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The Influence of Sleep Duration and Sleep Efficiency on Abdominal Adiposity and Blood Pressure in Adolescents Ages 16 to 18 Who Participated in the Cleveland Children's Sleep and Health Study: A Secondary Data Analysis

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THE INFLUENCE OF SLEEP DURATION AND SLEEP EFFICIENCY ON ABDOMINAL ADIPOSITY AND BLOOD PRESSURE IN ADOLESCENTS AGES 16 TO 18 WHO PARTICIPATED IN THE CLEVELAND CHILDREN'S SLEEP AND HEALTH STUDY: A SECONDARY DATA ANALYSIS

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THE INFLUENCE OF SLEEP DURATION AND SLEEP EFFICIENCY ON ABDOMINAL ADIPOSITY AND BLOOD PRESSURE IN ADOLESCENTS AGES 16-18 WHO PARTICIPATED IN THE CLEVELAND CHILDREN'S SLEEP AND HEALTH STUDY: A SECONDARY DATA ANALYSIS

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NURSING

ABSTRACT

Introduction: Abdominal adiposity and blood pressure (BP) are two major modifiable risk factors for cardiovascular disease (CVD), the leading cause of death in the world. The impact of abdominal adiposity and BP on health, particularly CVD, begins in childhood. Older adolescents tend to have the highest prevalence of abdominal adiposity and BP in the pediatric population. Despite interventions like diet and exercise, the prevalence of excess abdominal adiposity and elevated BP continues to increase during late adolescence. Evidence suggests that sleep duration and sleep efficiency impact abdominal adiposity and BP in adults and the pediatric population, but limited studies have focused on these relationships during late adolescence. Therefore, the purpose of this study is to determine if sleep duration and sleep efficiency influence abdominal adiposity and BP during late adolescence.

Methods: A secondary data analysis was conducted on data extracted from the third cohort of the Cleveland Children's Sleep and Health Study (CCSHS). Actigraphy data (objective sleep duration, sleep efficiency), subjective sleep duration data from sleep diaries, waist circumference (WC) percentiles, WC and height (used to calculate waist-to-height ratio [WHtR]), BP, BMI percentiles, age, race, ethnicity, and assigned sex were extracted for analysis.

Results: Two hundred and ninety-seven adolescents ages 16.1 – 18.9 (mean 17.7±0.4) were included in this study. The majority of the participants were female (55.6%), White (63.3%), non-Hispanic (96.0%), and normal weight (67.7%). The participants on average had inadequate objective sleep duration, adequate subjective sleep duration, normotensive systolic and diastolic BP, and did not have excess abdominal adiposity. Sleep efficiency had a negative relationship with WHtR and SBP. However, these relationships did not persist after controlling for BMI percentiles, race, and assigned sex.

Conclusions: In this sample, there were no relationships between sleep duration and sleep efficiency and abdominal adiposity and BP. Future research should examine the differences between objective and subjective sleep duration in late adolescents and differences based on BMI percentiles, race, and assigned sex. There is also a need for research exploring whether other sleep health variables beyond duration and efficiency (e.g., satisfaction, sleepiness, timing, behaviors) have a relationship with abdominal adiposity or blood pressure.

Keywords: sleep duration, sleep efficiency, abdominal adiposity, blood pressure, adolescents, late adolescence

DEDICATION

To all the children from small, rural, and underserved towns, especially those from my hometown of Georgiana, Alabama, and the Black girls who feel like they do not belong. You are valuable. You can do anything using your mind, innate talent, and imagination.

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LIST OF ABBREVIATIONS

AASM	American Academy of Sleep Medicine
BMI	body mass index
BP	blood pressure
CCSHS	Cleveland Children's Sleep and Health Study
CDC	Centers for Disease Control and Prevention
CVD	cardiovascular disease
DBP	diastolic blood pressure
HPA	hypothalamic-pituitary-adrenal
HTN	hypertension
NSF	National Sleep Foundation
NSRR	National Sleep Research Resource
PSG	polysomnography
SBP	systolic blood pressure
U.S.	United States

WC	waist circumference
WHtR	waist-to-height ratio

CHAPTER 1

INTRODUCTION

Abdominal adiposity, fat mass located in the abdominal region, and blood pressure (BP), the amount of pressure blood exerts on the body's vasculature, are two of the most important modifiable risk factors for cardiovascular disease (CVD). The leading cause of death around the world, CVD includes coronary heart disease (CHD), heart failure, hypertension (HTN), and stroke (Virani et al., 2021; World Health Organization [WHO], 2020). Along with mortality, CVD has a high economic burden; in the United States, the direct cost of stroke alone was $36.7 billion in 2015 and is projected to increase to $94.3 billion by 2035 (Virani et al., 2021). Unfortunately, the impact of abdominal adiposity and BP on health begins in childhood (Antonakoudis et al., 2007; Virani et al., 2021; Wu et al., 2021).

It is during childhood that the number of adipocytes, or fat cells that determine abdominal adiposity, is set (Walker et al., 2014). This means that if a child has excess abdominal adiposity in childhood, their chances for excess abdominal adiposity in adulthood, regardless of adult weight loss, are increased (Walker et al., 2014). Furthermore, elevated BP in childhood is associated with organ damage and subclinical atherosclerosis, a beginning sign and risk for CVD (Freedman et al., 1999; Riley & Bluhm, 2012. This is concerning since the prevalence of excess abdominal adiposity and elevated BP continues to increase in the pediatric population and has been associated with increased risk for CVD and other leading causes of death like type 2 diabetes and cancer (Jackson et al., 2018; Virani et al., 2021; Xi et al., 2014). It is estimated that 36.5% of males and 44% of females ages 2 to 19 have excess abdominal adiposity (waist-to-height ratio [WHtR] greater than 0.5) (Wang et al., 2020). Also, 1.3 million children ages 12 to 19 have HTN (BP greater than the 90th percentile for age and gender or 130/89) (Centers for Disease Control and Prevention [CDC], 2021c; Flynn et al., 2017).

Most research on the impact of abdominal adiposity on health tends to focus on how excess abdominal adiposity (i.e., waist circumference [WC] greater than the 70th percentile in children, WHtR greater than 0.5 across the lifespan) increases the risk for CVD and other cardiometabolic diseases (Xi et al., 2014). The same is true for BP, since elevated BP (i.e., 120/<80 to 129/<80 mmHg) and HTN (stage 1: 130/80 to 139/89 mmHG, stage 2: greater or equal to 140/90mm Hg) are often associated with increased CVD risk (Virani et al., 2021). However, although excess abdominal adiposity and elevated BP can increase health risks, some evidence suggests that normal abdominal adiposity (WHtR below 0.5) and normotensive BP (below 120/80) can be protective or help mitigate increased health risks in adults (Després et al., 2008; Kshirsagar et al., 2006; Porter et al., 2009).

While developmental changes in childhood affect body systems differently depending on age, many investigators tend to cluster several developmental stages into one group (Campbell et al., 2012; May et al., 2012; Reinehr & Toschke, 2009). However, it is important to explore these factors in individual developmental stages because the impact of abdominal adiposity and BP on health or future health tends to increase with age (Virani et al., 2021). Adolescents (ages 12–18) are at an age where CVD risk, like excess abdominal adiposity and elevated BP, increases (Aatola et al., 2017). Since abdominal adiposity increases with age, late adolescence (ages 16–18) potentially has the highest prevalence of excess abdominal adiposity (Solanki et al., 2020). Evidence suggests that adolescents with elevated BP can develop HTN within a 2-year period (Falkner, 2010). Additionally, adolescents with increasing independence from parents often develop lifelong habits that impact abdominal adiposity and BP, like poor diet quality, increased sedentary behaviors, poor sleep habits, and lack of physical activity (Ewald & Haldeman, 2016; Xi et al., 2014). Many factors that impact abdominal adiposity and BP are based on stress, or on actual or expected external or internal stimuli that lead to physiological, psychological, and behavioral responses typically associated with a need to act or pay attention (Fink, 2016; Karatsoreos & McEwen, 2011; Schuler, 1980; Schulkin et al., 1994). Adolescents can have a heightened stress response to exogenous stressors (National Academies of Sciences, Engineering, and Medicine, 2019). However, interventions during adolescence can potentially help mediate the impact of stressors that influence abdominal adiposity and BP (National Academies of Sciences, Engineering, and Medicine, 2019). Furthermore, it is during late adolescence that providers get their last chances to address health behaviors before adulthood (Alderman et al., 2019; WHO, 2010). Therefore, there is a need to identify modifiable behavior-related factors that impact abdominal adiposity and BP in late adolescence.

Most research on factors that influence abdominal adiposity and BP tends to focus on diet and exercise (Falkner & Lurbe, 2020; Oude Luttikhuis et al., 2019). Despite interventions including diet and exercise, the prevalence of excess abdominal adiposity and elevated BP continues to increase (Virani et al., 2021). Therefore, there is a need to look at other factors associated with abdominal adiposity and BP, especially in late adolescence.

In adults, it is known that factors such as sleep duration (the amount of time one sleeps after bedtime) and sleep efficiency (the ratio of time asleep compared to the time in bed) can have a deleterious or protective influence on abdominal adiposity and BP (Chaput, Bouchard, et al., 2014; McGrath et al., 2017; Stock et al., 2017). Also, a recent report on the prevention of high BP in childhood notes that sleep is an often overlooked behavior-related factor that impacts BP (Falkner & Lurbe, 2020). Furthermore, inadequate sleep duration and poor sleep efficiency are frequently seen in childhood, especially in adolescents (Koren et al., 2016). However, there is limited research on the effect of sleep duration and sleep efficiency on abdominal adiposity and BP in adolescents, especially during late adolescence.

Influences of Sleep Duration and Sleep Efficiency on Abdominal Adiposity and Blood Pressure

Sleep duration and sleep efficiency are behavioral and physiological factors that impact the function of all body systems (Agostini & Centofanti, 2021). As stressors, alterations in sleep duration and sleep efficiency influence the body's hypothalamic-pituitary-adrenal axis (HPA axis) and autonomic nervous system (sympathetic and parasympathetic) (Castro-Diehl et al., 2015, 2016; Karatsoreos & McEwen, 2011; Makarem et al., 2019; McEwen, 1998b; Spiegel et al., 1999). These systems regulate appetite, energy expenditure, inflammatory markers, BP, and insulin (Sherwood et al., 2002, 2011; Spiegel et al.,1999, 2004), all of which impact abdominal adiposity and/or

BP (Drapeau et al., 2003; Edwards et al., 2011; Makarem et al., 2019; McEwen, 1998b; Spiegel et al., 1999). These responses by the HPA axis and the autonomic nervous system link poor sleep duration and sleep efficiency to an increased risk for hypertension, obesity, CVD, and type 2 diabetes across the lifespan (Cespedes Feliciano et al., 2018; McEwen, 1998b; Virani et al., 2021).

In the U.S., in 2015, on average, 72.7% of high school students (9^{th}–12^{th} grade, typically ages 14–18) nationwide reported inadequate sleep duration at night (less than 8 hours) (Wheaton et al., 2018). Also, the number of high school adolescents experiencing sufficient sleep duration continues to decrease with age, with the highest prevalence of inadequate sleep duration being in 12^{th} graders (77.6%) (Wheaton et al., 2018). However, these findings are based on subjective, or self- or parent-reported, perceptions of sleep, versus objective observations, collected in this case from polysomnography (PSG), the gold standard for measuring sleep duration. Unfortunately, subjective sleep duration is often overestimated, meaning that the prevalence of inadequate sleep duration may be higher (Lauderdale et al., 2008; Quist et al., 2016). Yet, over the last 100 years, sleep duration has decreased by 1 hour on average for all children and adolescents (based on samples from across the world including the U.S., Canada, and Asia), supporting the CDC's decision to consider inadequate sleep duration an endemic issue (Koren et al., 2016; Matricciani et al., 2012).

Along with sleep duration, sleep efficiency is an important component of sleep to consider. However, the prevalence of poor sleep efficiency is not well known (Javaheri et al., 2008). Javaheri and colleagues (2008) estimated that 26% of children have poor sleep efficiency, although they felt this may be underestimated since they excluded children with comorbidities and sleep disorders. Likewise, Albqoor and Shaheen (2021), focusing on young adults in college, reported that 27% of participants had poor sleep efficiency. The reasons for poor sleep efficiency and inadequate sleep duration may be due, in part, to adolescents' tendency to have more academic requirements, increased chances for extracurricular activities, and higher chances of working for pay (Carskadon et al., 1998).

While most studies that investigate pediatric sleep tend to focus on inadequate sleep duration or poor sleep efficiency, some evidence suggests that having adequate sleep duration and sleep efficiency can be protective (Cespedes Feliciano et al., 2018; Chaput, Leduc, et al., 2014). Also, evidence suggests that excessive sleep duration, greater than the recommended range of sleep duration (sleep efficiency does not have a maximum), is associated with excess abdominal adiposity and elevated BP in adults (Hairston et al., 2010). Therefore, there is also a need to explore how the continuum of sleep duration and sleep efficiency impact abdominal adiposity and BP in late adolescence.

Sleep Duration, Abdominal Adiposity, and Blood Pressure

In the younger pediatric population and adults, sleep duration is associated with abdominal adiposity and BP, but there is limited research in late adolescence (Chaput & Dutil, 2016; Guo et al., 2013; Mezick et al., 2014; Ogilvie et al., 2016; Quist et al., 2016; Thosar et al., 2021). Based on guidelines from The National Sleep Foundation (NSF) and The American Academy of Sleep Medicine (AASM), adolescents' sleep duration should be 8 to 10 hours of sleep per night (Hirshkowitz et al., 2015; Paruthi et al., 2016). These same panels of experts considered inadequate sleep duration in adolescents as less than 8 hours and greater than 10 hours of sleep as excessive sleep duration. More emphasis is placed on inadequate sleep duration, but excessive sleep duration can also be problematic (Ohayon et al., 2013). Evidence suggests that excessive sleep duration can also have a negative impact on abdominal adiposity (Hairston et al., 2010; Padez et al., 2009) and BP (Gottlieb et al., 2006; Guo et al., 2013; Jike et al., 2018).

Sleep Efficiency, Abdominal Adiposity, and Blood Pressure

The National Sleep Foundation defines sleep efficiency equal to or greater than 85% (example in bed for 10 hours and sleeping for 8.5 hours) as adequate, while anything less than 85% (in bed for 8 hours and sleeping for 6 hours) is poor sleep efficiency (Ohayon et al., 2017). Despite evidence suggesting that sleep efficiency is important for physical health, mental health, and overall wellness, there is limited research on the impact of sleep efficiency on abdominal adiposity and BP in adolescents (Cespedes Feliciano et al., 2018; Ogilvie et al., 2016). Evidence suggests that sleep efficiency has an influence on abdominal adiposity and BP in young adolescents (10–14 years of age), but there is a lack of research in late adolescence (Au et al., 2014; Cespedes Feliciano et al., 2018; Javaheri et al., 2008). Furthermore, in adults, poor sleep efficiency is associated with excess abdominal adiposity and BP (Hirata et al., 2019; Mezick et al., 2014; Ogilvie et al., 2016).

Study Control Variables

Age, race, ethnicity, assigned sex, and body mass index (BMI) percentiles have been associated with sleep duration, sleep efficiency, abdominal adiposity, and BP across the lifespan. Much of the work has been done in children, young adolescents, and adults, but evidence suggests that these variables must be considered for older adolescents as well.

Age

As children age, they experience hormonal shifts and changes in behavior (e.g., diet changes, physical activity changes) that impact their sleep duration, sleep efficiency, abdominal adiposity, and BP (Campbell et al., 2012; Reinehr & Toschke, 2009). Sleep duration and sleep efficiency change as children age, especially in adolescents who consistently decline in sleep duration as they get older (Basch et al., 2014; McLaughlin Crabtree & Williams, 2009). These changes are notable when looking at the increasing prevalence of inadequate sleep duration in high school adolescents, with the highest prevalence in Grade 12 (Basch et al., 2014; Wheaton et al., 2016). Age also significantly affects abdominal adiposity and BP across the lifespan; both increase with age (Muntner et al., 2004; Wells et al., 2008).

Race/Ethnicity

In addition to age, race and ethnicity have also been shown to influence not only abdominal adiposity and BP but also sleep duration and sleep efficiency. Race is a social construct that groups people, often based on cultural backgrounds, physical appearance, or social factors (National Human Genome Research Institute, 2022). Ethnicity is typically collected along with race, and it is a way of grouping people based on cultural heritage (National Library of Medicine, 2022). In the U.S., there tends to be a higher prevalence of excess abdominal adiposity, inadequate sleep duration, poor sleep efficiency, and elevated BP in Black and Hispanic populations than in others across the lifespan (Guglielmo et al., 2018; Jean-Louis et al., 2015; Rao, 2016; Schiller et al., 2012; Stamatakis et al., 2007; Virani et al., 2021). In adults, White males and females have a higher prevalence of visceral abdominal adiposity than Black males and females, who tend to have more subcutaneous abdominal adiposity (Katzmarzyk et al., 2010). In addition, White adolescents tend to have stronger relationships between inadequate sleep duration, poor sleep efficiency, and elevated BP than Black adolescents (Mezick et al., 2012).

Assigned Sex

Assigned sex, along with race/ethnicity and age, has also been noted to impact sleep duration, sleep efficiency, abdominal adiposity, and BP. Assigned sex, commonly referred to as sex and previously as gender, is assigned to infants at birth based on their visible sex organs (genitalia and other physical characteristics) (National Institute of Health Office of Equity, Diversity, and Inclusion, n.d.). Global studies have shown that males tend to have a greater prevalence of inadequate sleep duration than females across the lifespan (Chaput & Dutil, 2016; El-Sheikh & Sadeh, 2015; Knutson, 2005; Sekine et al., 2002). Also, males tend to perceive that their sleep duration is longer than what is objectively measured (Short et al., 2012). Further, male adolescents tend to have poorer sleep efficiency compared to females as determined by actigraphy (Sadeh et al., 2009; Short et al., 2012). There are also sex differences in BP and abdominal adiposity. Females tend to have a higher prevalence of elevated BP and excess overall adiposity (Virani et al., 2021). Males, on the other hand, have more abdominal adiposity (Stevens et al., 2010).

BMI Percentile

In the pediatric population, BMI percentiles are the standard for determining weight status or the categorical label of one's overall adiposity (CDC, 2021a). BMI percentiles below the 5^{th} percentile are considered underweight, normal weight is above the 5^{th} but below the 85^{th} percentile, BMI percentiles equal to or greater than the 85^{th} percentile are considered overweight, and those equal to or over the 95^{th} percentile are considered obese (CDC, 2021a). BMI percentiles have been associated with sleep duration, sleep efficiency, abdominal adiposity, and BP (Grandner, 2017; Gundogdu, 2008; Quist et al., 2016; Virani et al., 2021). Children who are overweight or obese have a higher risk for elevated BP and excess abdominal adiposity and frequently have elevated BP and excess abdominal adiposity as comorbidities (Virani et al., 2021). Also, a person who is overweight or obese has a higher risk for inadequate sleep duration and poor sleep efficiency (Bagley & El-Sheikh, 2013; Bawazeer et al., 2009; Lumeng et al., 2007).

Purpose

Evidence suggests that inadequate sleep duration, excessive sleep duration, and poor sleep efficiency are stressors that activate the HPA axis and sympathetic nervous system and can affect abdominal adiposity and BP. Despite this knowledge, there has been limited research exploring the relationships among sleep duration, sleep efficiency, abdominal adiposity, and BP during late adolescence. Therefore, the purpose of this cross-sectional, secondary data analysis is to describe the relationships among sleep duration, sleep efficiency, abdominal adiposity, and BP in adolescents ages 16 to 18 who participated in the Cleveland Children's Sleep and Health Study (CCSHS) while controlling for age, race, ethnicity, assigned sex, and BMI percentiles. The CCSHS was a longitudinal cohort study examining the impact of sleep disturbances on health outcomes and pediatric sleep disorders.

Significance of the Study

Excess abdominal adiposity and elevated BP in the pediatric population continue to rise in the U.S. (Arteaga et al., 2018; CDC, 2021b; Virani et al., 2021). Evidence suggests elevations in abdominal adiposity and BP follow a child into adulthood, which can increase their risk for several leading causes of death in the U.S. such as CVD, type 2 diabetes, and cancer (Arteaga et al., 2018; CDC, 2021b; Cespedes Feliciano et al., 2018; Reilly & Kelly, 2011; Virani et al., 2021). Additionally, these increases in abdominal adiposity and BP are linked to substantial and increasing health care costs in both children and adults (Gilmer et al., 2014; Virani et al., 2021). Understanding the influence of sleep duration and sleep efficiency on abdominal adiposity and BP during late adolescence can inform interventions aimed at preventing disease or promoting health. Also, with the increasing prevalence of children and adults with sleep problems and associated health care costs in the U.S., there is a need to develop interventions to address the prevalence of inadequate sleep duration, poor sleep efficiency, and related health issues like excess adiposity and elevated BP (Ferrie et al., 2011). This research will explore the relationships among these variables, potentially informing efforts to prevent excess abdominal adiposity and elevated BP in adolescence and to improve sleep duration and sleep efficiency. Furthermore, this research will provide some insight on how to help address the following Healthy People 2030 objectives: EMC-03 – to increase the proportion of children who get sufficient sleep; SH-04 – to increase the proportion of high school students who get enough sleep; and NWS-04 – to reduce the proportion of children and adolescents with obesity (Office of Disease Prevention and Health Promotion, 2021).

Research Aims and Questions

Aim 1: Describe sleep duration and sleep efficiency in adolescents ages 16 to 18 years who participated in the Cleveland Children's Sleep and Health Study (CCSHS).

1. What is the mean, standard deviation, median, and range of subjective sleep duration, objective sleep duration, and sleep efficiency of adolescents ages 16 to 18 years who participated in the CCSHS?

2. What categories of objective and subjective sleep duration (adequate, inadequate, and excessive) and sleep efficiency (good and poor) are present in adolescents ages 16 to 18 years who participated in the CCSHS?

Aim 2: Describe abdominal adiposity and blood pressure in adolescents ages 16 to 18 years who participated in the CCSHS.

1. What is the mean, standard deviation, median, and range of waist circumference (WC) percentile in adolescents ages 16 to 18 years who participated in the CCSHS?
2. What is the mean, standard deviation, median, and range of waist-to-height ratio (WHtR) in adolescents ages 16 to 18 years who participated in the CCSHS?
3. What categories of abdominal adiposity (not excess or excess), measured by WC percentiles and WHtR, are present in adolescents ages 16 to 18 years who participated in CCSHS?
4. What is the mean, standard deviation, median, and range of systolic BP (SBP) and diastolic BP (DBP) of adolescents ages 16 to 18 years who participated in the CCSHS?
5. What categories of SBP and DBP (i.e., normotensive, elevated BP, stage 1 hypertension, stage 2 hypertension) are evident in adolescents ages 16 to 18 years who participated in the CCSHS?

Aim 3: Determine the influence of objective and subjective sleep duration and sleep efficiency on abdominal adiposity and BP in adolescents ages 16 to 18 years who participated in the CCSHS, controlling for age, race, ethnicity, assigned sex, and BMI percentiles.

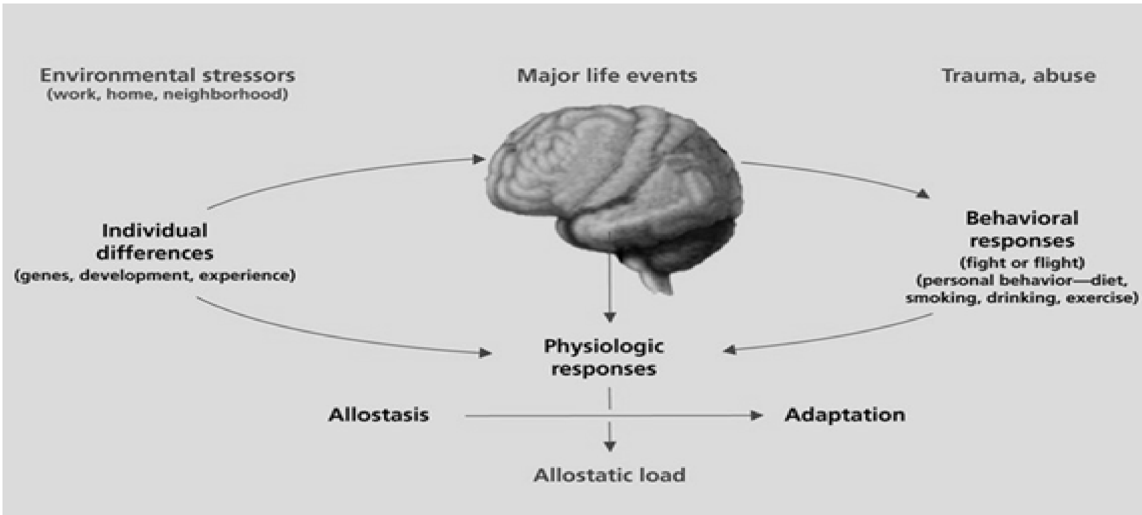
1. What is the influence of objective sleep duration, subjective sleep duration, and sleep efficiency on abdominal adiposity in adolescents ages 16 to 18 years who participated in the CCSHS, controlling for age, race, ethnicity, assigned sex, and BMI percentiles?
2. What is the influence of objective sleep duration, subjective sleep duration, and sleep efficiency on BP in adolescents ages 16 to 18 years who participated in the CCSHS, controlling for age, race, ethnicity, assigned sex, and BMI percentiles?

Theoretical and Conceptual Framework

McEwen's Theory of Allostatic Load (Figure 1) is the theoretical framework that undergirds this study. Allostatic load is the result of chronic stress on the systems that regulate the brain and body (McEwen, 2005). When unexpected events like natural disasters, pandemics, and other disturbances caused by the environment and society compound pre-existing allostatic load, allostatic overload can result, increasing a person's risk for disease (McEwen, 2005). Examples of allostatic overload are HTN, diabetes, and metabolic syndrome (McEwen, 1998). The Theory of Allostatic Load is based on allostasis, or the ability of the body to remain stable through the regulation of the autonomic nervous, neuroendocrine, and immune systems, including the activation of the HPA axis (McEwen, 2005). Activation of the HPA axis produces allostasis mediators or modulators (depending on what relationships are being examined) like cortisol and leptin, which affect abdominal adiposity and BP (McEwen, 1998b; McEwen, 2005; Sterling and Eyer, 1988). Furthermore, most of these mediators or modulators of allostasis have activity during the sleep-wake cycle, meaning that changes in the sleep-wake cycle impact their ability to function in the proper capacity (Karatsoreos & McEwen, 2011).

Figure 1

McEwen's Theory of Allostatic Load



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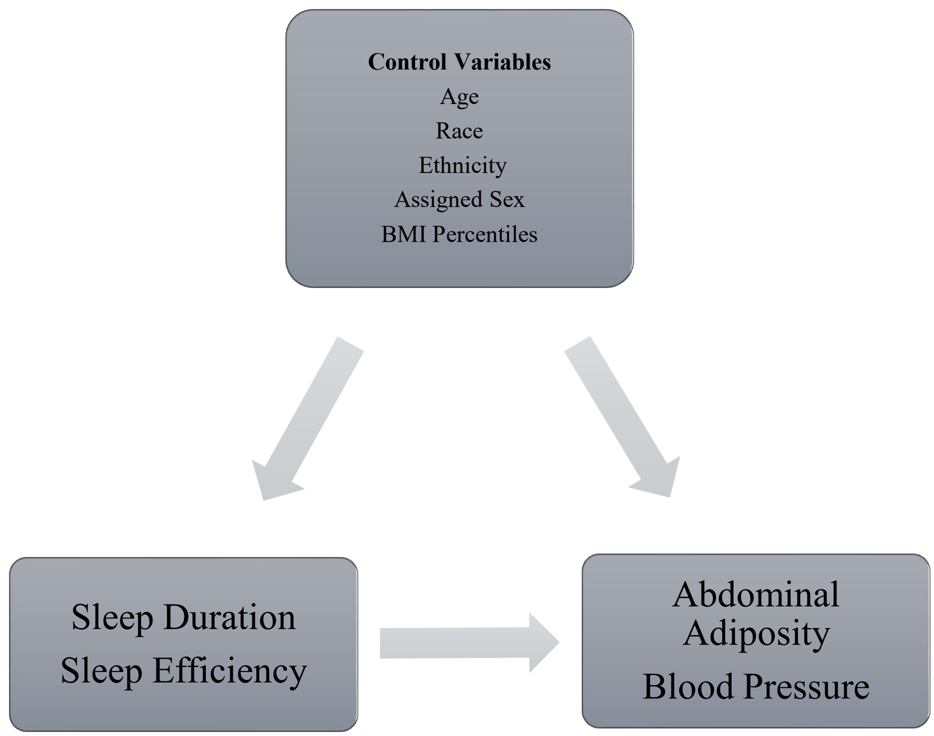
There is no physiological model describing the relationships among sleep duration, sleep efficiency, abdominal adiposity, and BP specifically. Therefore, a model was constructed (Figure 2) based on McEwen's Theory of Allostatic Load. The model is a visual aid created for this study depicting the influence of sleep duration and sleep efficiency on abdominal adiposity and BP. Sleep duration and sleep efficiency are stressors that can impact abdominal adiposity and BP through HPA activation and the autonomic nervous system. Age, race, ethnicity, assigned sex, and BMI percentiles have independent relationships with the independent and dependent variables. Therefore, these variables were controlled during the analyses.

Figure 2

Conceptual Model



Changes in sleep duration and sleep efficiency lead to circadian disruption, which acts as a stressor impacting allostasis (McEwen & Karatsoreos, 2015). A few days of inadequate sleep duration or poor sleep efficiency can lead to allostatic load, which changes appetite (via leptin and ghrelin shifts), calorie intake, energy expenditure, excretion of proinflammatory markers, parasympathetic and sympathetic tone, cortisol, BP, and insulin (Ahmad & Didia, 2020; Magee & Hale, 2012; McEwen, 2005; McEwen & Karatsoreos, 2015; Spiegel et al., 1999, 2004). These alterations can in turn impact abdominal adiposity and BP, which can lead to allostatic overload (seen in the form of obesity, HTN, or CVD) (McEwen, 2005; McEwen & Karatsoreos, 2015). Unfortunately, many humans currently live with a high allostatic load or overload; societal changes have caused many people to have a sleep-wake cycle that is not guided by the presence or absence of sunlight, impacting their overall sleep (Karatsoreos & McEwen, 2011; Lederbogen et al., 2011).

Inadequate and excessive sleep duration can impact abdominal adiposity through the HPA axis and autonomic nervous system (Chaput et al., 2011; Drapeau et al., 2003). Both inadequate sleep duration and excessive sleep duration are stressors that activate the HPA axis, a collection of the central nervous system and peripheral tissues that are known to impact adipose accumulation in the abdominal region as well as the secretion of leptin, the hormone that decreases appetite (Bjorntorp, 2001; Chaput et al., 2011; Drapeau et al., 2003). These sleep stressors can also engage the sympathetic nervous system, which impacts BP (Gangwisch et al., 2006; Lusardi et al., 1995).

