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Impact of sleep duration, sleep quality, and physical activity on obesity indices among adolescents

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Adolescent prevalence of obesity and at-risk WC has continued to rise worldwide. Sleep duration, sleep quality, and physical activity have been hypothesized as contributing factors to this increase. **PURPOSE:** This study aimed to examine the sleep–obesity relation in adolescents. **METHODS**: Using data from the 2015-2016 NHANES(n=454; ages 16-18 years), the effect of sleep duration, sleep quality, and MVPA on BMI and WC by gender was analyzed using appropriate sampling weights. **RESULTS**: Longer sleep duration was associated with increased BMI (β=0.07; 0.065, p<0.05) and WC (β=0.069; 0.13, p<0.05) among males and females. Poor sleep quality was associated with increased BMI among males and females (β= 0.04; 0.08, p< 0.05). A significant main effect was observed across sleep duration, sleep quality and MVPA via multiple regression for both BMI and WC. **CONCLUSIONS:** For both males and females, BMI and WC were impacted by excessive sleep, poor sleep quality, and low MVPA, with greater associations among males.

DEDICATION

This thesis is dedicated to my husband, Levi. I am so thankful for his endless support, patience, and encouragement. He has been my rock through all of the stressful times and I couldn't have made it through without him.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

DEFINITIONS

Autonomic dysfunction – Impaired regulation of the autonomic processes such as cardiovascular, ventilatory, digestive, metabolic, etc. processes.

Autonomic nervous system – Division of the nervous system that controls unconscious bodily functions such as breathing, heart rate and digestive processes

Body mass index – Weight-to-height ratio, calculated by dividing weight (kg) by height (m) squared

Circadian rhythm – Internal clock that regulates sleep pattern

Glucose metabolism – Chemical reactions that occur in the body to break down glucose into usable energy

Heart rate variability (HRV) – Variation in the time (s) between heartbeats influenced by the combined effects of both sympathetic and parasympathetic nervous systems

High frequency HRV – Autonomic fluctuations in heart rate from changes in respiration

Low frequency HRV - Autonomic fluctuations in vasomotor tone and blood pressure

Low frequency: high frequency ratio – An index of sympathovagal imbalance

MET- Metabolic equivalent: 1 MET is defined as the amount of oxygen consumed while sitting at rest and is equivalent to 3.5 ml O_2/kg/min. Easy and practical procedure of determining energy cost of activity

Metabolism – Chemical reactions that occur in the body to digest food, transfer energy, produce heat and maintain life

Non-REM sleep – Portion of sleep in which brain wave activity and metabolic processes are reduced

Wake after sleep onset – Time awake during the sleep period. Awakenings > 41 minutes indicate poor sleep quality in children, teens and young adults

Obese – Defined as having a BMI of 30.00 kg/m^2 or higher

Overweight – Defined as having a BMI between 25.00 and 29.99 kg/m^2

PA – Physical Activity

Physical activity – Any bodily movement produced by the skeletal muscles that results in energy expenditure above the resting rate

Polysomnography – Examination of brain wave patterns, heart rate variability and breathing patters during sleep

REM sleep – Portion of sleep in which there are rapid eye movements and high brain wave activity

Sleep awakenings – Numbers of awakenings lasting less than 5 minutes from onset of sleep to rise time. 3 awakenings < 5 minutes per night indicate poor sleep quality in teens

Sleep chronotype – Synonymous with sleep pattern: a person's clock-hour schedule of bedtime and rise time as well as nap behavior; the sleep pattern may also include time and duration of sleep interruptions

Sleep duration – Duration of hours asleep during the night

Sleep efficiency – The ratio of total time spent in bed to total time spent asleep. Sleep efficiency < 74% indicates poor sleep quality across all age groups

Sleep latency – Duration of time from "lights out" to falling asleep. >45-60 minutes denotes poor sleep quality

Sleep macrostructure - Represents the cyclical pattern of sleep as it shifts between the different sleep stages, including non-rapid eye movement (NREM) and rapid eye movement (REM) sleep

Sleep pattern - A person's clock-hour schedule of bedtime and rise time as well as nap behavior; the sleep pattern may also include time and duration of sleep interruptions

Sleep quality – One's satisfaction of the sleep experience, integrating aspects of sleep initiation, sleep maintenance, sleep quantity, and refreshment upon awakening; does not have a clear definition. Appropriate measures of good sleep quality are sleep latency, number of awakenings < 5 minutes, wake after sleep onset, and sleep efficiency)

Suprachiasmatic nucleus – The body's central biological clock

Sympathovagal imbalance – Characterized by sympathetic hyperactivity and or parasympathetic withdrawal resulting from autonomic dysfunction mediated changes in heart rate

Waist circumference – distance (cm) around the waist at the level of the navel

ABBREVIATIONS

ANS – Autonomic nervous system

BMI – Body mass index: Weight-to-height ratio, calculated by dividing weight (kg) by height (m) squared

HRV – Heart rate variability: Variation in the time (s) between heartbeats influenced by the combined effects of both sympathetic and parasympathetic nervous systems

MET – Metabolic Equivalent: : 1 MET is defined as the amount of oxygen consumed while sitting at rest and is equivalent to 3.5 ml O2/kg/min. Easy and practical procedure of determining energy cost of activity

MVPA – Moderate and vigorous physical activity

NHANES – National health and nutrition examination survey conducted bi-annually

NSF – National Sleep Foundation

PA – Physical Activity

REM – Rapid eye movement (sleep)

WC – Waist circumference

CHAPTER I

INTRODUCTION

Background

The increasing prevalence of childhood and adolescent obesity has become a momentous public health concern over the past three decades (Ogden et al., 2016). Roughly 23% of adolescents (12-19-years old) are overweight or obese world-wide (Ng et al., 2014). Currently, 18.5% of 2-19-year-olds in the United States are overweight or obese (Hales, Fryar, Carroll, Freedman, & Ogden, 2018). Excessive weight, having a body mass index (BMI) greater than the 85^{th}% tile on age and gender specific growth charts, is correlated with higher rates of morbidity and mortality, making recognition of the factors contributing to the adolescent obesity epidemic crucial for establishment of interventions. Sleep duration, sleep quality and physical activity levels are three of many variables correlated with incidence of youth overweight and obesity. Numerous studies, both longitudinal (Carroll, Navaneelan, Bryan, & Ogden, 2015; Snell, Adam, & Duncan, 2007) and cross-sectional (Eisenmann, Ekkekakis, & Holmes, 2006; Lumeng et al., 2007; Patel & Hu, 2008), have reported increased risk of developing obesity with short sleep duration (i.e., consistent sleep duration of less than 8 hours per night). Sleep duration is shown to be impacted negatively by sedentarism (time allotted for sedentary behavior), leading to higher obesity rates, while more physically active adolescents presented lower body mass index (BMI) and recommended sleep duration (Al-Haifi et al., 2015). Adequate sleep (achieving 8-10 hours of sleep per night) and sufficient physical activity (achieving PA recommendations) is critical for maintaining a healthy weight during the transition from youth to adulthood as these influence many physical, emotional, biological, and physiological changes during puberty (Garaulet et al., 2011).

Shorter sleep duration has been linked to dysfunction of the autonomic nervous system (de Zambotti, Trinder, Silvani, Colrain, & Baker, 2018; Jarrin, McGrath, Poirier, & Quality Cohort Collaborative, 2015). Increased sympathetic activity during sleep is demonstrated to decrease the amount of time spent in rapid eye movement (REM) sleep (Liu et al., 2008), further increasing the likelihood of adolescent weight gain, since duration of REM sleep is linked with higher energy expenditure (Mishra & Colgin, 2019).

Physical activity is defined as any bodily movement produced by skeletal muscles that results in energy expenditure above the resting rate (Health & Services, 2018). The current physical activity guidelines for adolescents recommend youth, aged six through seventeen should participate in at least 60 minutes of moderate to vigorous physical activity daily, incorporating muscle and bone strengthening exercises. (Health & Services, 2018). The guidelines recommend that physical activity should be of vigorous intensity three days per week (Health & Services, 2018). Recent estimates suggest only 27.1% of high school aged youth meet the recommendation of 60 minutes of physical activity per day (Kann et al., 2016).

Guidelines for adults aged 18 and older recommend reducing sedentary behavior and increasing time spent in moderate to vigorous aerobic activity (Health & Services, 2018). Guidelines suggest 150 minutes of moderate or 75 minutes of vigorous activity or more per week are suggested for optimal health benefits (Health & Services, 2018). Furthermore, recommendations suggest adults should partake in muscle strengthening activities two or more days per week encompassing all major muscle groups (Health & Services, 2018).

Numerous studies have revealed higher amounts of physical activity are associated with decreased body weight among all age-groups (Hoos, Gerver, Kester, & Westerterp, 2003; Slater et al., 2010). Researchers have also found that structured exercise training in adolescents improves sleep duration, sleep quality and overall ability to physical performance (Mendelson et al., 2016). This training leads to increased caloric expenditure. Mendelson and colleagues associated physical activity with longer REM sleep at night and higher physical activity levels during the day. Integration of all components is difficult because research examining the effects of sleep, sedentarism, physical activity and energy intake on obesity has mainly been conducted independently, not cohesively (Mendelson et al., 2016). The ecological validity of this approach is flawed, as in vivo, health is a symphony of all behaviors. Nevertheless, associations between obesity, sleep duration, sleep quality, and physical activity can be concluded from current literature; however much of the literature does examines these variables independently. Because of the numerous factors acting in a cyclic relationship leading to the onset and progressive nature of adolescent obesity, researchers should examine these variables cohesively, which is the overall purpose of this study.

Purpose

The purpose of this thesis is to integrate adolescent health behaviors relating to sleep duration, sleep quality, and physical activity into one approach by examining their impact on obesity using the most recent data collected through the 2015-2016 National Health and Nutrition Examination Survey (NHANES). This study aims to determine if United States high-school students are achieving recommended amounts of sleep and physical activity in an average school week; if sleep status is associated with higher obesity indices; examine the relation between physical activity levels, sleep duration and sleep quality; and determine differences by sex. Recognizing the controllable factors that may significantly influence the current adolescent obesity epidemic, such as sleep duration and physical activity level, is an important step in altering its course.

Research Questions and Hypotheses

1. Are high-school aged adolescents achieving the recommended amount of sleep and physical activity in an average school week?

   Aim: To describe the proportion of adolescents who are achieving the sleep and physical activity recommendations.

   Hypothesis: This is not a hypothesis driven aim.

2. Is shorter sleep duration associated with increased body mass index (BMI) in high school-aged adolescents?

   Hypothesis: Shorter sleep duration will be associated with increased BMI in high school-aged adolescents.

   H_0: Shorter sleep duration will not be associated with increased BMI in high school-aged adolescents.

3. Is shorter sleep duration associated with increased waist circumference (WC) in high school-aged adolescents?

   Hypothesis: Shorter sleep duration will be associated with increased WC in high school-aged adolescents.

   H_0: Shorter sleep duration will not be associated with increased WC in high school-aged adolescents.

4. Does a difference in BMI exist between categories of sleep (under the recommended amount, achieves the recommended amount, over the recommended amount) among high school-aged adolescents?

   Hypothesis: High school-aged adolescents sleeping less than the recommended amount will have a greater BMI compared to those who met or exceeded the recommendations for sleep.

   H_0: There will not be a difference in BMI between categories of sleep among high school aged adolescents

5. Does a difference in WC exist between categories of sleep (under the recommended amount, achieves the recommended amount, over the recommended amount) among high school-aged adolescents?

   Hypothesis: High school-aged adolescents sleeping less than the recommended amount will have a greater WC compared to those who met or exceeded the recommendations for sleep.

   H_0: There will not be a difference in BMI between categories of sleep among high school aged adolescents.

6. Does not meeting the recommendations for sleep (sleep categories) increase the risk for being classified as overweight or obese (BMI categories) among high school-aged adolescents?

   Hypothesis: Not meeting the recommended amount of sleep will increase the risk for being classified as overweight or obese among high school-aged adolescents.

H_0: Not meeting the recommended amount of sleep will not increase the risk for being classified as overweight or obese high school aged adolescents.

7. Is there an association between increased BMI and feeling overly sleepy throughout the day (poor sleep quality categories) among high school-aged adolescents?

   Hypothesis: Increased BMI will be associated with regularly feeling overly sleepy throughout the day among high school-aged adolescents.

   H_0: Increased BMI will not be associated with regularly feeling overly sleepy throughout the day among high school aged adolescents.

8. Does a difference in BMI exist between categories of sleep quality (poor sleep quality, moderate sleep quality, good sleep quality) among high school-aged adolescents?

   Hypothesis: High school-aged adolescents reporting poor sleep quality will have a greater BMI compared to those who report moderate or good sleep quality.

   H_0: There will not be a difference in BMI between categories of sleep quality among high school aged adolescents.

9. Does a difference in WC exist between categories of sleep quality (poor sleep quality, moderate sleep quality, good sleep quality) among high school-aged adolescents?

   Hypothesis: There will be a difference in WC between categories of sleep quality among high school-aged adolescents.

   H_0: There will not be a difference in WC between categories of sleep quality among high school aged adolescents.

10. Does having poor sleep quality (sleep quality categories) increase the risk for being classified as overweight or obese (BMI categories) among high school-aged adolescents?

    Hypothesis: High school-aged adolescents reporting poor sleep quality will have a greater WC compared to those who report moderate or good sleep quality.

    H_0: Having poor sleep quality will not increase the risk for being classified as overweight or obese among high school aged adolescents.

11. Is there an association between sleep duration, sleep quality, moderate-vigorous-physical-activity (MVPA) and increased BMI among high school-aged adolescents?

    Hypothesis: Short sleep duration, low duration of MVPA, and poor sleep quality will be associated with increased BMI among high school-aged adolescents.

    H_0: Sleep duration, duration of MVPA, and sleep quality will not be associated with increased BMI among high school aged adolescents.

12. Is there an association between sleep duration, sleep quality, MVPA and increased WC among high school-aged adolescents?

    Hypothesis: Short sleep duration, low duration of MVPA, and poor sleep quality will be associated with increased WC among high school-aged adolescents.

