INDIVIDUAL FACETS OF SLEEP HYGIENE AS PREDICTORS OF HEALTH

by

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Licensing for Gender Differences Affecting the Relationship Between Sleep Attitudes, Sleep Behaviors and Sleep Outcomes

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ABSTRACT

PHILIP ZENDELS: Individual Facets of Sleep Hygiene as Predictors of Health. (Under the direction of DR. JANE F. GAULTNEY)

Sleep is an important health behavior that many people struggle with. Sleep Hygiene is a set of behaviors and conditions that promote optimal sleep at night. These include avoiding physiologically arousing situations, avoiding unhealthy eating behaviors, having an environment conducive to sleep and having a well-maintained sleep schedule. However, many individuals struggle to maintain these behaviors due to factors of their living situation or larger societal confounds. This dissertation includes three separate studies investigating arousal, timing and environment factors of sleep hygiene and how aspects of these may be beyond an individual's control. We explored how gender interacts with sleep attitudes and sleep hygiene, especially along arousal pathways to predict sleep outcomes. Notably, women who favor sleep do not have as much difference in actual sleep outcomes from women who don't favor sleep compared to differences observed in men. In exploring sleep timing, we investigated whether chronotype or social jetlag were greater predictors of health outcomes. While for self-reported health, being a morning-person was the stronger predictor, for depression and stress, managing social jetlag was the stronger predictor. Lastly, we investigated the relationship of air quality on sleep and cognitive functioning. Nightly particulates did not impair sleep or cognition but carbon dioxide exposure and perceived air quality did. These manuscripts highlight how factors such as gender, work scheduling, and air quality, though associated with Sleep Hygiene, may be important but beyond one's control.

DEDICATION

I’d like to dedicate my dissertation to my family, who have supported me and encouraged me to seek education and continue to understand how the world works. I could not have completed this work without their help and the guidance I received from them.

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Beyond the support of my family, I need to acknowledge all of the support I have had in my education career. I have always been pushed and encouraged to work on multiple research projects at once by my advisor, Dr. Jane Gaultney, which has allowed me to write this manuscript. She encouraged my interdisciplinary interests and helped me form connections such that I could work on many of these projects and many more, helping me develop who I am as a researcher. The guidance of my committee members, Dr. Markant and Dr. Moore-Harrison, also cannot be understated, as they accepted me into their labs and granted me new perspectives on research during my time here. I've made many other great connections at UNC Charlotte within the department, and I've received so much support and guidance from other students in the program that has helped me complete my coursework and research goals. The interdisciplinary connections I have made have also helped contribute to this dissertation, such as the skills I learned from Dr. Magi. The help of other professors from my undergraduate career and teachers from schooling even before, encouraging me to ask questions and explore my interests in sleep also cannot be understated. Everybody who has helped me on my education journey, whether it be teaching me research skills and reviewing my writing, supporting my work, or not getting too upset if I fell asleep in class, has contributed to where I am now and deserve some acknowledgement.

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LIST OF ABBREVIATIONS

CATS	Charlotte Attitudes Towards Sleep scale
CO_2	Carbon Dioxide
DASS	Depression, Anxiety and Stress scale
MEQ	Morningness-Eveningnes Questionnaire
MOS	Medical Outcomes Survey
MTurk	Amazon's Mechanical Turk
OSA	Obstructive Sleep Apnea
PM	Particulate Matter
PM $N_{2.5}$	Particulate Matter molecule counts of 2.5 microns
PM_{10}	Weight of Particulate Matter if 10 microns
$PM_{2.5}$	Weight of Particulate Matter if 2.5 microns
PROMIS	Patient Reported Outcomes Measurement Information System
PSQI	Pittsburgh Sleep Quality Index
RH	Relative Humidity
SE	Sleep Efficiency
SES	Socioeconomic Status
SHPS	Sleep Hygiene Practice Scale
SWSD	Shift Work Sleep Disorder

CHAPTER 1 - INTRODUCTION

Sleep is an essential behavior for maintaining a variety of important health and cognitive functions in humans. The costs of inadequate sleep are severe, with individuals reporting more negative emotions, difficulties in completing social tasks, cognitive impairments and health issues related to sleep problems (Goel et al., 2009). A variety of health outcomes are tied to sleep and improper sleep duration can be life threatening (Akerstedt et al., 2017). Individuals who get insufficient sleep are often at greater risk for digestion and metabolism issues (Taheri et al., 2004), cardiorespiratory problems (Tobaldini et al., 2017), and are at heightened risk for cancer and other chronic health conditions due to weakened immune function (Redline & Burger, 2014). Mental health is thought to have a strong, bidirectional relationship with sleep; many conditions such as depression and anxiety are associated with poorer sleep outcomes and these sleep outcomes can in-turn result in worsening mental health (Cardoso et al., 2019). Many key psychological behaviors also depend on adequate sleep including working memory, executive functioning, learning, emotion regulation, sustained attention, decision making and more (Goel et al., 2009). Additionally, within the United States, sleep deprivation is costly; estimates suggest worker productivity impairments related to sleep deprivation cost $60 billion each year and vehicle accidents from drowsy driving cost an additional $50 billion each year (Goel et al., 2009; Zak & Winn, 2016). With the important role sleep plays in many life facets of life, ensuring one can receive an adequate night of rest is vital for health and behavior.

Having good sleep hygiene practices can help ensure an individual gets sufficient, good-quality sleep. Sleep hygiene is a set of related behaviors and conditions that help promote restful sleep (Lin et al., 2007; Yang et al., 2010). An individual who limits engaging in unhealthy sleep hygiene behaviors is thus likely to sleep better and have better overall health outcomes (Ruggiero et al., 2020). A variety of types of sleep-hygiene behaviors and conditions exist with an individual having varying control over each of them. Arousal-related behaviors, including physically or mentally stimulating tasks that are unlikely to be associated with restful sleep, are often more in the control of an individual. Timing-related behaviors, such as having a consistent sleep time, are often controllable, though external pressures from work and life can interfere with these (Ko, 2013). Environment-related conditions, such as having a cool, dark and quiet space free from distraction to sleep in are often beyond the control of individuals as many of these factors relate to others sharing the same sleep environment or factors within the local community (Hunter & Hayden, 2018). As sleep hygiene promotes good sleep, problematic behaviors or conditions can lead to health issues, such as inconsistent sleep schedules leading to greater risk for metabolic syndrome and related health problems (Gaultney, 2014).

Past research indicates that simply educating individuals about sleep may not be sufficient, but education on sleep hygiene can lead to overall improvements in sleep outcomes, such as quality and duration (De Sousa et al., 2007; Peach & Gaultney, 2017). With an estimated prevalence of about 20% of the United States population having a sleep disorder, more people than ever are at risk for poor or shortened sleep and unhealthy outcomes (American Sleep Association, 2021). Non-clinical populations also benefit from proper sleep hygiene, leading to greater overall health and functioning in life (De Sousa et al., 2007). As sleep hygiene involves multiple interrelated behaviors and conditions, individual aspects can also be targeted in clinical interventions for those with sleep-related disorders (Yang et al., 2010). Thus, researching sleep hygiene and individual components of it can be beneficial for the overall health of those with or without sleep disorders, as one may only need to address some issues with their sleep hygiene. Investigating individual facets of sleep hygiene may provide more specific information for individual clinical and non-clinical sleep issues and thus result in better understanding of sleep processes.

Sleep Hygiene arousal- and eating-related behaviors

Sleep hygiene behaviors related to arousal deal with cognitively and physically stimulating activities immediately prior to sleep such as arguments, exercise and watching TV during sleep (Yang et al., 2010). Eating-related behaviors involve consumption of food and drugs that could inhibit sleep at irregular or suboptimal points (Yang et al., 2010). Arousal-related sleep hygiene behaviors are somewhat more controllable for many individuals as compared to other facets of sleep hygiene; an individual can ensure that they are able to relax themselves before bed with minimal distractions. Eating behaviors are also largely controllable, though certain work schedules can cause problems in this facet of sleep hygiene, leading to poorer sleep outcomes. Arousal-related behaviors of sleep hygiene can impair sleep quality and may disproportionately affect women compared to men (Ruggiero et al., 2020). Arousing activities can be especially impairing to sleep compared to other facets of sleep hygiene and have growing prevalence among many individuals (Lemola et al., 2015), with device use and negative rumination being particularly common threats (Berset et al., 2011; Lemola et al., 2015; National Sleep Foundation, 2011).

Engaging in arousing behaviors that impair sleep hygiene has been shown to be linked with insomnia (Yang et al., 2017). Insomnia is a highly prevalent sleep disorder experienced by one in three adults that involves trouble falling asleep, difficulty in maintaining sleep, shortened sleep duration and in severe cases, inability to sleep (Perlis et al., 2021). Insomnia poses a risk in many health outcomes, leading to cognitive impairments such as inability to sustain attention and correctly process episodic memory (Frotier-Brochu & Morin, 2014). and health issues including greater reporting of comorbid chronic health conditions, lower health-related quality of life, greater risk of self-harm and heightened morbidity. (Combs et al., 2016). Modifying arousal- and eating-related sleep hygiene behaviors may serve as an effective way to improve overall sleep in individuals who experience insomnia and other related sleep issues, given the observed relationship between this facet and related sleep complaints (Yang et al., 2010).

Sleep Hygiene timing-related behaviors

The timing of when people sleep is strongly related with many sleep and health outcomes. Chronicity refers to an individual's circadian preferences for when to sleep being morning-oriented, evening-oriented or neither morning- nor evening-oriented (Horne & Östberg, 1976). Chronicity has been associated with a variety of sleep and health outcomes; morning-oriented individuals tend to be at less risk for depression, insomnia and other mental health conditions than evening-oriented individuals and are at lower risk for diabetes and neurological disorders (Knutson & von Schantz, 2018; Partonen, 2015). Chronicity is tied with other cognitive and personality traits as well; research shows that evening-oriented individuals may be more creative and score better on some cognitive measures such as emotional perception and performance on IQ tests. (Drezno et al., 2019). While the preference for sleep and activity as a morning- or evening-oriented individual clearly interacts with health, changes in sleep schedules, possibly as a result of conforming to a different chronotype, have also been shown to affect health. Social jetlag is a phenomenon where individuals experience discrepancies between the time they sleep between weeknights and weekends (Wittmann et al., 2006). Social jetlag has been shown to be a predictor for worse cardiorespiratory health and metabolic health, such as in metabolic syndrome, and emotional disorders such as depression and anxiety (Caliandro et al., 2021). As such, promoting consistent bedtimes and waketimes for individuals is one of the most common modifiable behaviors to improve sleep hygiene.

However, a variety of factors may prevent adequate sleep hygiene timing-related behaviors, preventing an individual from adequately controlling their sleep schedule. Shift-work sleep disorder (SWSD) is a growing concern; individuals who often work very late and/or changing shifts are less likely to manage a healthy sleep schedule (Smith & Eastman, 2012). SWSD can lead to other comorbid sleep disorders and health conditions and is related to insomnia (Figueiro & White, 2013). The impairment to sleep quality from SWSD can result in impairments in health including metabolic dysregulation, increased risk for cardiovascular disease, reproductive disfunction and cancer (Smith & Eastman, 2012), and impairments in productivity and safety in work and everyday life (Figueiro & White, 2013). Notably, SWSD can result in greater risk of vehicular accidents and thus injury or death due to fatigue and poor visibility conditions as an individual returns home (Liu et al., 2018). SWSD and other work schedules incongruent with an individual's chronotype may lead to social jetlag and the negative consequences of it.

Research has investigated policy-level changes to reduce the risk of accidents and health issues from timing-related sleep issues (Sadeghniiat et al., 2015) and how individual's sleep and activity timing preferences relate to health outcomes (Partonen, 2015). With remote work becoming a more common trend, new opportunities arise to understand how individuals' control of their own schedule and sleep-timing may affect their mental and physical health. Individuals may have more ability to meet their own sleep needs and see greater control of timing-related sleep hygiene behaviors if in a work-from-home environment, thus leading to better sleep and health outcomes.

Sleep Hygiene environment-related conditions

Sleep is easiest to obtain when in an environment that promotes it, free from distraction or stimulus. This involves a dark room to stimulate the production of melatonin, little obtrusive noise and a comfortable temperature range, often on the cooler side (Caddick et al., 2018). While many of these conditions can be somewhat controlled by an individual, others who share the same sleep environment or aspects of the surrounding environment can impair adequate conditions to sleep (Hunter & Hayden, 2018). Light pollution and noise pollution both can contribute to poor sleep by causing delayed onsets or interruptions, especially in areas of lower-socioeconomic status (Hunter & Hayden, 2018). Additionally, concerns about safety in the surrounding environment while sleeping can lead to unhealthy rumination and impact other facets of sleep hygiene (such as arousal behaviors) (Hill et al., 2014; Hunter & Hayden, 2018). Many individuals who do not have control over their work schedule may also be forced to sleep during the day, when there are more likely to be greater light and noise interruptions as well (Smith & Eastman, 2012).

An aspect of the surrounding environment that is sometimes considered for safety purposes is presence of pollution, such as air quality (Caddick et al., 2018; Hunter & Hayden, 2018). Having air access is essential for good-quality sleep; obstructive sleep apnea (OSA) is a disorder affecting at least 14% of the United States (likely more due to obesity prevalence) where individuals are unable to breathe properly throughout the night and may result in poorer sleep outcomes (Bibbins-Domingo et al., 2017). Those diagnosed with OSA often report poorer sleep quality, higher drowsiness and lower scores on physical health-related quality of life (Journal of Sleep Research, 2019) and struggle with cognitive tasks such as verbal learning (Spruyt et al., 2009). High prevalence of carbon dioxide is associated with OSA, but also with poorer sleep in healthy sleepers, highlighting the importance of having clean air for optimal sleep. Issues related to air pollution as a possible concern are again more prevalent in communities of lower socioeconomic status, who see other negative health outcomes as well (Jerrett et al., 20015; Jerrett et al., 2005).

Research into the role of air quality and sleep is new but has primarily focused on outdoor environments. Work by Strøm-Tejsen et al. (2016) found that indoor environments with higher carbon dioxide promoted worse sleep quality and cognitive impairments the following morning. Other research has shown that most bedrooms do not have adequate air circulation, leading to the potential for other air pollutants to build in concentration and be a potential environmental hazard to optimal sleep and health (Canha et al., 2017). The bedroom is a controllable part of the sleep environment, and reducing the concentration of air pollutants within it may promote better sleep overall.

Present Studies and Overarching Theory

Many sleep disorders have been linked to unhealthy sleep hygiene habits, whether that be a result of the individual's habits and behaviors or systemic issues that prevent optimal conditions for sleep. Research has shown the value of practicing sleep hygiene to improve sleep for those with sleep issues and how it can lead to improvements in health and performance. However, research has not fully explored the discrepancies observed among many individuals who are not diagnosed with sleep disorders and how this may impact sleep outcomes, health and behavior (Ruggiero et al., 2020). Women, people from a lower SES background, and other groups that may be disadvantaged or underrepresented in research, may be put into situations where they have less control over their sleep hygiene (Ruggiero et al., 2020). However, individual factors vary greatly between different facets of sleep hygiene, leading to multiple research questions to address unique situations.

Given the variety of experiences people face, it is important for researchers to recognize that many aspects of help extend beyond the individual. This includes sleep, and targeting individual aspects of sleep hygiene may help people better in specific situations. Some models have explored how individual sleep behaviors are a product of multiple interacting networks, including one's biology, one's psychological decisions and behaviors, and the social networks and opportunities available in the surrounding community (Becker, Langberg & Byars, 2015). One model that has looked into a variety of these systems and how they affect one's growth and development is the Bioecological model (Bronfenbrenner & Morris, 2006). The Bioecological model explores how an individual's biological factors like genetics, as well as their behaviors, interact with increasingly large social systems such as their immediate friends and family, their local community, and larger societal norms and values. Many sleep related behaviors (e.g. waking up early) are based in larger norms, and some situations (e.g. noisy neighborhood) may represent surrounding community influences that affect one's sleep. These factors also need to be acknowledged when studying sleep hygiene recommendations.

Three research projects are presented here to explore the role of individual facets of sleep hygiene and how they affect health outcomes. Each of these studies utilizes unique samples, methodology and research questions though all are united under the theme of sleep hygiene, as well as exploring larger influences that can affect sleep via the bioecological model (Bronfenbrenner & Morris, 2006). The first explores all facets of sleep hygiene through self-report measure and how gender differences influence them, primarily focusing on the relationship between arousal-behaviors and sleep quality, given that these are more controllable behaviors. The other two studies explore broader aspects of sleep hygiene related to timing and sleep environment as they effect health, as these are less within power of an individual. The second explores how chronotype and social jetlag impact physiological and mental health, looking at timing-related behaviors. The last explores how air contaminants (carbon dioxide and particulate matter) within the bedroom can contribute to disturbed sleep and cognitive functioning as environment-related conditions.

Study 1

Across numerous health behaviors and outcomes, discrepancies exist between genders, with women often having poorer health outcomes despite more positive attitudes towards maintaining health. This phenomenon has also been observed within sleep; women tend to have more favorable attitudes towards sleep and better sleep hygiene practices, but receive worse sleep than men. In this study, we sought to explore the relationship between gender, sleep attitudes, sleep hygiene, and sleep outcomes. Participants filled out self-report measures examining their sleep attitudes, sleep hygiene, sleep quality and sleep duration along with demographic information. Given the discrepancy between men and women, we predicted that sleep attitudes would interact with gender to indirectly predict sleep outcomes. Additionally, using the PROCESS macro for SPSS we predict each facet of sleep hygiene will act as a mediator between sleep attitudes and sleep outcomes. Lastly, we predict that the indirect pathways would be moderated by gender.