Activation of the HPA axis increases cortisol, which is often cleared by glucocorticoid receptors that are predominantly located in abdominal versus peripheral adipose tissue (Drapeau et al., 2003). Therefore, it is suggested that changes in adipose tissue are associated with the amount of cortisol that needs to be cleared; increased cortisol can lead to increased abdominal adipose tissue to excrete the excess cortisol (Drapeau et al., 2003). Evidence suggests that inadequate and excessive sleep duration are associated with a higher presence of cortisol (Chaput et al., 2011). Furthermore, changes in cortisol are directly related to changes in abdominal adiposity across the lifespan (Donoho et al., 2011. This is especially noted in those with Cushing Syndrome, a disease process marked by excess cortisol levels and prominent abdominal adiposity (Chaput et al., 2011).

Both elevated and reduced leptin may explain the relationship between sleep duration and abdominal adiposity. Leptin secretion typically increases after eating to help signal decreased appetite and tends to counteract the impact of cortisol release from HPA axis activation (Drapeau et al., 2003; Spiegel et al., 2004). Therefore, during stressors like inadequate sleep duration, leptin may increase to decrease the stress response. In studies by Omisade and colleagues (2010) and Simpson and colleagues (2010), leptin levels were higher in adults with inadequate sleep. Since leptin secretion is activated by adipose tissue, increasing abdominal adipose tissue could release more leptin to dampen HPA activation to address stressors. One study in adults found elevated leptin and abdominal adiposity in participants with inadequate sleep (Sweatt et al., 2018). These findings could support the association between inadequate sleep duration and abdominal adiposity (Quist et al., 2016).

Leptin levels are generally elevated during sleep. However, changes in sleep duration, either excessive or inadequate, can lead to decreases in leptin, which can lead to higher caloric intake due to inadequate leptin to signal appetite decrease (Taheri et al., 2004). Also, decrease leptin can lead to increases in adipose tissue to excrete more leptin (Spiegel et al., 2004; Taheri et al., 2004). The decrease in leptin can also lead to higher caloric intake due to Further, inadequate sleep duration often leads to fatigue that decreases physical activity, limiting energy expenditure (St-Onge et al., 2016). Therefore, decreased leptin can lead to unbalanced energy intake and expenditure, resulting in increased abdominal adiposity (Taheri et al., 2004). In children, adequate sleep duration was associated with lower leptin levels, decreased food intake, and lower weight, suggesting that adequate sleep duration can potentially be helpful in achieving and maintaining better health (Hart et al., 2013). In young adolescents, evidence suggests that adequate sleep duration is associated with favorable adiposity (Cespedes Feliciano et al., 2018).

Along with the mechanisms undergirding sleep duration and abdominal adiposity, sleep duration can also affect BP. Blood pressure typically decreases during sleep and rises when a person wakes; however, in the presence of inadequate sleep duration, BP tends to be elevated during the night, leading to higher daytime BP (Gangwisch et al., 2006; Kairo et al., 2000). Inadequate sleep duration may act as a stressor that increases sympathetic nervous system activity, a part of the autonomic system, resulting in elevated BP (Gangwisch et al., 2006). Furthermore, stress has been linked to an increased desire for salty foods and reduction in renal salt-fluid, which can lead to elevated BP (Folkow, 2001). Leptin can also impact vasculature and sympathetic tone that regulates BP (Soliman et al., 2012). Excessive sleep duration has also been associated with an increased risk for elevated BP (Guo et al., 2011; Paciencia et al., 2013), which may be explained by the relationship that sleep duration has with leptin, as noted earlier (Omisade et al., 2010; Simpson et al., 2010; Spiegel et al., 2004).

Poor sleep efficiency also impacts the HPA axis and has been associated with increased levels of leptin and cortisol (Raikkonen et al., 2010; Sweatt et al., 2018). Changes in leptin and cortisol lead to changes in abdominal adiposity (Sweatt et al., 2018). Researchers found that in participants with poor sleep efficiency there were higher levels of leptin and greater abdominal adiposity, but not total fat, pointing to sleep efficiency having a specific relationship with abdominal adiposity (Drapeau et al., 2003; Spiegel et al., 2004; Sweatt et al., 2018). In female adolescents, researchers found that an increase in sleep efficiency led to a decrease in leptin in those with low adiposity. Participants with higher adiposity tended to have lower sleep efficiency and higher leptin (Boeke et al., 2013). These findings coincide with the work of Cespedes Feliciano and colleagues (2018), who found that, in young adolescents, poor sleep efficiency was associated with excess abdominal adiposity, and adequate sleep efficiency was associated with more satisfactory abdominal adiposity.

Furthermore, there is a negative relationship between sleep efficiency and measures of the autonomic nervous system, which regulates BP (heart rate, high-frequency variability) (Castro-Diehl et al., 2016). In contrast, sufficient sleep efficiency has been found to have a negative association with BP (Cespedes Feliciano et al., 2018).

Assumptions

1. Pediatric health can influence adult health.
2. Sleep duration and sleep efficiency are essential for overall health.
3. Actigraphy accurately measures sleep duration and sleep efficiency in adolescents.
4. Abdominal adiposity and BP were accurately measured in this sample.

Chapter Summary

This research project examined the influence of sleep duration and sleep efficiency on abdominal adiposity and BP in adolescents ages 16 to 18 who participated in the Cleveland Children's Sleep and Health Study. Age, assigned sex, race, ethnicity, and BMI percentiles influence both dependent and independent variables and were controlled during this study. McEwen's Theory of Allostatic Load undergirds the conceptual framework that depicts the influences of sleep duration and sleep efficiency on abdominal adiposity and BP.

CHAPTER 2

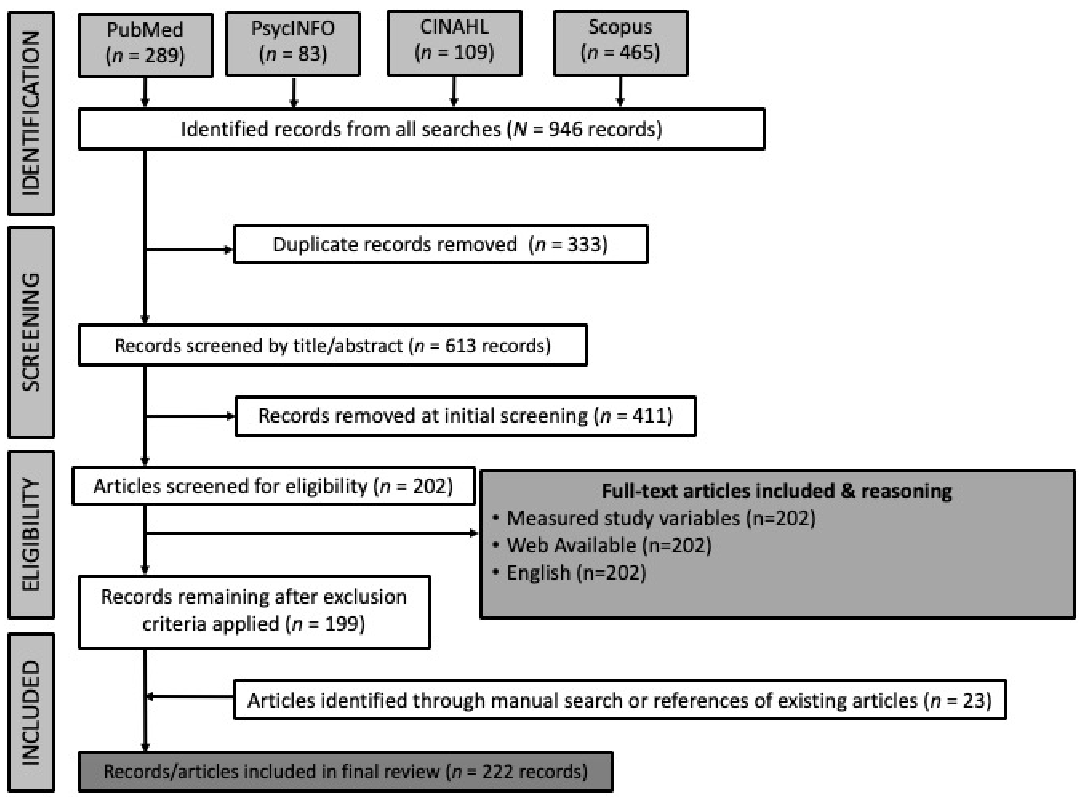
LITERATURE REVIEW

The purpose of this study was to describe the influence of sleep duration and sleep efficiency on abdominal adiposity and BP in adolescents ages 16 to 18. In the following section, a literature review of the research related to relationships among sleep duration, sleep efficiency, abdominal adiposity, and BP was completed. This section also includes an examination of the literature concerning the following control variables that have been associated with sleep duration, sleep efficiency, abdominal adiposity, and BP: age, race/ethnicity, assigned sex, and BMI percentiles. The adolescent population (ages 12–18 years), with a specific focus on late adolescence (ages 16–18 years), when literature was available, was the primary focus of this review. However, due to the limited research on the study variables in these populations, some sections include a variety of ages other than adolescence (e.g., school-aged [ages 6–12 years], adults [older than 18 years]). Furthermore, there is limited research on the concept of abdominal adiposity across the lifespan. Therefore, overall adiposity is discussed in relation to the other study variables when literature on abdominal adiposity was not available.

Initially, materials published by professional and national organizations such as the American Heart Association, National Sleep Foundation, and Centers for Disease Control and Prevention were searched for literature on the diagnosis, prevention, study, and treatment of HTN, obesity, and sleep disorders. Additionally, the following terms were used in various combinations to search CINAHL, PubMed, PsycINFO and SCOPUS: “sleep duration,” “sleep efficiency,” “sleep quality,” “sleep time,” “waist,” “waist to height ratio,” “waist to hip ratio,” “abdominal adiposity,” “central adiposity,” “visceral adiposity,” “blood pressure,” “hypertension,” “hypotension,” “children,” “adolescents,” and “teen” (Figure 3). From the databases, 946 articles including human subjects were found. After excluding duplicate articles, 613 articles were screened for inclusion in the review. After title and abstract review, only 202 articles were reviewed for inclusion based on the following criteria: a) measured study variables, b) web available, and c) published in English. The total number of articles included was 222 after adding 23 articles found during manual searches.

Figure 3

PRISMA Diagram



In the following sections, the epidemiology of the dependent variables (abdominal adiposity and BP) and the independent variables (sleep efficiency and sleep duration) are discussed. Literature concerning the pediatric population, especially adolescents and late adolescents, is emphasized if information on these groups was available.

Abdominal Adiposity

The importance of abdominal adiposity was first discussed in 1956 by J. Vague (Okosun et al., 1999). However, it was not until the late 1980s and early 1990s that researchers began to examine the impact on the human body of abdominal adiposity rather than BMI, a more generalized measure of adiposity, which was the focus in the 1970s (Blackburn & Jacobs, Jr., 2014; Rexrode et al., 1998). Excess abdominal adiposity, WHtR greater than 0.5 or WC greater than the 70th percentile, is considered obesity; however, most research on obesity focuses on BMI (Okosun et al., 2004). In the 1990s, researchers noted that abdominal adiposity had an independent and more significant impact on some disease risks (e.g., metabolic syndrome and cardiovascular disease) and mortality, compared to BMI (Okosun et al., 2004; Reis et al., 2013).

However, since most research on abdominal adiposity has only been conducted over the last four decades, there are limited data to determine the national or worldwide prevalence of excess abdominal adiposity, especially in the pediatric population (Blackburn & Jacobs, Jr., 2014; Rexrode et al., 1998). In 2015-2016, 59% of U.S. adults had excess abdominal adiposity, a prevalence that had significantly increased over the previous 18 years (CDC, 2021a). However, since evidence suggests a positive association between abdominal adiposity and BMI, it is apparent that an increase in overall obesity includes an increase in excess abdominal adiposity (Walls et al., 2011). Since the prevalence of obesity, measured by BMI, almost doubled between 1980 and 2008, it is expected that the prevalence of excess abdominal adiposity is similar (Araujo de Franca et al., 2014; Elobeid et al., 2007). Yet, some evidence suggests that people who are not obese by BMI standards can have excess abdominal adiposity (Lee et al., 2017; Thaikruea & Thammasarot et al., 2016; Zhang et al., 2016). In particular, Solanki and colleagues (2020) found that there was a higher prevalence of excess abdominal adiposity in older adolescents who were normal weight by BMI standards. So, the prevalence of excess abdominal adiposity may surpass the prevalence of obesity as defined by a BMI greater than the 95th percentile (CDC, 2021a; Walls et al., 2011).

Along with a potential for increasing prevalence of excess abdominal adiposity in adolescents, there is a greater lifetime risk for excess abdominal adiposity in adulthood if first evidenced during childhood (Reis et al., 2013). Additionally, evidence suggests that excess abdominal adiposity is more reflective of CVD risk than overall adiposity in adolescents because abdominal adiposity is a risk factor for arteriosclerosis development, an underlying risk for CVD (Mokha et al., 2010; Sturm et al., 2009). Using the 90th percentile cutoff of waist circumference, excess abdominal adiposity increased by 65.4% and 69.4% for male and female children and adolescents, respectively, between 1988 and 2004 (Li et al., 2006). However, recent research suggests that excess abdominal adiposity may be present at the 70th percentile, thus possibly increasing the number of adolescents with excess abdominal adiposity (Goyal et al., 2021).

Along with the limited research on abdominal adiposity during adolescence, there are limited data on factors that impact abdominal adiposity across the lifespan. However, evidence suggests that abdominal adiposity is impacted by age, diet, ethnicity, race, sex, genotype, physical activity, medications, and hormone levels (Shuster et al., 2012). There also tends to be more abdominal adiposity in females and those who are overweight (Shuster et al., 2012). In the pediatric population, maternal nutritional status, female gender, BMI for age, and maternal abdominal obesity are associated with child abdominal adiposity, regardless of socioeconomic status (Melzer et al., 2015). Further, evidence suggests that abdominal adiposity in children is related to the risk for metabolic syndrome, CVD, and type 2 diabetes in adulthood (Arteaga et al., 2018; Virani et al., 2021).

Along with other factors, the way abdominal adiposity is measured may impact the prevalence of abdominal adiposity and its relationship with disease. Most research on the relationships between abdominal adiposity and other factors tend to measure WC. Waist circumference has been validated against the gold standard, computed tomography (CT), and magnetic resonance imaging (MRI). However, evidence suggests that WHtR is also an important measure of abdominal adiposity and potentially a better measure of abdominal adiposity in the pediatric population in that it accounts for their disproportionate growth (Nambiar et al., 2010). Furthermore, WHtR measurement and calculation is consistent across all ages and demographics, making it easier to assess and analyze for research. However, WHtR does not consider differences in race, ethnicity, and sex like WC percentiles, which are factors that have been shown to impact abdominal adiposity (Ashwell & Hsieh, 2005). Therefore, there is a need for more research to include both WC and WHtR measures of abdominal adiposity. WC and WHtR are both cost-effective, user-friendly measures of abdominal adiposity compared to the gold standards. Furthermore, both measures have been validated and determined to be specific and highly sensitive when compared to both CT and MRI (Bacopoulou et al., 2015; Okosun et al., 2004; Shuster et al., 2012; Taylor et al., 2000).

Summary

Abdominal adiposity is a measure of the fat mass around the abdomen. In excess, abdominal adiposity is considered obesity. However, the measure is not used as frequently as BMI, a more general measure of obesity or overall adiposity. Yet, evidence suggests that abdominal adiposity is a better measure of CVD risk, the leading cause of death, compared to BMI. There are several ways to measure abdominal adiposity, but evidence suggests that WC and WHtR are the best measures for the pediatric population because of their ease of use and ability to account for disproportionate growth, respectively. Despite the awareness of the impact of abdominal adiposity, there has been limited research quantifying the prevalence of abdominal obesity or on the factors that impact abdominal adiposity, beyond demographics, diet, physical activity, and medical disorders, especially during adolescence.

Blood Pressure

Elevated BP, or HTN, is the worldwide leading risk factor for disease and disability (Rahimi et al., 2015). In the 1960s, early epidemiological evidence considered the association between elevated BP and the risk of death (Rahimi et al., 2015). However, it was not until the 1970s that the National Heart and Lung Institute formed a task force that recommended treating BP to prevent and treat atherosclerosis, a risk factor for CVD (Rahimi et al., 2015). Elevated BP in childhood, even briefly, increases the risk for HTN in adulthood (Flynn, 2008).

The focus on elevated BP in children is relatively recent. It was not until 2004 that researchers realized that the BP of children in the U.S. overall had increased over the previous decade (Flynn, 2008). It is now commonly recognized that elevated BP can be detected in the pediatric population, and that BP should be monitored starting at the age of 3 years (Falkner, 2010). However, there tends to still be a lack of data about BP for the entire pediatric population. It is projected that the prevalence of elevated BP in children will increase due to its close relationship with obesity, which is currently considered an epidemic in the pediatric population (Falkner, 2010). Primary HTN, or elevated BP not caused by another disease process (e.g., congenital disease, cancer, organ failure), is typically diagnosed in adolescence (Bell et al., 2019). Unfortunately, adolescence is a time for increased CVD risks, like increases in sedentary lifestyle and high-salt diets, which are also risks for elevated BP (Aatola et al., 2017; Cespedes Feliciano et al., 2018). Falkner and colleagues (2010) found in a study of 8,535 adolescents ages 13 to 15 years that adolescents with elevated BP developed HTN within 2 years of that diagnosis. Also, Bao and colleagues (1995) noted that, in a group of 1,505 young adults diagnosed with HTN, 48% and 41% had an elevated systolic or diastolic BP in childhood, respectively (Bao et al., 1995).

Much like abdominal adiposity, a complex combination of behavioral, environmental, and genetic factors can lead to primary HTN in children (Falkner, 2010). Elevated BP in children has been associated with a family history of HTN, lifestyle factors (e.g., physical activity, sleep, diet quality), and obesity (Falkner, 2010). There are limited longitudinal data to support the impact of childhood BP on adult cardiovascular health (Falkner, 2010). However, there is some evidence to suggest a relationship between elevated childhood BP and risk factors for cardiovascular health like left ventricular hypertrophy, carotid artery intimal medial thickness, microalbuminuria, and peripheral vasculature changes (Falkner, 2010).

Measurement of BP, like abdominal adiposity, is also an issue. Inaccurate measures of BP limit the validity of BP statistics and how BP impacts other factors.

Blood pressure should be assessed at least two times with 2-minute intervals of rest in between (Mattoo & Fulton, 2019). Furthermore, since BP tends to change throughout the day, it is important to take BP during different times to receive an accurate average of BP (Flynn et al., 2017). The readings include systolic (SBP) and diastolic (DBP) blood pressure, which are used to determine overall BP status. In children younger than 13, the average of BP readings is used along with the child's height, age, and gender to determine BP percentile (Flynn et al., 2017). As with adults, absolute BP readings are used to determine adolescents' (greater than age 13) BP status (Flynn et al., 2017).

Summary

Blood pressure, like abdominal adiposity, is an important factor for assessing CVD risk. Research on pediatric BP is still fairly new. However, evidence suggests that not only is the prevalence of pediatric hypertension increasing, but childhood BP impacts adult BP and CVD risk factors. Like abdominal adiposity, factors that impact BP, such as diet, physical activity, adiposity, and family history, have been explored, but the prevalence continues to increase despite interventions in these areas. Therefore, there is a need to explore the relationships among BP and other factors. Furthermore, even though BP is measured similarly across all age groups, sometimes clinicians or researchers do not take multiple BP readings in one setting and throughout the day, therefore limiting the accuracy.

Sleep Duration

Despite the fact that sleep has received scholarly interest since recorded history began, the epidemiology of sleep has only been examined for the last 50 years, and major advances in sleep science have only been seen within the current century (Ferrie et al., 2011; Ohayon et al., 2010; Pollak et al., 2010; Shepard et al., 2005). There is an increasing focus on sleep due to its association with several aspects of life (e.g., mental health, cardiometabolic health, occupational hazards) and the projected increase in sleep problems (Ferrie et al., 2011).

Sleep duration, the total hours one sleeps after bedtime, is one of the easiest components of sleep to measure (Ogilvie & Patel, 2017). In 2010, benchmarks for sleep duration were included for the first time in the Healthy People 2020 initiatives (United States Department of Health and Human Services, 2010). Inadequate sleep duration, less than the recommended sleep duration (e.g., less than 8 hours in adolescents), is associated with poor overall health (Ogilvie & Patel, 2017). In humans, inadequate sleep duration has been linked to accidents, human errors, premature all-cause mortality, increased biomarkers of inflammation, hormone changes, and disrupted endocrine function (Ferrie et al., 2011). According to the National Sleep Foundation, sleep duration falls into three categories: normal, inadequate, or excessive (Ohayon et al., 2017). However, it was not until recently that parameters were suggested for what is considered excessive sleep. Therefore, there is a paucity of literature that captures the continuum of sleep duration, including excessive sleep duration. Yet, evidence suggests that sleep duration can have a u-shaped relationship with mortality and markers of health (e.g., CVD, CVD risk factors), which means that both inadequate and excessive sleep are associated with those factors (Ferrie et al., 2011).

Compared to the adult literature, there is less research on sleep duration across the pediatric population. However, adolescents, especially during late adolescence, have the highest prevalence of inadequate sleep duration across the pediatric population (Chen et al., 2006; Felden et al., 2016; Mindell et al., 1999). Furthermore, evidence suggests that adolescent students who both work and attend school tend to have progressively inadequate sleep during the week (Fischer et al., 2008). Additionally, older adolescents tend to have later bedtimes, increased evening activities, and, thus, inadequate sleep duration compared to younger adolescents (Colrain & Baker, 2011).

The factors that impact adolescent sleep duration are complex and are a mixture of behavioral, biological, and social factors including age (Felden et al., 2016), sex (McKnight-Eily et al., 2011), race/ethnicity (McKnight-Eily et al., 2011), BMI, physical activity (Chen et al., 2006; McKnight-Eily et al., 2011), diet quality (Chen et al., 2006; McKnight-Eily et al., 2011), caffeine intake (Fischer et al., 2008), stress management (Chen et al., 2006), smoking (McKnight-Eily et al., 2011), alcohol intake (McKnight-Eily et al., 2011), academic responsibilities (Carskadon et al., 2004), neighborhood factors (Desantis et al., 2013), employment (Fischer et al., 2008), screen time (McKnight-Eily et al., 2011), and acculturation (integrating into a new culture) (Whinnery et al., 2014). Inadequate or excessive sleep duration can lead to academic, emotional, and physical health issues in adolescents (Ogilvie & Patel, 2017). Specifically, both inadequate and excessive sleep duration have been linked to increased risk for obesity, HTN, and type 2 diabetes across the lifespan (Arteaga et al., 2018; Ogilvie & Patel, 2017; Virani et al., 2021).

Discrepancies in sleep duration measurement hinder researchers from determining accurate sleep duration. Sleep duration can be measured objectively and subjectively. The gold standard for overall sleep duration measurement is polysomnography (PSG), an objective method for assessing brain activity and sleep waves (Swihart et al., 2008). However, PSG is a high-cost procedure that requires a specialized technician and an overnight stay at a hospital or sleep center (Ancoli-Israel et al., 2003). Furthermore, PSG only captures one night of sleep in an unfamiliar setting, so it cannot be a generalized estimate of a person's sleep at home (Ancoli-Israel et al., 2003). Therefore, the most frequently used measure for objective sleep duration is actigraphy, measured by a portable device typically worn on the wrist that captures activity and inactivity (Sadeh & Acebo, 2002). Actigraphy has been validated against polysomnography and allows researchers and health care providers the ability to assess a participant's average sleep within their home environment (Ancoli-Israel et al., 2003). However, evidence suggests that at least 5 days of actigraphy data need to be collected per participant for researchers to consider the data valid (Acebo et al., 1999; Sadeh & Acebo, 2002). Unfortunately, several studies, especially those in the pediatric population, were unable to collect the recommended days of actigraphy data, mostly due to participant noncompliance with wearing the device (Sadeh & Acebo, 2002). Furthermore, actigraphy measures all periods of inactivity, which may not necessarily be sleep. Therefore, some form of subjective sleep duration is needed to better inform actigraphy results.

Validated questionnaires and sleep diaries are the main methods for examining subjective sleep duration (Erwin & Bashore, 2017). However, most subjective questionnaires have not been validated or have psychometrics, and are often not tailored to specific communities, not applicable to all age groups, and limited by participant understanding of items (Erwin & Bashore, 2017). The easier and more commonly used method for collecting data about subjective sleep is a sleep diary, which typically asks the participants their bedtime, waketime, sleep duration, and any other notes about their sleep (e.g., night awakenings) (Mazza et al., 2020). Sleep diaries in combination with an objective measure of sleep duration can offer more details than objective sleep duration alone, like the consistency of sleep duration throughout an extended period of time. Unfortunately, sleep diaries like questionnaires are subject to participant bias because often the participant is not aware of every aspect of their sleep or the time they actually fall asleep (Mazza et al., 2020). Furthermore, in some studies of children, typically under the age of 8, parents complete the sleep diaries for the children, further increasing the risk for inaccuracy (Mazza et al., 2020).

Summary

Even though the concept of sleep has been discussed since the beginning of recorded history, the focus on the epidemiology of sleep only began over the last 5 decades. Unfortunately, sleep duration, one of the most measured components of sleep, has been associated with mortality, CVD, accidents, and occupational hazards. Despite research suggesting that the risk for sleep-associated diseases begins in childhood, there has been limited research on sleep duration in the pediatric population, especially examining the mechanisms behind the relationship between sleep duration and associated diseases. Furthermore, adolescents have the highest prevalence of inadequate sleep among children and tend to have the highest prevalence of excess abdominal adiposity and BP, which are associated with sleep duration in adults. Limitations to measuring objective and subjective sleep duration may be one of the reasons there is a paucity of research on sleep duration in the pediatric population.

Sleep Efficiency

Sleep efficiency captures an essential aspect of sleep, spending too much time in bed compared to being asleep (Reed & Sacco, 2016). Sleep efficiency is also the objective reflection of one's quality of sleep, which is vital for physical and mental health (St-Onge et al., 2016; Yan et al., 2021). Issues with sleep efficiency are central markers of the risk for and presence of insomnia, consistent difficulty falling and staying asleep, the most common sleep disorder (Reed & Sacco, 2016).

Sleep efficiency has not been explored as extensively as sleep duration due to inconsistencies in how the concept is defined (Reed & Sacco, 2016). These inconsistencies in defining sleep efficiency have also led to gaps about its specific role in health and the mechanisms behind its relationship with disease and risk factors (Reed & Sacco, 2016). However, it is known that the prevalence of poor sleep efficiency increases with age and grade level in pediatric populations, with older adolescents having the highest prevalence (Xu et al., 2012). Furthermore, adolescence includes several significant shifts in sleep behavior that impact sleep efficiency, like later bedtimes and the use of electronics directly before or during bedtime (Colrain & Baker, 2011; Magee & Hale, 2012).

Like sleep duration, behavioral, biological, and social factors impact sleep efficiency in the pediatric population. These factors include age (Pucci & Pereira, 2016), sex (Galland et al., 2017), BMI, race, ethnicity, socioeconomic status (El-Sheikh et al., 2014), caffeine intake (Lodato et al., 2013; Pucci & Pereira, 2016), family sleep behavior (Pucci & Pereira, 2016), home environment (El-Sheikh et al., 2014), electronic and media use (Fobian et al., 2016), and psychological health (El-Sheikh et al., 2014). Further, poor sleep efficiency is associated with CVD risks (elevated BP and excess abdominal adiposity) (Hirata et al., 2019), depressed mood, irritability (Jung et al., 2016), and low energy (Wong et al., 2013). Poor sleep efficiency is also associated with diabetes, cancer, metabolic syndrome, mood disorders (Medic et al., 2017), mortality (Kripke et al., 2011), and neurodegenerative disorders (Lucey et al., 2021.

The gold standard for measuring sleep efficiency is PSG (Jackson et al., 2018). However, as is the case with sleep duration, PSG is expensive and only captures one night of sleep efficiency (Ancoli-Israel et al., 2003). Actigraphy has also been validated against PSG as a measure of sleep efficiency, which allows for sleep efficiency to be captured over days and is less expensive (Sadeh & Acebo, 2002). Part of the difficulty with the measurement of sleep efficiency is the inconsistencies in defining sleep efficiency. Sleep quality, one's perception of the quality of their sleep, is often described as a subjective measure of sleep efficiency (Phillips et al., 2020). However, sleep quality may be a broader term and a more comprehensive view of overall sleep that includes sleep efficiency (Buysse et al., 2008; Phillips et al., 2020). Furthermore, some researchers consider sleep efficiency an objective measure of sleep quality, which leads to the terms being used interchangeably. Therefore, this impacts the review and assessment of the relationships between sleep efficiency and other factors.

Summary

Sleep efficiency is another important component of sleep that has been associated with physical health, behavior, and cognition. It is also considered one of the central markers of insomnia, which is the leading sleep disorder. Sleep efficiency has only been measured objectively via PSG or actigraphy, limiting its inclusion in research since there are substantial costs associated with using these devices. Furthermore, in the pediatric population, PSG only shows one day of efficiency, which may not be representative of sleep efficiency. Additionally, it can be difficult to obtain consistent measures of sleep efficiency using actigraphy with some pediatric age groups. Despite limited measurement, evidence suggests that sleep efficiency decreases with increasing age. Thus, older adolescents may have the highest prevalence of poor sleep efficiency in the pediatric population.

Theoretical Frameworks

There is a lack of knowledge about the mechanisms that undergird the relationships among sleep duration, sleep efficiency, abdominal adiposity, and BP. Furthermore, few researchers have included information about the theories that underpin their studies. However, there are common groupings for the mechanisms behind these relationships: physiological, behavioral, and ecological (Colrain & Baker, 2011; Hagenauer et al., 2009). Given these groupings, there are two theories, Bronfenbrenner's Bioecological Theory of Human Development and McEwen's Theory of Allostatic Load, that can capture these relationships and mechanisms. In the following sections, each theory is addressed as it relates to the relationships among sleep duration, sleep efficiency, BP, and abdominal adiposity.

Bronfenbrenner's Bioecological Theory of Human Development is a revision of Bronfenbrenner's ever-evolving Ecological Systems Model. The purpose of the theory was to describe the relationship between a person and the different aspects of their life (Bronfenbrenner, 1999). Furthermore, this model captures how a person's surrounding environment impacts their development, or changes in their biopsychological characteristics. These aspects were captured in a tiered system starting from the individual outward including the microsystem (family, school, peers, neighborhood, etc.), mesosystem (religious affiliation, workplace, etc.), exosystem (economic system, political system, etc.), macrosystem (overall beliefs and values), and the chronosystem (the dimension of time) (Bronfenbrenner, 1999).

Several of the systems within the bioecological model impact sleep, abdominal adiposity, and BP (Blunden et al., 2016). Most studies that utilize this model to support sleep interventions tend to focus on the micro- and mesosystems because of the influence of the home, family, school, and neighborhood environments on sleep (Blunden et al., 2016). These same aspects also have been associated with abdominal adiposity and BP (Boonpleng et al., 2013; McGrath et al., 2006). Additionally, other systems within the model that have also been associated with sleep, abdominal adiposity, and BP, such as socioeconomic influence (exosystem), culture and beliefs (macrosystem), and age and developmental stages (chronosystem), have been addressed in research (Grandner et al., 2010). Grandner and colleagues used Bronfenbrenner's theory to support their exploration of the relationships between sleep and mortality, which include the relationships among sleep duration, obesity, and hypertension. In particular, the researchers discussed how the Bioecological Theory could undergird the mechanisms among those relations.

