects of sleep or sleep x breakfast interaction were observed for daily dietary energy and macronutrient intake (Table 9). However, there was a main effect of breakfast on daily protein intake (HP: 85.9 ± 20.3 vs. HC: 62.9 ± 18.0 g, $p<0.001$), but breakfast protein content did not influence daily energy, fat, or carbohydrate intake. The mean difference of daily protein intake between HP and HC was 23 g, which was consistent with increased protein provided by the HP breakfast condition. The daily percent energy intake from protein was 12.0%, 17.8%, 13.3%, and 16.9% for CSHC, CSHP, HSHC, and HSHP, respectively. There were no main effects of sleep, breakfast, or sleep x breakfast interaction on energy intake or macronutrient intake after lunch (Table 10).

Throughout the 4 laboratory visits, participants liked the ad libitum lunch of macaroni and cheese equally (CSHC: 58 ± 23, CSHP: 56 ± 23, HSHC: 60 ± 23, HSHP: 58 ± 25 mm, $p=0.584$). However, there were no main effects of sleep ($F(1, 26)=0.629$, $p=0.435$), breakfast

(F(1, 26)=1.423, p=0.244), or sleep x breakfast interaction (F(1, 26)=0.404, p=0.531) on the amount of ad libitum lunch consumption (Table 10).

Table 9. Daily energy and macronutrient intake

	CS		HS		Sleep effect	Breakfast effect	Sleep x breakfast
	HC	HP	HC	HP			
Energy (kcal)	2001.6 ± 645.3	1985.1 ± 643.8	1981.4 ± 509.1	1972.1 ± 479.4	0.799	0.892	0.960
Protein (g)	59.8 ± 19.7	88.2 ± 29.2	66.0 ± 20.3	83.5 ± 17.5	0.804	<0.001	0.083
Carbohydrate (g)	282.8 ± 77.7	258.5 ± 80.9	286.7 ± 72.9	269.7 ± 65.3	0.440	0.091	0.699
Fat (g)	62.7 ± 25.0	66.7 ± 33.0	64.5 ± 23.7	61.1 ± 23.2	0.498	0.946	0.365

Values are mean ± standard deviation. CS: curtailed sleep; HS: habitual sleep; HC: high carbohydrate; HP: high protein.

Table 10. Energy and macronutrient intake during lunch and after lunch

	CS		HS		Sleep effect	Breakfast effect	Sleep x breakfast
	HC	HP	HC	HP			
Lunch intake							
Energy (kcal)	565.6 ± 225.0	531.7 ± 219.8	569.6 ± 218.1	555.5 ± 200.6	0.435	0.244	0.531
Protein (g)	19.7 ± 7.8	18.5 ± 7.6	19.8 ± 7.6	19.3 ± 7.0	0.435	0.244	0.531
Carbohydrate (g)	100.8 ± 40.1	94.8 ± 39.2	101.5 ± 38.9	99.0 ± 35.8	0.435	0.244	0.531
Fat (g)	9.8 ± 3.9	9.2 ± 3.8	9.9 ± 3.8	9.7 ± 3.5	0.435	0.244	0.531
Intake after lunch							
Energy (kcal)	1034.8 ± 565.0	1040.6 ± 615.5	1010.3 ± 444.8	1024.1 ± 469.1	0.778	0.920	0.958
Protein (g)	32.2 ± 18.9	39.3 ± 28.7	39.8 ± 20.6	34.1 ± 16.7	0.688	0.811	0.053
Carbohydrate (g)	116.2 ± 64.0	119.0 ± 72.6	120.4 ± 54.8	127.0 ± 70.3	0.574	0.702	0.841
Fat (g)	41.0 ± 24.5	44.6 ± 33.3	41.4 ± 24.2	40.3 ± 22.9	0.550	0.762	0.550

Values are mean ± standard deviation. CS: curtailed sleep; HS: habitual sleep; HC: high carbohydrate; HP: high protein.

3.6 Discussion

This study examined the effects of a HP breakfast on appetitive sensations, food cravings, and dietary intake after one night of HS and CS. Participants reduced their total sleep time by 34-36%, felt sleepier, and experienced greater tiredness after CS, which confirmed the effectiveness of the sleep curtailment protocol. Regardless of whether a HP or a HC breakfast was consumed, participants reported feeling hungrier, less full, and experienced greater desire to eat after sleep curtailment. The HP breakfast increased participants' feelings of fullness after experiencing HS but not after CS. Regardless of the sleep condition, the HP breakfast reduced food cravings. However, breakfasts differing in macronutrient content did not influence participants' feelings of hunger or desire to eat after either a night of HS or CS and had no effect on their lunch intake and daily energy intake. Also, participants' lunch and daily energy consumption were not influenced by the sleep condition. In summary, although sleep curtailment negatively impacts appetitive sensations and food cravings, and HP breakfasts positively impact these responses, those changes did not influence energy intake at lunch or over the course of the day.

Short sleep duration has been demonstrated to be a risk factor for weight gain because several maladaptive changes occur after nights of CS (Chaput & St-Onge, 2014). In the current study, sleep curtailment increased hunger, decreased fullness, and increased desire to eat. These results are consistent with other studies that reported participants felt hungrier (Yang et al., 2019) and less full (Ness et al., 2019) after sleep curtailment. These appetitive sensation changes might be due to changes in appetite-regulating hormones after short sleep, including increased ghrelin (Broussard et al., 2016b) and decreased leptin (Taheri et al., 2004), but this hypothesis requires further testing.

Despite the previously reported undesirable changes thought to promote dietary intake after sleep curtailment (Ness et al., 2019; Yang et al., 2019), findings regarding the effects of sleep duration on dietary intake are mixed. In the present study, the sleep condition had no influence on lunch or total daily energy intake, which is consistent with another previous study (Nedeltcheva et al., 2009). In that study, participants underwent 5.5 h and 8.5 h sleep opportunities (5.2 h vs. 7.2 h TST) for 14 days each, and the observed 14-d average daily energy intake for the 5.5 h sleep condition was 76 kcal higher than the 8.5 h sleep condition, but the difference did not reach statistical significance. In contrast, two other studies observed short sleep duration increased daily energy intake (Markwald et al., 2013; St-Onge et al., 2011). These studies used more extreme sleep curtailment protocols, which could explain the discrepancies. For example, one of the studies observed that daily energy intake increased after 4 consecutive nights of 3.8 h compared to 7.6 h TST (St-Onge et al., 2011); the other study noted an increased average daily energy intake over 5 nights of 4.6 h compared to 7.7 h TST (Markwald et al., 2013). Participants in the current study averaged 4.5 h and 7 h TST and this reduction lasted just one night. It is possible that the current study's sleep intervention might be too mild or too brief to see changes in dietary intake.

The discrepancy between appetitive sensation findings – increased hunger, decreased fullness, and increased desire to eat – and lack of changes in dietary intake after sleep curtailment should be noted. However, these differences are not entirely unexpected as changes in appetitive sensations and appetite-regulating hormones do not always translate to changes in energy intake [47,49]. While the current study was designed to examine acute changes, given the variability of dietary intake from one day to the next (Palaniappan et al., 2003), the brief study duration might not have allowed for the capture of dietary changes. Still, fullness was noted to be

the most strongly associated with total daily energy intake compared to desire to eat, prospective food consumption, and hunger in previous work (Drapeau et al., 2005), which suggests that appetite measures meaningfully contribute to the understanding of feeding behaviors.

Since protein has been reported to provide greater satiation and satiety than other macronutrients (Dhillon et al., 2016; Paddon-Jones et al., 2008), it was hypothesized that a HP breakfast would better control appetite than a lower protein breakfast. While the HP breakfast did increase fullness after a night of HS, the HP breakfast did not reduce hunger or desire to eat in either the HS or CS conditions. These null findings were inconsistent with previous studies that observed less hunger and desire to eat after consuming HP diets (Gwin et al., 2017) and breakfasts (Fischer et al., 2004). However, these studies used protein supplements rather than foods to provide 100 g of protein at a meal (Fischer et al., 2004) or provided nearly twice the Dietary Reference Intake for protein over the course of the day (Gwin et al., 2017). Although appetitive differences were observed, these approaches are not particularly advisable longer term as current research suggests approximately 30 g of protein is the amount that can be used for anabolism at one meal (Symons et al., 2009). Consuming excess amounts of protein results in its storage as glycogen and fat, which is not beneficial for weight management (Pesta & Samuel, 2014), and high levels of protein intake have been associated with diminished renal function in people who have chronic kidney disease (Huang et al., 2008). Therefore, the present study incorporated 30 g of protein for the HP condition in order to adequately test the hypothesis regarding HP breakfasts; yet, even at these physiologically relevant but upper limit levels, changes in hunger and desire to eat were not noted.

HP foods have been demonstrated to increase fullness (Dhillon et al., 2016; Douglas et al., 2019), and the present study confirmed this finding, but only under the HS condition. The

same effect was not observed under the condition of CS. Thus, based on these results, obtaining sufficient sleep is necessary to benefit from the effects of high protein intake on fullness.

Studies have demonstrated that dietary macronutrients could alter food cravings in adults (Apolzan et al., 2014; Jakubowicz et al., 2012). One study noted that overeating a high-carbohydrate and low-energy density diet reduced carbohydrate and starch cravings compared to a high-fat and high-energy density diet in adults (Apolzan et al., 2014). Another study observed that a sixteen-week HC and HP breakfast diet reduced more food cravings and promoted better weight loss maintenance in overweight and obese adults compared to a low carbohydrate diet in a weight loss program (Jakubowicz et al., 2012). Consistent with previous studies, the present study observed that the HP breakfast better reduced food cravings after HS and CS than the HC breakfast. This finding is inconsistent with another study conducted in adolescent girls that observed that the differences in the reduction of food cravings between a HP breakfast and a breakfast with lower protein were not significant (Hoertel et al., 2014). While protein differences between breakfasts were similar, the two studies differed in food craving measurement tools and sample populations, which could have contributed to the discrepancies. Although the study in adolescents did not observe the impact of macronutrients on food cravings, studies in adults support the ability of different macronutrients to change food cravings.

Reducing food cravings is important, as some studies noted that greater food cravings were related to greater energy intake (Lafay et al., 2001) and higher BMI (Chao et al., 2014). However, increased food cravings do not always predict greater dietary intake as people do not always consume the food they crave (Hill, 2007). Understanding that cravings do not always result in dietary intake is consistent with the findings of the current study as reductions in dietary intake after the HP breakfast decreased food cravings did not occur. Furthermore, this study did

not observe changes in food cravings after different sleep conditions. This finding contradicts our previous work (Yang et al., 2019) that noted food cravings increased after sleep curtailment in a similar sample population. However, the timing of the food cravings measurements were different between the two studies. The present study measured participants' food cravings after fasting for 8 hours, and our previous study measured food cravings before lunch time (Yang et al., 2019). Therefore, food cravings after insufficient sleep appear to vary based on time of day, and further study of this possibility is warranted. Overall, food cravings change after consuming food with different macronutrient composition, but cravings do not always influence dietary intake.

The effects of protein intake on energy intake are mixed. Our hypothesis, that a HP breakfast would suppress subsequent energy intake compared to a HC breakfast was not confirmed. This result agrees with short-term (Douglas et al., 2019; Gwin et al., 2017; Leidy & Racki, 2010) and long-term (Leidy et al., 2015) studies that observed HP foods had no influence on daily dietary intake. In contrast to those findings, one study demonstrated that a breakfast with lower protein resulted in greater evening snack intake and daily energy intake compared to a breakfast higher in protein (Leidy et al., 2013); however, that study provided participants with a variety of snack options they could consume ad libitum; thus, that study design was markedly different from the current study. This difference is important as one review noted that when participants were presented with a great variety of food options with different sensory properties, energy consumption was 22-25% higher than when one food item was available (McCrory et al., 2012). Based on our findings and the work of others, the short-term effects of protein on daily energy intake appear to be minimal; however, these effects could accumulate and be meaningful over time. Further work is required.