    H_0: Sleep duration, duration of MVPA, and sleep quality will not be associated with increased WC high school aged adolescents.

Limitations

This study was limited by the use of data from 16-18-year-olds only because NHANES does not report sleep questionnaire data for other adolescent age-groups. Younger adolescent's sleep patterns may be of more significance to obesity level than older age-groups. Since NHANES sleep data was self-reported, adolescents may have exaggerated or inaccurately recalled their typical sleep and wake times. Finally, only one cycle of NHANES data was examined in this study. Examining multiple years of NHANES data collectively may yield a better representation of the sleep-obesity relation, since the population-representative sample would include sleep patterns from multiple years.

CHAPTER II

REVIEW OF THE LITERATURE

Introduction

This review of the literature examines the current epidemic of adolescent (12-19-year-olds) overweight and obesity. Adolescent overweight and obesity are defined by having a BMI greater than the 85th or 95th percentile on adolescent growth charts, respectively. Increasing rates of adolescent obesity are becoming a public health concern worldwide (Ng et al., 2014). Currently, over 23.8% (CI, 22.9%-24.7%) of adolescent females and 22.6% (CI, 21.7%-23.6%) of adolescent males are overweight or obese throughout developed countries (Ng et al., 2014). 19% of 13-17-year-olds in the United States are overweight or obese (Hales et al., 2018). In developing countries, the prevalence of adolescent obesity has risen from 8.1% to 12.9% among males and from 8.4% to 13.4% among females within the previous 20 years (Ng et al., 2014). The rise in obesity level among developing countries is a possible indication of factors associated with the convenience and sedentary lifestyle of developed countries. Sleep duration, sleep quality, and physical activity level are few of many factors associated with the increasing prevalence of adolescent obesity. For this review, literature regarding sleep duration, sleep quality, physical activity level (PAL), and mechanisms associated with weight among adolescents are examined.

Sleep Duration

Sleep duration is quantified by the time (hours or minutes) spent asleep during the night. (Max Hirshkowitz et al., 2015). The National Sleep Foundation (NSF) released updated recommendations for adequate sleep across all age groups in 2015 (Max Hirshkowitz et al., 2015). Adolescents 14-17-years-old should obtain 8-10 hours of sleep each night (Max Hirshkowitz et al., 2015), but 7-11 hours may be appropriate. Sleeping less than 7 hours or over 11 hours throughout the night is not recommended (Max Hirshkowitz et al., 2015). Carskadon and colleagues suggest "sleep-need," the duration of sleep achieved when given ten hours of sleep-time, remains consistent at around nine hours for adolescents (Carskadon & Acebo, 2002). Carskadon and colleagues concluded that adolescents are not meeting the physiological sleep-need (Carskadon & Acebo, 2002) based off of a sleep-survey distributed to over 3000 high-school students (Wolfson & Carskadon, 1998). Although there are recommended sleep durations, the prevalence of adolescents sleeping less than the recommended amount is exceedingly great (Hales et al., 2018).

Researchers using data from the 2017 Youth Risk Behavior Surveillance System (YRBSS) observed a 26% [95% CI, 24.5-27.6] adherence rate to the eight hours of sleep recommended in a sample of 8,194 adolescents 13-years and older (Narcisse et al., 2019). One-in-four adolescents reported less than eight hours of sleep on average (Narcisse et al., 2019). The National Sleep Foundation conducts an annual *Sleep in America Poll* to determine the average sleep hygiene of Americans. Using data from the 2006 *Sleep in America Poll*, Carskadon reported older adolescents (17-18-year-olds) self-reported a mean sleep duration of 6.9 hours per night compared to 8.1 hours per night among younger adolescents (11-12 years-olds) (Carskadon, 2011). Differences between younger and older adolescents could be largely due to later bedtimes. Older adolescents were aware of being sleep deficient, but due to social, educational, and sporting influences, they felt unable to achieve recommended sleep duration (Carskadon, 2011). Keyes et al. report adolescent sleep duration has significantly declined over the past 20 years and the percentage of adolescents sleeping over 7 hours per night declines with age (Keyes, Maslowsky, Hamilton, & Schulenberg, 2015).

Inadequate sleep duration is associated with a wide range of adverse outcomes including issues in school performance (Wolfson & Carskadon, 2003), reckless behavior (Meldrum & Restivo, 2014), mental health (Smaldone, Honig, & Byrne, 2007), and more pertinent to this literature review, weight gain (O'Dea, Dibley, & Rankin, 2012). In a 4-year longitudinal study examining the association of sleep duration and obesity in Australian adolescents, consistent short sleep was associated with an increase in BMI of 1.84 kg/m^2 (CI: 1.22, 2.46) on average from year one to year four that was independent of BMI changes due to growth (O'Dea et al., 2012). Scientific literature repeatedly suggests short sleep duration is associated with higher adiposity levels in adolescents and contributes to the increasing prevalence of adolescent obesity.

Sleep Duration and Obesity

Although associations between short sleep duration and obesity are consistently found among adolescents, results appear to differ between sexes in which stronger associations are observed among males. Chen, Beydoun, and Wang (2008) found persistent evidence linking short sleep duration and adolescent obesity in a systematic review and meta-analysis of 17 observational, cohort, cross-sectional, and case-control studies (Chen, Beydoun, & Wang, 2008). Adolescents sleeping less than nine hours were at a 58% increased risk of becoming overweight. The association between short sleep duration and obesity appeared to be stronger for boys than girls (odds ratios: 2.50, 1.24; CI: 1.91-3.26, 1.07-1.45), respectively. The reason for this sex difference is not well understood. Another cross-sectional study revealed linear associations between short sleep duration and increased BMI in boys, but not girls (Eisenmann et al., 2006), along with conflicting evidence demonstrating BMI with short sleep in girls only (Garaulet et al., 2011). When examined longitudinally rather than cross-sectionally, short sleep duration is associated with higher incident obesity in both boys and girls (Risk Ratio: 1.2; 95% CI, 1.0 – 1.6) (Suglia, Kara, & Robinson, 2014). Thus, sex inconsistencies are removed when examined over a longer time period (Suglia, Kara, & Robinson, 2014). Mitchel et al. followed a sample of 1,336 adolescents from 9th through 12th grade to investigate the effect of sleep duration on BMI changes from mid to late adolescence (Mitchell, Rodriguez, Schmitz, & Audrain-McGovern, 2013). Less sleep was associated with greater increases in BMI for both sexes, whereas increasing sleep from 7.5 hours to 10 hours per night predicted a 4% reduction in adolescents who were overweight. Mitchell et al. concluded a long-term impact of adolescent sleep deprivation may include weight gain (Mitchell et al., 2013). Unfortunately, the sleep-obesity relation is also an issue in other countries. Germany, France, Portugal (Patel & Hu, 2008), and China (Cao et al., 2015) have also reported the association between sleep deficiency and weight gain during adolescence, making this relationship a global issue.

An association between short sleep duration and higher obesity levels in adolescence is evident. Efforts to explain the relationship first attempt to explain why adolescent have shorter sleep patterns. Existing knowledge suggests adolescents have inconsistent sleep patterns due to many pressing obligations such as schoolwork, side jobs, and extracurricular activities (Carskadon, 2011). Researchers observing sleep inconsistencies throughout this age period have collectively associated these patterns with the Adolescent Sleep Delay (Carskadon, Acebo, & Jenni, 2004; Carskadon, Vieira, & Acebo, 1993).

Bedtimes are progressively delayed as children progress through adolescence. The delay typically results from participation in school-related activities, sports practices, social outings, and the onset of independent driving. Due to competing interests (homework, socializing, practicing sports, or surfing the internet (Falbe et al., 2015)), adolescents preferred sleep patterns shift toward a later chronotype and result in decreased sleep time (Owens, Adolescent Sleep Working, & Committee, 2014). "Sleep chronotype" is synonymous with "sleep pattern" and refers to the preferred sleep and wake times of an individual and is driven their central biological clock (Owens et al., 2014). Since bedtime is delayed and school start times remain constant throughout grade school, sleep deprivation can accumulate (Owens et al., 2014). Sleep patterns may influence obesity risk by altering the time of day individuals eat, sleep, or exercise (Owens et al., 2014), and are an important mechanism associated with the adolescent sleep-obesity relation.

Several possible mechanisms explaining the association between short sleep duration or poor sleep quality and adolescent obesity exists. Thus, a complete examination of all these variables is beyond the scope of this review. However, a brief review of these possible mechanisms is necessary.

Mechanisms Associated with Short-Sleep and Obesity

Hormones

The role of hormones involved in appetite regulation has been examined as a factor associated with the adolescent sleep-obesity relation (Gohil & Hannon, 2018). With laboratory induced sleep restriction (four hours of sleep for six nights) among young men (18-24 years-old), the appetite-suppressing-hormone, leptin, is reduced by 18% ($p = 0.04$), and the appetite-stimulating-hormone, ghrelin, is increased by 28% ($p = 0.04$) when caloric intake and energy expenditure are fixed (Spiegel, Tasali, Penev, & Cauter, 2004). The ratio of ghrelin to leptin concentration increased by 71% (95% CI, 0.07 – 1.35) with sleep restriction indicating increased appetite stimulation. Spiegel et al. found sleep restriction was associated with a 27% increase in hunger ratings and 23% increase in appetite ratings for all food categories ($p < 0.01$ and $p = 0.01$, respectively) (Spiegel, Tasali, et al., 2004). Compared with dietary intake after nine hours of sleep, adolescents undergoing sleep restriction recorded diets with a higher glycemic index ($p = 0.046$), higher carbohydrate content ($p = 0.070$), and reduced consumption of vegetables ($p = 0.016$) (Beebe et al., 2013). Sleep-induced changes in leptin and ghrelin are a likely factor in the obesity epidemic, possibly by reducing diet quality (Golley, Maher, Matricciani, & Olds, 2013).

Diet Quality

Golley et al. (2013) reported sleep patterns are associated with diet quality (Golley et al., 2013). Compared with adolescents who fell asleep earlier, adolescents who had later chronotypes had poorer overall diet quality, marked by higher intake of energy dense, nutrient-poor foods, and lower consumption of fruit and vegetables ($p < 0.0001$; 95% CI, -5.7 to -2.3) (Golley et al., 2013). These findings are similar to research reporting dietary changes with shorter sleep duration only (Beebe et al., 2013; Spiegel, Tasali, et al., 2004). Multiple researchers have observed associations between short sleep duration and poor diet quality, but sleep pattern shifts have just recently been suggested as an independent predictor of diet quality (Gonnissen, Hulshof, & Westerterp-Plantenga, 2013).

Furthermore, repeatedly shifting sleep patterns can result in “social jetlag” (Roenneberg, Allebrandt, Merrow, & Vetter, 2012). Social jetlag has been shown to lead to appetite changes (Lucassen et al., 2013), and slower metabolic rates directly associated with obesity (Roenneberg et al., 2012). Many adolescents report restricting sleep on the weekdays followed by over-sleeping on the weekends (Roenneberg et al., 2012). Randler, Haun and Schaal (2013) reported chronotype and social jetlag may be more important statistical predictors of the sleep-obesity relation than average sleep duration (Randler, Haun, & Schaal, 2013). Determining sleep pattern may be a useful way to examine different variables regarding the adolescent sleep and obesity relation, as adolescents are heavily influenced by school start times, after school activities, and the developmental switch towards a late chronotype following the onset of puberty.

Sleep Macrostructure

The study of sleep macrostructure includes features such as sleep duration, sleep efficiency and the organization of the four sleep stages recognized by the American Academy of Sleep Medicine. Sleep stage 1 (N1) includes a brief transition between wake and sleep (Moser et al., 2009). Sleep stage 2 (N2) makes up most of the sleep duration (Moser et al., 2009). Sleep stage 3 (N3) is characterized by slow waves of electrical current and is commonly referred to as "deep" sleep (Moser et al., 2009). Sleep stage 4 is known as rapid eye movement (REM) sleep and is characterized by dreaming (Moser et al., 2009). Throughout sleep, the sleep stage cycle is continuously rotating, beginning with N3, followed by N2, and REM sleep completing the final stage of each sleep cycle (Porkka-Heiskanen, Zitting, & Wigren, 2013). According to analyses by Chamorro, Algarin, and Garrido, the frequency and mean duration of both Non-REM and REM sleep stages may contribute to a more developed understanding of the time distribution across sleep stages and may determine characteristics of sleep more closely related to obesity (Chamorro et al., 2014).

Both sleep duration (Nixon et al., 2008) and sleep patterns (Randler et al., 2013) have been shown to affect the four sleep stages, which play major roles in metabolism, cognition, learning, growth, and maturation (Nixon et al., 2008; Randler et al., 2013). Often, sleep assessment is based off self-reported sleeping variables such as time in bed, sleep-time and wake-time. Researchers using more objective methods of sleep assessment (e.g. accelerometry) report similar outcomes compared to self-reported data (Nixon et al., 2008). Sleep macrostructure through nocturnal sleep has been given little attention. Sleep organization is assessed most effectively using polysomnographic (PSG) evaluation which examines brain wave patterns, heart rate variability and breathing patterns during sleep.

The organization of sleep may have a greater impact on overweight and obesity than sleep duration alone. REM sleep is directly involved in regulation of both the endocrine system and metabolism (Chamorro et al., 2014; Liu et al., 2008), which both influence weight status. Many studies in humans have identified that the sleeping metabolic rate is highest during REM sleep (Fontvieille, Rising, Spraul, Larson, & Ravussin, 1994; Zhang et al., 2002), due to increased glucose utilization in the brain during REM sleep (Fontvieille et al., 1994). Liu, Forbes, and colleagues (2008) found significant associations between reduced REM sleep and increased weight. They observed a 1-hour decrease in total sleep time was associated with approximately 2-fold increased risk of being overweight (odds ratio: 1.85), and 1-hour less of REM sleep was associated with approximately 3-fold risk of overweight (odds ratio: 2.91) (Liu et al., 2008). A causal relation between short REM duration and lower REM density and overweight is suggested due to associated decrease in sleeping metabolic rate (Liu et al., 2008).Their conclusions suggest the sleep-obesity relation may in part be attributed to the association between BMI z score, reduced REM duration ($\beta = -0.027$) and REM density ($\beta = -0.256$) (Liu et al., 2008).

