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Glucose as a Mediator of the Relationship Between Sleep and Cognitive Performance

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GLUCOSE AS A MEDIATOR OF THE RELATIONSHIP BETWEEN SLEEP AND COGNITIVE PERFORMANCE

by

Mercedes Gremillion, B.S.

A Dissertation Presented in Partial Fulfillment
of the Requirements for the Degree
Doctor of Philosophy

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be accepted in partial fulfillment of the requirements for the degree of

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ABSTRACT

The Centers for Disease Control and Prevention (Y. Liu et al., 2016) reports that 34.8% of adults living in the United States of America are getting less than their recommended amount of sleep per night. Additionally, the National Sleep Foundation (2014) reports that 35% of adults have poor sleep quality. Sleep problems appear most prevalent in young adults (Hershner, 2015). Rates of type 2 diabetes mellitus are also on the rise in this specific population (Kaufman, 2002). Interestingly, research has consistently found that both sleep quantity and quality are associated with glucose levels (Ip & Mokhlesi, 2007; Padilha et al., 2011; Taub & Redeker, 2008). Further, both sleep quantity and quality, as well as glucose, can have a significant effect on cognitive performance (Alhola & Polo-Kantola, 2007; Zilliox et al., 2016). The purpose of the present study was to investigate the mediating effect of glucose on the relationship between sleep and cognitive performance. Sleep included sleep quantity and quality. Cognitive performance included both sustained attention and visuospatial working memory. It was predicted that sleep would be positively related to cognitive performance, and negatively related to glucose levels. It was also predicted that glucose levels, even in a prediabetic range, would be negatively related to cognitive performance, and that this would mediate the relationship between sleep and cognitive performance. To test these hypotheses, data were collected from 82 young adults. Participants answered demographic questionnaires, and surveys assessing their sleep quantity and quality. They then had their glucose levels assessed via finger-stick glucose monitoring. Following this, they completed computerized tasks measuring sustained attention and visuospatial working memory. A hierarchical multiple regression analysis was conducted to test the proposed hypotheses. After cleaning, 81 cases were found to be viable for analysis. Results obtained were in partial support of hypotheses. Poor sleep quality, as measured by the Adult Sleep-Wake Scale (ADSWS; Fortunato et al., 2008), was found to be associated with decreased visuospatial working memory ($\beta = -.02$, $p = .039$). No other hypotheses were supported, though some trending results were found. It is believed had a larger and/or more diverse sample been used, more significant results would have been found. Implications exist not only for students, but for all young adults. They are likely to be of interest to young adults, as well as those working with young adults. This includes mental health professionals, various medical personnel, teachers, and school administrators.

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DEDICATION

To my grandfather, Winston Belgard. I dedicate this to you. If it were not for the hard work and perseverance you instilled in me, I am unsure I would have ever completed my dissertation or even pursued my PhD. I love you, and I miss you.

- Sadie

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CHAPTER ONE

INTRODUCTION

Sleep is a large, important, and familiar part of the human life. In fact, along with diet and exercise, sleep is considered one of the three pillars of a healthy, happy, and fruitful life (National Sleep Foundation, 2009). Sleep is required for all hum functioning, and is highly important for learning, and physical repair and restoration overall (Frank, 2006).

Despite this importance, it appears that sleep is often neglected by many. Specifically, the Centers for Disease Control and Prevention (Y. Liu et al., 2016) reports that only 61.6% of adults living in the United States of America are getting the recommended amount of sleep they need per night. That is to say, they are obtaining 7-9 hours of sleep per night as recommended by the National Sleep Foundation (Hirshkowitz et al., 2015). Meanwhile, 34.8% of adults living in the United States of America are getting less than the recommended amount of sleep they need per night, and 3.6% of adults are getting more than the recommended amount of sleep they need.

Sleep is also problematic for many. The National Sleep Foundation (2014) reports only 65% of adults living in the United States of America have “excellent,” “very good,” or “good” sleep quality. Meanwhile, 35% of adults report “only fair” or “poor” sleep quality.

Perhaps not surprisingly, college students are recognized as being the most sleep deprived of all adults, and as having the poorest sleep quality (Hershner & Chervin, 2014). Though is it recommended that they obtain 7-9 hours of sleep per night, every night, it is estimated that a majority of college students get less than 8 hours of sleep per night during the week, and many get less than 7 hours (Hershner, 2015). Additionally, it has been found that only 11.5% of college students have good sleep quality, while 69.5%

have occasional sleep problems, and 19% have poor sleep quality (Buboltz et al., 2009). Sleep problems are various and occur in both men and women, but many have been found to be more prevalent in women (Buboltz et al., 2009; Hershner & Chervin, 2014).

Both sleep quantity and sleep quality have been found to be highly correlated to the academic performance of students, commonly assessed via grade-point average (GPA) (Gilbert & Weaver, 2010; Lowry et al., 2010; Seun-Fadipe & Mosaku, 2017). Researchers report students who do not get the proper amount and/or type of sleep have lower GPAs.

Sleep quantity and sleep quality have also been found to be highly correlated to the health of all persons (AlDabal & BaHammam, 2011; Hungin & Close, 2010). Poor sleep quantity, or lengths below 7 hours and above 9 hours, and poor sleep quality have been found to be linked to various ailments, including type 2 diabetes mellitus and attention-deficit/hyperactivity disorder (ADHD).

Expanding on this, researchers have found that sleep quantity, as well as sleep quality can have a significant effect on cognition and cognitive performance (Alhola & Polo-Kantola, 2007). Cognitive performance has been assessed using numerous cognitive domains. The most frequently assessed domains, however, are sustained attention and visuospatial working memory.

Researchers have found that poor sleep quantity rather consistently contributes to declines in sustained attention (Arnal et al., 2015; Belenky et al., 2003; Chua et al., 2014). It can also lead to declines in visuospatial working memory, though mixed results have been found specific to this (Del Angel et al., 2015; Drummond et al., 2012; Gosselin et al., 2017; Richards et al., 2016). Meanwhile, poor sleep quality has been found to consistently contribute to declines in both sustained attention and visuospatial working memory (Rana et al., 2018; Steenari et al., 2003; Yun et al., 2015).

Researchers have also found that sleep quantity and sleep quality can have a significant effect on human glucose levels (Ip & Mokhlesi, 2007; Padilha et al., 2011; Taub & Redeker, 2008). Poor sleep quantity and poor sleep quality have been found to be linked to an increased risk for prediabetes in the short-term, and type 2 diabetes mellitus in the long-term. This is an interesting finding alone, but especially when considered in combination with the fact that rates of type 2 diabetes mellitus are on the rise in teenagers and young adults, including college students (Kaufman, 2002).

Like sleep quantity and sleep quality, it has been found that glucose can have a significant effect on cognition and cognitive performance (Bellisle, 2001; Cox et al., 2005; Moheet et al., 2015; Mortby et al., 2013; Ryan et al., 2016; Zilliox et al., 2016).

Unfortunately, it is noted that most studies conducted specific to glucose and cognitive performance in adults have assessed only those diagnosed with diabetes mellitus or compared the performance of those diagnosed with diabetes mellitus to nondiabetics. Additionally, these studies have primarily only been done with middle-aged or older adults.

Few studies have assessed the cognitive performance of persons with glucose levels in a prediabetic range, whether in isolation, in comparison to persons with glucose levels in a normal range, or in comparison to those diagnosed with type 2 diabetes mellitus. Nevertheless, it has been found that glucose levels in a high "normal" or prediabetic range have a similar effect on cognition as elevated glucose levels (Mortby et al., 2013).

Researchers have found that elevated glucose levels can lead to declines in both sustained attention and visuospatial working memory, specifically, though mixed results have also been found (Cukierman-Yaffe et al., 2009; Hawkins et al., 2016; Mooradian & Siverly, 1993; Novak et al., 2014; Takeuchi et al., 2012). It is noted that research regarding glucose levels and cognitive performance remains relatively new.

Despite the many studies connecting sleep to cognitive performance, sleep to glucose, and glucose to cognitive performance, it appears that only one study, to date, has assessed all of these variables together (Saetung et al., 2018). This particular study even assessed persons with glucose levels in a prediabetic range in comparison to those with type 2 diabetes mellitus. As is common, however, this study was carried out in middle-aged and older adults. This study also assessed the impact of glucose on sleep rather than the impact of sleep on glucose, and did not include the domains of sustained attention and/or visuospatial working memory.

Saetung et al. (2018) found that, in their study, sleep quality, but not sleep quantity, was related to cognitive performance. Glucose also had a significant effect on cognitive performance. This was apparent in persons with glucose levels in a prediabetic range, as well as those with type 2 diabetes mellitus. Effects were more pronounced, however, in those with diabetes mellitus than those with prediabetes.

Collectively, literature suggests that sleep quantity and sleep quality can have a significant effect on cognitive performance, including sustained attention and visuospatial working memory. Additionally, sleep quantity and sleep quality can have a significant effect on glucose levels. Beyond this, glucose levels can have a significant effect on cognitive performance, including sustained attention and visuospatial working memory. This is true even when levels are in a prediabetic range.

Statement of the Problem

The purpose of the present study was to investigate the mediating effect of glucose on the relationship between sleep and cognitive performance. To date, no study had examined this. Further, this study sought to explore and solidify the relationships that exist between sleep, glucose, and cognitive performance. It was noted that previous research found a combination of significant and nonsignificant results as it relates to these various relationships. It was also noted there was a dearth in the literature specific to the relationship these variables had altogether.

Beyond this, it was observed that most studies conducted specific to glucose and cognitive performance in adults, had assessed only individuals diagnosed with diabetes mellitus, or compared the performance of individuals diagnosed with diabetes mellitus to that of nondiabetics. Additionally, these studies had primarily only been conducted with middle-aged or older adults. This study sought to expand the literature by comparing the cognitive performance of young adults who had glucose levels in a high "normal" or prediabetic range, or above, to the cognitive performance of young adults who had glucose levels in a normal or average range.

Justification

Problems with sleep, including poor sleep quantity and poor sleep quality, are pervasive throughout the United States of America. Specifically, it is estimated that some 83.6 million adults living in the United States of America are not getting enough sleep (Y. Liu et al., 2016), or the right type of sleep (National Sleep Foundation, 2014). Due to the pervasiveness of this, and the various health consequences of such, the Centers for Disease Control and Prevention (2016) has declared a "public health epidemic."

Efforts are now underway to improve sleep throughout the country for all persons, but especially young adults, who have been identified as being the most sleep deprived and as having the poorest sleep quality overall (Hershner & Chervin, 2014).

The Centers for Disease Control and Prevention (Clay, 2017) has also found there are now 29 million people living with diabetes mellitus in the United States of America. Reportedly, 95% of persons with diabetes mellitus have type 2 diabetes mellitus, while 5% have type 1 diabetes mellitus. Additionally, 86 million people have prediabetes which increases their risk of developing type 2 diabetes mellitus. The Centers for Disease Control and Prevention projects that cases of diabetes mellitus will continue to grow if intervention is not taken. For this reason, they have declared this an epidemic too, and have called for immediate action on the part of numerous providers.

Similarly, the American Diabetes Association, as well as the American Psychological Association have called for action on the part of providers, but more specifically, psychologists (Clay, 2017). They note that psychologists can be integral in the treatment of type 1 diabetes mellitus and type 2 diabetes mellitus, as well as the prevention of type 2 diabetes mellitus. They encourage providers to engage in more research specific to diabetes mellitus and to work with clients on lifestyle interventions and/or health-behavior changes which could lower glucose levels.

Researchers report that sleep quantity and sleep quality have a significant effect on glucose levels (Ip & Mokhlesi, 2007; Padilha et al., 2011; Taub & Redeker, 2008). Poor sleep quantity and poor sleep quality have been linked to an increased risk for prediabetes in the short-term, and type 2 diabetes mellitus in the long-term. This is an interesting finding alone, but especially when considered in combination with the fact that rates of type 2 diabetes mellitus are on the rise in teens and young adults, including college students (Kaufman, 2002), the group most sleep deprived and with the poorest sleep quality overall (Hershner & Chervin, 2014).

Beyond this, sleep quantity, sleep quality, and glucose have also been found to have a significant effect on cognition (Alhola & Polo-Kantola, 2007; Zilliox et al., 2016).

Based on this data, it is anticipated that findings from this study are likely to be of great relevance to all people in the United States of America. Most especially, however, young adults, including college students. Findings are also likely to be intriguing to persons working in the fields of mental health, internal medicine, and academics, including teachers and administrators. Findings from this study may influence lifestyle choices and the practices of many. They may also lead to a greater development of interventions aimed at addressing sleep problems.

Literature Review

Sleep – The Basics

It is estimated that the average person spends approximately one-third of their life sleeping or attempting to sleep (Aminoff et al., 2011). Nevertheless, it appears that many aspects of sleep remain mysterious or misunderstood by many. This includes the definition of sleep, how it works, why we sleep, types of sleep, stages of sleep, and sleep architecture.

Definition

Sleep is a naturally-occurring, reversible, periodic, and recurring state in which consciousness is temporarily suspended or diminished, and responsiveness is reduced (Carskadon & Dement, 2011). It is not a time when our normal mental and physical activities shut down or are put on hold. Rather, it is a time when the brain remains active and engaged. Some brain activity even increases during sleep, as does the secretion of specific hormones.

Sleep Regulation

The dominant model for sleep regulation, or how sleep works, is the two-process model (Borbély, 1982; Borbély et al., 2016). This model posits that sleep, or the sleep-wake cycle, is regulated by two biological mechanisms or processes in the body, which interact together to control when you are awake and when you are asleep. These processes are circadian rhythm, or the drive for arousal, and sleep-wake homeostasis, or the drive for sleep; Process C and Process S.

Circadian rhythm directs a wide variety of functions ranging from daily fluctuation in wakefulness, to body temperature, metabolism, and the release of hormones in the body (National Institute of Neurological Disorders and Stroke, 2018). Circadian rhythm also controls a person's timing of sleep, causing the majority of people to be sleepy at night, and awake in the morning without an alarm. The body's biological clock, which is based on a roughly 24-hour day, is controlled by circadian rhythm. Circadian rhythm synchronizes with environmental cues, such as light and temperature, about the time of day, but continues on even without cues.

Sleep-wake homeostasis keeps track of an individual's biological need for sleep (National Institute of Neurological Disorders and Stroke, 2018). This drive gets progressively stronger every hour a person remains awake. It also causes individuals to sleep for a longer period of time and more deeply following a period of total or partial sleep deprivation.

Both circadian rhythm and sleep-wake homeostasis are influenced, to some extent, by an individual's genes (National Institute of Neurological Disorders and Stroke, 2018). External factors, such as diet, medications, meal time, ambient temperature, naps, stress, exercise, daily schedule, alarm clocks, and the like, can also have an effect on a person's sleep-wake cycle.

Function

The exact function of sleep, or why we sleep, has long been one of the mysteries of biology, and science in general (Assefa et al., 2015; Frank, 2006). Many theories have been proposed to explain the reason(s) for the necessity of sleep. To date, however, researchers have been unable to identify a definitive, comprehensive explanation as to the reason that sleep is a required part of human functioning. In accordance, researchers generally rely upon some compilation of theories when carrying out their work, rather than one theory exclusively.

Two theories frequently cited in sleep literature, specifically in relation to cognition and physical health, are the learning theory and restoration theory (Frank, 2006).

Learning Theory. Learning theory holds that the purpose of sleep is for individuals to learn (Assefa et al., 2015; Maquet, 2001). Sleep, it is noted, is imperative for the process of learning.

Learning theorists postulate that sleep helps learning in two distinct, yet interconnected ways. First, sleep allows for the ability to focus attention on a task when awake and thereby learn more efficiently (Kirszenblat & Van Swinderen, 2015). Persons who are sleep deprived have been found to have reduced activation of attentional networks in both the frontal and parietal lobes across a range of cognitive tasks

(Drummond et al., 2004). Persons who are sleep deprived have also been found to have an increased difficulty filtering incoming stimuli based on relative salience (Kirszenblat & Van Swinderen, 2015). Such a task requires coordinated synaptic activity across the brain. Sleep is necessary for coordinated synaptic activity across the brain.

Second, sleep allows for the consolidation of memory, which is essential for learning new information (Rasch & Born, 2013). Even if a person has sufficient attention to take in new information, in a process known as acquisition, they may not be able to store away the information, a process known as consolidation. Without consolidation, recall, or the ability to access information after it has been stored, is impossible. This is because the information was never properly stored away to begin with. Interestingly, while both acquisition and recall occur only during wakefulness, research suggests that consolidation takes place only during sleep.

Learning theorists emphasize that sleep is important prior to the presentation of new data, if it is to be truly learned. Sleep is also important after the presentation of new data, if it is to be truly learned. Yoo et al. (2007), and Scullin et al. (2011) illustrated this.

Yoo et al. (2007) looked at learning and memory formation in young persons with or without a night of sleep deprivation. Participants included 28 adults, ages 18-30 years, who were divided among two groups. One group was sleep-deprived for one night. The other, obtained a normal amount of sleep. Both groups were then shown 150 pictures of people, objects, landscapes, and more complex scenes, and asked to classify each as an indoor or outdoor picture. Two days later, following normal sleep, both groups were retested. This time, participants were shown the same 150 pictures, mixed together with 75 new ones, and asked to identify the pictures they had been shown previously.

Remarkably, the sleep-deprived group was found to not recognize almost twice as many of the original pictures as the group that was well-rested.

Meanwhile, Scullin et al. (2011) assessed how sleep after the presentation of new information can affect learning. Participants included 102 undergraduate students with no previous exposure to a lecture on microeconomics. Students were randomly assigned to one of two groups. The first group watched the lecture in the morning and then came back that evening to take a test on what they had been taught. The second group watched the lecture in the evening and came back the following morning to take the test. The time from the presentation of the lecture to test was held constant, but only the second group slept between the lecture and test. The test was divided into two parts. Half of the questions were similar to the type of questions that were used as examples during the lecture. The other half of the questions were more integrative and required students to incorporate the information to solve complex problems.

Scullin et al. (2011) found that students who slept following the presentation of new information performed about 8% better on the problems that were similar to those from the lecture, than did their peers who did not sleep following the presentation of new information. Further, and more impressively, students who slept following the presentation of new information performed 32% better on the problems that were more integrative, than did their peers. Findings suggest that sleep helps individuals retain more information, and also improves their ability to understand and apply that information. Theorists note the understanding and application of information is indicative of learning.

Restoration Theory. Comparatively, restoration theory holds that sleep is a process by which the body may be repaired and/or restored (Shapiro & Flanigan, 1993).

Repair and restoration, it is noted, is necessary following the "damage" that occurs to the body even in a typical day.

Restoration theorists posit that while in sleep, the body enters into a state of anabolism, while during wakefulness it remains in catabolism (Shapiro & Flanigan, 1993). Anabolism is all the metabolic processes that build molecules in the body. Catabolism is all the metabolic processes that tear down molecules (*Mosby's medical dictionary*, 2012).

During catabolism, the consumption of oxygen is increased (Shapiro & Flanigan, 1993). This results in a higher metabolic rate. During anabolism, however, the consumption of oxygen is decreased. This results in a lower metabolic rate. Low metabolic rates allow the concentration of protein in the body to increase as a result of both an increase in synthesis, as well as a decrease in degradation. Protein is used to build and repair tissues in the body. It is also used to make enzymes, hormones, and other body chemicals. Protein is considered an important "building block" of bones, muscles, cartilage, skin, and blood (*Mosby's medical dictionary*, 2012).

Hormones which have a predominantly anabolic function are also released during sleep (Assefa et al., 2015). This includes growth hormone. Growth hormone helps to spur growth in children and adolescents. It also helps to regulate muscle and bone growth, body composition, body fluids, sugar and fat metabolism, and heart functioning (*Mosby's medical dictionary,* 2012).

Comparatively, hormones which have a predominantly catabolic effect, such as cortisol, are released during periods of wakefulness (Assefa et al., 2015). Cortisol has many functions. It helps the body use sugar, or glucose, and fat for metabolism. It also helps the body regulate stress (*Mosby's medical dictionary*, 2012). Cortisol is largely suppressed during times of rest (Weitzman et al., 1974). This helps to suppress metabolism and decrease energy expenditure.

Restoration theorists posit that sleep also gives the brain a chance to "clean" itself (Xie et al., 2013). Specifically, sleep gives the brain a chance to do away with potentially neurotoxic waste products, or metabolites, which accumulate as a function of the neural activity that occurs during wakefulness. This process, it is noted, helps ensure metabolic homeostasis.

Restoration theorists point out that persons not obtaining proper sleep, thereby, preventing their bodies from being properly repaired and/or restored, have an increased risk for both short-term and long-term diseases, including various cardiometabolic diseases, as well as Alzheimer's disease (Aho et al., 2013; Assefa et al., 2015; Ju et al., 2013; Ju et al., 2014). Persons not obtaining proper sleep also have an increased risk for death (Yin et al., 2018). Rates of mortality are estimated to be increased by anywhere from 17-26% for men and women who sleep too little or too much, with the highest rates noted for men (Hublin et al., 2007). Restoration theorists argue these findings give support to the restorative function of sleep overall.

Types

Sleep is divided into two types, or states, each with its own distinct physiological, neurological, and psychological features (Carskadon & Dement, 2011). These types are non-rapid eye movement (NREM) sleep and rapid eye movement (REM) sleep. NREM sleep may be referred to as "quiet sleep". Meanwhile, REM sleep may be referred to as "active sleep." It is estimated adults spend 75-80% of the night in NREM sleep and 20-25% in REM sleep.

Stages

Sleep is further divided into stages (Carskadon & Dement, 2011). Specifically, NREM is divided into three (formerly four) stages: N1, N2, and N3. REM is usually not divided.

N1, formerly "Stage 1," constitutes roughly 2-5% of sleep (Carskadon & Dement, 2011). In this stage, individuals are between being awake and asleep (National Sleep Foundation, n.d.).

N2, formerly "Stage 2," constitutes anywhere from 45-55% of a person's sleep (Carskadon & Dement, 2011). This is "light sleep" (National Sleep Foundation, n.d.). In this stage of sleep, individuals experience the onset of sleep. They become disengaged from their surroundings. Body temperature drops from its baseline. Heartrate also begins to slow down.

N3, formerly "Stages 3 and 4," makes up roughly 13-23% of an individual's sleep (Carskadon & Dement, 2011). This is "deep sleep" (National Sleep Foundation, n.d.). During this stage of rest, individuals achieve their deepest and most restorative sleep. Blood pressure drops and breathing slows. Muscles become more relaxed as their blood supply increases. Tissue growth and repair occurs. Energy is restored. Hormones, such as growth hormone, are also released.

During REM sleep, individuals are provided with energy to their brain and their body which supports daytime performance (National Sleep Foundation, n.d.). The brain is most active in this stage, resulting in the occurrence of dreams. Eyes dart back and forth, and the body becomes immobile and relaxed, as muscles, with the exception of the heart and lungs, turn off.

Architecture

Sleep architecture refers to the structural organization, or design, of normal sleep (Institute of Medicine, 2006). Normal sleep generally progresses in a series of five (more or less) sleep cycles of NREM and REM sleep (Peraita-Adrados, 2005). The first sleep cycle proceeds in these stages: N1, N2, N3, a return to N2, and REM sleep (Carskadon & Dement, 2011). It lasts approximately 70-100 minutes. Subsequent sleep cycles generally proceed in these stages: N2, N3, a return to N2, and REM sleep. These cycles last anywhere from roughly 90-120 minutes.