This study had several strengths. One strength is that objective sleep parameters were used instead of subjective reports for the sleep protocol confirmation. The current study also incorporated a randomized study design to reduce allocation bias and a washout period to minimize carryover effects. In addition, this was a single-blinded study as participants were not notified which type of breakfast they were consuming. The breakfasts were equally liked; believed to be equally healthy; and serving sizes (grams), energy, and fat content were matched to minimize any confounding ingestive or post-ingestive effects. During the visits, participants consumed foods and completed questionnaires while staying in the laboratory, which prevented other factors (e.g. physical activity) from influencing appetite. Follicular and luteal phases were distributed equally in each sleep and breakfast condition, which mitigate the effects of menstrual cycle on the study results.

There are several limitations that should be noted. First, underreporting is always a possibility when collecting self-reported diet data, but the ASA24® utilizes multiple passes to help minimize this issue (Tucker, 2007), and only information about food consumed after the ad libitum lunch was requested, so participants' memory burden was reduced. Given that researchers asked participants to eat in the laboratory and asked about their dietary intake, participants might have been aware that researchers were interested in how much food they consumed, which could have influenced behavior. Participants' usual dietary intake was not assessed, including breakfast content, which might impact the results. However, participants were habitual breakfast consumers. While the HP breakfast contained additional dietary fiber, one review suggested that most studies do not observe changes in satiety and food intake following a short-term change in fiber consumption (Clark & Salvin, 2013). The present study only included non-obese female participants, which limits the generalizability. Future studies

should test whether protein and sleep interact the same way in other populations. This study did not exclude participants for using oral contraceptive pills or other medications, which could influence dietary intake (Eck et al., 1997), but because menstrual cycle did not differ and participants served as their own controls, the likelihood that this had a profound impact on the results is minimal. Although information about the menstrual cycle was collected, hormone levels were not measured, and as a result, the potential effects of hormones on appetite and dietary intake could not be verified. Still, the lack of difference in distribution of menstrual cycle phases across all treatments suggests this factor has been controlled for. Finally, participants were unable to be blinded for different sleep conditions.

3.7 Conclusions

The present study observed increased hunger and desire to eat and decreased fullness after sleep curtailment compared to habitual sleep. While the high protein breakfast resulted in increased fullness after a habitual night of sleep, increased protein intake at breakfast did not diminish increased appetite after curtailed sleep. Daily dietary energy intake was not influenced by sleep and breakfast protein content in this short-term study, and further work should explore the effects of a high protein breakfast on dietary intake over a longer period of sleep curtailment. Overall, it appears that protein reduces food cravings regardless of sleep condition in this population, but obtaining sufficient sleep is necessary to benefit from the effects of high protein intake on fullness.

Chapter 4: SNACKING BEHAVIOR DIFFERS BETWEEN EVENING AND MORNING CHRONOTYPE INDIVIDUALS BUT NO DIFFERENCES OBSERVED IN OVERALL ENERGY INTAKE, DIET QUALITY, OR FOOD CRAVINGS

4.1 Abstract

There is a growing body of literature that links chronotype to certain undesirable eating behaviors. However, the relationship between chronotype and dietary intake is poorly characterized among adults in the United States (U.S.). This cross-sectional study examined the associations among chronotype, snacking habits, dietary intake and quality, and food cravings. One-hundred adults living in the U.S. completed the study. Based on the Monoester Morningness-Eveningness Questionnaire score, an individual was categorized as having either a morning (M)-type, intermediate (I)-type, or evening (E)-type chronotype. Snack intake was assessed using a previously published specialized food frequency questionnaire. Sugar-sweetened beverage (SSB) intake was assessed using the updated version of the Beverage Intake Questionnaire-15. Alcohol misuse was measured using the Alcohol Use Disorders Identification Test-Consumption. Diet quality was obtained using the Diet History Questionnaire III. The validated General Food Cravings Questionnaire-Trait measured participants' food cravings. E-type individuals reported consuming snacks more often over the course of a week than M-types ($p=0.002$) but not I-types. In terms of timing of snacking, E-type individuals consumed more snacks after dinner than M-types ($p<0.001$). E-type individuals consumed more energy-dense snacks ($p=0.005$), especially candies ($p=0.005$), than M-types. However, there were no significant differences in healthy snack frequency, diet quality, energy and macronutrient intake, SSB consumption, alcohol misuse, or food cravings among chronotypes ($p>0.05$, for all). In

conclusion, E-type individuals consumed snacks more frequently and later than M-types; however, chronotype was not associated with an individual's energy intake, diet quality, and food cravings, which suggests that chronotype is negligibly associated with weight gain-related behaviors in this population.

4.2 Keywords

Chronotype; snacking; diet quality; dietary intake; food cravings

4.3 Introduction

Chronotype has been linked to certain undesirable dietary behaviors and patterns (Arora & Taheri, 2015; Li et al., 2018; Zhang et al., 2018), but these relationships are not universally observed (Gontijo et al., 2019). For those studies that demonstrated relationships, these undesirable outcomes are typically attributed to evening-type individuals who are more active at night. For example, Finnish adults who were classified as evening types had lower diet quality, as measured by their adherence to a healthy Nordic diet, in comparison to morning types (individuals with morning preferences) and intermediate types (individuals who are neither morning types nor evening types) (Maukonen et al., 2016). Daily consumption of unhealthy snacks was also associated with evening-type individuals in a study of British adolescents (Arora & Taheri, 2015). Finally, evening type was also associated with greater consumption of sugar-sweetened beverages (SSB) (Li et al., 2018; Zhang et al., 2018) and alcohol among undergraduates in China (Zhang et al., 2018). However, in the study that did not show an association between chronotype and diet quality, the sample population consisted of pregnant

women in Brazil (Gontijo et al., 2019), which may have been a factor in the discrepant findings. To date, there has been no study conducted in the U.S. that examines the relationship between chronotype and SSB consumption, nor has the relationship between chronotype and snacking habits been described. While one study conducted in the U.S. did assess the association between alcohol intake and chronotype, the study was conducted among first-year university students (Culnan et al., 2013), a population with drinking habits that are not necessarily representative of the larger population (Grant et al., 2004). To our knowledge, the relationships among chronotype and dietary behaviors and patterns are poorly characterized among U.S. adults. Evidence suggests that these eating behaviors and patterns, including lower diet quality (Maukonen et al., 2016), timing of snacking (Barrington & Beresford, 2019), and SSB (DellaValle et al., 2005) as well as alcohol consumption (Traversy & Chaput, 2015), may predispose an individual to weight gain.

The relationships between chronotype and factors known to be associated with weight gain have not been fully investigated in U.S. adults. For example, diet quality, as measured by Healthy Eating Index (HEI), has been shown to be inversely associated with the risk of obesity in U.S. adults (Tande et al., 2010). The HEI assesses the degree to which dietary intake aligns with the 2015-2020 Dietary Guidelines for Americans (DGA) (Krebs-Smith et al., 2018). Since overall diet quality is related to obesity, it is important to assess its relationship with chronotype to identify possible risk factors for poor diet quality. In addition to diet quality, the relationship between chronotype and food cravings in adults has not been fully characterized. Food craving is a multifaceted phenomenon which represents a person's desire to consume foods that are deemed to be palatable and is associated with greater likelihood of night eating (Meule et al., 2014) and uncontrolled eating behaviors (Nijs et al., 2007). Studies suggest that the frequency of

experiencing food cravings does not differ among chronotypes in university students (Meule et al., 2012) and pregnant women (Teixeira et al., 2020). Given that the previous studies that examine the relationship between chronotype and food cravings only focus on certain populations in Brazil (Meule et al., 2012) and Germany (Teixeira et al., 2020) but not in the U.S., expanding our understanding of these relationships in other populations is warranted.

Since questions remain regarding dietary patterns and chronotype in the U.S., the purpose of this study was to examine the associations among chronotype, dietary intake, and food cravings. We hypothesized that evening chronotypes would consume snacks more frequently; consume more unhealthy snacks, SSB, and alcohol; report lower diet quality; and experience higher food cravings than the morning-type or intermediate-type individuals based on the literature discussed above.

4.4 Materials and methods

4.4.1 Participants

Adults between the ages of 19 and 55 years old and living in the United States participated in the study. Participants who had chronic diseases, endocrine disorders, the diagnosis of clinically significant depression, self-reported sleep problems, did not follow a standard American diet (e.g., vegan, vegetarian, ketogenic (keto), weight loss, low sodium, or consistent carbohydrate diet), gained or lost 5 pounds (2.3 kg) of weight in the past month, people who worked night shifts, or were pregnant or lactating were excluded from participating. Participants who took steroids, high blood pressure medication, or beta blockers were also excluded.

Participants were recruited from Michigan State University's Paid Research Pool and social media. The Michigan State University Human Research Protection Program (East Lansing, MI) approved the study. All participants provided informed consent.

4.4.2 Questionnaires

This cross-sectional study included two online surveys: a screening survey and a food frequency questionnaire (FFQ). Participants completed the screening survey to confirm their eligibility for the study. The participants received $20 for completing both surveys.

4.4.2.1 Questionnaires- screening survey

Demographic, anthropometric, sleep, and physical activity information were collected to describe participants. Participants' age, gender, and race were collected. Self-reported height and body weight were used to calculate body mass index (BMI). Sleep quality and sleep duration during the past month were obtained from the Pittsburgh Sleep Quality Index (PSQI) (Buysse et al., 1989). A greater PSQI score represents worse sleep quality. Participants' physical activities during the past week were assessed by the International Physical Activity Questionnaire – Short (Wolin et al., 2008). The total estimated metabolic equivalents (MET) of physical activity was calculated.

The validated HorneÖstberg Morningness-Eveningness Questionnaire (MEQ) was used to measure participants' chronotype (Horne & Ostberg, 1976). The MEQ consists of 19 questions which ask about participants' preference of time to sleep, rise, and engage in activities. Total MEQ scores range from 16 to 86, and an individual's score can be categorized into morning (M)-type (score: 59-86), intermediate (I)-type (42-58) and evening (E)-type (16-41) chronotype (Horne & Ostberg, 1976; Kandeger et al., 2019; Suh et al., 2017; Tran et al., 2014).

Snacking was defined as the consumption of foods and beverages between meals (Hess et al., 2016). To understand participants' snack food choices and frequency, a modified food frequency questionnaire with 12 snack categories was used (Thomson et al., 2008). The questionnaire included seven relatively energy-dense snack choices (salty snacks, soft/fruit drinks, candy, baked goods, ice cream/frozen yogurt, salted meats, and snack bars) and five relatively healthy snack choices (fruits, dairy, vegetables, nuts, and breads/rolls/biscuits). Scores can range from 0 (never ate the snack) to 4 (consumption exceeded five times in 1 week) for each category (Block et al., 2000). The categories were also summed and used to create two scores, which were energy-dense snacks and healthy snacks. In addition, the timing and frequency of snacking were also collected using the following question: "How often did you consume snacks during the following time periods (between breakfast and lunch, between lunch and dinner, and after dinner) in the past month?" Possible responses ranged from 0 to 7 times a week during the past month. The sum of snacking frequency during all time periods was calculated.