Study 2

Chronotype, a trait for when individuals are most active and perform best that originates from both biology and social environment, can be assessed as morning-oriented or evening-oriented. Morning-oriented individuals often times report better health, lower stress and greater conscientiousness than evening-oriented individuals. When forced to engage with a schedule that does not suit an individual well, they may experience social jetlag, a phenomenon where their bedtime and waketime across the week is inconsistent, leading to poorer sleep. During the initial stages of the COVID-19 pandemic, stay at home orders gave individuals more flexibility and control over their own schedule, possibly reducing the risk for social jetlag. Given the flexibility offered, we examine whether chronicity or social jetlag is a greater prediction of negative health outcomes. In this study conducted in march of 2020, participants submitted a variety of personality and health assessments, including information about their chronotype, their sleep-timing, their global health and their mental health. We predict that social jetlag will have a stronger effect in predicting negative health outcomes as opposed to chronotype as individuals had more control over their schedule and activity.

Study 3

Sleep and breathing disorders such as obstructive sleep apnea can be a severe impairment for health and cognitive functioning. This relationship has been less studied for healthy sleepers, whether or not contaminated air can impair the ability to fully benefit from a clean night's sleep. Carbon dioxide and particulate matter are two pollutants that are prevalent in indoor environments and may not be adequately circulated and filtered out overnight. To assess this relationship, participants were given devices to measure the air quality in their bedroom and their sleep and activity over a three-day period. Each morning, participants filled out a brief subjective report on their sleep and performed a cognitive battery. Due to lack of air circulation in indoor environments, especially at night when there is less motion in the room, only the top 10% of particulate matter readings were used to allow sufficient variability for analysis. Carbon dioxide was used as a control. We predict that high concentrations of particulate matter will impair sleep and cognitive functioning the next morning.

CHAPTER 2 – ARTICLE 1

Abstract

Research has found that discrepancies exist in many health-related behaviors, leading to discrepancies in health outcomes, between men and women. Among these, women tend to have more positive attitudes towards sleep and better sleep hygiene practices despite often having poorer sleep quality and insufficient sleep duration. The present study operationalized sleep hygiene as multi-faceted behaviors rather than a unitary construct. Using the PROCESS macro, we analyzed whether an interaction exists between gender and sleep attitudes to predict sleep hygiene, if sleep hygiene mediated the relationship between sleep attitudes and sleep outcomes, and if this indirect relationship is moderated by gender. Within our sample, gender moderated sleep attitudes predicting environment- and eating-related sleep hygiene behaviors. Sleep quality was indirectly predicted by sleep attitudes via pre-sleep arousal-related sleep hygiene behaviors. Additionally, gender moderated the indirect relationship between sleep attitudes and sleep quality through environment-related sleep hygiene behaviors. These findings reinforce the relevance of studying sleep attitudes in combination with demographic characteristics as predictors of sleep outcomes, and the usefulness of conceptualizing sleep hygiene as separable factors. It may help inform development of potential interventions intended to improve sleep and suggest directions for future studies.

Key words: sleep, sleep attitudes, sleep hygiene, gender differences, sex differences

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Gender Differences Affecting the Relationship between Sleep Attitudes, Sleep Behaviors and Sleep Outcomes

Most individuals will spend about one-third of their lifetime sleeping, a behavior essential for a variety of health functions including regulating homeostasis across multiple systems of the body and mind (Vyazovskiy, 2015). Adequate sleep is important for many immediate benefits to health and behavior, including regulating the immune system, cardiorespiratory health, and preventing fatigue (Tobaldini et al., 2017; Vyazovskiy, 2015). Additionally, sleep is essential in maintaining long-term health, likely involved in mechanisms for fighting chronic health conditions such as obesity, hypertension, metabolic syndrome, and even cancer (Gaultney, 2014; Redline & Berger, 2014; Tobaldini et al., 2017). Not only is sleep important for health, but it is also essential for many aspects of cognition, such as memory, executive functioning, attention, and emotion regulation, allowing individuals to perform at their best (Goel et al., 2009). The costs of poor sleep can be severe; thus it is important to investigate potential factors that can impair one's ability to receive adequate rest throughout the night.

Among the factors that can contribute to or impair the quality of sleep one receives at night is sleep hygiene. Sleep hygiene is a set of guidelines for behavioral practices and environmental factors that promote optimal sleep duration and quality (Yang, Lin, Hsu & Cheng, 2010). Recent work has reported sleep attitudes to successfully predict sleep hygiene, and sleep outcomes indirectly via sleep hygiene (Ruggiero, Peach, Zendels & Gaultney, 2020). Sleep attitudes refer to one's perception of the value and utility of sleep, as well as their preference for sleeping over engaging in other activities (Peach & Gaultney, 2017). Past studies have found some demographic variance in these constructs. For example, sleep hygiene habits related to consuming caffeinated beverages differ across adolescent boys and girls (Galland et al., 2017).

Galland and colleagues (2017) also found significant gender differences in in arousal behaviors prior to bed, bedtime, time in bed, and delayed onset of sleep. Sleep attitudes also seem to vary across gender, with women placing a higher value on sleep over other activities at night than men do (Ruggiero, Peach & Gaultney, 2019). These gender differences in sleep hygiene, sleep attitudes and sleep outcomes suggest that gender may alter the associative patterns.

Sleep attitudes can indirectly predict sleep outcomes through sleep hygiene practices (Ruggiero, Peach, Zendels & Gaultney, 2020). Recent findings suggest that demographic variables, such as age, gender, race, and socioeconomic status (SES), likely moderate the relationship between sleep attitudes and sleep hygiene, thus affecting the indirect pathway (Ruggiero et al., 2020). Many health behaviors, including coping, treatment seeking, smoking and exercise, exhibit gender differences (Gibbons, Barnett, Hickling, Herbig-Wall & Watts, 2012; O'Hea, Wood & Brantley, 2003), leading to the inclusion of gender as a possible mediator. Though research has found that sleep attitudes indirectly predict sleep outcomes via a global measure of sleep hygiene (Ruggiero, Peach & Gaultney, 2019), research has yet to investigate if individual factors of sleep hygiene, such as environment or eating behaviors, may best explain this relation, and whether the indirect association varies by gender.

Sleep Hygiene and Sleep Outcomes

Sleep outcomes include both duration, the number of hours one spends asleep at night, and sleep quality, which includes duration, sleep efficiency (total time asleep out of total time in bed; Buysse et al., 1989) sleep latency, sleep disturbances, and subjective restfulness. Measures of sleep quality are often used in examining sleep outcomes, as these allow comparisons to disordered or irregular sleep (Buysse et al., 1989). Both of these outcomes are important to measure. Evidence associates duration with many health factors, such as metabolic function, and quality with factors such as cardiorespiratory health and immune health, even for individuals not diagnosed with sleep disorders (Taheri et al., 2004; Tobaldini et al., 2017). Both duration and quality vary with sleep hygiene, conditions such as a consistent bedtime and a relaxing environment can help improve both (Yang et al., 2010).

Disturbances due to environmental conditions like light, noise, or temperature can lead to delayed sleep onset, waking throughout the night, lowering efficiency, duration, and quality. Sleep onset and quality may also be impaired by engaging in presleep arousing behaviors, or consumption of food or other substances, preventing key sleep-specific processes for regulating health from occurring (Galland et al., 2017; Vyazovskiy, 2015). Furthermore, allowing sufficient time to sleep, and maintaining a consistent sleep schedule contribute to healthy sleep outcomes (Chaput et al., 2020).

As a set of behaviors, sleep hygiene can be broken into several components, all of which can affect sleep outcomes of quality and duration. Lin et al., (2007) considered general health practices, optimal environmental conditions, sleep-related behaviors and presleep activities in defining four factors of sleep hygiene: physiological and cognitive arousal, eating and consumption behaviors, environmental factors of the bedroom, and timing factors of the sleep schedule. Optimal sleep occurs when an individual has low arousal, has not eaten recently, is in a quiet, dark, and cool environment, and has a consistent bedtime (Lin et al., 2007). Though some components of sleep hygiene are under volitional control, facets such as timing and eating may be harder to maintain for individuals who work varying shifts, leading to poorer sleep outcomes (Ko, 2013). Residents halls and apartment complexes may weaken one's control of the sleep environment.

Often times, attitudes towards behaviors can be an important predictor of those behaviors, and thus must be considered in research or clinical settings. Based on a model of health-related behaviors (Eagly & Chaiken, 2007), sleep attitudes reflect values placed sleep over other activities, including socializing, work, or recreational activities (Peach & Gaultney, 2017). Individuals who have more positive sleep attitudes tend to also have better sleep hygiene scores, resulting in better sleep quality and appropriate sleep durations (Ruggiero et al., 2019). Research has shown disparities in connections between sleep attitudes, sleep hygiene, and sleep outcomes as a function of demographic characteristics, with women reporting poorer hygiene and sleep quality-(Ruggiero et al., 2019). However, women with favorable attitudes about sleep reported better sleep hygiene practices, longer and better quality sleep than men with positive attitudes (Ruggiero et al., 2019).

Health-Related Gender Differences

Various differences at the biological and personality domain may contribute to differences in health decision making and attitudes. Literature comparing gender and concern surrounding health found significant differences in trait-based personality outcomes for health-related and health-seeking behaviors (Weller, Ceschi, Hirsch, Satori & Constantini, 2018). Broadly, females tend to have more positive attitudes towards health information seeking and health behaviors compared to males, yet report lower overall health outcomes (Gibbons et al., 2012; Gil-Lacruz & Gil-Lacruz, 2010; O'hea et al., 2003; Ruggiero et al., 2019).

A variety of objective and subjective measures of sleep have investigated gender differences. Polysomnography studies indicate that while males tend to be diagnosed with obstructive sleep apnea at higher rates, females tend to have higher rates of diagnoses for insomnia (Auer, Frauscher, Hochleitner & Högl, 2018). When medical students reported whether they were receiving sufficient sleep and sleep quality, females reported higher rates of poor sleep quality and insufficient sleep than males (Vajda et al., 2017). Physiological factors related to sleep outcomes and sleep hygiene may exist as well, including different circadian preferences, such as women reporting stronger morning-orientation (Roky, Benaji & Benchekroun, 2006).

Mixed findings about gender and associations between sleep attitudes, hygiene and outcomes suggest a need to examine sleep hygiene as a multi-faceted construct rather than a global measure. Sleep hygiene includes both personal decisions, such as arousal behaviors and consumption prior to bed, as well as factors that may be beyond an individual's control, such as environmental conditions and sleep timing. The present study analyzed sleep hygiene as four parallel variables. The four facets were entered simultaneously to examine a finer-grained potential indirect paths from sleep attitudes to sleep outcomes via the four components of sleep hygiene. Presently, no published studies were found that separated sleep hygiene into subcomponents. Gender was used as a moderator of each indirect pathway. We hypothesized that (1) sleep attitudes would interact with gender in predicting the components of sleep hygiene (2) We predicted significant indirect pathways of sleep attitudes with sleep outcomes via each of the four components of sleep hygiene. Additionally, (3) we predicted that the indirect pathways would be moderated by gender, in that indirect paths would be significant for females. This hypothesized relationship is shown in Figure 1.

Methods

Participants

This study's sample (*N*=173) recruited participants using Amazon's Mechanical Turk (MTurk) pool. MTurk allows researchers to distribute surveys through their service, with the researchers paying any individuals who participate. The study reported here is a secondary analysis of archived data (Ruggiero, Peach & Gaultney, 2019). The original study was approved by the IRB at the University of North Carolina Charlotte, study #17-0226. The original study sought to explore the relationship between demographic characteristics (age, race, gender, SES) and sleep attitudes in predicting overall sleep hygiene and sleep outcomes (Ruggiero et al., 2019). Participants had to reside in the United States and be at least 21 years old to be included and were compensated $2.50 for their participation. Demographic data about the sample are shown in Table 1. Descriptive and correlational data for the measures are presented in Table 2. Gender differences in sleep attitudes, sleep hygiene, and sleep outcomes are shown in Table 3. Participants who identified as neither male nor female (N=1) were excluded from analyses as the study's focus was on comparing the difference between genders and the sample size for individuals in this category was not sufficient for comparative analyses.

Materials

Sleep attitudes. The study used the Charlotte Attitudes Towards Sleep Scale (CATS; Peach & Gaultney, 2017 to measure sleep attitudes. Items utilized a 7-point Likert scale ranging from strongly disagree (1) to strongly agree (7). Ten items assessed two dimensions of sleep attitudes, the perceived benefits and time commitments of sleep, as well as a global measure of sleep attitude. Higher scores indicated more positive attitudes. Five items were reverse-coded and scores were averaged, with higher scores indicating more positive attitudes towards sleep. Internal consistency between the items showed good reliability in the present data (α = .79), similar to the validation study (α = .76).

Sleep Hygiene. The Sleep Hygiene Practice Scale (SHPS) measured self-reported sleep hygiene (Lin et al., 2007; Yang et al., 2010). This measure contains 30 items each measuring the frequency of a behavior's occurrence on a scale of 1-6, with 1 representing the behavior never occurring and 6 representing always. The scale consists of four domains assessing sleep hygiene. Arousal-related behaviors were composed of nine items including engaging in activities before bed or while in bed that could disrupt sleep. Eating/Drinking behaviors were composed of five items such as eating too much or too little, and consumption of caffeine, alcohol, and other possible stimulants close to bedtime. Sleep environment-related behaviors, eight items total, included noise, brightness, ambient temperature and air, and comfort as well as other non-sleep related distractors in the room. Lastly, sleep scheduling and timing behaviors were measured by seven items and included inconsistent bedtimes, wake times, sleeping or staying in bed late, napping excessively, and lack of sunlight and exercise. Higher scores represent poorer sleep hygiene. Internal consistency between items on the scale was high ($\alpha = .93$) for the present study.

Sleep Outcomes. This study collected data on sleep quantity measured in hours and sleep quality measured via the Pittsburgh Sleep Quality Index (PSQI; Buysse et al., 1989). The PSQI is a standardized measure including 19 self-report questions for participants to describe their sleep habits over the past month. After summing individuals scores, a global score can be calculated, ranging from 0-16. Higher scores represent poorer sleep quality, with a five or above indicative of poor sleep quality. The PSQI is considered an acceptable, reliable and validated measure used for subjective sleep quality. A single item from the PSQI estimated sleep duration as hours of sleep obtained at night, differentiating it from hours spent in bed. Higher scores here indicated higher sleep duration. The data produced no significant differences throughout the week (Ruggiero et al., 2019); therefore, sleep duration was operationalized as a single score.

Perceived **Socioeconomic Status (SES).** This variable was estimated using the MacArthur Scale of Subjective Social Status (Adler et al., 2000). Participants are presented with a ladder and are instructed to place themselves upon one of the ladder's rungs. The highest rung represents individuals of higher incomes, education, and social status, whereas the lowest rung represents those who are worst off in these aspects. Participants were asked to rank themselves on this ladder compared to both the general populations of the United States (reported in this study) and their local communities. Potential scores ranged from 1-10, with higher scores indicating higher perceived social status.

Procedure

Participants were able to access and register for the present study through MTurk's website, which redirected them to Qualtrics (www.qualtrics.com) to take the survey. An informed consent screen was presented, and all participants had to acknowledge that they were United States residents and at least 21 years old. This study was approved by the institutional review board at the university which the study was conducted. Participants then proceeded to fill out demographic information, including Socioeconomic Status, gender, race and age. Individuals were also asked to report whether or not they have been diagnosed with any clinical sleep disorders, including insomnia, narcolepsy, sleep apnea or sleepwalking. Participants also responded to surveys describing their stress, exercise and eating habits before filling out the relevant sleep surveys (including sleep attitudes, sleep hygiene, and sleep outcomes).

Plan of Analysis

Demographic data for race was dummy coded and dichotomized by two researchers and checked for accuracy and inter-rater reliability. Race was an open ended prompt, and was coded for 0 to represent racial minorities. Gender was dummy coded with males as 0 and females as 1; one individual identified outside of the gender binary and was excluded from analyses due to insufficient sample size for a separate dummy-coded group. Data for SES and age were left as continuous variables.

Initial descriptive statistics and bivariate correlations were run using SPSS 26.0 (IBM Corporation, Armonk NY, USA). Additionally, differences in focal variables (sleep attitudes, sleep hygiene and facets of it, sleep duration and sleep quality) were compared using independent samples T-Tests using SPSS. The path analyses included race, gender, SES and age as covariates. The test of moderated mediation controlled for race, SES, and age. Hypotheses 1, the interaction between sleep attitudes and gender to predict sleep hygiene, was tested by a simple moderation analysis using the PROCESS macro (Model 1, Hayes, 2018). Hypothesis 2 used a parallel path analysis to examine the indirect effects of attitudes on duration or quality via the four subcomponents, entered as simultaneous indirect paths (PROCESS Model 4). The third hypothesis, examining if gender moderated the indirect effects of attitudes onto sleep outcomes via sleep hygiene, was tested using separate analyses for sleep duration and sleep quality (PROCESS Model 8). Nonstandardized coefficients are reported, and indirect effects were supported by bootstrapping.

Due to the large number of individuals reporting sleep disorders, analyses were run in three separate ways. Each analysis was run first including all individuals with sleep disorders without any change to the overall model. The analyses were then re-run excluding any individuals who reported sleep disorders as well as run including individuals reporting sleep disorders but using disorder status as a covariate.

Results

Descriptive statistics for demographic characteristics of the sample are provided in Table 1. The sample was mostly young-adult, 39% self-reported as members of underrepresented groups, that reported feeling neither high nor low in their subjective socioeconomic status. Most of the sample (81.50%) reported no diagnosed sleep disorders.

Descriptive statistics surrounding sleep are shown in Table 2. Participants reported generally good sleep hygiene practices, an average sleep duration of 7.35 hours, and poor average sleep quality PSQI$\geq$5).. The four components of sleep hygiene were intercorrelated. Worse sleep hygiene was associated with worse sleep quality, while only the arousal and time components significantly associated with sleep duration. Individuals with more positive attitudes towards sleep reported better sleep hygiene practices, longer sleep duration, and better sleep quality. Additionally, duration and sleep quality had a strong negative correlation; individuals who slept for longer periods reported better quality sleep.