In normal sleep, N1 sleep is usually not revisited unless a person experiences an awakening, in which case, they return to the pattern seen in the first sleep cycle and progress on (Carskadon & Dement, 2011). The time spent in N2 sleep gradually increases over the course of the sleep cycles. Also, the time spent in N3 sleep gradually decreases, and the time spent in REM sleep gradually increases, so that there is a greater amount of N3 sleep in earlier sleep cycles and a greater amount of REM sleep in later sleep cycles, particularly during the final two cycles of rest. A normal, complete sleep cycle, it is noted, always ends in the occurrence of REM sleep.

Sleep Quantity and Quality

To fully understand the concept of sleep, it is important to understand what is meant by sleep quantity and quality. Sleep quantity and quality are the ways in which sleep is assessed.

Sleep Quantity

Sleep quantity, also known as sleep duration or sleep length, is defined as the total number of hours a person sleeps per night. Sleep length varies from person to person, and can be influenced by stress, medications, a variety of medical conditions, lifestyle choices, such as diet and exercise, as well as environment (Carskadon & Dement, 2011; Charles et al., 2011; Dimitriou et al., 2015; Finan et al., 2013). Sleep length is also influenced, perhaps most heavily, by a person's biological need and/or their chronological age (Carskadon & Dement, 2011).

The National Sleep Foundation (Hirshkowitz et al., 2015) provides specific recommendations for sleep quantity based on age. For newborns (0-3 months), it is advised that sleep duration last 14-17 hours per night. For infants (4-11 months), it is recommended that sleep duration last 12-15 hours. The National Sleep Foundation suggests that toddlers (1-2 years) get 11-15 hours of sleep per night, while preschoolers (2-3 years) get 10-13 hours, and school-aged children (6-13 years) get 9-11 hours. For teenagers (14-17 years), 8-10 hours of sleep per night is advised. For young adults (18-25 years) and adults (26-64 years), 7-9 hours of sleep is suggested. For older adults (65+ years), the National Sleep Foundation recommends 7-8 hours of sleep.

Despite these recommendations, the Centers for Disease Control and Prevention (Y. Liu et al., 2016) reports that only 61.6% of adults living in the United States of America are getting 7-9 hours of sleep per night. Specifically, 29.5% of adults are getting 7 hours of sleep per night, 27.7% are getting 8 hours of sleep, and 4.4% are getting 9 hours of sleep per night.

The Centers for Disease Control and Prevention reports that 34.8% of adults living in the United States of America are getting less than their recommended amount of sleep per night. Some 23% of individuals are getting only 6 hours of sleep, while 11.8% of individuals are getting only 5 or fewer hours of sleep. Beyond this, it is reported that

3.6% of adults are getting 10 or more hours of sleep, thereby exceeding their recommended amount of sleep per night.

Sleep Quality

Sleep quality is broadly defined because it is much more subjective in nature than is sleep quantity (Harvey et al., 2008). Harvey et al. (2008) report that sleep quality can be measured, subjectively, by reports of tiredness on waking and throughout the day, as well as feelings of being rested and restored upon waking. Objectively, sleep quality can be measured by the number of awakenings an individual experiences in one night. Some combination of subjective and objective reports is common in most researchers' definitions of sleep quality.

Like sleep quantity, sleep quality may also be influenced by stress, medications, numerous medical conditions, lifestyle choices, such as diet and exercise, environment, and age (Caldwell et al., 2009; Charles et al., 2011; Fietze et al., 2016; Finan et al., 2013; Gowda et al., 2010; Gursky & Krahn, 2000; Jain & Glauser, 2014; St-Onge et al., 2016; Vitiello et al., 2004).

The National Sleep Foundation (2014) reports that only 65% of adults living in the United States of America report that they are achieving "excellent," "very good," or "good" sleep quality. Specifically, 12% of adults report "excellent" sleep quality, 18% report "very good" sleep quality, and 35% of adults report "good" sleep quality. Comparatively, 35% of adults in the United States of America report that their sleep quality is "only fair" or "poor." Specifically, 23% of adults report "only fair" sleep quality, while 12% of adults report "poor" sleep quality.

The National Sleep Foundation (2014) also reports that of those surveyed, 25% of individuals report that they did not feel refreshed upon waking any of the past seven days. This is suggestive of poor sleep quality. This 25% included 24% of all women surveyed and 14% of all men surveyed. In addition, it is noted that some 53% of individuals reported napping within the past seven days. This is also suggestive of poor sleep quality. Among this 53%, 23% took a nap 1-2 days in a week, 13% took a nap 3-4 days, and 17% took a nap at least 5 days in a week.

Sleep Problems in College Students

Many college students, like many adults in the United States of America, are not getting enough sleep or good sleep quality. It is reported, in fact, that college students are the most sleep deprived of all groups, and that they have the poorest sleep quality (Hershner & Chervin, 2014).

Sleep Quantity

Though the National Sleep Foundation (Hirshkowitz et al., 2015) recommends young adults, or persons 18-25 years old, obtain 7-9 hours of sleep per night, every night, it is estimated that a majority of college students get less than 8 hours of sleep per night during the week, and many get less than 7 hours of sleep (Hershner, 2015). Sleep is generally extended on weekends.

Buboltz et al. (2009) found that among a sample of 742 undergraduate students attending three universities in different regions of the United States of America, the average sleep time during the week was 7 hours, 37 minutes (minimum: 1.5 hours; maximum: 14.5 hours). This time, it is noted, falls within the range recommended by the National Sleep Foundation (Hirshkowitz et al., 2015) for young adults, but is towards the lower end overall. The average sleep time during the weekend was 8 hours, 19 minutes (minimum: 1 hour; maximum: 17 hours).

Buboltz et al. (2009) report that mean bedtimes were delayed and mean rise times were extended on weekends. Specifically, respondents reported a mean bedtime of 11:25 PM during the week, and a mean bedtime of 12:31 AM during the weekend. Respondents reported a mean rise time of 7:22 AM during the week, and a mean rise time of 9:11 AM during the weekend. Students surveyed were found to underestimate the time they spent sleeping, during the week and on weekends. They also expressed a desire for more sleep during the week and on weekends.

Lund et al. (2010) found that among a sample of 1,125 college students, the mean total sleep time was 7.02 hours (*SD* = 1.15). Again, this time falls within the range advised by the National Sleep Foundation (Hirshkowitz et al., 2015), but is at the lower end. Lund et al. (2010) report that only 29.4% of students surveyed reported getting 8 or more hours of sleep per night, while 70.6% of students reported getting less than 8 hours of sleep per night. Further, among students getting less than 8 hours of sleep per night, 25% reported getting less than 6.5 hours.

Like Buboltz et al. (2009), Lund et al. (2010) report that students had the most restricted sleep on weeknights. Mean bedtimes were delayed and mean rise times were extended on weekends. Additionally, 20% of students surveyed reported staying up all night at least once in the last month, and 35% of students reported staying up until 3AM at least once per week.

Beyond this, Kelly (2004) found that among a sample of 212 college students, the average sleep length reported was 6.96 hours (*SD* = 1.92) per 24-hour period. Such a length, it is noted, is just below the range advised by the National Sleep Foundation (Hirshkowitz et al., 2015). Kelly (2004) reports that there were no significant differences between genders for sleep length.

Additionally, Pilcher et al. (1997) found that among 30 university students, the mean total sleep times was 6 hours, 41 minutes. This time falls below the range recommended by the National Sleep Foundation (Hirshkowitz et al., 2015). Pilcher et al. (1997) highlight that stress can have a modest effect on sleep length. They replicated their study later in the same semester, at a reportedly less stressful time, and found that among 87 university students, the mean total sleep time was 7 hours, 4 minutes. This time, it is noted, yet again, falls within the range advised by the National Sleep Foundation (Hirshkowitz et al., 2015), but is at the lower end overall.

Sleep quantity in college students has been found to be affected by a host of variables, including those common to all adults, as well as some which are unique to or more prevalent in students. Specifically, an increased amount of time spent on schoolwork, expecting a test, and alcohol use have been found to predict less sleep (Galambos et al., 2009). Stress has also been found to have a negative impact on sleep quantity (Lee et al., 2013), as has, though unsurprisingly, energy drink use (Gashkarimov et al., 2021; Patrick et al., 2018; Stasio et al., 2011). Additionally, Delayed Sleep Phase Syndrome, a sleep disorder that occurs when a person's circadian rhythm is delayed from the typical day/night cycle, has also been found to have a negative impact on sleep quantity (Lack, 1986). While this disorder is found to be common in many, it appears to be most prevalent in college students (Brown et al., 2001; Urner et al., 2009).

Sleep Quality

Just as many college students do not get the proper quantity of sleep, it has been found that a majority of college students also do not achieve a good quality of sleep.

Buboltz et al. (2001) found that among 191 undergraduate students, only 11% of those surveyed using the Sleep Quality Index (Urponen et al., 1991) had good sleep quality. Meanwhile, approximately 73% of those surveyed indicated occasional sleep problems, and roughly 15% of those surveyed had poor sleep quality. Problems reported most frequently were feeling “mostly tired” during mornings, taking more than 30 minutes to fall asleep, disturbed night sleep three or more times a week, waking too early three or more times a week, nocturnal awakenings most nights, difficulties falling asleep three or more times a week, insomnia three or more times a week, and using sleep medicines at least once a week, respectively.

Interestingly, Buboltz et al. (2001) found that women endorsed some problems more than men. Specifically, women had higher rates of disturbed night sleep, nocturnal awakenings, difficulties falling asleep, and poorer overall sleep quality. No significant gender differences were found for the amount of time it takes to fall asleep, ratings of insomnia, morning tiredness, early morning awakenings, or use of sleep medicines. Tsai and Li (2004) found similar results.

In a follow-up study to this, Buboltz et al. (2009) found that among 742 undergraduate students, only 11.5% of those surveyed using the Sleep Quality Index (Urponen et al., 1991) had good sleep quality. Meanwhile, 65.9% of those surveyed indicated occasional sleep problems, and 22.6% had poor sleep quality. Results, it is noted, are similar to those found eight years prior (Buboltz et al., 2001), except that a larger percentage of students reported poor sleep quality.

In both studies (Buboltz et al., 2001; Buboltz et al., 2009), approximately 54% of students reported feeling “mostly tired” during mornings. Responses to all other items of the Sleep Quality Index (Urponen et al., 1991), however, were more frequent in 2009. Specifically, a higher percentage of students reported it took them greater than 30 minutes to fall asleep (24.2% versus 19.9%), and that they had difficulties falling asleep three or more times a week (17.3% versus 12.1%). A higher percentage of students also reported that they experienced disturbed night sleep three or more night a week (19.7% versus 14.7%), woke up too early three or more times a week (18.0% versus 13.6%), experienced nocturnal wakening most nights (20.1% versus 13.6%), and used sleep medicines at least once a week (3.0% versus 1.0%). Additionally, and rather alarmingly, more than double the percentage of students surveyed in 2001 reported insomnia three or more time a week when surveyed in 2009 (11.1% versus 4.2%).

In addition to finding low sleep quantity, Lund et al. (2010) found that among their sample of 1,125 college students, the majority also reported poor sleep quality. Using the Pittsburgh Sleep Quality Index (PSQI; Buysse et al., 1989), they found that 38.2% of students had “poor” sleep quality, while only 34.1% had “good” sleep quality; 27.7% had “borderline.”

Lund et al. (2010) report that 32% of students surveyed reported an inability to fall asleep within 30 minutes at least once a week, and 25% endorsed significant levels of daytime sleepiness, another marker of poor sleep quality. Lund et al. (2010) further report that 75% of students surveyed reported feeling “dragged out, tired, or sleepy” once a week or more, 52% reported lacking enthusiasm to get things done at least once a week, and 15% reported falling asleep in their classes once a week or more. These are all markers of poor sleep quality, overall.

Similar results were found by Pilcher et al. (1997). They report that many of the university students they surveyed reported poor sleep quality. Further, poor sleep quality, as measured by the Pittsburgh Sleep Quality Index (PSQI; Buysse et al., 1989) was associated with increased sleepiness. Researchers also used the Epworth Sleepiness Scale (ESS; Johns, 1991), and the Stanford Sleepiness Scale (SSS; Hoddes et al., 1973) to assess students' sleepiness.

Similar results were also found by Forquer et al. (2008). They found that among a sample of 313 university students, 33% took longer than 30 minutes to fall asleep. Additionally, 43% of students reported waking more than once a night, and 33% reported feeling tired during the day. No significant differences were found for academic rank.

Sleep quality in college students has been found to be affected by a host of variables, including those common to all adults, as well as some which are unique to or more prevalent in students. Specifically, alcohol use has been found to predict poor sleep quality in students (Galambos et al., 2009; Lohsoonthorn et al., 2013). Negative affect, and stress have been found to have a negative impact on sleep quality (Galambos et al., 2009; Lee et al., 2013; Lund et al., 2010; Özlem Örsal et al. (2012), as has the use of caffeinated beverages, including energy drinks (Lohsoonthorn et al., 2013; Mwape & Mulenga, 2019; Sanchez et al., 2013; Stasio et al., 2011). Beyond this, it is reported that cigarette smoking has been found to predict poor sleep quality (Lohsoonthorn et al., 2013), as has poor sleep hygiene practices (Brown et al., 2002), excessive environmental noise (Lund et al., 2010), and mobile phone use (White et al., 2011). Additionally, Delayed Sleep Phase Syndrome has been found to negatively impact sleep quality (Lack, 1986).

Sleep and Academic Performance

Both sleep quantity and sleep quality have been found to be highly correlated to academic performance, commonly assessed via grade-point average (GPA) (Gilbert & Weaver, 2010; Kim, 2019; Maheshwari & Shaukat, 2019; Seun-Fadipe & Mosaku, 2017). It remains uncertain, however, if sleep quantity or quality is a better predictor of GPA, as mixed results have been found.

Sleep Quantity

William Kelly et al. (2001) assessed the relationship between sleep length and GPA among college students. Sleep length was measured by self-report, and respondents were divided into groups based on their answers. Groups included short-sleepers, those who reported sleeping an average of 6 or fewer hours per night; average sleepers, those who slept 7-8 hour per night; and long-sleepers, those who reported sleeping 9 or more hours per night. A total of 148 undergraduate students were assessed. Results indicated that long-sleepers had significantly higher GPAs than did short-sleepers. Average sleepers were not significantly different.

Similar results were found by Gikunda et al. (2014). They too assessed the relationship between sleep quantity and GPA, or academic performance, in university students. A total of 100 students were assessed. Results indicated a positive correlation between sleep quantity and academic performance. Thus, persons with better sleep quantity performed better academically, and persons with poorer sleep quantity performed poorer academically. Gikunda et al. (2014) note that stress was a major predictor for sleep quantity, such that those with higher amounts of stress in their lives obtained less sleep, and those with lower amounts of stress got more sleep.

Lowry et al. (2010) surveyed 103 undergraduate students inquiring about their sleep quantity, sleep quality, and academic success. Four aspects of sleep quantity were assessed. This included number of nights spent with less than five hours of sleep during the past week, number of nights spent with less than five hours of sleep during an average week, number of hours of sleep obtained in an average night, and number of "all-nighters" pulled in the past year.

Lowry et al. (2010) report finding a significant positive correlation between the amount of sleep obtained per night and GPA. Thus, students who slept for more hours on an average night tended to obtain slightly better grades. They also found a significant negative correlation between the average number of nights per week that students obtained less than five hours of sleep and GPA. Thus, as the average number of days per week a student got less than five hours of sleep increased, GPA decreased. Lowry et al. (2010) found no correlation between students' GPA and the number of all-nighters students experienced in the past year. They also found no correlation between students' GPA and the number of nights they got less than five hours of sleep in the past week, or students' GPA and their sleep quality scores, as assessed by the Groningen Sleep Quality Scale (GSQS; Mulder-Hajonides Van Der Meulen et al., 1981).

Sleep Quality

Gilbert and Weaver (2010) assessed the relationship between sleep quality and academic performance, or GPA, in university students. Sleep quality was measured using global sleep quality scores obtained via the Pittsburgh Sleep Quality Index (PSQI; Buysse et al., 1989). It is noted that higher global sleep quality scores are indicative of poorer sleep quality, while lower scores suggest better sleep quality. A total of 557 students were assessed. Results indicated a significant negative correlation between global sleep quality scores and GPA. Thus, persons with better sleep quality had higher GPAs, and persons with poorer sleep quality had lower GPAs.

Similar results were found by Rasekhi et al. (2017). They too assessed the relationship between sleep quality and academic performance in college students. In their study, a total of 177 students were assessed. Results obtained indicated that abnormal scores on the Pittsburgh Sleep Quality Index (PSQI; Buysse et al., 1989) were associated with lower academic achievement. Rasekhi et al. (2017) further report that women had poorer sleep quality than did men. This finding is consistent with the reports of Buboltz et al. (2001), and Tsai and Li (2004).

Lemma et al. (2014) surveyed 2,173 college students inquiring about their sleep quantity, sleep quality, and GPA. They found that students with better sleep quality scores, as assessed by the Pittsburgh Sleep Quality Index (PSQI; Buysse et al., 1989), achieved higher GPAs. Sleep quantity, or duration, which was self-reported, was not found to be significantly linked to GPA.

Similar results were found by Seun-Fadipe and Mosaku (2017). They too assessed the relationship between sleep quantity, sleep quality, and GPA, or academic performance, in university students. A total of 317 students were assessed. Results obtained indicated that the academic performance of students with good sleep quality, as assessed by scores obtained from the Pittsburgh Sleep Quality Index (PSQI; Buysse et al., 1989), was significantly better than those with poor sleep quality. Seun-Fadipe and

Mosaku (2017) report that stress was a major predictor of sleep quality, such that those with higher amounts of stress in their lives obtained poorer sleep quality. Sleep quantity was not found to have a significant association with GPA.

Sleep and Health

Sleep quantity and sleep quality have been found to be critical to human health, including both physical health and mental health (AlDabal & BaHammam, 2011; Hungin & Close, 2010; Pilcher et al., 1997). Though many argue sleep quality is better related to measures of health and well-being, than is sleep quantity (Pilcher et al., 1997), it seems important still to consider both.

Sleep Quantity

When it comes to sleep quantity and health, generally researchers assess the effects of reduced sleep quantity, or sleep deprivation, on health. Some researchers, however, have also examined the effects of prolonged sleep on health. Both can have deleterious effects on a person.

Sleep Deprivation. Sleep deprivation is defined as an insufficient duration of sleep in a 24-hour period (American Sleep Association, n.d.). For most adults, this is less than 7 hours.

Physical Health. Sleep deprivation has been linked to numerous diseases and impairments in physical health. Among those most commonly reported are an increased risk for cardiometabolic diseases such as type 2 diabetes mellitus (Buxton et al., 2010; Donga et al., 2010), hypertension (Calhoun & Harding, 2010; Marzano et al., 2010), cardiovascular disease, including coronary heart disease (Ayas et al., 2003; Lao et al., 2018; Wolk et al., 2005), and obesity (Beccuti & Pannain, 2011; Chang & Chen, 2015).

Additionally, sleep deprivation has been linked to an increased risk for dementia, including Alzheimer's disease (Bubu et al., 2017; Ju et al., 2014). Sleep deprivation has also been linked to cell damage and impairments in cellular repair, both in the brain and body (AlDabal & BaHammam, 2011; Everson et al., 2014).

Beyond this, sleep deprivation has been linked to an increased risk for cancer, including colorectal cancer (Thompson et al., 2011) and breast cancer (Kakizaki et al., 2008). Sleep deprivation has also been linked to the onset and increased perception of physical pain (Haack & Mullington, 2005). Further, sleep deprivation has been linked to having a weakened immune system (Irwin et al., 1996), and an increased risk of mortality (Gradner et al., 2010).

Mental Health. Sleep deprivation has also been linked to numerous disorders and impairments in mental health. This includes an increased risk of anxiety (Baum et al., 2013; Matsuda et al., 2017), depression (Matsuda et al., 2017; Rosen et al., 2006), social withdrawal (Simon & Walker, 2018), loneliness (Ramsey et al., 2019; Simon & Walker, 2018) and decreased levels of empathy (Rosen et al., 2006). Sleep deprivation has also been linked to a greater propensity for confusion, irritability, and decreased mood regulation (Baum et al., 2013), as well as fatigue and/or exhaustion, and anger (Baum et al., 2013; Ramsey et al., 2019).

Further, sleep deprivation has been linked to difficulties with focused attention and difficulties modulating impulses, characteristic of attention-deficit/hyperactivity disorder (ADHD) (Dahl, 1996). Sleep deprivation has also been linked to higher rates of substance use and/or abuse (Dolsen & Harvey, 2017; Gillin, 1998), a desire to self-harm (Ramsey et al., 2019), as well as increased suicidal ideation (Kim et al., 2013; X. Liu, 2004; Ramsey et al., 2019), and an increased risk of committing suicide (Becker et al., 2018; Goldstein et al., 2008; X. Liu, 2004).

Prolonged Sleep. Prolonged sleep is defined as an excessive duration of sleep in a 24-hour period (Ohayon et al., 2013). For most adults, this is greater than 9 hours of sleep a night.

Physical Health. Like sleep deprivation, prolonged sleep has been linked to an increased risk for numerous diseases and impairments in physical health. Among those most commonly reported are an increased risk for cardiometabolic diseases such as type 2 diabetes mellitus (Chaput et al., 2007; Engeda et al., 2013; Tan et al., 2018), hypertension (Y. Wang et al., 2015), cardiovascular disease, including coronary heart disease (Ayas et al., 2003; Strand et al., 2016), and obesity (Tan et al., 2018; Theorell-Haglöw et al., 2014). Prolonged sleep has also been linked to an increased risk for dementia, including Alzheimer's disease (Westwood et al., 2017). Beyond this, prolonged sleep has been linked to an increased risk for cancer, including colorectal cancer (Chen et al., 2018; Jiao et al., 2013) and breast cancer (Lu et al., 2017). Prolonged sleep has also been linked to having a weakened immune system (Irwin et al., 1996), and an increased risk of mortality (Cappuccio et al., 2010b; Hublin et al., 2007; Kwok et al., 2018).

Mental Health. Prolonged sleep has also been linked to numerous impairments in mental health. This includes an increased risk of anxiety (Gradner & Kripke, 2004) and depression (Bishop et al., 2021; Nutt et al., 2008; Patel et al., 2006), as well as a greater propensity for fatigue and/or exhaustion (Bishop et al., 2021; Gradner & Kripke, 2004). Additionally, prolonged sleep has been linked to higher rates of substance use and/or abuse (Dolsen & Harvey, 2017; Gillin, 1998), increased suicidal ideation (Kim et al., 2013), and an increased risk of committing suicide (Goldstein et al., 2008; Michaels et al., 2017).

Sleep Quality

Sleep quality, like sleep quantity, has been shown to have a significant impact on a person's health and general well-being. Poor sleep quality can have detrimental effects.