Mishra and Colgin suggest brain energy expenditure is higher during REM sleep because of heightened brain wave activity (Mishra & Colgin, 2019). REM sleep is characterized by loss of muscle tone (i.e. atonia) along with wake-like electroencephalogram (EEG) patterns, denoting increased brain wave activity. Mishra and Colgin concluded only high frequency (e.g. fast) brain waves resulted in amplified blood flow during REM (Mishra & Colgin, 2019). Bergel et al. demonstrated REM sleep is associated with increased blood flow to multiple brain areas by displaying spurts of hippocampal brain wave activity during REM sleep, expending a large amount of energy compared to Non-REM sleep (Bergel, Deffieux, Demene, Tanter, & Cohen, 2018). Sequences of blood-flow changes were observed across the brain, suggesting increased whole-brain communication during REM and as result, increased metabolic rate (Bergel et al., 2018). High frequency brain waves provide inputs from the spatial environment when awake, therefore a possibility exists these waves are active during REM to navigate through the dreamworld (Bergel et al., 2018). Consequently, metabolic rate could be heightened during periods of dreaming, and could be an important variable to further the association of sleep and obesity in adolescents but is not included in this study.

Brain wave patterns during sleep are unconscious processes controlled by the autonomic nervous system (ANS). The ANS is responsible for many other possible mechanisms associated with the short-sleep-obesity relation.

Autonomic Nervous System

The autonomic nervous system controls the body’s unconscious internal processes (e.g., breathing rate, heat rate, blood pressure, myocardial function, body temperature, digestion, urination, etc.), coordinates energy homeostasis, and may be involved in the pathophysiology of adolescent sleep-obesity-relation (Jarrin, McGrath, Poirier, & Quality Cohort Collaborative, 2015). The ANS is subdivided into sympathetic and parasympathetic nervous systems which control the bodies responses to stressful stimuli and restful conditions, respectively. Under normal conditions, sympathetic nervous system activity results in an increase in heart rate and metabolism, while parasympathetic activity slows heart rate and metabolism. Under conditions of sleep deprivation, both divisions of the ANS have been shown to dysregulate, leading to sympathovagal imbalance (de Zambotti et al., 2018; Jarrin, McGrath, Poirier, & Quality Cohort Collaborative, 2015; Rodríguez-Colón et al., 2011). Autonomic dysfunction is a likely contributor to the connection between sleep and obesity (de Zambotti et al., 2018). ANS dysfunction can impair the autonomic function of the heart, leading to variation in the time (seconds) recorded between heart beats. Time variation between heart beats is defined as heart rate variability (HRV) and results from sympathetic and parasympathetic activity on the sinoatrial node (Jarrin, McGrath, Poirier, Seguin, et al., 2015). HRV is one of the most widely used indicators of ANS activity during sleep and can be easily observed during sleep with a heart rate monitor (Jarrin, McGrath, Poirier, Seguin, et al., 2015).

Increases in sympathetic nervous system activity during sleep are associated with the onset of adolescent obesity (Jarrin, McGrath, Poirier, & Quality Cohort Collaborative, 2015). Overweight and obese children display significant sympathetic hyperactivity and decreased parasympathetic activity, especially at bedtime and throughout the night (de Zambotti et al., 2018). In adults, experimental sleep deprivation is associated with decreased parasympathetic activity and increased sympathovagal imbalance (Spiegel, Leproult, et al., 2004). Under partial sleep deprivation (4 hours) over 6 nights, healthy young males exhibited significant increases in sympathovagal imbalance compared to conditions of sleep recovery. Evidence of sympathovagal imbalance was evident the next morning (9 am – 1pm) with heart rate increases of 16% compared to when sleep recommendations were met. Therefore, experimental sleep restriction results in greater autonomic dysfunction (Spiegel, Leproult, et al., 2004).

Sympathovagal imbalance can be measured by the low frequency: high frequency ratio (LF:HF). Low frequency HRV refers to autonomic fluctuations in vascular tone and blood pressure. High frequency HRV refers to the effects of respiration on heart rate. Among healthy adolescents, short sleep duration and poor sleep quality were associated with greater sympathovagal imbalance and greater LF:HF ratio ($p = 0.030$). Larger central adiposity and BMI were observed (Jarrin, McGrath, Poirier, & Quality Cohort Collaborative, 2015). Rodriquez-Colon and colleagues observed and association between shorter sleep duration and greater LF:HF ratio and greater sympathovagal imbalance (Rodríguez-Colón et al., 2011). In youth at-risk for obesity, Hakim et al. observed higher sympathovagal imbalance and disordered breathing (Hakim, Gozal, & Kheirandish-Gozal, 2012). Graziano proposed short-sleep induced sympathovagal imbalance at 5.5-years-old was predictive of obesity five years later ($p = 0.02$; 95% CI, 1.35-36.64), even after controlling for expected BMI increase after 5.5 years (Graziano, Calkins, Keane, & O'Brien, 2011).

Along with sleep duration, sleep pattern is another factor associated with sympathovagal imbalance (Gangwisch, 2009). Sleep pattern, as previously discussed, is controlled by circadian rhythm, the body's central biological clock. Circadian rhythm is controlled by the suprachiasmatic nucleus (SCN) which uses metabolic cues from light exposure, sleep, physical activity, and nutrient intake to generate autonomic rhythms (Gangwisch, 2009). Therefore, napping throughout the day or consistently changing bedtime may alter the circadian function of the ANS, causing an imbalance between the sympathetic and parasympathetic systems. Altered sleep-phase patterns, are associated with a reduced HRV and higher BMI in adolescents ($p < 0.05$) (Jarrin, McGrath, Poirier, Seguin, et al., 2015).

These observed links are all in support of autonomic-dysfunction-regulated sympathovagal imbalance as a feasible pathogenic pathway of the association between short sleep and obesity among adolescents. ANS dysfunction is a small predictor of adolescent obesity compared to other factors such as physical activity.

Physical Activity

Physical activity is defined as any bodily movement produced by skeletal muscles that results in energy expenditure above the resting rate (Health & Services, 2018). The current physical activity guidelines for adolescents recommend youth aged six through seventeen should participate in at least 60 minutes of moderate to vigorous physical activity daily, incorporating muscle and bone strengthening exercises. (Health & Services, 2018). The guidelines recommend that physical activity should be of vigorous intensity three days per week (Health & Services, 2018). Recent estimates suggest only 27.1% of high school aged youth meet the recommendation of 60 minutes of physical activity per day (Kann et al., 2016).

Guidelines for adults aged 18 and older recommend reducing sedentary behavior and increasing time spent in moderate to vigorous aerobic activity (Health & Services, 2018). Guidelines suggest 150 minutes of moderate or 75 minutes of vigorous activity or more per week are suggested for optimal health benefits (Health & Services, 2018). Furthermore, recommendations suggest adults should partake in muscle strengthening activities two or more days per week encompassing all major muscle groups (Health & Services, 2018).

Meeting the current physical activity guidelines (Health & Services, 2018) is thought to elicit many health benefits in adolescents. A few health benefits of physical activity among adolescents include prevention of chronic diseases (e.g., type II diabetes and cardiovascular disease), increased muscle and bone strength, improved academic performance, lower stress levels, increased energy and self-esteem, weight maintenance and fat loss, and improvement in both quality and quantity of sleep (Strong et al., 2005).

Intensity of physical activity can be determined by the metabolic equivalent (MET) necessary to maintain the desired level of physical activity. MET's are an easy and practical procedure of determining energy cost of physical activity (Byrne, Hills, Hunter, Weinsier, & Schutz, 2005; Ainsworth, 2011). One MET is defined as the amount of oxygen consumed while sitting at rest and is equivalent to 3.5 ml O_2/kg/min (Byrne et al., 2005). Physical activity can be categorized into three intensities: light (1.6-2.9 MET e.g, slow walking or household chores), moderate (3.0-6.0 MET e.g, walking, light cycling, dancing) or vigorous (> 6.0 MET e.g, football, tennis, running, boxing)(Ainsworth, 2011). Physical activity intensities can be measured objectively using accelerometry (METs can be estimated from accelerometry data) or subjectively based off of individual perception of intensity.

The NHANES physical activity questionnaire defines moderate physical activity as any recreational physical activity resulting in small increases in breathing and heartrate lasting over ten minutes in duration (Control & Prevention, 2006). Vigorous activity is defined as any recreational physical activity that causes large increases in breathing and heartrate of over ten minutes in duration (Control & Prevention, 2006). Janz et al (2002) reported an association between low levels of vigorous activity and higher body fat levels in children; however no association with moderate activity was observed (Janz et al., 2002). In conrast, Lohman et al. reported an inverse relationship between body fatness and all physical actvity intensities among adolescent girls (Lohman et al., 2006), indicating more physical activity of any intensity was associated with lower fat mass and higher fat-free mass.

In a meta-analysis analyzing sedentary time and MVPA in relation to cardiometabolic risk factors in adolescents, Ekuland et al. found higher levels of MVPA were associated with less cardiometabolic risk factors when examined across tertiles of sedentary time (Ekelund et al., 2012). Cardiometabolic risk factors such as WC, systolic blood pressure (mmHg), high-density lipoprotein cholesterol, low-density lipoprotein cholesterol, insulin, and triglycerides were more optimal with increased MVPA time and less time spent sedentary (Ekelund et al., 2012).

Among the associated benefits of meeting physical activity guidelines is a reduction in body weight. Lower PALs are consistent with higher body weights and “unregulated” energy intake levels, while higher PALs are associated with lower body weight and more balanced energy intake levels (T. Church & Martin, 2018). Researchers analyzing NHANES data (1960-2010) reveal energy expenditure in men has decreased from 1567 to 1424 kilocalories per day in a 50 year span with an accompanying with a rise in average weight from ~76.9kg to ~96.8kg (T. Church & Martin, 2018; T. S. Church et al., 2011). Researchers propose a physiological drive to match energy intake to energy expenditure (Bassett, Schneider, & Huntington, 2004; T. Church & Martin, 2018). Due to the decrease in occupation-related physical activity, energy intake is more difficult to regulate leading to energy intakes regularly exceeding energy expenditure. This idea is supported by research from Basset et al. observing high energy intake and high energy expenditure with low obesity levels in an Amish community (Bassett et al., 2004). Basset discusses the physiological drive to increase caloric consumption is associated with higher expenditure levels (Bassett et al., 2004). With the increasing prevalence of sedentary careers and activities, overall energy expenditure is reduced in both adults and adolescents (T. Church & Martin, 2018; Garaulet et al., 2011) while energy intake continues to increase (Garaulet et al., 2011). Consequently, if a higher percentage of the population were meeting the physical activity guidelines, overall energy expenditure would increase, increasing the physiologically driven energy balance and reducing body weight.

Sleep and Sedentary Behavior

Sedentary adolescents have more difficulty sleeping, possibly leading to further energy intake (Al-Haifi et al., 2015; Garaulet et al., 2011). Kuwaiti adolescents exhibited insufficient sleep duration and sleep quality which was associated with higher BMI among girls ($p < 0.05$), poor eating habits ($p < 0.05$) and more sedentary behaviors ($p < 0.05$) among both boys and girls (Al-Haifi et al., 2015). The authors suggest poor sleep quality can be combatted by reducing sedentary behavior and increasing PAL (Al-Haifi et al., 2015). To further explain the possible correlation between PAL and sleep, Mendelson and colleagues (2015) demonstrated physically active adolescents display an increase in overall sleep duration and sleep quality exemplified by a 4% increase in REM sleep duration (effect size: 0.88; $p = 0.025$), and a 7.6% increase in sleep-efficiency index (effect size: 0.76) (Mendelson et al., 2016). With exercise training, PALs were visibly higher, denoted by increased steps per day (actigraphy) and higher average MET ($p < 0.05$) (Mendelson et al., 2016). Furthermore, a positive association was examined between sleep duration and average daily MET ($r = 0.48$), indicating a potential causal relationship between greater sleep duration and intensity of physical activity the following day (Mendelson et al., 2016). Current literature suggests a potential influence of PALs may positively be affecting sleep duration and sleep quality in adolescents, stressing the importance of further research in this area.

Conclusions

Short sleep duration, poor sleep quality, sedentarism, and obesity are concurrent epidemics among adolescents (Al-Haifi et al., 2015; Eisenmann et al., 2006; Garaulet et al., 2011; Hales et al., 2018; Hedley et al., 2004; Lumeng et al., 2007; Ogden et al., 2016; Patel & Hu, 2008; Snell et al., 2007). Sleep deprivation, along with poor sleep quality and shifted sleep-stages, are linked to increased BMI, reduced physical activity, (Garaulet et al., 2011) autonomic dysfunction, alterations in sympathovagal balance (Jarrin, McGrath, Poirier, & Quality Cohort Collaborative, 2015) and reduced diet quality (Spiegel, Tasali, et al., 2004). Sleep and physical activity interventions can improve these metabolic and behavioral alterations associated with obesity (Mendelson et al., 2016). This review discussed the literature examining the adolescent sleep-obesity relation and the impact of physical activity on adolescent obesity. Currently, little research exists which examines the correlation of adolescent sleep duration, sleep quality and physical activity level on weight status. This study aims to expand the current body of literature examining sleep, physical activity, and obesity in adolescents and help bridge gaps between the interrelation of these variables, which may translate into more effective intervention strategies to address adolescent obesity.

CHAPTER III

METHODS

Study Design and subjects

The National Health and Nutrition Examination Survey (NHANES) is an assessment tool used by the Centers for Disease Control and Prevention (CDC) to evaluate the overall health status of adults and children in the nation bi-annually. The NHANES interview contains socioeconomic, demographic, dietary and health-related questions, while the examination includes medical, dental, physiological and biochemical assessments. Using data from the 2015-2016 NHANES, this study was designed to replicate and expand on the work of Eisenmann et al (2006) (Eisenmann et al., 2006) which examined the relation between sleep duration, BMI and WC in Australian adolescents. This study furthers the work of Eisenmann et al. by examining the relation between sleep duration, sleep quality, physical activity level and obesity in adolescents.

