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The effects of sleep on neurobehavioral outcomes

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Introduction

The U.S. Centers for Disease Control and Prevention (CDC) (2018) recommends that adults get 7 or more hours of sleep per night. In the United States, however, 32.2% of adults ages 18–24 years sleep < 7 h per night (CDC, 2018). Spending more hours in bed does not mean that individuals have good sleep quality (CDC, 2018; National Sleep Foundation, 2018) because waking during the night, being interrupted while sleeping, or tossing and turning can decrease sleep quality and efficiency. Lack of sleep is associated not only with physiologic consequences (Alkadhi, Zagaar, Alhaider, Salim, & Aleisa, 2013; CDC, 2018; Liu et al., 2013), but may also affect behavioral and cognitive functions (Cunningham, Wheaton, & Giles, 2015; del Angel et al., 2015; Kumar & Chanana, 2014). For example, sleep is linked to alterations in depression and mood (Hoge et al., 2004). Among populations with specific considerations, college students are vulnerable to depression, body weight concerns, and poor sleep quantity and quality practices, which may put them at further risk for mental health problems.

Purpose

The purpose of this study was to determine the effects of sleep time and quality on memory, irritability, and depression measures among college students. We also examined the relationships of sleep time and quality on body mass indices (BMI) and serotonin, cortisol, and glucose lab values.

Background

Sleep and memory

Previous work on sleep and memory has yielded mixed results. Some studies have indicated that decreased sleep time can negatively affect memory (del Angel et al., 2015; Frenda & Fenn, 2016). For example, in a study of 13 college students, sleep restriction to 4 h per night for 5 days, as measured by sleep diaries and sleep scales, negatively affected working memory tasks (del Angel et al., 2015). In a study involving actigraphs and the Pittsburgh Sleep Quality Index (PSQI), a self-report of sleep and sleep reduction measures, working memory deficits developed among 18 young adults who were restricted to 4 h of sleep for five consecutive nights (Gosselin, De Koninck, & Campbell, 2017).

In contrast, 20 students ages 18–24 years performed similarly in a working memory study whether they had 7 h of sleep per night or > 7 h per night (Yeung, Lee, Cheung, & Chan, 2018). In another study, 24 young adults restricted to 4 h of sleep per night for 4 nights, were measured using actigraphy and showed no significant impairments in working memory (Drummond, Anderson, Straus, Vogel, & Perez, 2012). Another group found that memory did not change significantly among 64 college students after a night of sleep deprivation when compared to a normal night of sleep (Patrick et al., 2017). Among these studies, memory tasks and sleep times were not the same, which could have contributed to the inconsistent results. In addition, the sleep measures ranged from self-report to actigraphy; thus making comparisons of the findings difficult.

Sleep, irritability, and depression

Sleep also is thought to be associated with irritability, which some authors refer to as "mood." Studies on sleep and irritability (mood) have yielded inconsistent results (Gobin, Banks, Fins, & Tartar, 2015; Lo, Ong, Leong, Gooley, & Chee, 2016). For example, among 154 undergraduate college students, poor sleep quality based on the PSQI was associated with greater mood disturbances (Gobin et al., 2015). However, in another study, 56 adolescents and young adults restricted to 5 h of sleep per night for 7 nights had no significant change in negative mood (irritability) (Lo et al., 2016). Few reports are available that focus on how sleep affects mood/irritability in college students; and published results are inconsistent.

Additional research also has revealed a relationship between poor sleep and depression (Gobin et al., 2015; Wallace, Boynton, & Lytle, 2017; Zhang, Peters, & Chen, 2018). In a study of 78 individuals who completed the PSQI, and Actiwatch 2™ (Minimitter, Philips Respironics, Andover, MA) actigraphs to measure sleep quality and quantity, results indicated an association of poor sleep quality or sleep disturbances with depression (Klumpp et al., 2017). Additionally, Celik, Ceylan, Unsal, and Cagan (2018) conducted a study of 445 college students using PSQI measurements and found that poor sleep quality was tied to a 3.28-fold

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increased risk for depressive symptoms. Although relationships between decreased sleep and poor sleep efficiency and depression have been noted in the literature, the exact amounts of sleep deprivation are often unclear.