A strength of the Bioecological Theory of Human Development is that it encompasses the several levels of the environment that can affect the individual (Bronfenbrenner & Morris, 2007). Furthermore, the theory is directed at the individual versus disease processes. The weakness of this theory is that it does not address physiological mechanisms. In particular, it would be difficult to use this theory to explain the physiological mechanisms that relate sleep duration and sleep efficiency to abdominal adiposity and BP.

A second theory, the Theory of Allostatic Load, has been used as a basis for the examination of the mechanisms undergirding the relationships in this study (McEwen, 1998b; Karatsoreos & McEwen, 2015). Unlike the Bioecological Theory of Human Development, some studies have examined the study variables with the Theory of Allostatic Load; however, the variables were included in a composite score of allostatic load (Bei et al., 2017; Carroll et al., 2015; Chen et al., 2014; Clark et al., 2014). Bei and colleagues (2017) and Chen and others (2014) found that inadequate sleep duration was associated with composite score of allostatic load. However, Clark et al. (2014) found that allostatic load was associated with excessive sleep duration, while Carroll and others

(2015) found that allostatic load was associated with both inadequate and excessive sleep duration. No studies have used the Theory of Allostatic Load when assessing the relationships among sleep efficiency, abdominal adiposity, and BP (Carroll et al., 2015).

The Theory of Allostatic Load is a sound theoretical underpinning for this study because it offers a physiological mechanism that can explain the relationships among sleep duration, sleep efficiency, abdominal adiposity, and BP. A weakness of this theory is that it only discusses how stress can lead to the relationships among the variables. It is possible for sleep duration and sleep efficiency to impact abdominal adiposity and BP through other mechanisms not related to stress (Grandner et al., 2010). However, the field of sleep research is fairly new; therefore, there are limited data on other pathways and even more limited research on frameworks that support these relationships. Unfortunately, no studies were found that assessed these variables with either of these theoretical underpinnings in the pediatric population. However, both theories have been applied to the individual variables within the pediatric population (Blunden et al., 2016; Whelan et al., 2021).

Influences on Abdominal Adiposity

In the following section, literature that focuses on the influences of sleep duration and sleep efficiency on abdominal adiposity will be discussed.

Abdominal Adiposity and Sleep Duration

The influence of sleep duration on abdominal adiposity has not been widely studied, especially in late adolescence (Theorell-Haglow et al., 2010). Many of the studies that involved participants in late adolescence included other developmental stages, which makes it difficult to determine the specific relationship between sleep duration and abdominal adiposity in late adolescents. Since sleep duration and abdominal adiposity change with age, it is important to look at these relationships during specific developmental stages like late adolescence.

In the studies that did focus on late adolescents, researchers found that inadequate sleep duration was associated with excess abdominal adiposity (Al-Hazzaa, 2014; Narang et al., 2012; Shaikh et al., 2010; Skidmore et al., 2013). Yet only two of these studies, Al-Hazzaa (2014) and Skidmore et al. (2013), included WHtR. Furthermore, none of those studies included objective measures of sleep duration. Instead, the researchers used questionnaires that asked participants to give an estimated average sleep duration rather than sleep diaries, which ask participants for a sleep duration for each night of collection to formulate an average.

Few studies have captured the relationship between excessive sleep duration and abdominal adiposity. A longitudinal study by Ma and colleagues (2021) that included late adolescents (ages 16–17) found that excessive sleep duration was associated with decreased risk for excess abdominal adiposity. This study did not collect objective sleep duration or WC percentiles but did use WHtR.

Overall, when examining the relationship between sleep duration and abdominal adiposity in studies that include, but do not focus on, late adolescents, there is an inverse relationship between sleep duration and abdominal adiposity (Duan et al., 2020; Eisenmann et al., 2006; Guo et al., 2011; Jansen et al., 2018; Jarrin et al., 2013; Lee & Park, 2014; Nam et al., 2017; Ozturk et al., 2009; Seo & Shimm, 2019; Yu et al., 2007). Furthermore, a meta-analysis of eight cross-sectional studies using 16 databases found an overall negative association between sleep duration and abdominal adiposity in children and adolescents (Quist et al., 2016). Conversely, some studies yielded no relationships between sleep duration and abdominal adiposity (Martinez-Gomez et al., 2011; Mi et al., 2019; Patel et al., 2012; Sung et al., 2011). When evidence was separated by developmental stages, only relationships within the school-age range (ages 6–12 years) were noted (Duan et al., 2020; Guo et al., 2011). The inconsistencies in results from studies examining the influence of sleep duration on abdominal adiposity could be due to small sample sizes and the number of participants with inadequate or excessive sleep duration (Quist et al., 2016).

In the studies that do focus on abdominal adiposity and sleep duration, there are inconsistencies in the instruments used to measure abdominal adiposity. Among the studies reviewed, WC was the most commonly used measurement for abdominal adiposity. However, evidence suggests that WHtR may be a better measure of abdominal adiposity and overall adiposity in the pediatric population compared to WC and BMI (Shuster et al., 2012; Taylor et al., 2000). There were also inconsistencies when measuring sleep duration. Most studies included subjective sleep measures that, while correlated with objective measures, can overestimate or underestimate sleep duration

(Lauderdale et al., 2008; Quist et al., 2016). Nevertheless, some studies used actigraphy and/or PSG, the gold standard of measuring sleep duration (Jansen et al., 2018; Mi et al., 2019; Sung et al., 2011). Of these, only Jansen and colleagues (2018) found that inadequate objective sleep duration was associated with excess abdominal adiposity. The other studies did not support a relationship between the variables.

Abdominal Adiposity and Sleep Efficiency

There is a paucity of data on the influence of sleep efficiency on abdominal adiposity in late adolescence. Evidence suggests that there is an inverse relationship between sleep efficiency and abdominal adiposity in school-aged children (ages 9–11) (McNeil et al., 2015) and adolescents (ages 11.9–16.6) (Cespedes Feliciano et al., 2018). However, neither of these studies used WHtR as a measure of abdominal adiposity. Furthermore, on average, the study by Cespedes Feliciano and colleagues (2018) enrolled young adolescents (mean age 13.2) but did not include older adolescents. In a second study, Simon and colleagues (2020) found that, in adolescents (ages 12–21) with polycystic ovary syndrome (PCOS), there was an inverse relationship between sleep efficiency and WC. However, PCOS has been associated with an increased risk for metabolic syndrome, which typically includes excess abdominal adiposity.

In young adults (ages 21–35), the developmental stage after late adolescence, McMahon and colleagues (2019) found that poor sleep efficiency was associated with elevated abdominal adiposity. This study also used WHtR as a measure of abdominal adiposity. In a wider range of adults (ages 18–91), an inverse relationship between sleep efficiency and abdominal adiposity has been noted (Koolhaas et al., 2019; Martinez Aguirre-Betolaza et al., 2019; Mezick et al., 2014; Ogilvie et al., 2016; Tom et al., 2018). However, none of these studies used WHtR to measure abdominal adiposity.

The lack of evidence on the impact of sleep efficiency on abdominal adiposity, especially in the pediatric population, may be due to inconsistencies in the measurement of sleep efficiency (Reed & Sacco, 2012). The gold standard for measuring sleep efficiency, PSG, can be costly and difficult to obtain due to the scarcity of sleep centers that are required for this measurement (Jackson et al., 2018). Actigraphy has been validated against PSG as a suitable measurement of sleep efficiency, and it also offers an average of sleep efficiency compared to the one night with PSG (Sadeh & Acebo, 2002). Still, procuring actigraph devices can be costly, although cheaper than PSG. Further, actigraph devices are often lost or not worn consistently in the pediatric population (Sadeh & Acebo, 2002). Therefore, most researchers tend to use subjective instruments to measure sleep efficiency. However, most studies report this concept as sleep quality, which does not necessarily capture what is represented by objective sleep efficiency, the ratio of time spent asleep compared to being in bed.

Summary

Overall, there has been limited research on the influence of sleep duration and sleep efficiency on abdominal adiposity in late adolescence. However, in the studies that have focused on sleep duration and abdominal adiposity in late adolescence, a negative relationship between the variables was noted, with inadequate sleep duration being associated with excess abdominal adiposity. Only a few of those studies included WHtR, despite evidence suggesting that WHtR may be a better measure of abdominal adiposity and overall adiposity in the pediatric population. Furthermore, most studies used questionnaires as a measure of sleep duration, which only collect a subjective view and have a higher risk for inaccuracies compared to objective measures like PSG and actigraphy.

There were no studies that examined sleep efficiency and abdominal adiposity specifically during late adolescence. However, the studies that did include adolescents found an inverse relationship between the two variables. Studies in adults found similar results. As with the studies of sleep duration and abdominal adiposity, there was a paucity of studies that used WHtR. The absence of studies focusing on sleep efficiency and abdominal adiposity may be due to the need to use PSG and actigraphy, which are expensive technologies, to measure the concept.

Influences on Blood Pressure

In the following section, the literature on the influences of sleep duration and sleep efficiency on BP will be discussed.

Blood Pressure and Sleep Duration

Much like the literature on the relationship between sleep duration and abdominal adiposity, there are limited studies on the influence of sleep duration on BP specifically during late adolescence. In the studies that do focus on late adolescence, there was an overall inverse relationship between sleep duration and BP (Countryman et al., 2013; Mezick et al., 2012; Paciencia et al., 2013). Specifically, Paciencia and colleagues (2016), in a longitudinal study with 1,403 adolescent participants, found that sleep duration at 13 years of age was associated with elevated BP at 17 years old. Archbold and colleagues (2012) completed a similar longitudinal study in 6- to 11-year-old school-aged children and found that inadequate sleep duration was negatively associated with SBP and DBP 5 years later. However, Mezick et al. (2012) and Archbold et al. (2012) were the only researchers to collect objective sleep duration. Furthermore, only Mezick and colleagues (2012) collected BP over different times of the day, which is important since BP changes throughout the day (Bovet et al., 2003). Also, only Archbold and colleagues (2012) analyzed SBP and DBP as separate variables, which is important because evidence suggests that changes in SBP and DBP have different impacts on cardiovascular health (Sun et al., 2007). Conversely, Leung and colleagues (2011) found that there was no relationship between sleep duration and the risk for elevated BP in 6,193 adolescents (mean age 15.2 years).

Some studies included older adolescents in their population (overall ages 10–17.9), but the analyses were not separated by developmental stages. In those studies, evidence suggests that inadequate sleep duration is associated with elevated BP (Au et al., 2014; Javaheri et al., 2008; Kuciene & Dulskiene, 2014). Also, inadequate sleep duration has been associated with elevated BP in adults (Fang et al., 2012; Gangwisch et al., 2006; Gottlieb et al., 2006; Knutson et al., 2009; Makarem et al., 2019; Wang et al., 2015). In fact, evidence suggests that inadequate sleep duration has a negative relationship with elevated BP in school-aged children and young adolescents (Guo et al., 2011; Hjorth et al., 2016).

Although most studies focus on inadequate sleep duration, some evidence suggests that excessive sleep duration is associated with an increased risk for elevated BP in adults (Gottlieb et al., 2006; Guo et al., 2013). In late adolescents (ages 15–18 years), Guo and colleagues (2011) did not find a significant relationship between excessive sleep duration and BP. Paciencia and colleagues (2013) did find that excessive sleep duration was associated with higher BP in 13-year-old adolescents, but they measured only subjective sleep duration.

Blood Pressure and Sleep Efficiency

Few studies have examined the relationship between sleep efficiency and BP across the lifespan, especially in late adolescence (Cespedes Feliciano et al., 2018). The lack of evidence about the relationships between sleep efficiency and BP may be due to the previously mentioned inconsistencies in the terminology and sleep efficiency measures (Reed & Sacco, 2012). One study that specifically examined the relationship between sleep efficiency and BP in older adolescents found no relationship (Mezick et al., 2012). However, there have been other studies on these relationships in adolescents (overall age range of 11.9–16.6 years) that include older adolescents. Cespedes Feliciano and colleagues (2018) noted in 829 adolescents ages 11.9 to 16.6 that higher sleep efficiency was associated with a better BP regardless of obesity. Likewise, Javaheri and others (2008) noted in a study of 238 adolescents ages 13 to 16 that poor sleep efficiency measured by actigraphy and PSG was associated with an increased risk for pre-hypertension measured by SBP and DBP. However, Cespedes Feliciano and others (2018) analyzed only SBP.

Studies of adults note a relationship between sleep efficiency and BP, but findings were limited by the lack of assessment for or the presence of sleep disorders, like sleep-disordered breathing, which can impact BP (Hirata et al., 2019; Javaheri et al., 2008). However, Ramos and colleagues (2018) found that, in adults, reductions in sleep efficiency were associated with increases in BP independent of sleep-disordered breathing.

Summary

Evidence suggests there is an inverse relationship between sleep duration and BP. However, these studies were limited by not collecting objective sleep duration. Furthermore, there has been a paucity of studies that include or focus on excessive sleep duration and BP. The one study that examined this relationship in older adolescents did not find a relationship between the variables. However, evidence from one study in young adolescents did find a relationship between excessive sleep duration and BP.

Although evidence suggests a relationship between sleep efficiency and BP in the overall adolescent population, the one study in older adolescents did not find a relationship between the variables. There were studies that included older adolescents but did not separate the findings based on developmental age groups. Furthermore, one of the studies only captured SBP versus both DBP and SBP.

Control Variables

Age

As children age, especially during adolescence, they have hormonal shifts that impact their sleep, adiposity, and BP (Campbell et al., 2012; Reinehr & Toschke, 2009). Studies examining the relationships among sleep duration, BP, and abdominal adiposity were age-dependent because these variables tend to change as people age (Cao et al., 2015; El-Sheikh et al., 2014; Marceau et al., 2019; Quist et al., 2016; Tripathi & Mishra, 2019). A study by Yu and colleagues (2007) found that sleep duration decreased during adolescence, reaching the lowest point between 16 and 17 years old. Furthermore, the same study found that abdominal adiposity increased after age 12 (Yu et al., 2007).

In a study of children and adolescents between the ages of 5 and 18, researchers found that short sleep duration increased the chances of excess abdominal adiposity in only males between 11 and 14 years old (Guo et al., 2011). In the same study, inadequate sleep duration was associated with risk for excess BP in only 11- to 14-year-old males, but inadequate sleep duration was associated with less risk for elevated BP in females 15 to 18 years old (Guo et al., 2011). When examining children and adolescents between 6 and 17 years old, Duan and colleagues (2020) found an association between inadequate sleep duration and excess abdominal adiposity only in females ages 6 to 12.

Race/Ethnicity

Race and ethnicity impact sleep, abdominal adiposity, and BP individually, and they are typically used as a control variable when assessing these relationships (Quist et al., 2016). Evidence suggests that there is a relationship between sleep duration and BP in White children, something not always noted in Black children (Mezick et al., 2012). Quist and colleagues (2016) also noted that inconsistencies with the relationships among sleep, BP, and abdominal adiposity between White and Black children are somewhat attributed to the lack of significantly heterogeneous samples based on race (Quist et al., 2016). However, the review of the literature indicates that race and ethnicity tends to be a social construct assessed in studies only in countries that have a marked difference in race (e.g., U.S., United Kingdom). Unfortunately, a majority of the studies reviewed did not assess race and were based in countries with few racial differences (e.g., China, Korea, India). Furthermore, there are some racial differences in BP and abdominal adiposity based on race. Foreign racial/ethnic populations in comparison to those prominent in the U.S. (e.g., Whites, Blacks, Hispanics) tend to have a lower prevalence of elevated BP and excess abdominal adiposity. An example is that Asians tend to have the lowest prevalence of elevated BP and excess abdominal adiposity when compared to Whites, Blacks, and Hispanics (Tsao et al., 2022). Therefore, examining these relationships in the U.S. could be significantly different.

Assigned Sex

There is evidence suggesting that assigned sex is associated with biological processes that impact sleep duration, sleep efficiency, BP, and abdominal adiposity individually, as well as the relationships among them (Quist et al., 2016; Storfer-Isser et al. 2012; Tripathi & Mishra, 2019). Some of the relationships only become noticeable after puberty, which is typically during adolescence (Krishnan & Collop, 2006). Results from several studies suggest that inadequate sleep duration is associated with higher abdominal adiposity in male children only (Guo et al., 2011; Quist et al., 2016; Shaikh et al., 2010). Guo and colleagues (2011) also found that inadequate sleep duration was only associated with BP in adolescent males (Guo et al., 2011). Another study found that adequate and excessive sleep duration (greater than 8 hours) was associated with a lower risk for excess adiposity compared to inadequate sleep, but only in males (Azadbakht et al., 2013). Associations between sleep efficiency and adiposity variability were only present among female adolescents in another study (Cespedes Feliciano et al., 2018).

Brandalize and colleagues (2011) found that adequate or excessive sleep duration was only associated with a lower DBP in adolescent females. In contrast, one study found that excessive sleep duration was associated with a higher risk for elevated BP compared to inadequate sleep duration in adolescent females (Paciencia et al., 2013). A study by Dos Santos and De Souza (2020) found that in adolescents a 1-hour increase in sleep duration led to decreased SBP in males and an increase in SBP in females.

BMI Percentiles

Evidence suggests that BMI percentiles influence the relationships among sleep duration, sleep efficiency, BP, and abdominal adiposity (Quist et al., 2016; Virani et al., 2021). Sleep duration was associated with abdominal adiposity independent of BMI percentiles in a study of school-aged children (Chaput & Tremblay, 2007). Another study found that longer sleep duration and higher sleep efficiency had a relationship with better BP and abdominal adiposity independent of BMI in adolescents (Cespedes Feliciano et al., 2018). Javaheri and colleagues (2008) also found that inadequate sleep duration was associated with an increased risk for elevated BP after adjusting for BMI in adolescents. This is important since evidence suggests that the relationship between sleep duration and elevated BP in adolescents is mediated by BMI (Peach et al., 2015).

Gaps Within the Literature

Although evidence suggests that sleep duration and sleep efficiency impact abdominal adiposity and BP in adults and young adolescents, there has been limited research across the lifespan, among specific age groups (Bailey et al., 2014). This is particularly apparent in the late adolescent population and is concerning since older adolescents have the highest prevalence of poor sleep efficiency and inadequate sleep duration within the pediatric population (Chen et al., 2006; Felden et al., 2016; Mindell et al., 1999). Further, poor sleep efficiency and inadequate sleep duration have been associated with abdominal adiposity and BP in young adolescents (Cespedes Feliciano et al., 2018; Javaheri et al., 2008). Since poor sleep efficiency, inadequate sleep duration, excess abdominal adiposity, and elevated BP increase with age, it is important to determine if these continue in late adolescence (Basch et al., 2014; McLaughlin Crabtree & Williams, 2009; Muntner et al., 2004; Wells et al., 2008).

Much of the research on sleep duration and sleep efficiency focuses on the impact of overall adiposity versus abdominal adiposity. Abdominal adiposity is a better marker of risk for cardiometabolic diseases (e.g., CVD, diabetes), some of the leading causes of death in the U.S. (Shuster et al., 2012; Taylor et al., 2000; Tsao et al., 2022). The focus on abdominal adiposity may be due to the more recent adoption of abdominal measures such as WC.

Further, most studies address sleep duration and its effect on abdominal adiposity and BP and focus less on sleep efficiency. However, evidence suggests that sleep efficiency is also important to overall health, and that it influences the HPA axis and sympathetic nervous system, which impact abdominal adiposity and BP (Raikkonen et al., 2010; Sweatt et al., 2018). The lack of focus on sleep efficiency may be due to the inconsistencies in defining sleep efficiency and the expenses, training, and access required to measure it via actigraphy and PSG (Reed & Sacco, 2016; Sadeh & Acebo, 2002).

Much of the focus on sleep duration research has been on inadequate sleep duration, with less focus on excessive sleep duration. Evidence suggests that sleep duration has a u-shaped relationship with some diseases and risk factors like mental health (Fitzgerald et al., 2011), insulin resistance (Koren et al., 2016), and overall adiposity (Danielsen et al., 2010). Thus, both inadequate and excessive sleep duration could impact abdominal adiposity and BP. These relationships also receive little attention in older adolescents. Exploring the continuum of sleep duration and effects on abdominal adiposity and BP could inform interventions to decrease excess abdominal adiposity and elevated BP.

Finally, most of the studies conducted on the relationships among the study variables were conducted in foreign countries. This is concerning since the United States is one of the top five countries with the highest rates of CVD deaths (The American College of Cardiology [ACC], 2020). Therefore, this study will be one of the few to examine these relationships in the U.S. late adolescent population. Also, in the studies conducted in the U.S., there were smaller sample sizes compared to those in other countries. A smaller sample size often does not allow researchers to make strong conclusions about their results.

Chapter Summary

Overall, the study's variables have only been recently explored within the pediatric population. Therefore, there is limited research on the epidemiology of these variables and the mechanisms undergirding the relationships among the variables. The mechanisms that undergird the influence of sleep duration and sleep efficiency on abdominal adiposity and BP are typically categorized into physiological, behavioral, and ecological. Bronfenbrenner's Bioecological Theory of Human Development and McEwen's Theory of Allostatic Load are two commonly used frameworks that support physiological, behavioral, and/or ecological mechanisms. Despite both theories' support of the study's variables, the Theory of Allostatic Load is a better fit for this study since it includes a physiological framework.

There has been limited research on the influences of sleep duration and sleep efficiency on abdominal adiposity and BP in older adolescents. Overall, there were inverse relationships with the variable combinations. However, some of these studies were limited by not collecting WHtR and objective sleep duration. Despite the limited research in late adolescence, there were similar findings in the overall adolescent population, school-aged children, and adults. Furthermore, these findings were impacted by some combination of age, race/ethnicity, assigned sex, and BMI percentiles. The gaps in the literature support the need for this study since there is an overall lack of research on the study's variables in late adolescence, limited research on abdominal adiposity and sleep efficiency across the lifespan, minimal studies that cover excessive sleep duration, and only a few studies examining these variables within the United States.

CHAPTER 3

METHODOLOGY

The purpose of this secondary data analysis was to explore the relationships among sleep duration, sleep efficiency, abdominal adiposity, and BP in adolescents ages 16 to 18 who participated in the Cleveland Children's Sleep and Health Study (CCSHS). Evidence suggests that sleep duration and sleep efficiency influence abdominal adiposity and BP in adults and young adolescents. However, there have been limited studies on this relationship during late adolescence (Cespedes et al., 2014; Magee & Hale, 2012; Quist et al., 2016). In this chapter, the parent study, methodology, research design, sample, setting, measurements, and the data analysis of the study are addressed.

Parent Study

The CCSHS was an urban, community-based, longitudinal cohort study that evaluated the impact of sleep disturbances on health outcomes, specifically obesity and pediatric sleep disorders (Boeke et al., 2013; Zhang et al., 2018). This study consisted of three exam cycles between 1998 and 2010 (first cycle: 1998–2001, second cycle: 2002–2006, third cycle: 2006–2010) (Zhang et al., 2018). The CCSHS included children born in three hospitals in the Cleveland, Ohio, area between 1988 and 1993; thus, participants were between the ages of 8 and 12 during the first exam cycle and 10 to 14 in the second exam cycle (Rosen et al., 2003). The current study will focus on Exam Cycle 3 (2006–

2010), when the participants were between the ages of 16 and 19 years. In the following section, the details of the CCSHS study with an emphasis on Exam Cycle 3 are discussed.

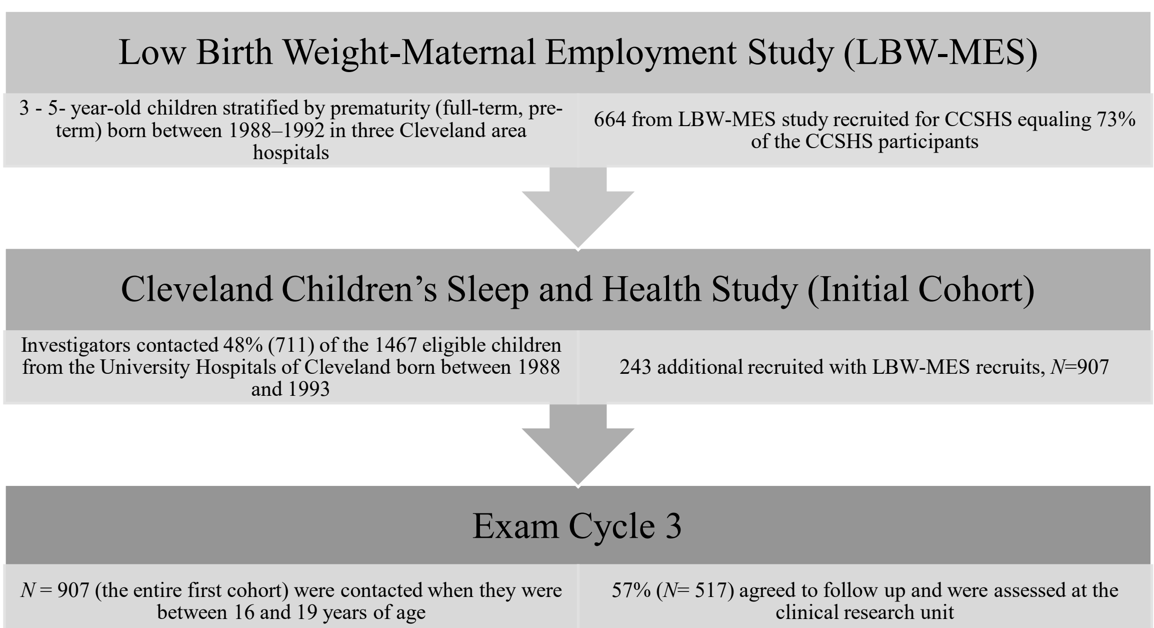
Recruitment of CCSHS Participants

Participant recruitment in Cycle 1 included two stages (Figure 4). First, the investigators recruited from an existing study, the Low Birth Weight-Maternal Employment Study (LBW-MES), a longitudinal study about cognition and behavior with a random sample of 3- to 5-year-old children stratified by prematurity (full-term, pre-term) (Rosen et al., 2003). Participants in the LBW-MES study were pre-term or full-term and born between 1988 and 1993 in three Cleveland area hospitals (Rosen et al., 2003). The LBW-MES study enrolled equal numbers of 3-, 4-, and 5-year-old children for each of the 5 consecutive birth years (Youngblut et al., 2001). Inclusion criteria for pre-term participants were: (a) born less than 36 weeks' gestation, (b) birth weight of less than 2500 g, (c) birth weight appropriate for gestational age, (d) hospitalized in a Level III NICU for greater than 1 week, and (e) survival of the child (Rosen et al., 2003; Youngblut et al., 2001). Inclusion criteria for full-term participants were: (a) born between 38 and 42 weeks' gestation, (b) hospitalized in a standard nursery, and (c) discharged home with the mother (Rosen et al., 2003; Youngblut et al., 2001). Participants were excluded if they had developmental delays present for greater than 2 years (Rosen et al., 2003; Youngblut et al., 2001). From the LBW-MES, the investigators recruited 664 participants for the CCSHS, which equaled 73% of the CCSHS participants (Rosen et al., 2003).

In the second phase of recruitment, the investigators specifically targeted African American children since only 23% of participants from the LBW-MES were from minority groups. Investigators contacted 48% (711) of the 1,467 eligible children born between 1988 and 1993 in the University Hospitals of Cleveland (Rosen et al., 2003). Fifty-two percent of the potential participants had moved or could not be located, and 10% were ineligible because of severe developmental delays like intellectual disability or severe cerebral palsy (Rosen et al., 2003). Of the 320 eligible children who agreed to participate, 243 (76%) completed the study, bringing the total for Exam Cycle 3 of the CCSHS to 907 participants (Rosen et al., 2003).

Figure 4

CCSHS Recruitment and Attrition



Cohort Characteristics

The original cohort (Exam Cycle 1) enrolled in the CCSHS included 490 full-term and 417 pre-term children (Hibbs et al., 2014). During the initial examination (1998–2001), the mean age was 9.6 ± 0.7 years for full-term and 9.3 ± 0.8 for pre-term. Forty-nine percent of the participants were females, and 59% were White (Rosen et al., 2003). Thirty percent of the full-term participants and 27% of the pre-term population had a BMI percentile greater than 85%, categorizing them as overweight according to the CDC guidelines (CDC, 2021a; Rosen et al., 2003). Sixteen percent in both groups were considered obese with a BMI greater than the 95th percentile (CDC, 2021a).

Exam Cycle 3

Participants from the initial exam cycle (*N* = 907) were contacted when they were between the ages of 16 and 19 to participate in the third exam cycle (Figure 4). Fifty-seven percent of the original cohort (*N* = 517) agreed to the follow-up study and were assessed at the clinical research unit. During this exam cycle, participants free from acute illness completed an overnight PSG test and a self-reported assessment about their demographics, medical history, food, and sleep. Actigraphy was measured 5 to 7 consecutive days before the visit. In addition, the participants were measured for height, weight, and WC (Hibbs et al., 2014). The mean age of the participants was 17.7 ± 0.43 years; 51% of the participants were male, and 59.7% were Black. Of the 517 participants, 501 did not have sleep apnea, as evidenced by an apnea-hypopnea index (AHI) less than 5 as noted on the PSG examination (Hibbs et al., 2014). Seventy percent of the participants ($N = 350$) had their pubertal status assessed. More than 99% of the participants with pubertal assessment were at Tanner stage five, the highest Tanner stage, reflecting the culmination of puberty (Emmanuel & Bokor, 2017; Hibbs et al., 2014).

Measurements

One week before the clinical research unit visit, participants wore wrist actigraphy (Octagonal Sleep Watch 2.01, Ambulatory Monitoring Inc., Ardsley, NY) to determine objective sleep duration and sleep efficiency. They also completed daily sleep diaries for 5 to 7 consecutive days (24-hour periods) to capture subjective sleep duration (Hibbs et al., 2014; Storfer-Isser et al., 2012 Weiss et al., 2010).

The actigraphy data were analyzed using Action-W software with the time-above-threshold algorithm (Javaheri et al., 2008). Sleep duration via actigraphy was calculated by observing extended periods of inactivity near the participant's self-reported bedtime and calculating the total hours of those inactive periods until arousal (Hibbs et al., 2014). Sleep efficiency was measured via actigraphy by determining the ratio between these inactive periods after bedtime versus the period of activity while still in bed (Hibbs et al., 2014).

Subjective sleep duration was measured by self-reported sleep diaries that accompanied the actigraphy. Participants recorded their bedtime and waketime on each day they wore the actigraphy. Researchers calculated the overall subjective sleep duration via a weighted average of sleep time over weekdays and the weekend (ysleeptime_hr =

5/7 *wd_slpdur_hr + 2/7*we_slpdur_hr) (National Sleep Research Resources [NSRR], n.d.).