The NHANES study design and procedures have been described in detail elsewhere (Control & Prevention, 2007). Only procedures of variables analyzed in the present study are included here. Variables collected via NHANES, that were used in the present study included anthropometric variables (i.e. weight, height, BMI, and WC), sleep questionnaire data, and physical activity questionnaire data from male and female adolescents 16 to 18 years old (N=454). Participants with data missing from NHANES were excluded from this study.

Anthropometry

NHANES technicians were trained in anthropometric and laboratory techniques with standard methodology. Technicians recorded NHANES participants height, weight, and WC in duplicate. Standing height was measured in centimeters using a stadiometer with participants barefoot and standing in the Frankfort plane (Control & Prevention, 2007). Body weight was recorded in kilograms, using a digital analog scale, with participants barefoot and minimally clothed with weight evenly distributed on the scale (Control & Prevention, 2007). Weight in kilograms divided by height in meters squared was used to calculate Body Mass Index (BMI) (Control & Prevention, 2007). BMI was used to classify overweight and obesity status based on age and sex specific reference values (Control & Prevention, 2017) and was analyzed as both continuous and categorical variables. Among youth 2-19 years old, BMI categories included: underweight (< 5th percentile for age and sex), normal (5th – 85th percentile for age and sex), over-weight (> 85th percentile for age and sex), and obese (> 95th percentile for age and sex) (CDC, defining childhood obesity, 2011; control and prevention, 2017). Waist circumference was measured in duplicate in the standing position at the level of the iliac crest to the nearest 0.1 cm using an overlapping Gulick tape (Control & Prevention, 2007). WC was analyzed as a continuous variable.

Sleep

The Sleep Disorder Questionnaire (SLQ-1) was administered, on paper, to NHANES participants 16 years and older by NHANES technicians (Control & Prevention, 2006). The questionnaire consisted of six questions, three of which asked about sleep disorders and were not included in the present study. The question relating to sleep duration asked, “How much sleep do you usually get at night on weekdays or workdays?” (Control & Prevention, 2006), and responses were converted to represent sleep duration in hours-on-average. Sleep duration data were transformed into categories based on the National Sleep's Foundations sleep recommendations (M. Hirshkowitz et al., 2015); less than the recommended amount of sleep (less than 8 hours), achieves recommended amount of sleep (8 to 10 hours), and more than the recommended amount of sleep (more than 10 hours). The National Sleep Foundations definition for poor sleep quality is observing frequent sleep disturbances along with feeling overly sleepy throughout the day (Ohayon et al., 2017). The question relating to sleep quality on the NHANES sleep questionnaire asked, "How often do you feel excessively or overly sleepy during the day?" Answers were recorded as never (0 times per month), rarely (1 time per month), sometimes (2-4 times per month), often (5-15 times per month), or almost always (16-30 timers per month) (Control & Prevention, 2006). Participants were classified as having poor sleep (poor quality) if they answered "often" or "almost always" (together defined as 5–30 times a month) to feeling excessively or overly sleepy during the day; having moderate sleep quality if they answered "sometimes" to feeling overly sleepy during the day; and having good sleep quality if they answered "rarely" or "never" to feeling overly sleepy during the day (Control and Prevention, 2006).

Physical Activity

Physical activity data was collected via questionnaire pertaining to amount of time spent in moderate and vigorous recreational activity per week (Control & Prevention, 2006). Questions included, "In a typical week (do you) do any vigorous-intensity sports, fitness, or recreational activities that cause large increases in breathing or heart rate, like running or basketball, for at least 10 minutes continuously?" If participant answered yes, further questioning included, "In a typical week, how many days (do you) do vigorous-intensity sports, fitness or recreational activities?" and "how much time (do you) spend doing vigorous-intensity sports, fitness or recreational activities on a typical day?" Responses were converted to represent vigorous physical activity in days per week and minutes per day. The questionnaire included identical questions pertaining to time spent in moderate physical activity (Control & Prevention, 2006). Time spent in moderate and vigorous activity were summed to create minutes spent in moderate-vigorous-physical-activity (MVPA) per week. To determine sedentary time, the following question was asked, "how much time (do you) usually spend sitting on a typical day?" Participants were told to include time spent sitting at school, travelling, reading, watching tv, or playing games, but do not include time spent sleeping. Responses were converted to represent minutes spent in sedentary activity per day.

Statistical Analysis

Analyses were conducted on adolescents 16 to 18 years old and for the total sample by sex. All analyses were conducted using SPSS 25. All analyses were conducted using NHANES Exam sampling weights to account for over sampling of the population. P-values were set to 0.05 to determine significance.

Descriptive data were summarized as mean ± standard deviation for continuous variables (sleep duration, MVPA, BMI, and WC) and as frequencies for categorical variables (sleep duration categories, sleep quality categories, and BMI categories). T-tests were used to determine differences between gender.

To determine if shorter sleep duration is associated with increased BMI (research question 2), an ordinary least squares linear regression was used with sleep duration as the predictor and BMI as the outcome. Gender was used as a covariate in the model.

To determine if shorter sleep duration is associated with increased WC (research question 3), an ordinary least squares linear regression was used with sleep duration as the predictor and WC as the outcome. Gender was used as a covariate in the model.

An analysis of covariance (ANCOVA) was used to determine if differences exist between BMI and sleep duration categories (research question 4). Gender was used as a covariate in the model. A Bonferroni *post hoc* test was used to determine the significance of the differences between categories of sleep duration.

An ANCOVA was used to determine if differences exist between WC and sleep categories (research question 5). Gender was used as a covariate in the model. A Bonferroni *post hoc* test was used to determine the significance of the differences between categories of sleep duration.

To determine if not meeting the sleep recommendations increases the risk for being classified as overweight or obese (research question 6), an ordered logistic regression was used with sleep duration categories as the predictor, and BMI categories as the outcome. Gender was used as a covariate in the model.

To determine if there is an association between increased BMI and sleep quality (feeling overly sleepy throughout the day) (research question 7), a linear regression was used with sleep quality as the predictor and BMI as the outcome. Gender was used as a covariate in the model.

An ANCOVA was used to determine if a difference in BMI exists between categories of sleep quality (research question 8). Gender was used as a covariate in the model. A Bonferroni *post hoc* test was used to determine the significance of the differences between categories of sleep duration.

An ANCOVA was used to determine if a difference in WC exists between categories of sleep quality (research question 9). Gender was used as a covariate in the model. A Bonferroni *post hoc* test was used to determine the significance of the differences between categories of sleep duration.

To determine if poor sleep quality increases the risk for being classified as overweight or obese (research question 10), an ordered logistic regression was used with sleep quality categories as the predictors and BMI category as the outcome. Gender was used as a covariate in the model.

To determine if there is an association between sleep duration, sleep quality, MVPA and increased BMI (research question 11), a multiple regression analysis was used with sleep duration, sleep quality categories, and MVPA as predictors and BMI as the outcome. Gender was used as a covariate in the model.

To determine if there is an association between sleep duration, sleep quality, MVPA and increased BMI (research question 12), a multiple regression analysis was used with sleep duration, sleep quality categories, and MVPA as predictors and WC as the outcome. Gender was used as a covariate in the model.

CHAPTER IV

RESULTS

Demographics

Of the total sample (N = 454), 218 (48%) were male and 236 (52%) were female. All participants in this study completed each examined section of the NHANES. All data were included in these analyses. To satisfy the aim of research question 1, frequencies and descriptive statistics were analyzed for the total sample and by gender. Frequencies of the categorical variables and descriptive statistics of the continuous variables are listed in Table 1. as percentages and mean ± standard deviation, respectively.

Table 1

Descriptive Characteristics

Variable	Boys (n=218)	Girls (n=236)	Total (n=454)
Age (years)	16.87 (.79)	16.82 (0.78)	16.90 (0.81)
Height (cm)	174.45 (7.32)	161.90 (6.81)	167.10(9.4)
Weight (kg)	75.52 (20.28)	68.57 (17.77)	71.78 (20.46)
BMI (kg/m^2)	27.27 (7.0)	26.02 (6.53)	25.66 (6/76)
WC (cm)	85.00 (17.07)	84.31 (14.73)	84.64 (15.89)
MVPA (min/day)	117.06 (94.73)	74.94 (94.94)	95.16 (97.05)
Sleep duration (hours)	8.11 (1.52)	8.03 (1.57)	8.06 (1.54)
% Under/normal weight	64.7%	53.0%	58.6%
% Overweight/obese	35.3%	47.0%	41.4%
% Under recommended	36.2%	41.5%	39.0%
% Over recommended	6.9%	8.5%	7.7%

Table 1 (continued)

Variable	Boys (n=218)	Girls (n=236)	Total (n=454)
% Poor sleep quality	26.6%	37.7%	32.4%

Values are: Mean (Standard Deviation); BMI: body mass index; Underweight/normal: <85th%, Overweight/obese: >85th%; Sleep Cat: under recommended: >8 hours per night, recommended: 8-10 hours per night, over recommended: >10 hours per night; Sleep Qual: poor: often or always feel overly sleepy during the day, moderate: sometimes feel overly sleepy throughout the day, good: rarely or never feel overly sleepy throughout the day; WC: waist circumference (cm); MVPA: moderate-vigorous physical activity; Sleep duration: hours spent sleeping per night

Average sleep duration was approximately 8 hours for both males and females (male: 8.11 hours; female: 8.03 hours), with sleep durations ranging from 4.00 hours to 14.50 hours among the males and 4.50 hours to 14.00 hours among the females. On average, both males and females met the requirements for MVPA of 60 minutes of moderate to vigorous aerobic activity per day (male: 117.06min, female: 74.94min). Average BMI was 25.27kg/m^2 and 26.02kg/m^2 for males and females, respectively, with BMI's ranging from near 16.00 kg/m^2 to 51.30 kg/m^2. Average WC was 85.00cm and 84.31cm for males and females, respectively, with WC's ranging from 64.00cm and 60.80cm to 149.80cm and 152.50cm among males and females, respectively.

Of the total sample, 35.3% and 47% of males and females were classified as being overweight or obese, respectively. 56.4% of the males, and 50% of the females examined reported meeting sleep recommendations. 36.2% and 41% of males and females reported sleeping less than the recommended amount, respectively, while 6.9% and 8.5% of males and females reported sleeping over the recommended amount of sleep, respectively. 26.6% and 37.7% of males and females reported having poor sleep quality, respectively, while roughly one third of both males and females reported having moderate (32.6%, 31.5%) and good sleep quality (40.8%, 30.8%).

Sleep Duration and Obesity

A linear regression was used to determine the influence of average sleep duration on BMI among adolescents. To assess linearity, a scatterplot of BMI against sleep duration with superimposed regression line was plotted and is presented as Figure 1. and Figure 2. for male and females, respectively. Visual inspection of these two plots indicated a linear relationship between the variables, homoscedasticity and normality of the residuals**.** The prediction equations were: BMI = 23.84 + 0.28 *sleep duration for males and BMI = 22.53 + 0.43*sleep duration for females.

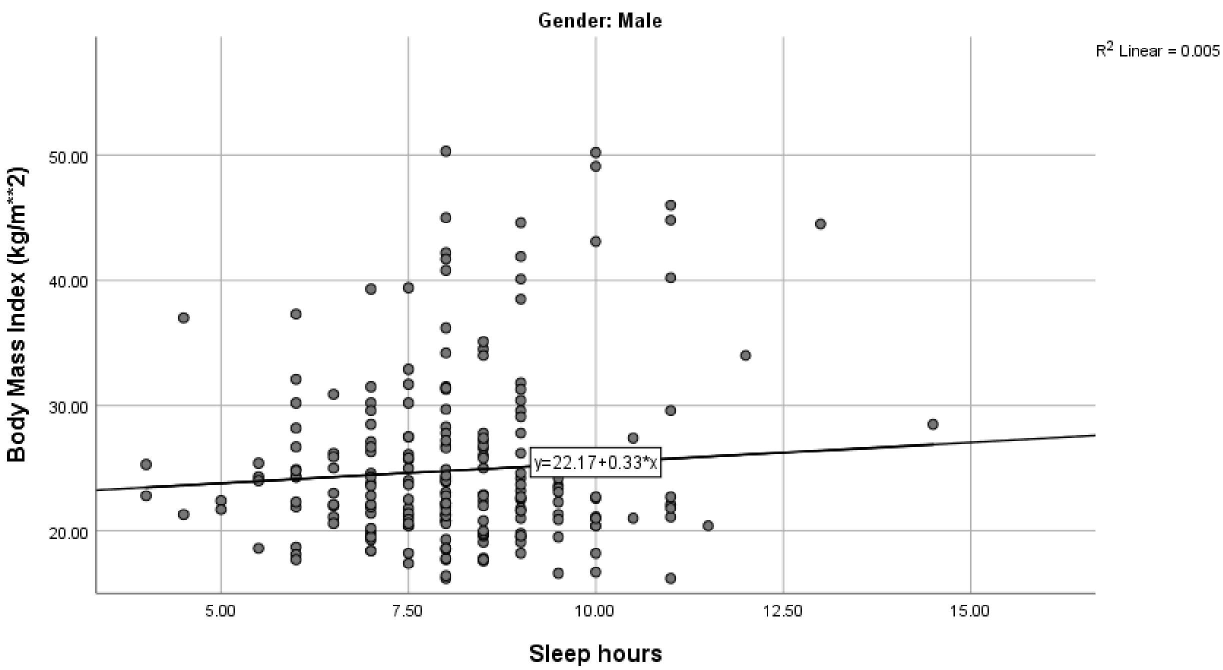

Figure 1. *Linear regression analysis of sleep duration and BMI among males. Sleep duration significantly predicted BMI.*