SSB intake was assessed using the updated version of the Beverage Intake Questionnaire-15 (BEVQ-15), which is a validated food frequency questionnaire that assesses beverage consumption during the past month (Fausnacht et al., 2020). Energy from SSB consumption as well as amount (fluid ounces (fl oz)) were calculated.

Alcohol misuse during the past year was assessed using the Alcohol Use Disorders Identification Test-Consumption (AUDIT-C) (Bush, 1998). The AUDIT-C is a validated questionnaire which contains three questions (Bush, 1998). The scoring for AUDIT-C is 0-12 points, with scores of 4 or more points indicating alcohol misuse in men and 3 or more points

indicating alcohol misuse in women (Frank et al., 2008). The participants were dichotomized into two groups: alcohol misusers and non-misusers.

The validated General Food Cravings Questionnaire-Trait (G-FCQ-T) measured cravings as stable traits (Nijs et al., 2007). The questionnaire consists of a total of 21 questions. Responses for each question use a Likert scale, which ranges from 1 to 6. A higher score represents stronger food cravings.

4.4.2.2 Questionnaires- food frequency questionnaire (FFQ)

After participants completed the screening survey and were eligible for the study, they were contacted by email to complete the FFQ. To assess dietary intake, participants indicated the foods and beverages consumed during the past month using the DHQ III (Subar et al., 2001). The DHQ III is a validated FFQ, which consists of questions regarding frequency of consumption and portion sizes of 135 foods and beverages and 26 dietary supplements. The DHQ III queried eating habits over the past month and assessed participants' energy, macronutrient, and micronutrient intake; food group consumption; and alcohol intake. The information from the DHQ III was used to assess diet quality by calculating the HEI. The HEI assessed the degree to which participants' diets follow the DGA (Krebs-Smith et al., 2018). A higher score represents higher overall diet quality. Dietary data indicating implausible energy intake was excluded from the analysis (<600 or >3500 kcal for women or <800 or >4200 kcal for men) (Subar et al., 2001).

4.4.3 Statistical analysis

Pearson's chi-squared test with Bonferroni correction was used to detect differences in categorical variables (gender and race) among chronotypes. One-way analysis of variance

(ANOVA) with Bonferroni correction was used to assess the differences in continuous variables (age, BMI, sleep quality, sleep duration, and physical activity) among chronotypes. Given that there were demographic differences that could contribute to outcomes, we used one-way analysis of covariance (ANCOVA) with Bonferroni correction to further test the difference in outcomes (BMI, sleep quality, sleep duration, and physical activity) among chronotypes, which were controlled for age, race, and gender (Carnethon et al., 2016; Caspersen et al., 2000; Du et al., 2021; Madrid-Valero et al., 2017; Paeratakul et al., 2002; Taeho Yoh et al., 2008). Continuous variables were reported as means and standard deviations; categorical variables were reported as counts and percentages. The differences in M-type versus E-type chronotype and I-type versus E-type chronotype for each outcome variable were assessed by regression models. The E-type chronotype was used as the reference group, since undesirable eating behaviors frequently are attributed to the evening chronotype, and it is the convention in the field to compare the E-type chronotype to other chronotypes (Patterson et al., 2016; Taylor et al., 2020; Teixeira et al., 2020). Chronotype was dummy coded for both the linear regression and logistic regression models. Linear regression was used for continuous outcome variables including snacking behaviors, SSB consumption, energy and macronutrient intake, diet quality, and food cravings. Binary logistic regression was used for examining the relationship between chronotypes and alcohol misuse. Covariates that differed among chronotypes and were related to outcome variables, including race, age, BMI, and sleep quality, were adjusted in both the linear and logistic regression models. Based on the analyses, parameter estimates and 95% confidence intervals were noted in regression models. The Benjamini-Hochberg procedure with a false discovery rate (FDR) of 0.1 was used to control type I error for multiple comparisons in the regression analyses (Benjamini & Hochberg, 1995). The 0.1 threshold for the FDR was chosen due to the exploratory nature of

the study (Ansoleaga et al., 2015; Szczygiel, Cho, Snyder, et al., 2019). Statistical significance was taken at $p<0.05$. All data were analyzed using SPSS version 27 (IBM Corp., Armonk, NY).

4.5 Results

A total of 160 participants completed the screening survey; 143 participants qualified for the study and completed the FFQ. Data from 43 participants who reported implausible daily energy intake (11 participants under-reported and 32 participants over-reported) were not analyzed. The final sample consisted of 100 participants. Participants' characteristics according to chronotype are shown in Table 11. I-type individuals were significantly younger than M-types ($p=0.007$) and E-types ($p=0.003$) and leaner than M-types ($p=0.001$). The I-type category included more Asian respondents than the M-type and E-type categories ($p<0.05$). Before adjustment, M-type individuals had better sleep quality compared to I-types ($p=0.008$) and E-types ($p=0.041$). There were no differences in physical activity and sleep duration among chronotypes in the ANOVA analysis.

Due to demographic differences that could contribute to outcome variables, ANCOVA analysis that adjusted for age, race, and gender was conducted. There were no differences in BMI among chronotypes ($p=0.119$) after adjustment. There was a relationship between chronotype and sleep quality ($p=0.004$), as M-type individuals had better sleep quality than E-types ($p=0.003$), but not I-types ($p=0.311$) after adjustment. Sleep duration remained unrelated to chronotype ($p=0.117$). Physical activity was significantly different among chronotypes ($p=0.023$), as M-type individuals engaged in greater physical activity than I-types ($p=0.022$) but not E-types ($p=0.191$).

Snacking habits differed by chronotype (Table 12). E-type individuals consumed snacks more often over the course of a week than M-types ($p=0.002$), but not I-types ($p=0.086$). In terms of the timing of snacking, E-type individuals consumed more snacks over the course of the week after dinner than M-types ($p<0.001$), but the number of snacks consumed were not different among chronotypes between breakfast and lunch or between lunch and dinner ($p>0.05$ for all). In terms of snack categories, E-type individuals consumed more energy-dense snacks ($p=0.005$), especially candies ($p=0.005$), than M-types, but there was no significant difference in healthy snack frequency among chronotypes ($p>0.05$ for all). Although the p-value for salty snacks showed that E-type individuals consumed more than M-types, the p-value ($p=0.01$) became insignificant after adjusting for FDR.

Results of food cravings, SSB consumption, diet quality, as well as energy and macronutrient intake according to chronotype are listed in Table 13. There were no significant differences in food cravings and diet quality among chronotypes ($p>0.05$ for all). SSB amount and energy consumed did not differ among chronotypes ($p>0.05$ for all). There was also no significant difference in energy, protein, fat, saturated fat, alcohol, carbohydrate, total sugars, or dietary fiber intake among chronotypes ($p>0.05$ for all).

Logistic regression analysis was used to assess alcohol intake among chronotypes. The odds of misusing alcohol did not differ by chronotype after controlling for race, age, BMI, and sleep quality in the logistic regression model (M-type vs E-type, $p=0.219$; I-type vs E-type, $p=0.553$).

Table 11. Characteristics of 100 participants according to chronotype

	M-type (n=30)	I-type (n=34)	E-type (n=36)	Total	p-value[1]	p-value adjusted[2]
Age (years)	30.2 ± 8 [a]	24.8 ± 4.5 [b]	30.4 ± 7.7 [a]	28.4 ± 7.3	0.001	
Gender [N (%)]					0.841	
Male	12 (40)	13 (38)	12 (33)	37 (37)		
Female	18 (60)	21 (62)	24 (67)	63 (63)		
Race [N (%)]					0.01	
Asian	2 (6.7) [a]	15 (44.1) [b]	5 (13.9) [a]	22(22)		
Black	7 (23.3)	3 (8.8)	8 (22.2)	18 (18)		
White	20 (66.7)	14 (41.2)	22 (61.1)	56 (56)		
More than one	1 (3.3)	2 (5.9)	1 (2.8)	4 (4)		
BMI	25.6 ± 3.5	22.2 ± 3.6	24.3 ± 3.5	24.0 ± 3.8	0.001	0.119
Sleep quality	3.2 ± 2.9 [a]	5.7 ± 2.5 [a,b]	5.2 ± 4.0 [b]	4.8 ± 3.4	0.007	0.004
Sleep duration (hr)	7.9 ± 0.7	8.2 ± 1.1	8.0 ± 0.9	8.0 ± 0.9	0.447	0.117
Physical activity (MET)	3805.3 ± 4515.1 [a]	2094.5 ± 2152.8 [b]	2324.8 ± 2175.0 [a,b]	2690.6 ± 3120.3	0.06	0.023

Data expressed as mean ± standard deviation or count (%). [1] Pearson's chi-squared test with Bonferroni correction was used for categorical variables. One way ANOVA with Bonferroni correction was used for continuous variables. [2] One way ANCOVA with Bonferroni correction was used to control for age, race, and gender. Different superscript letters indicate significant differences among chronotypes based on Pearson's chi-squared test (race), one way ANOVA (age), and ANCOVA (BMI, sleep quality, sleep duration, and physical activity) with Bonferroni correction. Abbreviations: M-type, morning-type; I-type, intermediate-type; E-type, evening-type; BMI, body mass index; MET, metabolic equivalent.

Table 12. Snacking frequency according to chronotype

Dependent variable	E-type versus M-type					E-type versus I-type			
	E-type, mean ± SD	M-type, mean ± SD	β	95% CI	p-value	I-type, mean ± SD	β	95% CI	p-value
Number of snacks per week	13.9 ± 4.5	11.2 ± 4.6	-0.317	-0.514 to -0.120	0.002	10.1 ± 4.1	-0.181	-0.388 to 0.026	0.086
Number of snacks between breakfast and lunch	3.4 ± 2.3	3.1 ± 2.4	-0.115	-0.301 to 0.071	0.223	2.1 ± 1.9	-0.062	-0.258 to 0.134	0.533
Number of snacks between lunch and dinner	5.1 ± 1.6	4.4 ± 1.8	-0.181	-0.411 to 0.050	0.123	4.1 ± 1.9	-0.139	-0.381 to 0.103	0.258
Number of snacks after dinner	5.3 ± 1.6	3.7 ± 2.2	-0.422	-0.641 to -0.202	<0.001	3.9 ± 2.2	-0.215	-0.445 to 0.016	0.067
Energy dense snacks	14.4 ± 4.4	11.3 ± 4.7	-0.289	-0.489 to -0.089	0.005	10.5 ± 4.0	-0.165	-0.375 to 0.045	0.123
Salty snacks	2.6 ± 0.9	2.2 ± 1.1	-0.305	-0.535 to -0.075	0.010[a]	2.2 ± 1.1	-0.137	-0.378 to 0.105	0.264
Soft drinks	2.0 ± 1.1	1.5 ± 1.1	-0.141	-0.357 to 0.075	0.197	1.4 ± 1.3	-0.080	-0.306 to 0.147	0.488
Candy	2.0 ± 1.0	1.1 ± 0.9	-0.342	-0.576 to -0.107	0.005	1.5 ± 1.2	-0.164	-0.41 to 0.083	0.190
Baked goods	2.1 ± 1.0	1.8 ± 1.1	-0.149	-0.356 to 0.058	0.156	1.5 ± 0.8	-0.057	-0.274 to 0.160	0.604

Table 12 (cont'd)