Physical Health. Poor sleep quality has been linked to numerous diseases and impairments in physical health. Among those most commonly reported are an increased risk for cardiometabolic diseases such as type 2 diabetes mellitus (Hungin & Close, 2010; Lou et al., 2012; Meisinger et al., 2005), hypertension (K. Lo et al., 2018; Yang et al., 2021), cardiovascular disease, including coronary heart disease (Kwok et al., 2018; Lao et al., 2018; Wolk et al., 2005), and obesity (Beccuti & Pannain, 2011; Chang & Chen, 2015; Gohil & Hannon, 2018). Additionally, poor sleep quality has also been linked to an increased risk for cognitive decline and dementia, including Alzheimer's disease (Blackman et al., 2022; Ju et al., 2013; Spira et al., 2015).

Beyond this, poor sleep quality has been linked to an increased risk for indigestion, including gastroesophageal reflux disease (GERD) (Fass, 2009; Vege et al., 2004), as well as irritable bowel syndrome (IBS) (Heitkemper et al., 2005; Vege et al., 2004; B. Wang et al., 2018). Poor sleep quality has also been linked to the onset and increased perception of physical pain (Ağargün et al., 1999; Smith et al., 2009). Additionally, poor sleep quality has been linked to an increased risk of mortality overall (Elder et al., 2008; Martin et al., 2011; Rod et al., 2011).

Mental Health. Poor sleep quality has also been linked to numerous disorders and impairments in mental health. This includes an increased risk of anxiety (Hungin & Close, 2010; Matsuda et al., 2017), and depression (Matsuda et al., 2017; Pilcher et al., 1997), and lower levels of life satisfaction (Lacruz et al., 2016; Pilcher et al., 1997). Poor sleep quality has also been linked to a greater propensity for fatigue, confusion, tension, and anger (Pilcher et al., 1997).

Further, poor sleep quality has been linked to difficulties with focused attention and difficulties modulating impulses, characteristic of ADHD (Hvolby, 2015; Spruyt & Gozal, 2012). Poor sleep quality has also been linked to higher rates of fighting, tobacco smoking, and alcohol consumption, as well as increased suicidal ideation (Vail-Smith et al., 2009), and an increased risk of committing suicide (Bernert et al., 2014; Gui et al., 2022; Rod et al., 2011).

Cognitive Performance

Cognitive performance is defined as the efficiency with which an individual carries out or accomplishes any or all mental processes of cognition. Cognition is a range of mental processes relating to the acquisition, storage, manipulation, and retrieval of data (Cambridge Cognition, 2015). Mental processes include sensation and perception, attention, memory, and higher reasoning.

Attention

Of all the mental processes, attention has been, and remains, one of the more frequently assessed in psychological research. Attention is defined as the process of focusing on a chosen stimuli under varying levels of environmental distractions (Sohlberg & Mateer, 2010).

Sohlberg and Mateer (1987) proposed that there are five types of attention. This includes focused attention, sustained attention, selective attention, alternating attention, and divided attention. The notion that there are five types of attention remains generally accepted today.

As described by Sohlberg and Mateer (1987, 2001), focused attention is the ability to respond to a specific stimulus. Sustained attention, also known as vigilance, is the ability to continuously respond to a specific stimulus. Selective attention is the ability to respond to a specific stimulus in the presence of distracting stimuli. Alternating attention is the ability to efficiently shift attention from one stimulus to another. Divided attention is the ability to attend to two or more simultaneously occurring stimuli. This is more commonly known as multitasking.

Memory

Like attention, memory has been, and remains, a frequently assessed mental processes in psychological research. Memory is defined as the process of maintaining information over time (Matlin, 2005). This includes the storage, encoding, and retrieval of information, or data.

Atkinson and Shiffrin (1968) proposed that there are three primary types of memory: sensory memory; short-term memory, also known as working memory; and long-term memory.

As described by Atkinson and Shiffrin (1968), sensory memory is defined as a very brief recall (about 3 seconds) of a sensory experience, such as what was seen or heard. Short-term memory involves the recall of information encountered anywhere from 30 seconds to a few days prior. Generally, information decays after 30 seconds, however, it can be maintained longer through a process known as rehearsal. Long-term memory involves the recall of information encountered anywhere from a few days to decades prior. Long-term memory is generally eternal.

Atkinson and Shiffrin (1968) posited that each type of memory was a unitary store. Many researchers have argued, however, that each type consists of numerous stores or subtypes. For example, Baddeley and Hitch (1974, 2000) proposed that working memory consists of four stores: a central executive, phonological loop, visuospatial sketchpad, and an episodic buffer.

Baddeley and Hitch (2000) report that the central executive acts as an attention sensory store. It channels information to the three component processes: the phonological loop, visuospatial sketchpad, and episodic buffer. The phonological loop stores auditory information by silently rehearsing sounds or words in a continuous loop. It is also known as auditory or verbal working memory. The visuospatial sketchpad stores visual and spatial information. It is also known as visual or visuospatial working memory. The episodic buffer is dedicated to linking data across domains to form integrated units of visual, spatial, and verbal information and chronological ordering. It is thought to have links to long-term memory and semantic meaning.

Sleep and Cognitive Performance

Both sleep quantity and sleep quality have been found to have a significant effect on cognition and cognitive performance (Alhola & Polo-Kantola, 2007; Deak & Stickgold, 2010; Lim & Dinges, 2010; Wilckens et al., 2014; Yun et al., 2015). The two most widely studied cognitive domains in sleep research are attention and memory.

Among these, it seems that sustained attention and visuospatial working memory are the most frequently examined.

Sleep Quantity

To assess the impact of sleep quantity on cognitive performance, researchers have employed the use of sleep deprivation, as well as prolonged sleep. Sleep deprivation studies include the use of both total sleep deprivation, and partial sleep deprivation, or sleep restriction.

Total sleep deprivation is defined as the avoidance of sleep for a period of at least one night (Alhola & Polo-Kantola, 2007). Partial sleep deprivation, or sleep restriction, is defined as a reduction in the total sleep time relative to one’s usual baseline during a 24-hour period. For adults, this is generally understood to include any amount less than 7 hours, but greater than 0.

Total Sleep Deprivation. Total sleep deprivation has been found to lead to declines in cognition and cognitive performance, especially sustained attention. Mixed results have been found, however, with regard to total sleep deprivation and visuospatial working memory.

Sustained Attention. To investigate variability in cognitive performance, specifically sustained attention, as a function of sleep deprivation, Doran et al. (2001), tested persons every two hours using the Psychomotor Vigilance Test (PVT; Dinges & Powell, 1985) throughout 88 hours of sleep deprivation. They then compared this to a control group who was permitted a two hour nap every 12 hours throughout the 88-hour time period. Results indicated that Psychomotor Vigilance Test reaction times increased markedly among persons and within each individual subject in the sleep deprivation condition relative to those in the nap condition.

Doran et al. (2001) note that during total sleep deprivation, variability in performance reflected a combination of normal timely responses, errors of omission or lapses, and errors of commission or responding when no stimulus was present. Errors of omission and errors of commission were highly intercorrelated across deprivation. Doran et al. (2001) note that such a finding is indicative of the fact that performance instability is more likely to include compensatory effort rather than a general lack of motivation or lack of effort overall.

Similar results were found by Graw et al. (2004). They compared participants' performance on the Psychomotor Vigilance Test (PVT; Dinges & Powell, 1985) during a period of 40 hours of sleep deprivation to that of participants' performance on this same measure who were allowed a 75-minute nap every 150 minutes. Graw et al. (2004) report that persons who were sleep deprived showed increased reaction times and a greater number of lapses comparatively.

In another study, Chua et al. (2014) examined the effects of 26 hours of sleep deprivation on sustained attention performance. Their study consisted of healthy volunteers aged 22-32 years from the general population. These persons were kept awake for 26 hours and every two hours their attention was assessed using the Psychomotor Vigilance Test (PVT; Dinges & Powell, 1985). Results garnered showed that during sleep deprivation, participants exhibited more variable response times when completing the Psychomotor Vigilance Test than they did at baseline. Furthermore, participants exhibited lower and more variable heart rates than they did at baseline.

Dixit et al. (2012) report that even 24 hours of sleep deprivation can be enough to impact sustained attention. Participants included 30 medical undergraduate students. They ranged in age from 18-25 years. Sustained attention was assessed using the Digit Symbol Substitution Test (DSST; Wechsler, 1939), the Digit Vigilance Test (DVT; Lewis & Rennick, 1979), and the Letter Cancellation Test (LCT; Diller et al., 1974), in both the single- and double-letter forms. Results revealed an increase in errors on the Digit Vigilance Test and Letter Cancellation Test. Additionally, a significant decrease in correct response was seen on the Letter Cancellation Test. Beyond this, it was noted that the time taken to complete all tests increased with lack of sleep, with the Digit Symbol Substitution Test being most affect by total sleep deprivation overall.

Jung et al. (2011) performed a comparison of sustained attention, as assessed by both auditory and visual psychomotor vigilance tasks, prior to and during sleep deprivation. Baseline included several nights of 8 hours of sleep, while sleep deprivation lasted for 40 consecutive hours. Results obtained indicated that during sleep deprivation, there was a significant increase in response times, response lapses, anticipations, and time on task for both auditory and visual vigilance tasks. In general, however, visual vigilance was slower and more variable than was auditory vigilance, with larger differences between auditory and visual psychomotor vigilance tasks seen during sleep deprivation than at baseline comparatively.

Visuospatial Working Memory. Chee and Chuah (2007) examined the effect that total sleep deprivation has on cognitive performance, specifically, visual working memory. Their study consisted of 30 undergraduate students whom they assessed following one night of normal sleep and again after one night of total sleep deprivation.

Results obtained indicated that one night of total sleep deprivation significantly reduced visual working memory capacity.

Adding to this, Chuah and Chee (2008) again examined the effect that total sleep deprivation has on visual working memory. This time, they also assessed the effect of the acetylcholinesterase inhibitory Donepezil (Aricept) on task performance. Donepezil is a medication frequently used in the treatment of Alzheimer's disease. Chuah and Chee (2008) hypothesized that cholinergic augmentation, provided by administration of Donepezil, would modulate visual working memory performance in individuals who were sleep deprived.

To carry out their study, Chuah and Chee (2008) conducted a 2 x 2 double-blind, placebo-controlled crossover study. Participants included 28 healthy, young adult volunteers who were assessed following one night of normal sleep and again after one night of total sleep deprivation. Results obtained indicated that one night of total sleep deprivation significantly reduced visual working memory capacity. Further, Donepezil had beneficial effects in some persons when sleep deprived. It had no effect on task performance following normal sleep.

Similar results were also found by Wee et al. (2013). They examined the effect that total sleep deprivation has on visual working memory. Specifically, they examined how sleep deprivation and maintenance duration interact to influence the number and precision of items in visual working memory. Participants included 19 young, college students. They were assessed following one night of normal sleep, then reassessed after one night of total sleep deprivation. Wee et al. (2013) found that total sleep deprivation significantly reduced visual working memory. Specifically, sleep deprivation selectively reduced the number of integrated representations that can be retrieved after a delay, while leaving the precision of object information in the stored representations intact. Delay interacted with sleep deprivation to lower the rate of successful recall.

Comparatively, Nilsson et al. (2005) found that, in their study, total sleep deprivation did not impact visuospatial working memory. Using a cross-sectional design, they compared the performance of 11 adults following one night of total sleep deprivation with 11 adults who were not sleep deprived. Participants' cognitive performance, including visuospatial working memory was assessed using the modified Six Elements Test (SET; Burgess & Shallice, 1996). Results indicated that following total sleep deprivation, general cognitive performance was significantly impaired. There were no group differences, however, in visuospatial working memory.

Adding to this, Drummond et al. (2012) found that in their study, total sleep deprivation did and did not impact visual working memory. They examined the effect that both total sleep deprivation and partial sleep deprivation have on visual working memory capacity, as well as filtering efficiency. Their study consisted of 44 healthy young adults whom they assessed following six nights of 9 hours of sleep, then again after one night of total sleep deprivation and four nights of partial sleep deprivation, or 4 hours of rest per night, in a counter-balanced order. Visual working memory testing consisted of two tasks, each measuring a different part of visual working memory. The first task measured capacity, or the amount of visual information that a person can maintain and/or keep readily accessible for tasks. The second measured a person's filtering efficiency, that is, their ability to ignore distractor stimuli in a visual scene.

Drummond et al. (2012) found that neither total nor partial sleep deprivation reduced visual working memory capacity. However, total sleep deprivation did impair performance in the filtering task overall. Drummond et al. (2012) note these results suggest that components of visual working memory are differentially vulnerable to the effect of sleep deprivation, and that different types of sleep deprivation impact visual working memory to different degrees.

Partial Sleep Deprivation. Numerous studies have examined the impact of partial sleep deprivation on cognitive performance. Interestingly, though, it is noted that studies examining the effect of partial sleep deprivation on cognitive performance are much fewer in number compared to studies examining the effect of total sleep deprivation on cognitive performance.

Like total sleep deprivation, however, partial sleep deprivation has been found to lead to declines in cognition and cognitive performance, especially sustained attention. Mixed results have also been found with regard to partial sleep deprivation and visuospatial working memory.

Sustained Attention. Van Dongen et al. (2003) examined the effect of chronic sleep restriction on cognitive performance, including sustained attention. Their study consisted of 35 healthy adults who spent two weeks sleeping either 4, 6, or 8 hours per night, as well as 13 healthy adults who were restricted from sleeping for 88 hours straight. Each person was assessed every two hours during wakefulness using a neurobehavioral test battery that included the Psychomotor Vigilance Test (PVT; Dinges & Powell, 1985). Results obtained indicated that 4 or 6 hours of sleep per night over two weeks resulted in significant cumulative, dose-dependent deficits in cognitive performance on all tasks within the respective test battery.

Alarmingly, Van Dongen et al. (2003) note that a comparison of chronic sleep restriction to total sleep deprivation showed that chronic restriction of sleep to 6 hours or less per night produced cognitive performance deficits equivalent to up to two nights of total sleep deprivation.

Similar results were found by Philip et al. (2012). They too note that chronic sleep restriction can produce cognitive performance deficits, specifically deficits in sustained attention, equivalent to those seen following a period of total sleep deprivation. Building on this, however, they found that even just two nights of sleep restriction can have such deleterious effects.

In completing their study, Philip et al. (2012) compared participants' performance on a simple reaction time test during five consecutive days of 4 hours of sleep per night to that of participant's performance on this same measure who were sleep deprived for one night. Results indicated that lapse occurrences increased after the second day of sleep restriction and reached levels equivalent to those observed after one night of total sleep deprivation. Reaction times were not significantly affected by either partial sleep deprivation or total sleep deprivation. Recovery to baseline levels of alertness and performance occurred after a single eight hour night of rest.

In another study, Belenky et al. (2003) examined sustained attention changes during chronic sleep restriction, augmentation, and following recovery sleep. Their study consisted of 66 volunteers who spent seven nights sleeping either 3, 5, 7, or 9 hours per night, followed by three nights of 8 hours of sleep per night. It was found that in the three-hour group, speed on the Psychomotor Vigilance Test (PVT; Dinges & Powell, 1985) declined and lapses increased steadily across the seven days of partial sleep restriction. In the five-hour and seven-hour groups, speed initially declined, then appeared to stabilize at a reduced level. Lapses were increased in the five-hour group, but not the seven-hour group comparatively. In the nine-hour group, it is reported that speed and lapses remained at baseline levels throughout the entirety of the study.

Belenky et al. (2003) found that during recovery, the five hour and seven-hour groups' speed on the Psychomotor Vigilance Test (PVT; Dinges & Powell, 1985), remained at the stable, but reduced levels seen during the last days of sleep restriction. The five-hour groups' rate of lapses also remained at the stable, but reduced levels seen during the last days of partial sleep restriction. The three-hour group recovered rapidly following the first night of recovery sleep, however, recovery was still not comparable with that of the five hour and seven-hour groups. Performance in the nine-hour group remained at baseline levels during the recovery phase. Belenky et al. (2003) note their results indicate that the brain can adapt to chronic sleep restriction.

Visuospatial Working Memory. Del Angel et al. (2015) found that partial sleep deprivation can have a significant impact on working memory, including both auditory and visual working memory. To carry out their study, Del Angel et al. (2015) examined the effects of sleep reduction for five days on working memory. Participants of this study included 13 undergraduate students. Participants were assessed using the dual n-back task. This task was given at the same time each day prior to sleep reduction, then again on the first, fourth, and fifth days of sleep reduction, as well as one day after free sleep. Results indicated that sleep reduction produced a decrease in accuracy on the auditory section of the n-back task the fifth day of sleep reduction. Sleep reduction also produced a decrease in accuracy, and an increased reaction time, on the visual section of the n-back task on the first and fifth day of sleep reduction.

Similarly, Gosselin et al. (2017) found that partial sleep deprivation can have a significant impact on visuospatial working memory. They assessed the impact of partial sleep deprivation on cognitive performance. This included visuospatial working memory. They also, for comparison, assessed the impact of total sleep deprivation on cognitive performance. Participants included 12 university students with a mean age of 24.3 years. They were assessed using a comprehensive cognitive battery following total sleep deprivation, then again following just four hours of sleep. Overall, it was found that total sleep deprivation, as well as partial sleep deprivation can have detrimental effects on cognitive performance in various domains. As it relates to visuospatial working memory, specifically, Gosselin et al. (2017) report that both total sleep deprivation and partial sleep deprivation were found to impact task performance, however, the effects of partial sleep deprivation were more subtle, comparatively.

Comparatively, Gray (2013) found that in their study, partial sleep deprivation did not impact visuospatial working memory. They examined the relationship between partial sleep deprivation and cognitive performance on measures of visuospatial working memory, inhibition, and alternating attention. Participants included ten children, ranging in age from 4-6 years. Sleep was assessed via actigraphs and sleep diaries maintained by parents. Cognitive performance was assessed using three different computer games. Cognitive performance was tested twice after children followed a strict sleep-wake schedule. For the first four nights, all children slept an average amount of time. On the fifth night, some slept an average amount of time, and some received three hours less than is typical. The next morning, they were tested. Children completed this schedule twice so they would each be tested following typical rest and sleep restriction.

Gray (2013) found that sleep restriction had no significant effect on visuospatial working memory. With regard to inhibition, sleep restriction had no effect on response times, however, it did contribute to less accurate responding comparatively. Meanwhile, with regard to alternating attention, the opposite was true. Sleep restriction was found to have no effect on response accuracy, however, it did contribute to slower response times comparatively.

Adding to this, Sharma et al. (2009) found that in their study, partial sleep deprivation did and did not impact visual working memory. They examined the effect of partial sleep deprivation on cognitive performance, including both visual working memory and sustained attention. Their study consisted of 15 male volunteers, age 28-34 years who slept for only 4 hours for four nights. Sleep was recorded using a sleep diary. Visual working memory was assessed using the Visual Memory Task (VMT), and sustained attention was assessed using the Vigilance Task. Cognitive performance was assessed at baseline and following sleep restriction each night.

Sharma et al. (2009) found that generally, partial sleep restriction did not have an effect on visual working memory compared to performance at baseline. It did, however, have a significant impact on one of the ten aspects of visual working memory assessed. Comparatively, partial sleep restriction, had a significant effect on sustained attention, overall, when compared to performance at baseline. It affected three of the six aspects of sustained attention assessed.

Prolonged Sleep. Several studies have examined the impact of prolonged sleep on cognitive performance. It is noted, however, that studies examining this effect are much fewer in number compared to studies examining the effect of sleep deprivation on cognitive performance. Further, these studies have more often been carried out on children and teens rather than adults. Interestingly, prolonged sleep has generally been found to lead to improvements, not declines, in sustained attention. Mixed results have been found, however, for visuospatial working memory.

Sustained Attention. Sadeh et al. (2003) examined the relationship between partial sleep deprivation and prolonged sleep on cognitive performance, including sustained attention. Participants included 77 children with a mean age of 10.6 years. They were assessed over a period of five nights. All children maintained their normal sleep schedule for the first two nights. They were then given a battery of tests, including the Continuous Performance Test (CPT; Conners, 1995) to measure sustained attention. Following this, students either extended or restricted their sleep by an hour for three nights. They were then reassessed using the same tests.

Sadeh et al. (2003) found that partial sleep deprivation was associated with a decline in performance as it relates to sustained attention. Meanwhile, prolonged sleep was associated with an increase in performance as it relates to sustained attention. Results were relative to baseline.

Adding to this, Kamdar et al. (2004) examined the relationship between prolonged sleep and cognitive performance, specifically sustained attention, as well as daytime alertness and mood in adults. Participants included 15 healthy college students reporting minimal daytime sleepiness at baseline. Participants were allowed to sleep as much as possible during a sleep extension period. Sustained attention, alertness, and mood were assessed at baseline, during, and following sleep extension. Sleep was measured via actigraphs and journals. Sustained attention was measured via the Psychomotor Vigilance Test (PVT; Dinges & Powell, 1985).

Kamdar et al. (2004) found that during and following times of prolonged sleep, participants had an improved performance on the Psychomotor Vigilance Test from baseline. Vigor and fatigue also showed improvement, as did mood overall for most participants.

Similar results were found by Arnal et al. (2015). They examined the relationship between prolonged sleep and sustained attention before, and during, total sleep deprivation, and after recovery. Participants included 14 healthy men, ranging in age from 26-37 years. Subjects participated in two experimental conditions: prolonged sleep (9.8 ± 0.1 hours of sleep) and habitual sleep (8.2 ± 0.1 hours of sleep). In each condition, subjects performed two consecutive phases: six nights of either prolonged sleep or habitual sleep, and then three days in-laboratory. In the laboratory, participants engaged in one night of either prolonged or habitual sleep to establish a baseline, then a period of total sleep deprivation, and then a night of recovery sleep. Attention was assessed using the Psychomotor Vigilance Test (PVT; Dinges & Powell, 1985).

Arnal et al. (2015) report that prolonged sleep was found to improve individuals' performance on the Psychomotor Vigilance Test (PVT; Dinges & Powell, 1985). Specifically, it was noted that persons who engaged in prolonged sleep had fewer attentional lapses and a faster speed, or reaction time, comparatively. Prolonged sleep also limited attentional lapses during total sleep deprivation. Differences in both attentional lapses and speed were maintained after one night of recovery sleep. Arnal et al. (2015) note that these results highlight how prolonged sleep can improve sustained attention. Further, results highlight how prolonged sleep can help protect against lapses in sustained attention during times of total sleep deprivation.

Visuospatial Working Memory. Dewald-Kaufmann et al. (2013) examined the effect of prolonged sleep on cognitive performance, including visuospatial working memory and sustained attention. To carry out their study they recruited, 55 youth ranging in age from 12-19 years, with symptoms of chronic sleep reduction. They were monitored for three weeks. During the first week, sleep was merely monitored to obtain a baseline. Then, for two weeks, participants were instructed to either maintain their usual schedule or to engage in an extended amount of sleep. Cognitive performance was assessed using three different cognitive measures. Test were given at baseline, and again at the end of the study. Tests were taken from the Amsterdam Neuropsychological Tasks (ANT; de Sonneville, 1999), and given via computer.

Dewald-Kaufmann et al. (2013) report that as it relates to visuospatial working memory, the response time on correct responses decreased from the pretest to the posttest for all participants. However, the response time on correct responses significantly decreased more in the persons who engaged in sleep extension than those who did not. Although not significant, accuracy decreased from the pretest to the posttest in those who engaged in sleep extension, but not those who did not engage in sleep extension. Results suggest that persons who engaged in prolonged sleep had a significantly better visuospatial working memory performance overall.