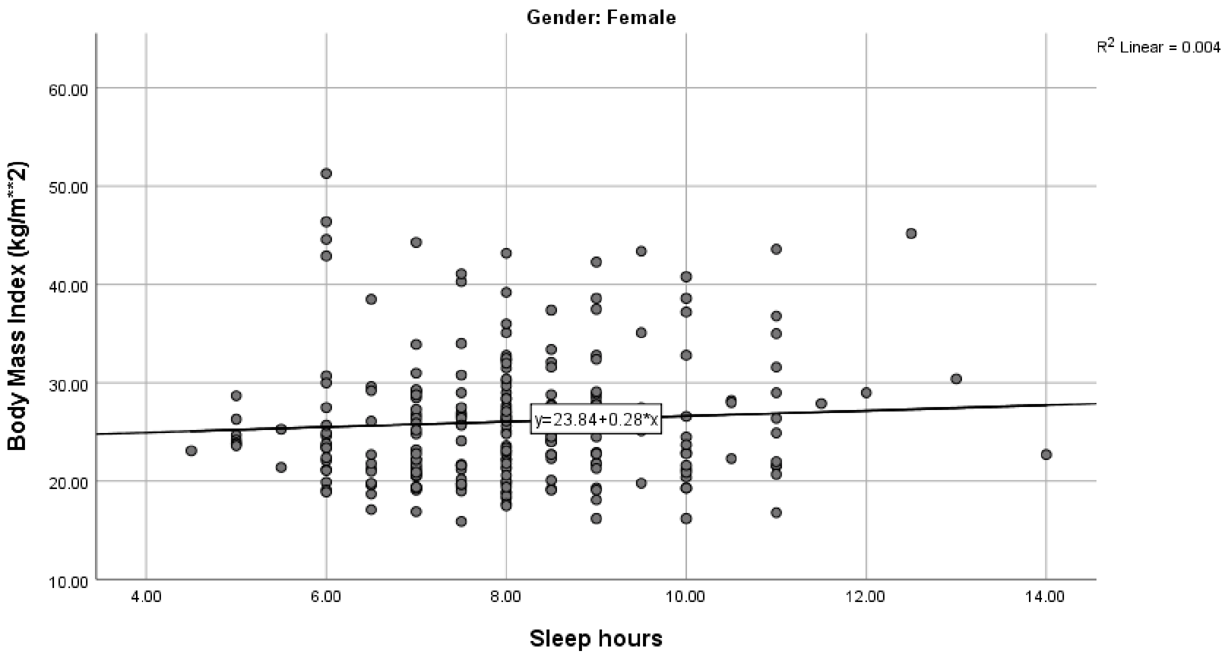

Figure 2. *Linear regression analysis of sleep duration and BMI among females. Sleep duration significantly predicted BMI*

Results from the linear regression analyses on BMI are presented in Table 2. Results demonstrate the influence of sleep duration on BMI among both males ($F(1, 5533341) = 26943.60$, $p < 0.05$) and females ($F(1, 6425923) = 26883.49$, $p < 0.05$) which accounts for 0.5% and 0.4% of the variance in BMI among males ($R^2= 0.005$) and females ($R^2 = 0.004$), respectively. Each additional hour increase in sleep leads to a concomitant increase in BMI of 0.33 kg/m^2, 95% CI [.322,.329] among males, and an increase in BMI of 0.28 kg/m^2, 95% CI [0.275, 0.281] among females.

Table 2

Linear regression of sleep duration predicting BMI

	Variable	B	SE	β	t	*p*
Male	(Constant)	22.17	.016		1356.45	.000*
	BMI	0.33	.002	0.07	164.15	.000*
Female	(Constant)	23.84	.014		1701.94	.000*
	BMI	0.28	.002	0.065	163.96	.000*

*p< 0.05; F_{male} = 26943.60; F_{female}= 26883.50; R^2_{male} = 0.005; R^2_{female} = 0.004

A linear regression was used to determine the influence of average sleep duration on WC among adolescents. To assess linearity, a scatterplot of WC against sleep duration with superimposed regression line was plotted and is presented as Figure 3. and Figure 4. for males and females, respectively. Visual inspection of these two plots indicated a linear relationship between the variables, homoscedasticity and normality of the residuals**.** The prediction equations were: WC = 78.06 + 0.8 *sleep duration for males and BMI = 22.53 + 0.43*sleep duration for females.

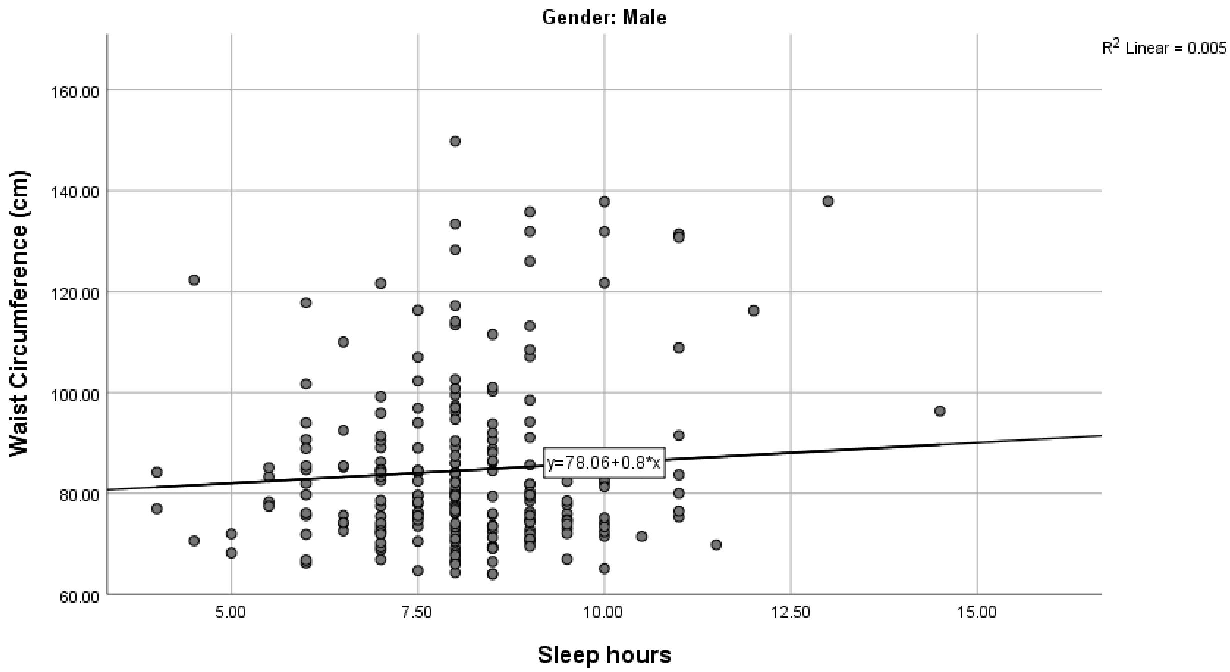

Figure 3. *Figure 3: Linear regression analysis of sleep duration and WC among males. Sleep duration significantly predicted WC*

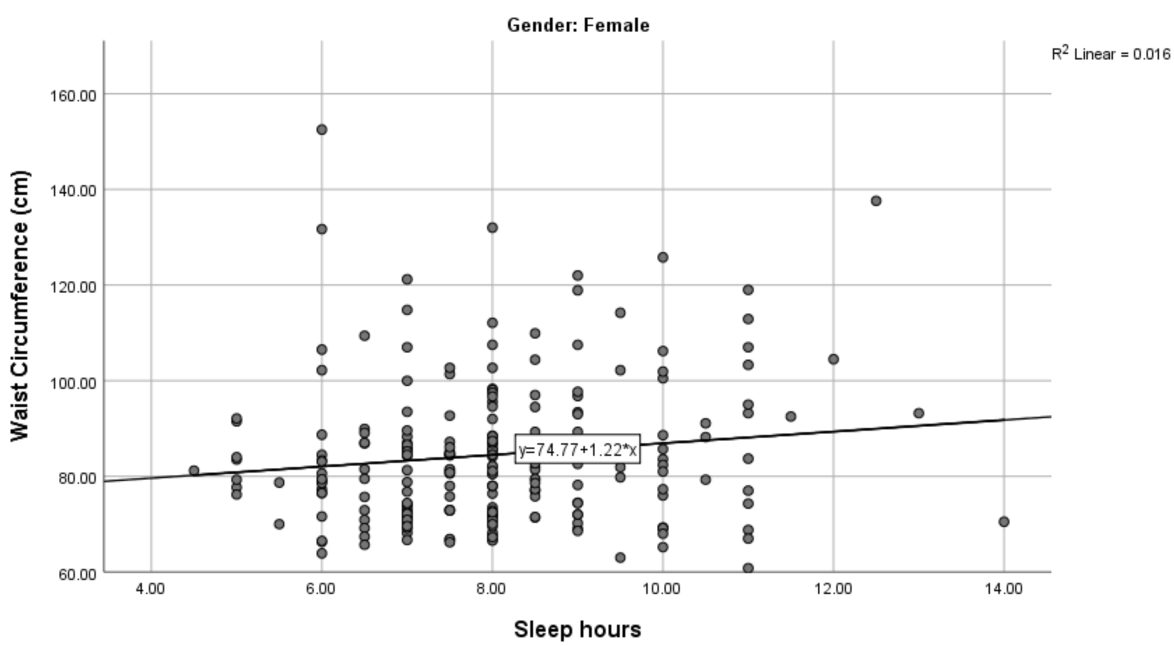

Figure 4. *Linear regression analysis of sleep duration and WC among females. Sleep duration significantly predicted WC.*

Results of the linear regression analyses on WC are presented in Table 3. Results demonstrate the influence of sleep duration on WC among both males (F(1, 54773031) = 26329.23, $p < 0.05$) and females (F(1, 6177308) = 103068.60, $p < 0.05$) which accounts for 0.5% and 1.6% of the variance in WC for males ($R^2 = 0.005$) and females ($R^2 = 0.016$), respectively. Each additional hour increase in sleep leads to a concomitant increase in WC of 0.80 cm, 95% CI [0.791, 0.810] among males, and 1.22cm, 95% CI [1.21, 1.22] among females.

Table 3

Linear regression on sleep duration predicting WC

	Variable	B	95% CI	β	t	*p*
Male	(Constant)	78.05	0.04		1920.40	0.000*
	WC	0.80	0.005	0.069	162.39	0.000*
Female	(Constant)	74.77	0.03		2391.90	0.000*
	WC	1.22	0.004	0.13	321.04	0.000*

*p< 0.05; $F_{male} = 26329.23$;$F_{female} = 103068.6$; $R^2_{male} = 0.005$; $R^2_{female} = 0.016$

An ANCOVA was used to satisfy the aim of research question 4; to determine if there are differences in BMI among categories of sleep duration by gender. There was a significant difference in sleeping over the recommended amount compared to meeting recommendations for sleep and sleeping under the recommended amount among both males (F(2,553345) = 46434.64, p <0 .05, partial $\eta^2 = 0.017$) and females (F(2,6425927) = 22864.19, $p < 0.05$, partial $\eta^2 = 0.007$. Post hoc analyses were performed with a Bonferroni adjustment. Results are displayed in Table 4. BMI was greater in the group who slept over the recommended amount among both males ($M_{diff} = 3.803$ kg/m^2, 95% CI [3.78,3.83], $p < 0.05$) and females ($M_{diff} = 1.98$ kg/m^2, 95% CI [1.96, 2.01], $p < 0.05$. The group who achieved recommended sleep had the lowest BMI, which was lower than the group who slept under the recommended amount among both males (M_{diff} = -.303 kg/m^2, 95% CI [-.0316, -0.289], $p < 0.05$) and females (M_{diff} = -0.049 kg/m^2, 95% CI [-0.061, -0.036], $p < 0.05$).

An ANCOVA was used to satisfy the aim of research question 5; to determine if there are differences in WC among sleep duration categories by gender. There was a statistically significant difference in sleeping over the recommended amount compared to meeting recommendations and sleeping under the recommended amount among both males ($F(2,5477307) = 44348.99$, $p < 0.05$, partial $\eta^2 = 0.016$) and females ($F(2,6176313) = 56756.38$, $p < 0.05$, partial $\eta^2 = 0.018$. Post hoc analyses were performed with a Bonferroni adjustment.

Results are displayed in Table 4. WC was greater in the group who slept over the recommended amount among both males (M_{diff} = 9.27cm, 95% CI [9.20], $p < 0.05$) and females (M_{diff} = 6.25cm, 95% CI [6.19, 6.30], $p < 0.05$). The group who achieved recommended sleep had the lowest WC, which was lower than the group who slept under the recommended amount among males (M_{diff} = -.0965cm, 95% CI [-0.999, -0.931], $p < 0.05$) but not females.

Table 4

Mean BMI and WC in relation to categories of sleep duration by gender

Variable	Under Recommended	Recommended	Over Recommended	F	*p*
BMI (kg/m^2)					
Male	24.81 (0.005)^{a,c}	24.51 (0.004)^{a,b}	27.90 (0.009)^{b,c}	46434.64	0.000*
n	2008265	3237004	2888079		
Female	25.97 (0.004)^{a,c}	25.92 (0.003)^{a,b}	27.90 (0.009)^{b,c}	22864.19	0.000*
n	2372044	3535698	518188		
WC (cm)					
Male	84.70 (0.011)^{a,c}	83.74 (0.009)^{a,b}	93.00 (0.030)^{b,c}	44348.99	0.000*
n	1990016	3204607	282687		

Table 4 (continued)

Variable	Under Recommended	Recommended	Over Recommended	F	*p*
Female	83.49 (0.009)[a,c]	84.50 (0.008)[a,b]	90.75 (0.020)[b,c]	56756.38	0.000*
n	2339772	3318356	518188		

Values are gender adjusted means (SE)
[a]Under recommended statistically different than recommended
[b]Recommended statistically different than over recommended
[c]Over recommended statistically different than under recommended

A binomial logistic regression was performed to ascertain the effects of gender, and sleep duration category on the likelihood that participants were overweight. The logistic regression model was statistically significant, $\chi^2(2) = 233623.79$, $p < 0.05$. Results are displayed in Table 5. The model explained 2.6% (Nagelkerke R^2) of the variance in weight status. Both predictor variables were statistically significant: gender and sleep category. Males had 1.77 times higher odds to being overweight than females. Increasing sleep duration was associated with an increased odds, 1.05 [CI: 1.049, 1.054] of being overweight or obese.