The clinical research examination, which included overnight PSG, began at 1700 and ended at 1100 on the following day. Lights-off, indicating the beginning of the sleep period, began at 2200 and ended at 0700. Prior to PSG, the participants and their parents completed questionnaires about demographics (including race/ethnicity, assigned sex, and age), medical history, and behavioral information (Hibbs et al., 2014). To measure height and weight, research team members used a stationary stadiometer (Holtain Ltd, Pembrokeshire, UK) and a digital scale (Health-o-meter, Shelton, CT, USA), respectively. The investigators determined BMI percentiles, according to the CDC growth charts, by dividing the weight in kilograms by height in meters squared and adjusting for sex and age (Javaheri et al., 2008).

Trained team members used a cloth, inelastic tape measure to determine WC (S. Redline, personal communication, June 21, 2021).The participant stood erect with a relaxed abdomen, arms at the sides, and feet together. The measurement was assessed at the natural waist or narrowest part of the torso. In participants with limited waist narrowing (e.g., participants with obesity), the smallest horizontal circumference measured at the area between the ribs and iliac crest was used. The measurement, recorded to the nearest 0.1 cm, was taken at the end of a normal expiration, without the tape compressing the skin.

Trained nurses used a calibrated sphygmomanometer to measure BP based on the 1980 American Heart Association guidelines for human BP (Javaheri et al., 2008). Three BP readings were obtained during each BP reading, which occurred two times, once in the morning and once in the evening (Javaheri et al., 2008; NSRR, n.d.). There was a 10-minute rest period between each BP reading (Javaheri et al., 2008). The researchers calculated an average of the three BP readings collected at each time point and then averaged those two readings to determine an overall average BP (Javaheri et al., 2008).

Current Study

The current study focused on data from participants ages 16 to 18 obtained during the third exam cycle (2006–2010) of the CCSHS study. This section includes the sample, setting, measurements, and data analysis for the current study. A retrospective, cross-sectional, correlational research design using secondary data was employed to address the study aims.

Sampling and Inclusion/Exclusion Criteria

Cases were extracted from the database based on the following inclusion criteria for the current study: (a) aged 16–18 years, (b) complete actigraphy data, (c) complete sleep diary, (d) available SBP and DBP readings, and (e) available height, weight, and WC measurements. Cases were excluded if the following were absent: (a) at least 5 days of actigraphy data, (b) at least two SBP and DBP readings, and (c) an AHI greater than 5, which indicates sleep apnea.

Participants older than 18 years old were excluded because the American Academy of Sleep Medicine’s sleep duration recommendations specify a range for adolescents between 13 and 18 years old (Paruthi et al., 2016). Actigraphy data were used to determine objective sleep duration and sleep efficiency. The sleep diary information was used to determine subjective sleep duration. Average SBP and DBP readings were extracted to determine SBP and DBP. Also, height, weight, and WC data were used to determine abdominal adiposity. Previous pediatric actigraphy studies suggest that at least 5 or more nights of usable recordings are needed to obtain accurate sleep data in children and adolescents (Acebo et al., 1999). Therefore, cases with fewer than 5 days of actigraphy were excluded. The mean of two BP readings is needed to calculate an accurate BP (Mattoo & Fulton, 2019). Therefore, participants without two BP readings were excluded. Sleep apnea, diagnosed by an AHI of greater than 5, increases the incidence of elevated BP across the lifespan (Enright et al., 2003; Marcus et al., 1998). Therefore, participants with an AHI of greater than 5 were excluded in order to measure the influence of sleep duration and sleep efficiency on BP in an essentially well population without sleep apnea.

Data Extraction

Data from the CCSHS were made publicly available by the National Resource for Sleep Research (www.sleepdata.org). This is a repository of several sleep-related cohort studies funded by the National Institutes of Health (Zhang et al., 2018). After completing a proposal to access data, permission was received on February 23, 2021.

Human Subjects Protections

Approval to complete Non-Human Subjects Research from the University of Alabama at Birmingham Institutional Review Board was obtained (see Appendix A). This approval was based on having de-identified data without the ability to identify individual participants from the included data. This study fits the criteria for Non-Human Subjects Research according to the Office for Human Research Protections (OHRP, 2020).

Variable Definitions and Operationalization

The independent variables of this study are objective and subjective sleep duration and sleep efficiency. Dependent variables include SBP, DBP, and abdominal adiposity (as measured by WC and WHtR). Control variables are age, race, ethnicity, sex, and BMI percentiles.

Independent Variables

The independent variables of this study are objective sleep duration, subjective sleep duration, and objective sleep efficiency. Objective and subjective sleep duration are the number of hours spent asleep after bedtime (Ohayon et al., 2017). Subjective sleep duration is a self-report of the amount of sleep a participant thinks they had after bedtime. The measurement of objective sleep duration is derived from actigraphy data by averaging the hours of inactivity between the self-reported bedtime and waketime.

Adolescents, beginning at age 13, should obtain between 8 and 10 hours of sleep; inadequate sleep duration is less than 8 hours, and excessive sleep duration is more than 10 hours (Ohayon et al., 2017). Sleep efficiency is the ease of falling asleep and returning to sleep (Buysse, 2014). Sleep efficiency is objectively determined by using actigraphy data to measure the ratio of time spent asleep versus time in bed (Ohayon et al., 2017). Adolescents with less than 85% sleep efficiency have poor sleep efficiency (Javaheri et al., 2008; Ohayon et al., 2017).

Data from actigraphy were used to capture objective sleep duration and sleep efficiency. The precalculated actigraphy data were extracted for mean objective sleep duration and efficiency. The researchers precalculated the average subjective sleep duration using the participant's sleep diary; these data were extracted for subjective sleep duration.

Dependent Variables

The dependent variables for this study are SBP, DBP, and abdominal adiposity.

Abdominal Adiposity. For this study, abdominal adiposity was determined by WC data. Waist circumference percentiles were extracted from the data, and the WHtR was calculated. Abdominal adiposity was determined by WC percentiles and WHtR. Abdominal adiposity status was determined by the presence or absence of excess abdominal adiposity with either measure.

Waist Circumference Percentile. In the pediatric population, percentiles are often used to compare a child's growth to a national average, adjusting for sex and age. A WC percentile greater than the 90^{th} percentile is considered excess abdominal adiposity (obesity) (Bassali et al., 2010). However, excess abdominal adiposity may be present at lower percentiles, even as low as the 70^{th} percentile (Goyal et al., 2021; Katzmarzyk et al., 2004). Therefore, for this study, the cutoff for excess abdominal adiposity was the 70^{th} percentile or greater.

Waist-to-Height Ratio. WHtR was calculated using the measured WC in centimeters divided by height in centimeters. WHtR measures are consistent across all ages, sexes, races, and ethnicities (Brady, 2017). A WHtR of 0.5 or greater indicates excess abdominal adiposity (Yoo, 2016).

Blood Pressure. Averaged BP readings (average of morning and night readings combined) were extracted. Based on 2017 BP guidelines for children and youth, in adolescents greater than the age of 13, a normotensive BP reading is below 120/80 mmHg. A BP reading is considered in the elevated BP category if the BP is 120/<80 to 129/<80 mmHg (Flynn et al., 2017). There are two stages of hypertension: Stage 1, a BP reading of 130/80 to 139/89 mmHg, and Stage 2, a BP reading greater than or equal to 140/90 mmHg.

Control Variables

The control variables for this study are race, ethnicity, age, assigned sex, and BMI percentiles. The data for the participant's age, assigned sex, race, and ethnicity were extracted from the self-reported demographic questionnaires. Age was a continuous variable based on their date of birth and the examination date. Assigned sex was categorized as male or female. Race was classified as African American/Black, White, or other (Asian, Indigenous, and other), and ethnicity was Hispanic or non-Hispanic. The original investigators calculated the BMI percentiles. The BMI percentiles were categorized into weight status for those considered overweight and obese. The BMI percentiles were used to categorize participants' weight as normal weight, underweight, overweight, or obese. A BMI greater than or equal to the 85^{th} percentile but less than the 95^{th} percentile is considered overweight (CDC, 2021a). A BMI percentile greater than or equal to the 95^{th} percentile is considered obese (CDC, 2021a). A normal BMI is between the 85^{th} and 5^{th} percentile, with percentiles lower than the 5^{th} percentile considered underweight (CDC, 2021a).

Data Analysis

All data were analyzed using IBM SPSS Version 28. Descriptive statistics were calculated to determine the means, standard deviations, medians, ranges, frequencies, and proportion of each variable as appropriate. To explore the differences or relationships between the control variables with the independent or dependent variables the following analysis techniques were used: a) one-way ANOVA for race, b) *t*-tests for ethnicity and assigned sex, and c) simple linear regressions to calculate Pearson's Correlation Coefficients for age and BMI percentiles. Multiple linear regressions were conducted for the following scenarios: a) to assess if the findings from univariate analysis persisted when analyzed together (e.g., BMI percentiles and race with sleep efficiency), and b) to determine if the relationships between the dependent and independent variables persisted after controlling for the control variables. The *p*-values, effect sizes, and confidence intervals were calculated to determine scientific and clinical significance, respectively. The following section includes the data analysis for each research question, as applicable.

Aim 1: Describe sleep duration and sleep efficiency in adolescents ages 16 to 18 years who participated in the CCSHS

RQ 1.1 *What is the mean, standard deviation, median, and range for subjective sleep duration, objective sleep duration, and sleep efficiency of adolescents ages 16 to 18 years who participated in the CCSHS?*

Descriptive statistics (mean, standard deviation, median and ranges) were calculated for objective sleep duration, objective sleep efficiency, and subjective sleep duration. Univariate testing techniques, (one-way ANOVA, *t*-tests, simple linear regression), were used to assess the differences or relationships between each individual independent variable and each control variable. A multivariate model was produced to determine if the differences or relationships between the significant control variables and each respective independent variable remained significant when analyzed together.

RQ 1.2 *What categories of objective sleep duration (adequate, inadequate, and excessive) and sleep efficiency (good and poor) are present in adolescents ages 16 to 18 years who participated in the CCSHS?*

The objective and subjective sleep duration and sleep efficiency data were categorized into adequate, inadequate, or excessive sleep duration and good or poor sleep efficiency, respectively. These categories were determined by guidelines from the National Sleep Foundation (Ohayon et al., 2017). The frequencies and proportions of the categorical sleep variables were determined to describe the sample.

Aim 2: Describe blood pressure and abdominal adiposity in adolescents ages 16 to 18 years who participated in the CCSHS

RQ 2.1 *What is the mean, standard deviation, median, and range of waist circumference (WC) percentile in adolescents ages 16 to 18 years who participated in the CCSHS?*

Descriptive statistics for WC percentiles were calculated to determine the mean, standard deviation, median, and range for abdominal adiposity. In addition, univariate testing, as previously described, was used to determine the relationships between WC percentile and each control variable. A multivariate model was used to determine if the differences and relationships found between the control variables and WC percentiles were significant when analyzed together.

RQ 2.2 *What is the mean, median, standard deviation, and range of waist-to-height ratio (WHtR) in adolescents ages 16 to 18 years who participated in the CCSHS?*

Mean, standard deviation, median, and range of WHtR were calculated to describe the sample. Next, univariate statistical techniques were used to determine the differences and correlations between WHtR and each control variable. A multivariate model was produced to determine if the differences and relationships between WHtR and significant control variables persisted after examining them together.

RQ 2.3 *What categories of abdominal adiposity (not excess or excess), measured by waist circumference percentiles and waist-to-height ratio, are present in adolescents ages 16 to 18 years who participated in CCSHS?*

The WC percentiles (0.70 cutoff) and WHtR (0.50 cutoff) were recoded into categories of not excess or excess abdominal adiposity. The categorical variables were used to describe the frequency and percentage of participants not having excess or having excess abdominal adiposity in this population.

RQ 2.4 *What is the mean, standard deviation, median, and range of SBP and DBP of adolescents ages 16 to 18 years who participated in the CCSHS?*

The mean, standard deviation, median, and range for SBP and DBP were calculated to describe the sample. Univariate analyses were conducted to determine the differences and relationships between SBP and DBP with each control variable. Multiple linear models were developed to determine if the relationship between the significant control variables and SBP and DBP individually remained when analyzed together.

RQ 2.5 *What categories of SBP and DBP (i.e., normotensive, elevated BP, stage 1 hypertension, stage 2 hypertension) are evident in adolescents ages 16 to 18 years who participated in the CCSHS?*

In addition to the continuous variables of SBP and DBP percentiles, the data were recoded into BP status (normotensive, elevated BP, hypertension [stage 1 and stage 2]) according to the pediatric guidelines published in 2017 (Flynn et al., 2017; Riley et al., 2018). These categorical variables were used to describe the frequency and proportions of the BP categories present in this sample.

Aim 3: Determine the influence of objective and subjective sleep duration and sleep efficiency on abdominal adiposity and BP in adolescents ages 16 to 18 years who participated in the CCSHS, controlling for age, race, ethnicity, assigned sex, and BMI percentiles

RQ 3.1 *What is the influence of objective sleep duration, subjective sleep duration, and sleep efficiency on abdominal adiposity in adolescents ages 16 to 18 years who participated in the CCSHS, controlling for age, race, ethnicity, assigned sex, and BMI percentiles?*

Simple linear regressions were conducted to determine how much of the variance in abdominal adiposity, measured by WC percentile and WHtR individually, was influenced by objective sleep duration, subjective sleep duration, and sleep efficiency. Hierarchical multiple linear regressions were conducted to determine how much of the variance in the dependent variables was due to the independent variables when controlling for other associated variables found during Aims 1 and 2.

RQ 3.2 *What is the influence of objective sleep duration, subjective sleep duration, and sleep efficiency on BP in adolescents ages 16 to 18 years who participated in the CCSHS, controlling for age, race, ethnicity, assigned sex, and BMI percentiles?*

To determine how much of the variance in SBP and DBP was influenced by the independent variables, simple linear regressions were conducted. Next, hierarchical multiple linear regression techniques were used to determine the variance in the dependent variables attributed to the independent variables when controlling for other associated variables determined during Aims 1 and 2.

Chapter Summary

In this chapter, the methodology for this predictive study using secondary data was discussed. The data for this secondary analysis were extracted from the third stage of the Cleveland Children's Sleep and Health Study. The original researchers measured objective sleep duration and sleep efficiency with actigraphy. Subjective sleep duration was collected from the mean self-reported sleep time recorded in sleep diaries while participants wore actigraphy devices. A trained nurse collected anthropometrics and BP at the clinic visit to measure abdominal adiposity and BP. Participants over 18 signed informed consent, and participants under 18 gave assent after their parents completed informed consent. The data analysis includes descriptive statistics, inferential analysis, and effect size calculation to describe the sample and address the study's research questions.

CHAPTER 4

FINDINGS

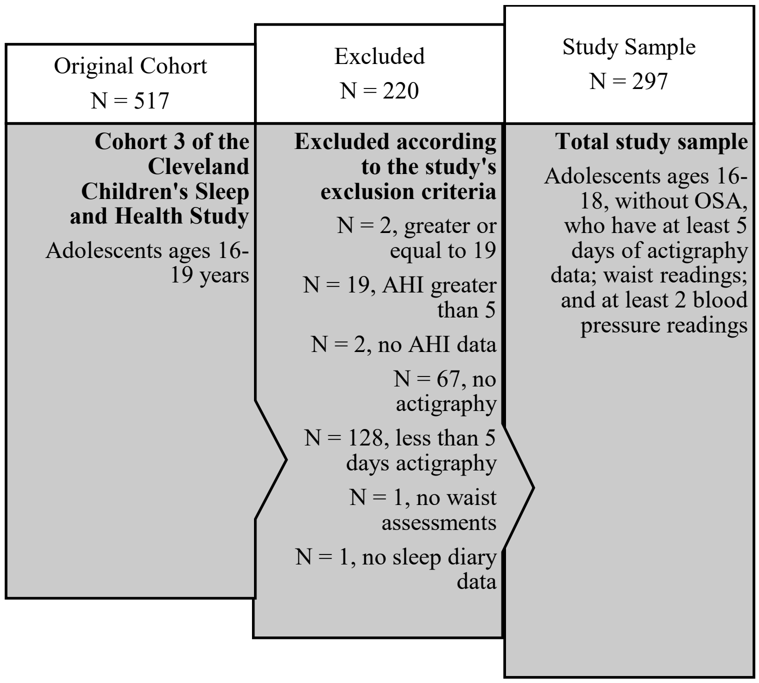
The purpose of this study was to examine the influence of sleep duration and sleep efficiency on abdominal adiposity and blood pressure in adolescents ages 16 to 18 years. The primary aim of this study was to determine how much variance in abdominal adiposity and blood pressure, respectively, was due to sleep duration or sleep efficiency when controlling for associated control variables. This chapter describes sample demographics and findings in relation to the study variables and research questions.

Sample and Setting

Eligible cases were selected from the National Sleep Research Resource Database from the third cohort of the Cleveland Children's Sleep and Health Study (*N* = 517) (Figure 5). There was a final sample of 297 adolescents after excluding 220 cases based on the following exclusion criteria: greater or equal to 19 years old (*n* = 2), obstructive sleep apnea (OSA) with an apnea-hypopnea index of greater than 5 (*n* =19), no AHI data (*n* = 2), no actigraphy (*n* = 67), less than 5 days actigraphy (*n* = 128), no waist assessments (*n* = 1), and no sleep diary data (*n* = 1). Challenges with actigraphy were the primary causes of exclusion of cases from the study.

Figure 5

Attrition Rates



Demographics

Extracted demographic data included participant age, race, ethnicity, assigned sex, and BMI percentiles. Participants were between the ages of 16.1 and 18.9 years with a mean age of 17.7±0.4 (Table 1). Most of the participants were White (63.3%), non-Hispanic (96.0%), and females (55.6%). On average and for the majority, the participants had normal BMI percentiles (64.1± 27.4, 67.7%). In the cases included, there was a mean of 6±1 days of actigraphy data, with 51.9% having 5 days of actigraphy and only 8.8% having a week of data. Based on the inclusion criteria of an AHI of less than 5, the participants had a mean AHI of 0.90± 0.98.

Table 1

Descriptive Statistics (N = 297)

Variable	*n* (%)	Mean (SD)	Median (Range)
Age (years)		17.7 (0.4)	17. 7 (16.1 – 18.9)
Race			
White	188 (63.3)		
Black	97 (32.7)		
Other	12 (4.0)		
Ethnicity			
Hispanic	12 (4)		
Not Hispanic	285 (96)		
Assigned sex			
Female	165 (55.6)		
Male	132 (44.4)		
BMI percentiles		64.1 (27.4)	67.0 (0.3 – 99.7)
Underweight	3 (1.0)		
Normal weight	201 (67.7)		
Overweight	42 (14.1)		
Obese	51 (17.2)		
AHI		0.90 (0.98)	0.57 (0 – 4.8)
Days of actigraphy		6 (1)	5 (5 – 9)

Analysis of Research Questions

Cases for the study variables were extracted from demographic, actigraphy, sleep diaries, blood pressure, and anthropometric data collected by the original investigators. In the following section, the analysis of the research questions will be discussed. The section will also include a discussion of the descriptive data for the study's independent and dependent variables (sleep duration, sleep efficiency, abdominal adiposity, and blood pressure), as a response to Aims 1 (RQ 1.1 – 1.2) and 2 (RQ 2.1 – 2.5). Cohen's (1988) definitions for effect sizes along with 95% confidence interval were used to further describe the results. Relationships were statistically significant if the *p*-value was less than 0.05. Clinically meaningful relationships for BP were indicated by a reduction of at least 2 mmHg in SBP or DBP (Mozaffarian et al., 2015). However, guidelines for clinically meaningful changes in abdominal adiposity have not been developed due to the absence of internationally acceptable cutoffs for WC percentiles and lack of exploration of the impact of WHtR (Bluher et al., 2013).

RQ 1.1 What is the mean, standard deviation, median, and range of subjective sleep duration, objective sleep duration, and sleep efficiency of adolescents ages 16 to 18 years who participated in the CCSHS?

Summary of Sleep Variables

In this sample, the average objective sleep duration measured by actigraphy ranged from 4.7 to 10.8 hours (median 7.6) with a mean of 7.6 ± 1.0 hours (Table 2). Based on the average subjective sleep duration, measured by self-reported sleep diaries, participants slept a median of 8.3 hours with a range of 4.0 to 13.9 hours and a mean of 8.4 ± 1.4 hours. Sleep efficiency for this sample ranged from 78.2% to 99.8% with a median of 97% and a mean of 96.0 ± 3.4 percent. Therefore, on average, this sample had inadequate objective sleep duration, adequate subjective sleep duration, and good sleep efficiency.

Table 2

Descriptive Statistics for Sleep Variables

Variable	*N* (%)	Mean (SD)	Median (Range)
Objective sleep duration (hours)		7.6 (1.0)	7.6 (4.7 – 10.8)
Inadequate	187 (63.0)		
Adequate	107 (36.0)		
Excessive	3 (1.0)		
Subjective sleep duration (hours)		8.4 (1.4)	8.3 (4.0 – 13.9)
Inadequate	104 (35.0)		
Adequate	168 (56.6)		
Excessive	25 (8.4)		
Sleep Efficiency (%)		96.0 (3.4)	97 (78.2 – 99.8)
Poor	5 (1.7)		
Good	292 (98.3)		

Subgroup Analysis

Objective Sleep Duration. There was a significant difference in objective sleep duration based on race ($F_{2, 294} = 8.889$, $p < 0.001$). According to Cohen's (1988) parameters for effect sizes, the relationship had a small-medium effect size ($\eta^2 = 0.057$, 95% CI [0.014, 0.111]). Post hoc tests revealed that the differences in race with objective sleep duration were only noted when comparing White adolescents' sleep duration to that of Black adolescents (mean difference = 0.499 hours, 95% CI [0.217 hours, 0.782 hours]; $p < 0.001$). White adolescents had a higher objective sleep duration than those who were Black. There was also a significant difference in objective sleep duration based on assigned sex ($t_{288} = 2.489$, $p = 0.013$). Females had a higher objective sleep duration compared to males (mean difference = 0.281 hours, 95% CI [0.059 hours, 0.503 hours]).

Differences in assigned sex and race remained significant when examined during a multiple linear regression.

Subjective Sleep Duration. There were no statistically significant differences with race, ethnicity, or assigned sex when examining subjective sleep duration. Also, age and BMI percentiles did not have any significant relationships with subjective sleep duration.

Sleep Efficiency. There were significant differences in race ($F_{2,294} = 17.248$, $p < 0.001$) and assigned sex ($t_{282} = 2.615$, $p = 0.009$) when exploring sleep efficiency. Race had a medium to large effect on sleep efficiency ($\eta^2 = 0.105$, 95% CI [0.045, 0.170]). Similar to objective sleep duration, the differences in race when exploring sleep efficiency were only present when comparing Black adolescents to White adolescents (mean difference = -2.353%, 95% CI [-1.4%, 1.3%]). White participants had the highest and Black participants had the lowest sleep efficiency. Assigned sex had a small effect on sleep efficiency. Males had poorer sleep efficiency than females (mean difference = 1.024%, 95% CI [0.3%, 1.8%]). Also, BMI percentiles had a significant, negative correlation with sleep efficiency, which had a small effect size ($r = -0.138$, 95% CI [-0.248, -0.25]); $p = 0.017$). Therefore, BMI percentiles decreased as sleep efficiency increased. Relationships between assigned sex, race, and BMI percentiles when assessing sleep efficiency remained significant when analyzed in a multiple linear regression.

RQ 1.2 What categories of objective sleep duration (adequate, inadequate, and excessive) and sleep efficiency (good and poor) are present in adolescents ages 16 to 18 years who participated in the CCSHS?

The adolescents in this sample had inadequate objective sleep duration (63.0%), adequate subjective sleep duration (56.6%), and good sleep efficiency (98.3%) (Table 2). Few participants had excessive objective (n = 3) and subjective (n = 25) sleep duration. Furthermore, few participants had poor sleep efficiency (n = 25). In addition, there were more participants who were considered to have inadequate sleep duration measured by actigraphy (n = 187) compared to sleep diaries (n = 104). In contrast, more participants reported adequate subjective sleep duration (n = 168) compared to what was captured with actigraphy for objective sleep duration (n = 107).

RQ 2.1 What is the mean, standard deviation, median, and range of waist circumference (WC) percentiles in adolescents ages 16 to 18 years who participated in the CCSHS?

The mean and standard deviation for the participants' waist circumference percentiles were 41.5 ± 30.2, which is normal abdominal adiposity (Table 3). The range was from 0.1 to 97.9, with a mean of 37.9. There was a significant difference between males and females when exploring WC percentiles (t_{295} = -6.207, p < 0.001; mean difference = -20.2, 95% CI [- 26.7, -13.6]). On average, males had higher WC percentiles compared to females. Also, BMI percentiles were found to have a large, positive correlation with WC (r = 0.787, 95% CI [0.740, 0.827]; p <0.001). The higher the BMI percentile, the higher the WC. There were no other significant relationships. Both assigned sex and BMI percentiles remained significant predictors of WC percentile when examined via a multiple linear regression.

Table 3

Descriptive Statistics for Abdominal Adiposity

Variable	*N* (%)	Mean (SD)	Median (Range)
WC percentiles		41.5 (30.2)	(37.9) 0.1 – 97.9
Not excess abdominal adiposity	229 (77.1)		
Excess abdominal adiposity	68 (22.9)		
WHtR		0.45 (0.07)	(0.4) 0.4 – 0.8
Not excess abdominal adiposity	237 (79.8)		
Excess abdominal adiposity	60 (20.2)		

RQ 2.2 What is the mean, standard deviation, median, and range of waist-to-height ratio (WHtR) in adolescents ages 16 to 18 years who participated in the CCSHS?

The average WHtR for this sample was 0.45 ± 0.07, with a range of 0.4 to 0.8 and a median of 0.4, which is not considered excess abdominal adiposity. Bivariate analysis suggested that only BMI percentiles had a significant correlation with WHtR ($r = 0.752$, 95% CI [0.698, 0.798]; $p < 0.001$). The relationship was large and positive, which means that WHtR increased as BMI percentiles increased.

RQ 2.3 What categories of abdominal adiposity (not excess or excess), measured by waist circumference percentiles and waist-to-height ratio, are present in adolescents ages 16 to 18 years who participated in CCSHS?

Most of this sample did not have excess abdominal adiposity measured by WC percentiles (77.1%) or WHtR (79.8%). Of the 24.3% of adolescents with excess abdominal adiposity, 5.4% had excess adiposity based on one measure, and 18.9% had excess abdominal adiposity on more than one measure. Eight more participants were categorized by WC percentiles versus WHtR, which may mean that WC percentiles are a more sensitive measure of abdominal adiposity (Table 3).

RQ 2.4 What is the mean, standard deviation, median, and range of systolic and diastolic BP of adolescents ages 16 to 18 years who participated in the CCSHS?

Summary of Blood Pressure Variables

In this sample, the mean SBP was 115 ± 10 mmHg, and the mean DBP was 64 ± 9 mmHg, which are both considered normotensive. The range for SBP was 90 to 160 mmHg (114 median) and 39 to 91 mmHg for DBP (64 median).

Subset Analysis

Systolic Blood Pressure. There were differences in systolic blood pressure based on assigned sex ($t_{287} = -7.80$, $p < 0.001$). The mean difference between assigned sex was -7.8 mmHg (95% CI [0.1 mmHg, 0.33 mmHg]). Males had the highest mean SBP (118.8 ± 8.4 mmHg). Also, BMI percentiles had a significant, positive relationship with SBP and a small to medium effect size ($r = 0.223$, 95% CI [0.112, 0.329]); $p < 0.001$). Therefore, as BMI percentiles increased, so did SBP. There were no other relationships with SBP. The relationships between BMI percentiles and assigned sex with SBP remained significant after completing a multiple linear regression.

Diastolic Blood Pressure. There was a difference in DBP between females and males ($t_{295} = -2.188$, $p = 0.029$). The mean difference in assigned sex was – 2.2 mmHg (95% CI [-4.1mmHg, -0.2 mmHg]). Males had the highest mean DBP (65.2 ± 9.4 mmHg). No other factors were found to have significant relationships with DBP.

RQ 2.5 What categories of SBP and DBP (i.e., normotensive, elevated BP, stage 1 hypertension, stage 2 hypertension) are evident in adolescents ages 16 to 18 years who participated in the CCSHS?

The majority of this sample had a normotensive DBP (96.6%) and SBP (72.4%) (Table 4). Only 4.4% and 0.3% of the participants had HTN as measured by SBP and DBP, respectively. Therefore, on average, this sample was homogenous, with a majority having a normal BP measured by both SBP and DBP.

Table 4

Descriptive Statistics for Blood Pressure

Variable	*N* (%)	Mean (SD)	Median (Range)
SBP (mmHg)		115 (10)	114 (90 – 160)
Normal	215 (72.4)		
Elevated BP	69 (23.2)		
Stage 1	11 (3.7)		
Stage 2	2 (0.7)		
DBP (mmHg)		64 (9)	64 (39 – 91)
Normal	287 (96.6)		
Elevated BP	9 (3)		
HTN	3 (0.3)		

RQ 3.1 What is the influence of objective sleep duration, subjective sleep duration, and sleep efficiency on abdominal adiposity in adolescents ages 16 to 18 years who participated in the CCSHS, controlling for age, race, ethnicity, assigned sex, and BMI percentiles?

Sleep efficiency had a negative correlation with WHtR (r = -0.147, 95% CI [-0.257, -0.034]; p = 0.011). This relationship had a small effect size. Therefore, in this sample, as sleep efficiency decreased, WHtR increased. The other relationships between the sleep variables and abdominal adiposity measures were not significant (Table 5). Sleep efficiency no longer had a significant relationship with WHtR when controlling for race, assigned sex, and BMI percentiles (β = -0.046, p = 0.268) (Table 6). This sample did not allow for age and ethnicity to be included in these models due to their lack of variability and sample size, respectively. Sleep efficiency, race, assigned sex, and BMI percentiles accounted for over 56% of the variance in WHtR. After including sleep efficiency in the model, the variance did not change. Therefore, sleep efficiency did not account for any of the variance with WHtR in this model.

Table 5

Correlation Matrix for Abdominal Adiposity and Sleep Variables

	Pearson's r (95% CI)				
	1	2	3	4	5
1.Objective Sleep Duration	1				
2.Subjective Sleep Duration	0.317* (0.211, 0.416)	1			
3.Sleep Efficiency	0.195* (0.083, 0.302)	-0.100 (-0.211, 0.014)	1		
4.WC Percentiles	-0.094 (-0.206, 0.020)	-0.029 (-0.142, 0.085)	-0.113* (-0.223, -0.001)	1	
5.WHtR	-0.082 (-0.194, 0.032)	-0.022 (-0.135, 0.092)	-0.147* (-0.257, -0.034)	0.855* (0.821, 0.883)	1

*$p < 0.05$

Table 6

Hierarchical Multiple Linear Regression Between Sleep Efficiency and WHtR

Model	Unstandardized B	Standard Error	Beta Coefficient	Sig.	95% CI for B
			Model 1		
Constant	0.334	0.007		<0.001	[0.319, 0.348]
Other	-0.005	0.013	-0.015	0.705	[-0.031, 0.021]
Black	0.001	0.006	0.005	0.895	[-0.010, 0.012]
White – Reference	-	-	-	-	-
Female	0.002	0.005	0.018	0.643	[-0.008, 0.013]
Male – Reference	-	-	-	-	-
BMI Percentiles	0.002	0.000	0.752	<0.001	[0.002, 0.002]
			Model 2		
Constant	0.424	0.082		<0.001	[0.263, 0.585]
Sleep Efficiency	-0.001	0.001	-0.046	0.268	[-0.003, 0.001]
Other	- 0.006	0.013	-0.018	0.640	[-0.033, 0.020]
Black	-0.001	0.006	-0.010	0.814	[-0.013, 0.010]
White – Reference	-	-	-	-	-
Female	0.001	0.005	0.011	0.784	[-0.009, 0.012]
Male – Reference	-	-	-	-	-
BMI Percentiles	0.002	0.000	0.746	<0.001	[0.002, 0.001]

Note. Model 1: Adjusted R^2 = 0.561; Model 2: Adjusted R^2 = 0.561

RQ 3.2 What is the influence of objective sleep duration, subjective sleep duration, and sleep efficiency on BP in adolescents ages 16 to 18 years who participated in the CCSHS, controlling for age, race, ethnicity, assigned sex, and BMI percentiles?