PROCESS Analysis produced initial tests of the main effects of sleep attitudes and gender on each of the four components of sleep hygiene. When controlling for race, SES and age, sleep attitudes remained significantly associated with each component ($b \leq -3.75$, $p < .001$). Gender was a significant moderator of the eating ($b = 1.95$, $p = .02$) and environment ($b = 3.23$, $p < .01$) components only, thereby partially supporting hypothesis 1, showing an interaction component between gender and attitudes for predicting two facets of sleep hygiene. See Fig. 2 and 3 for illustration of these interactions. In both instances, males with high sleep attitudes see a greater difference compared to males with lower sleep attitudes than females in each category of sleep attitudes suggesting a moderating effect of gender. While, in both cases, more favorable sleep attitudes associated with better sleep hygiene behaviors, the difference in behaviors was most pronounced among males

Analyses of the second hypothesis, whether sleep attitudes would predict sleep outcomes indirectly via sleep hygiene subcomponents, are shown in Table 4. The path analysis explained 9% of the variability in sleep duration, and did not reach significance. The analysis of sleep quality explained a significant 40% of the variability. Sleep attitudes had a significant, direct contribution to each sleep hygiene component (the ‘a’ path). More favorable attitudes towards sleep predicted fewer unhealthy sleep behaviors. Sleep hygiene components did not significantly predict sleep duration (‘b’ paths), nor were any indirect paths significant. However, analysis using sleep quality as the outcome indicated that hygiene behaviors related to pre-bedtime arousal did significantly predict the outcome. Likewise, the indirect effect of sleep attitudes on sleep quality via arousal behaviors was significant. Thus, the second hypothesis was supported for the arousal subcomponent only.

The final hypothesis, that indirect pathways would be moderated by gender (mediated moderation), was not supported. The indices of moderated mediation generated by the PROCESS analysis all had 95% confidence intervals that included 0, indicating that gender did not moderate indirect pathways (sleep duration indices $\leq .03$; sleep quality indices $\leq .27$).

Across all three types of analyses (including individuals with sleep disorders, excluding individuals with sleep disorders, and including individuals but marking sleep disorders as a covariate), near identical results were found. All significant findings were conserved across the three studies and effect sizes remained similar and consistent. For the model testing hypothesis three, the moderation of gender effecting the indirect relationship of sleep attitudes onto sleep quality, one additional finding emerged only when sleep disorder status was treated as a covariate. In this analysis, we found that gender did have a non-zero interaction effect on the arousal pathway only, with men seeing a greater effect of sleep attitudes indirectly affecting sleep outcomes through arousal-related behaviors (Men: b = -.74, SE = .26, CI = -1.33 - -.30; Women: b = -.54, SE = .22, CI = -1.02. - -.17). Additionally, as these data have been analyzed before, a Bonferoni adjustment was done for all tests but all outcomes remained significant regardless.

Discussion

While knowledge of a health behavior plays an important role in making decisions to engage in health behaviors, the broader literature in health psychology has indicated that attitudes towards the behavior may be a better predictor than knowledge (Gil-Lacruz & Gil-Lacruz, 2010). This has been seen for healthy sleep behaviors, as well (Ruggiero et al., 2019). Furthermore, attitudes about and implementation of healthy behaviors may vary by gender (Gil-Lacruz & Gil-Lacruz, 2010). This study investigated the relationship between sleep attitudes, sleep hygiene (operationalized as four sub-components), and sleep outcomes, further expanding the literature and nomological network for these constructs. The analyses indicated that gender interacts with sleep attitudes to predict two of four components of sleep hygiene (presleep eating and sleep environment). Sleep attitudes predicted sleep quality but not sleep duration indirectly via presleep arousal behaviors; however, indirect paths were not moderated by gender.

One strength of the present study was to operationalize sleep hygiene as multifaceted rather than as a single construct. This was first investigated by Yang et al. (2010), who found that individuals with insomnia only showed significant correlations between arousal-related behaviors and sleep quality. Additionally, though for good sleepers all four domains of sleep hygiene correlated with sleep quality, eating/drinking-related behaviors did not correlate with insomnia risk (Yang et al., 2010). The current study continues to explore upon the differences between these subcomponents to best understand their relationship with both sleep attitudes and sleep outcomes. Sleep outcomes can be investigated more precisely and directly based on the individual’s needs by better understanding individual mechanisms associated with the four subcomponents of sleep hygiene.

Other work has found gender differences in sleep attitudes, sleep hygiene, and sleep practices (Dimakos et al., 2019; Chang & Choi, 2016; Joshi et al., 2015; Ruggiero et al., 2019), raising the possibility that gender must be taken into consideration to understand the mechanisms by which sleep attitude predict sleep practices and outcomes. Our first hypothesis, whether gender would interact with sleep attitudes to predict components of sleep hygiene, was shown to be true for the eating and environment subscales, but not for other subscales. Sleep hygiene problems were more frequent among those with negative sleep attitudes; however, attitude seemed to play a more significant role in presleep eating behaviors and providing an environment conducive to sleep among males. The findings are similar to those of many previous researchers who have found that women tend to have more favorable attitudes towards sleep (Cha & Eun, 2018; Ruggiero et al., 2019; Venn, Meadows & Arber, 2013) but that sleep-behaviors and sleep-outcomes differed across gender and other demographic characteristics (Hantsoo, Khou, White & Ong, 2013; Ruggiero et al., 2019).

Males with less regard for sleep appear to invest less in sleep-related behaviors relative to other groups, possibly due to personality or societal differences as seen in other studies (O'hea et al., 2003; Gil-Lacruz & Gil-Lacruz, 2010). Among personality and physiological differences, various outcomes associated with sleep have been observed across gender. Personality traits, such as assertiveness, are often lower in women as well as individuals reporting greater symptoms of clinical insomnia and other sleep disruptors (Cerolini et al., 2017; Leaper & Robnett, 2011). These differences in personality across gender may explain differences in sleep attitudes, sleep hygiene behaviors and sleep outcomes experienced separately by men and women given the similarities observed to those with other sleep disorders. Though not specific to sleep research, concern surrounding health-behaviors may be related to higher neuroticism and humility, observed more often among women than among men (Weller et al., 2018). Higher neuroticism and lower conscientiousness have been shown to be associated with poorer sleep outcomes (Duggan et al., 2014). Personality and physiological differences may be related as well; morning-oriented circadian rhythms, a preference found more strongly in females (Roky et al., 2006) is possibly related to conscientiousness (Rahafar, Castellana, Randler & Antunez, 2017; Randler, 2008).

Sleep attitudes indirectly predicted sleep quality via presleep arousal behaviors. Individuals may have more control over arousal-related sleep hygiene behaviors than other aspects (such as a supportive environment, and timing) which may vary due to work schedule and interaction with others interfering with optimal sleep conditions (Shriane et al., 2020). No indirect path was seen for sleep duration. Though sleep quality is not necessarily under one's control, sleep duration may involve greater volitional control, leading to possible differences in outcomes. Individuals may choose to sleep for longer durations of time in order to attempt to compensate for a night of poor sleep quality, leading to longer duration, though sleep quality remains sensitive to sleep hygiene related deficits.

Lastly, we were able to find a significant moderation effect of gender when looking at the indirect pathway of sleep attitudes to sleep quality via environmental behaviors. Other pathways through sleep hygiene to sleep quality did not show any moderated mediation effects, nor did any pathways to sleep duration. This may suggest the moderating effect of gender on establishing a conducive sleep environment reported above. Those with more positive attitudes about sleep may be more motivated to arrange their environment to facilitate sleep quality, as research has shown those with more positive health attitudes tend to make greater efforts to adjust their health behaviors (O'Hea et al., 2003).

This study had several strengths. The use of MTurk for distributing the surveys and recruiting participants allowed for a more diverse sample by including a variety of ages, races, and socioeconomic statuses. Notably, a larger percentage of participants were male, relative to many samples of college students (e.g. Peach & Gaultney, 2017). Although no claim is made here of an ethnically representative sample of adults in the United States, the percentage of participants who identified as members of an under-represented population was somewhat higher than the general population of Americans (31% vs. 24%; United States Census Bureau, 2020). The findings are also useful in that they apply to non-clinical populations, as most studies investigating differences in sleep across gender tend to look at those with diagnosed sleep conditions (Auer et al., 2018). Additionally, though the CATS scale was originally validated for college students (Peach & Gaultney, 2017), it maintained high internal consistency in this study, suggesting its scope has broader applications in future studies. Use of the PROCESS macro for SPSS allowed exploration of whether indirect pathways were moderated by gender. This study expands upon previous work (Ruggiero et al., 2019) which primarily looked at dichotomized interactions. Additionally, this study is novel in looking at the four components of sleep hygiene as separate components, rather than grouping them as a single variable. It may be useful to further explore volitional and nonvolitional elements of sleep hygiene.

Several limitations must be taken into consideration. Notably, no objective data were collected on the sample, as all information was self-report. For some variables, such as subjective SES, this could be especially problematic due to individuals having little reference for assessment, however, research shows that subjective and objective SES are highly correlated and related for predicting health outcomes (Kim et al., 2018). Due to the nature of self-report and biases, participants may have not answered some of the survey items honestly, including aspects of the SHPS regarding consumption of alcohol, caffeine, and stimulants. Some items from the SHPS can be vague about what behaviors to report and the measure does not specify a timeframe. Additionally, participants were not asked about any shift work, which may confound sleep hygiene and sleep outcome measures (Schwartz & Roth, 2006). Though MTurk is a useful tool for acquiring data from a diverse sample across the country, the nature of it being unmonitored through an online survey may have led individuals to rush through it or become distracted and our survey did not include any attention checks, a large potential limitation.

Though some data were collected on mental health (Depression and Stress), we chose to leave this out of the analyses. Previous studies have shown that mental health issues including depression and anxiety are strongly correlated with poorer sleep outcomes (Gregory et al., 2011), though the relationship appears bidirectional. Because data for this study was collected at a single time point and did not go in-depth into facets of mental health, these variables were left out of analyses. This limitation should be further explored in future studies to address the role that depression, anxiety, stress, and similar facets of mental health may have in predicting different sleep behaviors and outcomes, as well as the role that better sleep behaviors may have in predicting them.

Due to only one individual reporting their gender as nonbinary, this was insufficient for analyses exploring the role that other gender identities (transgender, nonbinary, etc.) play in sleep attitudes, sleep hygiene and sleep outcomes, leading to possible future research topics to explore. Although gender differences are present in these data, we have no basis to speculate on what aspect of gender (such as biological sex, gender identity) may underlie the differences. The finding that gender did not interact with controllable behaviors such as arousal may reflect differences in concern about health behaviors in general (Weller et al., 2018). Additionally, many of the items related to sleep hygiene factors in the environment such as external light, noise, or temperature may be less within the control of individuals if have a shared sleeping environment or they can't choose factors such as light and noise. Other aspects of sleep such as chronicity, timing, and consistency, were not included. It is also worth noting that because participants on MTurk can choose which studies to participate in, there could likely be a self-selection bias for those who are interested in sleep (thus having more favorable and healthier sleep attitudes and behaviors, respectively) or those concerned with their sleep (having poorer sleep outcomes), likely contributing to the large number of individuals diagnosed with sleep disorders. However, approximately 20% of the United States population is diagnosed with a sleep disorder, suggesting good external validity and generalizability (American Sleep Association, 2021).

This study serves as an exploration between gender differences as they relate to sleep attitudes and outcomes. The findings of this study support further research into demographic difference in sleep related attitudes and behaviors to improve overall sleep. Sleep interventions, which often feature increasing knowledge about sleep (e.g. reducing engaging activity and eating before bed, having consistent bed and wake times and a calm sleep environment) may be improved by considering the role of attitudes among various demographic groupings. Intervention strategies that successfully improve sleep may contribute to improvements in mental and physical health. It appears useful to view both sleep and sleep hygiene as multi-faceted constructs rather than unitary ones.

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Table 2.1
Description of Sample demographic statistics

Variable	Mean ± SD	Range
Age		
Mean ± SD	33.31 ± 9.87	21-70
Gender (%)		
Male	101 (58.38)	
Female	71 (41.04)	
Nonbinary	1 (0.58)	
Race (%)		
White/Caucasian	119 (68.79)	
Black/African American	22 (12.72)	
Asian American	20 (11.56)	
Mixed Race/Other	12 (6.93)	
SES		
Mean ± SD	4.76 ± 1.76	1-9
Diagnosed Sleep Disorder (%)		
No diagnosed disorder	141 (81.50)	
Insomnia	14 (8.10)	6 male, 8 female
Narcolepsy	1 (0.57)	1 male
Sleep Apnea	15 (8.67)	12 male, 3 female
Sleepwalking	2 (1.16)	2 male

Note. $N = 173$.

Table 2.2

Bivariate Correlations for focal variables

Variable	*M*	*SD*	1.	2.	3.	4.	5.	6.
1. Attitudes	5.15	0.94						
2. Duration	7.35	1.47	.18*					
3. Quality	5.55	3.78	-.35**	-.49**				
4. Arousal	23.97	8.28	-.51**	-.22**	.60**			
5. Eat	14.41	5.79	-.50**	-.13	.43**	.61**		
6. Enviro	19.07	7.85	-.47**	-.15	.55**	.74**	.71**	
7. Time	20.77	6.31	-.53**	-.19*	.47**	.70**	.53**	.63**

*Note. N = 173. *p < .05. **p < .01. M* = Mean; SD = Standard Deviation. Attitudes = Sleep attitudes score. Duration = Average nighttime sleep duration. Quality = Average sleep quality. Arousal = Sleep Hygiene arousal subscore. Eat = Sleep Hygiene eating subscore. Enviro = Sleep Hygiene Environment subscore. Time = Sleep Hygiene timing subscore.

Table 2.3

Descriptive Statistics of focal variables by gender

	Males *M* (*SD*)	Females *M* (*SD*)
Attitudes	4.98 (.93)*	5.37 (.92)
Hygiene	79.69 (26.60)	76.45 (20.97)
Arousal	23.97 (8.62)	24.06 (7.85)
Eating	15.30 (5.60)*	13.25 (5.31)
Environment	19.34 (8.29)	18.73 (7.27)
Time	21.09 (6.77)	20.41 (5.60)
Sleep Quality	5.22 (3.79)	6.05 (3.74)
Sleep Duration	7.48 (1.64)	7.17 (1.17)

Note $N = 172$. *$p < .05$. *M* = Mean; SD = Standard Deviation. Attitudes = Sleep attitudes score. Hygiene = Sleep Hygiene Total score.Arousal = Sleep Hygiene arousal subscore. Eat = Sleep Hygiene eating subscore. Enviro = Sleep Hygiene Environment subscore. Time = Sleep Hygiene timing subscore. Quality = Average sleep quality. Duration = Average nighttime sleep duration.

Table 2.4
Path Analyses of Direct and Indirect Effects Of Sleep Attitudes On Sleep Outcomes Through Sleep Hygiene (Hypothesis 2)

	Arousal	Time	Eating	Environment
Direct (SA to SH; 'a' path)	-4.46 (.58)**	-3.57 (.44)**	-3.08 (.41)**	-3.97 (.56)**
Sleep Duration R^2 = .09, *p* =.06, c=.28, c'=.14				
Direct (SH to Sleep Duration; 'b' path)	-.03 (.02)	-.01 (.03)	-.00 (.03)	.01 (.02)
Indirect (H2; via SH)	.15 (.08)	.05 (.11)	-.01 (.07)	-.05 (.09)
95% CI for Indirect Effect	-.01, .31	-.18, .14	-.18, .14	-.25, .10
Sleep Quality R^2 = .40, *p* < .001, c=-1.38**, c'=-.04				
Direct (SH to Sleep Quality; 'b' path)	.19 (.05)**	.03 (.05)	-.002 (.06)	.10 (.05, p=.05)
Indirect (H2; via SH)	-.84 (.24)**	-.11 (.20)	-.11 (.18)	-.40 (.22)
95% CI for Indirect Effect	-1.39, -.45	-.53, .27	-.33, .38	-.83, .10

Note: Standard error in parentheses. **p* < .05, ***p* < .01. Abbreviations: SH = Sleep Hygiene, SA = Sleep Attitude. H2 = Hypothesis 2. CI = Confidence Interval.