Ice cream	1.7 ± 0.9	1.3 ± 0.8	-0.127	-0.361 to 0.108	0.286	1.7 ± 1.1	0.078	-0.169 to 0.324	0.533
Salted meats	1.7 ± 1.2	1.3 ± 1.2	-0.185	-0.374 to 0.005	0.056	0.7 ± 0.8	-0.200	-0.399 to -0.001	0.049
Snack bars	2.2 ± 1.1	2.1 ± 1.1	-0.001	-0.214 to 0.213	0.995	1.4 ± 1.3	-0.108	-0.332 to 0.116	0.341
Healthy snacks	12.1 ± 5.1	10.8 ± 5.7	-0.131	-0.303 to 0.041	0.133	8.5 ± 3.7	-0.085	-0.266 to 0.095	0.351
Fruits	2.9 ± 1.1	2.9 ± 1.3	-0.037	-0.257 to 0.182	0.736	2.5 ± 1.1	-0.018	-0.249 to 0.212	0.874
Dairy	2.8 ± 1.3	2.4 ± 1.5	-0.094	-0.293 to 0.105	0.350	1.9 ± 1.4	-0.056	-0.265 to 0.153	0.596
Vegetables	2.6 ± 1.4	2.4 ± 1.4	-0.092	-0.295 to 0.111	0.369	1.8 ± 1.2	-0.065	-0.278 to 0.149	0.549
Nuts	1.7 ± 1.2	1.6 ± 1.3	-0.113	-0.305 to 0.079	0.246	1.2 ± 1.1	-0.034	-0.236 to 0.168	0.739
Breads/rolls/biscuits	2.1 ± 1.1	1.6 ± 1.2	-0.185	-0.371 to 0.002	0.052	1.2 ± 1.1	-0.168	-0.364 to 0.028	0.092

Each linear regression model was adjusted for race, age, body mass index, and sleep quality. Standardized and adjusted beta estimates and 95% confidence intervals are presented. p-values for the adjusted model are noted. [a] The p-value of salty snacks was not significant after correcting for FDR. Evening chronotype was used as the reference category. Abbreviations: M-type, morning-type; I-type, intermediate-type; E-type, evening-type; SD, standard deviation; CI, confidence interval.

Table 13. Food cravings, SSB consumption, diet quality, and energy and macronutrient intake according to chronotype

	E-type versus M-type					E-type versus I-type			
Dependent variable	E-type, mean ± SD	M-type, mean ± SD	β	95% CI	p-value	I-type, mean ± SD	β	95% CI	p-value
Food cravings	60.5 ± 15.0	57.3 ± 14.7	-0.089	-0.317 to 0.140	0.444	60.4 ± 17.8	-0.124	-0.365 to 0.116	0.307
Total SSB (fl oz)	10.3 ± 10.1	9.2 ± 10.8	0.118	-0.086 to 0.323	0.253	9.0 ± 14.1	0.007	-0.208 to 0.222	0.948
Total SSB (kcal)	121.2 ± 119.4	104.5 ± 132	0.108	-0.092 to 0.308	0.284	101.9 ± 161.3	-0.014	-0.224 to 0.197	0.898
Diet quality	65.2 ± 8.0	65.9 ± 7.2	-0.002	-0.238 to 0.233	0.984	63.5 ± 10.7	-0.022	-0.270 to 0.225	0.857
Energy (kcal)	2284.4 ± 855.0	2339.4 ± 929.1	0.023	-0.139 to 0.184	0.781	1614.1 ± 710.0	-0.077	-0.247 to 0.092	0.367
Protein (g)	96.8 ± 47.0	104.6 ± 51.6	0.035	-0.119 to 0.189	0.654	64.9 ± 33.6	-0.028	-0.190 to 0.133	0.730
Fat (g)	89.8 ± 33.4	92.1 ± 39.0	0.004	-0.168 to 0.177	0.961	62.2 ± 30.6	-0.104	-0.285 to 0.077	0.258
Saturated fat	28.6 ± 10.8	29.5 ± 12.4	0.011	-0.167 to 0.190	0.899	20.2 ± 9.6	-0.077	-0.264 to 0.111	0.418
Alcohol (g)	9.5 ± 10.6	8.0 ± 9.8	0.014	-0.215 to 0.244	0.901	5.3 ± 8.5	-0.071	-0.312 to 0.170	0.560

Table 13 (cont'd)

Carbohydrate (g)	265.0 ± 98.5	268.4 ± 101.9	0.028	-0.140 to 0.195	0.743	196.0 ± 82.3	-0.067	-0.243 to 0.109	0.450
Sugars (g)	109.6 ± 43.7	110.7 ± 42.5	0.062	-0.108 to 0.232	0.473	83.9 ± 38.2	-0.020	-0.199 to 0.158	0.821
Dietary fiber (g)	22.9 ± 9.4	24.1 ± 10.2	0.010	-0.146 to 0.166	0.897	15.6 ± 6.7	-0.142	-0.306 to 0.022	0.088

Each linear regression model was adjusted for race, age, body mass index, and sleep quality. Standardized and adjusted beta estimates and 95% confidence intervals are presented. p-values for the adjusted model are noted. Evening chronotype was used as the reference category. Abbreviations: M-type, morning-type; I-type, intermediate-type; E-type, evening-type; SD, standard deviation; CI, confidence interval; Sugar Sweetened Beverages, SSB.

4.6 Discussion

The purpose of this study was to characterize the relationships among chronotype, snacking behaviors, SSB and alcohol intake, dietary intake and quality, and food cravings in U.S. adults. Results indicated that M-type individuals had better sleep quality than E-types, and M-type individuals also engaged in greater physical activity than I-types. M-type individuals consumed fewer snacks after dinner and over the course of the week than E-types. In terms of snack options, E-type participants consumed more energy-dense snacks, which was driven by increased intake of candies, compared to M-types. However, there were no significant differences in healthy snack frequency, food cravings, diet quality, and energy or macronutrient intake among chronotypes.

M-type individuals reported better sleep quality than E-types and higher physical activity than I-types after adjustment, but sleep duration did not differ among the three chronotypes in our sample population. These results are consistent with previous studies (Makarem et al., 2020; Sun et al., 2019). One study noted that the M-type chronotype had better sleep quality than the E-type chronotype, but sleep duration did not differ among chronotypes in adult females (Makarem et al., 2020). Another study demonstrated that M-type and I-type individuals had a lower risk of experiencing poor sleep quality (PSQI>5) than E-type individuals (Sun et al., 2019). Both poor sleep quality and short sleep duration have been shown to be related to higher risk of chronic health conditions, including cardiovascular diseases (Hoevenaar-Blom et al., 2011), type 2 diabetes (Knutson et al., 2006), and obesity (Fatima et al., 2016; Reutrakul & Van Cauter, 2018). Based on the findings regarding sleep quality, it is possible that E-type individuals are at higher risk of developing these chronic diseases. In addition to sleep parameters, physical activity was higher in M-type individuals compared to I-types after adjusting for age, race, and gender. This

result was partially supported by a previous study that observed that M-type participants had more physical activity than other chronotypes (Patterson et al., 2016). Based on study results of the present and previous studies, sleep quality in E-type individuals is lower and physical activity in M-type is higher, but chronotypes do not differ in sleep duration.

Participants with different chronotypes displayed different snacking behaviors. E-types consumed more energy-dense snacks than M-types, but no differences were observed for healthy snacks. This finding is consistent with a previous study conducted among adolescents in the United Kingdom (Arora & Taheri, 2015). That study reported the E-type chronotype was related to consuming unhealthy snacks, including chips, chocolate, biscuits, cakes, and sweets, more frequently (Arora & Taheri, 2015). Besides snack options, E-type participants consumed greater numbers of snacks after dinner and during the day. A previous study supported this finding as lower chronotype scores (tendency to E-type) were related to greater energy intake later in the day (after 8:00 p.m.) (Lucassen et al., 2013). Others have reported that consuming snacks after dinner could lead to choosing more unhealthy snacks (Barrington & Beresford, 2019). In that study, evening snacking was related to a higher obesogenic dietary index, which meant that participants consumed more French fries, soft drinks, and fast food (Barrington & Beresford, 2019). Overall, the E-type chronotype is related to more frequent snack consumption and unhealthy snacking behaviors.

Intake of energy-dense snacks has been shown to increase a person's risk of weight gain (Barrington & Beresford, 2019), but chronotypes did not differ in BMI after adjusting for age, race, and gender in the present study. One study noted that BMI was higher in adults who consumed a greater percent of energy from desserts and sweets as snacks, which suggests that consuming unhealthy snacks could lead to weight gain (Barnes et al., 2015). Although E-type

individuals consumed more energy-dense snacks, they did not report a higher BMI, which suggests that the E-type chronotype was not associated with greater BMI in our sample population. One possible explanation of why BMI did not differ by chronotype is because energy intake also did not differ. One previous study conducted in Finland also reported no differences in energy intake and BMI among chronotypes, and this result is consistent with our findings (Maukonen et al., 2016). In addition, our sample population is relatively young, so we might not be able to see the difference in BMI at this point (Mota et al., 2016). However, whether consequences of poor snacking behaviors in E-type individuals accumulate over time and could lead to the development of obesity is unknown and should be tested.

Other factors that could lead to obesity, including consuming SSB, did not differ among chronotypes in the present study. Previous studies conducted in China reported a positive relationship between E-type chronotype and SSB consumption among undergraduate students (Li et al., 2018; Zhang et al., 2018). One explanation for this discrepancy is that the questionnaires used to assess SSB intake were different, as the study in China did not use a validated questionnaire. Another explanation is that race and mean age were different among studies, as the studies in China mainly included Asian undergraduates while the current study recruited an older and more varied population in terms of race. Evidence suggests there are variations in SSB consumption in different race and age groups (Han & Powell, 2013). The study reported that Blacks and Hispanics had higher odds of consuming SSB than other demographic groups, and the prevalence of heavy SSB consumption (>500 kcal) was 20-29% in young adults (20-34 years old) and 11-12% in adults (≥35 years old) (Han & Powell, 2013). Overall, the present study suggests that chronotype is not associated with SSB consumption in U.S. adults.

Findings of the relationship between alcohol consumption and chronotypes are mixed. As with SSB, the present study did not find differences in alcohol intake (amount) and alcohol misuse (AUDIT-C) among chronotypes. This result agrees with previous studies performed in other populations. One study noted that alcohol consumption in first-year university students did not differ among chronotypes (Culnan et al., 2013). Another study observed no relationship between the severity of alcohol dependence and chronotype in alcohol-dependent individuals (Nowakowska-Domagała et al., 2016). A different study found that the symptoms of alcohol use disorder were higher in E-type individuals, but all participants were under the threshold of alcohol misuse (Taylor et al., 2020). However, other studies have reported contradictory results. One study observed later sleep timing was related to greater alcohol consumption among male and female undergraduate students in China (Zhang et al., 2018), but this study did not use a validated questionnaire to assess consumption. Another study in Finland found a negative relationship between MEQ score and alcohol consumption measured as a percentage of energy (Kanerva et al., 2012). This study used a shortened form of the MEQ, which could explain the discrepant findings. Based on the available studies, E-type individuals reported increased alcohol intake among undergraduates in China and adults in Finland, but chronotype was not related to alcohol intake and alcohol misuse in U.S. adults.