Sleep efficiency had a significant, negative relationship with SBP (r = -0.210, $p <$ 0.001). This relationship also had a small-medium effect size (95% CI [-0.316, 0.098]). In this sample, as sleep efficiency decreased, SBP increased. No other relationships between the sleep and BP variables were significant (Table 7). The relationship between sleep efficiency and SBP was no longer significant or clinically meaningful after controlling for sleep efficiency, assigned sex, race, and BMI percentiles (β = -0.106, p = 0.057) with a small-medium effect size (r^2 = 0.218; 95% CI [0.034, 0.105]) (Table 8). This sample did not allow for age and ethnicity to be included in these models due to their lack of variability and sample size, respectively. Over 21% of the variance in SBP was explained by assigned sex, race, and BMI percentiles. Adding sleep efficiency to the model only increased the variance by 0.7%. Therefore, most of the variance in SBP was explained by the control variables but not by sleep efficiency.

Table 7

Correlation Matrix for Blood Pressure and Sleep Variables

	Pearson's ***r*** (95% CI)				
	1	2	3	4	5
1. Objective sleep duration	1				
2. Subjective sleep duration	0.317* (0.211, 0.416)	1			
3. Sleep efficiency	0.195* (0.083, 0.302)	-0.100 (-0.211, 0.014)	1		
4. SBP	-0.107 (-0.218, 0.007)	0.094 (-0.020, 0.206)	-0.210* (-0.316, -0.098)	1	
5. DBP	-0.110 (-0.221, 0.004)	-0.069 (-0.182, 0.045)	-0.024 (-0.138, 0.090)	0.458* (0.363, 0.543)	1

*p < 0.05

Table 8

Hierarchical Multiple Linear Regression Between Sleep Efficiency and SBP

Model	Unstandardized B	Standard Error	Beta Coefficient	Sig.	95% CI for B
			Model 1		
Constant	105.629		1.363	<0.001	[102.947,108.312]
Other	0.130	0.003	2.523	0.959	[-4.835, 5.095]
Black	1.846	0.091	1.061	0.083	[-0.242, 0.934]
White – Reference	-		-	-	-
Female	7.779	0.406	0.990	<0.001	[5.831, 9.727]
Male – Reference	-		-	-	-
BMI percentiles	0.074	0.213	0.018	<0.001	[0.039, 0.110]
			Model 2		
Constant	134.889		15.402	<0.001	[104.575, 165.204]
Sleep Efficiency	-0.298	-0.106	0.156	0.057	[-0.606, 0.010]
Other	- 0.260	-0.005	2.520	0.918	[-5.219, 4.699]
Black	1.153	0.057	1.117	0.406	[-1.045, 3.352]
White – Reference	-	-	-	-	-
Female	7.465	0.390	0.999	<0.001	[5.499, 9.431]
Male – Reference	-	-	-	-	-
BMI percentiles	0.070	0.018	0.018	<0.001	[-0.606, 0.010]

Note. Model 1: Adjusted $R^2 = 0.211$; Model 2: Adjusted $R^2 = 0.218$

Chapter Summary

In this chapter, the findings from the data analysis were included. *P*-values, effect sizes, and confidence intervals were calculated. This sample included 297 adolescents who were a mean age of over 17, and the majority of whom were females, White, non-Hispanic, with normal BMI percentiles. On average, the participants had inadequate objective sleep duration, adequate subjective sleep duration, and good sleep efficiency.

Objective sleep duration had a relationship with race and assigned sex. Subjective sleep duration did not have any relationships with the control variables. Sleep efficiency had a significant relationship with BMI percentiles, race, and assigned sex.

This sample also had a mean SBP and DBP that reflected normal blood pressure. There were differences in SBP and DBP based on assigned sex. SBP also had a positive relationship with BMI percentiles. For abdominal adiposity, measured by both WHtR and WC percentiles, on average the participants did not have excess abdominal adiposity. Body mass index percentiles were also associated with both WC percentiles and WHtR. There were differences between females and males when assessing WC percentiles.

When examining the relationships between the independent and dependent variables, the only significant relationships occurred between sleep efficiency and SBP and between sleep efficiency and WHtR. Sleep efficiency had a small effect on and a negative relationship with SBP that did not remain after controlling for race, sex assigned at birth, and BMI percentiles. As sleep efficiency decreased, SBP increased. Sleep efficiency also had a negative association with WHtR; as sleep efficiency decreased, WHtR increased. This relationship had a small effect size and did not remain after controlling for race, assigned sex, and BMI percentiles.

CHAPTER 5

DISCUSSION

The purpose of this correlational, secondary data analysis was to explore the influence of sleep duration and sleep efficiency on abdominal adiposity and blood pressure in adolescents ages 16 to 18 years. In this chapter a discussion of the study's findings, which includes the sample, setting, demographics, study variables, and relationships among the research questions, is included. This chapter also describes study limitations, implications for practice and policy, and recommendations for future research.

Sample, Setting, and Demographics

In this study, 297 cases were included, which is comparable to previous studies examining the relationships among sleep duration, sleep efficiency, abdominal adiposity, and blood pressure in adolescents (Javaheri et al., 2008; Mezick et al., 2012). However, there were studies that had larger sample sizes ranging from 489 to 4,104 (Cespedes Feliciano et al., 2018; Narang et al., 2012; Paciencia et al., 2016; Shaikh et al., 2010; Skidmore et al., 2013). Larger sample sizes can allow for examining associations. However, studies with larger sample sizes may not include data on objective sleep measures, such as actigraphy or PSG, due to expense. The setting for the parent study was in the midwestern U.S. (Ohio), a similar setting to that of the study conducted by

Javaheri and colleagues (2008), which included the current study participants at younger ages. Furthermore, few studies have focused on these variables within the U.S. (Cespedes Feliciano et al., 2018; Javaheri et al., 2008; Meininger et al., 2014). Other studies on these variables were conducted in Canada, China, Australia, India, New Zealand, and Portugal (Guo et al., 2011; McNeil et al., 2015; Narang et al., 2012; Shaikh et al., 2010; Short et al., 2012; Skidmore et al., 2013). Demographics can be different based on the country and the part of each country, especially in the U.S.; geographical, cultural, and environmental differences in the U.S. could impact sleep differently than in other countries. Therefore, there is a need for studies based in the United States, and this study adds to the literature in that area.

This sample included late adolescents ages 16 to 18 years; however, most of the participants were around age 17 (mean age 17.7±0.4). Previous research addressing the study variables during late adolescence (ages 16-18) had a mean age of 16 years (Al-Hazzaa, 2014; Brandalize et al., 2011; Javaheri et al., 2008), and few studies included participants over the age of 17 (Al-Hazzaa et al., 2012; Guo et al., 2011; Shaikh et al., 2010; Short et al., 2012). Studies that included but did not separate or focus on late adolescents tended to also include participants from the school-aged population (ages 6-12) and early adolescence (ages 13-15) (Azadbakht et al., 2013; Brandalize et al., 2011). Including several developmental groups in one study without separate analysis for each group impacts the ability to determine the effect of specific developmental periods on the relationships.

Evidence suggests that older adolescents, usually 16 to 18 years of age, have the highest prevalence of inadequate sleep duration (Wheaton et al., 2018). Also, the instance of excess abdominal adiposity and elevated blood pressure increases with age, with the highest prevalence in late adolescence (Hardy et al., 2021; Muntner et al., 2004; Wells et al., 2008). Furthermore, older adolescents tend to have more autonomy than younger children in developing their daily schedules, including bedtime and evening activities, which can impact their sleep duration and sleep efficiency (Laberge et al., 2001). In this study, only older adolescents were included to determine the influence of sleep duration and sleep efficiency on abdominal adiposity and blood pressure in late adolescence.

Most of the participants in this sample were female. The initial database before exclusion criteria were applied included a more even sample of males and females; however, more male cases were excluded, due to issues with actigraphy data; an AHI of > 5, which is indicative of OSA; or a lack of anthropometric data. Prior studies focusing on sleep duration, sleep efficiency, blood pressure, and abdominal adiposity in adolescents tend to have a higher percentage of males or a more equal distribution of participants across assigned sex (Cespedes Feliciano et al., 2018; Narang et al., 2012; Short et al., 2012; Skidmore et al., 2013). Furthermore, evidence suggests that some relationships between sleep duration and abdominal adiposity and between sleep duration and blood pressure were only noted in males (Guo et al., 2011; Paciencia et al., 2016; Skidmore et al., 2013). Therefore, with the preponderance of female cases, it is possible that some relationships were not identified because they are more prominent in males.

This sample had a higher percentage of White participants, which was nationally representative (51% of U.S. adolescents are white) (Office of Population Affairs [OPA], n.d.). However, this sample had more Black participants (32.7%) than the national average of 14% (OPA, n.d.). It is difficult to compare these findings to other studies;

studies based in other countries did not capture race because those study settings did not have the racial diversity found in the U.S. In the few studies conducted within the U.S., there was a higher prevalence of White participants in two studies (Cespedes Feliciano et al., 2018; Javaheri et al., 2008). However, one study included a higher percentage of ethnic and racial minorities (e.g., Hispanic, Black) (Countryman et al., 2013). Mezick and colleagues (2012) included a somewhat equal proportion of Black and White adolescents since they wanted to assess racial differences; yet there tended to be a higher prevalence of Black adolescents.

In addition to somewhat disproportionate representation in sex and race, there was a higher prevalence of non-Hispanic participants in this study. However, due to there being such a high percentage of participants who were non-Hispanic (96%), the differences in the independent and dependent variables based on ethnicity could not be analyzed. The concept of Hispanic or not Hispanic as a measure of ethnicity is more central to the U.S. However, few studies within the U.S. examined ethnicity while exploring the relationships among sleep duration, sleep efficiency, abdominal adiposity, and BP. Those few studies revealed a higher prevalence of non-Hispanic participants (Cespedes Feliciano et al., 2018; Meininger et al., 2014).

The average BMI percentile for this study was 64.1, which is considered normal weight. The prevalence of obesity in this population was 17.2%, which is less than the national prevalence of 20.6% for adolescents 12 to 19 years from 2015 to 2018, based on National Health and Nutrition Examination Survey (NHANES) data (Sanyaolu et al., 2019). This sample overall was cardiometabolically healthy; therefore, it is not surprising that there were few adolescents considered obese by BMI. Also, it is notable that the findings suggest that more participants had excess abdominal adiposity, considered obesity (WC percentiles – 22.9%; WHtR – 20.2%), than those categorized as obese by BMI percentiles (17.2%). This finding is similar to those by Solanki and colleagues (2020), who found a higher prevalence of excess abdominal adiposity in late adolescents who had a normal BMI.

Study Variables

Sleep Duration

Both objective and subjective sleep duration were included in this study; these variables were also addressed in studies by Cespedes Feliciano et al. (2018) and Short et al. (2012). Subjective sleep duration is often overestimated, so measuring objective sleep duration can help confirm amount of sleep (Quist et al., 2016; Short et al., 2012). On average, the sample in this study had inadequate objective sleep duration, a finding also noted in other studies in the late adolescent population (Mezick et al., 2012; Short et al., 2012). However, few studies focus specifically on late adolescence. Many studies (Au et al., 2014; Felden et al., 2016; Seo & Shim, 2019; Sung et al., 2008; 2011; Yu et al., 2007) tend to include school-aged children and adolescents, two developmental groups with different parameters for inadequate sleep duration (adolescents less than 8 hours, school-aged children less than 9 hours). It is easy to underestimate or overestimate inadequate sleep duration when examining two developmental groups together. Therefore, in this study, focus only on late adolescence allowed the exact parameters for sleep duration to be assessed.

The average objective sleep duration for this sample was a little over 7 hours, which is considered inadequate sleep duration and is congruent with other studies that examined sleep duration (Cespedes Feliciano et al., 2018; Short et al., 2012). For subjective duration, the average was slightly over 8 hours, which is considered adequate sleep duration. Previous studies also reported an adequate subjective sleep duration of slightly over 8 hours in adolescents (Narang et al., 2012; Paciencia et al., 2016; Short et al., 2012). However, some studies have reported subjective sleep durations slightly over 7 hours, which would be considered inadequate sleep duration (Al-Hazzaa et al., 2012). The participants in this study tended to report a higher subjective sleep duration versus the objective sleep duration obtained by actigraphy. Short and colleagues (2012) presented similar findings when they compared subjective and objective sleep duration measured via sleep diaries and actigraphy, respectively. Thus, it is important to capture objective and subjective sleep duration because the two measures tend to differ (Short et al., 2012). One measure could show adequate sleep duration when the participant actually had inadequate sleep duration. These differences are typically due to adolescents not being aware of what time they actually fall to sleep or not recalling nighttime awakenings, which can shorten the objective sleep duration (Quist et al., 2016).

Sleep Efficiency

The participants in this sample on average had a sleep efficiency of 96%, which is good sleep efficiency (greater than or equal to 85%). This is different than the few studies (Cespedes Feliciano et al., 2018; Mezick et al., 2012) that found a lower sleep efficiency. Javaheri and colleagues (2008) found a similar sleep efficiency in a younger cohort of the participants used in this sample. There are limited studies that measure sleep efficiency in the pediatric population, perhaps because of the decreased access to actigraphy and PSG needed to measure sleep efficiency. Thus, it is difficult to compare these findings with those of other studies.

Blood Pressure

The average SBP for this sample was 115 mmHg (less than 120 is normotensive), and the average DBP was 64 mmHg (less than 80 is normotensive). These findings were slightly higher than the national average for 13- to 17-year-olds based on the NHANES (SBP – 108.4; DBP – 60.8) data from 2015-2018 (Hardy et al., 2021). Although the mean BP for the NHANES data and this current study are considered normotensive, the average SBP for this population is closer to the parameters for elevated BP (120 mmHg). The NHANES data found that over 8% of adolescents ages 13 to 17 had elevated BP, which was less than the 23% of participants with elevated SBP and higher than the 3% of the participants who had elevated DBP in this study. However, the NHANES data did not separate the BP findings by SBP and DBP.

In comparison to studies that examined the relationships among sleep duration, sleep efficiency, and BP, the mean SBP for this current study was similar (Paciencia et al., 2016; Shaikh et al., 2010). Paciencia and others (2016) reported a comparable DBP as the current study. However, other studies found a higher average DBP that was still qualified as normotensive (Mezick et al., 2012; Shaikh et al., 2010). In this sample, our participants on average had normotensive SBP and DBP, which is consistent with previous studies in this population (Mezick et al., 2012; Shaikh et al., 2010).

Abdominal Adiposity

In this sample, most participants did not have excess abdominal adiposity as measured by WC percentiles or WHtR. The mean WC percentile was the 41st percentile, (70th percentile is excess), and the mean WHtR was 0.45 (0.50 is excess). These findings are comparable to those of previous studies that reported most participants did not have excess WC (Cespedes Feliciano et al., 2018; Narang et al., 2012; Shaikh et al., 2010) or excess WHtR (Al-Hazzaa et al., 2012).

Studies that capture WC percentile (Cespedes Feliciano et al., 2018; Narang et al., 2012; Shaikh et al., 2010) tend to categorize the findings into less than or greater than certain percentile ranges or only report the raw waist reading in centimeters. A systematic review of excess abdominal adiposity in adolescents revealed that there are differences in the prevalence of excess abdominal adiposity based on geographic location, cutoff points, and measurements (de Moraes et al., 2011). For instance, NHANES data had a cutoff of the 90th percentile; however, evidence suggests that excess abdominal adiposity can be present at the 70th percentile. The NHANES data, considered representative of the United States, showed that between 2011 and 2012, 18.78% of adolescents ages 12 to 18 had excess abdominal adiposity measured by a WC greater than or equal to the 90th percentile (Xi et al., 2014). However, 35.59% of the NHANES participants had excess abdominal adiposity measured by a WHtR greater than or equal to 0.5 (Xi et al., 2014). Since data for the current study were collected around the time of the NHANES data, this sample had higher excess WC percentiles and lower excess WHtR compared to the national averages. Furthermore, the NHANES findings contradict those from this study indicating that WC percentile categorized more participants as having excess abdominal adiposity compared to WHtR (WC percentiles – 22.9%; WHtR – 20.2%).

Relationships Among the Research Questions

Control Variables

As predicted, race, assigned sex, and BMI percentiles were associated with different primary variables and should still be considered as control variables in future studies. However, they were not associated with every variable. Race was only associated with objective sleep duration and sleep efficiency. Black adolescents had lower objective sleep duration and poorer sleep efficiency than White adolescents. These findings are similar to those found in a literature review by Guglielmo and colleagues (2018). Specifically, Rao and colleagues (2009) found that Black adolescents had a higher prevalence of poor sleep efficiency compared to those who were White. Several studies found racial differences when assessing sleep duration (Basch et al., 2014; Eaton et al., 2010; Keyes et al., 2015; Maslowsky et al., 2014; Matthews et al., 2014). Overall, White adolescents had a longer sleep duration than Black adolescents (Guglielmo et al., 2018).

Assigned sex was associated with objective sleep duration, sleep efficiency, SBP, DBP, and WC percentiles. In the current study, females had a higher objective sleep duration and sleep efficiency, and males had higher SBP, DBP, and WC percentiles.

Evidence suggests that objective sleep duration is higher in male adolescents than females, which contradicts the findings of this study (Guedes et al., 2016). Conversely, Matthews and others (2014) found that males had a lower objective sleep duration than females, which is similar to results found in the current study. A study in young adults (ages 18-30 years) found that females had a better sleep efficiency than males, which is consistent with the findings in the current study (Goel et al., 2005). Wang and colleagues (2006) found that males had higher SBP and DBP in a 15-year longitudinal study, supporting the current study's findings. In relation to WC percentiles, females have lower abdominal adiposity than males (Kuk & Lee, 2019; Lee et al., 2008).

In this study, BMI percentiles were associated with sleep efficiency, SBP, WC percentiles, and WHtR. Sleep efficiency had a negative correlation with BMI percentiles, and the relationship had a small effect size. These findings were similar to those found by Bagley and El-Sheikh (2013), who found a negative relationship between sleep efficiency and BMI in school-aged children. Also, in young adults (21-35 years old), there was a negative relationship between sleep efficiency and BMI percentiles (McMahon et al., 2019). In the current study, there was also a negative correlation between BMI percentiles with SBP, and the effect size was small. The relationship between BMI percentiles and SBP was similar to that found by Javaheri and colleagues (2008) and Kuciene and Dulskiene (2014), who reported that adolescents who tended to have higher BMI percentiles also had higher BP. Kuciene and Dulskiene (2014) also found that BMI had a positive association with WC and WHtR in adolescents, which coincides with the positive relationships and large effect size found between these variables in the current study.

Despite the previous review of the literature that supported age and ethnicity as control variables in this study, there was not enough variability in age or ethnicity to be assessed during analysis. In future studies, age may not need to be included as a control variable, since the range is so narrow. However, ethnicity should be considered a control variable in future studies because evidence suggests that there are differences based on ethnicity, especially between those who are Hispanic and non-Hispanic (Rao et al., 2009; Tsao et al., 2022; Virani et al., 2021).

Blood Pressure

In this study, sleep efficiency had a negative relationship with SBP. However, this relationship did not remain after controlling for race, assigned sex, and BMI percentiles. Similar findings were noted in the studies by Cespedes Feliciano et al. (2018) and Javaheri et al. (2008) when examining sleep efficiency and SBP in adolescents. However, those studies did not focus on older adolescents. Cespedes Feliciano and colleagues (2018) included older adolescents, but the maximum age for participants was 16.6 years. Mezick and colleagues (2012) examined the relationship between sleep efficiency and BP in 14- to 19-year-olds but did not find relationships between the two variables. Further, Mezick and colleagues (2012) also controlled for race, assigned sex, and BMI percentiles and did not find that the sleep variables contributed significantly to the model. A majority of the variance in SBP was attributed to assigned sex and BMI percentiles. It may be that these relationships are only noted in females, in males, or in certain BMI percentiles. Furthermore, the average SBP for this sample was normotensive. So, the association of sleep efficiency and BP may only be present in individuals with elevated BP after controlling for race, assigned sex, and BMI percentiles.

This study did not find any relationships between sleep efficiency and DBP or between sleep duration and any of the BP variables. However, earlier studies in older adolescents found negative relationships between sleep duration and blood pressure (Countryman et al., 2013; Mezick et al., 2012; Paciencia et al., 2016) and between sleep efficiency and DBP (Javaheri et al., 2008). Yet, Guo and colleagues (2011) only found a relationship between sleep duration and BP in school-aged and young adolescent boys. Therefore, a relationship between sleep duration and BP may only be found at a certain age or with a certain assigned sex. Furthermore, the majority of this sample was normotensive; therefore, it is probable that associations with BP were not found because it is only present in those with elevated BP or HTN. Also, some studies only focused on the relationship between sleep efficiency and SBP (Cespedes Feliciano et al., 2018) because relationships are usually found with SBP rather than DBP (Lewington et al., 2002). Consequently, it may be that DBP is rarely correlated with diseases or risks related to elevated BP in comparison with SBP in late adolescents (Lewington et al., 2002).

Abdominal Adiposity

In this study, a negative relationship between sleep efficiency and WHtR was noted. Yet, this relationship did not persist after accounting for BMI percentiles, race, and assigned sex. Although McNeil and colleagues (2015) found a negative relationship between sleep efficiency and WHtR in young children and adolescents, there were no studies that specifically examined this relationship during late adolescence. In a study examining sleep efficiency with truncal fat, Cespedes Feliciano and others (2018) found that, in adolescents, sleep efficiency was associated with truncal fat, measured by a bone density scan (DXA), a more direct measure of abdominal adiposity. In the current study, most of the variance in WHtR was attributed to BMI percentiles. This finding may be due to the use of BMI percentiles and WHtR to measure the same concept, which is plausible since evidence suggests that WHtR is a better marker of overall adiposity in the pediatric population (Nambiar et al., 2010). Conversely, BMI percentiles may be a mediator, or the relationship between the variables may only be present in certain BMI percentile ranges (e.g., overweight, obese).

Even though a relationship between sleep efficiency and WC percentiles was not found in this study, other studies (Cespedes Feliciano et al., 2018; McNeil et al., 2015) noted a negative relationship between sleep efficiency and WC percentiles in school-aged children and adolescents. In this study, no relationships between sleep duration and WC percentiles or WHtR were noted. However, previous studies have found negative relationships between sleep duration and WC (Narang et al., 2012; Shaikh et al., 2010) or WHtR (Al-Hazzaa et al., 2012). In a study by Skidmore and colleagues (2013), there was only a negative relationship with WC and WHtR in adolescent boys. Similar findings may have been absent in the current study because participants had normal WC percentiles. Therefore, it may be that these relationships only exist in certain assigned sex or in younger adolescents (the mean age in the study by Skidmore et al. was 15.8 years). Also, most of the current study's sample did not have excess abdominal adiposity. It is possible that the relationships between these variables are only present in those with excess abdominal adiposity.

Conceptual Framework

The results of the study partially supported the conceptual framework because the relationships between sleep efficiency and WHtR and between sleep efficiency and SBP were significant. However, these relationships did not remain after controlling for BMI, race, and assigned sex, which indicates that those control variables may need to be considered moderators in the conceptual framework. Even though there were no significant findings between sleep efficiency and the other variables, the conceptual framework should still include abdominal adiposity and BP in its entirety. It is possible that the other relationships were not present because the majority of the population had normotensive DBP and normal WC percentiles. Furthermore, no relationships among sleep duration, abdominal adiposity, and BP were noted. Relationships among these variables may not have been observed because this sample had adequate subjective sleep duration, normotensive blood pressure, and a lack of excess abdominal adiposity. The variables should still be included in the conceptual framework and tested with a population that has a more heterogenous profile for sleep duration, abdominal adiposity, and blood pressure. It is also important to include both subjective and objective sleep duration since this study found differences between the two measures.

Relationships with all control variables within the conceptual framework were not supported. Only race, assigned sex, and BMI percentiles had relationships with the study variables and impacted the relationships between the predictor and outcome variables. The age range of the sample was very narrow; therefore, the impact of the variable could not be assessed. Furthermore, this sample was majority non-Hispanic, so the impact of ethnicity could not be examined. Yet, evidence suggests that age (Campbell et al., 2012; Reinehr & Toschke, 2009) and ethnicity (Jean-Louis et al., 2015; Rao et al., 2009; Schiller et al., 2012) have a relationship with these variables. Therefore, age and ethnicity should remain in the conceptual framework, and a future study can examine the relationships among these variables in a more heterogenous sample in terms of age and ethnicity.

Limitations

The primary limitation of this study was the lack of variability in the data. Although the sample size for the study was similar to those of previous studies and allowed testing of hypotheses, there was an absence of variability in sleep efficiency, sleep duration, and abdominal adiposity data. Not having variability in the data eliminated some opportunities to determine if the relationships among the variables exist when the variables are abnormal (e.g., poor sleep efficiency, excess abdominal adiposity). Most participants had normal sleep efficiency, adequate sleep duration by self-report, and inadequate sleep duration by objective measures. However, few participants had excessive objective or subjective sleep duration or poor sleep efficiency. Therefore, the full continuum of sleep duration and sleep efficiency could not be assessed. It is possible that the relationships between the variables existed among those whose sleep duration, sleep efficiency, abdominal adiposity, and blood pressure were not captured in this sample (e.g., excessive sleep duration).

Location was another limitation of this study. This study was conducted in Ohio in the midwestern United States; therefore, it is possible that the relationships only exist in areas with higher prevalence of poor sleep and cardiometabolic health, like the southern United States (Matthews et al., 2017). Furthermore, data on geographic location (rural/urban) were not available. Although Cleveland, Ohio, is an urban area, participants could have resided in rural areas and still participated in the study. There are differences in sleep, abdominal adiposity, and BP based on geographical location (Matthews et al., 2017).

Beyond heterogeneity in the primary variables, this study lacked variability in ethnicity. Evidence suggests that Hispanic populations have a higher prevalence of abdominal adiposity and blood pressure (Virani et al., 2021). However, a majority of this population (96%) were not Hispanic. Therefore, the impact of ethnicity on the variables could not be assessed. It is possible that the relationships between the predictor and outcome variables only existed in those who were ethnically Hispanic.

Another limitation of this study was the lack of details about the actigraphy data. The current study averaged 5 days, which is the period of time needed to validate actigraphy data; however, 5 days of both weekday and weekend days may not offer the best representation of a participant's average weekly sleep duration, especially during adolescence. Information about this sample did not include how many days were weekend or weekday sleep. Since catch-up sleep, often done on the weekends, occurs frequently in adolescence, there is a potential for the actigraphy data to be skewed if participants slept significantly longer on the weekends (Chung et al., 2020).

There have also been differences in the worldwide environment since these data were initially collected. The most notable event has been the COVID-19 pandemic. The pandemic has altered the daily schedules and habits of the pediatric population, including older adolescents, which could impact their sleep duration, sleep efficiency, abdominal adiposity, and blood pressure (Bates et al., 2020). Therefore, the relationships among these variables using a more current sample may be significantly different.

Implications for Clinical Practice and Policy

The findings from this study support the importance of measuring both objective and subjective sleep duration. Adolescents tend to overreport their sleep duration, and as the findings suggest, there is a difference in subjective and objective sleep duration (Short et al., 2012). This is important because, even if an adolescent reports adequate subjective sleep duration, it is possible for them to have objectively inadequate sleep duration. If an adolescent self-reports inadequate sleep duration, it is important for health providers to consider referring them to a sleep specialist for further evaluation. However, it is also important that all pediatric patients and their parents receive sleep education at least during their annual visit.

Health care providers also need to be aware of the need to measure abdominal adiposity in addition to a BMI reading. As previously mentioned, in this sample there was a higher prevalence of excess abdominal adiposity than of obesity measured by BMI percentiles. Furthermore, abdominal adiposity should be measured via several measurements, including WC percentiles and WHtR, because some participants had excess abdominal adiposity based on one measurement but not the other.

The findings of this study also support the need for some policy changes. Policies should be developed to support consistent sleep health evaluations, which include sleep questionnaires to examine one's subjective sleep health and their sleep hygiene (i.e., Children's Report of Sleep Patterns) during primary care visits. Annual sleep health evaluations could potentially capture abnormal sleep health before causing any long-term impacts on health. There is also a need for policies to support education on improving sleep duration in multiple environments often frequented by adolescents and their parents (e.g., school, workplace, community buildings), which can help build a higher chance for the knowledge to be seen and shared. Sleep education is needed because the sample in this study on average had inadequate sleep duration, which has relationships with other health and behavior outcomes (e.g., anxiety, depression, academic performance) (Short et al., 2020; Tonetti et al., 2015). Policies could include adding sleep education to yearly training for educators and including it in core curriculum for students each school year. Also, there is a need for a policy that supports health care providers in measuring abdominal adiposity along with BMI percentiles, since there is potential for a person to have excess abdominal adiposity despite a normal BMI percentile. This is important since evidence suggests that abdominal adiposity is risk factor for CVD (Virani et al., 2021). These policies not only apply to an adolescent's current lifestyle, but they help set a standard for health when entering adulthood.

Future Research

Future research should incorporate other variables of sleep health, which is a fairly new concept that features a more comprehensive view of sleep (Buysse, 2014; Meltzer et al., 2021). Sleep health includes sleep duration and sleep efficiency along with behaviors, satisfaction, alertness, and timing. It is probable that a comprehensive sleep health score or individual sleep variables measured as part of sleep health may have a relationship with abdominal adiposity and blood pressure (Meltzer et al., 2021).

Furthermore, there is a need for future research to continue including both subjective and objective measurements of sleep. Even though there were no relationships between sleep duration and the outcome variables in this study, there were differences in objective and subjective sleep duration. It is possible that relationships may exist with objective versus subjective sleep duration depending on the outcome variable (Quist et al., 2016; Short et al., 2012). Also, there is a need to assess the study's variables in the context of inadequate, adequate, or excessive sleep duration to see if the categories impact the relationships.

Along with including both subjective and objective measures of sleep duration, there is a need for more studies in pediatric actigraphy to determine the appropriate amount of data needed to capture an overall average objective sleep duration. This study did not examine differences between weekday and weekend sleep, but previous studies have found that adolescents tend to have catch-up sleep on the weekends, which may result in shorter sleep duration during the week and longer sleep duration on the weekend (Chung et al., 2020). Significantly differing weekend and weeknight durations can skew the overall sleep duration, which can impact the ability to explore the relationships between sleep duration and health outcomes or behaviors.