Figure 2.1

Proposed model of moderated mediation (Hypothesis 3)

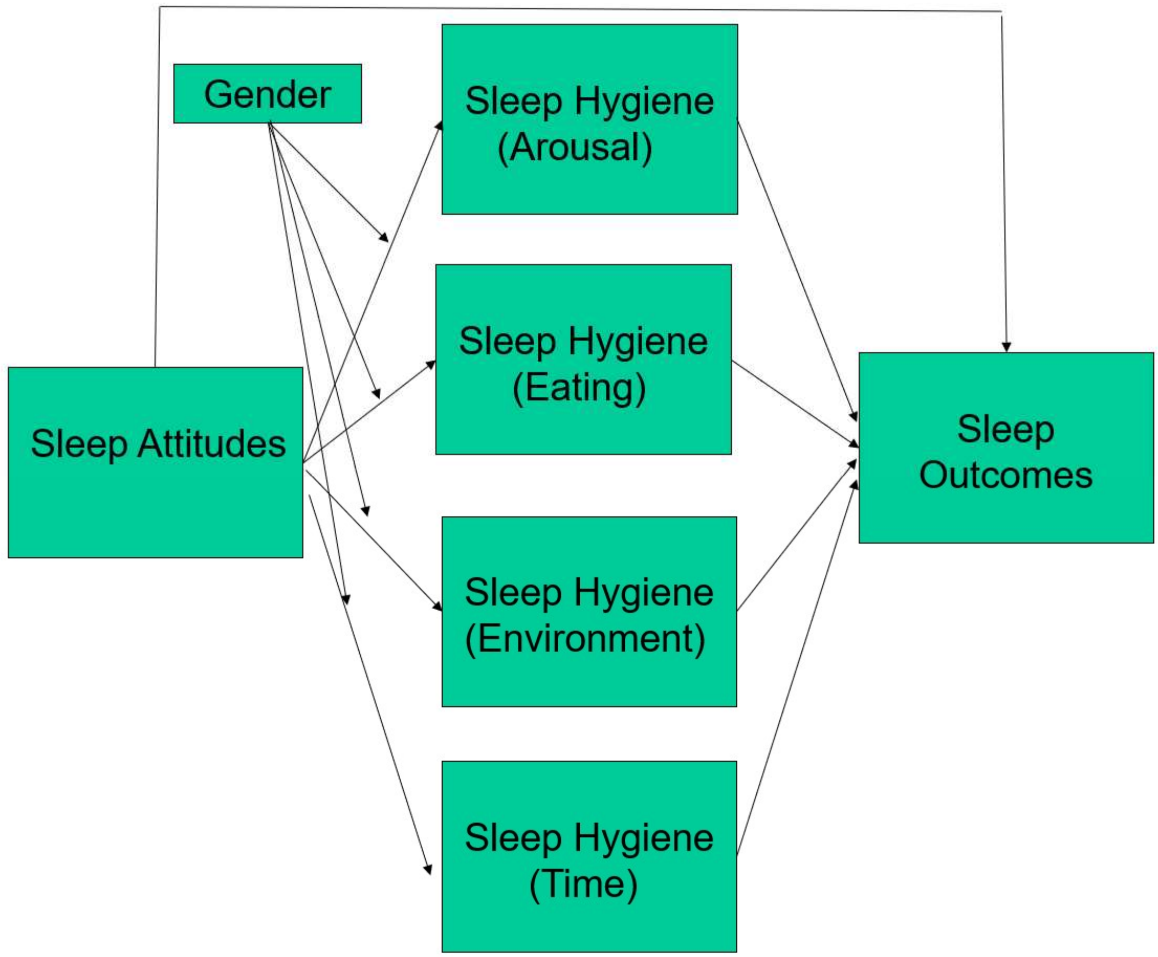


Figure 2.2
Moderating Effects of Gender on Sleep Hygiene Eating sub-score (Hypothesis 1; Higher Scores Indicate Worse Hygiene Behaviors)

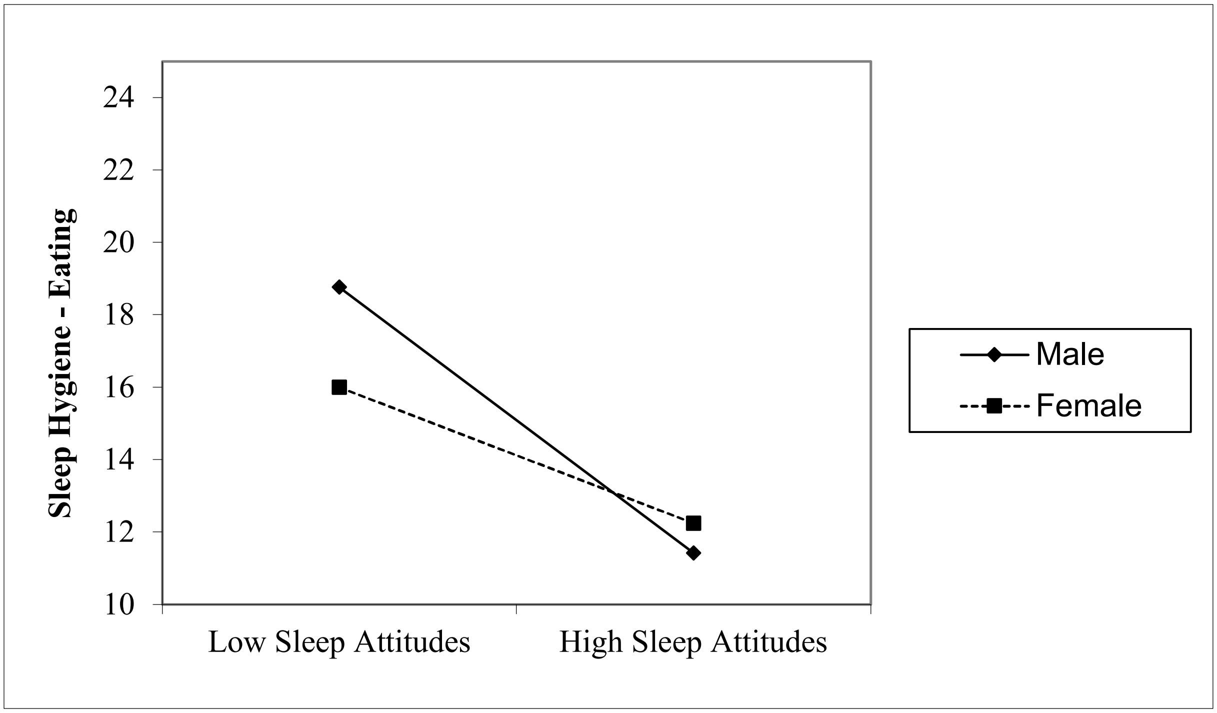
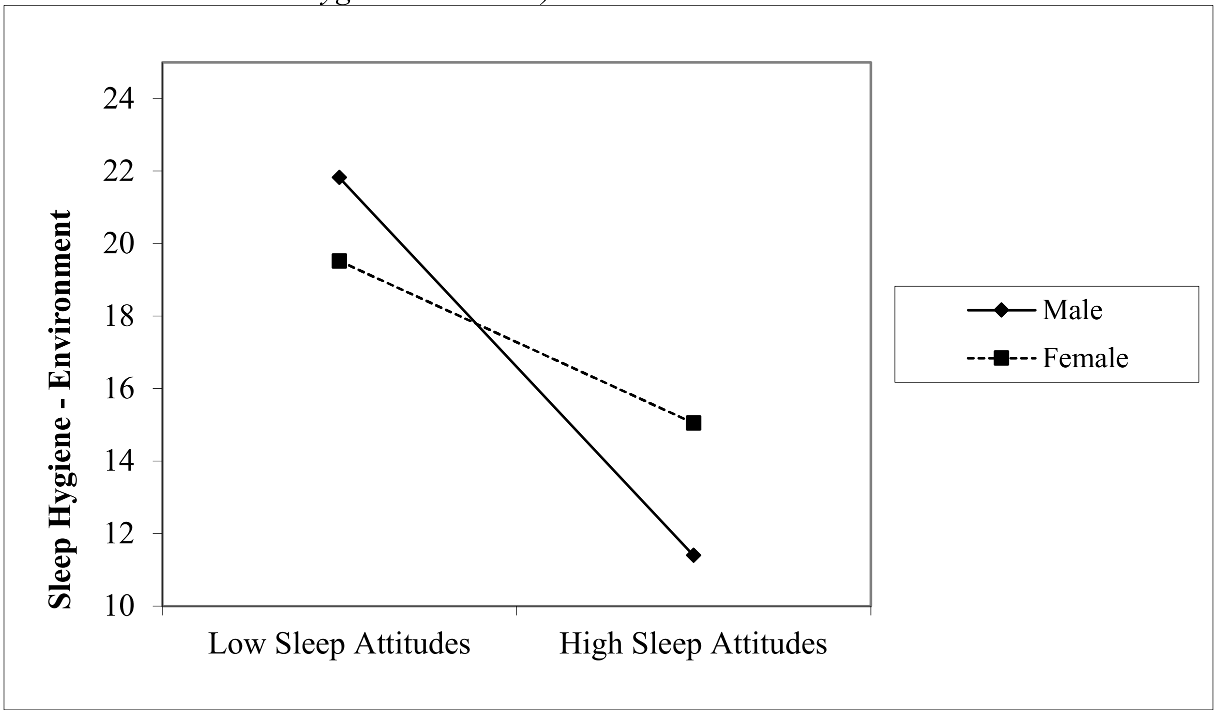


Figure 2.3

Moderating Effects of Gender on Sleep Hygiene Environment sub-score(Hypothesis 1; Higher Scores Indicate Worse Hygiene Behaviors)



CHAPTER 3 – ARTICLE 2

Abstract

It is well known that sleep duration and quality are important predictors for physical and mental health outcomes. Additionally, past research has shown that the timing individuals sleep at is a strong predictor for many health behaviors, with people who go to bed and awaken earlier (morning chronotypes) often having healthier outcomes related to smoking, metabolism and mental health compared to those who stay up and sleep later (evening chronotypes). Some people experience circadian misalignment, or social jetlag, when they have vastly different bedtimes and waketimes on days with versus without commitments such as school or work. This study explores how both social jetlag and chronotype predict self-reported health, depression, anxiety and stress. Data were collected from a larger survey investigating personality, behavior and health outcomes through MTurk. Through standardized linear regressions, we found that both chronotype and social jetlag were associated with self-reported health. For depression and stress, social jetlag was strongly associated with these outcomes, while chronotype was not. These findings suggest that it may be circadian misalignment experienced, as opposed to chronotype, leading to observed discrepancies in health, as somebody more evening-oriented may be more likely to sleep at their preferred times on days without commitment and conform to morning-oriented schedules for work or school.

Chronotype and Social Jetlag as predictors of health in free schedules

Chronotype is the trait-like preferences individuals exhibit for activities and sleep throughout the day, believed to originate from a mix of both genetic influences and environmental conditions (Watson et al., 2015; Wittman et al., 2006). It exists on a spectrum with individuals having stronger preferences for activity in the morning to individuals having stronger preferences for activity in the evening (Horne & Östberg, 1976). Generally, it follows a slightly positive-skewed normal distribution; most individuals have either a slight morning preference or no morning or evening preference, though these vary by age and sex (Fischer et al., 2017). A “morning lark” or person with preferences earlier in the day will often wake up from sleep feeling refreshed and grow tired later throughout the day, whereas a “night owl” or evening-oriented individual will wake up feeling tired but find themselves more alert and active closer to night. Chronotype does not necessarily correlate with how much sleep one gets (Fischer et al., 2017) but later chronotype individuals often self-report worse sleep quality compared to morning-oriented individuals (Wittman et al., 2006). Beyond sleep related outcomes, chronotype is correlated with a number of other personality traits and behaviors, as well as a variety of health outcomes (Drezno et al., 2019).

Morning-oriented individuals tend to score higher on measures of conscientiousness and lower on measures of neuroticism than evening-oriented individuals (Drezno et al., 2019). Additionally, morning-oriented individuals generally maintain better emotional regulation skills, have less engagement in risky behaviors that could jeopardize health, and report greater overall life satisfaction (Drezno et al., 2019). While some studies suggest that evening-oriented individuals report better cognitive skills, evening-oriented individuals still usually are disadvantaged compared to morning-oriented individuals. Evening-oriented individuals are more likely to smoke, drink excessively and have unhealthy diet and exercise (Partonen, 2015). Numerous physiological and mental health issues are thus more prevalent in evening-oriented individuals including substance abuse, sleep disorders, mood disorders, respiratory complications and infertility (Partonen 2015). Knutson and von Schantz (2018) examined morbidity and mortality and found that evening-oriented chronotypes were strongly associated with greater risk for psychological disorders, diabetes, neurological disorders, gastrointestinal disorders and respiratory disorders when compared to morning-oriented individuals. Evening chronotype was also associated with greater mortality (Knutson & von Schantz, 2018). Genetic analyses also suggest that morning-oriented individuals may be at less risk for mental health issues as compared to evening-oriented counterparts (Jones et al. 2019). Despite eveningness being associated with sleep disorders such as insomnia and sleep apnea, research in genetics and public health finds there is little that changes sleep duration between morning- and evening-oriented individuals (Jones et al., 2019; Knutson & von Schantz, 2018).

In everyday life, many individuals have activities that align with morning-oriented chronotype schedules, regardless of whether or not this is their preference for activity. Schedules for regular commitments, such as work and school, tend to be more biased towards morning-oriented individuals, despite many reporting that this leads to poorer sleep outcomes (Werner et al., 2021; Wittman et al., 2006). For those with more evening-oriented behaviors, performance in work and school are impacted by conforming to these schedules imposed upon them (Shimura et al., 2022; Werner et al., 2021). Additionally, many individuals that are not morning-type will report more sleep problems when conforming to these different schedules, with those sleep problems likely contributing to some of the observed outcomes in health and performance (Wittman et al., 2006). While environmental factors and culture contribute some to chronotype, evidence suggests that genetics is also an importing contributing factor (Komada et al., 2019; Partonen, 2015). Thus, some of these cultural values surrounding earlier schedules in the day could be contributing to some of the observed problems in sleep and health outcomes as individuals fail to conform.

As chronotype is not inherently associated with sleep differences, other factors may cause this discrepancy observed in health outcomes. Most schedules, including in schools and the workplace, are tailored towards strong-morning preferences, occurring earlier than many individuals would report best function and activity (Wittman et al., 2006). Many who experience these scheduling discrepancies will find themselves sleeping more in accordance to their chronotype on days without scheduling pressure, possibly resulting in later bedtimes and waketimes and leading to circadian misalignment (Roenneberg et al., 2012; Wittman et al., 2006). This circadian misalignment can be quantified as social jetlag, a measure for the difference between the weeknight and weekend (or day without scheduled pressures) sleep timing. In extreme cases, such as those with shift-work, where getting consistent sleep is not an option, social jetlag may be even greater, leading to detrimental outcomes. Many individuals who are more evening-oriented struggle to adapt to new sleep schedules, leading them to accumulate sleep debt in the mornings and compensate by sleeping in on the weekends, leading to social jetlag (Roenneberg et al., 2012).

Social jetlag has been associated with a wide variety of health issues including greater risk for obesity, metabolic syndrome, depression and more (Gaultney 2014; Hendersen et al., 2019; Roenneberg et al., 2012). Thus, some of the observed unhealthy behaviors and health problems evening-oriented individuals face may be a result of social jetlag rather than their chronotype itself. Past research investigating differences in chronotype and social jetlag has supported the idea of social jetlag being the primary predictor of negative health outcomes, such as smoking (Wittman et al., 2006). Many people, including those who have shift-work, evening-oriented individuals, and individuals who are neither morning- nor evening-oriented may experience some degree of social jetlag due to social, morning-oriented clocks, possibly leading to the observed health discrepancies, as opposed to chronotype directly (Roenneberg et al., 2012).

Exploring whether these chronic health issues are a result of evening-oriented individuals conforming to systematic schedules designed for others, thus facing social-jetlag, or their chronotype itself is difficult to accomplish. Within early 2020, as the COVID-19 pandemic first began spreading, many institutions implemented stay-at-home orders, causing changes in scheduling and communication for all individuals across the world. Work from home procedures changed rapidly in the initial transition but ultimately many individuals reported greater happiness and more flexibility, leading to some companies implementing lasting work-from home polices (Mehta, 2021). With the flexibility awarded to schedules in work-from-home environments and no commute time, individuals have more opportunity to set their own schedule according to their chronotype, potentially reducing social jetlag and the negative outcomes of it.

This study seeks to explore how mental and physical health outcomes in march of 2020 were predicted by chronotype and social jetlag. Despite literature suggesting that chronotype contributes negatively to health, we hypothesize that social jetlag will have a stronger contribution overall to mental and physical health outcomes than chronotype.

Methods

Participants

Participants were recruited through Amazon's Mechanical Turk (MTurk), a platform that sources individuals from across the United States population (Buhrmester, Kwang & Goslin, 2011). This allows greater engagement with the public for online research studies and provides a diverse sample that tends to be more nationally representative than many college campuses (Buhrmester et al., 2011; Roulin, 2015). Within the study, all participants needed to be at least 18 years old and English speaking. A total of 304 American adults were recruited, which was reduced to 262 after removing individuals who failed to complete attention checks throughout the survey. Most participants identified as white (74.43%), non-Hispanic or Latino (74.05%), male (59.16%), held a bachelor's degree (53.05%) and were employed full time (72.14%). Ages ranged from 20 to 69 years old (M = 36.69, SD = 10.96). Due to sample size, race was dichotomized as majority or minority for analyses. Education was measured on an ordinal scale (1 = less than 8th grade, 2 = some high school without a degree, 3 = high school graduate or equivalent, 4 = some college without a degree, 5 = trade or vocational certificate or degree, 6 = associate's degree, 7 = bachelor's degree, 8 = master's degree, 9 = doctoral degree). The sample was more educated and had a higher percentage of males than females but otherwise is fairly representative of the United States' population demographics (US Census Bureau, 2019). A full break down of demographics including distribution of individuals and descriptive variables surrounding is presented in Table 1.

Procedure

Data collected for this study were part of a larger online survey compiled using Qualtrics in March of 2020. Participants were provided a link to the survey via their Mturk account and could complete the survey from any location and device following the signing of an electronic informed consent document. Individual measures from the survey were presented in a randomized order and had attention checks to ensure participants were answering questions to the best of their ability. Following completion of all measures, participants provided demographic information including age, biological sex, race, ethnicity, educational attainment, employment and job title. Participants were paid $2.00 for completion of the survey. At any point while taking the survey, participants could withdraw from the study, though they would lose their compensation if they did so.

Materials

Chronicity. The Morningness-Eveningness Questionnaire (MEQ) was used to assess chronotype (Horne & Östberg, 1976). This is a 19-item measure where individuals select their preferences for optimal times in which they would engage with various activities, sleep, and circadian behaviors. Participants also respond with the frequency that some of these behaviors occur at. Questions each have unique answers and scoring, with a total score being a sum of all the items. higher scores indicate stronger preference for morning behaviors. The scale has acceptable internal consistency (alpha = .78) with the sample in this study reporting similarly consistent answers (alpha = .796) (Smith, Reilly & Midkiff, 1989). Individual scores ranged from 29 (strongly evening-type) to 77 (strongly morning-type) with an average of 54.95 (neither morning- nor evening-type; *SD* = 9.42). Within the sample, 1.2% identified as strong evening-types, 8.8% were moderate evening-types, 54.7 were neither morning- nor evening-types, 30.5% were moderate morning-types and 4.8% were strong morning-types.