Beyond this, Dewald-Kaufmann et al. (2013) report that with regard to sustained attention, response time did not significantly change from the pretest to the posttest for any participants, whether they engaged in sleep extension or not. Further, persons engaged in sleep extension did not significantly differ from those who did not engage in sleep extension. Taken together, results suggest that prolonged sleep did not have a positive or negative effect on sustained attention.

Similarly, Richards et al. (2016) also examined the effect of sleep quantity, including prolonged sleep, on cognitive performance, including visuospatial working memory. They found, however, that prolonged sleep was not beneficial for visuospatial working memory. Using a cross-sectional design, they analyzed performance data gathered between January 2012 and September 2013 for 512,823 first-time players of three online cognitive training games. Subjects ranged in age from 15-89 years. Sleep was measured via self-report, and cognitive performance was assessed by both response time and accuracy. Results garnered suggest that cognitive performance peaked following 7 hours of sleep on all tasks for all participants, except those of the oldest age. Decrements in performance were noted for sleep durations shorter and longer than 7 hours on all tasks in all participants. This was most pronounced for persons of a younger age.

Adding to this, Nakagawa et al. (2016) assessed the impact of sleep quantity, including prolonged sleep, on verbal and visuospatial working memory, among men and women separately. Participants included 779 healthy individuals (434 males and 345 females) with a mean age of 20.7 years. Results garnered suggested that sleep quantity was positively correlated with verbal working memory in both males and females. Sleep quantity was also positively correlated with visuospatial working memory in female subjects, but not in male subjects. Nakagawa et al. (2016) note that such a finding may help explain the variable results that are found as it relates to sleep quantity, in general, and visuospatial working memory, specifically.

Sleep Quality

Several studies have examined the impact of sleep quality on cognitive performance. It is noted, however, that studies examining this impact are much fewer in number compared to studies assessing the effect of sleep quantity on cognitive performance. Nevertheless, it has been found that, like sleep quantity, sleep quality can have a significant effect on sustained attention. Sleep quality has also been found to a significant effect on visuospatial working memory.

Sustained Attention. Gobin et al. (2015) examined the relationship between sleep quality, sustained attention, and emotional memory. Sleep quality was assessed via the Pittsburgh Sleep Quality Index (PSQI; Buysse et al., 1989). Attention was assessed using the Sustained Attention to Response Task (SART; Robertson et al., 1997). Emotional memory was assessed via an emotion picture recognition task the researchers developed themselves. This   was developed from the International Affective Picture System (IAPS; Lang et al., 2008). Participants included 154 undergraduate students. Results indicated that poor sleep quality was associated with better memory for negative stimuli and a deficit in sustained attention to non-emotional stimuli. Results were independent of stress, chronotype, and time of day.

Yun et al. (2015) also found that sleep quality was associated with sustained attention. They assessed sleep quality and sustained attention in 2,499 community dwelling Korean adults using the Psychomotor Vigilance Task (PVT; Dinges & Powell, 1985) and Epworth Sleepiness Scale (Johns, 1991). Results garnered indicated that persons with excessive daytime sleepiness had a slower mean reciprocal response time, a higher probability for increased lapses, and a more negative reciprocal response time slope. Notably, these results were found to be most prevalent in participants who were of an older age, female gender, lower education level, and/or depressed.

Berdzenishvili and Tabagua (2017) found similar results as it relates to sleep quality and cognitive performance, including, sustained attention. They assessed this, however, exclusively in participants who were diagnosed with clinical depression or Major Depressive Disorder.

To complete their study, Berdzenishvili and Tabagua (2017) compared the cognitive performance of persons with Major Depressive Disorder and poor sleep quality with the cognitive performance of persons with Major Depressive Disorder and good sleep quality. Cognition was assessed using the Continuous Performance Test (CPT; Conners, 1995), the Wisconsin Card Sorting Test (WCST; Grant & Berg, 1948), and the Color Trails Test (CTT; D'Elia et al., 1996), a language-free version of the Trail Making Test (TMT; Reitan, 1958). Sleep quality was measured using the Pittsburgh Sleep Quality Index (PSQI; Buysse et al., 1989). Results indicated that participants with Major Depressive Disorder and poor sleep quality performed worse than those with Major Depressive Disorder and good sleep quality on all tasks. Thus, sleep quality has an effect on sustained attention, processing speed, and mental flexibility. Results highlight the impact of sleep quality on cognitive performance regardless of mood.

Visuospatial Working Memory. Steenari et al. (2003) found that sleep quality can also have a significant effect on working memory, specifically, verbal and visual working memory. Steenari et al. (2003) carried out their study using schoolchildren ages 6- to 13-years-old. Sleep was assessed using actigraphy measurements taken during a typical school week for 72 consecutive hours. Working memory was assessed using the dual n-back task. Results indicated that lower sleep efficiency and longer sleep latency, indicators of poor sleep quality, were associated with a higher percentage of incorrect responses in both verbal and visual working memory tasks.

Rana et al. (2018) found similar results, but in an adult population. They examined the relationship between sleep quality, memory, and executive functioning. Participants included 1220 middle-aged male twins, ages 51-60 years, from the Vietnam Era Twin Study of Aging. Sleep quality was assessed using the Pittsburgh Sleep Quality Index (PSQI; Buysse et al., 1989). Memory, which included both verbal and visuospatial episodic, or working, memory, was assessed using a battery of cognitive tests. Results garnered indicated that sleep quality was positively associated with performance in numerous memory-related domains. This included visuospatial working memory. That is to say, poorer sleep quality was found to be associated with decreased visuospatial working memory performance, and vice versa. Interestingly, however, sleep quality was not found to be associated with verbal working memory, specifically.

Adding to this, Wilckens et al. (2014) examined the relationship between sleep continuity, an indicator of sleep quality, sleep quantity, and cognitive performance in both young adults and older adults. Cognitive performance included working memory, specifically, visual working memory, as well as processing speed, verbal fluency, inhibition, and recall. Cognitive performance was assessed using a battery of neurocognitive tasks, including computerized versions of the Sternberg Working Memory Task and a visual form of the n-back task. Sleep was assessed using a sleep-detection device that measured sleep continuity and length.

Wilckens et al. (2014) found that higher sleep continuity, that is, better sleep quality, was associated with better cognitive performance, overall, for both young adults and older adults. In young adults, higher sleep continuity was associated with better visual working memory and inhibitory control. Meanwhile, in older adults, higher sleep continuity was associated with better inhibitory control, memory recall, and verbal fluency. No effects were found for sleep continuity and processing speed in either young adults or older adults. In young adults, short (3-4 hours) and long (greater than 10 hours) sleep times, were associated with poorer visual working memory and verbal fluency. No effects were found for sleep quantity and cognitive performance in older adults.

Wilckens et al. (2014) note these findings uphold the importance of good sleep quality, including continuous sleep, in that it allows for proper cycling through non-REM and REM sleep stages for top executive functioning. Good sleep quality is important for cognition in all ages. Sleep quantity, however, may be more vital for cognition in young adults rather than older adults.

Glucose

Glucose, also known as dextrose, and colloquially known as blood sugar, is a simple sugar which the body produces from protein, fat, and, in largest part, carbohydrates in the diet (*Mosby's medical dictionary,* 2012). It is absorbed directly into the blood from the intestines and provides energy to all cells in the body. Cells cannot use glucose, however, without insulin.

Glucose is regulated by insulin, a hormone produced by the beta cells of the pancreas (*Mosby's medical dictionary*, 2012). The main job of insulin is to keep the level of glucose in the bloodstream within a normal range. This is achieved by moving glucose from the bloodstream into tissues for energy and storage. Without insulin, or the right amount of insulin, the level of glucose in the bloodstream becomes elevated. This is the hallmark feature of diabetes mellitus.

Diabetes, or diabetes mellitus, refers to a group of diseases in which the body's ability to produce or respond to insulin is impaired (*Mosby's medical dictionary,* 2012). This results in abnormal metabolism of protein, fat, and carbohydrates, and elevated levels of glucose in the blood and urine. Chronic diabetes mellitus includes both type 1 and type 2 diabetes mellitus.

Type 1 diabetes mellitus occurs when the pancreas produces little or no insulin (*Mosby's medical dictionary,* 2012). Type 1 diabetes mellitus can occur at any age, but is most common in children. Type 1 diabetes mellitus was formerly known as juvenile-onset diabetes, juvenile diabetes, insulin-dependent diabetes mellitus, brittle diabetes, and ketosis-prone diabetes.

Type 2 diabetes mellitus occurs when the body, as a whole, fails to use insulin properly (*Mosby's medical dictionary,* 2012). This is known as insulin resistance. Insulin resistance, however, can also occur as a precursor to type 2 diabetes mellitus. The onset of type 2 diabetes mellitus is typically after the age of 40, but may occur sooner. Today, in fact, the prevalence of type 2 diabetes mellitus in children and young adults, alike, is on the rise (Kaufman, 2002). Type 2 diabetes mellitus was formerly known as adult-onset diabetes, maturity-onset diabetes, non-insulin dependent diabetes mellitus, stable diabetes, and ketosis-resistant diabetes.

Terms commonly associated with type 2 diabetes mellitus, both in research and practice, include insulin sensitivity, glucose tolerance, impaired glucose tolerance, and glucose intolerance.

Insulin sensitivity describes how sensitive the body is to the effects of insulin overall *(Mosby's medical dictionary,* 2012). Low or decreased insulin sensitivity suggests insulin resistance, and denotes that larger amounts of insulin are needed to keep glucose levels stable.

Glucose tolerance refers to the body's response to glucose, or how well it can absorb glucose (*Mosby's medical dictionary,* 2012). Reduced, abnormal, or impaired glucose tolerance, also known as glucose intolerance, refers to an inability of the body to properly metabolize glucose. Impaired glucose tolerance may also refer to the transition phase between normal glucose tolerance and diabetes mellitus. This is known as "borderline diabetes" or prediabetes. Prediabetes is not a guarantee for the development of type 2 diabetes mellitus, but it does put a person at higher risk of having the disorder in future times (American Diabetes Association, 2016).

Diabetes can be diagnosed and monitored by measuring the level of glucose in a person's bloodstream (Joslin Diabetes Center, n.d.; Mayo Clinic, 2018). Glucose can be assessed in terms of whole blood or plasma, a part of whole blood. This provides a reading known as a blood glucose level or a plasma glucose level, respectively, though often these terms are used interchangeably.

Blood glucose is generally assessed numerous times in a day, prior to and after eating (Mayo Clinic, 2018; *Mosby's medical dictionary,* 2012). A glucose measurement taken after a person has abstained from eating or drinking for least 8 hours is known as a fasting blood glucose level or a fasting plasma glucose level, depending on the type of sample which is taken.

Blood glucose levels can be classified into three categories. This includes hypoglycemia, euglycemia, and hyperglycemia (*Mosby's medical dictionary,* 2012). Hypoglycemia means "low glucose" and is indicative of glucose levels which are lower than average. Euglycemia means "good" or "normal glucose" and is indicative of an average glucose level. Hyperglycemia means "high glucose" and is indicative of glucose levels which are higher than average.

Acute hypoglycemia is used to describe severe, or extreme, low glucose levels *(Mosby's medical dictionary*, 2012). Comparatively, acute hyperglycemia is used to describe severe, or extreme, high glucose levels. Both are considered serious medical emergencies.

In persons with diabetes mellitus, specifically, glucose may also be assessed in terms of A1C levels, also known as glycated hemoglobin (*Mosby's medical dictionary,* 2012). Glycated hemoglobin refers to hemoglobin to which glucose has bound. The more glucose that enters the bloodstream, the higher the amount of glycated hemoglobin and vice versa. An A1C measurement provides an overview of a person's 2-3 month average plasma glucose concentration. This is suggestive of glycemic control, and may be described as "good" or "poor."

Insulin and glucose can also be measured via AUC, or area under the curve. This is a measurement of the bioavailability of a drug or substance based on a plot of blood concentrations sampled at frequent intervals (*Mosby's medical dictionary,* 2012). A high insulin AUC suggests an increased amount of insulin in the blood. This is indicative of insulin resistance, as well as a decreased insulin sensitivity (Kauffman, 2003; Mayo Clinic, 2017). A high glucose AUC suggests an increased amount of glucose in the blood. A high insulin AUC and a high glucose AUC, whether independently or together, is suggestive of impaired glucose tolerance overall.

Beyond this, insulin and glucose levels can be used to determine a person's disposition index. Disposition index is the product of insulin sensitivity multiplied by the amount of insulin secreted in response to blood glucose levels (Bergman et al., 2002). A low disposition index predicts the conversion of insulin resistance to type 2 diabetes mellitus.

Sleep and Glucose

Scientists agree that both sleep quantity and sleep quality have a significant effect on glucose, or more specifically, glucose metabolism (Ip & Mokhlesi, 2007; Knutson, 2007; Padilha et al., 2011; Spiegel et al., 2009; Taub & Redeker, 2008). They note that persons who sleep too much or too little and/or persons who do not obtain a restful sleep, are at an increased risk for prediabetes in the short-term and type 2 diabetes mellitus in the long-term.

Sleep Quantity

To assess the impact of sleep quantity on glucose, researchers have employed the use of both total sleep deprivation and partial sleep deprivation. Some studies, though much fewer in number, have also assessed the impact of prolonged sleep, or excessive sleeping, on glucose.

Total Sleep Deprivation. The first studies evaluating the impact of sleep on glucose involved varying durations of total sleep deprivation (Morselli et al., 2011).

In the late 1960s, Kuhn et al. (1969) compared glucose tolerance in 28 young healthy volunteers after four to five control nights with normal bedtimes and after 72-126 hours of total sleep deprivation. They found that glucose response to an oral glucose tolerance test was higher following 72-126 hours of total sleep deprivation, indicating reduced glucose tolerance, when compared with results obtained following nights of normal rest.

Vondra et al. (1981) tested the effect of 120 hours of total sleep deprivation on the activity of selected enzymes of energy metabolism in skeletal muscle. Results indicated that the activity of all enzymes assessed was decreased, with those involved in the Krebs cycle and in anaerobic glycolysis reaching statistical significance. It is noted that these results suggest a "prediabetic" type of muscle metabolism during sleep deprivation. Vondra et al. (1981) further report that fasting blood glucose levels were increased at the end of the sleep deprivation period.

In another study, conducted by VanHelder et al. (1993), results obtained after 7 hours of rest were compared with those obtained after 60 hours of total sleep deprivation in young healthy male volunteers. Results indicated that 60 hours of total sleep deprivation increased insulin response to an oral glucose tolerance test. No changes were observed, however, specific to plasma glucose levels. VanHelder et al. (1993) note these results indicate that total sleep deprivation can contribute to the development of insulin resistance.

González-Ortiz et al. (2000) tested the effect of one night of total sleep deprivation on insulin sensitivity in healthy adults. A randomized, single-blind, controlled design was used; 14 individuals were studied before and after 24 hours of sleep deprivation, and compared with 14 individuals with normal sleep periods. Results indicated that one night of total sleep deprivation was enough to significantly increase steady state glucose levels during an insulin suppression test. Persons with normal sleep periods showed no changes in steady state glucose levels. There were also no significant differences in cortisol levels at any time for either group. This suggests, yet again, that sleep deprivation can decrease insulin sensitivity in healthy adults.

Partial Sleep Deprivation. Studies assessing the impact of partial sleep deprivation on glucose have similarly employed various durations of sleep deprivation (Morselli et al., 2011).

The first studies that investigated the effect of partial sleep deprivation on metabolic and endocrine functions assessed carbohydrate metabolism, 24-hour profiles of the counterregulatory hormones cortisol and growth hormone, and cardiac sympathovagal balance (Spiegel et al., 1999; Spiegel et al., 2000; Spiegel et al., 2004). This was done by comparing results obtained following a period of partial sleep deprivation, specifically, 4 hours of rest for six nights, with results obtained after a period of sleep recovery, specifically, 12 hours of rest for six to seven nights. Results garnered indicated that glucose tolerance, assessed by means of an intravenous glucose tolerance test, drawn during the intake of a high-carbohydrate breakfast, was significantly lower following partial sleep deprivation than it was following sleep recovery.

Partial sleep deprivation was also found to be associated with increased evening cortisol concentrations, increased durations of elevated growth hormone concentrations during the day, as well as increased cardiac sympathovagal balance (Spiegel et al., 1999; Spiegel et al., 2000; Spiegel et al., 2004). Such results are indicative that semi-chronic partial sleep deprivation can have a clinically significant negative effect on glucose metabolism and cardiometabolic risk.

Adding to this, Leproult and Van Cauter (2006) tested the effect of partial sleep deprivation on insulin sensitivity. Using a baseline period of three days with 10 hour bedtimes followed by eight nights of partial sleep deprivation, or 5 hour bedtimes, an intravenous glucose tolerance test was performed on 13 young, healthy individuals. This test was given after the second baseline night and after seven nights of partial sleep deprivation. Results indicated that following sleep restriction, participants experienced a 40% decrease in insulin sensitivity, without adequate compensation of insulin release, putting them at an increased risk for diabetes.

Similar results were found by Buxton et al. (2010), who note that seven days of partial sleep deprivation, or five hour bedtimes, was found to result in a significant reduction in insulin sensitivity, even after controlling for diet and activity. Participants of their study included 20 healthy men, age 20- to 35-years-old. Each participant spent 10 hours per night in bed for eight or more nights (sleep-replete condition). They then spent 5 hours per night in bed for seven nights (sleep-restricted condition). On the last two days of each condition, the glucose metabolism of each individual was assessed via a glucose tolerance test, and the hyperinsulinemic-euglycemic clamp technique, considered the "gold standard" for assessing insulin sensitivity in humans (Tam et al., 2012). Buxton et al. (2010) found that insulin sensitivity was decreased as a function of sleep restriction when measured with the glucose tolerance test, as well as the hyperinsulinemic-euglycemic clamp technique. Additionally, glucose tolerance and disposition index were found to be reduced following sleep restriction.

In another study, conducted by Nedeltcheva et al. (2009) it was found that exposure to recurrent sleep restriction in the setting of both high caloric intake and physical inactivity can result in increased insulin resistance and reduced glucose tolerance. Specifically, semi-chronic sleep restriction, two weeks of 5.5 hours of sleep versus 8.5 hours of sleep, in middle-aged overweight adults was associated with decreased insulin sensitivity as assessed by an intravenous glucose tolerance test and reduced glucose tolerance as measured by an oral glucose tolerance test. Despite this, it was determined participants did not have an increased risk for diabetes. This was assessed by mathematical calculation of each person's disposition index.

Donga et al. (2010) evaluated insulin sensitivity in middle-aged men and women after a single night of partial sleep restriction, or 4 hours of rest. This was assessed using the hyperinsulinemic-euglycemic clamp technique. Donga et al. (2010) found a reduction in glucose infusion and disposal rates, indicative of a deterioration of glucose tolerance and insulin sensitivity.

Donga et al. (2010) also assessed endogenous hepatic glucose production rate, by continuous infusion of glucose. Following sleep restriction, endogeneous hepatic glucose production was found to be increased by approximately 22%. Free fatty acid levels were also increased, a sign of higher insulin resistance. Cortisol and glucagon levels were unchanged.

Prolonged Sleep. Several studies have also examined the effect of prolonged sleep on glucose. It is noted, however, these studies are fewer in number compared to studies of deprivation.

The Sleep Heart Health Study conducted by Gottlieb et al. (2005) found that sleep durations of 6 hours or less per night, as well as 9 hours or more per night, were associated with an increased odds for diabetes and impaired glucose tolerance, compared with 7-8 hours of sleep per night. Scores for all persons were adjusted based on sleep apnea ratings and other confounders.

Yaggi et al. (2006) found similar results when examining sleep duration as a risk factor for type 2 diabetes mellitus. They note that among a sample of more than 1,100 men in the Massachusetts Male Ageing Study, those reporting shorter and longer sleep duration were two and three times as likely, as others, to develop incident diabetes mellitus, respectively. Incident diabetes mellitus is defined as cases of diabetes that are newly diagnosed. This can be compared to prevalent diabetes mellitus, which refers to cases, or persons, whose disease developed or was diagnosed before the time of the study (*Mosby's medical dictionary,* 2012).

Chaput et al. (2007) also found similar results when examining sleep duration as a risk factor for type 2 diabetes mellitus and/or impaired glucose tolerance. Using adults who obtained 7-8 hours of sleep per night as a reference, they found that the adjusted odds ratio for type 2 diabetes mellitus and/or impaired glucose tolerance was 1.58 (1.13-2.31) for those who obtained 9-10 hours of sleep per night and 2.09 (1.34-2.98) for those who obtained 5-6 hours of sleep per night, even after accounting for potential confounding variables. Chaput et al. (2007) note that while a lack of sleep and an excess of sleep can both be bad for a person's health, including their chance of developing diabetes, sleep restriction seems to be most damaging.

Chaput et al. (2007) note that both short and long sleepers presented significantly higher total insulin AUC ($p < 0.05$), whereas total glucose AUC was not different between the three sleeper groups in both sexes. The mean glucose area below fasting glucose concentrations was significantly higher in short ($p < 0.01$) and long sleepers ($p < 0.05$) compared with "normal" sleepers, and significantly higher in short ($p < 0.05$) compared with longer sleepers in both sexes.

Sleep Quality

Several studies have examined the impact of sleep quality on glucose. It is noted, however, that studies examining the effect that sleep quality has on glucose appear to be fewer in number compared to studies examining the effect that sleep quantity has on glucose.

To assess the impact of sleep quality on glucose, researchers have used cross-sectional designs, as well as, and perhaps more frequently, longitudinal designs (Ip & Mokhlesi, 2007).

Jennings et al. (2007) examined the association between self-reported sleep quality and the presence of metabolic syndrome and its component factors. Metabolic syndrome is the name for a group of risk factors that raise an individual's risk for coronary heart disease and other health problems, such as type 2 diabetes mellitus or stroke (*Mosby's medical dictionary,* 2012). Jennings et al. (2007) note that after adjusting for sex and age, logistic regression showed that poor global sleep quality scores, as assessed by the Pittsburgh Sleep Quality Index (PSQI; Buysse et al., 1989), were significantly related to the presence of, or having, metabolic syndrome. Linear regression results showed that Pittsburgh Sleep Quality Index global sleep quality scores were significantly related to waist circumference, body mass index, body fat percentage, serum insulin and glucose levels, and estimated insulin resistance, specifically.

Lou et al. (2012) examined the relationship between sleep quality and sleep duration, and type 2 diabetes. They found, among a sample of 16,893 participants, that both poor sleep quality and sleep quantity were associated with an increased prevalence for diabetes. Compared with persons who achieved good sleep quality and sleep quantity, or 6-8 hours of sleep per night, diabetes was more prevalent in persons with poor sleep quality and sleep quantity. Poor sleep quantity was defined as 6 hours or less of sleep per night, or 8 hours or more of sleep per night.

In a longitudinal study investigating the possible relationship among sleep disturbances and diabetes, over an estimated 14.8 year period, in a sample of initially healthy, nondiabetic men, Nilsson et al. (2004) found that sleep disturbances were significantly related to diabetes. They note that among their sample, 9.3% of subjects reported either difficulties falling asleep or regular use of hypnotics, both markers of sleep disturbances, and 2.4% reported both. Altogether, 4.3% of all participants studied had developed diabetes by the follow-up period. Logistic regression models showed difficulties in falling asleep and/or regular use of hypnotics, and resting heart rate to be associated with the development of type 2 diabetes mellitus.