Table 5

Logistic regression predicting overweight from sleep duration category

	B	SE	Wald	*df*	*p*	Odds	95% CI	
							Lowe	Uppe
Gender	0.57	0.001	277065.2	1	0.000*	1.77	1.76	1.77
Sleep Duration	0.50	0.001	2477.32	1	0.000*	1.05	1.04 9	1.054
Constant	-1.31	0.003	257840.8	1	0.000*	0.21		

Note: Gender is for males compared to females; *p< 0.05

Sleep Quality and Obesity

A linear regression was used to determine the influence of sleep quality on BMI among adolescents. Results from the linear regression analyses of sleep quality on BMI are presented in Table 6. Results demonstrate the influence of sleep quality on BMI among both males ($F(1, 5533341) = 8388.26$, $p < 0.05$) and females ($F(1, 6425923) = 43336.87$, $p < 0.05$) which account for 0.2% and 0.7% of the variance in BMI among males ($R^2= 0.002$) and females ($R^2 = 0.007$), respectively. Having moderate or poor sleep quality compared to good sleep quality leads to a concomitant increase in BMI of 0.32 kg/m^2, 95% CI [0.308, 0.322] among males, and an increase in BMI of 0.63 kg/m^2, 95% CI [0.627, 0.639] among females.

Table 6

Linear regression of sleep quality predicting BMI

	Variable	B	SE	β	t	*p*
Male	(Constant)	24.20	0.007		3304.69	0.000*
	BMI	0.32	0.003	0.04	91.59	0.000*
Female	(Constant)	24.75	0.007		3557.58	0.000*
	BMI	0.63	0.003	0.08	208.18	0.000*

*p< 0.05; $F_{male} = 8388.26$; $F_{female:}$ 43336.87; $R^2_{male} = 0.002$; R^2_{female}: 0.007

An ANCOVA was used to satisfy the aim of research question 8; to determine if there are differences in BMI among categories of sleep quality by gender. There was a statistically significant difference in BMI among those who reported poor sleep quality compared to moderate sleep quality and good sleep quality among both males ($F(2,5533345) = 18889.90$, $p < 0.05$, partial $\eta^2 = 0.007$) and females ($F(2,6425927) = 24704.64$, $p < 0.05$, partial $\eta^2 = 0.008$). Post hoc analyses were performed with a Bonferroni adjustment. Results are displayed in Table 7.

BMI was greater in the group who reported poor sleep quality compared to good sleep quality among both males (M_{diff} = .661 kg/m^2, 95% CI [0.645, 0.678], $p < 0.05$) and females (M_{diff} = 1.32 kg/m^2, 95% CI [1.30, 1.33], $p < 0.05$). Among females, the group who reported having good sleep quality had the lowest BMI, which was lower than the group who reported having moderate sleep quality (M_{diff} = -.1.08 kg/m^2, 95% CI [-1.09, -1.07], $p < 0.05$) Among males, the group who reported having moderate sleep quality had the lowest BMI, which was lower than the group who reported good sleep quality (M_{diff} = -0.648 kg/m^2, 95% CI [-0.664, -0.632], $p < 0.05$).

An ANCOVA was used to satisfy the aim of research question 9; to determine if there are differences in WC among categories of sleep quality by gender. There was a difference in WC among those who reported poor sleep quality compared to moderate sleep quality and good sleep quality among both males (F(2,5477307) = 48151.44, $p < 0.05$, partial $\eta^2 = 0.017$) and females (F(2,6176313) = 14291.76, $p < 0.05$, partial $\eta^2 = 0.005$). Post hoc analyses were performed with a Bonferroni adjustment. Results are displayed in Table 7.

WC was greater in the group who reported poor sleep quality compared to good sleep quality among both males (M_{diff} = 2.40cm, 95% CI [2.36, 2.44], $p < 0.05$) and females (M_{diff} = 2.29cm, 95% CI [2.26, 2.33], $p < 0.05$). Among females, the group who reported having good sleep quality had the lowest WC, which was lower than the group who reported having moderate sleep quality (M_{diff} = -0.925cm, 95% CI [-0.961, -0.888], $p < 0.05$) Among males, the group who reported having moderate sleep quality had the lowest WC, which was lower than the group who reported good sleep quality (M_{diff} = -2.75cm, 95% CI [-.2.788, -2.710], $p < 0.05$).

Table 7

Mean BMI and WC in relation to categories of sleep quality by gender

	Poor Sleep Quality	Moderate Sleep Quality	Good Sleep Quality	F	*p*
BMI (kg/m^2)					
Male	25.51 (0.005) [a,c]	24.20 (0.005)[a,b]	24.85 (0.005)[b,c]	18889.90	0.000*
n	1691444	1996115	1845789		
Female	26.54 (0.005)[a,c]	26.30 (0.005)[a,b]	25.22 (0.004)[b,c]	24704.64	0.000*
n	2668540	1956944	1800446		
WC (cm)					
Male	87.23 (0.012)[a,c]	82.08 (0.011)[a,b]	84.82 (0.012)[b,c]	48151.44	0.000*
n	1673195	1980644	1823471		
Female	85.68 (0.009)[a,c]	84.31 (0.010)[a,b]	83.38 (0.011)[b,c]	14291.76	0.000*
n	2652800	1829047	1694469		

Values are gender adjusted means (SE) [a]Poor sleep quality statistically different than moderate sleep quality [b]Moderate sleep quality statistically different than good sleep quality [c]Good sleep quality statistically different than poor sleep quality

A binomial logistic regression was performed to ascertain the effects of gender, and sleep quality category on the likelihood that participants were overweight or obese. The logistic regression model was statistically significant, $\chi^2(2) = 288433.73$, $p < 0.05$. Results are displayed in Table 8. The model explained 3.2% (Nagelkerke R^2) of the variance in weight status. Both predictor variables were statistically significant: gender and sleep quality category. Males had 1.72 times higher odds to being overweight than females. Worsening sleep quality was associated with an increased odds, 1.19 CI: [1.189, 1.193] of being overweight or obese.

Table 8

Logistic regression predicting overweight from sleep quality category by gender

	B	SE	Wald	*df*	*p*	Odds Ratio	95% CI Lower	95% CI Upper
Gender	0.55	0.001	205366.51	1	0.000*	1.72	1.72	1.73
Sleep Quality Cat	0.18	0.001	57057.05	1	0.000*	1.19	1.18	1.19
Constant	-1.55	0.002	419797.22	1	0.000*	0.21		

Note: Gender is for males compared to females; *p< 0.05

Sleep Duration, Sleep Quality, MVPA and Obesity

A multiple regression analysis was used to predict BMI from gender, sleep duration, MVPA and sleep quality. The multiple regression model statistically significantly predicted BMI, $F(4,11959253) = 82934.62$, $p < 0.05$, adj. $R^2 = 0.027$. All four variables added to the prediction, $p < 0.05$. Regression coefficients and standard errors can be found in Table 9.

Table 9

Multiple regression results for BMI

BMI	*B*	95% CI for *B* LL	95% CI for *B* UL	SE *B*	β	R^2	ΔR^2
Model						0.027*	0.027*
Constant	20.29	20.26	20.32	0.014			
Gender	1.032	1.02	1.04	0.004	0.080*		
Sleep Duration	0.365	0.362	.367	0.001	0.081*		
Sleep Quality	0.597	0.593	.602	0.002	0.076*		
MVPA	-0.006	-0.006	-.006	0.000	-0.082*		

B = unstandardized regression coefficient; CI = confidence interval; LL = lower limit; UL = upper limit; SE *B* = standard error of the coefficient; β = standardized coefficient; R^2 = *coefficient of determination;* ΔR^2 *= adjusted R2; p< 0.05**

BMI was 1.03 kg/m^2 higher among males than females on average. Each additional hour increase sleep resulted in an increase in BMI of 0.37 kg/m^2. Having moderate sleep quality as opposed to good sleep quality resulted in an increase in BMI of 0.60 kg/m^2. Each additional minute of MVPA per day resulted in a decrease in BMI of 0.006 kg/m^2.

A multiple regression was used to predict WC from gender, sleep hours, MVPA and sleep quality. The multiple regression model statistically significantly predicted WC, $F(4,11653610) = 74813.73$, $p < 0.05$, adj. $R^2 = 0.025$. All four variables added to the prediction, $p < 0.05$. Regression coefficients and standard errors can be found in Table 10.

Table 10

Multiple regression for WC

WC	*B*	95% CI for *B*		SE *B*	β	R^2	ΔR^2
		LL	UL				
Model						0.025*	0.025*
Constant	73.96	73.89	74.02	0.033			
Gender	-0.552	-.0569	-0.534	0.009	-0.018*		
Sleep Duration	1.202	1.196	1.21	0.003	0.115*		
Sleep Quality	1.52	1.51	1.54	0.006	0.083*		
MVPA	-0.015	-0.015	-0.014	0.000	-0.088*		

B = unstandardized regression coefficient; CI = confidence interval; LL = lower limit; UL = upper limit; SE *B* = standard error of the coefficient; β = standardized coefficient; R^2 = *coefficient of determination;* ΔR^2 *= adjusted* $R^{2;}$ *p< 0.05**

WC was 0.552cm less among males than females on average. Each additional hour of sleep resulted in an increase in WC of 1.20cm. Having moderate sleep quality as opposed to good sleep quality resulted in an increase in WC of 1.52cm. Each addition minute of MVPA per day resulted in a decrease in WC of 0.015cm.

CHAPTER V

CONCLUSIONS

Discussion

This study expands the literature regarding the association of sleep duration, sleep quality, and physical activity with adolescent obesity by examining the variables by gender both independently and cohesively. The result of this study indicates significant associations between sleep duration over the recommended amount, poor sleep quality, low physical activity, and mean higher BMI and WC among both genders, with stronger associations among males. However, contrary to the hypotheses of this study, short sleep duration (under the recommended amount), was not significantly associated with increased BMI or WC among adolescent males or females. A major strength of this study was the large, nationally representative sample size, but limited to the examination of a small adolescent age-range.

Sleep Duration and Obesity Indices

Concordant with previous research, (Eisenmann, 2006; Hitze, 2009) average sleep duration across the nationally representative sample was within the recommended range (8.06h ± 1.54). The percentage of adolescents who were classified as overweight or obese was 35.5% and 47% among males and females, respectively, indicating roughly 1/3 of U.S. adolescent males and almost ½ of U.S. adolescent females are overweight/obese.

A large body of evidence demonstrates associations between short sleep duration and higher obesity indices (O’dea et al, 2012; Chen, Beydoun, & Wang, 2008; Eisennman, 2006;

Garaulet, 2011). Contrary to the literature, in which sleep duration is inversely associated with obesity indices (Hitze, 2009; Chaput, 2011; Garaulet, 2011), results from this study propose a slight linear relation between hours of sleep and both BMI and WC among both genders. Our results suggest sleep duration over the recommended amount is associated with slightly higher obesity indices among both males and females, although effect sizes are small. Each additional hour increase in sleep led to a small increase in BMI of 0.33 kg/m^2, 95% CI [0.322,0.329] among males, and an even smaller increase of 0.28 kg/m^2, 95% CI [0.275, 0.281], among females. For long sleep duration to noticeably effect BMI, consistent patterns of over sleeping would be required, however, only 7.7% of the nationally representative sample in this study reported sleeping over the recommended amount on average. Concurrently, long sleep duration is uncommon among adolescents due to the social and school-related demands to stay up late and comply with consistent school start times (Carskadon, Acebo, & Jenni, 2004; Carskadon, Vieira, & Acebo, 1993). Adoelscents who are able to sleep for long durations may be more at risk for becoming overweight or obese.

When examining differences between categories of sleep duration, sleep duration over the recommended amount was associated with higher BMI and WC among both genders but was greater among males. Additionally, short sleep duration was associated with higher BMI than sleep duration within the recommended amount among both genders but was more profound among males. Short sleep duration was associated with higher WC values among males only.

The gender disparities observed in this study comply with results from other cross-sectional observations (Chen, Beydoun, & Wang, 2008; Eisenmann, 2006). The increase in obesity indices examined with both excessive sleep duration and, possibly, short sleep duration, are indicative of a potential U-shaped relationship between sleep duration and obesity among both genders. However, the association between short sleep duration and obesity indices is too small to confidently conclude clinical significance. The NSF sleep duration cut-points used in this study were likely not sensitive enough to clearly portray clinical significance of short duration sleep and overweight. The NSF recommends 8-10 hours of sleep for older adolescents, but they report 7-11 hours of sleep may be appropriate (Hirshkowitz, 2015). Therefore, it may be necessary to further examine the association with short sleep and obesity indices using one-hour or half-hour increments for any duration below 8 hours to determine clinical significance. Given that the difference between those who slept less than 8 hours and those who slept 8-10 hours was so small (24.81 vs. 24.51 kg/m^2 (male); 25.97 vs. 25.92 kg/m^2 (female)), this line of inquiry was not pursued. This is not the first to observe a possible U-shaped relationship between sleep duration and overweight. Chaput et al. examined a possible U-shaped curve among sleep duration and both BMI and WC among Quebec adolescents, however, only short duration sleepers (< 10 hours) had a clinically significant increased odds of being overweight (OR 2.08, 95% CI 1.16–3.67) that was more profound among males (Chaput, 2011). The significance of increased obesity indices in relation to long sleep duration is a novel finding. Further research reproducing this finding is necessary to determine validity.