Previous studies reported mixed results regarding the relationship between chronotype and adherence to healthy diets (Gontijo et al., 2019; Makarem et al., 2020; Maukonen et al., 2016). First, the odds of E-type individuals not following the American Heart Association (AHA) diet, which includes recommendations of fruits, vegetables, grains, and SSB and sodium intake, was higher compared to M-types and I-types among U.S. women (Makarem et al., 2020). Another study conducted in Finland noted that E-type individuals had lower adherence to a

healthy Nordic diet (Baltic Sea diet score) than M-types and I-types (Maukonen et al., 2016). Finally, a study in Spain observed that E-type university students had a lower adherence to the Mediterranean diet (Rodríguez-Muñoz et al., 2020). However, based on three days of 24h-diet recall data, one study in Brazil that used the Brazilian Healthy Eating Index-Revised to assess overall diet quality observed no significant relationship between chronotype and diet quality (Gontijo et al., 2019). This result is consistent with our study that reported that chronotype was not related to overall diet quality. Our study results suggest that the E-type chronotype should not be considered a risk factor for poor diet quality in young U.S. adults. Based on the majority of studies, there appears to be a link between adherence to healthy diets and chronotype. However, studies that used different tools to measure dietary components noted different results. Given that the goal for the AHA diet is to achieve ideal cardiovascular health instead of assessing general diet quality as with the HEI (Lloyd-Jones. et al., 2010), we argue that the HEI assesses overall diet quality better than the AHA diet score. The Mediterranean diet stems from traditional eating habits shared by countries bordering the Mediterranean sea (Lăcătușu et al., 2019), while the healthy Nordic diet includes Nordic fruits and vegetables, whole grain cereals and fish easily obtained in northern latitudes (Kanerva et al., 2014). These two diets are different from the Dietary Guidelines for Americans; therefore, cultural and regional differences might contribute to discrepancies in the findings. However, future studies are needed to further test this hypothesis.

In addition to diet quality, the present study did not detect a relationship between chronotype and food cravings. This result is consistent with previous studies that observed chronotype was not associated with cravings of high-calorie foods (Lai & Say, 2013) and food craving as a trait (Meule et al., 2012; Teixeira et al., 2020). Overall, the present study and

previous studies suggest that chronotype does not serve as a risk factor for susceptibility to food cravings.

There are limitations to this study. First, this is a cross-sectional study which limits the ability to make causal inferences. Second, participants' self-reported height and weight were collected, which might lead to inaccurate BMI data as people tend to under-report their weight (Olfert et al., 2018). Third, dietary data could suffer from under-reporting as well; however, the present study excluded implausible dietary data from the analysis (Subar et al., 2001). Finally, the sample size was limited compared to other large population-based studies (Kanerva et al., 2012; Patterson et al., 2016) but was similar to previous cross-sectional studies (Gontijo et al., 2019; Meule et al., 2012; Mota et al., 2016).

The present study is one of the first studies conducted in the U.S. adult population that evaluates the relationships among chronotype, dietary behaviors, and food cravings. Findings from this work revealed the relationship between chronotype and eating behaviors in adults in the United States, which could serve to guide the development of appropriate dietary suggestions for different chronotypes to improve snack choices. Future studies should assess the same relationships in middle or older U.S. adults, which could provide personalized weight management interventions to different age groups, should chronotype play more of a role in dietary behaviors, intake, and health outcomes.

4.7 Conclusions

Chronotypes differ in snacking behavior, in which E-type individuals consume more snacks after dinner and over the course of a week than M-types. Energy-dense snacks, especially candies, were consumed more often by E-type than M-type individuals, but the frequency of

healthy snack consumption did not differ among chronotypes. There were no differences in energy and macronutrient intake, SSB consumption, alcohol misuse, and food cravings among chronotypes. Overall, chronotype is negligibly associated with weight gain-related behaviors in this young adult population.

CHAPTER 5: CONCLUSIONS AND FUTURE DIRECTIONS

5.1 Conclusions

The results noted in this dissertation demonstrate the relationship between sleep, food cravings, and dietary behaviors. The following topics are examined in each chapter:

A. The effects of a 33% reduction of sleep on appetite, food cravings, food reward, and portion size selection (Chapter 2).
B. The effects of breakfasts with different protein and carbohydrate content on appetite, food cravings, and dietary intake after nights of habitual sleep and sleep reduction (33%) (Chapter 3).
C. The relationships between chronotype, food cravings, and dietary behavior (Chapter 4).

Based on the research conducted, the following are the most important findings in this dissertation:

A. Participants reported greater tiredness and sleepiness, and they experienced higher hunger sensation, food cravings, and food reward after curtailed sleep night.
B. Larger portion sizes were selected after a curtailed sleep night, which led to higher energy plated for lunch.
C. A high-protein breakfast decreased food cravings regardless of the sleep duration participants experienced the previous night. However, a high-protein breakfast only increased their fullness after a habitual night of sleep but not after a curtailed night of sleep.

D. Energy dense snacks, especially candies, were consumed more often by evening-type individuals compared to morning-types.
E. No differences were observed in healthy snack consumption, diet quality, food cravings, or energy and macronutrient intake among chronotypes.

The study reported in chapter 2 used a modest sleep curtailment protocol to explore the effects of insufficient sleep on factors that could lead to weight-gain in non-obese women. The sleep curtailment protocol successfully and significantly reduced total sleep time on curtailed nights compared to habitual nights. In terms of sleep stages, slow wave sleep and rapid eye movement sleep were also shorter during the curtailed night compared to the normal night. Participants felt hungrier and experienced greater sleepiness and tiredness after sleep curtailment. They also reported poorer sleep quality on curtailed sleep nights. Participants experienced greater food cravings and consumed more chocolate candies, the measure used for food reward, after sleep curtailment. Further, participants selected greater portion sizes of potato chips and rice after they experienced a curtailed sleep night. Participants ended up choosing more protein, fat, and total calories for the meal options and higher fat content for the snack options. The results presented in chapter 2 suggest that insufficient sleep could lead to increased intake due to increased hunger sensation, food cravings, and food reward, and plated greater portion size for lunch.

Based on the findings in chapter 2 that noted increased protein selection for meal-associated foods after sleep curtailment, chapter 3 further tested whether a high protein breakfast was able to serve as a strategy to combat increased appetite after sleep curtailment. Chapter 3 used the same sleep curtailment protocol. Again, the protocol significantly reduced participants' total sleep time. Participants had increased hunger after curtailed sleep nights, which was

consistent with the result in chapter 2. In addition, sleep curtailment increased desire to eat, and reduced fullness compared to habitual sleep. In terms of the effects of breakfast on appetite, a high protein breakfast did provide greater fullness after participants had habitual sleep; however, this effect was eliminated after participants experienced curtailed sleep. This result suggests that having sufficient sleep is required to obtain the beneficial effects of high protein foods on fullness. Moreover, a high protein breakfast reduced food cravings more than a high carbohydrate breakfast, regardless of the sleep condition. Even though we observed differences in appetite and food cravings in different breakfast and sleep conditions, energy intake throughout the day did not differ. This result suggests that the short-term effects of high protein food and sleep curtailment on energy intake tend to be minimal, but long-term effects merit future studies.

Chapter 4 explored the relationships between chronotype and weight-gain related eating behavior among U.S. adults. Evening-type (E-type) individuals consumed snacks more frequently after dinner and over the course of a week than morning-types (M-types). In terms of snack choices, E-type individuals consumed more energy-dense snacks than morning-types, but no difference was observed in healthy snack consumption among chronotypes. There were also no significant differences in diet quality, food cravings, consumption of energy, macronutrients, and sugar-sweetened beverages as well as alcohol misuse among chronotypes. This study suggests that chronotype is negligibly related to weight gain-related eating behaviors.

There are several noticeable findings in this dissertation that warrant further research. Several recommendations for future research are listed below.

5.2 Future directions

5.2.1 Determine whether the effects of sleep curtailment on appetite differ by gender

Chapters 2 and 3 demonstrated that one curtailed sleep night increased hunger sensations the next day in a non-obese female population, which contradicts with a previous study in men that observed no difference in hunger after experiencing 4.5 h of sleep compared to 7 h of sleep at night (Schmid et al., 2008). The aforementioned studies differ in the sleep curtailment protocol, as the studies in this dissertation kept the midpoint of sleep consistent between visits, and the other study did not. Also, studies in this dissertation implemented a 33% reduction of sleep, and the other study assigned a 5 h time in bed to each participant. As mentioned in chapter 2, assigning every participant a time in bed could lead to uneven curtailment because longer sleepers experienced a greater reduction, and shorter sleepers experienced a lesser reduction. However, it is unknown whether using the same sleep curtailment protocol reported in chapter 2 could lead to increased hunger in men. Given that, after experiencing less than 7 h of sleep, men have a higher chance of functioning at their best (which participants defined for themselves) during the day than women (Krishnan & Collop, 2006), the sleep curtailment protocol might not lead to the same results in men. Future studies could examine whether there are gender differences in the effects of short sleep on appetite.

5.2.2 Examine the effects of sleep curtailment on appetitive hormones in adults

Changes in appetitive hormones, including leptin and ghrelin that influence hunger and satiety sensations (Pinto et al., 2016), have been linked to short sleep duration, but the finding varies (Broussard et al., 2016b; Nedeltcheva et al., 2009; Pejovic et al., 2010; Simpson et al., 2010; Spiegel et al., 2004). A previous study observed increased ghrelin, decreased leptin, and

increased hunger sensations after two nights of four-hour sleep duration in twelve men (Spiegel et al., 2004). However, this study used an intravenous glucose infusion while collecting hormone data, which is different from real-life circumstances (Spiegel et al., 2004). These changes in hormones after insufficient sleep were not consistent with other studies. Some studies reported no influence on ghrelin (Nedeltcheva et al., 2009), no influence on leptin (Broussard et al., 2016b; Nedeltcheva et al., 2009), or increases in leptin after insufficient sleep (Pejovic et al., 2010; Simpson et al., 2010). Studies with inconsistent findings had some limitations, including that they were small in sample size (5 women and 6 men (Nedeltcheva et al., 2009)), or instead of moderate sleep curtailment, participants were tested after 4 nights of restricted time in bed (Broussard et al., 2016b) or after total sleep deprivation (Pejovic et al., 2010). Therefore, more studies with a larger sample size as well as the implementation of a moderate sleep curtailment protocol are needed to confirm the changes in appetitive hormones after short sleep duration to understand the possible mechanisms that could lead to increased intake.

5.2.3 Examine the effects of a high protein breakfast and sleep curtailment on satiety and food intake in men and obese populations

The study presented in chapter 3 demonstrated that high protein breakfast increased fullness after participants had habitual sleep but not curtailed sleep; however, this result was not generalizable to other populations because the study only included non-obese women. There are gender differences in sleep demand and sleep quality (Collop et al., 2004). In addition, obese individuals have been shown to experience more sleep disorders and lower sleep quality than people at a healthy weight (Resta et al., 2003). However, it is unknown whether men or obese populations would react the same while experiencing the sleep curtailment protocol implemented in chapter 3. Previous literature has demonstrated that protein provides a larger satiating effect

than carbohydrates and fat (Dhillon et al., 2016; Paddon-Jones et al., 2008). High protein foods have been shown to improve satiety compared to isocaloric food with higher carbohydrate or fat content in adolescents (Leidy et al., 2015), healthy women (Douglas et al., 2013), pre-obese or obese women (Leidy et al., 2007), and overweight or obese men (Leidy et al., 2010). These findings suggest that a high protein breakfast would provide greater fullness in a diverse population. However, it is unknown if the effects of a high protein breakfast on satiety will still apply to men and obese individuals experiencing insufficient sleep. Further research is needed. Also, studies should determine, if there are changes in satiety, whether those changes influence people's food intake as well.