Kawakami et al. (2004) found similar results when examining the relationship between sleep disturbances and diabetes. They note that persons who experienced a high frequency of difficulty initiating sleep had a significantly higher age-adjusted hazard ratio for type 2 diabetes mellitus when compared with those who experienced a low frequency of difficulty initiating sleep. A similar hazard ratio was also found for difficulty maintaining sleep. Hazard ratios were almost identical and remained statistically significant after controlling for other factors often associated with type 2 diabetes mellitus. This included age, education, occupation, shift work, body mass index, physical activity, smoking, alcohol consumption, and familial history.

In another study, conducted by Mallon et al. (2005), it was found that sleep complaints and sleep duration were both related to the development of diabetes prospectively over a 12-year period. Mallon et al. (2005) note that men reporting new diabetes at follow-up, more often reported shorter sleep durations, specifically 5 hours or less of sleep per night, difficulties initiating sleep, and difficulties maintaining sleep, when compared with men reporting that they had not developed diabetes at follow-up. Women reporting new diabetes at follow-up reported longer sleep durations, specifically 9 hours or more of sleep per night, when compared with women reporting that they had not developed diabetes at the time of follow-up.

Mallon et al. (2005) note that in multiple logistic regression models, the relative risk for the development of diabetes was higher in men with shorter sleep durations or difficulties maintaining sleep after adjustment for age and other relevant risk factors. Short or long sleep duration and sleep complaints did not influence the risk of new diabetes in women overall.

Comparatively, Meisinger et al. (2005) found that sleep disturbances were a predictor of type 2 diabetes mellitus in both men and women. Meisinger et al. (2005) report that in their follow-up with 4,140 men and 4,129 women, a total of 119 cases of incident type 2 diabetes mellitus were seen among men and a total of 69 cases of incident type 2 diabetes mellitus were seen among women. In both sexes, difficulty maintaining sleep was associated with a higher risk of type 2 diabetes. After adjustment for a host of confounding variables, it was determined that the hazard ratio in men was 1.60 (95% CI = 1.05-2.45) and the hazard ratio for women was 1.98 (95% CI = 1.20-3.29). In contrast, difficulty initiating sleep was not found to be associated with a significantly increased risk of developing type 2 diabetes mellitus. These results stand in opposition to those found by Mallon et al. (2005) and those found by Kawakami et al. (2004).

In a meta-analysis of longitudinal studies examining the effect of sleep quantity and sleep quality on type 2 diabetes mellitus, Cappuccio et al. (2010a) found that both sleep quantity and sleep quality had an effect on the risk for development of type 2 diabetes mellitus. Specifically, for short duration sleep, 6 hours or less of sleep per night, the risk ratio was 1.28 (95% CI = 1.03-1.60). For long duration sleep, 8 hours or more of sleep per night, the risk ratio was 1.48 (95% CI = 1.13-1.96). For difficulty initiating sleep, it was 1.57 (95% CI = 1.25-1.97), while for difficulty maintain sleep, it was 1.84 (95% CI = 1.39-2.43). Cappuccio et al. (2010a) note results are indicative of the fact that sleep quantity and sleep quality, consistently and significantly, predict the risk of the development of type 2 diabetes mellitus over time.

Glucose and Cognitive Performance

Like both sleep quantity and sleep quality, glucose has also been found to have a significant effect on cognition and cognitive performance (Bellisle, 2001; Cox et al., 2005; Moheet et al., 2015; Mortby et al., 2013; Ryan et al., 2016; Saedi et al., 2016; Zilliox et al., 2016).

Unfortunately, it is noted that most studies conducted specific to glucose and cognitive performance in adults, have assessed only individuals diagnosed with diabetes mellitus, or compared the performance of individuals diagnosed with diabetes mellitus to nondiabetics. Additionally, these studies have primarily only been conducted with middle-aged and older adults.

Few studies have assessed the cognitive performance of persons with glucose levels in a prediabetic range. This, whether in isolation, in comparison to persons with glucose levels in a normal range, or in comparison to persons diagnosed with type 2 diabetes mellitus. Nevertheless, research shows that glucose levels in a high "normal" or prediabetic range also have a significant effect on cognition and cognitive performance (Mortby et al., 2013; Saetung et al., 2018).

Researchers have assessed the impact of glucose on numerous cognitive domains including sustained attention and visuospatial working memory. Mixed results have been found, however, specific to glucose and sustained attention, as well as visuospatial working memory.

Sustained Attention

Fontbonne et al. (2001) found that glucose can have a significant impact on sustained attention. Fontbonne et al. (2001) assessed the relationship between fasting blood glucose and cognitive performance, in general, and with regard to specific cognitive domains, including sustained attention. They also assessed how cognitive performance changes over time, and as a function of glucose. Participants included individuals without any detectable cognitive deficits, aged 59-71 years at baseline. They were classified into three categories: normal, prediabetic, and diabetic. Classification was based on fasting blood glucose levels or known diabetes. Cognition was assessed using the Mini-Mental Status Exam (MMSE; Folstein et al., 1975), as well as eight domain-specific tests. Assessment was done at baseline and again, four years later.

Domain-specific tests included the Trail Making Test (TMT; Reitan, 1958); the Benton Facial Recognition Test (BFRT; Benton & Van Allen, 1968; Benton et al., 1983); the Rey Auditory Verbal Learning Test (AVLT; Rey, 1941, 1964); the Digit Symbol Substitution Test (DSST; Wechsler, 1939); the Benton Visual Retention Test (BVRT; Sivan, 1992); the Finger Tapping Test (FTT; Reitan & Davidson, 1974); the Paced Auditory Serial Addition Test (PASAT; Gronwall & Wrightson, 1974); and Raven's Matrices, or Raven's Progressive Matrices (RPM; Raven et al., 1998). The Digit Symbol Substitution Test was used to assess attention.

Fontbonne et al. (2001) found that at baseline, scores for all cognitive tests except for the Digit Symbol Substitution Test (DSST; Wechsler, 1939) were similar across glucose categories. It is noted, however, that persons with type 2 diabetes mellitus had a significantly poorer performance on this particular test than did persons without diabetes. After four years, those with type 2 diabetes mellitus had a lower performance on all tests, except the Mini-Mental Status Exam (MMSE; Folstein et al., 1975), when compared to persons without diabetes and persons with prediabetes. Fontbonne et al. (2001) note that differences reached statistical significance on four tests. This included the Trail Making

Test (Reitan, 1958), the Benton Facial Recognition Test (BFRT; Benton & Van Allen, 1968; Benton et al., 1983), the Rey Auditory Verbal Learning Test (AVLT; Rey, 1941, 1964), and the Digit Symbol Substitution Test. Differences were not statistically significant for the Benton Visual Retention Test (BVRT; Sivan, 1992); the Finger Tapping Test (FTT; Reitan & Davidson, 1974); the Paced Auditory Serial Addition Test (PASAT; Gronwall & Wrightson, 1974); or Raven's Matrices (RPM; Raven et al., 1998).

Ryan and Geckle (2000) also found that glucose has a significant impact on sustained attention. They examined the relationship between type 2 diabetes mellitus and cognitive performance on measures of learning, memory, problem-solving, and psychomotor efficiency, including sustained attention. Using a cross-sectional design, they compared the performance of 50 middle-aged adults with type 2 diabetes mellitus with the performance of 50 similar persons without diabetes. Subjects were assessed using a comprehensive test battery which consisted of an array of tests for each domain. Psychomotor efficiency, specifically, was measured with five tests. This included the Digit Vigilance Test (Lewis & Rennick, 1979) to assess sustained attention.

Ryan and Geckle (2000) found that learning, memory, and problem-solving were unaffected by type 2 diabetes mellitus. Psychomotor efficiency was, however, affected by type 2 diabetes mellitus, as evidenced by a general psychomotor slowing ($\triangle R^2 = 0.075$, $p < 0.002$). This was found to be associated with poorer glycemic control. The magnitude of psychomotor slowing on specific tests ranged from 12% (Digit Vigilance Test) to 23% (Grooved Pegboard).

Adding to this, Cukierman-Yaffe et al. (2009) examined the relationship between baseline glycemic control and cognitive function in individuals with type 2 diabetes

mellitus, and other various cardiovascular risk factors. More precisely, they assessed the relationship of A1C and fasting plasma glucose levels to performance on four cognitive tests. Tests included the Mini-Mental Status Examination (Folstein et al., 1975), the Rey Auditory Verbal Learning Test (AVLT; Rey, 1941, 1964), the Digit Symbol Substitution Test (DSST; Wechsler, 1939) and the Stroop Test, formally known as the Stroop Color and Word Test (SCWT; Stroop, 1935). The Digit Symbol Substitution Test, specifically, was used to assess an array of cognitive domains, such as visual motor speed, capacity for learning, sustained attention, and
working memory. Participants included 2,977 persons with type 2 diabetes mellitus, and a high risk for cardiovascular disease. All participants had poor glycemic control, as measured by a screening A1C greater than or equal to 7.5%. All participants were age 55 years or older.

Cukierman-Yaffe et al. (2009) found a statistically significant age-adjusted association between the degree of chronic hyperglycemia, as measured by A1C level, and scores on all four cognitive tests. Specifically, a 1% higher A1C value was associated with a significant 1.75-point lower Digit Symbol Substitution Test (DSST; Wechsler, 1939) score (95% CI = -1.22 to -2.28, $p < 0.0001$), a 0.20-point lower Mini-Mental Status Exam (MMSE; Folstein et al., 1975) score (95% CI = -0.11 to -0.28; $p < 0.0001$), a 0.11-point lower Rey Auditory Verbal Learning Test (AVLT; Rey, 1941, 1964) score, (95% CI = -0.02 to -0.19, $p < 0.0142$), and a worse Stroop Test (SCWT; Stroop, 1935) score (95% CI = 1.31-0.19, $p = 0.0094$). It is noted that the association between the Digit Symbol Substitution Test score and A1C persisted in all multiple linear regression models. Fasting plasma glucose was not found to be associated with scores on any test.

Comparatively, Hawkins et al. (2016) found that, in their study, glucose did not have a significant impact on sustained attention. They examined the relationship between a person's body mass index (BMI) and glucose, as well as glucose and cognitive performance on various cognitive domains, including sustained attention. Participants included 35 normal weight young adults and 35 obese young adults. Cognitive performance was assessed using a task from the Automated Neuropsychological Assessment Metrics (ANAM; Reeves et al., 1993). Each participant completed this. Their BMI and fasting blood glucose level was then determined.

Hawkins et al. (2016) report that overall, young adults who were obese were found to have higher fasting glucose levels compared with their normal weight peers. Further, higher fasting glucose levels were associated with poorer cognitive performance on tests of inhibitory control. There were no observed effects, however, for sustained attention or working memory.

Similarly, Sommerfield et al. (2004) found that glucose did not have a significant impact on sustained attention, even at levels in keeping with acute hyperglycemia. This was determined by examining the relationship between glucose and cognitive performance, as well as glucose and mood. Cognitive performance included numerous domains, including sustained attention.

To carry out their study, Sommerfield et al. (2004) recruited 22 subjects with type 2 diabetes mellitus. Participants had a median age of 61.5 years. Treatment modalities varied from antidiabetic medications to insulin. A hyperinsulinemic glucose clamp was used to maintain arterialized blood glucose at either euglycemia or hyperglycemia on two occasions in a randomized and counterbalanced fashion. Tests of information, processing, immediate and delayed memory, working memory, and attention, including sustained attention, specifically, were administered during each experimental condition, along with a mood questionnaire.

Sommerfield et al. (2004) found that speed of information processing, working memory, and some aspects of attention were impaired during acute hyperglycemia. Sustained attention, specifically, however, was not impaired. Sommerfield et al. (2004) further found that subjects were more dysphoric during hyperglycemia, with less energy, and greater sadness and anxiety.

Visuospatial Working Memory

Mooradian et al. (1988) found that glucose can have a significant impact on visuospatial working memory. They examined the relationship between type 2 diabetes mellitus and visuospatial working memory. Using a cross-sectional design, they compared the performance of 43 men with type 2 diabetes mellitus with the performance of 41 men without type 2 diabetes mellitus. Participants were all over the age of 60 years. Visuospatial working memory was assessed using the Benton Visual Retention Test (BVRT; Sivan, 1992). Results showed that diabetic participants were significantly inferior to the control group in their test performance.

Mooradian and Siverly (1993) also found that glucose can have a significant impact on visuospatial working memory. They examined the relationship between type 2 diabetes mellitus and visuospatial working memory. Using a cross-sectional design, they compared the performance of 46 men with type 2 diabetes mellitus to the performance of 59 men without type 2 diabetes mellitus. Participants were all over the age of 55 years. Visuospatial working memory was assessed using the Benton Visual Retention Test

(BVRT; Sivan, 1992). Results garnered showed that participants with type 2 diabetes mellitus had significantly higher error scores (10.96 $\pm$ 4.07) compared to participants without type 2 diabetes mellitus (9.08 $\pm$ 4.45), F (1,103) = 4.2923, $p < 0.029$. Individuals with type 2 diabetes were also more likely to make the following types of errors comparatively: omissions, distortions, size errors, and left errors.

Adding to this, Novak et al. (2014) found that intranasal insulin led to improvements in visuospatial working memory performance. Using a proof-of-concept, randomized, double-blind, placebo-controlled intervention, they evaluated the effects of a single 40-IU dose of insulin or saline on vasoreactivity and cognition in 15 persons with type 2 diabetes mellitus and 14 control subjects. Participants had a mean age of 62 years. Visuospatial working memory was assessed using the Brief Visuospatial Memory Test-Revised (BVMT-R; Benedict, 1997).

Novak et al. (2014) found that persons with type 2 diabetes mellitus had an inferior performance to those without diabetes on placebo-performances and intervention-performances. Performance in individuals with type 2 diabetes mellitus was improved, however, with the administration of intranasal insulin, as was the performance of individuals without diabetes.

Comparatively, Brands et al. (2007) found that in their study, glucose did not have a significant impact on visuospatial working memory. They examined the relationship between type 2 diabetes mellitus and cognitive performance on various cognitive domains, including visuospatial working memory. Using a cross-section design, Brands et al. (2007) compared the performance of 122 patients with type 2 diabetes and the performance of 61 controls. Subjects were between the ages of 52-80 years. They were assessed using a test battery which consisted of an array of tests for each domain. Visuospatial working memory was assessed using the Rey-Osterrieth Complex Figure Test (ROCF; Osterrieth, 1944; Rey, 1941, 1964; Taylor, 1969).

Brands et al. (2007) found that individuals with type 2 diabetes mellitus had an impaired cognitive performance on multiple domains when compared to persons without type 2 diabetes mellitus. Impairments were not seen, however, for visuospatial working memory, specifically.

Similarly, Takeuchi et al. (2012) found that glucose did not have a significant impact on visuospatial working memory. They examined the relationship between type 2 diabetes mellitus and cognitive performance with regard to specific cognitive domains, including visuospatial working memory. Using a cross-sectional design, Takeuchi et al. (2012) compared the performance of 42 individuals with type 2 diabetes mellitus to the performance of 32 individuals without diabetes. Persons with type 2 diabetes mellitus had a mean age of 62.4 years, while nondiabetics had a mean age of 63.8 years. Subjects were assessed using a test battery which consisted of an array of tests for each domain. Visuospatial working memory was assessed using the Rey-Osterrieth Complex Figure Test (ROCF; Osterrieth, 1944; Rey, 1941; Taylor, 1969).

Takeuchi et al. (2012) report that in their study, individuals with type 2 diabetes mellitus had an impaired cognitive performance on multiple domains when compared to persons without type 2 diabetes mellitus. Impairments were not seen, however, for visuospatial working memory.

Relationship Between Sleep, Glucose, and Cognitive Performance

Despite the many studies connecting sleep to cognitive performance, sleep to glucose, and glucose to cognitive performance, it appears that only one study, to date, has assessed all of these variables together (Saetung et al., 2018). This particular study even assessed persons with glucose levels in a prediabetic range in comparison to persons with type 2 diabetes mellitus. As is common, however, this study was carried out in middle-aged and older adults. This study also assessed the impact of glucose on sleep rather than the impact of sleep on glucose, and did not include the domains of sustained attention and visuospatial working memory, specifically.

Saetung et al. (2018) examined the relationship between sleep, glucose, and cognitive performance. Specifically, Saetung et al. (2018) explored the role of sleep in cognitive functioning in patients with abnormal glucose tolerance. Sleep included both sleep quantity and sleep quality, and was assessed over the course of seven days using actigraphy measurements. Cognitive performance included a general assessment, as well as measurements of performance in specific domains. Specifically, visuoexecutive function, attention, and delayed recall. It was assessed using the Montreal Cognitive Assessment (MoCA; Nasreddine et al., 2005). Participants included 162 persons total, age 44-65 years. Among the participants, 81 individuals met criteria for prediabetes, and 81 individuals had been previously diagnosed with type 2 diabetes mellitus.

Saetung et al. (2018) report no significant statistical differences between persons with prediabetes and those with type 2 diabetes mellitus with regard to sleep quantity or sleep quality.

Saetung et al. (2018) found that abnormal glucose tolerance was positively related to general cognitive performance. Thus, persons with more abnormal glucose tolerance had poorer cognitive performance, and vice versa. Abnormal glucose tolerance was also positively associated with visuoexecutive function and attention, but not delayed recall, specifically. It is noted that a significant percentage of persons with prediabetes and type 2 diabetes mellitus obtained overall cognitive performance scores that were below average. This included 57% of individuals with prediabetes and 69% of individuals with diabetes mellitus. Participants with diabetes mellitus had significantly lower overall scores compared to those with prediabetes, however, and lower visuoexecutive function and attention scores, comparatively. Delayed recall scores were similar between persons with prediabetes and those with type 2 diabetes mellitus.

Beyond this, Saetung et al. (2018) found that sleep quantity was not related to cognitive performance, either generally or specific to any cognitive domain. Sleep quality, however, was positively related to general cognitive performance. Thus persons, with poorer sleep quality had poorer cognitive performance, and vice versa. Sleep quality was also positively associated with visuoexecutive function. No association was found between sleep quality and attention or recall.

This study highlights the effects of glucose on cognitive performance, as well as the effects of sleep quality on glucose. It is limited, however, in that it only assessed the effects of abnormal glucose tolerance on cognitive performance and did not include those with a normal glucose tolerance, or persons without prediabetes or type 2 diabetes mellitus for comparison.

The Present Study

The purpose of the present study was to investigate the mediating effect of glucose on the relationship between sleep and cognitive performance. Sleep was assessed via sleep quantity and sleep quality. Cognitive performance was assessed via sustained attention, as well as visuospatial working memory. This study also sought to explore and further solidify the relationships that exist between sleep, glucose, and cognitive performance. Beyond this, this study aimed to add to the literature by assessing the cognitive performance of young adults (18-25 years) who have fasting blood glucose levels in a prediabetic range, or above, to the cognitive performance of young adults who have fasting blood glucose levels in a normal range.

Hypotheses

This study was carried out in 2021-2022. Based on the literature available at the time of this study, and extending from this, the following hypotheses were believed to be most probable.

Hypothesis One

Sleep will be positively related to cognitive performance. Participants who report having a low sleep quantity and/or poor sleep quality will have significantly decreased performance on a sustained attention task and/or a visuospatial working memory task when compared to participants who report having an adequate sleep quantity and/or good sleep quality.

Hypothesis 1A

Participants who have a low sleep quantity will have significantly decreased performance on a sustained attention task when compared to participants who have an adequate sleep quantity.

Hypothesis 1B

Subjects who have a low sleep quantity will have significantly poorer performance on a visuospatial working memory task when compared to those who have an adequate sleep quantity.

Hypothesis 1C

Participants who have poor sleep quality will have significantly decreased performance on a sustained attention task when compared to participants who have good sleep quality.

Hypothesis 1D

Participants who have poor sleep quality will have significantly decreased performance on a visuospatial working memory task when compared to those who have good sleep quality.

Justification for Hypothesis One (1A, 1B, 1C, 1D)

Researchers have found that sleep can have a significant effect on cognitive performance (Alhola & Polo-Kantola, 2007; Deak & Stickgold, 2010; Lim & Dinges, 2010; Yun et al., 2015). As it relates to sustained attention and visuospatial working memory, specifically, researchers have found that low sleep quantity consistently leads to declines in sustained attention (Belenky et al., 2003; Chua et al., 2014; Dixit et al., 2012; Doran et al., 2001; Graw et al., 2004; Jung et al., 2011; Philip et al., 2012; Van

Dongen et al., 2003), and can also lead to declines in visuospatial working memory (Chee & Chuah, 2007; Chuah & Chee, 2008; Del Angel et al., 2015; Gosselin et al., 2017; Wee et al., 2013). Results for the latter are inconsistent though (Drummond et al., 2012; Gray, 2013; Nilsson et al., 2005; Sharma et al., 2009). Meanwhile, poor sleep quality has been found to consistently lead to declines in both sustained attention (Berdzenishvili & Tabagua, 2017; Gobin et al., 2015; Siddarth et al., 2021; Yun et al., 2015), and visuospatial working memory (Rana et al., 2018; Steenari et al., 2003; Wilckens et al., 2014).

Hypothesis Two

Sleep will be negatively related to fasting blood glucose. Participants who report having a low sleep quantity and/or poor sleep quality will have elevated fasting blood glucose levels (greater than or equal to 100 mg/dl) compared to participants who report having an adequate sleep quantity and/or good sleep quality.

Hypothesis 2A

Participants who report having low sleep quantity will have elevated fasting blood glucose levels when compared to participants who report having adequate sleep quantity.

Hypothesis 2B

Participants who report having poor sleep quality will have elevated fasting blood glucose levels when compared to participants who report having adequate sleep quality.

Justification for Hypothesis Two (2A, 2B)

Researchers have found that sleep has a significant effect on glucose, or more specifically, glucose metabolism (Ip & Mokhlesi, 2007; Padilha et al., 2011). Researchers have found that low sleep quantity consistently results in elevated glucose levels (Buxton et al., 2010; Donga et al., 2010; González-Ortiz et al., 2000; Kuhn et al., 1969; Leproult & Van Cauter, 2006; Nedeltcheva et al., 2009; Spiegel et al., 1999; Spiegel et al., 2000; Spiegel et al., 2004; VanHelder et al., 1993; Vondra et al., 1981), as does poor sleep quality (Jennings et al., 2007; Kawakami et al., 2004; Mallon et al., 2005; Meisinger et al., 2005; P. M. Nilsson et al., 2004). Elevated glucose levels include those in a prediabetic range, as well as those in a diabetic range.

Hypothesis Three

Glucose will be negatively related to cognitive performance. Participants who have fasting blood glucose levels in a pre-diabetic range or above (greater than or equal to 100 mg/dl) will have significantly decreased performance on a sustained attention task and/or a visuospatial working memory task compared to those with normal fasting blood glucose levels (70-99 mg/dl).

Hypothesis 3A

Participants who have elevated glucose levels will have significantly decreased performance on a sustained attention task compared to participants with normal glucose levels.

Hypothesis 3B

Subjects who have elevated glucose levels will have significantly decreased performance on a visuospatial working memory task compared to subjects with normal glucose levels.

Justification for Hypothesis Three (3A, 3B)

Researchers have found that glucose can have a significant effect on cognition and cognitive performance (Ryan et al., 2016; Saetung et al., 2018; Zilliox, et al., 2016).