Social Jetlag and Sleep. Four additional items were used to calculate individuals' sleep time and behaviors and calculate social jetlag. Social jetlag was operationalized as inconsistency of sleep timing (having a different midpoint of sleep on weeknights and weekends). Individuals reported the time they usually fell asleep at and woke up at from the past two weeks. These times were recorded separately for both weeknights and weekends to calculate social jetlag. Sleep duration was calculated by subtracting the time awoken from the time they fell asleep. Participants reported an average of about 8 hours and 20 minutes (*SD* = 2.17 hours) of sleep on weeknights and 8 hours and 58 minutes (*SD* = 2.23 hours) of sleep on weekends. The average weeknight midpoint was 3:16 AM (*SD* = 1.61 hours) and the average weekend midpoint was 4:03 AM (*SD* = 1.83 hours). Sleep midpoint was also a little inconsistent (*M* = 1 hour 1 minute, *SD* = 1.18 hours). Duration differences were also calculated, but were not included in final analyses due to high correlation with midpoint inconsistencies, which better capture the construct of sleep timing (Wittman et al., 2006). Duration differences across weeknights and weekends were a little inconsistent (*M* = 1 hour 3 minutes, *SD* = 1.90 hours).

Health. Health outcomes were measured using the Patient Reported Outcomes Measurement Information System (PROMIS) Global Health questionnaire (Hays et al., 2009). The PROMIS is a self-report measure that consists of nine items that describe mental and physical health, quality of life, social activities and ability for individuals to complete activities of daily living. All items are measured on a 5-point Likert scale that assesses health quality (ranging from excellent to poor), how capable individuals feel, the frequency of behaviors and severity of fatigue experienced. Six items were reverse scored. Following reverse-scoring, scores were summed. The items showed good reliability (alpha = .763) and scores ranged from 18 to 45 (*M* = 32.24, SD = 5.49) with higher scores representing better overall health.

Mental Health. Mental Health was measured using the Depression, Anxiety and Stress Scale-21 (DASS21; Lovibond & Lovibond, 1995). This is a shortened version containing 21 items from the DASS. Individuals report on a 4-point Likert scale how often behaviors relating to depression, anxiety and stress apply to them. The items are mixed throughout the measure, and a score for each subscale can be calculated by summing the relevant items. The DASS21 presents strong reliability (alpha = .88) with our sample also presenting similarly strong reliability (alpha = .97). Scores for the anxiety and stress subscales ranged from 0 to 20 (anxiety: $M = 14.51$, $SD = 6.71$; stress: $M = 15.62$, $SD = 6.39$) and from 0 to 21 on the depression subscale ($M = 15.49$, $SD = 6.67$). Higher scores represent greater mental health issues.

Plan of Analysis

Data were cleaned and processed and analyzed using SPSS 28 (IBM Corporation, Armonk NY, USA). After removal of participants that did not complete the requisite attention checks, scores were calculated as needed for individual scales. Other than descriptive statistics and bivariate correlations, all analyses used demographic variables as covariates. The PROMIS and each subscale of the DASS were used as outcomes. Hierarchical linear regression was used to examine the role sleep and social jetlag played on health outcomes. In the first level, sleep duration, sleep midpoint and MEQ scores were used as predictors. In the second level, midpoint inconsistency across weeknights and weekends was also added as a predictor.

Results

We ran bivariate correlations to investigate the relationship between age as well as focal variables in the study. These included sleep duration, sleep midpoint, MEQ score, Midpoint discrepancy, and scores on the PROMIS and individual subscales of the DASS. Initially, Duration inconsistencies between sleep were included, but these were removed as a focal variable due to sharing a lot of covariance with midpoint discrepancy ($r = .73$, $p < .001$). A full list of means, standard deviations and bivariate correlations are presented in table 2.

Age was significantly correlated with sleep midpoint ($r = -.23$, $p < .001$) and with score on the MEQ ($r = .15$, $p < .001$); older individuals went to bed earlier and reported more morning-oriented behaviors. Age was also significantly correlated with all outcomes on the DASS, with older individuals reporting lower depression, anxiety and stress scores. Sleep duration was significantly, positively correlated with sleep midpoint ($r = .28$, $p < .001$); individuals who went to bed later reported getting more sleep. Sleep duration was also significantly correlated with depression, anxiety and stress subscales from the DASS. Later sleep midpoints were negatively correlated ($r = -.56$, $p < .001$) with morningness and health outcomes on the PROMIS ($r = -.24$, $p < .001$) and positively correlated with midpoint discrepancy ($r = .16$, $p = .013$) suggesting those with a later bedtime have greater differences between their weeknight and weekend bedtimes. Scores on the MEQ were negatively correlated ($r = -.24$, $p < .001$) with midpoint discrepancy; morning-oriented chronotypes experienced less social jetlag. Scores on the MEQ were also positively correlated with scores on the PROMIS ($r = .35$, $p < .001$). Greater midpoint inconsistencies were also negatively associated with self-reported health from the PROMIS ($r = -.16$, $p = .011$). PROMIS scores were negatively associated with all outcomes of the DASS, and all outcomes on the DASS were strongly correlated with each other.

We ran four hierarchical linear regressions to assess how sleep related variables including sleep duration, sleep midpoint, MEQ score and social jetlag impacted health outcomes. Results from these analyses are shown in Table 3. For all analyses, the first level included demographic variables (Age, Sex, Race, Ethnicity and Education) as well as a weighted sleep duration, sleep midpoint, and score on the MEQ as predictors. The second level added sleep discrepancy as a variable. In order to compare the contribution of both the MEQ and Sleep discrepancy, we reported standardized coefficients.

For the first level, all of our models were significant (R^2 = .16 for PROMIS, .25 for Depression, .34 for Anxiety, .26 for Stress). Education ($\beta = .14$, $p = .031$) and morningness (β =

.34, $p < .001$) were significant predictors of self-reported health scores. For all outcomes on the DASS, age, ethnicity, education and sleep duration were significant predictors. Age and ethnicity both had negative effects as predictors; older individuals and those who identified as neither Hispanic nor Latino reported fewer mental health issues. Education and sleep duration both had positive effects; people who were more educated and people who slept for longer periods on average reported more mental health issues. A list of all effects can be seen in Table 3.

In predicting self-reported health outcomes, adding social jetlag to the model accounted for an additional 2% of variance ($R^2 = .18$, p = .051). Education remained a significant predictor, with more educated individuals reporting better health outcomes ($\beta = .15$, $p = .02$). Morningness also remained a significant predictor ($\beta = .32$, $p < .001$) with morning-oriented individuals reporting better general health outcomes. Social jetlag, as measured through midpoint discrepancy between weeknights and weekends had a trend towards significance ($\beta = -.13$, $p = .051$), with those reporting less social jetlag reporting better health outcomes. A full list of effects is shown in table 3. Given the larger, significant effect of morningness, this does not support the hypothesis.

Adding social jetlag significantly accounted for an additional 2% of variance seen in depression ($R^2 = .27$, p = .038). Age ($\beta = .14$, $p = .026$), ethnicity ($\beta = -.33$, $p < .001$), education ($\beta = .13$, $p = .032$) and total sleep duration ($\beta = .26$, $p < .001$) all remained significant predictors of depression as well, in the same direction as in the previous model. Sleep discrepancy was also a significant predictor ($\beta = .13$, $p = .042$) suggesting greater social jetlag experienced contributes to greater depression.

When adding social jetlag to the model predicting anxiety scores, the change in variance was not significant ($R^2 = .01$, $p = .11$). As with depression, age ($\beta = .17$, $p = .006$), ethnicity ($\beta =$

-.40, $p < .001$), education ($\beta = .20$, $p < .001$) and duration ($\beta = .22$, $p < .001$) all remained significant predictors in expected directions. Sleep discrepancy was not a significant contributor to the model ($\beta = .10$, $p = .11$).

Lastly, in examining the contribution of social jetlag to stress, the change in variance was significant ($R^2 = .02$, $p = .009$). Similarly with the other subscales on the DASS, age ($\beta = .17$, $p = .01$), ethnicity ($\beta = -.34$, $p < .001$), education ($\beta = .15$, $p = .018$) and duration ($\beta = .25$, $p < .001$) remained significant in predicted directions. Sleep discrepancy was a significant predictor ($\beta = .17$, $p = .009$) for stress.

Discussion

These results add to the understanding of chronotype, social jetlag, and health outcomes. For self-reported general health outcomes, morningness was a strong predictor, with social jetlag having a trend towards significance. Greater morningness was associated with better overall general health, and this effect was stronger than that of social jetlag. However, for both depression and stress, high variability in sleep timing led to worse mental health outcomes. These standardized effects were much stronger than those of individuals chronotype. This suggests partial support for the hypothesis; social jetlag has a greater effect than chronotype for predicting aspects of mental health. Thus, individuals who are conforming to other schedules between weeknights and weekends may be at greater risk for negative outcomes.

It's very likely that eveningness can still contribute to negative health outcomes, however. Individuals with later chronotypes may experience negative health effects due to sleep discrepancies to conform to schedules for work or school, for example (Drezno et al., 2018; Shimura et al., 2022; Wittmann et al., 2006). Our data suggest that Morning oriented people experience less social jetlag than others, as shown from the correlation in Table 2. Additionally, past research on other aspects of personality and behavior as related to sleep, such as risky behavior engagement, could lead to poorer health outcomes, regardless of social jetlag (Drezno et al., 2018; Paine, Gander & Travier, 2006). It is possible that some of these correlations in personality and behavior with chronotype might be related to non-societal factors, such as genetics (Watson, Buchwald & Harden, 2013). Additionally, in certain environments individuals may suffer from poorer sleep quality if they would be exposed to more light, noise or other disruptions throughout their sleep time, such as sleeping through the morning (Roenneberg et al., 2013). Despite our findings suggesting social jetlag as a possible predictor for negative mental health outcomes, other aspects of chronotype should not be ruled out (Knutson & von Schantz, 2018; Partonen 2015).

Beyond our findings surrounding chronotype and social jetlag, other predictors were also significant for outcomes of self-reported and mental health. Notably, demographic variables such as age and ethnicity were significant predictors, with younger individuals and those who identified as Hispanic or Latino reporting greater symptoms of depression, anxiety and stress. Education also had a positive effect on all outcome variables; more educated people reported better overall health, but reported worse mental health outcomes. This is not entirely unheard of; people from socially advantaged backgrounds do not always see the same protective effects of education as those from disadvantaged individuals (Bauldry, 2015). Given the timing of the data collection, educated individuals may also have been more informed about the COVID-19 pandemic, leading to greater depression and worse mental health (Khademian et al., 2021; Yang et al., 2020). Out of non-demographic variables, sleep duration positively predicted mental health outcomes. Past literature indicates that individuals suffering with depression, anxiety and stress may sleep significantly more or less than those without mental health issues (Zhai et al., 2015).

Compared to healthy sleepers, those who sleep for longer durations also have an increased relative risk for depression, and the added free time provided by the pandemic may have contributed to this (Zhai et al., 2015) This propensity for greater sleep in some individuals, again combined with the unique timeframe of data collection providing greater opportunities for sleep, may lead to the observed findings.

The timing of when data were collected is noteworthy as this was during the early stages of the COVID-19 pandemic reaching the United States. For many, this was within a period when stay at home orders were imposed, but before telecommuting and work-from-home policies became prevalent (Chang et al., 2021). As a result, data collection during this time is not likely representative of most individuals' true schedules. Some individuals may sleep more aligned with their preferred schedules, reducing social jetlag experienced due to lack of professional and social obligations. Other stressors, including isolation and the lack of knowledge about the virus at the time, also likely contributed to sleep disturbances and overall poorer mental and physical health (Heinen et al., 2022; Yuksel et al., 2021). As a result, these results cannot be completely generalized, but provide insight for future work, especially in situations where individuals have freer schedules to set their own sleep.

Beyond the pandemic, this study has other limitations that should be considered. The data collected was all self-reported and does not represent any medical or clinical diagnoses of conditions experienced. While self-report data for health can be predictive of many conditions, it can be difficult to make specific attributions about health with simplified, general measures (Hays et al., 2009). Notably, the data are very limited in assessing sleep outcomes. As sleep questions focused primarily on sleep timing, we have no information about the sleep quality participants experienced. Sleep quality, the latency before falling asleep, the disturbances causing awakenings throughout the night, and self-reported restorativeness, can be strong predictors of health outcomes (Buysse et al., 1989). These may also reveal information about impairments of social jetlag on sleep quality in relation to conforming to other sleep schedules. Lastly, although the survey was distributed to a wide range of individuals online via MTurk, there are other limitations related to the generalizability of these findings, especially again in the context of the pandemic (Armah et al., 2022). Those taking the survey might not be representative of those of the general population, given the education distribution observed. Additionally, this study did not account for naps or daytime sleep individuals might have engaged in.

The study also has several unique strengths. Data collection through MTurk provided a sample that is largely representative of the United States, suggesting these findings may have broad applicability. Additionally, the use of multiple measures, such as the PROMIS and DASS, allow more insight into individuals health and well-being. While self-reported sleep may not be fully accurate, the survey was able to capture multiple important variables related to sleep, including duration, sleep midpoint and social jetlag. Additionally, having data surrounding sleep midpoint, bedtime and waketime separately for the weeknights and weekends provides more information than might otherwise be obtainable had we only asked for self-report measures on chronotype, such as the MEQ. Lastly, while the COVID-19 pandemic may lead to abnormalities in sleep behaviors and outcomes, the period of time for data collection in this study gives unique insights of how individuals sleep and health may change during initial phases of stay-at-home orders such as this, something other studies may be incapable of.

Our findings suggest that social jetlag is a greater predictor of mental health outcomes than chronotype alone. Minimizing social jetlag and providing more opportunities for individuals to have a sleep schedule according to their preferred chronotype could be beneficial. Encouraging individual sleep hygiene where possible, such as education surrounding consisting bed timing, can likely also promote sleep and health outcomes (de Sousa et al., 2007). However, research suggests that sleep hygiene practices alone may be insufficient to improving health outcomes in many situations and providing more opportunities for individuals to work and live on their own schedules could be beneficial for health outcomes (Peach & Gaultney, 2017; Shimura et al., 2022; Wittmann et al., 2006). Jobs that allow work-from-home opportunities, flexible hours, or working on other schedules may promote better worker satisfaction and productivity (Mehta, 2021). Encouraging more opportunities like these in school and work could lead to better health for those who function best at later hours (Mehta, 2021; Werner et al., 2022).

Given the unique time period of data collection and other limitations of this study, future research should continue to explore chronotype, social jetlag and health outcomes. Studies using objective measures, such as actigraphy for measuring sleep, could provide greater insight into both time periods for activity preferences as well as more accurate timing of sleep duration and midpoint. As the data was all collected via survey, it is difficult to infer directionality, and future studies could compare individuals who work schedules that best agree to their chronotype as well as those working schedules that disagree with their chronotype. Alternatively, controlling for chronotype by studying individuals with the same preference but varying amount of sleep discrepancy could reveal more information as to whether chronotype or social jetlag are greater predictors of health outcomes. Additionally, follow-up studies exploring whether chronotype predicts greater social jetlag, allowing possible mediation effects to be investigated of chronotype onto health outcomes through social jetlag.

This study investigated the relationship between chronotype, social jetlag and health outcomes. While literature suggests that eveningness tends to be associated with negative health outcomes, social jetlag showed a stronger standardized effect in contributing to mental health outcomes of depression and stress. This suggests that working a different schedule than an individual prefers, such as an evening-oriented individual working a morning-oriented schedule, will be at greater health risk. Chronotype and other factors may still contribute to social jetlag and should not be ignored as predictors. Future research should continue to explore how to minimize social jetlag to improve individuals health, as well as ways to further explore the relationships between these variables.

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Table 3.1

Description of Sample demographic statistics

Variable	Frequency (%)
Age	
Mean ± SD	36.69 (10.96)
Sex (%)	
Male	155 (59.2)
Female	107 (40.8)
Race (%)	
White/Caucasian	195 (74.4)
Black/African American	41 (15.6)
Asian American	14 (5.3)
Mixed Race/Other	12 (4.6)
Ethnicity (%)	
Hispanic or Latino	(25.95)
Not Hispanic or Latino	(74.05)
Education	
Less than 8th grade	0 (0)
Some high school without a degree	1 (.4)
High school graduate or equivalent	18 (6.9)
Some college without a degree	27 (10.3)
Trade/vocational certificate/degree	4 (1.5)
Associate’s degree	18 (6.9)
Bachelor’s degree	139 (53.1)
Master’s degree	52 (19.8)
Doctoral degree	3 (1.1)
Chronotype (%)	
Definite evening-type	3 (1.2)
Moderate evening-type	22 (8.8)
Neither morning- nor evening-type	136 (54.7)
Moderate morning-type	78 (31.3)
Definite morning-type	10 (4.0)

Note. $N = 262$.

Table 3.2

Descriptive statistics and correlations for focal variables

	Mean (SD)	1.	2.	3.	4.	5.	6.	7.	8.
1. Age	36.69 (10.96)								
2. Sleep Duration (hrs)	8.51 (1.97)	-0.10							
3. Sleep Midpoint	3:28 (1:33)	-.23**	.28**						
4. MEQ score	54.95 (9.42)	.15**	-.02	-.56**					
5. Midpoint Discrepancy	0:58 (1:01)	-.01	-.03	.16*	-.24**				
6. PROMIS	32.24 (5.49)	0.06	-.10	-.24**	.35**	-.16*			
7. Depression	15.49 (6.67)	-.20**	.36**	0.09	-.04	0.04	-.37**		
8. Anxiety	14.51 (6.71)	-.22**	.33**	-.03	0.10	-0.03	-.23**	.86**	
9. Stress	15.62 (6.39)	-.21**	.34**	0.04	0.03	0.05	-.37**	.88**	.87**

Note. $N = 262$. MEQ = Morningness-Eveningness Questionnaire. PROMIS = Patient Reported Outcomes Measurement Information System. Sleep Midpoint listed as time. Sleep midpoint SD measured in hours and minutes. Midpoint discrepancy measured in hours and minutes.