5.2.4 Examine the effects of napping on snacking behaviors in E-type individuals

Chapter 4 observed that E-type individuals snacked more frequently and consumed more energy-dense snacks than M-type individuals. E-type individuals also had poorer sleep quality than M-type. Previous studies suggest that consuming snacks can increase a person's ability to pay attention to tasks (Busch et al., 2002) and reduce tiredness (Thayer, 1987). It is possible that E-type individuals felt greater tiredness and sleepiness during the day, and in order to increase their attention to work, they consumed more snacks. Napping during the day can decrease sleepiness (Philip et al., 2006), increase a person's sustained attention, and increase sleep quality during nights (Ji et al., 2019). However, it is unknown whether taking a nap during the day can reduce sleepiness and increase attention, and as a result, decrease the frequency of consuming snacks in E-type individuals. Future studies should examine whether napping reduces snacking for E-type individuals.

5.2.5 Examine the relationship between snacking, energy and nutrient intake, and chronotype in older adults

In chapter 4, E-type chronotype was related to snacking more frequently in a young population, but it is unknown whether this association will appear in older adult populations. When people age, energy intake decreases (Giezenaar et al., 2016). Snacking is an important dietary behavior among older adults because it helps to ensure adequate energy and nutrient intake in this age group (Andersson et al., 2003). About 84% of older adults consume snacks during the day (Zizza et al., 2007), indicating that the majority of this age group consume snacks. Although snacking might pose problems of gaining weight in other age groups (Bertéus Forslund et al., 2005; Bes-Rastrollo et al., 2010), older adults might benefit from snacking as one study reported that older adults who do not consume snacks had very low energy intake (Zizza et al., 2007). Given that E-type chronotype was related to snacking more frequently in a young adult age group in chapter 4, it is possible that older adults with the E-type chronotype also have a higher snacking frequency than the M-type individuals. Future studies are needed to confirm whether older adults with the E-type chronotype consume snacks more often than M-types, and whether more E-type individuals meet their energy and nutrient needs than M-types.

5.2.6 Determine the relationship between chronotype and cardiovascular health in men

Previous studies noted that chronotype is associated with cardiovascular health in women (Makarem et al., 2020; Ritonja et al., 2019; Zuraikat et al., 2021), but no study has been conducted in men. One study reported that the E-type chronotype was related to poorer cardiovascular health (CVH) and lower adherence to the dietary guidelines recommended by the American Heart Association (AHA) (Makarem et al., 2020). In that study, CVH was measured by AHA's Life's Simple 7 score which consists of blood pressure, total cholesterol, body mass

index, and three health behaviors (dietary intake, physical activity, and nonsmoking) (Lloyd-Jones et al., 2010). Another study observed that dietary energy density was the mediator of the relationship between E-type chronotype and poorer CVH in U.S. women (Zuraikat et al., 2021). However, it is unclear whether the same association will be found in men. Given that higher cardiovascular disease mortality is associated with E-type chronotype in adults (Knutson & Schantz, 2018), it is possible that the E-type chronotype is related to poorer CVH risk in men as well. Therefore, it will be beneficial to conduct a study that examines the relationship between CVH and chronotype in men, and finds the mediator that ties the relationship, if there is one.

5.2.7 Determine the effects of sleep extension on food cravings and food reward in people who experience insufficient sleep

Based on the findings in chapter 2, food cravings and food reward increased after a short sleep night. These findings suggest that insufficient sleep increased people's desire to eat foods that are palatable, which are usually high in fat and sugar (Rodríguez-Martín & Meule, 2015). A sleep extension intervention has been shown to decrease the consumption of fat, carbohydrates, and sugar among participants who habitually sleep between 5-7 hours (Al Khatib et al., 2018). Also, sleep extension decreased the desire for sweet and salty foods by 64% in overweight young adults (Tasali et al., 2014). Therefore, it is possible that sleep extension decreases food cravings and food reward and, as a result, can lead to a decrease in dietary intake. However, no previous study has explored the effects of sleep extension on dietary intake while examining food cravings and food reward in participants. Understanding the effects and mechanisms behind sleep extension on dietary intake is important because these findings could assist in examining the beneficial effects of sleep extension on people who do not have sufficient sleep and determining whether people should use sleep extension as a strategy to prevent weight gain.

APPENDICES

Appendix A: The IRB approval letters

A. 1 The IRB approval letter "Sleep, Portion Size, and Food Reward"

MICHIGAN STATE
UNIVERSITY

Initial Study APPROVAL

February 19, 2018

To: Robin M. Tucker

Re: **MSU Study ID:** STUDY00000382
IRB: SIRB
Principal Investigator: Robin M. Tucker
Category: Expedited 4, 7
Submission: Initial Study STUDY00000382
Submission Approval Date: 2/16/2018
Effective Date: 2/16/2018
Project Expiration Date: 2/15/2019

Title: Sleep, Portion Size, and Food Reward, part 2

This submission has been approved by the Michigan State University (MSU) SIRB. the submission was reviewed by the Institutional Review Board (IRB) through the Non-Committee Review procedure. The IRB has found that this research project protects the rights and welfare of human subjects and meets the requirements of MSU's Federal Wide Assurance (FWA00004556) and the federal regulations for the protection of human subjects in research (e.g., 45 CFR 46, 21 CFR 50, 56, other applicable regulations).

Documents Approved:
• Revised consent, Category: Consent Form;
• Candy reward protocol/survey, Category: Other;
• Online advertisement, Category: Other;
• Diet record data sheet, Category: Other;
• Flyer, Category: Recruitment Materials;
• Lab visit surveys, Category: Other;
• BP and Heart Rate Data Sheet, Category: Other;
• Food weights data sheet, Category: Other;
• Pre-screening survey, Category: Other;
• Protocol, Category: IRB Protocol;

Continuing Review: IRB approval is valid until the expiration date listed above. If the research continues to involve human subjects, you must submit a Continuing Review request at least one month before expiration.

Modifications: Any proposed change or modification with certain limited exceptions discussed below must be reviewed and approved by the IRB prior to implementation of the change. Please submit a Modification request to have the changes reviewed. If changes are made at the time of continuing review, please submit a Modification and Continuing Review request.

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MICHIGAN STATE
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Modification and Continuing Review APPROVAL

January 10, 2019

To: Robin M. Tucker

Re: **MSU Study ID:** STUDY00000382
IRB: Social Science / Behavioral / Education Institutional Review Board
Principal Investigator: Robin M. Tucker
Category: Expedited 4, 7
Submission: Modification and Continuing Review MODCR00000597
Submission Approval Date: 1/10/2019
Effective Date: 1/10/2019
Study Expiration Date: 1/9/2020

Title: Sleep, Portion Size, and Food Reward, part 2

This submission has been approved by the Michigan State University (MSU) Social Science / Behavioral / Education Institutional Review Board. The submission was reviewed by the Institutional Review Board (IRB) through the Non-Committee Review procedure. The IRB has found that this study protects the rights and welfare of human subjects and meets the requirements of MSU's Federal Wide Assurance (FWA00004556) and the federal regulations for the protection of human subjects in research (e.g., 45 CFR 46, 21 CFR 50, 56, other applicable regulations).

How to Access Final Documents
To access the study's final materials, including those approved by the IRB such as consent forms, recruitment materials, and the approved protocol, if applicable, please log into the Click™ Research Compliance System, open the study's workspace, and view the "Documents" tab. To obtain consent form(s) stamped with the IRB watermark, select the "Final" PDF version of your consent form(s) as applicable in the "Documents" tab. Please note that the consent form(s) stamped with the IRB watermark must typically be used.

Continuing Review: IRB approval is valid until the expiration date listed above. If the research continues to involve human subjects, you must submit a Continuing Review request at least one month before expiration.

Modifications: Any proposed change or modification with certain limited exceptions discussed below must be reviewed and approved by the IRB prior to implementation of the change. Please submit a Modification request to have the changes reviewed. If changes are made at the time of continuing review, please submit a Modification and Continuing Review request.

Immediate Change to Eliminate a Hazard: When an immediate change in a research protocol is necessary to eliminate a hazard to subjects, the proposed change need not be reviewed by the IRB prior to its implementation. In such

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A. 2 The IRB approval letter "The effects of sleep curtailment and breakfast on eating behavior"

MICHIGAN STATE
UNIVERSITY

Initial Study APPROVAL
CONDITIONS MET
Revised Common Rule

June 27, 2019

To: Robin M. Tucker

Re: **MSU Study ID:** STUDY00002437
IRB: Biomedical and Health Institutional Review Board
Principal Investigator: Robin M. Tucker
Category: Full Board
Submission: Initial Study STUDY00002437
Submission Approval Date: 6/24/2019
Effective Date: 6/26/2019
Study Expiration Date: 6/23/2020

Title: The effects of sleep curtailment and breakfast on eating behavior

This submission has been approved by the Michigan State University (MSU) Biomedical and Health Institutional Review Board The submission was reviewed by the Institutional Review Board (IRB) through the Committee Review procedure. The IRB has found that this study protects the rights and welfare of human subjects and meets the requirements of MSU's Federal Wide Assurance (FWA00004556) and the federal regulations for the protection of human subjects in research (e.g., 2018 45 CFR 46, 21 CFR 50, 56, other applicable regulations).

The approval date is the date the convened IRB approved the research study. However, research may not begin until the conditions are met and accepted by the IRB chair or designee and the approval letter is sent to and received by the investigator(s).

This letter acknowledges that the conditions set out in the Modifications Required to Secure Approval letter dated 6/25/19 were met on 6/26/2019.

The Convened Board determined that this project involves no more than minimal risk to subjects; therefore, Continuing Review will qualify for Expedited 9

How to Access Final Documents
To access the study's final materials, including those approved by the IRB such as consent forms, recruitment materials, and the approved protocol, if applicable, please log into the Click™ Research Compliance System, open the study's workspace, and view the "Documents" tab. To obtain consent form(s) stamped with the IRB watermark, select the "Final" PDF version of your consent form(s) as applicable in the "Documents" tab. Please note that the consent form(s) stamped with the IRB watermark must typically be used.

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Continuing Review APPROVAL
Revised Common Rule

April 7, 2020

To: Robin Marie Tucker

Re: **MSU Study ID:** STUDY00002437
IRB: Biomedical and Health Institutional Review Board
Principal Investigator: Robin Marie Tucker
Category: Expedited 9
Submission: Continuing Review CR00001157
Submission Approval Date: 4/6/2020
Effective Date: 4/6/2020
Study Expiration Date: 4/5/2021

Title: The effects of sleep curtailment and breakfast on eating behavior

This submission has been approved by the Michigan State University (MSU) Biomedical and Health Institutional Review Board. The submission was reviewed by the Institutional Review Board (IRB) through the Non-Committee Review procedure. The IRB has found that this study protects the rights and welfare of human subjects and meets the requirements of MSU's Federal Wide Assurance (FWA00004556) and the federal regulations for the protection of human subjects in research (e.g., 2018 45 CFR 46, 21 CFR 50, 56, other applicable regulations).

The State of Michigan and Michigan State University (MSU) have placed temporary restrictions on human subject research conducted by MSU employees or agents. All MSU human research activities conducted by MSU employees or agents that take place in Michigan and cannot be done at home or place of residence with no inter-personal interaction with participants and others like research staff must stop unless the project is a clinical trial activity, that if discontinued, would negatively impact the patient's care, or projects related to COVID-19, particularly if they have a timeline for deployment that could address the crisis. Ongoing clinical trial activity, which if discontinued, would negatively impact the patient's care may continue with already enrolled participants. New enrollment in clinical trials conducted in Michigan is not permitted without additional institutional approval.

For MSU human research activities that take place outside of Michigan, the university has stated that unless there is the potential for direct therapeutic benefit to the participant (drug or device), any in-person participant interaction must immediately pause. This applies to both exempt and non-exempt research studies.