The significant findings of this study did not persist after controlling for BMI percentiles, race, and assigned sex. Therefore, there is a need for research that explores differences in the relationships among sleep duration, sleep efficiency, abdominal adiposity, and BP based on race, assigned sex, and BMI percentiles. Since this study found a strong correlation between WHtR and BMI percentiles, there is a need for studies that examine whether WHtR and BMI measure the same concept or if BMI is a mediator in the relationship between sleep efficiency and WHtR. Furthermore, there is a need for more research to explore whether those who are considered as having abdominal obesity also have obesity as measured by BMI percentiles.

Also, with the changes in adolescent and pediatric lifestyles since the start of the COVID-19 pandemic, there is a need for future research that reassesses the variables included in this study. Some of the risk factors for inadequate sleep duration, poor sleep efficiency, excess abdominal adiposity, and elevated blood pressure (e.g., increased screen time, increased sedentary lifestyle) have increased due to atypical restrictions ins response to the pandemic (Bates et al., 2020). It would be helpful to determine if these restrictions have resulted in greater abdominal adiposity, elevated BP, or less than optimal sleep duration and/or sleep efficiency.

Chapter Summary

The purpose of this study was to explore the relationships between sleep duration and sleep efficiency with abdominal adiposity and blood pressure in adolescents ages 16 to 18 years old. This study was a secondary data analysis of the third cohort of the Cleveland Children's Sleep and Health Study (CCSHS), which was a cohort study examining the impact of sleep disturbances on sleep disorders and health outcomes like obesity. The majority of this population was White, non-Hispanic, female, and had normal weight as measured by BMI percentiles. On average, this population had inadequate objective sleep duration, adequate subjective sleep duration, normotensive BP, and did not have excess abdominal adiposity.

After cross-sectional analysis of the data, the findings suggest that sleep efficiency has a negative relationship with WHtR and SBP, but these relationships do not persist after controlling for age, assigned sex, and BMI percentiles. The findings suggest that there may not be relationships among these variables during late adolescence. However, this study adds to the literature by being one of the few that has analyzed these specific variables in only the late adolescence development group. It is important to isolate age groups because it is possible for the relationships among variables to change as adolescents age. Furthermore, this study was one of the few that utilized both subjective and objective sleep duration during adolescence, especially during late adolescence. Also, this study found that participants had a higher prevalence of abdominal obesity compared to obesity measured by BMI percentiles, supporting the narrative that abdominal obesity may be present in those who are not considered obese as measured by BMI percentiles.

Given the extent of inadequate sleep in this sample, health care professionals and policy makers need to assess sleep health and incorporate and support sleep education during clinic visits and in schools, respectively. Also, health care providers should measure abdominal adiposity and BMI percentiles in adolescents to assess adiposity and risk for disease. Future research should include prospective studies that: (a) examine the influence of sleep health on health outcomes in the pediatric population; (b) analyze both subjective and objective sleep duration in health outcomes research; (c) determine parameters for validated actigraphy data that give an accurate estimate of average sleep duration in the adolescent population; (d) examine differences in sleep efficiency, sleep duration, abdominal adiposity, and BP based on race, assigned sex, and BMI percentiles; (e) explore the differences in abdominal obesity and overall obesity; and (f) examine the differences in the study variables post COVID-19 pandemic. Overall, this study supports the need for research that focuses on or separates developmental groups to examine sleep, abdominal adiposity, and blood pressure. Relationships may only exist in certain developmental stages or portions of the developmental stages (e.g., young adolescents compared to older adolescents).

LIST OF REFERENCES

Aatola, H., Koivistoinen, T., Tuominen, H., Juonala, M., Lehtimäki, T., Viikari, J. S., Raitakari, O. T., Kähönen, M., & Hutri-Kähönen, N. (2017). Influence of child and adult elevated blood pressure on adult arterial stiffness: The Cardiovascular Risk in Young Finns Study. *Hypertension*, *70*(3), 531-536. https://doi.org/10.1161/HYPERTENSIONAHA.117.09444

Acebo, C., Sadeh, A., Seifer, R., Tzischinsky, O., Wolfson, A. R., Hafer, A., & Carskadon, M. A. (1999). Estimating sleep patterns with activity monitoring in children and adolescents: How many nights are necessary for reliable measures? *Sleep*, *22*(1), 95–103. https://doi.org/10.1093/sleep/22.1.95

Agostini, A., & Centofanti, S. (2021). Normal sleep in children and adolescence. *Child and Adolescent Psychiatric Clinics of North America*, *30*(1), 1–14. https://doi.org/10.1016/j.chc.2020.08.011

Ahmad, A., & Didia, S. C. (2020). Effects of sleep duration on cardiovascular events. *Current Cardiology Reports*, *22*(4), 18. https://doi.org/10.1007/s11886-020-1271-0

Albqoor, M. A., & Shaheen, A. M. (2021). Prevalence and differences in habitual sleep efficiency, sleep disturbances, and using sleep medication: A national study of university students in Jordan. *Sleep & Breathing = Schlaf & Atmung*, *25*(2), 1127–1134. https://doi.org/10.1007/s11325-020-02174-2

Alderman, E. M., Breuner, C. C., Grubb, L. K., Powers, M. E., Upadhya, K., & Wallace, S. B. (2019). Unique needs of the adolescent. *Pediatrics*, *144*(6). https://doi.org/10.1542/peds.2019-3150

Al-Hazzaa, H. M. (2014). Joint associations of body mass index and waist-to-height ratio with sleep duration among Saudi adolescents. *Annals of Human Biology*, *41*(2), 111–117. https://doi.org/10.3109/03014460.2013.833291

Al-Hazzaa, H. M., Musaiger, A. O., Abahussain, N. A., Al-Sobayel, H. I., & Qahwaji, D. M. (2012). Prevalence of short sleep duration and its association with obesity among adolescents 15- to 19-year olds: A cross-sectional study from three major cities in Saudi Arabia. *Annals of Thoracic Medicine*, 7(3), 133–139. https://doi.org/10.4103/1817-1737.98845

Ancoli-Israel, S., Cole, R., Alessi, C., Chambers, M., Moorcroft, W., & Pollak, C. P. (2003). The role of actigraphy in the study of sleep and circadian rhythms. *Sleep*, *26*(3), 342–392. https://doi.org/10.1093/sleep/26.3.342

Antonakoudis, G., Poulimenos, L., Kifnidis, K., Zouras, C., & Antonakoudis, H. (2007). Blood pressure control and cardiovascular risk reduction. *Hippokratia*, *11*(3), 114–119.

Araújo de França, G. V., Restrepo-Méndez, M. C., Loret de Mola, C., & Victora, C. G. (2014). Size at birth and abdominal adiposity in adults: A systematic review and meta-analysis. *Obesity Reviews*, *15*(2), 77–91. https://doi.org/10.1111/obr.12109

Archbold, K. H., Vasquez, M. M., Goodwin, J. L., & Quan, S. F. (2012). Effects of sleep patterns and obesity on increases in blood pressure in a 5-year period: Report from the Tucson Children's Assessment of Sleep Apnea Study. *The Journal of Pediatrics*, *161*(1), 26–30. https://doi.org/10.1016/j.jpeds.2011.12.034

Arteaga, S. S., Esposito, L., Osganian, S. K., Pratt, C. A., Reedy, J., & Young-Hyman, D. (2018). Childhood obesity research at the NIH: Efforts, gaps, and opportunities. *Translational Behavioral Medicine*, *8*(6), 962–967. https://doi.org/10.1093/tbm/iby090

Ashwell, M., & Hsieh, S. D. (2005). Six reasons why the waist-to-height ratio is a rapid and effective global indicator for health risks of obesity and how its use could simplify the international public health message on obesity. *International Journal of Food Sciences and Nutrition*, *56*(5), 303–307. https://doi.org/10.1080/09637480500195066

Au, C. T., Ho, C. K. W., Wing, Y. K., Lam, H. S., & Li, A. M. (2014). Acute and chronic effects of sleep duration on blood pressure. *Pediatrics*, *133*(1), e64–72. https://doi.org/10.1542/peds.2013-1379

Azadbakht, L., Kelishadi, R., Khodarahmi, M., Qorbani, M., Heshmat, R., Motlagh, M. E., Taslimi, M., & Ardalan, G. (2013). The association of sleep duration and cardiometabolic risk factors in a national sample of children and adolescents: The CASPIAN III study. *Nutrition*, *29*(9), 1133–1141. https://doi.org/10.1016/j.nut.2013.03.006

Bacopoulou, F., Efthymiou, V., Landis, G., Rentoumis, A., & Chrousos, G. P. (2015). Waist circumference, waist-to-hip ratio and waist-to-height ratio reference percentiles for abdominal obesity among Greek adolescents. *BMC Pediatrics*, *15*, 50. https://doi.org/10.1186/s12887-015-0366-z

Bagley, E. J., & El-Sheikh, M. (2013). Familial risk moderates the association between sleep and zBMI in children. *Journal of Pediatric Psychology*, *38*(7), 775-784. https://doi.org/10.1093/jpepsy/jst031

Bailey, B. W., Allen, M. D., LeCheminant, J. D., Tucker, L. A., Errico, W. K., Christensen, W. F., & Hill, M. D. (2014). Objectively measured sleep patterns in young adult women and the relationship to adiposity. *American Journal of Health Promotion*, *29*(1), 46–54. https://doi.org/10.4278/ajhp.121012-QUAN-500

Bao, W., Threefoot, S. A., Srinivasan, S. R., & Berenson, G. S. (1995). Essential hypertension predicted by tracking of elevated blood pressure from childhood to adulthood: The Bogalusa Heart Study. *American Journal of Hypertension*, *8*(7), 657–665. https://doi.org/10.1016/0895-7061(95)00116-7

Basch, C. E., Basch, C. H., Ruggles, K. V., & Rajan, S. (2014). Prevalence of sleep duration on an average school night among 4 nationally representative successive samples of American high school students, 2007-2013. *Preventing Chronic Disease*, *11*, E216. https://doi.org/10.5888/pcd11.140383\

Bassali, R., Waller, J. L., Gower, B., Allison, J., & Davis, C. L. (2010). Utility of waist circumference percentile for risk evaluation in obese children. *International Journal of Pediatric Obesity, 5*(1), 97–101. https://doi.org/10.3109/17477160903111722

Bates, L. C., Zieff, G., Stanford, K., Moore, J. B., Kerr, Z. Y., Hanson, E. D., Barone Gibbs, B., Kline, C. E., & Stoner, L. (2020). COVID-19 impact on behaviors across the 24-hour day in children and adolescents: Physical activity, sedentary behavior, and sleep. *Children (Basel, Switzerland)*, *7*(9). https://doi.org/10.3390/children7090138

Bawazeer, N. M., Al-Daghri, N. M., Valsamakis, G., Al-Rubeaan, K. A., Sabico, S. L. B., Huang, T. T.-K., Mastorakos, G. P., & Kumar, S. (2009). Sleep duration and quality associated with obesity among Arab children. *Obesity*, *17*(12), 2251–2253. https://doi.org/10.1038/oby.2009.169

Bei, B., Seeman, T. E., Carroll, J. E., & Wiley, J. F. (2017). Sleep and physiological dysregulation: A closer look at sleep intraindividual variability. *Sleep*, *40*(9). https://doi.org/10.1093/sleep/zsx109

Bell, C. S., Samuel, J. P., & Samuels, J. A. (2019). Prevalence of hypertension in children. *Hypertension*, *73*(1), 148–152. https://doi.org/10.1161/HYPERTENSIONAHA.118.11673

Bjorntorp, P. (2001). Do stress reactions cause abdominal obesity and comorbidities? *Obesity Reviews*, *2*(2), 73–86. https://doi.org/10.1046/j.1467-789x.2001.00027.x

Blackburn, H., & Jacobs, Jr., D. (2014). Commentary: Origins and evolution of body mass index (BMI): Continuing saga. *International Journal of Epidemiology*, *43*(3), 665–669. https://doi.org/10.1093/ije/dyu061

Blüher, S., Molz, E., Wiegand, S., Otto, K.-P., Sergeyev, E., Tuschy, S., L'Allemand-Jander, D., Kiess, W., Holl, R. W., & Adiposity Patients Registry Initiative and German Competence Net Obesity. (2013). Body mass index, waist circumference, and waist-to-height ratio as predictors of cardiometabolic risk in childhood obesity depending on pubertal development. *The Journal of Clinical Endocrinology and Metabolism*, *98*(8), 3384–3393. https://doi.org/10.1210/jc.2013-1389

Blunden, S., Benveniste, T., & Thompson, K. (2016). Putting children's sleep problems to bed: Using behavior change theory to increase the success of children's sleep education programs and contribute to healthy development. *Children (Basel, Switzerland)*, *3*(3). https://doi.org/10.3390/children3030011

Boeke, C. E., Oken, E., Kleinman, K. P., Rifas-Shiman, S. L., Taveras, E. M., & Gillman, M. W. (2013). Correlations among adiposity measures in school-aged children. *BMC Pediatrics*, *13*, 99. https://doi.org/10.1186/1471-2431-13-99

Boonpleng, W., Park, C. G., Gallo, A. M., Corte, C., McCreary, L., & Bergren, M. D. (2013). Ecological influences of early childhood obesity: A multilevel analysis. *Western Journal of Nursing Research*, *35*(6), 742–759. https://doi.org/10.1177/0193945913480275

Bovet, P., Gervasoni, J.-P., Ross, A. G., Mkamba, M., Mtasiwa, D. M., Lengeler, C., Burnier, M., & Paccaud, F. (2003). Assessing the prevalence of hypertension in populations: are we doing it right? *Journal of Hypertension, 21*(3), 509–517. https://doi.org/10.1097/00004872-200303000-00016

Brady, T. M. (2017). Obesity-related hypertension in children. *Frontiers in Pediatrics, 5*, 197. https://doi.org/10.3389/fped.2017.00197

Brandalize, M., Pereira, R. F., Leite, N., Filho, G. L., & Louzada, F. M. (2011). Effect of morning school schedule on sleep and anthropometric variables in adolescents: A follow-up study. *Chronobiology International*, *28*(9), 779–785. https://doi.org/10.3109/07420528.2011.603452

Bronfenbrenner, U. (1999). Environments in developmental perspective: Theoretical and operational models. In S. L. Friedman & T. D. Wachs (Eds.), *Measuring environment across the life span: Emerging methods and concepts* (pp. 3–28). American Psychological Association. https://doi.org/10.1037/10317-001

Bronfenbrenner, U., & Morris, P. A. (2007). The bioecological model of human development. In W. Damon & R. M. Lerner (Eds.), *Handbook of child psychology*. John Wiley & Sons, Inc. https://doi.org/10.1002/9780470147658.chpsy0114

Buysse, D. J. (2014). Sleep health: Can we define it? Does it matter? *Sleep*, *37*(1), 9–17. https://doi.org/10.5665/sleep.3298

Buysse, D. J., Hall, M. L., Strollo, P. J., Kamarck, T. W., Owens, J., Lee, L., Reis, S. E., & Matthews, K. A. (2008). Relationships between the Pittsburgh Sleep Quality Index (PSQI), Epworth Sleepiness Scale (ESS), and clinical/polysomnographic measures in a community sample. *Journal of Clinical Sleep Medicine, 4*(6), 563–571. https://doi.org/10.5664/jcsm.27351

Campbell, I. G., Grimm, K. J., de Bie, E., & Feinberg, I. (2012). Sex, puberty, and the timing of sleep EEG measured adolescent brain maturation. *Proceedings of the National Academy of Sciences of the United States of America*, *109*(15), 5740–5743. https://doi.org/10.1073/pnas.1120860109

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. https://doi.org/10.1186/s12889-015-2359-0

Carroll, J. E., Irwin, M. R., Stein Merkin, S., & Seeman, T. E. (2015). Sleep and multisystem biological risk: A population-based study. *Plos One*, *10*(2), e0118467. https://doi.org/10.1371/journal.pone.0118467

Carskadon, M. A., Acebo, C., & Jenni, O. G. (2004). Regulation of adolescent sleep: Implications for behavior. *Annals of the New York Academy of Sciences*, *1021*, 276–291. https://doi.org/10.1196/annals.1308.032

Carskadon, M. A., Wolfson, A. R., Acebo, C., Tzischinsky, O., & Seifer, R. (1998). Adolescent sleep patterns, circadian timing, and sleepiness at a transition to early school days. *Sleep*, *21*(8), 871–881. https://doi.org/10.1093/sleep/21.8.871

Castro-Diehl, C., Diez Roux, A. V., Redline, S., Seeman, T., Shrager, S. E., & Shea, S. (2015). Association of Sleep Duration and Quality With Alterations in the Hypothalamic-Pituitary Adrenocortical Axis: The Multi-Ethnic Study of Atherosclerosis (MESA). *The Journal of Clinical Endocrinology and Metabolism, 100*(8), 3149–3158. https://doi.org/10.1210/jc.2015-1198

Castro-Diehl, C., Diez Roux, A. V., Redline, S., Seeman, T., McKinley, P., Sloan, R., & Shea, S. (2016). Sleep duration and quality in relation to autonomic nervous system measures: The Multi-Ethnic Study of Atherosclerosis (MESA). *Sleep*, *39*(11), 1927-1940. https://doi.org/10.5665/sleep.6218

Centers for Disease Control and Prevention. (2021a). *Defining childhood weight status.* https://www.cdc.gov/obesity/childhood/defining.html

Centers for Disease Control and Prevention. (2021b). *Leading cause of death.* https://www.cdc.gov/nchs/fastats/leading-causes-of-death.htm

Centers for Disease Control and Prevention. (2021c). *High blood pressure in kids and teens.* Retrieved from https://www.cdc.gov/bloodpressure/youth.htm

Cespedes Feliciano, E. M., Quante, M., Rifas-Shiman, S. L., Redline, S., Oken, E., & Taveras, E. M. (2018). Objective sleep characteristics and cardiometabolic health in young adolescents. *Pediatrics*, *142*(1). https://doi.org/10.1542/peds.2017-4085

Cespedes, E. M., Rifas-Shiman, S. L., Redline, S., Gillman, M. W., Peña, M.-M., & Taveras, E. M. (2014). Longitudinal associations of sleep curtailment with metabolic risk in mid-childhood. *Obesity, 22*(12), 2586–2592. https://doi.org/10.1002/oby.20894

Chaput, J.-P., Bouchard, C., & Tremblay, A. (2014). Change in sleep duration and visceral fat accumulation over 6 years in adults. *Obesity*, *22*(5), E9–12. https://doi.org/10.1002/oby.20701

Chaput, J.-P., & Dutil, C. (2016). Lack of sleep as a contributor to obesity in adolescents: Impacts on eating and activity behaviors. *The International Journal of Behavioral Nutrition and Physical Activity*, *13*(1), 103. https://doi.org/10.1186/s12966-016-0428-0

Chaput, J.-P., Lambert, M., Gray-Donald, K., McGrath, J. J., Tremblay, M. S., O'Loughlin, J., & Tremblay, A. (2011). Short sleep duration is independently associated with overweight and obesity in Quebec children. *Canadian Journal of Public Health*, *102*(5), 369–374.

Chaput, J.-P., Leduc, G., Boyer, C., Bélanger, P., LeBlanc, A. G., Borghese, M. M., & Tremblay, M. S. (2014). Objectively measured physical activity, sedentary time and sleep duration: Independent and combined associations with adiposity in Canadian children. *Nutrition & Diabetes*, *4*(6), e117. https://doi.org/10.1038/nutd.2014.14

Chaput, J.-P., & Tremblay, A. (2007). Does short sleep duration favor abdominal adiposity in children? *International Journal of Pediatric Obesity*, *2*(3), 188–191. https://doi.org/10.1080/17477160701306144

Chen, M.-Y., Wang, E. K., & Jeng, Y.-J. (2006). Adequate sleep among adolescents is positively associated with health status and health-related behaviors. *BMC Public Health*, *6*, 59. https://doi.org/10.1186/1471-2458-6-59

Chen, X., Redline, S., Shields, A. E., Williams, D. R., & Williams, M. A. (2014). Associations of allostatic load with sleep apnea, insomnia, short sleep duration, and other sleep disturbances: Findings from the National Health and Nutrition Examination Survey 2005 to 2008. *Annals of Epidemiology*, *24*(8), 612–619. https://doi.org/10.1016/j.annepidem.2014.05.014

Chung, J. H., Kim, J. B., & Kim, J. H. (2020). Effects of sleep duration and weekend catch-up sleep on falling injury in adolescents: A population-based study. *Sleep Medicine*, *68*, 138–145. https://doi.org/10.1016/j.sleep.2019.12.005

Clark, A. J., Dich, N., Lange, T., Jennum, P., Hansen, A. M., Lund, R., & Rod, N. H. (2014). Impaired sleep and allostatic load: Cross-sectional results from the Danish Copenhagen Aging and Midlife Biobank. *Sleep Medicine*, *15*(12), 1571–1578. https://doi.org/10.1016/j.sleep.2014.07.013

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Lawrence Erlbaum Associates. https://doi.org/10.4324/9780203771587

Colrain, I. M., & Baker, F. C. (2011). Changes in sleep as a function of adolescent development. *Neuropsychology Review*, *21*(1), 5–21. https://doi.org/10.1007/s11065-010-9155-5

Countryman, A. J., Saab, P. G., Llabre, M. M., Penedo, F. J., McCalla, J. R., & Schneiderman, N. (2013). Cardiometabolic risk in adolescents: Associations with physical activity, fitness, and sleep. *Annals of Behavioral Medicine*, *45*(1), 121–131. https://doi.org/10.1007/s12160-012-9428-8

Danielsen, Y. S., Pallesen, S., Stormark, K. M., Nordhus, I. H., & Bjorvatn, B. (2010). The relationship between school day sleep duration and body mass index in Norwegian children (aged 10-12). *International Journal of Pediatric Obesity*, *5*(3), 214–220. https://doi.org/10.3109/17477160903473739

de Moraes, A. C. F., Fadoni, R. P., Ricardi, L. M., Souza, T. C., Rosaneli, C. F., Nakashima, A. T. A., & Falcão, M. C. (2011). Prevalence of abdominal obesity in adolescents: A systematic review. *Obesity Reviews*, *12*(2), 69–77. https://doi.org/10.1111/j.1467-789X.2010.00753.x

Desantis, A. S., Diez Roux, A. V., Moore, K., Baron, K. G., Mujahid, M. S., & Nieto, F. J. (2013). Associations of neighborhood characteristics with sleep timing and quality: The Multi-Ethnic Study of Atherosclerosis. *Sleep*, *36*(10), 1543–1551. https://doi.org/10.5665/sleep.3054

Després, J. P., Lemieux, I., Bergeron, J., Pibarot, P., Mathieu, P., Larose, E., Rodés-Cabau, J., Bertrand, O. F., & Poirier, P. (2008). Abdominal obesity and the metabolic syndrome: Contribution to global cardiometabolic risk. *Arteriosclerosis, Thrombosis, and Vascular Biology*, *28*(6), 1039-1049. https://doi.org/10.1161/ATVBAHA.107.159228

Donoho, C. J., Weigensberg, M. J., Emken, B. A., Hsu, J.-W., & Spruijt-Metz, D. (2011). Stress and abdominal fat: Preliminary evidence of moderation by the cortisol awakening response in Hispanic peripubertal girls. *Obesity*, *19*(5), 946–952. https://doi.org/10.1038/oby.2010.287

Dos Santos, E. D. S. G., & De Souza, O. F. (2020). Association of sleep duration and blood pressure in adolescents: A multicenter study. *American Journal of Hypertension*, *33*(1), 77–83. https://doi.org/10.1093/ajh/hpz129

Drapeau, V., Therrien, F., Richard, D., & Tremblay, A. (2003). Is visceral obesity a physiological adaptation to stress? *Panminerva Medica*, *45*(3), 189–195.

Duan, Y., Sun, J., Wang, M., Zhao, M., Magnussen, C. G., & Xi, B. (2020). Association between short sleep duration and metabolic syndrome in Chinese children and adolescents. *Sleep Medicine*, *74*, 343–348. https://doi.org/10.1016/j.sleep.2020.08.018

Eaton, D. K., McKnight-Eily, L. R., Lowry, R., Perry, G. S., Presley-Cantrell, L., & Croft, J. B. (2010). Prevalence of insufficient, borderline, and optimal hours of sleep among high school students - United States, 2007. *The Journal of Adolescent Health*, *46*(4), 399–401. https://doi.org/10.1016/j.jadohealth.2009.10.011

Edwards, K. M., Wilson, K. L., Sadja, J., Ziegler, M. G., & Mills, P. J. (2011). Effects on blood pressure and autonomic nervous system function of a 12-week exercise or exercise plus DASH-diet intervention in individuals with elevated blood pressure. *Acta Physiologica*, *203*(3), 343–350. https://doi.org/10.1111/j.1748-1716.2011.02329.x

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

Elobeid, M. A., Desmond, R. A., Thomas, O., Keith, S. W., & Allison, D. B. (2007). Waist circumference values are increasing beyond those expected from BMI increases. *Obesity*, *15*(10), 2380-2383. https://doi.org/10.1038/oby.2007.282

El-Sheikh, M., & Sadeh, A. (2015). I. Sleep and development: Introduction to the monograph. *Monographs of the Society for Research in Child Development*, *80*(1), 1–14. https://doi.org/10.1111/mono.12141

El-Sheikh, M., Tu, K. M., Erath, S. A., & Buckhalt, J. A. (2014). Family stress and adolescents' cognitive functioning: Sleep as a protective factor. *Journal of Family Psychology*, *28*(6), 887–896. https://doi.org/10.1037/fam0000031

Emmanuel, M., & Bokor, B. R. (2017). *Tanner stages.* https://www.ncbi.nlm.nih.gov/books/NBK470280/buford

Enright, P. L., Goodwin, J. L., Sherrill, D. L., Quan, J. R., Quan, S. F., & Tucson Children's Assessment of Sleep Apnea study. (2003). Blood pressure elevation associated with sleep-related breathing disorder in a community sample of white and Hispanic children: The Tucson Children's Assessment of Sleep Apnea study. *Archives of Pediatrics & Adolescent Medicine*, *157*(9), 901–904. https://doi.org/10.1001/archpedi.157.9.901

Erwin, A. M., & Bashore, L. (2017). Subjective sleep measures in children: Self-Report.

Frontiers in Pediatrics, *5*, 22. https://doi.org/10.3389/fped.2017.00022

Ewald, D. R., & Haldeman, L. A. (2016). Risk factors in adolescent hypertension. *Global Pediatric Health*, *3*, 2333794X15625159. https://doi.org/10.1177/2333794X15625159

Falkner, B. (2010). Hypertension in children and adolescents: Epidemiology and natural history. *Pediatric Nephrology*, *25*(7), 1219–1224. https://doi.org/10.1007/s00467-009-1200-3

Falkner, B., & Lurbe, E. (2020). Primordial prevention of high blood pressure in childhood: An opportunity not to be missed. *Hypertension*, *75*(5), 1142–1150. https://doi.org/10.1161/HYPERTENSIONAHA.119.14059

Fang, J., Wheaton, A. G., Keenan, N. L., Greenlund, K. J., Perry, G. S., & Croft, J. B. (2012). Association of sleep duration and hypertension among US adults varies by age and sex. *American Journal of Hypertension*, *25*(3), 335–341. https://doi.org/10.1038/ajh.2011.201

Felden, É. P. G., Filipin, D., Barbosa, D. G., Andrade, R. D., Meyer, C., & Louzada, F. M. (2016). Factors associated with short sleep duration in adolescents. *Revista Paulista de Pediatria (English Edition)*, *34*(1), 64–70. https://doi.org/10.1016/j.rppede.2015.10.007

Ferrie, J. E., Kumari, M., Salo, P., Singh-Manoux, A., & Kivimäki, M. (2011). Sleep epidemiology—a rapidly growing field. *International Journal of Epidemiology*, *40*(6), 1431–1437. https://doi.org/10.1093/ije/dyr203

Fink, G. (2016). Stress, definitions, mechanisms, and effects outlined: Lessons from anxiety. In *Stress: Concepts, cognition, emotion, and behavior* ,(Vol. 1, pp. 3-11) .Academic Press. https://doi.org/10.1016/B978-0-12-800951-2.00001-7

Fischer, F. M., Nagai, R., & Teixeira, L. R. (2008). Explaining sleep duration in adolescents: The impact of socio-demographic and lifestyle factors and working status. *Chronobiology International*, *25*(2), 359–372. https://doi.org/10.1080/07420520802110639

Fitzgerald, C. T., Messias, E., & Buysse, D. J. (2011). Teen sleep and suicidality: Results from the youth risk behavior surveys of 2007 and 2009. *Journal of Clinical Sleep Medicine, 7*(4), 351–356. https://doi.org/10.5664/JCSM.1188

Flynn, J. T. (2008). Pediatric hypertension: Recent trends and accomplishments, future challenges. *American Journal of Hypertension*, *21*(6), 605–612. https://doi.org/10.1038/ajh.2008.159

Flynn, J. T., Kaelber, D. C., Baker-Smith, C. M., Blowey, D., Carroll, A. E., Daniels, S. R., de Ferranti, S. D., Dionne, J. M., Falkner, B., Flinn, S. K., Gidding, S. S., Goodwin, C., Leu, M. G., Powers, M. E., Rea, C., Samuels, J., Simasek, M., Thaker, V. V., Urbina, E. M., & Subcommittee on Screening and Management of High Blood Pressure in Children. (2017). Clinical practice guideline for screening and management of high blood pressure in children and adolescents. *Pediatrics*, *140*(3). https://doi.org/10.1542/peds.2017-1904

Fobian, A. D., Avis, K., & Schwebel, D. C. (2016). Impact of media use on adolescent sleep efficiency. *Journal of Developmental and Behavioral Pediatrics*, *37*(1), 9–14. https://doi.org/10.1097/DBP.0000000000000239

Folkow, B. (2001). Mental stress and its importance for cardiovascular disorders; physiological aspects, “from-mice-to-man.” *Scandinavian Cardiovascular Journal, 35*(3), 163–172.

Freedman, D. S., Dietz, W. H., Srinivasan, S. R., & Berenson, G. S. (1999). The relation of overweight to cardiovascular risk factors among children and adolescents: The Bogalusa Heart Study. *Pediatrics, 103*(6 Pt 1), 1175–1182.