Table 3.3

Regression Analyses

Model	PROMIS β	Depression β	Anxiety β	Stress β
Controls (ΔR^2)	.16**	.25**	.34**	.26**
Age	0.01	-.14*	-.17*	-.17*
Sex	-0.04	.03	.05	.04
Race	0.02	-.05	-.05	-.04
Ethnicity	0.08	-.30**	-.38**	-.30**
Education	0.14*	.14*	.21**	.16*
Duration	-0.07	.26**	.22**	.25**
Midpoint	-0.02	-.06	-.08	-.10
MEQ	0.34**	-.10	.04	-.05
Social Jetlag (ΔR^2)	.02#	.02*	.01	.02*
Age	0.02	-.14*	-.17*	-.17*
Sex	-0.03	.02	.04	.03
Race	0.02	-.05	-.05	-.04
Ethnicity	0.11	-.33**	-.40**	-.34**
Education	0.15*	.13*	.20**	.15*
Duration	-0.07	.26**	.22**	.25*
Midpoint	-0.01	-.07	-.09	-.11
MEQ	0.32**	-.07	.05	-.02
Sleep Discrepancy	-0.13#	.13*	.10	.17*

Note. #$p < .07$, *$p < .05$, **$p < .001$. β = standardized regression coefficient.

CHAPTER 4 – ARTICLE 3

Abstract

Many environmental conditions, such as exposure to light and noise, temperature, and humidity can impact sleep outcomes. Sleep is an important predictor for a variety of cognitive outcomes, such as working memory and executive functioning. For individuals with obstructive sleep apnea, a disorder in which breathing disruptions impair sleep, there can be severe cognitive impairment. Little research has explored similar pathways in healthy sleepers, such as how poor air quality can impair sleep and cognition. Additionally, long-term exposure to pollutants such as particulate matter could impair cognition, and sleep is a potential mediator of this effect. This study explores how particulate matter and subjective air quality within an individual's bedroom may impair their sleep and cognitive performance. Across three nights, individuals used two devices to objectively record air quality and subjectively reported on their preferences (e.g. the room was too hot or too cold, too humid or too dry, too dust/stale), used actigraphy and self-report measures to assess sleep and took a brief cognitive battery. While particulate matter had no significant effects, air quality reported as poor by the individual was associated with worse sleep quality and working memory performance. Though we did not observe any mediation effects, these data suggest that facets of air quality may contribute to sleep and cognitive performance. Future research should investigate what components of air may lead to these impairments, as well as interventions to protect vulnerable populations.

Bedroom Subjective and Objective Air Quality Associations with Sleep and Cognition

Sleep is an important, nightly physiological process that helps maintain health, growth and development, functioning immune system and optimal cognitive performance. Adequate sleep is important for multiple aspects of cognitive functioning, such as working memory, executive functioning, attention, perception and decision making (Goel et al., 2009). Many individuals suffer from some type of sleep disorder, with estimates suggesting around one out of five people being diagnosed with some condition that may impact their sleep or related health outcomes due to sleep abnormalities (American Sleep Association). In many cases, individuals who are receiving insufficient sleep will experience some kind of cognitive impairment (Goel et al., 2009). Conditions like insomnia, where an individual receives shortened or restricted sleep, are strongly associated with cognitive impairment (Bastien et al., 2003). Many other sleep disorders have been linked to cognitive impairment; when controlling for the amount of sleep, students with obstructive sleep apnea (OSA) still perform worse on learning tasks than those who were not diagnosed with the condition (Spruyt et al., 2009).

A wealth of literature has shown the importance of being able to acquire adequate oxygen during sleep. Sleep and breathing-related respiratory disorders, such as OSA, are growing in prevalence and prevent individuals from obtaining adequate sleep (Bibbins-Domingo et al., 2017). Individuals who suffer from OSA will experience more snoring, and, in severe cases, wake themselves up from snoring or inability to breathe throughout the night, often leading to fragmented sleep, higher daytime sleepiness and lower health related quality of life outcomes (Hoon et al., 2019). Medical bills from other comorbid conditions linked to OSA as well as vehicle accidents from drowsy driving as a result of OSA have been estimated to cost over 20 billion euros in Italy alone (Borsoi et al., 2022). A large body of literature exists that shows the importance of sleep for health and optimal functioning as well as the importance of clean air for health and optimal functioning. However, little research has explored how clean air is important for sleep beyond clinical cases such as obstructive sleep apnea. Few studies have explored the importance of air quality within the sleep environment, despite an abundance of literature demonstrating the need for oxygen access and proper respiratory function during sleep.

Sleep Environment

It is well known that there are optimal environmental conditions that promote better sleep, such as having a dark, quiet, cool room of average humidity (Caddick et al., 2018). Some researchers have investigated sleep at different altitudes and air pressure as well, finding that environments closest to sea level conditions with adequate ventilation for carbon dioxide (CO_2; e.g. opening a window) promote the best sleep (Caddick et al., 2018; Urlaub et al., 2015). However, most bedroom environments do not meet these conditions; many bedrooms do not allow for adequate circulation and most individuals sleep with their doors and windows closed, leading to accumulation of air contaminants such as CO_2, particulate matter, volatile organic compounds and more (Canha et al., 2017). While not studied in the bedroom environment directly, public health disparities related to neighborhood safety have shown that high concentrations of particulate matter and ozone can also be a concern for sleep and health outcomes (Hunter & Hayden, 2018).

Sleep and Cognition

Sleep also plays several important roles in health and cognitive performance. Sleep is essential for optimal performance in a variety of cognitive functions including executive functioning, long-term memory consolidation, working memory, sustained attention, emotional regulation and more (Goel et al., 2009). Cases of OSA have been shown to impair cognitive performance, even when individuals obtain similar sleep to those without diagnoses. It is still unclear what causes cognitive decline in sleep apnea patients, but fragmented sleep, especially due to breathing issues such as hypoxemia, likely contributes (Sforza & Roche, 2012). Additionally, when provided surgical treatment or correction for OSA, adults reported lower overall sleepiness and performed better in attention and driving assessments, highlighting the practical importance of these cognitive skills for health (Alkan et al., 2021). These cognitive outcomes have also manifested in non-clinical samples; students who slept with their bedroom windows open had lower CO_2 in their bedroom overnight and better performance on cognitive tests (Strøm-Tejsen et al., 2016; Zendels, Magi & Gaultney, in progress).

Air Quality and Cognition – Sleep as a Mediator

A variety of safety concerns, ranging from crime to exposure to contaminants, can also affect sleep outcomes (Hunter & Hayden, 2018). Air quality has also been linked to sleep conditions such as OSA, with exposure to fine particles, ozone and sulfur dioxide associated with greater odds of developing OSA and worse symptoms in periods of high exposure (Tung et al., 2021). Growing evidence also suggests that chronic exposure to man-made pollutants, such as those from vehicles and industrial sites, can inhibit cognitive processes later in life (Fang et al., 2015; Pan et al., 2022). Given the connection between exposure to poor air quality and links to OSA (Tung et al., 2021), and the links between OSA and cognitive performance, some studies propose that sleep may mediate the relationship between air quality and sleep (Pan et al., 2022). Exposure to pollutants including carbon, potassium, iron and ammonium were linked to cognitive decline among urban Chinese residents, with sleep partially mediating this relationship (Pan et al., 2022). Additionally, more vegetation and green space in the surrounding environment helped decrease these impairments (Pan et al., 2022).

Many groups have established a variety of guidelines for limiting exposure to air pollutants in outdoor environments in order to preserve health. However, research is limited in the effects of indoor air quality on sleep and cognition. Some studies have looked at broader health outcomes, such as sick building syndrome. This is a collection of symptoms including fatigue, troubles focusing, dizziness, and nausea, often occurs when individuals are in environments that do not provide adequate ventilation and has been associated with high concentrations of CO_2 within indoor environments (Canha et al., 2017; Redlich et al., 1997; Zhang et al., 2011). While research has investigated the role of indoor air quality, sleep and academic performance, some studies been inconclusive in determining any relationship. (Klausen et al., 2023). However, many studies have seen an effect. Other contaminants, such as particles like pollen, smoke, mold and dust in the outdoor environment can interfere with optimal learning in classroom settings and lead to poorer academic performance (Kim et al., 2020; Zhang et al., 2011).

A few studies have begun to explore the impacts of indoor exposure of CO_2 on sleep, cognitive functioning and performance. One study examined participants staying in a controlled, college-dormitory environment where they slept in conditions with the windows closed (higher CO_2) or open (lower CO_2; Strøm-Tejsen et al., 2016). Participants reported qualitatively on their air and sleep quality, as well as having their air monitored and wearing an actigraph, before taking a cognitive test. Those who were exposed to high concentrations of CO_2 found through objective air quality measures got worse sleep, reported feeling less refreshed and performed worse on tests of logical thinking (Strøm-Tejsen et al., 2016). Other studies have replicated these findings in a more naturalistic setting, letting students bring air quality recording devices and actigraphs into their own bedrooms, finding again that high CO_2 exposure impairs sleep and working memory (Zendels et al., in progress). However, a study investigating school children found no significant difference in cognitive performance and that high CO_2 led to better sleep, though the authors suggest this could be a chance finding (Klausen et al., 2023).

Sleep is important for a variety of health and cognitive outcomes, and access to adequate oxygen and clean air is important for sleep, health and cognition as well. Despite evidence from OSA highlighting the need for oxygen airflow, research into the role of air quality and sleep beyond temperature and humidity is relatively new, primarily exploring CO_2 as a predictor (Klausen et al., 2023; Strøm-Tejsen et al., 2016; Zendels et al., in progress). However, other pollutants may pose greater general health and cognition risks, with many being monitored with recommended guidelines set by the World Health Organization (Colvez, Castex & Carriere, 2003). While there are no clear guidelines for indoor environments, particulate matter ($PM_{2.5}$ and PM_{10}) has appeared in prior studies of bedroom ventilation and circulation and on lists for health and safety regulation (Canha et al, 2017; Colvez et al., 2003). Public health research has hypothesized that long-term exposure to particulates may impact health, especially as related to respiratory function (Lippman, 2012; Pope et al., 2002). Additionally, public health research in China exploring chronic particle exposure suggests that sleep may act as a mediator between exposure and observed cognitive decline (Pan et al., 2022).

Given the association between sleep and breathing, it is important to study the impact that breathing polluted air could have on sleep. Much of the existing research in this topic has explored limited variables, such as only investigating CO_2 or has approached the topic on a large scale, rather than looking at individuals' exposure to pollutants like particulate matter. This study seeks to explore whether exposure to high concentration of particulate matter within the bedroom can interfere with sleep and next-day cognitive performance in healthy sleepers. To do this, we designed two statistical models. We predict (H1) that exposure to high concentration of objectively recorded particulates will directly associate negatively with sleep outcomes, and indirectly have a negative association with next-day cognitive performance, as mediated by sleep. Additionally, we predict (H2) that perceived poor air quality will also directly impair sleep outcomes and indirectly have a negative association with next day cognitive performance in a similar model.

Methods

Participants

Data were collected from 61 individuals from a south-eastern city in the United States, primarily affiliated with a local university. This sample size was determined via a power analysis, indicating a minimum of 51 participants for a moderate effect of sleep on cognition at $p < .05$. Data collection occurred between February and November of 2021. The sample was primarily female (55.73%, 1.64% identified as transgender), white or Caucasian (59.02%), undergraduate students presently enrolled (54.10%) who lived in off-campus houses (50.82%). The average age was 23.15 (SD = 4.69) with participants ranging from 18-34. Most participants did not share their room with other individuals. Participants were recruited via the SONA system and received course credit as well as up to fifty dollars in gift cards for completing all tasks. Other undergraduate students, graduate students, and non-students also participated and were recruited by previous participants. Participants were ineligible for the study if they reported having any active sleep or breathing disorders. These data came from an existing study examining the effects of CO_2 on sleep and next day cognitive performance. This study serves as a secondary analysis to further explore how other facets of air quality may impact sleep and cognition.

Materials

Procedures

Participants scheduled a pick-up and drop-off time to meet with the researcher to be briefed on the study, receive the devices and be trained in their usage. As this occurred during the COVID-19 pandemic, safety protocols were in place including the researcher wiping down all equipment before pick-up and after drop off, the researcher wearing gloves and both individuals wearing masks. During the pick-up session, participants would sign informed consent and a device return agreement. They were also provided with instructions for using the devices. They received a wearable actigraph WGT3X to track sleep and an AutoPilot APCEMDL CO2 Monitor and PurpleAir PA-II to track air quality within their bedroom. Participants would then continue with their sleep, activity and other behavior as normal for the following three days until the drop-off. At the drop off-time, participants would return the devices and could see the results of their sleep and air quality. The pick-up and drop-off sessions lasted about 20 minutes each.

Each morning, participants would fill out a survey and cognitive battery emailed to them by the researcher within an hour of waking up. The survey allowed participants to report on how they felt their sleep and air quality was in the previous night, as well as list any possible disruptors to their sleep such as substances consumed, environmental influences or stress. These included fixed-response questions and open-ended questions. Participants then continued to four cognitive assessments examining state-based motivation, executive functioning and working memory. The morning survey took about 20 minutes to complete. Surveys and cognitive batteries were all distributed through PsyToolkit (Stoet, 2010; Stoet, 2017). Data were all linked to a participant ID number rather than any name or personal information for anonymity. All data collected were stored separately in a cloud file as to maintain confidentiality.

For each day of complete data provided (a completed morning survey, wearing the actigraph for the full day and having data collected by both the APCEMDL and PA-II), participants would be awarded $7 in gift cards and one-half a research credit for their classes (if enrolled through the SONA system). For completion of a full three days of data, participants were given an additional 1.5 research credits and $29 gift card, for a total of 3 research credits and $50. If participants were unable to complete one day of data, such as forgetting to fill out the morning survey, they were given the option to continue the study an extra day and return the devices later while still gaining the full compensation reward.

Measures

Air Quality. Temperature, humidity, CO_2 and particulate matter were used as the primary indicators of air quality. The AutoPilot APCEMDL CO2 Monitor (Gydrofarm, Petaluma, CA) provided to participants was used to measure CO_2. This device uses infrared gas sensors to take measurements every five seconds on temperature (°C), relative humidity (RH) (%), and CO_2 (ppm) and is comparable to similar devices used within the literature (Barnwell, 2021). The temperature range for the device is from 0 to +50 °C, with an accuracy of ±0.1°C, humidity data can be collected in ranges from 5% to 95% ±1%, and CO_2 ranges from 0 to 5,0000 ±50ppm. Data from the device were stored on an SD card and was downloaded by the researcher following the device drop-off. Participants were instructed to position this device at about head-height when they are in their bedroom.

Particulate matter was measured via PurpleAir PA-II (PurpleAir), a device that tracks particulates from range .30 to 10 µm with 98% efficiency rate for particles greater than 0.50 µm (Singer & Delp, 2018). Its effectivity is maintained from 0 to 500 µg of particles per cubic meter of air when measuring weight of particulates (PM). Notably, $PM_{2.5}$ and PM_{10} are listed as dangerous pollutants by the WHO and are readily tracked by the device (Magi et al., 2019; WHO, 2005). Particle size and count was measured via air circulating through the device and run through infrared scanners located within the bottom of the device. The device also measures temperature (optimal range -40 to 85°C), air pressure (optimal range 300 to 1,100hPa) and relative humidity (tolerance 3%). Participants were instructed to position this device at about head-height when they are in bed in their bedroom, with the bottom open to air circulation. Particle counts were then averaged across the night while the participant was recorded as asleep. For this study, we examined the number of particles of diameter 2.5 microns (PM $N_{2.5}$) or larger.

Initial particle counts were very low and had low variability ($M = 6.39$, $SD = 12.01$), with most guidelines suggesting health issues in outdoor environments do not manifest unless exposed to a count of PM $N_{2.5} = 25$ or larger for 24 continuous hours (Colvez et al., 2003). However, there was still variability within the night, so we looked at the highest ten percent of readings a participant experienced. Many participants would have “spikes” of higher PM readings where for periods of ten minutes to a couple of hours larger counts of PM $N_{2.5}$ were recorded (see figure 1 for examples). After selecting the recordings during which the participant was asleep, we took the top ten percent of values from each night and took an average of those. In order to ensure these results were still representative, a composite score of average particles across all sizes was still included in correlations. The high particle count score strongly correlated with particles of all sizes ($r = .91$, $p < .001$).

Participants also reported a subjective report of air quality each morning. Participants were given a single item question in which they could report on the air quality in their bedroom upon waking. They selected one of three options, “Stuffy, Dusty or Bad”, “Normal” or “Clearer than normal”. On average, participants reported air quality being a little poorer than what they would normally expect (*M* = 1.86; *SD* = .44). These values were turned into a 3-point Likert scale with higher numbers reporting better air quality.

Sleep Quality. Each morning, during the survey and cognitive battery, participants reported on subjective sleep quality. This involved filling out four questions from the Medical Outcomes Scale (MOS; Hays et al., 2005) on a six-point Likert scale describing the frequency of encountering various sleep disturbances (ranging from “All of the Time” to “None of the Time”). Three of these items were reverse coded and higher scores represent greater sleep disturbances throughout the night. Additionally, participants filled out a morning report of a sleep diary from the National Sleep Foundation (Byrne, 2015). This included listing their bed time, wake-time, reporting any sleep disturbances and reporting how rested they felt on a three-point Likert scale (refreshed, somewhat refreshed or fatigued).

Sleep was also objectively measured by Actigraph wGT3X-BT. This recorded when a participant went to bed, when they fell asleep and when they woke up. From this, the device calculated a total sleep duration, a sleep onset latency, any waking after sleep onset instances throughout the night and a total sleep efficiency (SE; total time asleep out of total time in bed). The actigraphs measured this via use of accelerometers and light sensors to detect body position, motion and activity. Participants wore the actigraphs on their non-dominant hand and were instructed to wear it for all normal activities across the three-day period, including activities done while awake.

Executive Function and Working Memory. Following completion of the survey questions, participants were presented with three tasks in a random order. Working memory was measured by the N-back task. This task was originally created by Kirchner (1958) requires participants to regularly update information presented to them. Participants are presented a single character at a time and have to respond with whether or not they saw the same character "n" instances ago. This study used a 3-back task implemented by PsyToolkit; participants had to respond if the letter they saw was previously shown to them 3 instances ago (Stoet, 2010; Stoey, 2017). Previous studies have found that sleep affects performance in lower values of N, such as the 3-back task (Terán-Pérez et al., 2012).