For all human research activities, research procedures involving no direct in-person interactions with participants may continue (e.g. data analysis, online surveys, telephone interviews), so long as any research procedure conducted in Michigan are done at home or place of residence and follow the restrictions set forth in

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A. 3 The IRB approval letter "Chronotype and dietary intake"

MICHIGAN STATE
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EXEMPT DETERMINATION
Revised Common Rule

November 11, 2020

To: Robin Marie Tucker

Re: **MSU Study ID:** STUDY00005373
Principal Investigator: Robin Marie Tucker
Category: Exempt 2(ii)
Exempt Determination Date: 11/11/2020
Limited IRB Review: Not Required.

Title: Examination of the relationship between chronotype and dietary intake in healthy adults

This study has been determined to be exempt under 45 CFR 46.104(d) 2(ii).

Institutional restrictions to in-person human subject research activities conducted by MSU employees, MSU students, or agents of MSU are in place, but MSU is phasing in human research that has the potential for in-person interactions with participants, using a Tier approach. Restrictions to in-person interactions with human research participants by MSU employees, MSU students, or agents of MSU are in place until the activity is permitted under a Tier and a Human Research Plan for a Safe Return is approved. Visit http://hrpp.msu.edu/COVID-19/index.html for the restrictions, Tiers, forms, and the process.

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Principal Investigator (PI) Responsibilities: The PI assumes the responsibilities for the protection of human subjects in this study as outlined in Human Research Protection Program (HRPP) Manual Section 8-1, Exemptions.

Continuing Review: Exempt studies do not need to be renewed.

Modifications: In general, investigators are not required to submit changes to the Michigan State University (MSU) Institutional Review Board (IRB) once a research study is designated as exempt as long as those changes do not affect the exempt category or criteria for exempt determination (changing from exempt status to expedited or full review, changing exempt category) or that may substantially change the focus of the research study such as a change in hypothesis or study design. See HRPP Manual Section 8-1, Exemptions, for examples. If the study is modified to add additional sites for the research, please note that you may not begin the research at those sites until you receive the appropriate approvals/permissions from the sites.

Please contact the HRPP office if you have any questions about whether a change must be submitted for IRB review and approval.

Appendix B: Consent forms

B. 1 Consent form "Sleep, Portion Size, and Food Reward"

Research Participant Information and Consent Form

You are being asked to participate in a research study. Researchers are required to provide a consent form to inform you about the research study, to convey that participation is voluntary, to explain risks and benefits of participation, and to empower you to make an informed decision. You should feel free to ask the researchers any questions you may have.

Study Title: Sleep, Portion Size, and Food Reward
Researcher and Title: Robin Tucker, PhD, RD, Assistant Professor
Department and Institution: Food Science & Human Nutrition, Michigan State University
Address and Contact Information: 2110 S. Anthony Hall, 517-353-3408, tucker98@msu.edu
Sponsor: None

1. PURPOSE OF RESEARCH

- You are being asked to participate in a research study that is investigating how sleep affects decisions about food intake.
- You have been selected as a possible participant in this study if you do not have any sleep problems, you routinely sleep the recommended amount, you do not have any food allergies, you enjoy the test foods, and you rely on appetite sensations to control food intake
- From this study, the researchers hope to learn how sleep influences decisions about portion sizes and food intake. Information gained from this study may help scientists understand how sleep changes a person's response to the rewarding properties of foods.
    - Your participation in this study will depend on whether you qualify for the second part of the study. If you decide to participate, you will spend about 30 minutes at this visit. If you qualify for further testing, it will take about 17.5 hours – about 16 hours of which will occur while you are sleeping at home. Only 1.5 hours will take place in the laboratory. In the entire study, 300 people are being asked to participate, and we anticipate that 1 of every 5 people who are screened will qualify for our study.

2. WHAT YOU WILL DO

- Come to Trout Hall, room 111, to meet with the research staff. Dr. Tucker and her associates will ask you to read, ask questions, and sign this consent form, if you agree to participate. You should only sign this form once all of your questions have been answered.
    - Once you have signed the form:
        - You will complete the pre-screening survey. The research team will review your responses within one week to determine if you are eligible to participate in the study. If you are eligible, we will contact you to return to the lab for further instructions.

    The pre-screening survey will last about 30 minutes.
        - You will complete the online pre-screening questionnaire, answer questions about who you are (birthdate, race, ethnicity, etc.) and have your height, weight, and percent body fat measured. Body fat is measured using a special scale that sends a very weak electrical current through the body. The measurement is painless. You should not participate in this part of the study if you have a pacemaker, cardiac defibrillator, or any other electronic medical devices.

    If you are eligible, you will return to the lab in order to:
        - Receive instructions on how to use the Zmachine to assess your usual sleep habits.
            - The Zmachine measures how long and how well you sleep. The Zmachine measures the electrical activity of your brain to assess sleep patterns. Use of the Zmachine involves minimal discomfort.
        - You will use the Zmachine for 2 weeknights, at least two weeks apart.
        - Please note: the Zmachine cannot diagnose sleep disorders/abnormalities, and if you need sleep evaluation, you should pursue this with your physician.

Each night before lab testing – 2 nights in total

- Connect the Zmachine per the instructions provided to you during this visit.
- On one night, you will be instructed to go to bed at your usual time and wake at your usual time. On the other night, you will be instructed to go to bed approximately 1-1.5 hours LATER than your usual bed time and get up approximately 1-1.5 hours EARLIER than your usual time. You must wait at least 2 weeks between visits.

At each lab appointment:

- Your lab appointment will last about 45 minutes. It will occur at your usual lunch time. You should eat the same things for breakfast and snack(s) before each visit at the same time of day. Do not eat or drink anything for at least one hour before your visit.
- Bring your Zmachine to each lab appointment.
- Upon arriving, we will ask you to:
  - Tell us what you ate during the morning.
  - Tell us how tired you are, how sleepy you are, and answer other questions about last night's sleep.
- During testing, we will ask you to:
  - Drink 200 mL of water.
  - Tell us how hungry you are.
  - Show us your ideal portion size for the following foods: potato chips, salad, cookies, chicken breast, salad dressing, grapes, white rice, soda and gummy candies. You will also tell us how much you like the foods, but you will not eat the foods.
  - You will be shown a specific amount of each food. You will tell us how much you would pay for the food – no actual money is involved.
  - Earn Hershey's kisses by pressing a button on a computer screen. After you earn the candy, we will ask you to eat it. We ask that you participate long enough to earn at least one piece of candy.
  - Complete questionnaires about your eating habits.
- We will also measure your blood pressure and heart rate.

3. POTENTIAL BENEFITS

You will not directly benefit from your participation in this study. However, your participation in this study may contribute to the understanding of how sleep influences judgments about food and food intake.

4. POTENTIAL RISKS

- The potential risks of participating in this study are:
  - You may feel fatigued due to changes in the amount of sleep you get.
  - You should not participate if you have food allergies. Allergic reactions could occur.
  - Some people might experience irritation or allergic reactions from the sensors. If this occurs, immediately discontinue the use of the Zmachine and inform the researchers.
  - There is a risk of a breach of confidentiality.

5. PRIVACY AND CONFIDENTIALITY

- The data for this project will be kept confidential.
- Although we will make every effort to keep your data confidential there are certain times, such as a court order, where we may have to disclose your data. The principal investigator and research student assistants will have access to the data. The Human Research Protection Program (HRPP) may review records to insure researcher compliance with federal law and university policy.
- Your data will be stored in a locked filing cabinet in 2115 S. Anthony Hall and in a password-protected computer file. Hard copies of the data will be retained for 3 years after the project ends, after which they will be destroyed by shredding. Electronic files will be stored on a computer in password-protected documents and will not be destroyed. Your name will never be on any of the electronic files. The results of this study may

be published or presented at professional meetings, but the identities of all research participants will remain anonymous.

6. YOUR RIGHTS TO PARTICIPATE, SAY NO, OR WITHDRAW

- Participation is voluntary. Refusal to participate will involve no penalty or loss of benefits to which you are otherwise entitled. You may discontinue participation at any time without penalty or loss of benefits to which you are otherwise entitled.
- You have the right to say no.
- You may change your mind at any time and withdraw.
- You may choose not to answer specific questions or to stop participating at any time.

7. COSTS AND COMPENSATION FOR BEING IN THE STUDY

o After completion of the pre-screening test, you will receive $10. If you qualify for further testing, upon completion of both laboratory visits, the return of the Zmachine and its accessories, and completion of your food record, you will receive another $40. The total compensation for the entire study is $50.

8. THE RIGHT TO GET HELP IF INJURED

If you are injured as a result of your participation in this research project, Michigan State University will assist you in obtaining emergency care, if necessary, for your research related injuries. If you have insurance for medical care, your insurance carrier will be billed in the ordinary manner. As with any medical insurance, any costs that are not covered or in excess of what are paid by your insurance, including deductibles, will be your responsibility. The University's policy is not to provide financial compensation for lost wages, disability, pain or discomfort, unless required by law to do so. This does not mean that you are giving up any legal rights you may have. You may contact Dr. Robin Tucker (tucker98@msu.edu, 517-353-3408) with any questions or to report an injury.

9. CONTACT INFORMATION

If you have concerns or questions about this study, such as scientific issues, how to do any part of it, or to report an injury, please contact the researcher: Dr. Robin Tucker, Michigan State University, 2110 S. Anthony Hall, 274 S. Shaw Ln., East Lansing, MI 48824, tucker98@msu.edu, 517-353-3408).

If you have questions or concerns about your role and rights as a research participant, would like to obtain information or offer input, or would like to register a complaint about this study, you may contact, anonymously if you wish, the Michigan State University's Human Research Protection Program at 517-355-2180, Fax 517-432-4503, or e-mail irb@msu.edu or regular mail at 4000 Collins Rd, Suite 136, Lansing, MI 48910.

10. DOCUMENTATION OF INFORMED CONSENT

Your signature below means that you voluntarily agree to participate in this research study.

_____ _____

Signature Date

You will be given a copy of this form to keep.

B. 2 Consent form "The effects of sleep curtailment and breakfast on eating behavior"

Research Participant Information and Consent Form

Study Title: The effects of sleep curtailment and breakfast on eating behavior
Researcher and Title: Robin Tucker, PhD, RD, Assistant Professor
Department and Institution: Food Science & Human Nutrition, Michigan State University
Contact Information: 2110 S. Anthony Hall, 517-353-3408, tucker98@msu.edu
Sponsor: None

BRIEF SUMMARY
You are being asked to participate in a research study. Researchers are required to provide a consent form to inform you about the research study, to convey that participation is voluntary, to explain risks and benefits of participation including why you might or might not want to participate, and to empower you to make an informed decision. You should feel free to discuss and ask the researchers any questions you may have.

You are being asked to participate in a study of the effects of sleep and breakfast on feelings of hunger and food cravings. Your participation in this study will depend on whether you qualify for the second part of the study. If you decide to participate, you will be asked to spend about 30 minutes at this visit. If you qualify for further testing, it will take about 52 hours – about 32 hours of which will occur while you are sleeping at home. Only 20 hours will take place in the laboratory.

The most likely risks of participating in this study are feeling fatigued, an allergic reaction (if you have food allergies), and abdominal discomfort (if you have lactose intolerance). Therefore, **you should not participate if you have food allergies or lactose intolerance. In addition, you should not participate if you currently have or have ever had diabetes, kidney disease, metabolic diseases, chronic diseases, or eating disorders.**

You will not directly benefit from your participation in this study. However, your participation in this study may contribute to the understanding of whether sleep influences feelings of hunger and food cravings after different sleep conditions.