Sleep Quality and Obesity

Roughly 1/3 of the participants indicated they suffer from poor sleep quality, 1/3 reported having moderate sleep quality, and 1/3 reported enjoying good sleep quality. Consistent with previous research (Gupta, 2002), sleep quality was significantly associated with obesity in the present investigation. Both male and female adolescents who reported having poor and moderate sleep quality had higher indices of BMI and WC compared to those reporting good sleep quality. Poor sleep quality has been linked with high blood pressure, greater WC and BMI, and increased insulin and glucose concentrations among adults (Jennings, 2007). Theories have been postulated suggesting sleep quality estimates may be indirect markers of restorative slow wave sleep ((Edinger, 2000) Slow wave sleep (N2; i.e., the majority of sleep time), is important for regulation of metabolism and hormones related to metabolism, such as leptin and ghrelin. During slow wave sleep, parasympathetic activity is dominant and sympathetic activity is reduced, along with reductions in glucose utilization and stress hormone release (Hanlon, 2011). Among adults, experimental reduction in slow-wave sleep contributed to poor metabolism via insulin dysregulation, increases in cortisol, and reduced growth hormone, all of which are possible pathways leading to onset of weight gain (Tasali, 2008). Thus, the N2 sleep stage is especially important to obtain. Since poor sleep quality was associated with higher obesity indices in the present study, there is a possibility the participants who reported poor sleep quality spent less time in the N2 sleep stage, and thus, resulting metabolic and ANS changes led to weight gain. This conclusion, however, can only be inferred since aspects of sleep macrostructure, hormones, and ANS activity were not examined in this study.

.Another aspect of sleep quality that was not examined in this study, but potentially effected participants reported sleep quality, is nocturnal awakenings. Recurrent nocturnal awakenings are associated with concomitant sympathetic responses (e.g., increased norepinephrine, muscle activity, heart rate and blood pressure), and hypothalamic pituitary responses (e.g., cortisol) (Hanlon, 2011). These ANS alterations reduce sleep quality, increase day-time sleepiness and modify sleep architecture, reducing slow-wave sleep and REM sleep. The reduction in slow wave sleep alters the metabolic and hormonal pathways that accurately signal appropriate energy intake and expenditure cues and is irrespective of sleep duration (Stamatakis, 2010). Adolescents in the present study who reported poor sleep quality may have reported experiencing nocturnal awakenings, however this question was not asked on the NHANES questionnaire during the 2015-2016 survey.

The NHANES questionnaire asked about feelings of over-sleepiness, which may possibly be linked with both sleep duration and sleep quality. Evidence suggests an association between sleep duration and sleep quality (Jarrin, McGrath, Poirier, Seguin, et al., 2015). Adolescents who have inconsistent bedtimes and as a result, inconsistent sleep duration, have reported poor sleep quality, which can be attributed to disruptions in the ANS (Jarrin, McGrath, Poirier, Seguin, et al., 2015). Fluctuations within the parasympathetic and sympathetic nervous systems lead to feelings of over-sleepiness throughout the day, followed by a disrupted sleep pattern during the night (Hanlon, 2011). There is a possibility of an existing cyclic pattern between having short or long sleep duration leading to altered ANS activity and feelings of over sleepiness throughout the day, resulting in poor sleep quality the following night. As this sleep-pattern continues, along with the known associations between poor sleep quality, and metabolic and hormonal shifts, adolescents may develop cravings for nutrient poor foods (Lucassen et al., 2013; Roenneberg et al., 2012), have less energy for physical activity during the day (Al-Haifi et al., 2015; Mendelson et al., 2016), and ultimately have greater adiposity and poorer body composition than those who attain both adequate and quality sleep.

Ultimately, there is a wide expanse of factors that are associated with the sleep duration-sleep quality-obesity relation, thus a direct causal association cannot be inferred. However, relationships between sleep duration, sleep quality, and obesity are observed in this study. The results re-iterate the importance of examining both sleep duration and sleep quality together as factors in the etiology of obesity, instead of sleep duration alone.

Sleep, MVPA, and Obesity

Sleep duration over the recommended amount was significantly associated with higher obesity indices among both genders. This novel association may be rationalized by increased sedentary time during sleep, reducing overall minutes of physical activity. Results from this study suggest BMI and WC are decreased with every minute engaged in MVPA per day, suggesting minutes of MVPA are inversely associated with weight status. In concordance with Lohman et al. (Lohman et al., 2006), who demonstrated increases in MVPA lead to lower obesity indices, results from the mulitple regression demontrated a one minute increase in MVPA per day was associated with a decrease in BMI of 0.006 kg/m^2 and a decrease in WC of 0.015cm among both genders. On average, females in this nationally representative sample reported lower levels of MVPA and had a higher percentage of obesity than males. There may be a correlation among the adolescents who are overweight, reported longer sleep, and less MVPA, but examination of this hypothesis is beyond the scope of this study.

Conclusions

Sleep duration, sleep quality, and physical activity impact obesity indices among high school-aged adolescents, but the degree to which these factors are associated remains debated. Results from this study are indicative of a linear relation between excessive sleep duration and obesity indices among both males and females, with influences from both sleep quality and daily physical activity. Additionally, a possible U-shaped curve was observed, in which both short sleep duration and long sleep duration are associated with higher obesity indices. The results suggest examining sleep indices other than duration may yield more insightful associations between sleep and obesity. Furthermore, adolescents should achieve quantity and quality sleep as part of their daily routine, alongside an increase in physical activity to maintain a healthy weight.

Given that obesity is a risk factor for multiple chronic diseases (Srinivasan, Myers, Berenson, 2002; Renehan et al., 2008; Eisenman et al., 2005), it is of great importance to have a better understanding of the role of sleep, physical activity, and a multitude of the other factors built into the etiology of obesity.

Findings from this study can be used as an exploratory tool for researchers to further examine the impact of excessive sleep duration on obesity indices. Future studies should examine the interrelation of factors leading to obesity longitudinally. Longitudinal study designs offer the possibility of examining the multidimensional changes associated with sleep and physical activity behavior during childhood. Examining the associations over time could help explain how weight gain is influenced by sleep dimensions, such as sleep quality and sleep pattern changes. Further, following the chronobiological (e.g., sleep-wake preferences), physiological (e.g., ANS and metabolism changes across sleep stages), circumstantial (e.g., later bed-times and fixed school start times), behavioral (e.g., physical activity, sedentary behavior, diet), and psychological (e.g., stress, eating disorders) determinants of weight gain would be advantageous for determining a more accurate representation of the sleep-obesity relationship.

REFERENCES

Al-Haifi, A. A., AlMajed, H. T., Al-Hazzaa, H. M., Musaiger, A. O., Arab, M. A., & Hasan, R. A. (2015). Relative Contribution of Obesity, Sedentary Behaviors and Dietary Habits to Sleep Duration Among Kuwaiti Adolescents. *Glob J Health Sci, 8*(1), 107-117. doi: 10.5539/gjhs.v8n1p107

Bassett, D. R., Schneider, P. L., & Huntington, G. E. (2004). Physical activity in an Old Order Amish community. *Med Sci Sports Exerc, 36*(1), 79-85. doi: 10.1249/01.MSS.0000106184.71258.32

Beebe, D. W., Simon, S., Summer, S., Hemmer, S., Strotman, D., & Dolan, L. M. (2013). Dietary intake following experimentally restricted sleep in adolescents. *Sleep, 36*(6), 827-834. doi: 10.5665/sleep.2704

Bergel, A., Deffieux, T., Demene, C., Tanter, M., & Cohen, I. (2018). Local hippocampal fast gamma rhythms precede brain-wide hyperemic patterns during spontaneous rodent REM sleep. *Nat Commun, 9*(1), 5364. doi: 10.1038/s41467-018-07752-3

Brown, David R., Heath, Gregory, Martin, Sarah Levin, Coordinating Center for Health, Promotion, National Center for Chronic Disease, Prevention, Health, Promotion, . . . Obesity. (2010). *Promoting physical activity : a guide for community action*. Champaign, IL: Human Kinetics.

Byrne, N. M., Hills, A. P., Hunter, G. R., Weinsier, R. L., & Schutz, Y. (2005). Metabolic equivalent: one size does not fit all. *J Appl Physiol (1985), 99*(3), 1112-1119. doi: 10.1152/japplphysiol.00023.2004

Cao, M., Zhu, Y., He, B., Yang, W., Chen, Y., Ma, J., & Jing, J. (2015). Association between sleep duration and obesity is age- and gender-dependent in Chinese urban children aged 6-18 years: a cross-sectional study. *BMC Public Health, 15*, 1029. doi: 10.1186/s12889-015-2359-0

Carroll, Margaret D, Navaneelan, Tanya, Bryan, Shirley, & Ogden, Cynthia L. (2015). Prevalence of obesity among children and adolescents in the United States and Canada.

Carskadon, M. A. (2011). Sleep in adolescents: the perfect storm. *Pediatr Clin North Am, 58*(3), 637-647. doi: 10.1016/j.pcl.2011.03.003

Carskadon, M. A., & Acebo, C. (2002). Regulation of sleepiness in adolescents: update, insights, and speculation. *Sleep, 25*(6), 606-614. doi: 10.1093/sleep/25.6.606

Carskadon, M. A., Acebo, C., & Jenni, O. G. (2004). Regulation of adolescent sleep: implications for behavior. *Ann N Y Acad Sci, 1021*, 276-291. doi: 10.1196/annals.1308.032

Carskadon, M. A., Vieira, C., & Acebo, C. (1993). Association between puberty and delayed phase preference. *Sleep, 16*(3), 258-262. doi: 10.1093/sleep/16.3.258

Chamorro, R., Algarin, C., Garrido, M., Causa, L., Held, C., Lozoff, B., & Peirano, P. (2014). Night time sleep macrostructure is altered in otherwise healthy 10-year-old overweight children. *Int J Obes (Lond), 38*(8), 1120-1125. doi: 10.1038/ijo.2013.238

Chaput, J., Lambert, M., Gray-Donald, K. *et al.* Short Sleep Duration Is Independently Associated With Overweight and Obesity in Quebec Children. *Can J Public Health* **102,** 369–374 (2011). https://doi.org/10.1007/BF03404179

Chen, X., Beydoun, M. A., & Wang, Y. (2008). Is sleep duration associated with childhood obesity? A systematic review and meta-analysis. *Obesity (Silver Spring), 16*(2), 265-274. doi: 10.1038/oby.2007.63

Church, T., & Martin, C. K. (2018). The Obesity Epidemic: A Consequence of Reduced Energy Expenditure and the Uncoupling of Energy Intake? *Obesity (Silver Spring), 26*(1), 14-16. doi: 10.1002/oby.22072

Church, T. S., Thomas, D. M., Tudor-Locke, C., Katzmarzyk, P. T., Earnest, C. P., Rodarte, R. Q., . . . Bouchard, C. (2011). Trends over 5 decades in U.S. occupation-related physical activity and their associations with obesity. *PLoS One, 6*(5), e19657. doi: 10.1371/journal.pone.0019657

Control, Centers for Disease, & Prevention. (2006). National Center for Health Statistics (NCHS). National Health and Nutrition Examination Survey Questionnaire (or Examination Protocol, or Laboratory Protocol). *http://www. cdc. gov/nchs/nhanes. htm*.

Control, Centers for Disease, & Prevention. (2007). National health and nutrition examination survey (nhanes): Anthropometry procedures manual. *Atlanta: Centers for Disease Control and Prevention*.

Control, Centers for Disease, & Prevention. (2017). Defining childhood obesity: BMI for children and teens.

de Zambotti, M., Trinder, J., Silvani, A., Colrain, I. M., & Baker, F. C. (2018). Dynamic coupling between the central and autonomic nervous systems during sleep: A review. *Neurosci Biobehav Rev, 90*, 84-103. doi: 10.1016/j.neubiorev.2018.03.027

Edinger JD, Fins Al, Glenn DM, Sullivan Jr RJ, Bastian LA, Marsh GR et al. Insomnia and the ye of the beholder: are there clinical markers of objective sleep disturbances among adults with and without insomnia complaints? J Consult Clin Psychol 2000; 68: 586 – 593

Eisenmann, J. C., Ekkekakis, P., & Holmes, M. (2006). Sleep duration and overweight among Australian children and adolescents. *Acta Paediatr, 95*(8), 956-963. doi: 10.1080/08035250600731965

Ekelund, U., Luan, J., Sherar, L. B., Esliger, D. W., Griew, P., Cooper, A., & International Children's Accelerometry Database, Collaborators. (2012). Moderate to vigorous physical activity and sedentary time and cardiometabolic risk factors in children and adolescents. *JAMA, 307*(7), 704-712. doi: 10.1001/jama.2012.156

Falbe, J., Davison, K. K., Franckle, R. L., Ganter, C., Gortmaker, S. L., Smith, L., . . . Taveras, E. M. (2015). Sleep duration, restfulness, and screens in the sleep environment. *Pediatrics, 135*(2), e367-375. doi: 10.1542/peds.2014-2306

Fontvieille, A. M., Rising, R., Spraul, M., Larson, D. E., & Ravussin, E. (1994). Relationship between sleep stages and metabolic rate in humans. *Am J Physiol, 267*(5 Pt 1), E732-737. doi: 10.1152/ajpendo.1994.267.5.E732

Gangwisch, J. E. (2009). Epidemiological evidence for the links between sleep, circadian rhythms and metabolism. *Obes Rev, 10 Suppl 2*, 37-45. doi: 10.1111/j.1467-789X.2009.00663.x

Garaulet, M., Ortega, F. B., Ruiz, J. R., Rey-Lopez, J. P., Beghin, L., Manios, Y., . . . Moreno, L. A. (2011). Short sleep duration is associated with increased obesity markers in European adolescents: effect of physical activity and dietary habits. The HELENA study. *Int J Obes (Lond), 35*(10), 1308-1317. doi: 10.1038/ijo.2011.149

Gohil, A., & Hannon, T. S. (2018). Poor Sleep and Obesity: Concurrent Epidemics in Adolescent Youth. *Front Endocrinol (Lausanne), 9*, 364. doi: 10.3389/fendo.2018.00364

Golley, R. K., Maher, C. A., Matricciani, L., & Olds, T. S. (2013). Sleep duration or bedtime? Exploring the association between sleep timing behaviour, diet and BMI in children and adolescents. *Int J Obes (Lond), 37*(4), 546-551. doi: 10.1038/ijo.2012.212

Gonnissen, HKJ, Hulshof, T, & Westerterp-Plantenga, MS. (2013). Chronobiology, endocrinology, and energy-and food-reward homeostasis. *Obesity reviews, 14*(5), 405-416.