Galland, B. C., Gray, A. R., Penno, J., Smith, C., Lobb, C., & Taylor, R. W. (2017). Gender differences in sleep hygiene practices and sleep quality in New Zealand adolescents aged 15 to 17 years. *Sleep Health*, *3*(2), 77–83. https://doi.org/10.1016/j.sleh.2017.02.001

Gangwisch, J. E., Heymsfield, S. B., Boden-Albala, B., Buijs, R. M., Kreier, F., Pickering, T. G., Rundle, A. G., Zammit, G. K., & Malaspina, D. (2006). Short sleep duration as a risk factor for hypertension: Analyses of the first National Health and Nutrition Examination Survey. *Hypertension*, *47*(5), 833–839. https://doi.org/10.1161/01.HYP.0000217362.34748.e0

Gilmer, T. P., O’Connor, P. J., Sinaiko, A. R., Kharbanda, E. O., Magid, D. J., Sherwood, N. E., Adams, K. F., Parker, E. D., & Margolis, K. L. (2014). Impact of hypertension on health care costs among children. *The American Journal of Managed Care*, *20*(8), 622–628. PMID: 25295676

Goel, N., Kim, H., & Lao, R. P. (2005). Gender differences in polysomnographic sleep in young healthy sleepers. *Chronobiology International*, *22*(5), 905–915. https://doi.org/10.1080/07420520500263235

Gottlieb, D. J., Redline, S., Nieto, F. J., Baldwin, C. M., Newman, A. B., Resnick, H. E., & Punjabi, N. M. (2006). Association of usual sleep duration with hypertension: The Sleep Heart Health Study. *Sleep*, *29*(8), 1009–1014. https://doi.org/10.1093/sleep/29.8.1009

Goyal, R., Bhakhri, B. K., Goyal, J. P., Lohiya, N., & Khadilkar, V. (2021). Appropriateness of lower waist circumference cutoffs for predicting derangement in metabolic parameters among Asian children and adolescents: A pilot study. *Indian Pediatrics*, *58*(4), 392–394. https://doi.org/10.1007/s13312-021-2203-9

Grandner, M. A. (2017). Sleep and obesity risk in adults: Possible mechanisms; contextual factors; and implications for research, intervention, and policy. *Sleep Health*, *3*(5), 393–400. https://doi.org/10.1016/j.sleh.2017.07.014

Grandner, M. A., Hale, L., Moore, M., & Patel, N. P. (2010). Mortality associated with short sleep duration: The evidence, the possible mechanisms, and the future. *Sleep Medicine Reviews*, *14*(3), 191–203. https://doi.org/10.1016/j.smrv.2009.07.006

Guedes, L. G., Abreu, G. de A., Rodrigues, D. F., Teixeira, L. R., Luiz, R. R., & Bloch, K. V. (2016). Comparison between self-reported sleep duration and actigraphy among adolescents: Gender differences. *Revista Brasileira de Epidemiologia = Brazilian Journal of Epidemiology*, *19*(2), 339–347. https://doi.org/10.1590/1980-5497201600020011

Guglielmo, D., Gazmararian, J. A., Chung, J., Rogers, A. E., & Hale, L. (2018). Racial/ethnic sleep disparities in US school-aged children and adolescents: A review of the literature. *Sleep Health*, *4*(1), 68–80. https://doi.org/10.1016/j.sleh.2017.09.005

Gundogdu, Z. (2008). Relationship between BMI and blood pressure in girls and boys. *Public Health Nutrition*, *11*(10), 1085–1088. https://doi.org/10.1017/S1368980008002280

Guo, X., Zheng, L., Li, Y., Yu, S., Liu, S., Zhou, X., Zhang, X., Sun, Z., Wang, R., & Sun, Y. (2011). Association between sleep duration and hypertension among Chinese children and adolescents. *Clinical Cardiology*, *34*(12), 774–781. https://doi.org/10.1002/clc.20976

Guo, X., Zheng, L., Wang, J., Zhang, X., Zhang, X., Li, J., & Sun, Y. (2013). Epidemiological evidence for the link between sleep duration and high blood pressure: A systematic review and meta-analysis. *Sleep Medicine*, *14*(4), 324–332. https://doi.org/10.1016/j.sleep.2012.12.001

Hagenauer, M. H., Perryman, J. I., Lee, T. M., & Carskadon, M. A. (2009). Adolescent changes in the homeostatic and circadian regulation of sleep. *Developmental Neuroscience*, *31*(4), 276–284. https://doi.org/10.1159/000216538

Hairston, K. G., Bryer-Ash, M., Norris, J. M., Haffner, S., Bowden, D. W., & Wagenknecht, L. E. (2010). Sleep duration and five-year abdominal fat accumulation in a minority cohort: The IRAS family study. *Sleep*, *33*(3), 289–295. https://doi.org/10.1093/sleep/33.3.289

Hardy, S. T., Sakhuja, S., Jaeger, B. C., Urbina, E. M., Suglia, S. F., Feig, D. I., & Muntner, P. (2021). Trends in blood pressure and hypertension among US children and adolescents, 1999-2018. *JAMA Network Open*, *4*(4), e213917. https://doi.org/10.1001/jamanetworkopen.2021.3917

Hart, C. N., Carskadon, M. A., Considine, R. V., Fava, J. L., Lawton, J., Raynor, H. A., Jelalian, E., Owens, J., & Wing, R. (2013). Changes in children's sleep duration on food intake, weight, and leptin. *Pediatrics*, *132*(6), e1473–80. https://doi.org/10.1542/peds.2013-1274

Hibbs, A. M., Storfer-Isser, A., Rosen, C., Ievers-Landis, C. E., Taveras, E. M., & Redline, S. (2014). Advanced sleep phase in adolescents born preterm. *Behavioral Sleep Medicine*, *12*(5), 412–424. https://doi.org/10.1080/15402002.2013.825838

Hirata, T., Nakamura, T., Kogure, M., Narita, A., Miyagawa, K., Nochioka, K., Tsuchiya, N., Obara, T., Nakaya, N., Kuriyama, S., & Hozawa, A. (2019). Abstract P269: Combined associations of objective sleep efficiency and overweight with the prevalence of hypertension in Japanese adults. *Circulation*, *139*(Suppl_1). https://doi.org/10.1161/circ.139.suppl_1.P269

Hirshkowitz, M., Whiton, K., Albert, S. M., Alessi, C., Bruni, O., DonCarlos, L., Hazen, N., Herman, J., Katz, E. S., Kheirandish-Gozal, L., Neubauer, D. N., O'Donnell, A. E., Ohayon, M., Peever, J., Rawding, R., Sachdeva, R. C., Setters, B., Vitiello, M. V., Ware, J. C., & Adams Hillard, P. J. (2015). National Sleep Foundation's sleep time duration recommendations: Methodology and results summary. *Sleep Health*, *1*(1), 40–43. https://doi.org/10.1016/j.sleh.2014.12.010

Hjorth, M. F., Sjödin, A., Dalskov, S.-M., Damsgaard, C. T., Michaelsen, K. F., Biltoft-Jensen, A., Andersen, R., Ritz, C., Chaput, J.-P., & Astrup, A. (2016). Sleep duration modifies effects of free ad libitum school meals on adiposity and blood pressure. *Applied Physiology, Nutrition, and Metabolism*, *41*(1), 33–40. https://doi.org/10.1139/apnm-2015-0319

Jackson, C. L., Patel, S. R., Jackson, W. B., Lutsey, P. L., & Redline, S. (2018). Agreement between self-reported and objectively measured sleep duration among white, black, Hispanic, and Chinese adults in the United States: Multi-Ethnic Study of Atherosclerosis. *Sleep*, *41*(6). https://doi.org/10.1093/sleep/zsy057

Jansen, E. C., Dunietz, G. L., Chervin, R. D., Baylin, A., Baek, J., Banker, M., Song, P. X. K., Cantoral, A., Tellez Rojo, M. M., & Peterson, K. E. (2018). Adiposity in adolescents: The interplay of sleep duration and sleep variability. *The Journal of Pediatrics*, *203*, 309–316. https://doi.org/10.1016/j.jpeds.2018.07.087

Jarrin, D. C., McGrath, J. J., & Drake, C. L. (2013). Beyond sleep duration: Distinct sleep dimensions are associated with obesity in children and adolescents. *International Journal of Obesity*, *37*(4), 552–558. https://doi.org/10.1038/ijo.2013.4

Javaheri, S., Storfer-Isser, A., Rosen, C. L., & Redline, S. (2008). Sleep quality and elevated blood pressure in adolescents. *Circulation*, *118*(10), 1034–1040. https://doi.org/10.1161/CIRCULATIONAHA.108.766410

Jean-Louis, G., Grandner, M. A., Youngstedt, S. D., Williams, N. J., Zizi, F., Sarpong, D. F., & Ogedegbe, G. G. (2015). Differential increase in prevalence estimates of inadequate sleep among black and white Americans. *BMC Public Health*, *15*, 1185. https://doi.org/10.1186/s12889-015-2500-0

Jike, M., Itani, O., Watanabe, N., Buysse, D. J., & Kaneita, Y. (2018). Long sleep duration and health outcomes: A systematic review, meta-analysis and meta-regression. *Sleep Medicine Reviews*, *39*, 25–36. https://doi.org/10.1016/j.smrv.2017.06.011

Jung, D. W., Lee, Y. J., Jeong, D.-U., & Park, K. S. (2016). New predictors of sleep efficiency. *Chronobiology International*, *34*(1), 1–12. https://doi.org/10.1080/07420528.2016.1241802

Karatsoreos, I. N., & McEwen, B. S. (2011). Psychobiological allostasis: Resistance, resilience and vulnerability. *Trends in Cognitive Sciences*, *15*(12), 576-584.

Katzmarzyk, P. T., Bray, G. A., Greenway, F. L., Johnson, W. D., Newton, R. L., Ravussin, E., Ryan, D. H., Smith, S. R., & Bouchard, C. (2010). Racial differences in abdominal depot-specific adiposity in white and African American adults. *The American Journal of Clinical Nutrition*, *91*(1), 7–15. https://doi.org/10.3945/ajcn.2009.28136

Katzmarzyk, P. T., Srinivasan, S. R., Chen, W., Malina, R. M., Bouchard, C., & Berenson, G. S. (2004). Body mass index, waist circumference, and clustering of cardiovascular disease risk factors in a biracial sample of children and adolescents. *Pediatrics*, *114*(2), e198–205. https://doi.org/10.1542/peds.114.2.e198

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. https://doi.org/10.1542/peds.2014-2707

Knutson, K. L. (2005). Sex differences in the association between sleep and body mass index in adolescents. *The Journal of Pediatrics*, *147*(6), 830–834. https://doi.org/10.1016/j.jpeds.2005.07.019

Knutson, K. L., Van Cauter, E., Rathouz, P. J., Yan, L. L., Hulley, S. B., Liu, K., & Lauderdale, D. S. (2009). Association between sleep and blood pressure in midlife: The CARDIA sleep study. *Archives of Internal Medicine*, *169*(11), 1055–1061. https://doi.org/10.1001/archinternmed.2009.119

Koolhaas, C. M., Kocevska, D., Te Lindert, B. H. W., Erler, N. S., Franco, O. H., Luik, A. I., & Tiemeier, H. (2019). Objectively measured sleep and body mass index: A prospective bidirectional study in middle-aged and older adults. *Sleep Medicine*, *57*, 43–50. https://doi.org/10.1016/j.sleep.2019.01.034

Koren, D., Dumin, M., & Gozal, D. (2016). Role of sleep quality in the metabolic syndrome. *Diabetes, Metabolic Syndrome and Obesity: Targets and Therapy*, *9*, 281–310. https://doi.org/10.2147/DMSO.S95120

Kripke, D. F., Langer, R. D., Elliott, J. A., Klauber, M. R., & Rex, K. M. (2011). Mortality related to actigraphic long and short sleep. *Sleep Medicine*, *12*(1), 28–33. https://doi.org/10.1016/j.sleep.2010.04.016

Krishnan, V., & Collop, N. A. (2006). Gender differences in sleep disorders. *Current Opinion in Pulmonary Medicine*, *12*(6), 383–389. https://doi.org/10.1097/01.mcp.0000245705.69440.6a

Kshirsagar, A. V., Carpenter, M., Bang, H., Wyatt, S. B., & Colindres, R. E. (2006). Blood pressure usually considered normal is associated with an elevated risk of cardiovascular disease. *The American Journal of Medicine*, *119*(2), 133–141. https://doi.org/10.1016/j.amjmed.2005.08.023

Kuciene, R., & Dulskiene, V. (2014). Associations of short sleep duration with prehypertension and hypertension among Lithuanian children and adolescents: A cross-sectional study. *BMC Public Health*, *14*, 255. https://doi.org/10.1186/1471-2458-14-255

Kuk, J. L., & Lee, S. (2019). Sex and ethnic differences in the relationship between changes in anthropometric measurements and visceral fat in adolescents with obesity. *The Journal of Pediatrics*, *213*, 121–127. https://doi.org/10.1016/j.jpeds.2019.05.052

Laberge, L., Petit, D., Simard, C., Vitaro, F., Tremblay, R. E., & Montplaisir, J. (2001). Development of sleep patterns in early adolescence. *Journal of Sleep Research*, *10*(1), 59–67. https://doi.org/10.1046/j.1365-2869.2001.00242.x

Lauderdale, D. S., Knutson, K. L., Yan, L. L., Liu, K., & Rathouz, P. J. (2008). Self-reported and measured sleep duration: How similar are they? *Epidemiology*, *19*(6), 838–845. https://doi.org/10.1097/EDE.0b013e318187a7b0

Lederbogen, F., Kirsch, P., Haddad, L., Streit, F., Tost, H., Schuch, P., Wüst, S., Pruessner, J. C., Rietschel, M., Deuschle, M., & Meyer-Lindenberg, A. (2011). City living and urban upbringing affect neural social stress processing in humans. *Nature*, *474*(7352), 498–501. https://doi.org/10.1038/nature10190

Lee, J. A., & Park, H. S. (2014). Relation between sleep duration, overweight, and metabolic syndrome in Korean adolescents. *Nutrition, Metabolism, and Cardiovascular Diseases*, *24*(1), 65–71. https://doi.org/10.1016/j.numecd.2013.06.004

Lee, S., Kuk, J. L., Hannon, T. S., & Arslanian, S. A. (2008). Race and gender differences in the relationships between anthropometrics and abdominal fat in youth. *Obesity*, *16*(5), 1066–1071. https://doi.org/10.1038/oby.2008.13

Lee, S. C., Hairi, N. N., & Moy, F. M. (2017). Metabolic syndrome among non-obese adults in the teaching profession in Melaka, Malaysia. *Journal of Epidemiology / Japan Epidemiological Association*, *27*(3), 130–134. https://doi.org/10.1016/j.je.2016.10.006

Leung, L. C. K., Sung, R. Y. T., So, H.-K., Wong, S. N., Lee, K. W., Lee, K. P., Yam, M. C., Li, S. P. S., Yuen, S. F., Chim, S., Chan, K. K., & Luk, D. (2011). Prevalence and risk factors for hypertension in Hong Kong Chinese adolescents: Waist circumference predicts hypertension, exercise decreases risk. *Archives of Disease in Childhood*, *96*(9), 804–809. https://doi.org/10.1136/adc.2010.202770

Lewington, S., Clarke, R., Qizilbash, N., Peto, R., Collins, R., & Prospective Studies Collaboration. (2002). Age-specific relevance of usual blood pressure to vascular mortality: A meta-analysis of individual data for one million adults in 61 prospective studies. *The Lancet*, *360*(9349), 1903–1913. https://doi.org/10.1016/s0140-6736(02)11911-8

Li, C., Ford, E. S., Mokdad, A. H., & Cook, S. (2006). Recent trends in waist circumference and waist-height ratio among US children and adolescents. *Pediatrics*, *118*(5), e1390–8. https://doi.org/10.1542/peds.2006-1062

Lodato, F., Araújo, J., Barros, H., Lopes, C., Agodi, A., Barchitta, M., & Ramos, E. (2013). Caffeine intake reduces sleep duration in adolescents. *Nutrition Research, 33*(9), 726–732. https://doi.org/10.1016/j.nutres.2013.06.005

Lucey, B. P., Wisch, J., Boerwinkle, A. H., Landsness, E. C., Toedebusch, C. D., McLeland, J. S., Butt, O. H., Hassenstab, J., Morris, J. C., Ances, B. M., & Holtzman, D. M. (2021). Sleep and longitudinal cognitive performance in preclinical and early symptomatic Alzheimer's disease. *Brain, 144*(9), 2852–2862. https://doi.org/10.1093/brain/awab272

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. https://doi.org/10.1542/peds.2006-3295

Lusardi, P., Mugellini, A., Preti, P., Zoppi, A., Derosa, G., & Fogari, R. (1995). Effects of a restricted sleep regimen on ambulatory blood pressure monitoring in normotensive subjects. *American Journal of Hypertension*, *8*(4), 90A. https://doi.org/10.1016/0895-7061(95)97699-R

Ma, L., Ding, Y., Chiu, D. T., Wu, Y., Wang, Z., Wang, X., & Wang, Y. (2021). A longitudinal study of sleep, weight status, and weight-related behaviors: Childhood Obesity Study in China Mega-cities. *Pediatric Research*. https://doi.org/10.1038/s41390-021-01365-1

Magee, L., & Hale, L. (2012). Longitudinal associations between sleep duration and subsequent weight gain: A systematic review. *Sleep Medicine Reviews*, *16*(3), 231–241. https://doi.org/10.1016/j.smrv.2011.05.005

Makarem, N., Shechter, A., Carnethon, M. R., Mullington, J. M., Hall, M. H., & Abdalla, M. (2019). Sleep duration and blood pressure: Recent advances and future directions. *Current Hypertension Reports*, *21*(5), 33. https://doi.org/10.1007/s11906-019-0938-7

Marceau, K., Abel, E. A., Duncan, R. J., Moore, P. J., Leve, L. D., Reiss, D., Shaw, D. S., Natsuaki, M., Neiderhiser, J. M., & Ganiban, J. M. (2019). Longitudinal associations of sleep duration, morning and evening cortisol, and BMI during childhood. *Obesity*, *27*(4), 645–652. https://doi.org/10.1002/oby.22420

Marcus, C. L., Greene, M. G., & Carroll, J. L. (1998). Blood pressure in children with obstructive sleep apnea. *American Journal of Respiratory and Critical Care Medicine*, *157*(4 Pt 1), 1098–1103. https://doi.org/10.1164/ajrccm.157.4.9704080

MartinezAguirre-Betolaza, A., Maldonado-Martín, S., Corres, P., Gorostegi-Anduaga, I., Aispuru, G. R., & Mujika, I. (2019). Actigraphy-based sleep analysis in sedentary and overweight/obese adults with primary hypertension: Data from the EXERDIET-HTA study. *Sleep & Breathing = Schlaf & Atmung*, *23*(4), 1265–1273. https://doi.org/10.1007/s11325-019-01813-7

Martinez-Gomez, D., Eisenmann, J. C., Gomez-Martinez, S., Hill, E. E., Zapatera, B., Veiga, O. L., Marcos, A., & AFINOS Study Group. (2011). Sleep duration and emerging cardiometabolic risk markers in adolescents. The AFINOS study. *Sleep Medicine*, *12*(10), 997–1002. https://doi.org/10.1016/j.sleep.2011.05.009

Maslowsky, J., & Ozer, E. J. (2014). Developmental trends in sleep duration in adolescence and young adulthood: Evidence from a national United States sample. *The Journal of Adolescent Health*, *54*(6), 691–697. https://doi.org/10.1016/j.jadohealth.2013.10.201

Matthews, K. A., Croft, J. B., Liu, Y., Lu, H., Kanny, D., Wheaton, A. G., Cunningham, T. J., Khan, L. K., Caraballo, R. S., Holt, J. B., Eke, P. I., & Giles, W. H. (2017). Health-related behaviors by urban-rural county classification - United States, 2013. *MMWR. Surveillance Summaries: Morbidity and Mortality Weekly Report. Surveillance Summaries / CDC*, *66*(5), 1–8. https://doi.org/10.15585/mmwr.ss6605a1

Matthews, K. A., Hall, M., & Dahl, R. E. (2014). Sleep in healthy black and white adolescents. *Pediatrics*, *133*(5), e1189-96. https://doi.org/10.1542/peds.2013-2399

Matricciani, L., Olds, T., & Petkov, J. (2012). In search of lost sleep: Secular trends in the sleep time of school-aged children and adolescents. *Sleep Medicine Reviews*, *16*(3), 203–211. https://doi.org/10.1016/j.smrv.2011.03.005

Mattoo, T. K., & Fulton, D. R. (2019). Patient education: High blood pressure treatment in children (Beyond the Basics). *Up To Date*.

https://www.uptodate.com/contents/high-blood-pressure-treatment-in-children-beyond-the-basics/print?view=print

May, A. L., Kuklina, E. V., & Yoon, P. W. (2012). Prevalence of cardiovascular disease risk factors among US adolescents, 1999-2008. *Pediatrics*, *129*(6), 1035–1041. https://doi.org/10.1542/peds.2011-1082

Mazza, S., Bastuji, H., & Rey, A. E. (2020). Objective and subjective assessments of sleep in children: Comparison of actigraphy, sleep diary completed by children and parents' estimation. *Frontiers in Psychiatry*, *11*, 495. https://doi.org/10.3389/fpsyt.2020.00495

McEwen, B. S. (1998). Protective and damaging effects of stress mediators. *New England journal of medicine*, *338*(3), 171-179. https://doi.org/10.1056/NEJM199801153380307

McEwen, B. S. (1998). Stress, adaptation, and disease: Allostasis and allostatic load. *Annals of the New York Academy of Sciences*, *840*, 33–44. https://doi.org/10.1111/j.1749-6632.1998.tb09546.x

McEwen, B. S. (2005). Stressed or stressed out: What is the difference? *Journal of Psychiatry & Neuroscience*, *30*(5), 315–318.

McEwen, B. S., & Karatsoreos, I. N. (2015). Sleep deprivation and circadian disruption: Stress, allostasis, and allostatic load. *Sleep Medicine Clinics*, *10*(1), 1–10. https://doi.org/10.1016/j.jsmc.2014.11.007

McGrath, E. R., Espie, C. A., Power, A., Murphy, A. W., Newell, J., Kelly, C., Duffy, N., Gunning, P., Gibson, I., Bostock, S., & O'Donnell, M. J. (2017). Sleep to lower elevated blood pressure: A randomized controlled trial (SLEPT). *American Journal of Hypertension*, *30*(3), 319–327. https://doi.org/10.1093/ajh/hpw132

McGrath, J. J., Matthews, K. A., & Brady, S. S. (2006). Individual versus neighborhood socioeconomic status and race as predictors of adolescent ambulatory blood pressure and heart rate. *Social Science & Medicine*, *63*(6), 1442–1453. https://doi.org/10.1016/j.socscimed.2006.03.019

McKnight-Eily, L. R., Eaton, D. K., Lowry, R., Croft, J. B., Presley-Cantrell, L., & Perry, G. S. (2011). Relationships between hours of sleep and health-risk behaviors in US adolescent students. *Preventive Medicine*, *53*(4-5), 271–273. https://doi.org/10.1016/j.ypmed.2011.06.020

McLaughlin Crabtree, V., & Williams, N. A. (2009). Normal sleep in children and adolescents. *Child and Adolescent Psychiatric Clinics of North America*, *18*(4), 799–811. https://doi.org/10.1016/j.chc.2009.04.013

McMahon, D. M., Burch, J. B., Youngstedt, S. D., Wirth, M. D., Hardin, J. W., Hurley, T. G., Blair, S. N., Hand, G. A., Shook, R. P., Drenowatz, C., Burgess, S., & Hebert, J. R. (2019). Relationships between chronotype, social jetlag, sleep, obesity and blood pressure in healthy young adults. *Chronobiology International*, *36*(4), 493–509. https://doi.org/10.1080/07420528.2018.1563094

McNeil, J., Tremblay, M. S., Leduc, G., Boyer, C., Bélanger, P., Leblanc, A. G., Borghese, M. M., & Chaput, J.-P. (2015). Objectively-measured sleep and its association with adiposity and physical activity in a sample of Canadian children. *Journal of Sleep Research*, *24*(2), 131–139. https://doi.org/10.1111/jsr.12241

Medic, G., Wille, M., & Hemels, M. E. (2017). Short- and long-term health consequences of sleep disruption. *Nature and Science of Sleep*, *9*, 151–161. https://doi.org/10.2147/NSS.S134864

Meininger, J. C., Gallagher, M. R., Eissa, M. A., Nguyen, T. Q., & Chan, W. (2014). Sleep duration and its association with ambulatory blood pressure in a school-based, diverse sample of adolescents. *American Journal of Hypertension*, *27*(7), 948–955. https://doi.org/10.1093/ajh/hpt297

Melzer, M. R. T. F., Magrini, I. M., Domene, S. M. Á., & Martins, P. A. (2015). Fatores associados ao acúmulo de gordura abdominal em crianças [Factors associated with abdominal obesity in children]. *Revista paulista de pediatria*, *33*(4), 437–444. https://doi.org/10.1016/j.rpped.2015.04.002

Meltzer, L. J., Williamson, A. A., & Mindell, J. A. (2021). Pediatric sleep health: It matters, and so does how we define it. *Sleep Medicine Reviews*, *57*, 101425. https://doi.org/10.1016/j.smrv.2021.101425

Mezick, E. J., Hall, M., & Matthews, K. A. (2012). Sleep duration and ambulatory blood pressure in black and white adolescents. *Hypertension*, *59*(3), 747–752. https://doi.org/10.1161/HYPERTENSIONAHA.111.184770

Mezick, E. J., Matthews, K. A., Hall, M. H., Richard Jennings, J., & Kamarck, T. W. (2014). Sleep duration and cardiovascular responses to stress in undergraduate men. *Psychophysiology*, *51*(1), 88–96. https://doi.org/10.1111/psyp.12144

Mi, S. J., Kelly, N. R., Brychta, R. J., Grammer, A. C., Jaramillo, M., Chen, K. Y., Fletcher, L. A., Bernstein, S. B., Courville, A. B., Shank, L. M., Pomeroy, J. J., Brady, S. M., Broadney, M. M., Tanofsky-Kraff, M., & Yanovski, J. A. (2019). Associations of sleep patterns with metabolic syndrome indices, body composition, and energy intake in children and adolescents. *Pediatric Obesity*, *14*(6), e12507. https://doi.org/10.1111/ijpo.12507

Mindell, J. A., Owens, J. A., & Carskadon, M. A. (1999). Developmental features of sleep. *Child and Adolescent Psychiatric Clinics of North America*, *8*(4), 695–725. https://doi.org/10.1016/S1056-4993(18)30149-4

Mokha, J. S., Srinivasan, S. R., Dasmahapatra, P., Fernandez, C., Chen, W., Xu, J., & Berenson, G. S. (2010). Utility of waist-to-height ratio in assessing the status of central obesity and related cardiometabolic risk profile among normal weight and overweight/obese children: The Bogalusa Heart Study. *BMC Pediatrics*, *10*, 73. https://doi.org/10.1186/1471-2431-10-73

Mozaffarian, D., Benjamin, E. J., Go, A. S., Arnett, D. K., Blaha, M. J., Cushman, M., de Ferranti, S., Després, J.-P., Fullerton, H. J., Howard, V. J., Huffman, M. D., Judd, S. E., Kissela, B. M., Lackland, D. T., Lichtman, J. H., Lisabeth, L. D., Liu, S., Mackey, R. H., Matchar, D. B., … American Heart Association Statistics Committee and Stroke Statistics Subcommittee. (2015). Heart disease and stroke statistics—2015 update: A report from the American Heart Association. *Circulation*, *131*(4), e29-322. https://doi.org/10.1161/CIR.0000000000000152

Muntner, P., He, J., Cutler, J. A., Wildman, R. P., & Whelton, P. K. (2004). Trends in blood pressure among children and adolescents. *The Journal of the American Medical Association*, *291*(17), 2107–2113. https://doi.org/10.1001/jama.291.17.2107

Nam, G. E., Han, K., Kim, D. H., Lee, J. H., & Seo, W. H. (2017). Sleep duration is associated with body fat and muscle mass and waist-to-height ratio beyond conventional obesity parameters in Korean adolescent boys. *Journal of Sleep Research*, *26*(4), 444–452. https://doi.org/10.1111/jsr.12502

Nambiar, S., Hughes, I., & Davies, P. S. (2010). Developing waist-to-height ratio cut-offs to define overweight and obesity in children and adolescents. *Public Health Nutrition*, *13*(10), 1566–1574. https://doi.org/10.1017/S1368980009993053

Narang, I., Manlhiot, C., Davies-Shaw, J., Gibson, D., Chahal, N., Stearne, K., Fisher, A., Dobbin, S., & McCrindle, B. W. (2012). Sleep disturbance and cardiovascular risk in adolescents. *Canadian Medical Association Journal*, *184*(17), E913–920. https://doi.org/10.1503/cmaj.111589

National Academies of Sciences, Engineering, and Medicine. (2019). *The promise of adolescence: Realizing opportunity for all youth*. National Academies Press (US). https://doi.org/10.17226/25388

National Human Genome Research Institute. (2022). *Race.* https://www.genome.gov/genetics-glossary/Race

National Institute of Health Office of Equity, Diversity, and Inclusion. (n.d.). *Safe zone: Sexual & gender minority.* https://www.edi.nih.gov/people/sep/lgbti/safezone/terminology

National Library of Medicine. (2022). *Ethnicity.* https://www-ncbi-nlm-nih-gov./mesh/68005006

National Sleep Research Resorce. (n.d.). Clevland Children's Sleep and Health Study. https://www.sleepdata.org/datasets/ccshs

Office for Human Research Protections. (2020). *The protection of non-subjects from research harm.* https://www.hhs.gov/ohrp/sachrp-committee/recommendations/tab-c-the-protection-of-non-subjects-from-research-harm.html

Office of Disease Prevention and Health Promotion. (2021). Healthy people 2030: Objectives and data. https://health.gov/healthypeople/objectives-and-data/browse-objectives

Office of Population Affairs. (n.d.). *America's diverse adolescents.* https://opa.hhs.gov/adolescent-health/adolescent-health-facts/americas-diverse-adolescents#:~:text=In%202019%2C%20just%20over%20half,Pacific%20Islander%20(less%20than%201

Ogilvie, R. P., & Patel, S. R. (2017). The epidemiology of sleep and obesity. *Sleep Health*, *3*(5), 383–388. https://doi.org/10.1016/j.sleh.2017.07.013

Ogilvie, R. P., Redline, S., Bertoni, A. G., Chen, X., Ouyang, P., Szklo, M., & Lutsey, P. L. (2016). Actigraphy measured sleep indices and adiposity: The Multi-Ethnic Study of Atherosclerosis (MESA). *Sleep*, *39*(9), 1701–1708. https://doi.org/10.5665/sleep.6096

Ohayon, M. M., Guilleminault, C., & Chokroverty, S. (2010). Sleep epidemiology 30 years later: Where are we? *Sleep Medicine*, *11*(10), 961–962. https://doi.org/10.1016/j.sleep.2010.10.001

Ohayon, M. M., Reynolds, C. F., & Dauvilliers, Y. (2013). Excessive sleep duration and quality of life. *Annals of Neurology*, *73*(6), 785–794. https://doi.org/10.1002/ana.23818

Ohayon, M., Wickwire, E. M., Hirshkowitz, M., Albert, S. M., Avidan, A., Daly, F. J., Dauvilliers, Y., Ferri, R., Fung, C., Gozal, D., Hazen, N., Krystal, A., Lichstein, K., Mallampalli, M., Plazzi, G., Rawding, R., Scheer, F. A., Somers, V., & Vitiello, M. V. (2017). National Sleep Foundation's sleep quality recommendations: First report. *Sleep Health*, *3*(1), 6–19. https://doi.org/10.1016/j.sleh.2016.11.006

Okosun, I. S., Chandra, K. M. D., Boev, A., Boltri, J. M., Choi, S. T., Parish, D. C., & Dever, G. E. A. (2004). Abdominal adiposity in U.S. adults: Prevalence and trends, 1960-2000. *Preventive Medicine*, *39*(1), 197–206. https://doi.org/10.1016/j.ypmed.2004.01.023

Okosun, I. S., Prewitt, T. E., & Cooper, R. S. (1999). Abdominal obesity in the United States: Prevalence and attributable risk of hypertension. *Journal of Human Hypertension*, *13*(7), 425–430. https://doi.org/10.1038/sj.jhh.1000862

Omisade, A., Buxton, O. M., & Rusak, B. (2010). Impact of acute sleep restriction on cortisol and leptin levels in young women. *Physiology & Behavior*, *99*(5), 651–656. https://doi.org/10.1016/j.physbeh.2010.01.028

Oude Luttikhuis, H., Baur, L., Jansen, H., Shrewsbury, V. A., O'Malley, C., Stolk, R. P., & Summerbell, C. D. (2019). WITHDRAWN: Interventions for treating obesity in children. *Cochrane Database of Systematic Reviews, 3,* CD001872. https://doi.org/10.1002/14651858.CD001872.pub3

Ozturk, A., Mazicioglu, M., Poyrazoglu, S., Cicek, B., Gunay, O., & Kurtoglu, S. (2009). The relationship between sleep duration and obesity in Turkish children and adolescents. *Acta Paediatrica*, *98*(4), 699–702. https://doi.org/10.1111/j.1651-2227.2008.01169.x

Paciência, I., Barros, H., Araújo, J., & Ramos, E. (2013). Association between sleep duration and blood pressure in adolescents. *Hypertension Research*, *36*(8), 747–752. https://doi.org/10.1038/hr.2013.36

Paciência, I., Araújo, J., & Ramos, E. (2016). Sleep duration and blood pressure: a longitudinal analysis from early to late adolescence. *Journal of Sleep Research*, *25*(6), 702–708. https://doi.org/10.1111/jsr.12433

Padez, C., Mourao, I., Moreira, P., & Rosado, V. (2009). Long sleep duration and childhood overweight/obesity and body fat. *American Journal of Human Biology*, *21*(3), 371–376. https://doi.org/10.1002/ajhb.20884

Paruthi, S., Brooks, L. J., D'Ambrosio, C., Hall, W. A., Kotagal, S., Lloyd, R. M., Malow, B. A., Maski, K., Nichols, C., Quan, S. F., Rosen, C. L., Troester, M. M., & Wise, M. S. (2016). Recommended amount of sleep for pediatric populations: A consensus statement of the American Academy of Sleep Medicine. *Journal of Clinical Sleep Medicine, 12*(6), 785–786. https://doi.org/10.5664/jcsm.5866

Patel, M. C., Shaikh, W. A., & Singh, S. K. (2012). Association of sleep duration with blood glucose level of Gujarati Indian adolescents. *Indian Journal of Physiology and Pharmacology*, *56*(3), 229–233.