Executive function was measured through the go/no-go task and the Eriksen flanker task. The Go/No-go task (Criaud & Bounlingues, 2017) presents a signal that says either 'go', prompting participants to press a button, or 'no-go', where participants are instructed to do nothing. This task measures the ability for one to inhibit behaviors and has been shown to be affected by sleep (Renn & Cote, 2013). The Eriksen Flanker task also assesses executive function by requiring participants inhibition abilities in congruent and incongruent tasks. Participants are presented with a stimulus surrounded by other stimuli that are either in the same category as the target or a distractor. This task has also been shown to be impacted by sleep quality (Renn & Cote, 2013).

Plan of Analysis

Temperature, humidity and CO_2 were taken as raw scores from the AutoPilot APCEMDL. These scores were averaged for the times the participant was reported asleep according to the wGT3X actigraph. Due to variability of airflow and circulation being quite low throughout the evening, participants did not have much variability in particulate matter. The top 10% of readings for PM $N_{2.5}$ were taken and averaged for each participant each night to provide a predictive score. Composite scores were calculated by standardizing the Go/No-go score and Eriksen flanker task to determine an executive function score. Working memory was also standardized from the 3-back task. Analyses were completed in SPSS 28 (IBM Corporation, Almonk, NY) using the MLMed macro for SPSS for simple mediation. Air Quality (particulate matter and Subjective Air Quality) was used as the predictor, sleep quality as the mediator and cognitive function was the outcome variable. Other facets of air quality, as well as demographic variables that had significant correlations, were used as covariates. Separate analyses were ran for both objective and subjective sleep outcomes.

Results

Descriptive statistics are shown in table 1 and results from initial bivariate correlations are shown in table 2. Subjective air quality was negatively correlated with the MOS score, suggesting that cleaner perceived air was associated with fewer sleep problems. Subjective air quality was also positively associated with working memory; cleaner perceived air was associated with higher working memory scores. A standardized composite score of particles of all sizes strongly correlated with average of the top 10% of readings for particles. Cooler bedroom temperatures were associated with higher particle counts in the top 10% of readings. Higher CO_2 was associated with higher humidity, lower sleep efficiency and lower working memory performance. Higher humidity was associated with longer total sleep time. Total sleep time and sleep efficiency were positively correlated. Longer sleep times were also associated with participants reporting greater feelings of restoration from sleep. Scores on working memory and executive functioning were also positively correlated with each other.

For our primary analyses, we ran a total of four analyses to test each hypothesis (eight total multi-level mediation regressions). This was to account for subjective and objective sleep as separate mediators and to test separate outcomes for executive functioning and working memory. Given the nature of multi-level modeling, results include both within-group variance, how participants differ from day-to-day, as well as between-group variance, how different participants compare to each other.

To test our first hypothesis, whether or not objective air quality readings through particulate matter would directly impair sleep and indirectly associate with next morning cognition via sleep, we used temperature, humidity and CO_2 as level one covariates and demographic details such as race and living situation as level two covariates. Ultimately, we failed to find support for this hypothesis, as particulates were never a significant predictor for sleep nor cognitive outcomes. Among significant findings of objective air quality, higher CO_2 was a significant predictor of poorer sleep efficiency (b = -.003, p = .03). Higher CO_2 was also a predictor of more sleep disturbances (b = .003, p = .008) between participants, and dryer air (b = -.13, p = .03) was a significant predictor of more sleep disturbances between participants. Warmer temperatures were also a significant predictor of less refreshing sleep within participants; participants reported feeling more restored when their bedroom was cooler (b = .08, p = .04). More sleep disturbances impaired working memory performance (b = -.33, p = .01) within participants, and higher CO_2 impaired working memory between participants (b = -.001, p = .007).

Results from our second hypothesis, exploring how subjective air quality readings impacted sleep and cognition, are shown in table 3 and table 4. Table 3 depicts the relationship between subjective air quality and cognitive performance as mediated through objective sleep, recorded via actigraphy. Between subjects, those who were in rooms exposed to more CO_2 experienced worse sleep efficiency (b = -.003, p = .03). Additionally, those who lived in apartments were recorded as having poorer sleep efficiency (b = -3.57, p = .02). Warmer temperatures were associated with shorter total sleep time within participants (b = -11.48, p =

.03); participants reported shorter sleep times when they slept in a warmer room. Cleaner perceptions of air quality were associated with better working memory within-participants (b = 1.24, p < .01), participants scored better on days where they felt the air quality was better in their room. This indicates a direct effect between subjective air quality and next day cognitive performance. Participants living in a dorm scored worse on working memory (b = -1.21, p = .02). Additionally, participants who identified as non-white performed worse on Executive Functioning measures (b = -1.12, p = .02).

Table 4 depicts the relationship between subjective air quality and cognitive performance as mediated by subjective sleep variables. Within-participants, warmer temperatures predicted less restorative sleep (b = .09, p = .02), with individuals sleeping in warmer rooms reporting feeling more fatigued than when they slept in cooler rooms. Between participants, subjective air quality (b = -3.63, p < .01), CO_2 (b = .003, p < .01) and relative humidity (b = -.015, p = .01) all impacted disturbances reported across the night on the MOS. Rooms with better perceived air quality, lower CO_2 and higher humidity were associated with fewer sleep disturbances throughout the night. Subjective air quality that was perceived as cleaner was associated with better working memory (b = -1.45, p < .01), within subjects. Additionally, within subjects, fewer disturbances at night was associated with better working memory (b = -.37, p < .01). More CO_2 (b = -.001, p = .02) and living in a dorm (b = -1.14, p = .03) were associated with poorer working memory between subjects. Racial identity was the only significant predictor for executive functioning, with individuals who identified as non-white scoring lower (b = -.97, p = .04). Though subjective reports of air quality impacted sleep disturbances, and both subjective air quality and sleep disturbances impacted working memory, we failed to find a significant indirect effect between these variables. Thus we have partial support for our second hypothesis, that perceived air quality will impact sleep and cognitive performance.

Discussion

This study further expands the literature on the association of air quality with sleep among participants with no known breathing problems, as well as the possible effects to cognitive performance. Many of the results we observed regarding carbon dioxide are consistent with other findings in the literature regarding sleep and cognitive outcomes (Strøm-Tejsen et al., 2016). These findings suggest that facets of poor air quality can negatively impact sleep and cognitive performance, beyond temperature and humidity. We did not find results to suggest that sleep necessarily mediated the relationship between these variables, however, and more research should continue to investigate these relationships given other conflicting findings from prior studies (Klausen et al., 2023; Zhang et al., 2011).

Additionally, we failed to find support for our first hypothesis, that PM would negatively impact sleep and cognitive performance. The data showed consistent findings for impacts of CO_2, but not for PM. It is possible that this could be due to the participants who were exposed to large concentrations of PM were well adjusted to the PM and thus saw little change in effect due to the limited variance of it. Negative consequences from PM may also only be linked to long-term exposure, and it is possible that exposure for limited periods of time throughout the night in these spikes was not long enough to cause an effect on the respiratory system and impair sleep (Colvez, et al., 2003; Fang et al., 2015; Li et al., 2017). Particulates are also a broad category of many substances ranging in sizes of .3-10.0 microns in diameter (Liao et al., 2018; Sardar, Fine & Sioutas, 2005). Some particles will be naturally occurring from weather in the environment, while others are likely introduced from human activities (Canha et al., 2017; Sardar et al., 2005;

Zhai et al., 2019). Additionally, some particles, such as fragrances from lavender and other essential oils, may be beneficial for sleep due to relaxing properties (Beerappa & Chandrababu, 2022; Chester et al., 2020; Hamzeh et al., 2020, Lee et al., 2017). Using a single measurement for all particles may thus be insufficient to determine what components of air could interfere with health outcomes, such as sleep and cognition. While our results are insignificant, further research into more prolonged exposure to particles, higher particle concentration, and more precise particles could reveal significant results.

Our results did show significant findings for subjective self-report air quality. Participants indicating that their bedroom air felt “stuffy, dusty or bad” reported more sleep disturbances than those who reported cleaner air, and individual nights with poor air quality were associated with poorer performance on working memory compared to nights with cleaner air. These findings were surprising, as subjective air quality did not correlate with any other facet of air quality we recorded. It is possible that participants were reporting based on exposure to other pollutants that we did not collect data on, as a variety of contaminants can be present in the bedroom from various indoor and outdoor activities (Canha et al., 2017). Future research should continue to explore subjective air quality, including what may cause perceptions of better or worse air and how it may be related to other perceptions and behaviors.

The original study using these data investigated how CO_2 impacts sleep and cognitive performance. When introducing new variables (PM and Subjective Air Quality), we included CO_2 as a level-one covariate and observed similar relationships between CO_2 with sleep and cognitive functioning as previously seen (Strøm-Tejsen et al., 2016; Zendels et al., in progress). We also included temperature and humidity as level one covariates, and did indeed find that between our analyses, participants reported better, longer sleep when in cooler, dryer sleeping conditions. A few level two covariates were also significant predictors. Notably, participants in dorms and apartments as opposed to houses had lower working memory performances and objective sleep efficiency, respectively. There was also an observed significant effect of race on executive functioning, as expected and explained in our prior study.

This study has several strengths. As a short-term longitudinal study the design helped eliminate potential days with outlying behaviors (e.g. nights before an exam or other stressful event), especially as participants were able to sleep according to their own schedule and bedroom preferences. This helps ensure the sample is representative of normal sleep habits of the population, which included a diverse group of students and non-students. Additionally, our inclusion of both objective and subjective measures of sleep provide more insight into potential interferences into sleep quality, quantity and cognitive performance. Given that subjective perceptions of air quality may impact sleep and cognition, it is likely still worth exploring facets of bedroom environments beyond temperature, humidity and CO_2, as none of these correlated with subjective air quality. Subjective reports on sleep also add to the literature and indicate that it may not always matter how much sleep an individual gets, but how refreshed they feel after waking that determines aspects of their performance (Bastien et al., 2003). Objective measurements of air quality, sleep and cognitive performance also help ensure that observed effects are present and participants are not self-reporting with too much bias in their responses. This study also provides real-time data unique to each individual's environment about air quality, rather than collecting data from larger regions. Lastly, the easy access to many of the materials used for this study allow for clear replication and modification.

There are several notable limitations, however. While three to four nights of data helped account for outlying nights, longer durations would provide better insight and larger variability.

The lack of variability seen in particulates is also a concern; due to the correlational nature of the study we were unable to control for particulate matter exposure. Higher, prolonged exposure to particulates could possibly lead to confirmation of our first hypothesis, and should be studied in samples with greater variability in the future. Being able to assess individual potential contaminants within PM, as well as other air contaminants such as carbon monoxide, may provide more insight into what causes air to be described as "stuffy, dusty or bad" and what may contribute to poorer sleep and cognition. Finally, as data were collected during the COVID-19 pandemic, certain stressors may have impacted sleep and cognitive performance that would not otherwise be present.

Future research should continue to explore the multifaceted nature of air quality. While exposure to many components of air quality could be potentially harmful, experimental research should also be explore more, as studies are revealing the impact of CO_2 on cognition and performance in experimental settings (Klausen et al., 2023; Strøm-Tejsen et al., 2016). Investigating marginalized, people living in disadvantaged neighborhoods, or breathing-impaired populations should be additional priorities for researchers, as many neighborhoods stratified by SES and other demographic characteristics may experience worse particulate matter (Jerrett et al., 2001; Jerrett et al., 2005). Especially in vulnerable populations, researchers should also look into potential interventions to improve air quality and prevent sleep and cognitive decline. Past research indicates that plants and greenspaces can impact multiple facets of air quality, such as CO_2 and PM in positive ways for health and sleep (Kim, Yeo & Lee, 2020; Pan et al., 2022; Su & Lin, 2015). Air quality and its effects on sleep should be an important concern for sleep and public health researchers given the direct effects it may have and the importance of sleep for other health outcomes (Hunter & Hayden, 2018).

This study continued to explore the relationship between air quality, sleep and cognitive function, building on a growing field in the literature. By giving participants devices to measure their bedroom air quality, their objective sleep, and surveys for cognitive performance and subjective reports, we were able to examine the relationship between these variables. While we were unable to support our first hypothesis, that PM would impact sleep and cognitive performance, we did find support for our second hypothesis; subjective air quality impairs sleep and cognitive function. Future research should investigate what aspects of PM may impair cognition, as well as what can be done to improve air quality and sleep.

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Table 4.1
Descriptive statistics for focal variables

	Mean	Std. Deviation	Range
1. Subjective Air Quality	1.86	0.44	1.00-3.00
2. High Particle Exposure	20.80	86.58	0.00-1063.37
3. PM 2.5	6.39	12.01	.00-206.04
4. CO2 (ppm)	1325.55	499.70	636.89-4050.53
5. Temperature (F)	70.90	3.36	60.90-81.38
6. Relative Humidity (%)	49.87	7.82	27.43-73.30
7. SE	0.89	0.05	54.30%-98.20%
8. TST (minutes)	410.67	69.71	55.00-736.00
9. Restorativeness	2.05	0.53	1.00-3.00
10. Sleep Disturbances	9.41	3.60	4.00-20.00

Note. N = 61. CO2 = Carbon Dioxide. ppm = parts per million. PM = Particulate matter counts per 10 dL of air. Restorativeness = How refreshed individuals felt after waking.

Table 4.2
Correlations for focal variables

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.
1. Subjective Air Quality											
2. Standardized Particles	0.03										
3. High particle exposure	0.03	0.91**									
4. Carbon Dioxide	-0.07	-0.02	0.00								
5. Temperature	0.00	-0.14	-.15*	-0.03							
6. Humidity	-0.09	-0.06	0.00	.30**	0.08						
7. Sleep Efficiency	0.00	-0.06	-0.06	-.19**	-0.09	-0.01					
8. Total Sleep Time	0.02	-0.05	0.01	.18*	0.00	.17*	.17*				
9. Restorativeness	-0.10	-0.09	-0.13	0.01	0.11	-0.09	0.08	-.15*			
10. Sleep Disturbances	-0.21**	-0.07	0.45	0.00	0.08	0.04	0.12	0.86	0.00		
11. Executive Functioning	-0.04	0.11	0.06	0.10	-0.03	-0.04	0.02	-0.04	-0.10	-0.04	
12. Working Memory	0.21**	0.12	0.07	-.21**	0.05	-0.08	-0.05	-0.12	0.02	-0.04	.19**

Note. $N = 61$. * $p < .05$. ** $p < .01$.

Table 4.3

Subjective air quality onto objective sleep outcomes and cognitive performance

	Sleep Eff b	Sleep Eff SE	TST b	TST SE	WM b	WM SE	EF b	EF SE
Level 1 – Within								
Intercept	113.78**	15.17	258.38	218.58	-0.33	6.49	1.01	7.63
Subj AQ	-0.27	1.37	-33.68	21.89	1.24**	0.38	0.57	0.46
CO2	-0.00	0.00	0.02	0.03	-0.00	0.00	0.00	0.00
Temp	-0.43	0.33	-11.48*	5.35	0.02	0.09	0.09	0.11
Humid	0.10	0.15	1.35	2.38	0.06	0.04	-0.04	0.05
Sleep Eff	-	-	-	-	-0.02	0.03	-0.01	0.03
TST	-	-	-	-	-0.00	0.00	-0.00	0.00
Level 1 – Between								
Subj AQ	-0.23	1.89	35.95	27.27	0.66	0.57	-0.75	0.67
CO2	-0.003*	0.00	0.03	0.02	-0.00	0.00	0.00	0.00
Temp	-0.29	0.20	-0.10	2.87	0.01	0.06	-0.03	0.07
Humid	0.03	0.08	1.57	1.17	0.00	0.02	-0.01	0.03
Sleep Eff	-	-	-	-	0.01	0.04	0.04	0.05
TST	-	-	-	-	-0.00	0.00	-0.00	0.00
Level 2								
Race	-1.05	1.28	-30.17	18.47	-0.27	0.39	-1.12*	0.47
Apartment	-3.57*	1.49	-34.02	21.48	0.10	0.47	-0.13	0.55
Dorm	1.11	1.70	10.50	24.44	-1.21*	0.51	-0.51	0.60

Note. $N = 61$. b = effect size. SE = Standard Error. $^{*}p < .05$. $^{**}p < .01$. Subj AQ = Subjective Air Quality. Temp = Temperature. Humid = Humidity. Sleep Eff = Sleep Efficiency. TST = Total Sleep Time. WM = Working Memory. EF = Executive Functioning.

Table 4.4

Subjective air quality onto subjective sleep outcomes and cognitive performance

	Restore b	Restore SE	MOS b	MOS SE	WM b	WM SE	EF b	EF SE
Level 1 – Within								
Intercept	2.71	1.71	31.58**	10.64	-2.01	4.95	8.10	5.82
Subj AQ	-0.00	0.15	0.39	0.28	1.45**	0.37	0.67	0.46
CO2	-0.00	0.00	-0.00	0.00	-0.00	0.00	0.00	0.00
Temp	0.09*	0.04	0.04	0.07	0.08	0.09	0.15	0.12
Humid	-0.00	0.02	0.01	0.03	0.05	0.04	-0.04	0.05
Restore	-	-	-	-	0.00	0.22	-0.28	0.28
MOS	-	-	-	-	-0.37**	0.12	-0.17	0.15
Level 1 – Between								
Subj AQ	-0.37	0.21	-3.63**	1.29	0.86	0.61	-1.18	0.72
CO2	0.00	0.00	0.003**	0.00	-0.001*	0.00	0.00	0.07
Temp	0.01	0.02	-0.16	0.14	0.01	0.06	-0.05	0.00
Humid	-0.01	0.01	-0.15*	0.06	0.01	0.03	-0.02	0.03
Restore	-	-	-	-	0.20	0.39	-0.31	0.46
MOS	-	-	-	-	0.05	0.06	-0.06	0.07
Level 2								
Race	0.19	0.14	1.12	0.89	-0.34	0.39	-0.97*	0.46
Apartment	-0.22	0.17	-1.45	1.04	0.26	0.46	-0.32	0.54
Dorm	-0.07	0.19	-1.37	1.19	-1.14*	0.51	-0.59	0.60

Note. $N = 61$. b = effect size. SE = Standard Error. *$p < .05$. **$p < .01$. Subj AQ = Subjective Air Quality. Temp = Temperature. Humid = Humidity. Restore = Restorativeness. MOS = Medical Outcome Survey Sleep Disturbances. WM = Working Memory. EF = Executive Functioning.