Graziano, P. A., Calkins, S. D., Keane, S. P., & O'Brien, M. (2011). Cardiovascular regulation profile predicts developmental trajectory of BMI and pediatric obesity. *Obesity (Silver Spring), 19*(9), 1818-1825. doi: 10.1038/oby.2011.98

Gupta, N.K., Mueller, W.H., Chan, W. and Meininger, J.C. (2002), Is obesity associated with poor sleep quality in adolescents?. Am. J. Hum. Biol., 14: 762-768. doi:10.1002/ajhb.10093

Hakim, F., Gozal, D., & Kheirandish-Gozal, L. (2012). Sympathetic and catecholaminergic alterations in sleep apnea with particular emphasis on children. *Front Neurol, 3*, 7. doi: 10.3389/fneur.2012.00007

Hales, C. M., Fryar, C. D., Carroll, M. D., Freedman, D. S., & Ogden, C. L. (2018). Trends in Obesity and Severe Obesity Prevalence in US Youth and Adults by Sex and Age, 2007-2008 to 2015-2016. *JAMA, 319*(16), 1723-1725. doi: 10.1001/jama.2018.3060

Hanlon EC, Van Cauter, E. Quantification of sleep behavior and of its impact on the cross-talk between the brain and peripheral metabolism. PNAS 2011; 108: 15609-15616

Health, US Department of, & Services, Human. (2018). 2018 Physical activity guidelines advisory committee scientific report.

Hedley, A. A., Ogden, C. L., Johnson, C. L., Carroll, M. D., Curtin, L. R., & Flegal, K. M. (2004). Prevalence of overweight and obesity among US children, adolescents, and adults, 1999-2002. *JAMA, 291*(23), 2847-2850. doi: 10.1001/jama.291.23.2847

Hirshkowitz, M., Whiton, K., Albert, S. M., Alessi, C., Bruni, O., DonCarlos, L., . . . Ware, J. C. (2015). National Sleep Foundation's updated sleep duration recommendations: final report. *Sleep Health, 1*(4), 233-243. doi: 10.1016/j.sleh.2015.10.004

Hirshkowitz, Max, Whiton, Kaitlyn, Albert, Steven M, Alessi, Cathy, Bruni, Oliviero, DonCarlos, Lydia, . . . Kheirandish-Gozal, Leila. (2015). National Sleep Foundation’s sleep time duration recommendations: methodology and results summary. *Sleep health, 1*(1), 40-43.

Hoos, M. B., Gerver, W. J., Kester, A. D., & Westerterp, K. R. (2003). Physical activity levels in children and adolescents. *Int J Obes Relat Metab Disord, 27*(5), 605-609. doi: 10.1038/sj.ijo.0802246

Janz, K. F., Levy, S. M., Burns, T. L., Torner, J. C., Willing, M. C., & Warren, J. J. (2002). Fatness, physical activity, and television viewing in children during the adiposity rebound period: the Iowa Bone Development Study. *Prev Med, 35*(6), 563-571. doi: 10.1006/pmed.2002.1113

Jarrin, D. C., McGrath, J. J., Poirier, P., & Quality Cohort Collaborative, Group. (2015). Autonomic dysfunction: a possible pathophysiological pathway underlying the association between sleep and obesity in children at-risk for obesity. *J Youth Adolesc, 44*(2), 285-297. doi: 10.1007/s10964-014-0235-3

Jarrin, D. C., McGrath, J. J., Poirier, P., Seguin, L., Tremblay, R. E., Montplaisir, J. Y., . . . Seguin, J. R. (2015). Short-term heart rate variability in a population-based sample of 10-year-old children. *Pediatr Cardiol, 36*(1), 41-48. doi: 10.1007/s00246-014-0962-y

Jennnings JR, Muldoon MF, Hall M, Buysse DJ, Manuck SB. Self-reported sleep quality I associated with the metabolic syndrome. Sleep 2007; 30: 219-223

Kann, Laura, McManus, Tim, Harris, William A, Shanklin, Shari L, Flint, Katherine H, Hawkins, Joseph, . . . Chyen, David. (2016). Youth risk behavior surveillance—United States, 2015. *Morbidity and Mortality Weekly Report: Surveillance Summaries, 65*(6), 1-174.

Keyes, K. M., Maslowsky, J., Hamilton, A., & Schulenberg, J. (2015). The great sleep recession: changes in sleep duration among US adolescents, 1991-2012. *Pediatrics, 135*(3), 460-468. doi: 10.1542/peds.2014-2707

Liu, X., Forbes, E. E., Ryan, N. D., Rofey, D., Hannon, T. S., & Dahl, R. E. (2008). Rapid eye movement sleep in relation to overweight in children and adolescents. *Arch Gen Psychiatry, 65*(8), 924-932. doi: 10.1001/archpsyc.65.8.924

Lohman, T. G., Ring, K., Schmitz, K. H., Treuth, M. S., Loftin, M., Yang, S., . . . Going, S. (2006). Associations of body size and composition with physical activity in adolescent girls. *Med Sci Sports Exerc, 38*(6), 1175-1181. doi: 10.1249/01.mss.0000222846.27380.61

Lucassen, E. A., Zhao, X., Rother, K. I., Mattingly, M. S., Courville, A. B., de Jonge, L., . . . Sleep Extension Study, Group. (2013). Evening chronotype is associated with changes in eating behavior, more sleep apnea, and increased stress hormones in short sleeping obese individuals. *PLoS One, 8*(3), e56519. doi: 10.1371/journal.pone.0056519

Lumeng, J. C., Somashekar, D., Appugliese, D., Kaciroti, N., Corwyn, R. F., & Bradley, R. H. (2007). Shorter sleep duration is associated with increased risk for being overweight at ages 9 to 12 years. *Pediatrics, 120*(5), 1020-1029. doi: 10.1542/peds.2006-3295

Meldrum, R. C., & Restivo, E. (2014). The behavioral and health consequences of sleep deprivation among U.S. high school students: relative deprivation matters. *Prev Med, 63*, 24-28. doi: 10.1016/j.ypmed.2014.03.006

Mendelson, M., Borowik, A., Michallet, A. S., Perrin, C., Monneret, D., Faure, P., . . . Flore, P. (2016). Sleep quality, sleep duration and physical activity in obese adolescents: effects of exercise training. *Pediatr Obes, 11*(1), 26-32. doi: 10.1111/ijpo.12015

Mishra, A., & Colgin, L. L. (2019). The High Energy Cost of Theta-Gamma Activity during REM Sleep. *Trends Neurosci, 42*(4), 239-241. doi: 10.1016/j.tins.2019.02.004

Mitchell, J. A., Rodriguez, D., Schmitz, K. H., & Audrain-McGovern, J. (2013). Sleep duration and adolescent obesity. *Pediatrics, 131*(5), e1428-1434. doi: 10.1542/peds.2012-2368

Moser, D., Anderer, P., Gruber, G., Parapatics, S., Loretz, E., Boeck, M., . . . Dorffner, G. (2009). Sleep classification according to AASM and Rechtschaffen & Kales: effects on sleep scoring parameters. *Sleep, 32*(2), 139-149. doi: 10.1093/sleep/32.2.139

Narcisse, M. R., Long, C. R., Felix, H. C., Howie, E. K., Purvis, R. S., & McElfish, P. A. (2019). Adherence to sleep guidelines reduces risk of overweight/obesity in addition to 8-5-2-1-0 guidelines among a large sample of adolescents in the United States. *Sleep Health, 5*(5), 444-451. doi: 10.1016/j.sleh.2019.03.004

Ng, M., Fleming, T., Robinson, M., Thomson, B., Graetz, N., Margono, C., . . . Gakidou, E. (2014). Global, regional, and national prevalence of overweight and obesity in children and adults during 1980-2013: a systematic analysis for the Global Burden of Disease Study 2013. *Lancet, 384*(9945), 766-781. doi: 10.1016/S0140-6736(14)60460-8

Nixon, G. M., Thompson, J. M., Han, D. Y., Becroft, D. M., Clark, P. M., Robinson, E., . . . Mitchell, E. A. (2008). Short sleep duration in middle childhood: risk factors and consequences. *Sleep, 31*(1), 71-78. doi: 10.1093/sleep/31.1.71

O'Dea, J. A., Dibley, M. J., & Rankin, N. M. (2012). Low sleep and low socioeconomic status predict high body mass index: a 4-year longitudinal study of Australian schoolchildren. *Pediatr Obes, 7*(4), 295-303. doi: 10.1111/j.2047-6310.2012.00054.x

Ogden, C. L., Carroll, M. D., Lawman, H. G., Fryar, C. D., Kruszon-Moran, D., Kit, B. K., & Flegal, K. M. (2016). Trends in Obesity Prevalence Among Children and Adolescents in the United States, 1988-1994 Through 2013-2014. *JAMA, 315*(21), 2292-2299. doi: 10.1001/jama.2016.6361

Ohayon, M., Wickwire, E. M., Hirshkowitz, M., Albert, S. M., Avidan, A., Daly, F. J., . . . Vitiello, M. V. (2017). National Sleep Foundation's sleep quality recommendations: first report. *Sleep Health, 3*(1), 6-19. doi: 10.1016/j.sleh.2016.11.006

Owens, J., Adolescent Sleep Working, Group, & Committee on, Adolescence. (2014). Insufficient sleep in adolescents and young adults: an update on causes and consequences. *Pediatrics, 134*(3), e921-932. doi: 10.1542/peds.2014-1696

Patel, S. R., & Hu, F. B. (2008). Short sleep duration and weight gain: a systematic review. *Obesity (Silver Spring), 16*(3), 643-653. doi: 10.1038/oby.2007.118

Porkka-Heiskanen, T., Zitting, K. M., & Wigren, H. K. (2013). Sleep, its regulation and possible mechanisms of sleep disturbances. *Acta Physiol (Oxf), 208*(4), 311-328. doi: 10.1111/apha.12134

Randler, Christoph, Haun, Julia, & Schaal, Steffen. (2013). Assessing the influence of sleep-wake variables on body mass index (BMI) in adolescents. *Europe's Journal of Psychology, 9*(2), 339-347.

Rodríguez-Colón, Sol M, He, Fan, Shaffer, Michele L, Li, Xian, Vgontzas, Alexandros N, Bixler, Edward O, . . . Liao, Duanping. (2011). Insomnia symptoms and sleep duration are associated with impaired cardiac autonomic modulation in children. *Neurosci Med, 2*(3), 288-294.

Roenneberg, T., Allebrandt, K. V., Merrow, M., & Vetter, C. (2012). Social jetlag and obesity. *Curr Biol, 22*(10), 939-943. doi: 10.1016/j.cub.2012.03.038

Saidi, O, Rochette, E, Bovet, M, Merlin, E, Duché, P. Acute intense exercise improves sleep and decreases next morning consumption of energy-dense food in adolescent girls with obesity and evening chronotype. *Pediatric Obesity*. 2020; 15:e12613. https://doi.org/10.1111/ijpo.12613

Slater, S. J., Ewing, R., Powell, L. M., Chaloupka, F. J., Johnston, L. D., & O'Malley, P. M. (2010). The association between community physical activity settings and youth physical activity, obesity, and body mass index. *J Adolesc Health, 47*(5), 496-503. doi: 10.1016/j.jadohealth.2010.03.017

Smaldone, A., Honig, J. C., & Byrne, M. W. (2007). Sleepless in America: inadequate sleep and relationships to health and well-being of our nation's children. *Pediatrics, 119 Suppl 1*, S29-37. doi: 10.1542/peds.2006-2089F

Snell, E. K., Adam, E. K., & Duncan, G. J. (2007). Sleep and the body mass index and overweight status of children and adolescents. *Child Dev, 78*(1), 309-323. doi: 10.1111/j.1467-8624.2007.00999.x

Spiegel, Karine, Leproult, Rachel, L'Hermite-Balériaux, Mireille, Copinschi, Georges, Penev, Plamen D., & Van Cauter, Eve. (2004). Leptin Levels Are Dependent on Sleep Duration: Relationships with Sympathovagal Balance, Carbohydrate Regulation, Cortisol, and Thyrotropin. *The Journal of Clinical Endocrinology & Metabolism, 89*(11), 5762-5771. doi: 10.1210/jc.2004-1003

Spiegel, Karine, Tasali, Esra, Penev, Plamen, & Cauter, Eve Van. (2004). Brief Communication: Sleep Curtailment in Healthy Young Men Is Associated with Decreased Leptin Levels, Elevated Ghrelin Levels, and Increased Hunger and Appetite. *Annals of Internal Medicine, 141*(11), 846-850. doi: 10.7326/0003-4819-141-11-200412070-00008

Stamatakis KA, Punjabi NM, Effects of sleep fragmentation on glucose metabolism in normal subjects. Chest 2010; 137: 95-101

Strong, W. B., Malina, R. M., Blimkie, C. J., Daniels, S. R., Dishman, R. K., Gutin, B., . . . Trudeau, F. (2005). Evidence based physical activity for school-age youth. *J Pediatr, 146*(6), 732-737. doi: 10.1016/j.jpeds.2005.01.055

Suglia, S. F., Kara, S., & Robinson, W. R. (2014). Sleep duration and obesity among adolescents transitioning to adulthood: do results differ by sex? *J Pediatr, 165*(4), 750-754. doi: 10.1016/j.jpeds.2014.06.052

Tasali, E., Leproult, R., Ehrmann, D. A., & Van Cauter, E. (2008). Slow-wave sleep and the risk of type 2 diabetes in humans. *Proc Natl Acad Sci U S A, 105*(3), 1044-1049. doi:10.1073/pnas.0706446105

Wolfson, A. R., & Carskadon, M. A. (2003). Understanding adolescents' sleep patterns and school performance: a critical appraisal. *Sleep Med Rev, 7*(6), 491-506. doi: 10.1016/s1087-0792(03)90003-7

Zhang, K., Sun, M., Werner, P., Kovera, A. J., Albu, J., Pi-Sunyer, F. X., & Boozer, C. N. (2002). Sleeping metabolic rate in relation to body mass index and body composition. *Int J Obes Relat Metab Disord, 26*(3), 376-383. doi: 10.1038/sj.ijo.0801922