As it relates to sustained attention and visuospatial working memory, specifically, researchers have found that elevated glucose levels can lead to declines in sustained attention (Cukierman-Yaffe et al., 2009; Fontbonne et al., 2001; Ryan & Geckle, 2000), as well as visuospatial working memory (Mooradian et al., 1988; Mooradian & Siverly, 1993; Novak et al., 2014). Results are inconsistent though (Brands et al., 2007; Hawkins et al., 2016; Sommerfield et al., 2004; Takeuchi et al., 2012).

Hypothesis Four

Glucose will mediate the relationship between sleep and cognitive performance. Specifically, glucose will mediate the relationships between sleep quantity and/or sleep quality and sustained attention and/or visuospatial working memory.

Hypothesis 4A

Glucose will mediate the relationship between sleep quantity and sustained attention.

Hypothesis 4B

Glucose will mediate the bond between sleep quantity and visuospatial working memory.

Hypothesis 4C

Glucose will mediate the relationship between sleep quality and sustained attention.

Hypothesis 4D

Glucose will mediate the bond between sleep quality and visuospatial working memory.

Justification for Hypothesis Four (4A, 4B, 4C, 4D)

To date, it appears that there are no studies which have examined glucose as a mediator of the relationship between sleep and cognitive performance. Based on the support, however, for Hypothesis 1, 2, and 3, it seems intuitive that glucose may explain why and/or how sleep affects cognitive performance (Baron & Kenny, 1986). This includes sleep quantity, sleep quality, sustained attention, and visuospatial working memory.

CHAPTER TWO

METHOD

Participants

Participants of this study were undergraduate students from a public university in Louisiana, enrolled in a mix of psychology courses. Using G*Power software, it was determined that 120 participants were needed for this study. Unfortunately, only 82 participants could be retained, and after cleaning the data, only 81 cases were found to be viable for final analysis.

Participants included 32 males (39.51%) and 49 females (60.49%). They ranged in age from 18- to 24-years, and thus were all "young adults" (Hirshkowitz et al., 2015). The mean age was 19.63 years (SD = 1.48). Participants consisted of Whites (70.37%), African Americans (19.75%), and various other minorities (9.88%). This included Asians, Hispanics, and "Others." Participants were primarily Freshmen (41.98%). They had a mean GPA of 3.48 (SD = .44).

Participation was voluntary in nature and many students were offered extra credit in their courses for their involvement in this study. Additionally, all students who participated were made eligible for a chance to win one of five Amazon gift cards ranging in value from $25 to $100.

Research Design

This study had a mediation design; it sought to explain how and/or why two variables were related. Specifically, this study sought to explain how sleep and cognition were related. This study consisted of two independent variables, one mediator, and two dependent variables. Independent variables included sleep quantity or sleep length, and sleep quality. Glucose was the mediator. Dependent variables included sustained attention and visuospatial working memory.

Instruments

In total, seven instruments were used. Measures included a demographics questionnaire, the Sleep Habits Survey (Buboltz et al., 2001), the Sleep Quality Index (Urponen et al., 1991), and the Adult Sleep-Wake Scale (Fortunato et al., 2008). Finger-stick glucose monitoring was also employed, plus the Sustained Attention to Response Task (Robertson et al., 1997), and a computerized version of the Corsi Block-Tapping Test (Corsi, 1972) or the “Corsi Test.”

Demographics Questionnaire

A demographics questionnaire was given to obtain general information about each participant. This questionnaire was designed by the researcher. It included items regarding participants’ age, sex, academic rank, race, academic major, and grade-point average (GPA). Participants were also asked if they had ever been diagnosed with diabetes mellitus and/or attention-deficit/hyperactivity disorder (ADHD), and if they were currently taking any medication for these disorders. Additionally, participants were asked if they wear glasses or contact lenses, and whether or not they were wearing these the day of their participation.

Sleep Habits Survey (SHS; Buboltz et al., 2001)

The SHS is a 13-item scale which asks questions regarding sleep duration, length, and latency. Questions assess sleep the night prior, in the typical week, and on the typical weekend. All questions are open-ended in nature. Respondents are asked to write their answers in.

The SHS was used to assess sleep quantity. In this study, sleep quantity is described as either "low" or "adequate." It is noted, the National Sleep Foundation recommends that young adults get 7-9 hours of sleep per night (Hirshkowitz et al., 2015). In keeping, individuals who reported getting less than 7 hours of sleep per night were labeled as having "low" sleep quantity. Meanwhile, individuals who reported getting 7-9 hours of sleep per night were labeled as having "adequate" sleep quantity. Individuals who reported getting more than 9 hours of sleep per night were labeled as having "prolonged" sleep quantity. There were not enough data points, however, to assess prolonged sleep quantity in this sample, only low and adequate sleep quantity.

Sleep Quality Index (SQI; Urponen et al., 1991)

The SQI is an eight-item self-report measure used to assess sleep difficulties over a three-month span of time. Question 1 assesses the amount of time, on average, it takes to a person to fall asleep. Questions 2-5 and 7 assess sleep difficulties, specifically. Question 6 relates to tiredness upon waking, and Question 8 relates to use of hypnotics during the past 3 months. Responses to each item are weighted 0, 1, and 2. Individuals' total scores can range from 0 to 16.

Urponen et al. (1991) report that total sleep quality scores ranging from 0 to 1 indicate good sleep quality. Meanwhile, scores ranging from 2 to 8 indicate occasional sleep difficulties, and scores ranging from 9 to 16 indicate poor sleep quality, and great sleep difficulties overall.

The SQI was found to have adequate reliability and validity (Urponen et al., 1991). The internal consistency of the sum index SQI was acceptable with a Cronbach alpha of 0.73 for men and 0.75 for women. Researchers also report that poor subjective health was found to be associated with poor sleep, supporting that the SQI is a valid measure for sleep difficulties.

The SQI was used to assess sleep quality. In this study, sleep quality is described as either "good" or "poor." Persons with a total score of 0-8 on the SQI were deemed to have "good" sleep quality. Meanwhile, those with a score of 9-16 were deemed to have "poor" sleep quality.

Adult Sleep-Wake Scale (ADSWS; Fortunato et al., 2008)

The ADSWS is a 25-item self-report scale which measures five domains related to sleep quality, and sleep quality as a whole. Domains include Going to Bed, Falling Asleep, Maintaining Sleep, Reinitiating Sleep, and Returning to Wakefulness. All items are scored using a 6-point Likert-type scale ranging from (1) *Never* to (6) *Always*. Reverse scoring of several items is required for final analysis. Specifically, responses for Items 9, 14, 17, 18, 19, 21, and 22 are reverse scored, or recorded, so that a low score is transformed into a high score and vice versa. Individuals' total scores can range from 25-150. The median total score on the ADSWS is 87.5.

It is understood that lower total scores, those below 87.5, are indicative of "good" sleep quality. Meanwhile, higher scores, those above 87.5, are indicative of "poor" sleep quality.

Fortunato et al. (2008) found the ADSWS had an adequate reliability as evidenced by the coefficient alpha estimates and test-retest results. Specifically, researchers found an alpha of .71 for Going to Bed, .76 for Falling Asleep, .80 for Maintaining Sleep, .82 for Reinitiating Sleep, and .86 for Returning to Wakefulness. Test-retest reliability coefficients ranged from .67 to .82.

The validity of the ADSWS was also determined to be adequate (Fortunato et al., 2008). Fortunato et al. (2008) found scores on all domains, correlated positively and significantly with one another ($r = 0.53$, $p < 0.05$), with the exception of the correlation between scores on Reinitiating Sleep and Returning to Wakefulness. The construct validity of the ADSWS was found by computing correlations between the five sleep domains, as listed above, with variables of personality (e.g., Negative and Positive Affectivity), stress, and strain. Scores on the measures of Negative Affectivity, stress, and strain correlated negatively with the five sleep domains, while scores on the measure of Positive Affectivity correlated positively with all domains.

The ADSWS, in addition to the Sleep Quality Index (SQI; Urponen et al., 1991), was used to assess sleep quality. Again, in this study, sleep quality is described as “good” or “poor.” Persons with a lower total score on the ADSWS were deemed to have “good” sleep quality. Meanwhile, those with a higher score on the ADSWS were deemed to have “poor” sleep quality.

Finger-Stick Glucose Monitoring

Finger-stick glucose monitoring was used to measure the fasting blood glucose level of each participant. This was done by the researcher who was deemed qualified to do so following completion of several courses from the Collaborative Institutional

Training Initiative (CITI), including a course on bloodborne pathogens, and the proper handling and disposal of blood.

The process was as follows. First, the researcher gathered their supplies. This included, disposable latex-free gloves; a glucometer, a medical device used to determine the approximate concentration of glucose in the blood; test strips, alcohol wipes, blood lancets, and bandages. Next, they put on their gloves. The researcher then turned on the glucometer, and placed one unused test strip inside of it. Following this, they used the alcohol wipe to cleanse the finger of a participant. This was allowed to dry fully. Next, they pricked the participant's finger using a blood lancet so as to obtain a small drop of blood. This drop of blood was placed on the test strip inserted inside of the glucometer. The meter then analyzed the blood and provided a blood glucose reading on its digital display. Finally, participants had a small bandage placed over the site of their finger prick. The researcher recorded the participant's glucose level. They also disposed of all non-biohazardous materials in a trashcan, and placed all biohazardous materials in a biohazard bin. Blood lancets, specifically, were placed in a sharps container. Final disposal of all materials followed regulations of the Louisiana Department of Environmental Quality.

The glucometer used underwent control solution testing prior to its first use, and as needed. This included every time a new container of test strips was opened, if unusual results were obtained, if the glucometer was dropped, and at random intervals of time as deemed fit.

Finger-stick glucose monitoring was used to assess glucose, or fasting blood glucose. In this study, fasting blood glucose is described as either "normal" or "elevated."

It is noted, the American Diabetes Association (2016) identifies fasting blood glucose levels ranging from 70-99 mg/dl as “normal,” and fasting blood glucose levels greater than or equal to 100 mg/dl as “elevated.” The same parameters, and the respective labels for such, were used for this study.

Sustained Attention to Response Task (SART; Robertson et al., 1997)

The SART is a computer-administered go/no-go, continuous performance task. It requires a motor response to frequent stimuli, or non-targets, numbers ‘1-2’ and ‘4-9’, and a withheld motor response to a rare stimulus, or target, the number ‘3.’All stimuli are presented centrally on the computer screen in one of five randomly assigned fonts (48-, 72-, 94-, 100-, and 120-point), representing digit heights between 12 and 29 millimeters. Each stimulus is displayed for 250 milliseconds. It is then replaced by a “mask” which appears for 900 milliseconds. The “mask is a 29-millimeter circle with a cross in it. Participants are asked to ignore this. All stimuli and the “mask” are white on a black background. Timing is not influenced by a participant’s responses.

Participants complete a “training block,” then a “real block.” In the “training block,” each number in the range from 1-9 is used two times. This makes for a total of 18 “training” trials. Meanwhile, in the “real block,” each number is used 25 times. This equates to 225 “real” trials. Among the “real” trials, there are 200 trials in which “go” errors may be made, or errors or omission, and there are 25 trials in which “no-go” errors may be made, or errors of commission.

Participants are provided feedback about the number and percentage of mistakes they make after training, and after the “real block.” For final analysis, only “real block” data is used.

Wilson et al. (2016) report that the average error rate when it comes to errors of omission on the SART is 5-10%. The average error rate when it comes to errors of commission is 30-50%. Individuals with a higher error rate than average are seen as having “decreased” performance, or “below average” sustained attention. Meanwhile, individuals with an error rate that is within or lower than the average error rate, are seen as having “adequate” performance. Broken down further, it is understood that persons with an error rate of 5-10% when it comes to errors of omission and/or 30-50% when it comes to errors are commission have “average” sustained attention, and those with an error rate of 4% or lower when it comes to errors of omission and/or 29% or less when it comes to errors of commission have “above average” sustained attention.

Robertson et al. (1997) found that the SART had adequate reliability, as well as validity. They found that performance on the SART correlated significantly with performance on tests of sustained attention, but not other types of attention, supporting the view that this is indeed a measure of sustained attention. Additionally, they found significant correlations between self- and informant-reported everyday attentional failures and performance on the SART. Similar findings of external validity have been found again and again (Bellgrove et al., 2006; Cheyne et al., 2006; Christoff et al., 2009; Dockree et al., 2004; K. A. Johnson et al., 2007; Malegiannaki & Metallidou, 2012; Manly et al., 1999; Manly et al., 2001; Mullins et al., 2005).

The SART was used to assess sustained attention. In this study, individuals with an error rate of 0-10% when it comes to “go” errors, or errors of omission, were seen as having “adequate” performance. Similarly, those with an error rate of 0-50% when it comes to “no-go” errors, or errors of commission, seen as having “adequate” performance. Those with an error rate of 11% or higher when it comes to errors of omission and/or an error rate of 51% or higher when it comes to errors of commission, were seen as having "decreased" performance, comparatively.

Corsi Block-Tapping Test (CBTT; Corsi, 1972)

The CBTT, colloquially known as the "Corsi Test," is a test that assesses visuospatial working memory. Conceptually, it is similar to the Digit Span Task (DST; Miller, 1956), however, the CBTT requires no verbal communication. It can be given the "traditional" way, by a person, or in the "digital" way, by a computer. For this experiment, it was given digitally.

The CBTT requires participants to mimic a sequence "tapped out," by an examiner or a computer, on up to nine identical, spatially separated blocks, or pictures of such. The sequence starts out simple, usually using two blocks, but becomes more complex until performance wanes. The longest sequence a person can correctly repeat is their block span or their Corsi span.

In the digital-version of the CBTT, specifically, participants are provided a set of instructions. They then begin administration of the test. They start with a sequence of two blocks. Once this has been shown, they hear the word "go" from a computer-programmed voice. Participants are then required to click with the mouse the blocks in exactly the same order as shown before. When they are done, they click "Done." Participants receive immediate feedback on their performance. If correct, they go to the next number of blocks. If wrong, they get a second chance at answering. If they are wrong again, however, testing immediately ceases.

Kessels et al. (2000) found that the average block span for healthy adults was 6.2 blocks (*SD* = 1.3). Thus, the average block span for most adults is 5-7 blocks. Individuals with a block span of four or less blocks are seen as having “decreased” performance, or a “below average” visuospatial working memory. Meanwhile, individuals with a block span of five or more blocks are seen as having “adequate” performance. Broken down further, it is understood that persons with a block span of 5-7 blocks have an “average” visuospatial working memory, and those with a block span of eight or more blocks have an “above average” visuospatial working memory.

The CBTT (Corsi, 1972) has been proven extremely useful for both clinical and experimental purposes since its inception (Berch et al., 1998). Unfortunately, due to modifications made by various researchers over the years, many of which were done without explicit rationale, a systematic compilation and evaluation of the data has not yet been achieved. In keeping, psychometric properties in the form of reliability and validity coefficients fail to exist. See Berch et al. (1998) and/or Arce and McMullen (2021) for a thorough discussion of this.

The CBTT was used to assess visuospatial working memory. In this study, persons with a block span of four or less blocks were seen as having “decreased” performance, while those with a block span of five or more blocks were seen as having “adequate” performance, comparatively.

Procedure

Upon approval from the Biosafety and Radionuclide Institutional Review Committee (BRIRC), as well as the Institutional Review Board (IRB) at Louisiana Tech University, instructors of varying undergraduate psychology classes were contacted to inquire if they would like for their students to participate in this study. If the instructor so obliged, the researcher then visited their class and provided general information to introduce the study to the students. Students were provided dates and times for participation, as well as the location for such. They were also asked not to eat or drink anything after midnight on the day of their participation.

Data were collected on weekdays between 0700-1000 from April 2021 to April 2022. Students met with the researcher, one-on-one, in a private room that was approved for use by the BRIRC. Upon arrival, each student was given an informed consent form. The consent form included an explanation of the purpose of the study, the risk and benefits of participating in the study, and the approximated time that it would take to complete all tasks (roughly 15 minutes). Students were reminded that their involvement in the study was completely voluntary and that all data obtained would remain confidential and anonymous. Students were then asked to sign the informed consent indicating their understanding of these things and their willingness to participate. Each student's signed informed consent was then collected by the researcher.

Next, each participant was provided with a survey packet. Packets contained a demographics questionnaire, the Sleep Habits Survey (Buboltz et al., 2001), Sleep Quality Index (Urponen et al., 1991), and the Adult Sleep-Wake Scale (Fortunato et al., 2008). Participants were asked to complete their survey packets, and to then give these to the researcher for keeping.

Participants who indicated that they had been diagnosed with diabetes mellitus and/or attention-deficit/hyperactivity disorder (ADHD), and/or were currently taking any medication for these disorders were excluded from further participation in this study.

Additionally, participants who indicated that they were supposed to wear glasses or contact lenses, and were not wearing these the day of the study, were excluded from further participation in this study. These participants' data were destroyed. They were equally compensated, however, for their efforts.

Next, remaining participants underwent finger-stick glucose monitoring. This was done by the researcher. Each participant's glucose level was then recorded on their survey packet.

Following this, participants were provided with a computer for completing both the Sustained Attention to Response Task (SART; Robertson et al., 1997) and Corsi Test (Corsi, 1972). These tasks were proctored by the researcher, but facilitated by PsyToolkit (Stoet, 2010, 2017), a free-to-use toolkit for demonstrating, programming, and running cognitive-psychological experiments and surveys. The researcher provided instructions for each of the cognitive tasks prior to their administration. Participants were also provided more specific instructions, and a demonstration, as part of the tasks. Once participants completed their computer-based tasks, the researcher recorded each person's scores on their respective survey packet and/or coded their packet so their computer-based data could be retrieved at a later time and paired with their packet.

Finally, all participants were provided with information specific to improving sleep, and maintaining a healthy blood glucose level. Participants were also provided contact information for the Louisiana Tech University Office of Counseling Services, as well as information for the Louisiana Tech University chapter of the College Diabetes Network.

CHAPTER THREE

RESULTS

Data Preparation

All data collected were entered and analyzed using IBM SPSS Statistics for Windows (Version 28.0) (2021). Prior to final analysis, all data were inspected and cleaned, as needed.

In looking at the data, the researcher found no blatant data entry errors. There were, however, some missing values. Specifically, four participants failed to report their GPA. This was not corrected for as this was non-essential information for this particular study. One participant failed to respond to approximately half of all survey questions. In keeping, this person's answers were discarded completely. Finally, one participant failed to answer all questions on the Sleep Habits Survey (SHS; Buboltz et al., 2001). This was corrected by using mean imputation, or mean substitution. In mean substitution, missing values of a certain variable are replaced by the mean of non-missing cases of that variable. This technique was chosen per the recommendations of Tabachnick and Fidell (2013), and others (Hill, 1997; Peng et al., 2006).

Following this, outliers and influential data points were analyzed via the standardized residuals, Mahalanabis distance, centered leverage value maximum, and Cook's distance as was suggested by Stevens (2002) and Tabachnick and Fidell (2013). All standardized scores associated with the dependent variables were less than 3.29, except for four. These were –3.87, -3.87, 3.43, and 4.91. In keeping, it was determined that there were four univariate outliers in the data. Since the Mahalanabis distance did not exceed the crucial value obtained from the χ^2 table (D_i^2 = 32.48 > CV = 88.38, p = .01), it was determined that there were no multivariate outliers in the data. Similarly, since the centered leverage value maximum was calculated at .99, and the centered leverage value maximum for the data did not exceed this, it was deduced that there were no multivariate outliers present. Regarding influential data points, Cook's distance (CD_i = .145) was found to not exceed 1, thus no influential data points were detected in the data.

Results indicated that there were four outliers, total, in the data. Despite the presence of these outliers, a mediation analysis was ran. The outliers were then identified and removed and the mediation analysis was ran again. Results of the two analyses were not significantly different from one another, thus it was elected that the outliers be kept in for the final analysis.

Data Analysis

A hierarchical multiple regression analysis was conducted to determine whether glucose mediated the relationship between sleep and cognitive performance. Sleep included sleep quantity and quality. Cognitive performance included sustained attention and visuospatial working memory.

First, the internal consistency of all multi-item variables was assessed. This was done using Cronbach's alphas. The Sleep Habits Survey (SHS; Buboltz et al., 2001) was found to have a low reliability (α = .36). Meanwhile, the Sleep Quality Index (SQI; Urponen et al., 1991) was found to have a moderate, or acceptable, reliability (α = .79). The Adult Sleep-Wake Scale (ADSWS; Fortunato et al., 2008) was also found to have an acceptable reliability (α = .87). Despite its low reliability, the researcher opted to retain the SHS in this study. This decision was made as only a few items from the SHS were needed. For final analysis, only Item #3 was used.

Then, a Pearson's correlation was conducted to determine whether the variables of the study were significantly related to one another. Bivariate correlations are reported in Table 1.

Next, preliminary exploratory analysis was conducted to examine whether the data met the assumptions of multiple regression. These assumptions include an independence of errors, absence of multicollinearity, homoscedasticity, linearity, and normality of errors/residuals.

Durbin-Watson statistics ranged from 1.87-2.25. This indicated that there was no autocorrelation present, thus, the independence of errors assumption was met. To meet this assumption, all Durbin-Watson statistics must be close to 2 (Tabachnick & Fidell, 2013).

All variance inflation factors were less than 10. Specifically, the variance inflation factors ranged from 1-1.03. This indicated that there were no multicollinearity problems with the data, thus, the absence of multicollinearity assumption was met (Tabachnick & Fidell, 2013).

The scatterplot of standardized residuals and standardized predicted values produced in conducting exploratory analyses showed a pattern of homoscedasticity in the mediation involving sleep quantity, glucose, and errors of commission on the sustained attention task.

Table 1

Bivariate Correlations

Variable	1	2	3	4	5	6	7
1. Sleep Habits Survey – Item #3	-	-.178	·.351**	·.159	·.029	.030	.066
2. Sleep Quality Index		-	.780**	.027	·.027	.154	-.150
3. Adult Sleep-Wake Scale			-	·.002	.018	.056	-.230*
4. Glucose				-	.121	.148	-.090
5. Sustained Attn. to Resp. Task – Errors of Omission					-	596**	.017
6. Sustained Attn. to Resp. Task – Errors of Commission						-	.076
7. Corsi Block Tapping Test							-

Note. $N = 81$

** $p < .01$ level. * $p < .05$ level.

Additionally, the scatterplot of standardized residuals and standardized predicted values showed a pattern of homoscedasticity in the mediation involving sleep quality, glucose, and errors of commission. This held true whether using the Sleep Quality Index (SQI; Urponen et al., 1991) or the Adult Sleep-Wake Scale (ADSWS; Fortunato et al., 2008) to measure sleep quality. The scatterplot of standardized residuals and standardized predicted values showed a pattern of heteroscedasticity for all other mediations assessed. From this, it was concluded that only some of the data met the assumption of homoscedasticity (Field, 2009; Tabachnick & Fidell, 2013).

In looking at the scatterplot, it was concluded that there was linearity present in the regression. This indicated that the assumption of linearity was met (Tabachnick & Fidell, 2013).

In analyzing the normality of residuals, the skewness and kurtosis were first examined. The skewness of the data ranged from -1.48-2.77. All data were normally distributed, with the exception of errors of omission on the sustained attention task, and performance on the visuospatial working memory task. These were positively skewed, and negatively skewed, respectively. The kurtosis of the data ranged from -.80-9.79. All data were normally distributed, with the exception of errors of omission. This appeared leptokurtic in nature.