Peach, H., Gaultney, J. F., & Reeve, C. L. (2015). Sleep characteristics, body mass index, and risk for hypertension in young adolescents. *Journal of Youth and Adolescence*, *44*(2), 271–284. https://doi.org/10.1007/s10964-014-0149-0

Phillips, S. R., Johnson, A. H., Shirey, M. R., & Rice, M. (2020). Sleep quality in school-aged children: A concept analysis. *Journal of Pediatric Nursing*, *52*, 54–63. https://doi.org/10.1016/j.pedn.2020.02.043

Pollak, C., Thorpy, M. J., & Yager, J. (2010). *The encyclopedia of sleep and sleep disorders* (3rd ed.). Infobased Publishing

Porter, S. A., Massaro, J. M., Hoffmann, U., Vasan, R. S., O'Donnel, C. J., & Fox, C. S. (2009). Abdominal subcutaneous adipose tissue: A protective fat depot? *Diabetes Care*, *32*(6), 1068–1075. https://doi.org/10.2337/dc08-2280

Pucci, S. H. M., & Pereira, M. G. (2016). Sleep quality in adolescents: What's discriminates good from poor sleepers? *Journal of Sleep Disorders & Therapy*, *5*(2). https://doi.org/10.4172/2167-0277.1000237

Quist, J. S., Sjödin, A., Chaput, J.-P., & Hjorth, M. F. (2016). Sleep and cardiometabolic risk in children and adolescents. *Sleep Medicine Reviews*, *29*, 76–100. https://doi.org/10.1016/j.smrv.2015.09.001

Rahimi, K., Emdin, C. A., & MacMahon, S. (2015). The epidemiology of blood pressure and its worldwide management. *Circulation Research*, *116*(6), 925–936. https://doi.org/10.1161/CIRCRESAHA.116.304723

Räikkönen, K., Matthews, K. A., Pesonen, A.-K., Pyhälä, R., Paavonen, E. J., Feldt, K., Jones, A., Phillips, D. I. W., Seckl, J. R., Heinonen, K., Lahti, J., Komsi, N., Järvenpää, A.-L., Eriksson, J. G., Strandberg, T. E., & Kajantie, E. (2010). Poor sleep and altered hypothalamic-pituitary-adrenocortical and sympatho-adrenal-medullary system activity in children. *The Journal of Clinical Endocrinology and Metabolism*, *95*(5), 2254–2261. https://doi.org/10.1210/jc.2009-0943

Ramos, A. R., Weng, J., Wallace, D. M., Petrov, M. R., Wohlgemuth, W. K., Sotres-Alvarez, D., Loredo, J. S., Reid, K. J., Zee, P. C., Mossavar-Rahmani, Y., & Patel, S. R. (2018). Sleep patterns and hypertension using actigraphy in the Hispanic community health study/study of Latinos. *Chest*, *153*(1), 87–93. https://doi.org/10.1016/j.chest.2017.09.028

Rao, G. (2016). Diagnosis, epidemiology, and management of hypertension in children. *Pediatrics*, *138*(2). https://doi.org/10.1542/peds.2015-3616

Rao, U., Hammen, C. L., & Poland, R. E. (2009). Ethnic differences in electroencephalographic sleep patterns in adolescents. *Asian Journal of Psychiatry*, *2*(1), 17–24. https://doi.org/10.1016/j.ajp.2008.12.003

Reed, D. L., & Sacco, W. P. (2016). Measuring sleep efficiency: What should the denominator be? *Journal of Clinical Sleep Medicine, 12*(2), 263–266. https://doi.org/10.5664/jcsm.5498

Reilly, J. J., & Kelly, J. (2011). Long-term impact of overweight and obesity in childhood and adolescence on morbidity and premature mortality in adulthood: Systematic review. *International Journal of Obesity*, *35*(7), 891–898. https://doi.org/10.1038/ijo.2010.222

Reinehr, T., & Toschke, A. M. (2009). Onset of puberty and cardiovascular risk factors in untreated obese children and adolescents: A 1-year follow-up study. *Archives of Pediatrics & Adolescent Medicine*, *163*(8), 709–715. https://doi.org/10.1001/archpediatrics.2009.123

Reis, J. P., Hankinson, A. L., Loria, C. M., Lewis, C. E., Powell-Wiley, T., Wei, G. S., & Liu, K. (2013). Duration of abdominal obesity beginning in young adulthood and incident diabetes through middle age: The CARDIA study. *Diabetes Care*, *36*(5), 1241–1247. https://doi.org/10.2337/dc12-1714

Rexrode, K. M., Carey, V. J., Hennekens, C. H., Walters, E. E., Colditz, G. A., Stampfer, M. J., Willett, W. C., & Manson, J. E. (1998). Abdominal adiposity and coronary heart disease in women. *The Journal of the American Medical Association*, *280*(21), 1843–1848. https://doi.org/10.1001/jama.280.21.1843

Riley, M., & Bluhm, B. (2012). High blood pressure in children and adolescents. *American Family Physician*, *85*(7), 693–700.

Riley, M., Hernandez, A. K., & Kuznia, A. L. (2018). High blood pressure in children and adolescents. *American Family Physician*, *98*(8), 486–494.

Rosen, C. L., Larkin, E. K., Kirchner, H. L., Emancipator, J. L., Bivins, S. F., Surovec, S. A., Martin, R. J., & Redline, S. (2003). Prevalence and risk factors for sleep-disordered breathing in 8- to 11-year-old children: Association with race and prematurity. *The Journal of Pediatrics*, *142*(4), 383–389. https://doi.org/10.1067/mpd.2003.28

Sadeh, A., & Acebo, C. (2002). The role of actigraphy in sleep medicine. *Sleep Medicine Reviews*, *6*(2), 113–124. https://doi.org/10.1053/smrv.2001.0182

Sadeh, A., Dahl, R. E., Shahar, G., & Rosenblat-Stein, S. (2009). Sleep and the transition to adolescence: A longitudinal study. *Sleep*, *32*(12), 1602–1609. https://doi.org/10.1093/sleep/32.12.1602

Sanyaolu, A., Okorie, C., Qi, X., Locke, J., & Rehman, S. (2019). Childhood and adolescent obesity in the United States: A public health concern. *Global Pediatric Health*, *6*, 2333794X19891305. https://doi.org/10.1177/2333794X19891305

Schiller, J. S., Lucas, J. W., & Peregoy, J. A. (2012). Summary health statistics for U.S. adults: National health interview survey, 2011. *Vital and Health Statistics. Series 10, Data from the National Health Survey*, *256*, 1–218.

Schuler, R. S. (1980). Definition and conceptualization of stress in organizations. *Organizational Behavior and Human Performance*.

Schulkin, J., McEwen, B. S., & Gold, P. W. (1994). Allostasis, amygdala, and anticipatory angst. *Neuroscience and Biobehavioral Reviews*, *18*(3), 385–396. https://doi.org/10.1016/0149-7634(94)90051-5

Sekine, M., Chen, X., Hamanishi, S., Wang, H., Yamagami, T., & Kagamimori, S. (2002). The validity of sleeping hours of healthy young children as reported by their parents. *Journal of Epidemiology*, *12*(3), 237–242. https://doi.org/10.2188/jea.12.237

Seo, S. H., & Shim, Y. S. (2019). Association of sleep duration with obesity and cardiometabolic risk factors in children and adolescents: A population-based study. *Scientific Reports*, *9*(1), 9463. https://doi.org/10.1038/s41598-019-45951-0

Shaikh, W. A., Patel, M., & Singh, S. (2010). Association of sleep duration with arterial blood pressure profile of Gujarati Indian adolescents. *Indian Journal of Community Medicine, 35*(1), 125–129. https://doi.org/10.4103/0970-0218.62571

Shepard, J. W., Buysse, D. J., Chesson, A. L., Dement, W. C., Goldberg, R., Guilleminault, C., Harris, C. D., Iber, C., Mignot, E., Mitler, M. M., Moore, K. E., Phillips, B. A., Quan, S. F., Rosenberg, R. S., Roth, T., Schmidt, H. S., Silber, M. H., Walsh, J. K., & White, D. P. (2005). History of the development of sleep medicine in the United States. *Journal of Clinical Sleep Medicine, 1*(1), 61–82. https://doi.org/10.5664/jcsm.26298

Sherwood, A., Routledge, F. S., Wohlgemuth, W. K., Hinderliter, A. L., Kuhn, C. M., & Blumenthal, J. A. (2011). Blood pressure dipping: Ethnicity, sleep quality, and sympathetic nervous system activity. *American Journal of Hypertension*, *24*(9), 982–988. https://doi.org/10.1038/ajh.2011.87s

Sherwood, A., Steffen, P. R., Blumenthal, J. A., Kuhn, C., & Hinderliter, A. L. (2002). Nighttime blood pressure dipping: The role of the sympathetic nervous system. *American Journal of Hypertension*, *15*(2 Pt 1), 111–118. https://doi.org/10.1016/s0895-7061(01)02251-8

Short, M. A., Booth, S. A., Omar, O., Ostlundh, L., & Arora, T. (2020). The relationship between sleep duration and mood in adolescents: A systematic review and meta-analysis. *Sleep Medicine Reviews, 52*, 101311. https://doi.org/10.1016/j.smrv.2020.101311

Short, M. A., Gradisar, M., Lack, L. C., Wright, H., & Carskadon, M. A. (2012). The discrepancy between actigraphic and sleep diary measures of sleep in adolescents. *Sleep Medicine*, *13*(4), 378–384. https://doi.org/10.1016/j.sleep.2011.11.005

Shuster, A., Patlas, M., Pinthus, J. H., & Mourtzakis, M. (2012). The clinical importance of visceral adiposity: A critical review of methods for visceral adipose tissue analysis. *The British Journal of Radiology*, *85*(1009), 1–10. https://doi.org/10.1259/bjr/38447238]

Simon, S., Rahat, H., Carreau, A.-M., Garcia-Reyes, Y., Halbower, A., Pyle, L., Nadeau, K. J., & Cree-Green, M. (2020). Poor sleep is related to metabolic syndrome severity in adolescents with PCOS and obesity. *The Journal of Clinical Endocrinology and Metabolism*, *105*(4). https://doi.org/10.1210/clinem/dgz285

Simpson, N. S., Banks, S., & Dinges, D. F. (2010). Sleep restriction is associated with increased morning plasma leptin concentrations, especially in women. *Biological Research for Nursing*, *12*(1), 47–53. https://doi.org/10.1177/1099800410366301

Skidmore, P. M. L., Howe, A. S., Polak, M. A., Wong, J. E., Lubransky, A., Williams, S. M., & Black, K. E. (2013). Sleep duration and adiposity in older adolescents from Otago, New Zealand: Relationships differ between boys and girls and are independent of food choice. *Nutrition Journal*, *12*, 128. https://doi.org/10.1186/1475-2891-12-128

Solanki, D. K., Walia, R., Gautam, A., Misra, A., Aggarwal, A. K., & Bhansali, A. (2020). Prevalence of abdominal obesity in non-obese adolescents: A North Indian adolescent study. *Journal of Pediatric Endocrinology & Metabolism*, *33*(7), 853–858. https://doi.org/10.1515/jpem-2019-0026

Soliman, A. T., Yasin, M., & Kassem, A. (2012). Leptin in pediatrics: A hormone from adipocyte that wheels several functions in children. *Indian Journal of Endocrinology and Metabolism*, *16*(Suppl 3), S577–87. https://doi.org/10.4103/2230-8210.105575

Spiegel, K., Leproult, R., L'hermite-Balériaux, M., Copinschi, G., Penev, P. D., & Van Cauter, E. (2004). Leptin levels are dependent on sleep duration: Relationships with sympathovagal balance, carbohydrate regulation, cortisol, and thyrotropin. *The Journal of Clinical Endocrinology and Metabolism*, *89*(11), 5762–5771. https://doi.org/10.1210/jc.2004-1003

Spiegel, K., Leproult, R., & Van Cauter, E. (1999). Impact of sleep debt on metabolic and endocrine function. *The Lancet*, *354*(9188), 1435–1439. https://doi.org/10.1016/S0140-6736(99)01376-8

Stamatakis, K. A., Kaplan, G. A., & Roberts, R. E. (2007). Short sleep duration across income, education, and race/ethnic groups: Population prevalence and growing disparities during 34 years of follow-up. *Annals of Epidemiology*, *17*(12), 948–955. https://doi.org/10.1016/j.annepidem.2007.07.096

Sterling, P., & Eyer, J. (1988). *Handbook of life stress, cognition and health* (S. Fisher & J. Reason, Eds.). John Wiley & Sons.

Stevens, J., Katz, E. G., & Huxley, R. R. (2010). Associations between gender, age and waist circumference. *European Journal of Clinical Nutrition*, *64*(1), 6–15. https://doi.org/10.1038/ejcn.2009.101

Stock, A. A., Lee, S., Nahmod, N. G., Buxton, O. M., & Chang, A. (2017). Sleep and cardiometabolic health: Should college students be concerned? *Sleep*, *40*(suppl_1), A295. https://doi.org/10.1093/sleepj/zsx050.795

St-Onge, M.-P., Grandner, M. A., Brown, D., Conroy, M. B., Jean-Louis, G., Coons, M., Bhatt, D. L., & American Heart Association Obesity, Behavior Change, Diabetes, and Nutrition Committees of the Council on Lifestyle and Cardiometabolic Health; Council on Cardiovascular Disease in the Young; Council on Clinical Cardiology; and Stroke Council. (2016). Sleep duration and quality: Impact on lifestyle behaviors and cardiometabolic health: A scientific statement from the American Heart Association. *Circulation*, *134*(18), e367–e386. https://doi.org/10.1161/CIR.0000000000000444

Storfer-Isser, A., Patel, S. R., Babineau, D. C., & Redline, S. (2012). Relation between sleep duration and BMI varies by age and sex in youth age 8-19. *Pediatric Obesity*, *7*(1), 53–64. https://doi.org/10.1111/j.2047-6310.2011.00008.x

Sturm, W., Tschoner, A., Engl, J., Kaser, S., Laimer, M., Ciardi, C., Klaus, A., Weiss, H., Sandhofer, A., Patsch, J. R., & Ebenbichler, C. F. (2009). Effect of bariatric surgery on both functional and structural measures of premature atherosclerosis. *European Heart Journal*, *30*(16), 2038–2043. https://doi.org/10.1093/eurheartj/ehp211

Sun, S. S., Grave, G. D., Siervogel, R. M., Pickoff, A. A., Arslanian, S. S., & Daniels, S. R. (2007). Systolic blood pressure in childhood predicts hypertension and metabolic syndrome later in life. *Pediatrics, 119*(2), 237–246. https://doi.org/10.1542/peds.2006-2543

Sung, R. Y. T., Choi, K. C., So, H.-K., Nelson, E. A. S., Li, A. M., Kwok, C. W. L., Tong, G. N., Mak, K. H., Ng, P. C., & Fok, T. F. (2008). Oscillometrically measured blood pressure in Hong Kong Chinese children and associations with anthropometric parameters. *Journal of Hypertension*, *26*(4), 678–684. https://doi.org/10.1097/HJH.0b013e3282f42270

Sung, V., Beebe, D. W., Vandyke, R., Fenchel, M. C., Crimmins, N. A., Kirk, S., Hiscock, H., Amin, R., & Wake, M. (2011). Does sleep duration predict metabolic risk in obese adolescents attending tertiary services? A cross-sectional study. *Sleep*, *34*(7), 891–898. https://doi.org/10.5665/SLEEP.1122

Sweatt, S. K., Gower, B. A., Chieh, A. Y., Liu, Y., & Li, L. (2018). Sleep quality is differentially related to adiposity in adults. *Psychoneuroendocrinology*, *98*, 46–51. https://doi.org/10.1016/j.psyneuen.2018.07.024

Swihart, B. J., Caffo, B., Bandeen-Roche, K., & Punjabi, N. M. (2008). Characterizing sleep structure using the hypnogram. *Journal of Clinical Sleep Medicine, 4*(4), 349–355. https://doi.org/10.5664/jcsm.27236

Taheri, S., Lin, L., Austin, D., Young, T., & Mignot, E. (2004). Short sleep duration is associated with reduced leptin, elevated ghrelin, and increased body mass index. *PLoS Medicine*, *1*(3), e62. https://doi.org/10.1371/journal.pmed.0010062

Taylor, R. W., Jones, I. E., Williams, S. M., & Goulding, A. (2000). Evaluation of waist circumference, waist-to-hip ratio, and the conicity index as screening tools for high trunk fat mass, as measured by dual-energy X-ray absorptiometry, in children aged 3-19 y. *The American Journal of Clinical Nutrition*, *72*(2), 490–495. https://doi.org/10.1093/ajcn/72.2.490

Thaikruea, L., & Thammasarot, J. (2016). Prevalence of normal weight central obesity among Thai healthcare providers and their association with CVD risk: A cross-sectional study. *Scientific Reports*, *6*, 37100. https://doi.org/10.1038/srep37100

The American College of Cardiology. (2020). *Cardiovascular disease burden, deaths are rising around the world.* https://www.acc.org/about-acc/press-releases/2020/12/09/18/30/cvd-burden-and-deaths-rising-around-the-world

Theorell-Haglöw, J., Berne, C., Janson, C., Sahlin, C., & Lindberg, E. (2010). Associations between short sleep duration and central obesity in women. *Sleep*, *33*(5), 593–598.

Thosar, S. S., Chess, D., Bowles, N. P., McHill, A. W., Butler, M. P., Emens, J. S., & Shea, S. A. (2021). Sleep efficiency is inversely associated with brachial artery diameter and morning blood pressure in midlife adults, with a potential sex-effect. *Nature and Science of Sleep*, *13*, 1641–1651. https://doi.org/10.2147/NSS.S329359

Tom, C., Roy, B., Vig, R., Kang, D. W., Aysola, R. S., Woo, M. A., Harper, R. M., & Kumar, R. (2018). Correlations between waist and neck circumferences and obstructive sleep apnea characteristics. *Sleep and Vigilance*, *2*(2), 111–118. https://doi.org/10.1007/s41782-018-0041-1

Tonetti, L., Fabbri, M., Filardi, M., Martoni, M., & Natale, V. (2015). Effects of sleep timing, sleep quality and sleep duration on school achievement in adolescents. *Sleep Medicine*, *16*(8), 936–940. https://doi.org/10.1016/j.sleep.2015.03.026

Tripathi, M., & Mishra, S. K. (2019). Screen time and adiposity among children and adolescents: A systematic review. *Journal of Public Health*, 1–18. https://doi.org/10.1007/s10389-019-01043-x

Tsao, C. W., Aday, A. W., Almarzooq, Z. I., Alonso, A., Beaton, A. Z., Bittencourt, M. S., Boehme, A. K., Buxton, A. E., Carson, A. P., Commodore-Mensah, Y., Elkind, M. S. V., Evenson, K. R., Eze-Nliam, C., Ferguson, J. F., Generoso, G., Ho, J. E., Kalani, R., Khan, S. S., Kissela, B. M., … Martin, S. S. (2022). Heart disease and stroke statistics—2022 update: A report from the American Heart Association. *Circulation*, *145*(8), e153–e639. https://doi.org/10.1161/CIR.0000000000001052

United States Department of Health and Human Services. (2010). *Healthy People 2020.* https://www.healthypeople.gov/2020/topics-objectives

Virani, S. S., Alonso, A., Aparicio, H. J., Benjamin, E. J., Bittencourt, M. S., Callaway, C. W., Carson, A. P., Chamberlain, A. M., Cheng, S., Delling, F. N., Elkind, M. S. V., Evenson, K. R., Ferguson, J. F., Gupta, D. K., Khan, S. S., Kissela, B. M., Knutson, K. L., Lee, C. D., Lewis, T. T., … American Heart Association Council on Epidemiology and Prevention Statistics Committee and Stroke Statistics Subcommittee. (2021). Heart disease and stroke statistics—2021 update: A report from the American Heart Association. *Circulation*, *143*(8), e254–e743. https://doi.org/10.1161/CIR.0000000000000950

Walls, H. L., Stevenson, C. E., Mannan, H. R., Abdullah, A., Reid, C. M., McNeil, J. J., & Peeters, A. (2011). Comparing trends in BMI and waist circumference. *Obesity*, *19*(1), 216–219. https://doi.org/10.1038/oby.2010.149

Walker, G. E., Marzullo, P., Ricotti, R., Bona, G., & Prodam, F. (2014). The pathophysiology of abdominal adipose tissue depots in health and disease. *Hormone Molecular Biology and Clinical Investigation*, *19*(1), 57–74. https://doi.org/10.1515/hmbci-2014-0023

Wang, X., Poole, J. C., Treiber, F. A., Harshfield, G. A., Hanevold, C. D., & Snieder, H. (2006). Ethnic and gender differences in ambulatory blood pressure trajectories: results from a 15-year longitudinal study in youth and young adults. *Circulation*, 114(25), 2780–2787. https://doi.org/10.1161/CIRCULATIONAHA.106.643940

Wang, Y., Beydoun, M. A., Min, J., Xue, H., Kaminsky, L. A., & Cheskin, L. J. (2020). Has the prevalence of overweight, obesity and central obesity levelled off in the United States? Trends, patterns, disparities, and future projections for the obesity epidemic. *International Journal of Epidemiology*, *49*(3), 810–823. https://doi.org/10.1093/ije/dyz273

Wang, Y., Mei, H., Jiang, Y.-R., Sun, W.-Q., Song, Y.-J., Liu, S.-J., & Jiang, F. (2015). Relationship between duration of sleep and hypertension in adults: A meta-analysis. *Journal of Clinical Sleep Medicine, 11*(9), 1047–1056. https://doi.org/10.5664/jcsm.5024

Weiss, A. R., Johnson, N. L., Berger, N. A., & Redline, S. (2010). Validity of activity-based devices to estimate sleep. *Journal of Clinical Sleep Medicine*, *6*(4), 336-342. https://doi.org/10.5664/jcsm.27874

Wells, J. C. K., Hallal, P. C., Reichert, F. F., Menezes, A. M. B., Araújo, C. L. P., & Victora, C. G. (2008). Sleep patterns and television viewing in relation to obesity and blood pressure: Evidence from an adolescent Brazilian birth cohort. *International Journal of Obesity*, *32*(7), 1042–1049. https://doi.org/10.1038/ijo.2008.37

Wheaton, A. G., Jones, S. E., Cooper, A. C., & Croft, J. B. (2018). Short sleep duration among middle school and high school students—United States, 2015. *MMWR.*

Morbidity and Mortality Weekly Report, *67*(3), 85–90. https://doi.org/10.15585/mmwr.mm6703a1

Wheaton, A. G., Olsen, E. O., Miller, G. F., & Croft, J. B. (2016). Sleep Duration and Injury-Related Risk Behaviors Among High School Students--United States, 2007-2013. MMWR. *Morbidity and Mortality Weekly Report, 65*(13), 337–341. https://doi.org/10.15585/mmwr.mm6513a1

Wheaton, A. G., Perry, G. S., Chapman, D. P., McKnight-Eily, L. R., Presley-Cantrell, L. R., & Croft, J. B. (2011). Relationship between body mass index and perceived insufficient sleep among U.S. adults: An analysis of 2008 BRFSS data. *BMC Public Health*, *11*, 295. https://doi.org/10.1186/1471-2458-11-295

Whelan, E., O'Shea, J., Hunt, E., & Dockray, S. (2021). Evaluating measures of allostatic load in adolescents: A systematic review. *Psychoneuroendocrinology*, *131*, 105324. https://doi.org/10.1016/j.psyneuen.2021.105324

Whinnery, J., Jackson, N., Rattanaumpawan, P., & Grandner, M. A. (2014). Short and long sleep duration associated with race/ethnicity, sociodemographics, and socioeconomic position. *Sleep*, *37*(3), 601–611. https://doi.org/10.5665/sleep.3508

Wong, M. L., Lau, E. Y. Y., Wan, J. H. Y., Cheung, S. F., Hui, C. H., & Mok, D. S. Y. (2013). The interplay between sleep and mood in predicting academic functioning, physical health and psychological health: A longitudinal study. *Journal of Psychosomatic Research*, *74*(4), 271–277. https://doi.org/10.1016/j.jpsychores.2012.08.014

World Health Organization. (2010). *Stages of adolescent development.*

https://apps.who.int/adolescent/second-decade/section/section_2/level2_2.php

World Health Organization. (2020). *The top 10 causes of death.*

https://www.who.int/news-room/fact-sheets/detail/the-top-10-causes-of-death

Wu, A. J., Rifas-Shiman, S. L., Taveras, E. M., Oken, E., & Hivert, M.-F. (2021). Associations of DXA-measured abdominal adiposity with cardio-metabolic risk and related markers in early adolescence in Project Viva. *Pediatric Obesity*, *16*(2), e12704. https://doi.org/10.1111/ijpo.12704

Xi, B., Mi, J., Zhao, M., Zhang, T., Jia, C., Li, J., Zeng, T., Steffen, L. M., & Public Health Youth Collaborative and Innovative Study Group of Shandong University. (2014). Trends in abdominal obesity among U.S. children and adolescents. *Pediatrics*, *134*(2), e334–9. https://doi.org/10.1542/peds.2014-0970

Xu, Z., Su, H., Zou, Y., Chen, J., Wu, J., & Chang, W. (2012). Sleep quality of Chinese adolescents: Distribution and its associated factors. *Journal of Paediatrics and Child Health*, *48*(2), 138–145. https://doi.org/10.1111/j.1440-1754.2011.02065.x

Yan, B., Yang, J., Zhao, B., Fan, Y., Wang, W., & Ma, X. (2021). Objective sleep efficiency predicts cardiovascular disease in a community population: The Sleep

Heart Health Study. *Journal of the American Heart Association*, *10*(7), e016201. https://doi.org/10.1161/JAHA.120.016201

Yoo, E.-G. (2016). Waist-to-height ratio as a screening tool for obesity and cardiometabolic risk. *Korean Journal of Pediatrics*, *59*(11), 425–431. https://doi.org/10.3345/kjp.2016.59.11.425

Youngblut, J. M., Brooten, D., Singer, L. T., Standing, T., Lee, H., & Rodgers, W. L. (2001). Effects of maternal employment and prematurity on child outcomes in single parent families. *Nursing Research*, *50*(6), 346. PMID: 11725936

Yu, Y., Lu, B. S., Wang, B., Wang, H., Yang, J., Li, Z., Wang, L., Liu, X., Tang, G., Xing, H., Xu, X., Zee, P. C., & Wang, X. (2007). Short sleep duration and adiposity in Chinese adolescents. *Sleep*, *30*(12), 1688–1697. https://doi.org/10.1093/sleep/30.12.1688

Zhang, G. Q., Cui, L., Mueller, R., Tao, S., Kim, M., Rueschman, M., Mariani, S., Mobley, D., & Redline, S. (2018). The National Sleep Research Resource: Towards a sleep data commons. *Journal of the American Medical Informatics Association*, *25*(10), 1351-1358.

Zhang, Y.-X., Wang, Z.-X., Zhao, J.-S., & Chu, Z.-H. (2016). Trends in overweight and obesity among rural children and adolescents from 1985 to 2014 in Shandong, China. *European Journal of Preventive Cardiology*, *23*(12), 1314–1320. https://doi.org/10.1177/2047487316643830

APPENDIX A

INSTITUTIONAL REVIEW BOARD APPROVAL

THE UNIVERSITY OF ALABAMA AT BIRMINGHAM

Office of the Institutional Review Board for Human Use

470 Administration Building
701 20th Street South
Birmingham, AL 35294-0104
205.934.3789 | Fax 205.934.1301 | irb@uab.edu

NHSR DETERMINATION

TO: Rodgers, Shameka

FROM: University of Alabama at Birmingham Institutional Review Board
Federalwide Assurance # FWA00005960
IORG Registration # IRB00000196 (IRB 01)
IORG Registration # IRB00000726 (IRB 02)
IORG Registration # IRB00012550 (IRB 03)

DATE: 07-Jul-2021

RE: IRB-300007563
Sleep and Cardiometabolic Factors in Adolescents Ages 16-19 Participating in the Cleveland Children's Sleep and Health Study

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The Office of the IRB has reviewed your Application for Not Human Subjects Research Designation for the above referenced project.

The reviewer has determined this project is not subject to FDA regulations and is not Human Subjects Research. Note that any changes to the project should be resubmitted to the Office of the IRB for determination.

if you have questions or concerns, please contact the Office of the IRB at 205-934-3789.

Additional Comments:

De-identified publicly available data