In the entire study, 260 people are being asked to participate, and we anticipate that 1 of every 4 people who are screened will qualify for our study. We need 65 participants to participate in the second phase of the study but anticipate that we will need to screen many more people to identify enough participants who qualify for further testing.

PURPOSE OF RESEARCH
- The purpose of this research study is to investigate the effects of sleep and breakfast on feelings of hunger and food cravings after regular sleep and shortened sleep.
- You have been selected as a possible participant in this study because you have indicated that you are female, between the ages of 18 and 55; do not have any sleep problems; have a regular weekday bedtime; routinely sleep 7-9 hrs per night; routinely eat breakfast on weekdays; are not lactose intolerant; do not have any food allergies; enjoy eating granola bars, yogurt, and macaroni and cheese; willing to receive text messages as the reminder for tasks after the lab visit.
- Information gained from this study may help scientists understand how sleep influences feelings of hunger and food cravings.

WHAT YOU WILL BE ASKED TO DO

- Come to Trout Hall, room 111 to meet with the research staff. Dr. Tucker and her associates will ask you to read, ask questions, and sign the consent form, if you agree to participate. You should only sign this form once all of your questions have been answered.
    - Once you have signed the form:
        - You will complete the screening survey. The research team will review your responses within one week to determine if you are eligible to participate in the study. If you are eligible, we will contact you to return to the lab for further instructions.
- The screening survey will last about 30 minutes.
    - You will complete the online screening questionnaire, answer questions about who you are (age, race, ethnicity, etc.) and have your height, weight, and percent body fat measured. You should not participate in the body fat measurement part of the study if you have a pacemaker, cardiac defibrillator, or any other electronic medical devices.
- If you are eligible, you will return to the lab in order to:
    - Receive instructions on how to use the Zmachine to assess your usual sleep habits.
        - The Zmachine measures how long and how well you sleep. The Zmachine measures the electrical activity of your brain to assess sleep patterns. Use of the Zmachine involves minimal discomfort.
    - You will use the Zmachine for 4 weeknights, at least 1 week apart.
    - If the Zmachine becomes disconnected during the night, you will need to repeat the testing on another night.
    - Please note: the Zmachine cannot diagnose sleep disorders/abnormalities, and if you need sleep evaluation, you should pursue this with your physician.
- Each night before lab testing – 4 nights in total
    - Connect the Zmachine per the instructions provided to you during this visit.
    - On two nights, you will be instructed to go to bed at your usual time and wake at your usual time. On the other 2 nights, you will be instructed to go to bed approximately 1-1.5 hours **LATER** than your usual bed time and get up approximately 1-1.5 hours **EARLIER** than your usual time. You must wait at least 1 week between visits.
- At each breakfast visit - 4 breakfast visits in total:
    - Each breakfast visit will last about **5 hours**. You should arrive to the laboratory fasted for at least 8 hours. You will attend four breakfast visits and arrive at the lab at the same time each day. You must bring the Zmachine to each visit.
- At each visit, you will complete the following tasks:
- Before breakfast
    - Rate how well you slept last night and your current level of food cravings.
    - Complete a questionnaire asking about your hunger and fullness levels.

- Complete a questionnaire about your current mood.

- During breakfast
  - You will eat a breakfast consisting of **granola bars and strawberry yogurt**, in its entirety. Breakfast must be finished within 20 minutes.
  - A choice of drink will be provided to you.
- After breakfast
  - You will complete a questionnaire asking about your hunger and fullness levels, liking for the breakfast, eating behaviors, food cravings, and mood.
  - Every thirty minutes after the start of breakfast, you will fill out these questionnaires. These take just a few minutes to complete. When you are not filling out the questionnaires, you are free to quietly entertain yourself in the lab (complete homework, use the Internet, etc.).
  - You will not eat or drink anything other than 12 oz of water for the duration of the 240-minute period.
  - A macaroni and cheese lunch will be provided 4 hours after breakfast.
- During lunch
  - You will be provided with macaroni and cheese and instructed to eat until you are comfortably full (rating a 7 on a 10 point scale). Once 30 minutes have elapsed and you have completed all questionnaires, you will be free to leave.
- Rest of the day
  - You will enter all foods and beverages you consumed that day after the macaroni and cheese lunch using the Automated Self-Administered 24-Hour (ASA24®) Dietary Assessment Tool. Responses should be entered before you go to bed.
  - You will complete a daily stress questionnaire before you go to bed.
  - We understand that you might fall asleep before you complete the dietary assessment or the stress questionnaire. You will need to re-do the test visit if you do not finish either the ASA24 or the daily stress questionnaire the next day before 11:00 am at the latest.

POTENTIAL RISKS

- The potential risks of participating in this study include:
  - You may feel fatigued due to changes in the amount of sleep you get.
  - You should not participate if you are lactose intolerant. Abdominal discomfort could occur.
  - You should not participate if you have food allergies. Allergic reactions could occur.
  - Some people might experience irritation or allergic reactions from the Zmachine sensors. If this occurs, immediately discontinue the use of the Zmachine and inform the researchers.
  - There is a risk of a breach of confidentiality.

PRIVACY AND CONFIDENTIALITY

- The data for this project will be kept confidential.

- Although we will make every effort to keep your data confidential there are certain times, such as a court order, where we may have to disclose your data. The principal investigator and research student assistants will have access to the data. The Human Research Protection Program (HRPP) may review records to insure researcher compliance with federal law and university policy.
- Your data will be stored in a locked filing cabinet and in a password-protected computer file. Hard copies of the data will be retained for 3 years after the project ends, after which they will be destroyed by shredding. Electronic files will be stored on a computer in password-protected documents and will not be destroyed. Your name will never be on any of the electronic files. The results of this study may be published or presented at professional meetings, but the identities of all research participants will remain anonymous.
- Identifiers might be removed from the identifiable private information and that, after such removal, the information could be used for future research studies or distributed to another investigator for future research studies without additional informed consent from you.

YOUR RIGHTS TO PARTICIPATE, SAY NO, OR WITHDRAW

- You have the right to say no to any part of the research study. You can stop at any time after the study has started. There will be no consequences if you stop, and you will not be criticized. You will not lose any benefits that you normally receive.

COSTS AND COMPENSATION FOR BEING IN THE STUDY

- After completion of the screening test, you will receive $10. If you qualify for further testing, compensation for successfully recording a night of sleep, recording your diet and stress on the test day, and attending the first, second, third and fourth lab visit in the morning is $50, $50, $50, and $75. Total compensation for the completion of the entire study is $235.

CONTACT INFORMATION

If you have concerns or questions about this study, such as scientific issues, how to do any part of it, or to report an injury, please contact the researcher Dr. Robin Tucker, Michigan State University, 2110 S. Anthony Hall, 274 S. Shaw Ln., East Lansing, MI 48824, tucker98@msu.edu, 517-353-3408.

If you have questions or concerns about your role and rights as a research participant, would like to obtain information or offer input, or would like to register a complaint about this study, you may contact, anonymously if you wish, the Michigan State University's Human Research Protection Program at 517-355-2180, Fax 517-432-4503, or e-mail irb@msu.edu or regular mail at 4000 Collins Rd, Suite 136, Lansing, MI 48910.

DOCUMENTATION OF INFORMED CONSENT.

Your signature below means that you voluntarily agree to participate in this research study.

_____ _____

Signature Date

You will be given a copy of this form to keep.

B. 3 Consent form "Chronotype and dietary intake"

Informed Consent to Participate in Research

You are being asked to participate in a research study. Researchers are required to provide a consent form to inform you about the research study, to convey that participation is voluntary, to explain risks and benefits of participation, and to empower you to make an informed decision. Your participation is voluntary. You cannot skip questions, but you can withdraw at any time. This is because most of the questions are connected, and missing one answer could lead to data analysis difficulties. You must be 19 or older to participate. If you have any questions please email your questions to Dr. Robin Tucker, PhD, RD at tucker98@msu.edu. You indicate that you voluntarily agree to participate in this research study by submitting the survey.

Study Title: Chronotype and dietary intake

Researcher and Title: Robin Tucker, PhD, RD, Assistant Professor
Department and Institution: Food Science & Human Nutrition, Michigan State University
Contact Information: 2110 S. Anthony Hall, 517-353-3408, tucker98@msu.edu

PURPOSE OF RESEARCH

You are being asked to participate in a research study that examines the association between sleep and eating habits. You have been selected as a possible participant in this study because are an adult between the ages of 19 and 55 years old and are generally healthy. From this study, the researchers hope to better understand the relationship between sleep and eating habits in adults in the United States. The study will include a total of 200 participants.

WHAT YOU WILL DO

If you agree to participate, you will be asked to complete a survey. If you are eligible, researchers will contact you within 2 weeks, and you will be asked to complete a second survey. The surveys include questions about:

Who you are
Your weight and height
Your preference of timing in a day for activities and rest (chronotype)
Your diet, beverage, and alcohol consumption
Your sleep quality and physical activity
Your food cravings
It will take approximately 40 minutes to complete the first survey and 40 min to complete the second survey.

Please take the survey by yourself in a private location where you feel comfortable. Please take the survey on a personal computer or a password protected public computer.

YOUR RIGHTS TO PARTICIPATE, SAY NO, OR WITHDRAW

Participation is completely voluntary. Refusal to participate will involve no penalty or loss of benefits to which you are otherwise entitled. You may discontinue participation at any time without penalty or loss of benefits to which you are otherwise entitled. You have the right to say no. You may change your mind at any time and withdraw. You may choose to stop participating at any time.

COMPENSATION FOR BEING IN THE STUDY:

Within 2 weeks of successful completion of the first survey, you will receive a $10 Amazon.com gift card. If you qualify for further testing, compensation for successfully completing the second survey is a $10 Amazon.com gift card. The gift card will be sent within 2 weeks of successful completion of the second survey. Total compensation for the completion of the entire study is $20 in Amazon.com gift cards.

POTENTIAL RISKS

There are minimal risks to this study. Some participants might feel uncomfortable reporting current weight and height. If you need to seek help from University counseling services, please contact Michigan State University Counseling & Psychiatric Services at 517-355-8270, Olin Health Center, 463 E Circle Dr, East Lansing, MI 48824.
There is a risk of breach of confidentiality (see below).

PRIVACY AND CONFIDENTIALITY

The data for this project will be kept confidential. Although we will make every effort to keep your data confidential there are certain times, such as a court order, where we may have to disclose your data. The principal investigator and research student assistants will have access to the data. The Human Research Protection Program (HRPP) may review records to ensure researcher compliance with federal law and university policy. Your data will be stored in a password- protected computer file. Electronic files will be stored on a computer in password-protected documents and will not be destroyed. Once the study is complete, any personally identifiable information will be removed from the data files. The results of this study may be published or presented at professional meetings, but the identities of all research participants will remain anonymous.

CONTACT INFORMATION FOR QUESTIONS AND CONCERNS:

If you have concerns or questions about this study, such as scientific issues, how to do any part of it, or to report an injury, please contact the researcher: Dr. Robin Tucker, Michigan State University, 2110 S. Anthony Hall, 474 S. Shaw Ln., East Lansing, MI 48824, tucker98@msu.edu, 517-353-3408.

If you have questions or concerns about your role and rights as a research participant, would like to obtain information or offer input, or would like to register a complaint about this study, you may contact, anonymously if you wish, the Michigan State University's Human Research Protection Program at 517-355-2180, Fax 517-432-4503, or e-mail irb@msu.edu or regular mail at 4000 Collins Rd, Suite 136, Lansing, MI 48910.

By clicking the "next" button and continuing to the survey you are consenting to participate in this survey.

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