A Shapiro-Wilk test of significance was ran. This was significant for all variables, except sleep quality, as measured by the Adult-Sleep Wake Scale (ADSWS; Fortunato et al., 2008). This indicated that all variables were not normally distributed, except sleep quality, as measured by the Adult Sleep-Wake Scale, which was normally distributed.

Histograms were also created in addition to normality plots. The appearance of the histograms was quite varied. The histogram for errors of omission on the sustained attention task was positively skewed. The histograms for sleep quality, as measured by the Sleep Quality Index (SQI; Urponen et al., 1991); glucose; and errors of commission on the sustained attention task were slightly positively skewed. The histogram for sleep quality, as measured by the
Adult Sleep-Wake Scale (ADSWS; Fortunato et al., 2008), was normal. Finally, the histograms for sleep quantity and the visuospatial working memory task were slightly negatively skewed.

Among the normality plots, the normal Q-Q plots generally had a normal pattern. The detrended normal Q-Q plots had several outliers from the mean, however, thus deviating from the assumed normal pattern. The appearance of the box-and-whisker plots, like the histograms, was varied. The box-and-whisker plot for errors of omission on the sustained attention task was positively skewed. The box-and-whisker plots for errors of commission on the sustained attention task, and sleep quality, as measured by the Sleep Quality Index (SQI; Urponen et al., 1991), were slightly positively skewed. The box-and-whisker plots for glucose and sleep quality, as measured by the Adult Sleep-Wake Scale (ADSWS; Fortunato et al., 2008) were normal. The
box-and-whisker plot for sleep quantity was slightly negatively skewed. Meanwhile, the box-and-whisker plot for the visuospatial working memory task was negatively skewed. Several, though not all, of these box-and-whisker plots contained outliers. Based off of these results, it is suggested that the data, except for errors of omission on the sustained

attention task, meets the assumption of normality. One or more outliers, however, may need to be identified and removed.

As mentioned previously, it was determined that there four outliers in the data. Despite the presence of these outliers, a mediation analysis was ran. The outliers were then identified and removed and the mediation analysis was ran again. Results of the analyses were not significantly different from one another, thus it was elected that the outliers be kept in for the final analysis.

Next, the researcher assessed the characteristics of the sample. This was done to help better understand the final results. Means and standard deviations are reported in Table 2.

Table 2

Descriptive Statistics

	M	*SD*
Sleep Quantity	6.86	1.81
Time to Fall Asleep – Week	31	22.41
Time to Fall Asleep – Weekend	28	19.90
Desired Sleep – Week	8.0	.88
Desired Sleep – Weekend	8.58	1.10
Sleep Quality – SQI	13.41	3.68
Sleep Quality – ADSWS	79.62	18.42
Glucose	100.81	8.51
Sustained Attn. to Resp. Task - Errors of Omission	1.35	1.56
Sustained Attn. to Resp. Task - Errors of Commission	41.88	23.19
Corsi Block Span	5.43	1.41

Note. N = 81

Participants reported having an average sleep time the night prior to this study of 6 hours, 52 minutes (*SD* = 1.81). This falls under, though just so, of the range recommended by the National Sleep Foundation (Hirshkowitz et al., 2015), and thus, is considered "low." Participants also reported having an average sleep time during the week of 8 hours, 3 minutes (*SD* = 1.21), and an average sleep time during weekends of 8 hours, 54 minutes (*SD* = 1.34). These times, both, fall within the range recommended by the National Sleep Foundation (Hirshkowitz et al., 2015), and thus, are "adequate." The latter, however, is at the upper end.

Participants reported taking 31 minutes (*SD* = 22.41) to fall asleep during the week, and 28 minutes (*SD* = 19.90) to fall asleep during the weekend. They expressed a desire for 8 hours (*SD* = .88) of sleep during the week, and 8 hours, 35 minutes (*SD* = 1.10) during the weekend.

Participants reported mixed results as it relates to sleep quality. Specifically, they reported having "poor" sleep quality on the Sleep Quality Index (SQI; Urponen et al., 1991)
(*M* = 13.41, *SD* = 3.68), but "good" sleep quality on the Adult Sleep-Wake Scale (ADSWS; Fortunato et al., 2008) (*M* = 79.62, *SD* = 18.42). The reason(s) for this finding remain(s) unclear. Some speculations are made, however, in 'Chapter Four: Discussion.'

Participants were found to have an average glucose of 100.81 mg/dl (*SD* = 8.51). This is considered "elevated" using the parameters set by the American Diabetes Association (2016). It is noted, however, that this is at the lowest end of the range, with 99 mg/dl seen as "normal."

Participants had an average error rate of 1.35% (*SD* = 1.56) when it came to errors of omission on the Sustained Attention to Response Task (SART; Robertson et al., 1997). This is considered "adequate," and is suggestive of "above average" sustained attention. They had an average error rate of 41.88% (*SD* = 23.19) when it came to errors of commission on this same task. This is seen as "adequate," though "average," and is suggestive of "average" sustained attention.

Finally, participants were found to have an average block span of 5.43 (*SD* = 1.41) on the Corsi Block Tapping Test (CBTT; Corsi, 1972). This is considered "adequate" performance. It is "average," though low average, and is suggestive of "average" visuospatial working memory.

Next, the primary, or final, analysis was ran. This consisted of a series of regression analyses based on the aforementioned hypotheses. Restated, it was hypothesized that low sleep quantity and/or poor sleep quality would be associated with decreased cognitive performance, that is, sustained attention and/or visuospatial working memory. Note, again, sustained attention is assessed by "go" errors, or errors of omission, and "no-go" errors, or errors of commission. It was also hypothesized that low sleep quantity and/or poor sleep quality would be associated with elevated fasting blood glucose levels. Additionally, it was predicted that elevated fasting blood glucose levels would be associated with decreased cognitive performance. Ultimately, it was predicted that glucose would mediate the relationship between sleep and cognitive performance.

Results indicated that sleep quantity did not predict sustained attention, be it errors of omission (β = -.03, p = .8) or errors of commission (β = .38, p = .793). Sleep quantity also did not predict visuospatial working memory (β = .05, p = .557). Beyond this, sleep quality, as measured by the Sleep Quality Index (SQI; Urponen et al., 1991), did not predict sustained attention, be it errors of omission (β = -.01, p = .811), or errors of commission (β = .97, p = .171), though the latter is trending towards significance. Sleep quality, as measured by the

Adult Sleep-Wake Scale (ADSWS; Fortunato et al., 2008), also did not predict sustained attention, be it errors of omission (β = .001, p = .876) or errors of commission (β = .07, p = .621). Additionally, sleep quality, as measured by the SQI, did not predict visuospatial working memory (β = -.06, p = .180), though a trend towards significance was seen. Sleep quality, as measured by the ADSWS, did, however, predict visuospatial working memory (β = -.02, p = .039).

Beyond this, it was found that sleep quantity did not predict glucose (β = -.75, p = .156), though a trend towards significance was noted. Sleep quality also did not predict glucose, whether assessed using the Sleep Quality Index (SQI; Urponen et al., 1991) (β = .06, p = .810) or the Adult Sleep-Wake Scale (ADSWS; Fortunato et al., 2008) (β = -.001, p = .985).

Glucose did not predict sustained attention, be it errors of omission (β = .02, p = .283), or errors of commission (β = .40, p = .186), though the latter is trending towards significance. Glucose also did not predict visuospatial working memory (β = -.02, p = .422).

When glucose was included as a mediator in these various models, the relationship between sleep quantity and sustained attention was not significant, be it errors of omission

($\beta = -.01$, $p = .933$) or errors of commission ($\beta = .06$, $p = .631$). The relationship between sleep quantity and visuospatial working memory was also not significant ($\beta = .05$, $p = .643$).

Beyond this, the relationship between sleep quality, as measured by the Sleep Quality Index (SQI; Urponen et al., 1991), and sustained attention was not significant, be it errors of omission ($\beta = -.03$, $p = .788$) or errors of commission ($\beta = .15$, $p = .180$), though the latter is trending towards significance. The relationship between sleep quality, as measured by the Adult Sleep-Wake Scale (ADSWS; Fortunato et al., 2008), and sustained attention was also not significant, be it errors of omission ($\beta = .02$, $p = .874$) or errors of commission ($\beta = .06$, $p = .618$). Additionally, the relationship between sleep quality, as measured by the SQI, and visuospatial working memory was not significant ($\beta = -.15$, $p = .188$), though a trend towards significance was seen. The relationship between sleep quality, as measured by the ADSWS, and visuospatial working memory was, however, significant ($\beta = -.23$, $p = .039$). The strength of the relationship between sleep quality, as measured by the ADSWS, and visuospatial working memory was reduced, slightly, when glucose was included as a mediator.

Findings suggest that the initial conditions of mediation were not met for any of the models, as conceptualized originally using guidelines from Baron and Kenny (1986). Despite this, however, further analysis was conducted per the recommendation of various other researchers (Hayes, 2013, 2017; Hayes & Rockwood, 2017; MacKinnon & Fairchild, 2009; Meule, 2019; Zhao et al., 2010). Specifically, a bias-corrected bootstrap analysis with 95% confidence intervals was conducted to examine the significance of the indirect effect in each model. Using a macro (INDIRECT) created by Preacher and Hayes (2008a, 2008b), 5,000 bootstrap samples were made.

The results of the bootstrap analysis indicated that the indirect effect of sleep quantity on sustained attention through glucose was not significant, be it errors of omission (β = -.02, *SE* = .029, 95% CI [-.118, .019]) or errors of commission (β = -.32, *SE* = .356, 95% CI [-1.428, .119]). The indirect effect of sleep quantity on visuospatial working memory through glucose was also not significant (β = .01, *SE* = .021, 95% CI [-.016, .079]). Beyond this, the indirect effect of sleep quality, as measured by the Sleep Quality Index (SQI; Urponen et al., 1991), and sustained attention through glucose was not significant, be it errors of omission (β = .001, *SE* = .010, 95% CI [-.009, .038]) or errors of commission (β = .02, *SE* = .132, 95% CI [-.145, .409]). The indirect effect of sleep quality, as measured by the Adult Sleep-Wake Scale (ADSWS; Fortunato et al., 2008), and sustained attention through glucose was also not significant, be it errors of omission (β = .00, *SE* = .002, 95% CI [-.004, .004]) or errors of commission (β = -.0004, *SE* = .026, 95% CI [-.059, .049]). Additionally, the indirect effect of sleep quality, as measured by the SQI, and visuospatial working memory through glucose was not significant (β = -.0009, *SE* = .007, 95% CI [-.022, .008]). The indirect effect of sleep quality, as measured by the ADSWS, and visuospatial working memory through glucose was also not significant (β = .00, *SE* = .001, 95% CI [-.002, .003]).

Findings suggest that glucose does not mediate the relationship between sleep and cognitive performance. Discussion of this is provided in the next chapter, ‘Chapter Four: Discussion.’

CHAPTER FOUR
DISCUSSION

The purpose of the present study was to investigate the mediating effect of glucose on the relationship between sleep and cognitive performance. Sleep included sleep quantity and quality. Cognitive performance included sustained attention, as well as visuospatial working memory.

It was hypothesized that low sleep quantity and/or poor sleep quality would be associated with decreased cognitive performance. It was also hypothesized that low sleep quantity and/or poor sleep quality would be associated with elevated fasting blood glucose levels. Additionally, it was predicted that elevated fasting blood glucose levels would be associated with decreased cognitive performance. Finally, it was predicted that glucose would mediate the relationship between sleep and cognitive performance. Results obtained were in partial support of hypotheses.

Hypotheses

The present study consisted of four primary hypotheses. These primary hypotheses were broken down, or divided, into twelve sub-hypotheses for ease of analysis, as well as discussion.

Hypothesis One

This hypothesis stated that individuals with a low sleep quantity and/or poor sleep quality would have significantly decreased performance on a sustained attention task and/or a visuospatial working memory task when compared to individuals with an adequate sleep quantity and/or good sleep quality. This hypothesis was divided into four sub-hypotheses, described below.

Hypothesis 1A

Hypothesis 1A stated that sleep quantity would be positively related to sustained attention. Specifically, that low sleep quantity would be associated with decreased sustained attention. Results failed to support this hypothesis, in that no significant relationship was found between sleep quantity and sustained attention. This is a rather surprising finding, since all literature reviewed indicated that obtaining less than 7 hours of sleep per night leads to declines in sustained attention. It is believed results would have been different had a larger and/or more diverse sample of students been recruited. Unfortunately, as noted previously, data were collected from April 2021 to April 2022. This was in the midst of the COVID-19 pandemic, a time when many colleges and universities, including the one this researcher recruited from, were primarily offering online classes. In keeping, there were significantly fewer students on campus to collect data from, and there was also, seemingly, less diversity among the students, overall.

Had a larger and/or more diverse sample been recruited, it is believed that the average sleep length the night prior to this study would have been lower, in line with literature reviewed. Additionally, it is believed the average error rate on the Sustained Attention to Response Task (SART; Robertson et al., 1997) would have been higher, in keeping with literature reviewed.

Beyond this, it is believed that results may have been different had an objective means of measurement been used to assess sleep quantity, rather than self-report instruments. This is uncertain, however, since mixed results have been found regarding the validity of self-report. Specifically, while numerous researchers have found that sleep questionnaires do not closely correspond with objective measures of sleep, such as actigraphy, polysonography, or the like (Buysse et al., 2008; Girschik et al., 2012; Jackson et al., 2018; Landry et al., 2015; Lauderdale et al., 2008), others have found that they do (Combs et al., 2019; Hoch et al., 1987). Research shows that self-report measures of sleep can be as valid of a means for assessing total sleep time, sleep latency, and sleep efficiency as polysomnography (Combs et al., 2019). Of note, however, there are some differences in this based on sex. Specifically, Hoch et al. (1987) report that in their study, women had a higher proportion of significant and more stable correlations between subjective and objective measures of sleep than did men. This suggests women may report sleep more accurately than men, though the differences are statistically insignificant. Of note, the current study had significantly more female than male participants.

Hypothesis 1B

Hypothesis 1B stated that sleep quantity would be positively related to visuospatial working memory. Specifically, that low sleep quantity would be associated with decreased visuospatial working memory. Results failed to support this hypothesis, in that no significant relationship was found between sleep quantity and visuospatial working memory. It is somewhat unsurprising, however, that this hypothesis was not supported, as information obtained in conducting the literature review revealed mixed findings; some studies indicated there was a significant relationship between sleep quantity and visuospatial working memory, and others indicated there was not. It is noted this holds true for both total sleep deprivation and partial sleep deprivation, the latter of which was assessed in this study. Future research should continue to assess this relationship, as well as the reason(s) for the ongoing variability in results obtained.

Hypothesis 1C

Hypothesis 1C stated that sleep quality would be positively related to sustained attention. Specifically, that poor sleep quality would be associated with decreased sustained attention. Results failed to support this hypothesis, in that no significant relationship was found between sleep quality and sustained attention. Of note, however, there was found to be a trend towards significance between sleep quality and errors of commission, specifically, when using the Sleep Quality Index (SQI; Urponen et al., 1991) to measure sleep quality. Interestingly, there was no significance when it came to sleep quality and errors of omission using this same instrument. There was also no significance between sleep quality and either error type using the Adult Sleep-Wake Scale (ADSWS; Fortunato et al., 2008). This is a surprising finding, since all literature reviewed indicated that poor sleep quality leads to declines in sustained attention. It is believed, again, that results would have been different had a larger and/or more diverse sample of students been recruited. Additionally, results may have been different had an objective means of measurement been used for sleep quality, rather than self-report, though this is not certain.

Interestingly, results garnered suggest that, perhaps, the Sleep Quality Index (SQI; Urponen et al., 1991) is a more sensitive and/or valid measure for assessing sleep quality than is the Adult Sleep-Wake Scale (ADSWS; Fortunato et al., 2008). Such a conclusion is in contrast to Huber et al. (2020), who found a strong correlation between the Adolescent Sleep-Wake Scale (ASWS; LeBourgeois et al., 2005) and the “gold standard” for subjectively measuring sleep quality (Landry et al., 2015), the Pittsburgh Sleep Quality Index (PSQI; Buysse et al., 1989). It is noted that the ADSWS is nearly identical to the ASWS, but is designed for adults, comparatively (Fortunato et al., 2008). Huber et al. (2020) found that the ASWS is a reliable and valid measure of sleep quality in not only adolescents (12-18 years), but also young adults (18-25 years).

No studies were found comparing the SQI and the PSQI, even though many subjective sleep measures have been compared since their creation (Fabbri et al., 2021; Lewandowski et al., 2011).

Hypothesis 1D

Hypothesis 1D stated that sleep quality would be positively related to visuospatial working memory. Specifically, that poor sleep quality would be associated with decreased visuospatial working memory. Results supported this hypothesis, and are in keeping with the literature reviewed. Like with Hypothesis 1C, however, varying results were found using the Sleep Quality Index (SQI; Urponen et al., 1991) versus the Adult Sleep-Wake Scale (ADSWS; Fortunato et al., 2008). Specifically, while sleep quality was found to be significantly related to visuospatial working memory using the ADSWS, these two variables were found not to be significantly related when using the SQI. Of note, however, there was found to be a trend towards significance using the SQI. It is believed the SQI could have also yielded significant results had a larger and/or more diverse sample of students been recruited for this study.

Hypothesis Two

This hypothesis stated that individuals with a low sleep quantity and/or poor sleep quality would have elevated fasting blood glucose levels when compared to individuals with an adequate sleep quantity and/or good sleep quality. This hypothesis was divided into two sub-hypotheses.

Hypothesis 2A

Hypothesis 2A stated that sleep quantity would be negatively related to glucose. Specifically, that low sleep quantity would be associated with increased fasting blood glucose. Results failed to support this hypothesis, in that no significant relationship was found between sleep quantity and glucose. Of note, however, there was found to be a trend towards significance. This is a surprising finding, since all literature reviewed indicated the low sleep quantity leads to increases in glucose. It is believed that with a larger size and/or more diverse sample, significant results may have been found. Additionally, results may have been different had an objective means of measurement been used to assess sleep quantity, rather than self-report instruments. This, as indicated numerous times, however, is uncertain since mixed results have been found.

Beyond this, it is proposed that results may have been different had a different means been used to assess glucose, whether directly or indirectly. Other prospective means include measuring glucose using an oral glucose tolerance test. Participants' glucose could have also been assessed in terms of their A1C levels. Participants' glucose and/or insulin could have been assessed using AUC, or area under curve. Insulin sensitivity, alone, could have also been measured using an intravenous glucose tolerance test, as well as the hyperinsulinemic-euglycemic clamp technique. For the purpose of this study, logistically, however, these were not options.

Hypothesis 2B

Hypothesis 2B stated that sleep quality would be negatively related to glucose. Specifically, that poor sleep quality would be associated with increased fasting blood glucose. Results failed to support this hypothesis, in that no significant relationship was found between sleep quality and glucose. This is yet another surprising finding, since all literature reviewed indicated the poor sleep quality leads to increases in glucose. It is believed that the same changes proposed in discussion of Hypothesis 2A could also be beneficial for this particular hypothesis. With these changes, significant results may have been found, in keeping with literature reviewed.

Hypothesis Three

This hypothesis stated that individuals with elevated fasting blood glucose levels would have significantly decreased performance on a sustained attention task and/or a visuospatial working memory task when compared to individuals with normal fasting blood glucose levels. This hypothesis was divided into two sub-hypotheses, described below.

Hypothesis 3A

Hypothesis 3A stated that glucose would be negatively related to sustained attention. Specifically, that elevated glucose levels would be associated with decreased sustained attention. Results failed to support this hypothesis, in that no significant relationship was found between glucose and sustained attention. Of note, however, there was found to be a trend towards significance. It is somewhat unsurprising that this hypothesis was not supported, as information obtained in conducting the literature review revealed mixed findings; some studies indicated there was a significant relationship between glucose and sustained attention, and others indicated there was not. It is believed that with a larger sample size and/or more diverse sample, significant results may have been found. Additionally, results may have been different had a different means been used to assess glucose. Future research should continue to assess the relationship between glucose and sustained attention, and the reason(s) for the ongoing variability in results.

Hypothesis 3B

Hypothesis 3B stated that glucose would be negatively related to visuospatial working memory. Specifically, that elevated glucose levels would be associated with decreased visuospatial working memory. Results failed to support this hypothesis, in that no significant relationship was found between glucose and visuospatial working memory. It is, again, somewhat unsurprising that this hypothesis was not supports, as information obtained in conducting the literature review revealed mixed findings; some studies indicated that there was a significant relationship between glucose and visuospatial working memory, and others indicated there was not. It is believed that the same changes proposed in discussion of Hypothesis 3A could also be beneficial for this particular hypothesis. With these changes, significant results may have been found. Future research should continue to assess the relationship between glucose and visuospatial working memory, as well as the reason(s) for the ongoing variability in results.

Hypothesis Four

This hypothesis stated that glucose would mediate the relationship between sleep and cognitive performance. Specifically, that glucose would mediate the relationship between sleep quantity and/or sleep quality, and sustained attention and/or visuospatial working memory. This hypothesis was divided into four sub-hypotheses, described below.

Hypothesis 4A

Hypothesis 4A stated that glucose would mediate the relationship between sleep quantity and sustained attention. Results failed to support this hypothesis, in that no significant relationship was found between sleep quantity and sustained attention when glucose was included as a mediator. This held true when testing the direct effect, as well as the indirect effect. This is both a surprising and unsurprising finding. It is surprising because it seemed intuitive, based on most of the literature reviewed, that glucose would explain why and/or how sleep quantity affects sustained attention. It is unsurprising, however, in that some of the literature reviewed was mixed; specifically, there were mixed findings when it came to the relationship between glucose and sustained attention. It is also unsurprising because the initial conditions of mediation were not met for this specific model. It is believed that the same changes proposed in discussion of Hypothesis 1A, 2A, and 3A could also be beneficial for this particular hypothesis.

Hypothesis 4B

Hypothesis 4B stated that glucose would mediate the relationship between sleep quantity and visuospatial working memory. Results failed to support this hypothesis, in that no significant relationship was found between sleep quantity and visuospatial working memory when glucose was included as a mediator. This held true when testing the direct effect, as well as the indirect effect. This is both a surprising and unsurprising finding. It is surprising because it seemed intuitive, based on some of the literature reviewed, that glucose would explain why and/or how sleep quantity affects visuospatial working memory. It is unsurprising, however, in that most of the literature reviewed was mixed; specifically, there were mixed findings when it came to the relationship between sleep quantity and visuospatial working memory, as well as the relationship between glucose and visuospatial working memory. It is also unsurprising because the initial conditions of mediation were not met for this specific model. It is believed that the same changes proposed in discussion of Hypothesis 1B, 2A, and 3B could also be beneficial for this hypothesis.

Hypothesis 4C

Hypothesis 4C stated that glucose would mediate the relationship between sleep quality and sustained attention. Results failed to support this hypothesis, in that no significant relationship was found between sleep quality and sustained attention when glucose was included as a mediator. This held true when testing the direct effect, as well as the indirect effect. Of note, however, when testing the direct effect, there was found to be a trend towards significance between sleep quality and errors of commission, specifically, when using the Sleep Quality Index (SQI; Urponen et al., 1991) to measure sleep quality. Interestingly, there was no significance when it came to sleep quality and errors of omission using this same instrument. There was also no significance between sleep quality and either error type using the Adult-Sleep Wake Scale (ADSWS; Fortunato et al., 2008). When testing the indirect effect, there was found to be no significant relationship, or even a trend towards this, whether using the SQI or the ADSWS.