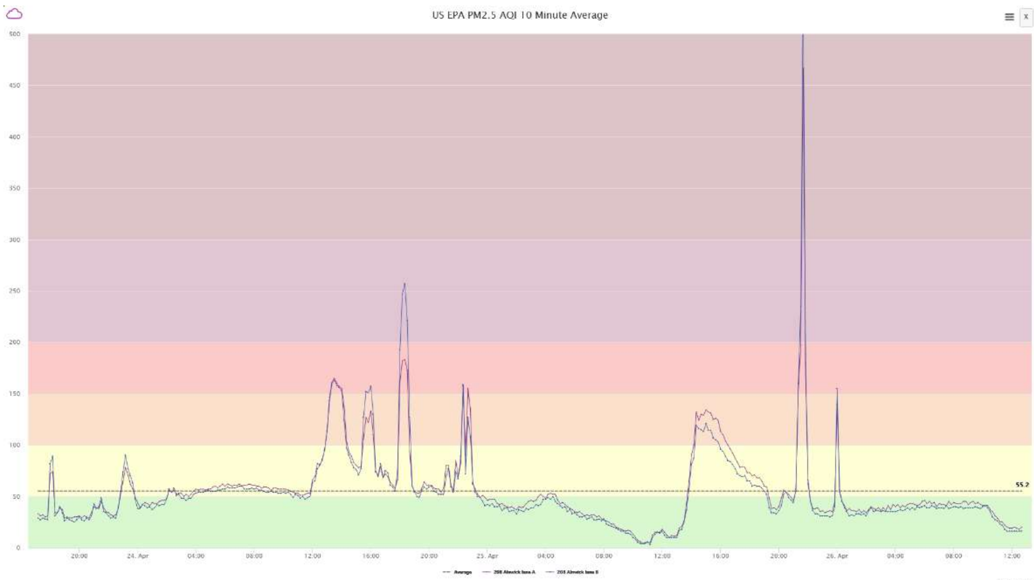

Figure 4.1

Example of particulates and "spikes" where air quality is significantly worse.

CHAPTER 5 - CONCLUSION

The role of adequate sleep hygiene for promoting optimal sleep outcomes has been well explored in the literature. By engaging in behaviors and situating oneself in conditions that promote sleep, they are more likely to have positive sleep outcomes such as quality and duration (Lin et al., 2007; Yang et al., 2010). Given the diversity of sleep difficulties and outcomes, and the cascading health effects observed, targeting individual facets of sleep hygiene allows for better understanding of the processes involved. Many of these hygiene behaviors and conditions promote different aspects of sleep and overall health, and the articles in this dissertation explored individual facets to better understand the role they may play (Zendels et al., 2021). The three study's core findings illustrate this: Reducing arousing behaviors prior to sleep plays a role in promoting sleep quality, having a consistent bedtime was associated with better mental health outcomes and having clean air in the bedroom environment was associated with better sleep and cognitive performance, a new direction for sleep hygiene environmental conditions to explore.

Additionally, it is clear that different facets of sleep hygiene are linked to different sleep disorders and sleep outcomes, lending more evidence for why these facets should sometimes be investigated in more precise, individual ways (Figueiro & White, 2013; Hill et al., 2014; Yang et al., 2010). Rather than operationalize sleep hygiene as a unitary construct, these studies examine a more nuanced, faceted consideration of sleep hygiene. The three studies presented here focus on individual aspects of the broad category of sleep hygiene behaviors, but explore individual elements in greater depth than looking at a more generalized construct of sleep hygiene as a whole. The first manuscript does address sleep hygiene, but breaks the overall construct of sleep hygiene into subcategories (i.e. arousal behaviors, eating practices, environmental conditions and Timing conditions). The article further examined differences between genders, especially along the arousal, eating and environment pathways, as a way to understand discrepancies in sleep outcomes (Zendels et al., 2021). The second and third manuscript each delve deeper into the role of sleep timing and sleep environmental conditions, respectively, as these factors are often less within an individual's control. By conducting three separate studies, it allows more focus on individual components, allowing for better understanding of what improves sleep that an individual can focus on, as well as what extends beyond the individual (Bronfenbrenner & Morris, 2006). Given that facets of health, such as sleep, involve behaviors within one's control as well as external factors, these three manuscripts each explore different facets of sleep to best understand the interacting systems of individuals and their communities.

While each of the studies presented above have strengths and limitations addressed within the manuscript, there are also notable strengths and limitations for their theme as a whole. The first manuscript addresses sleep hygiene as a whole construct while recognizing individual facets of it and the latter two further address behaviors and conditions related to specific facets (timing and environment, respectively). These two studies focus on individual aspects of sleep hygiene to understand targetable conditions that can change to aid sleep, as compared to relationships between sleep hygiene overall with other related predictors and outcomes. The topics of these manuscripts should be considered with other sleep hygiene measures in future research. A great deal of research suggests earlier, consistent bedtimes promote better health, The second manuscript compared whether inconsistent sleep timing (operationalized as social jet lag) or one's biologically-linked time-of-day preference more strongly associated with various physical and mental health outcomes, helping clarify sleep hygiene timing components more precisely than some measures of chronotypes are capable of (Wittman et al., 2006).

Similarly, environmental conditions such as temperature are known to impact sleep, and the third manuscript explores other facets of sleep environment air-quality that have received little attention (Strøm-Tejsen et al., 2016). Future studies may benefit from including sleep hygiene metrics (such as the SHPS) as well as these behavioral and device-measured data as a way to further unite these works (Yang et al., 2010; Zendels et al., in progress).

One other area that should be further explored involves the eating component of sleep hygiene. While good sleep hygiene suggests not going to bed hungry and avoiding substances like alcohol, caffeine, and other stimulants, little research has explored what food should be eaten and when (Iao et al., 2022). Eating late at night is often linked to other sleep and metabolism issues and is often not recommended (Meule et al., 2014; Vander Wal, 2012). However, some research has found that eating before bed can improve sleep, suggesting that some foods may be beneficial (Iao et al., 2022). Future studies should focus on eating-related sleep hygiene behaviors in a similar manner in order to better understand the facet individually, as well as integrating sleep hygiene as a whole to understand how eating behaviors contribute to sleep and health. More research needs to be done in what kinds of food one should eat, when one should eat before bed, how much one should eat, and how other external factors (e.g. gender differences, shift work schedule, food availability) may impact sleep (Iao et al., 2022).

Presently, much of the literature on sleep hygiene comes from clinical research to improve sleep (De Sousa et al., 2007; Yang et al., 2010). Many facets of sleep hygiene integrate everyday behaviors and conditions beyond those for clinical intervention, including concepts like social jetlag and indoor air quality. Incorporating more research that studies the eating behaviors, environment conditions and timing conditions that people have surrounding sleep that aren't necessarily about sleep hygiene directly could strengthen the literature on sleep hygiene as a whole (Iao et al., 2022; Yang et al., 2010). Additionally, future research should continue to explore what aspects of sleep hygiene are less strongly related to the quality and duration of nighttime. As many studies have found that aspects of sleep hygiene may not directly improve sleep for some individuals, it is important to investigate these facets separately rather than looking at sleep hygiene as a unitary construct (De Sousa et al., 2007). Notably, some of these conditions may be beyond an individual's control, leading to the lack of ability in modifying sleep hygiene (Bronfenbrenner & Morris, 2006).

As demonstrated by the bioecological model and the findings of these three studies, some aspects of sleep hygiene are likely also influenced by multilevel factors such as other individuals, households, communities, and broad social trends (Bronfenbrenner & Morris, 2006). Sharing a bedroom or housing unit with others could create arousing distractions or environmental conditions that do not promote sleep, even when an individual puts in effort to promote their sleep hygiene and sleep outcomes. In addition, societal views on demographic characteristics such as gender may contribute to this, with women possibly having less ability to advocate for their sleep health than men (Cerolini et al., 2007; Leaper & Robnett, 2011). Within local environments, individuals in lower-income communities are at greater risk for exposure to poor air quality, more light pollution, more noise pollution, and other environmental factors that inhibit one's ability to have a good sleeping environment (Hunter & Hayden, 2018). Culturally, much of the world conforms to schedules that promote waking early in the day (Shimura et al., 2022; Werner et al., 2021). For some individuals, there is little opportunity to have their preferred sleep schedule because of this, which could lead to negative health outcomes (Wittman et al., 2006). People's health outcomes as related to sleep are thus a product of both their own behaviors, and those of the people and community surrounding them (Bronfenbrenner & Morris, 2006).

External Influences to Sleep Hygiene in Study 1

Of the three manuscripts included, this one most directly measured the sleep hygiene as a multifaceted construct. Sleep hygiene was found to mediate the relationship between sleep attitudes and the duration one spent asleep across all four subscales. Arousal related behaviors were also found to mediate the relationship between sleep hygiene and sleep quality. Additionally, gender moderated the relationship between sleep attitudes and sleep hygiene for eating and environment behaviors, but not for other behaviors. Men, but not women, with favorable sleep attitudes reported much healthier sleep hygiene behavior compared to men with less favorable sleep attitudes. These findings suggest there may be some aspect of gender interacting with sleep hygiene. women often have more positive health attitudes and may seek more opportunities to improve health behaviors (Gil-Lacruz & Gil-Lacruz, 2010; O'hea et al., 2003). While we found a similar trend overall, men who did have more positive sleep attitudes had a positive association with better sleep hygiene behaviors. It is difficult to determine what caused these gender differences observed, though influences from both close acquaintances (e.g. noisy roommates, family eating late, disruptive neighbors) as well as large-scale societal views (e.g. health priorities between men and women, gender differences in home responsibilities, voicing concerns about sleep) may contribute to sleep hygiene components, despite being beyond an individual's control (Bronfenbrenner & Morris, 2006).

When controlling for sleep disorders, we found similar but noteworthy findings; gender moderated an indirect pathway of sleep attitudes onto sleep quality through sleep hygiene arousal behaviors. This suggests men with favorable sleep attitudes experienced better sleep quality via fewer arousing behaviors than women with similarly favorable sleep attitudes. However, among those with unfavorable sleep attitudes, men experienced significantly worse sleep hygiene and sleep quality along the arousal pathway than women did.

Other literature has also focused on the sleep hygiene arousal pathway as it related to insomnia and mental health (Yang et al., 2010). Additionally, research has found that women experience insomnia more often than men (Li et al., 2002; Theorell-Haglöw et al., 2018). It is still unclear whether these pathways are due to biological or social factors and future work should continue to explore how sleep hygiene arousal behaviors could be affected by large-scale social norms and customs. Sleep hygiene arousal behaviors appear to contribute to sleep quality, which, in turn, is associated with aspects of mental health, and further exploring what influences this relationship could help explain discrepancies in sleep disorder prevalence.

External Influences to Sleep Hygiene in Study 2

Sleep hygiene timing related behaviors include an inconsistent bedtime and wake up time, such as sleeping in late on the weekends and excessive napping (Yang et al., 2010). Many of these behaviors directly contribute to social jetlag (e.g. inconsistent bed times and wake times driven by social pressures that are not compatible with biologically-driven sleep preferences), which could be a predictor for many negative health outcomes (Wittman et al., 2006). While these are behaviors that could be controlled in an ideal situation, individuals who work shifts will likely not have the opportunity to set a regular bedtime and wake time for themselves, given the work schedules they face, leading to sleep and health issues (Ko, 2013; Smith & Eastman, 2012). Additionally, as explored in the second manuscript, individuals who have a chronotype that disagrees with their schedule for commitments are likely to experience poor sleep hygiene timing-related behaviors, given the difference in their preferred schedule on weeknights versus weekends contributing to social jetlag (Shimura et al., 2022; Wittman et al., 2006). Social influences due to local factors, such as work schedule, and large-scale societal norms (e.g. preference for morning-oriented schedules), could thus limit an individual's control over their sleep hygiene timing ability (Bronfenbrenner & Morris, 2006; Shimura et al., 2022; Smith & Eastman, 2012). Because the data were collected early within the pandemic and were representative of those recent weeks, individuals had relatively flexible schedules while work from home opportunities were being established. This survey asked about their sleep timing preferences, given the relatively flexible schedules, and their health. Individuals who reported greater discrepancies between weeknight and weekend sleep reported worse health and more symptoms of depression and stress. While much of the literature suggests that chronotype may contribute to outcomes like depression (Knutson & von Schantz, 2018), the demands of changing a sleep schedule to match one that does not agree with an individual's preference could instead be causing these negative effects (Wittman et al., 2006).

Sleep hygiene timing behaviors often involve other important components beyond consistent bedtime and waketime, however. There are likely genetic factors that contribute to one's chronotype preferences. Biological activity is strongly related to neural and endocrine activity associated with the circadian rhythm (Jones et al., 2019; Wittman et al., 2006). Ensuring adequate sunlight exposure during the day and sufficient nighttime fatigue are also important aspects of sleep hygiene timing that can often be difficult to incorporate into other measures of sleep hygiene (Yang et al., 2010). Future research into sleep hygiene timing behaviors ought to consider many of these components. Integrating more research of chronicity and social jetlag, and understanding the relationship between them could lead to more information on how to reconcile compatible sleep and activity schedules. Additionally, future research investigating delayed school schedules, flexible hours, work-from-home opportunities, and other practices that could allow individuals to have more control over their own schedule, which may help improve sleep outcomes (Mehta, 2021; Werner et al., 2022).

External Influences to Sleep Hygiene in Study 3

The third study in this dissertation explored how air quality impacted sleep and cognitive performance. Sleep hygiene has included many environmental guidelines that can promote healthy sleep, such as having a dark, quiet room and having a comfortable temperature and humidity (Yang et al., 2010). While individuals may have control over their room, neighborhood and community level influences could involve loud noises or presence of bright lights, both of which could interrupt or impair sleep (Hunter & Hayden, 2018). Public health work has already begun integrating the bioecological model and other broader theories into investigating sleep discrepancies, especially as related to noise, safety and pollution (Bronfenbrenner & Morris, 2006; Hunter & Hayden, 2018). Much of the reported findings investigating the role of external factors on sleep hygiene environment does not look the role of bedroom air quality.. Many studies have found evidence for sleep mediating the cognitive impairment observed from particulate matter exposure in outdoor air such as air pollution (Fang et al., 2015, Pan et al., 2022), though our study of bedroom air quality did not replicate these effects. While bedroom air does not often have much circulation (Canha et al., 2017), participants from our study may not be chronically exposed to pollutants as observed in other studies (Hunter & Hayden, 2018). The region our sample came from may also not have had enough variability in exposure or particle sources; geographic data has suggested that lower socioeconomic areas may experience more particle exposure and worse sleep outcomes (Hunter & Hayden, 2018; Jerrett et al., 2001). Furthermore, the participants were for the most part young and healthy. Greater impact may be seen in populations more vulnerable to poor air quality (such as those with breathing disorders, those living in areas with high pollution, or the elderly).

Regardless, we did find that participants who perceived poorer air quality had poorer sleep outcomes and cognitive performance, so there may be other components involved that we could not detect, or other facets of air quality exposure contributing to sleep outcomes. Research should continue to explore factors that individuals can control and those beyond an individual related to their sleep environment. Sleep hygiene guidelines may benefit from expanding definitions to include other facets of air quality and encourage more ventilation and/or plants in the bedroom to promote optimal health and functioning (Kim et al., 2020; Su & Lin, 2015). Given correlations observed between conditions such as OSA and exposure to various particles, it is also important to understand how the sleep environment may impact other sleep risk factors and research should explore what contaminants contribute most to these outcomes (Tung et al., 2021). More interdisciplinary work in this direction could help explain why improving the sleep environment may not promote better quality and longer sleep if a larger environment could interfere (Yang et al., 2010; Zendels et al., 2021). Future research exploring the environment one sleeps in should continue to integrate individual level control factors, such as sleep hygiene, with external factors, such as local level pollutants, to best evaluate what conditions promote and inhibit sleep.

Final Considerations

The impacts of sleep on physical and mental health are well established and maintaining sleep is an important health behavior. Many people struggle to get sufficient sleep due to a variety of causes, and some sleep disorders and/or impaired sleep are linked to specific behaviors and conditions surrounding sleep that are modifiable. Modifying these behaviors and conditions to promote sleep includes sleep hygiene, which can, in many cases, help promote better sleep and health outcomes (Lin et al., 2007; Ruggiero et al., 2020). However, people are a product of more than simply their own behaviors and exist in a complex, interconnected environment with a variety of other surrounding influences and factors that can impact their sleep and thus later health (Bronfenbrenner & Morris, 2006; Hunter & Hayden, 2018). When studying sleep disorders and sleep outcomes, it is important to recognize the effects that surrounding individuals, systems, and cultural values may impose on one's ability to get adequate sleep.

Future work should continue to investigate many of these factors that impair sleep beyond the individual level, as well as look into how to integrate larger changes to promote better sleep outcomes and health. Researchers should continue to investigate individual facets and behaviors within sleep hygiene, to best understand which facets are most targetable for those in need. However, examining the construct of sleep hygiene as a whole is also important in order to explore other potential mechanisms that could improve sleep behaviors. Increasing access to education surrounding sleep may help individuals promote their own sleep hygiene behaviors in some situations (De Sousa et al., 2007; Peach & Gaultney, 2017). However, policy changes to help facility healthy sleep, as well as environmental practices that may promote health and sleep in a community, should be considered as well (Kim et al., 2020; Mehta, 2021; Su & Lin, 2015; Werner et al., 2022). By examining sleep as a product of biology, behavior and external social factors, future research and intervention can better target individual facets of sleep hygiene to best promote sleep outcomes.

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