This is both a surprising and unsurprising finding. It is surprising because it seemed intuitive, based on most of the literature reviewed, that glucose would explain why and/or how sleep quality affects sustained attention. It is unsurprising, however, in that some of the literature reviewed was mixed; specifically, there were mixed findings when it came to the relationship between glucose and sustained attention. It is also unsurprising because the initial conditions of mediation were not met for this specific model. It is believed that the same changes proposed in discussion of Hypothesis 1C, 2B, and 3A could also be beneficial for this particular hypothesis.

Hypothesis 4D

Hypothesis 4D stated that glucose would mediate the relationship between sleep quality and visuospatial working memory. Results failed to support this hypothesis, in that no consistently significant relationship was found between sleep quality and visuospatial working memory when glucose was included as a mediator. Mixed results were found when testing the direct effect versus the indirect effect. Specifically, when testing the direct effect, there was found to be a trend towards significance between sleep quality and visuospatial working memory, when using the Sleep Quality Index (SQI; Urponen et al., 1991) to measure sleep quality. There was also found to be a significant relationship between sleep quality and visuospatial working memory, when using the Adult Sleep-Wake Scale (ADSWS; Fortunato et al., 2008) to measure sleep quality. When testing the indirect effect, however, there was found to be no significant relationship, or even a trend towards this, whether using the SQI or the ADSWS. This makes this a “direct-only nonmediation” (Zhao et al., 2010).

This is both a surprising and unsurprising finding. It is surprising because it seemed intuitive, based on most of the literature reviewed, that glucose would explain why and/or how sleep quality affects visuospatial working memory. It is unsurprising, however, in that some of the literature reviewed was mixed; specifically, there were mixed findings when it came to the relationship between glucose and visuospatial working memory. It is also unsurprising because the initial conditions of mediation were not met for this specific model. It is believed that the same changes proposed in discussion of Hypothesis 1D, 2B, and 3B could also be beneficial for this particular hypothesis. With these changes, significant results may have been found.

Implications

There exists a host of implications based on the literature reviewed and the findings of this study. These implications are applicable not only to students, but all young adults. They are likely to be of interest to young adults, as well as those working with young adults. This includes mental health professionals, various medical personnel, teachers, and school administrators.

First, and foremost, young adults are encouraged to get 7-9 hours of sleep per night as recommended by the National Sleep Foundation (Hirshkowitz et al., 2015). It is recommended that this amount, or quantity, of sleep be obtained consistently on weekdays and weeknights.

It is also recommended that young adults work to improve their sleep quality by adopting better sleep habits or better “sleep hygiene” (Centers for Disease Control and Prevention, 2022b). This includes, going to bed at the same time every night, and waking up at the same time every morning, even on weekends. Making sure that the room in which they are sleeping is quiet, dark, relaxing, and at a comfortable temperature. Removing electronic devices, such as televisions, computers, and smart phones, from the bedroom. Avoiding large meals, caffeine, and alcohol before bedtime, and getting some form of exercise in in the daytime. It is noted that persons who exercise in the daytime, generally have an easier time falling asleep at night. Again, exercise should be obtained in the daytime. It should be avoided in the four hours just before bedtime.

Unfortunately, it seems that these recommendations are not well-known among students and/or young adults (Quan et al., 2013; Thampy & Carter, 2019; Zhang et al., 2019). In keeping, mental health professionals and medical personnel should work to improve “sleep literacy,” or individuals’ knowledge about sleep. This may be achieved through simple discussion, informational handouts, educational videos, and/or the use of internet-based learning modules. Research shows that improving sleep literacy can lead to positive changes in sleep behaviors, and improve both sleep quantity and sleep quality (Quan et al., 2013; Thampy & Carter, 2019).

While there is no substitute for proper sleep quantity and/or good sleep quality, there are strategies which may provide some short-term relief for those who are feeling sleepy. Specifically, it is recommended that persons who are sleep deprived and/or feeling sleepy ingest 75-150 mg of caffeine in some form (American Academy of Sleep Medicine, 2008). This has been found to improve alertness and performance. Researchers also recommend that persons who are sleep deprived and/or feeling sleepy take a short nap of 30 minutes or less. This has been found to improve alertness, as well as certain aspects of mental and physical performance (American Academy of Sleep Medicine, 2008; J. C.-Y. Lo et al., 2022; Waterhouse et al., 2007). Researchers note that these strategies can be used independently, or together, and that there may be an additive effect to combined use (American Academy of Sleep Medicine, 2008). Again, these solutions may provide short-term relief. They are not, however, long-term solutions.

Beyond this, young adults are encouraged to more carefully monitor their glucose levels, and take steps to keep this in a “normal” range, that is, 70-99 mg/dl, as recommended by the American Diabetes Association (2016). To keep glucose levels in a "normal" range, it is recommended that all persons follow a healthy diet with plenty of fruits and vegetables (Centers for Disease Control and Prevention, 2022a). It is also recommended that they drink plenty of fluids, and opt for water over juice or soda. All individuals should also limit their alcohol consumption, maintain a healthy weight, and get regular exercise or physical activity.

Unfortunately, like with sleep, it seems these recommendations are not well known among students and/or young adults (Antwi et al., 2020; Diallo et al., 2021; Khan et al., 2012). In keeping, mental health professionals and medical personnel should work to improve "diabetes literacy," or individuals' knowledge about diabetes mellitus. This can be achieved through the same means recommended for improving "sleep literacy," discussed previously.

Limitations

Though this study has numerous strengths, it is not without limitations. These limitations should be considered, in conjunction, with analyzation of the previously presented results.

The biggest limitation of this study was, without a doubt, the time in which data were collected. As noted before, data were collected from April 2021 to April 2022. This was in the midst of the COVID-19 pandemic, a time when many colleges and universities, including the one this researcher recruited from, were primarily offering online classes. In keeping, there were significantly fewer students on campus to collect data from and there was also, seemingly, less diversity among the students, overall. This resulted in a small, rather non-diverse sample. Specifically, though it was determined that

120 students were needed for this study, only 82 participants could be retained. Among these, only 81 cases were found to be viable for analysis.

Participants were predominantly female (60.49%), White (70.37%), and Freshmen (41.98%). In keeping, results may not be generalizable based on sex, race, and class rank. Additionally, data were collected from only one university located in Louisiana, or the southern United States of America. In keeping, results may not be generalizable based on location. Beyond this, it is noted that all data were collected from students attending classes in-person;

no online data collection was done. In keeping, results may not be generalizable based on certain traits or personality characteristics, specifically, traits of persons who prefer one class format over another (i.e., in-person classes versus online classes) when given the choice between the two.

Another limitation of this study is the manner in which data were collected. All measures used to assess sleep were self-report. In keeping with this, it is understood that certain statistics may be under- or over-reported, as participants are likely to provide what they believe to be socially-desirable responses to certain questions, especially those related to their health.

Recommendations for Future Research

Future researchers should consider rerunning this same study with a larger sample size. They may consider examining if there are differences in results based on sex or race, as well as class rank, geographic location, and other demographic variables like grade-point average (GPA).

Based on previous research, it is hypothesized that there may be differences in the effect that sleep quantity has on visuospatial working memory based on sex (Nakagawa et al., 2016). It is also hypothesized that there may be differences in the effect that sleep quantity and/or sleep quality have on glucose based on sex (Mallon et al., 2005). Beyond this, it is hypothesized that there may be differences in sleep quantity and/or sleep quality, in general, based on race (D. A. Johnson et al., 2019; Kingsbury et al., 2013). It is also hypothesized that there may be differences in glucose levels, in general, based on race (Herman et al., 2007; Zizi et al., 2012).

Future researchers should also consider comparing personality features and/or characteristics of people who opt to take classes in-person versus online, or vice versa, when given the choice. The researcher ponders whether results of this study would have been different had data been obtained from students attending classes in-person, as well as students attending classes online. Currently, it seems there is no data specific as to what "type" of person prefers in-person versus online classes when given the option. It is hypothesized, however, that there are differences. This hypothesis is drawn from research indicating that there may be differences in personality (e.g., level of conscientiousness and/or self-discipline) between those who opt to take summer classes and those who do not (O'Connor & Paunonen, 2007; Price & Bradford, 2010).

Finally, future researchers should consider assessing differences in sleep quantity prior to, during, and after the COVID-19 pandemic. Additionally, future researchers should consider assessing differences in sleep quality prior to, during, and after the COVID-19 pandemic.

Both sleep quantity and sleep quality have, historically, been significant problems for college students and/or young adults (Buboltz et al., 2001; Buboltz et al., 2009; Kelly, 2004; Lund et al., 2010; Pilcher et al., 1997). This research was conducted prior to the COVID-19 pandemic. Results of this study, however, indicated that sleep quantity was, typically, not a problem for college students and/or young adults. Results of this study also indicated that sleep quality may or may not be a problem. This research was conducted during the pandemic.

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APPENDIX A

BIOSAFETY AND RADIONUCLIDE

INSTITUTIONAL REVIEW COMMITTEE

LETTER OF APPROVAL

LOUISIANA TECH
UNIVERSITY

ENVIRONMENTAL HEALTH & SAFETY

MEMORANDUM

TO: Dr. Walter Buboltz, Jr.

FROM: Don Braswell, BRIRC Chair

SUBJECT: BRIRC #44

DATE: April 27, 2021

RE: "Glucose as a Mediator of the Relationship Between Sleep and Cognitive Performance"

This proposal has been reviewed by the BRIRC and is recommended for approval.

The BRIRC recommended approval of this project is for one (1) calendar year from the date of approval. ***This approval was finalized on April 27, 2021 and this project will need to receive a continuation review by the BRIRC if the project, including data analysis, continues beyond April 26, 2022***. The project is to be terminated at that time unless the BRIRC receives a request for continuance.

Modification of an approved project is STRICTLY PROHIBITED without prior BRIRC review and the approval of the Chief Research & Innovation Officer of these modifications. **Request for continuance or protocol modification must be received by the Research & Innovation Office 30 days prior to the renewal date or before initiation of the modified protocol.**

If you have any questions, please contact me at 257-2120.

cc: Dr. Donna Thomas
Dr. Don Schillinger

A MEMBER OF THE UNIVERSITY OF LOUISIANA SYSTEM
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AN EQUAL OPPORTUNITY UNIVERSITY

APPENDIX B

INSTITUTIONAL REVIEW BOARD

LETTER OF APPROVAL

LOUISIANA TECH UNIVERSITY

MEMORANDUM

OFFICE OF SPONSORED PROJECTS

TO: Ms. Mercedes Gremillion and Dr. Walter Buboltz

FROM: Dr. Richard Kordal, Director of Intellectual Property & Commercialization (OIPC)
rkordal@latech.edu

SUBJECT: HUMAN USE COMMITTEE REVIEW

DATE: April 28, 2021

In order to facilitate your project, an EXPEDITED REVIEW has been done for your proposed study entitled:

"Glucose as a Mediator of the Relationship between Sleep & Cognitive Performance"

HUC 21-070

The proposed study's revised procedures were found to provide reasonable and adequate safeguards against possible risks involving human subjects. The information to be collected may be personal in nature or implication. Therefore, diligent care needs to be taken to protect the privacy of the participants and to assure that the data are kept confidential. Informed consent is a critical part of the research process. The subjects must be informed that their participation is voluntary. It is important that consent materials be presented in a language understandable to every participant. If you have participants in your study whose first language is not English, be sure that informed consent materials are adequately explained or translated. Since your reviewed project appears to do no damage to the participants, the Human Use Committee grants approval of the involvement of human subjects as outlined.

Projects should be renewed annually. ***This approval was finalized on April 28, 2021 and this project will need to receive a continuation review by the IRB if the project continues beyond April 28, 2022.*** **ANY CHANGES** to your protocol procedures, including minor changes, should be reported immediately to the IRB for approval before implementation. Projects involving NIH funds require annual education training to be documented. For more information regarding this, contact the Office of Sponsored Projects.

You are requested to maintain written records of your procedures, data collected, and subjects involved. These records will need to be available upon request during the conduct of the study and retained by the university for three years after the conclusion of the study. If changes occur in recruiting of subjects, informed consent process or in your research protocol, or if unanticipated problems should arise it is the Researchers responsibility to notify the Office of Sponsored Projects or IRB in writing. The project should be discontinued until modifications can be reviewed and approved.

A MEMBER OF THE UNIVERSITY OF LOUISIANA SYSTEM

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APPENDIX C

BIOHAZARD PARTICIPANT CONSENT FORM

BIOHAZARD PARTICIPANT CONSENT FORM

Title of Activity:
"Glucose as a Mediator of the Relationship Between Sleep and Cognitive Performance"

Biohazard and/or Radioisotopic Hazard Associated with This Study:
Human Tissue (i.e., Blood)

I, ____, a (circle one: faculty, staff, graduate student, undergraduate student), attest with my signature that I have read the "Application for Use of Biohazardous Agents or Radionuclide" to be submitted for this activity. I fully understand the purpose of and methods used to conduct this activity and have had the opportunity to have all questions about it answered to my satisfaction. I have received all necessary safety training appropriate to this activity and agree to adhere to all safety rules and protocols while so engaged with it. I understand that I shall be immediately dismissed from participation in this activity should I violate any of these. I am a full-time student, faculty, or staff that is over the age of 18 and have successfully completed at least 8 credit hours of chemistry or biological science (including 1 credit hour of lab) and have obtained all the necessary immunizations to participate in this activity (or signed a waiver to this effect). I understand that if I am not an employee of Louisiana Tech University, defined as, "a person who receives compensation from the University for services rendered to the University," that Louisiana Tech University is not able to offer financial compensation nor to absorb the cost of medical treatment should you become injured or become ill as a result of participating in this activity.

____ ________________________
Signature of Participant Date

Contact Information: The supervising faculty for this activity is Dr. Walter Buboltz, Jr. He can be contacted by email at buboltz@latech.edu or by phone at (318) 257-4039.

Members of the Biohazard and Radioisotope Institutional Review Committee may also be contacted if there is a problem that cannot be discussed with the supervising faculty.

APPENDIX D

HUMAN SUBJECTS CONSENT FORM

HUMAN SUBJECTS CONSENT FORM

The following is a brief summary of the project in which you are asked to participate. Please read all information before signing below. You must be 18+ years old to partake in this study.

TITLE: "Glucose as a Mediator of the Relationship Between Sleep and Cognitive Performance"

PURPOSE OF STUDY/PROJECT: The purpose of the present study is to investigate the relationship between sleep, glucose, and cognitive performance among a sample of young adults. This study has been reviewed and approved by the Institutional Review Board.

SUBJECTS: Participants will be undergraduate students from Louisiana Tech University, enrolled in either psychology or nursing classes.

PROCEDURE: Participation in this study is strictly voluntary. Those choosing to participate in this study will be asked to undergo finger-stick glucose testing. A sterile, push-button safety lancet will be used. Testing will be done by the researcher. The researcher will have successfully completed bloodborne pathogen, and HIPAA training. Proof of this will be available upon request. Participants will also be asked to complete two computer-based tasks, and answer a survey packet consisting of four questionnaires. Questionnaires will gather data about basic demographics, and sleep quantity and quality. You may skip any questions or tasks with which you feel uncomfortable answering or partaking in, but are encouraged to complete as many questions and tasks as you can. You may discontinue participation at any time without penalty. It is estimated that participation will take roughly 15 minutes.

BENEFITS/COMPENSATION: Some participants may be offered extra class credit for participation. If extra credit is provided, the instructor must offer an alternative assignment for extra credit for those students who do not choose to participate in this study.

RISKS, DISCOMFORTS, ALTERNATIVE TREATMENTS: Participation in this study does require collection of 1-2 drops of blood, via finger-stick, per participant. Universal precautions will be followed to ensure the safety of participants and researchers alike. Some participants may report experiencing mild discomfort and/or pain during and for a short time after their finger-stick. Computer tasks and questions asked may cause discomfort for some.

If you experience any discomfort as a result of tasks and/or questions or this study in general, please feel free to contact the Louisiana Tech University Office of Counseling Services Center at (318) 257-2488.

**** Louisiana Tech University is not able to offer financial compensation nor to absorb the costs of medical treatment should you be injured as a result of participating in this study. ****

I, ____, attest that I have read and understand the description of the study ("Glucose as a Mediator of the Relationship Between Sleep and Cognitive Performance"), and its purposes and methods. I understand my participation in this research is strictly voluntary and participation or refusal to participate in this study will not affect my relationship with Louisiana Tech University or my grades in any way. Further, I understand that I may withdraw at any time or refuse to answer any questions without penalty. Upon completion of the study, I understand that the results will be freely available to me upon request. I understand that the results of my survey will be confidential, accessible only to the principal investigators, myself, or a legally appointed representative. I have not been requested to waive nor do I waive any of my rights related to participating in this study.

____________________________________ ____________________________

Signature of Participant Date

CONTACT INFORMATION: The principal experimenters listed below may be reached to answer questions about the research, subjects' rights, or related matters.

PROJECT DIRECTOR(S): Mercedes Gremillion Dr. Walter
Buboltz, Jr.
Louisiana Tech University Louisiana Tech
University
EMAIL: mgr018@latech.edu
buboltz@latech.edu
PHONE: (318) 257-3413 (318) 257-4039

Members of the Human Use Committee of Louisiana Tech University may also be contacted if a problem cannot be discussed with the experimenters:

IRB CO-CHAIR(S): Dr. Richard Kordal Gary Stokley
Louisiana Tech University Louisiana Tech
University
EMAIL: rkordal@latech.edu
garystokley@gmail.com
PHONE: (318) 257-2484 (318) 278-3124

APPENDIX E

DEMOGRAPHICS QUESTIONNAIRE

Please provide the following information by filling in the blank or circling the suitable answer.

1. Age in years: __________

2. Sex: Male Female

3. Current year/status in school?

Freshman Sophomore Junior Senior Graduate student Other

4. With which <u>one</u> race do you <u>most</u> identify?

African American American Indian Asian Pacific Islander White Some Other Race

5. Current major (if any) or Undecided: ______________________________

6. Current Grade Point Average (GPA) for the last year of school you completed: __________

7. Have you ever been diagnosed with ADHD? Yes No

8. Are you currently taking any medication for ADHD? Yes No

9. Have you ever been diagnosed with diabetes mellitus (Type 1 or Type 2)? Yes No

10. Are you currently taking any medication for diabetes mellitus? Yes No

11. Is your vision corrected with glasses or contact lenses? Yes No

12. Are you wearing glasses or contact lenses today? Yes No

APPENDIX F

SLEEP HABITS SURVEY

Please answer the three following question for your sleep last night.

1. What time did you go to sleep last night? _______________

2. What time did you wake up today? _______________

3. How many hours of sleep did you get last night? _______________

Please answer the following questions by filling in the blank.

4. During the week, what time do you usually fall asleep? _______________

5. During the week, what time do you usually wake up? _______________

6. On the weekend, what time do you usually fall asleep? _______________

7. On the weekend, what time do you usually wake up? _______________

8. During the week, what is your average amount of sleep each night? _______________

9. During the weekend, what is your average amount of sleep each night? _______________

10. Ideally, I would like to get ______ hours of sleep each night during the week.

11. Ideally, I would like to get ______ hours of sleep each night during the weekend.

12. It usually takes me about ______ minutes to fall asleep on a weeknight.

13. It usually takes me about ______ minutes to fall asleep on a weekend night.

APPENDIX G

SLEEP QUALTIY INDEX

Please answer the following questions to the best of your ability by circling the response that best fits you. If unsure, please give your best guess.

1. Time to fall asleep

   Less than 10 minutes   11-30 minutes   More than 30 minutes

2. Suffered from insomnia during the past three months

   No   Less than 3 days/week   3-7 days/week

3. Difficulties falling asleep during the past three months

   No   Less than 3 days/week   3-7 days/week

4. Disturbed night sleep during the past three months

   No   Less than 3 days/week   3-7 days/week

5. Nocturnal awakenings during the past three months

   No   Less than 3 days/week   3-7 days/week

6. Tiredness in the morning

   Very or Mostly Alert   Don't Know   Very or Mostly Tired

7. Wake up too early in the morning during the past three months

   No   Less than 3 days/week   3-7 days/week

8. Use of sleeping medication during the past three months

   No   Occasionally   At least once per week

APPENDIX H

ADULT SLEEP-WAKE SCALE

Using the choices below, circle how often the following things happened.

During the past month…

1. … I want to stay up and do other things (for example: read, work, or watch TV).

   Never Once in a while Sometimes Quite often Frequently Always

In general…

2. … I have to make myself go to bed.

   Never Once in a while Sometimes Quite often Frequently Always

3. … it is very hard for me to go to bed on time.

   Never Once in a while Sometimes Quite often Frequently Always

4. … I "put off" or delay going to bed.

   Never Once in a while Sometimes Quite often Frequently Always

5. … how long do you usually "put off" or delay going to bed?

   Never Once in a while Sometimes Quite often Frequently Always

When I'm in bed and it is time to fall asleep…

6. … I am not sleepy.

   Never Once in a while Sometimes Quite often Frequently Always

7. … I am unable to settle down.

   Never Once in a while Sometimes Quite often Frequently Always

In general…

8. … I try to make myself go to sleep.

   Never Once in a while Sometimes Quite often Frequently Always

9. … I fall asleep quickly.

   Never Once in a while Sometimes Quite often Frequently Always

10. … how long does it usually take you to fall asleep after "lights out"?

Less than 15 minutes 15-30 min 30-45 min 45-60 min 60-90 min More than 90 minutes

After I fall asleep, but during the night…

11. … I toss and turn in bed.

Never Once in a while Sometimes Quite often Frequently Always

12. … I am very restless.

Never Once in a while Sometimes Quite often Frequently Always

13. … I awaken more than once.

Never Once in a while Sometimes Quite often Frequently Always

In general…

14. … I sleep without arousals or awakenings.

Never Once in a while Sometimes Quite often Frequently Always

15. … how often do you usually wake up during the night?

Never Once in a while Sometimes Quite often Frequently Always

After waking up during the night…

16. …. I have a hard time going back to sleep.

Never Once in a while Sometimes Quite often Frequently Always

17. … I drift back off to sleep easily.

Never Once in a while Sometimes Quite often Frequently Always

18. … I am calm and relaxed.

Never Once in a while Sometimes Quite often Frequently Always

19. … I roll over and go right back to sleep.

Never Once in a while Sometimes Quite often Frequently Always

20. … how long does it usually take you to go back to sleep after waking up during the night?

Less than 5 minutes 5-10 min 10-15 min 15-20 min 20-30 min More than 30 minutes

In the morning, I wake up…

21. … and feel ready to get up for the day.

Never Once in a while Sometimes Quite often Frequently Always

22. … rested and alert.

Never Once in a while Sometimes Quite often Frequently Always

23. … and just can't get going.

Never Once in a while Sometimes Quite often Frequently Always

In general…

24. … I am slow-to-start in the morning.

Never Once in a while Sometimes Quite often Frequently Always

25. … I find it difficult to get out of bed in the morning.

Never Once in a while Sometimes Quite often Frequently Always