Sleep and biochemical lab data

Sleep plays an important role in the homeostasis of normal glucose metabolism, and glucose in necessary for neurologic functions (Donga et al., 2010). In physiological studies, the link between glucose and cortisol fluctuations and sleep duration and sleep efficiency is unclear (Donga et al., 2010; van Leeuwen et al., 2010). For example, in one study, glucose levels among 16 young male participants changed little or not at all whether they slept 8 or 4 h, as measured by sleep polysomnography (Cedernaes et al., 2016). However, in a study of 23 healthy young men, glucose levels increased (along with increased diabetes risk) with decreased sleep (van Leeuwen et al., 2010).

The hormone cortisol is important in regulating physiology (Omisade, Buxton, & Rusak, 2010). In studies examining cortisol levels, one night of sleep restriction was associated with changes in hormone levels in a group of 15 young, healthy women (Omisade et al., 2010). However, Klinenberg et al. (2013) and Donga et al. (2010) noted no significant differences in cortisol levels with reduced sleep in comparison to increased sleep duration. Increased cortisol has also been associated with increased stress (Born & Wagner, 2009), and sleep efficiency has significant effects on cortisol responses during acute psychosocial stress (Bassett, Lupis, Gianferante, Rohleder, & Wolf, 2015).

Serotonin is one of several neurotransmitters involved in the sleep–wake cycle (Davies et al., 2014); and in a study of healthy young males, serotonin was elevated after 24 h of wakefulness (Davies et al., 2014). Serotonin is also closely linked to depression (Cowen & Browning, 2015; Klumpp et al., 2017). Although the literature indicates significant variations in sleep time when glucose, cortisol, and serotonin levels were accounted for; the reported results were inconsistent.

Sleep and body mass index (BMI)

Some study results have indicated possible relationships when body weight (often calculated as BMI) and sleep were studied (Hargens, Kaleth, Edwards, & Butner, 2013; Liu et al., 2013; Smith et al., 2014). However, other studies have associated insufficient sleep and sleep disturbances with higher BMIs and obesity (Beccuti & Pannain, 2011; Krističević, Štefan, & Sporiš, 2018; Quick et al., 2016; Vargas, Flores, & Robles, 2014). Also, in a study of college students evidence showed that being overweight or obese resulted in increased depressive or mental health disorders (Odlaug et al., 2015). While the literature indicates possible bidirectional associations between obesity and poor sleep and vice versa; our intent was to correlate BMI levels with sleep times and sleep quality scores to determine possible relationships with the neurobehavioral measures of cognitive memory, depression, or irritability.

In summary, previous study results have been inconsistent about the associations of sleep quantity and quality with memory, depression, and irritability measures among young adults (Ballesio, Cerolini, Ferlazzo, Cellini, & Lombardo, 2018; del Angel et al., 2015). Given, the varying effects of sleep on glucose, cortisol, and serotonin levels and of BMIs on sleep quantity and quality, we further examined these measures for their neurobehavioral effects. Although partial sleep deprivation and poor sleep efficiency are common in today's society (CDC, 2018), these aspects of sleep have been studied less than total sleep deprivation (Gosselin et al., 2017).

Methods

Study design

This descriptive, correlational study examined the effects of good and poor sleep times and sleep efficiency on cognitive memory, depression, and irritability among young adult study participants. Each participant's hours of sleep and sleep efficiency scores were recorded using sleep actigraphy for a 4-day week over 12 study weeks. The participants' BMI, serotonin, salivary cortisol, and serum glucose lab tests were also measured.

Operational definitions

Sleep time was defined as the hours slept per night when measured using sleep actigraphy. Partial sleep deprivation was considered to be < 6 h of sleep per night, insufficient sleep was defined by 6 to 7.5 h per night, and good sleep was > 7.5 h of sleep per night.

Sleep efficiency was defined as the percentage of time spent sleeping while in bed. Sleep efficiency was measured using sleep actigraphy. A sleep efficiency score of < 85% was considered to indicate poor sleep efficiency. A sleep efficiency score above 85% was considered normal sleep efficiency, and a score of 90% or higher was considered to be good sleep efficiency (Lemma et al., 2012; Shirvastava, Jung, Saadat, Sirohi, & Crewson, 2014).

Cognitive memory, the ability to recall relevant information while completing another task, was measured using the Sternberg Item Recognition Test. Response time increases were measured linearly with a memory set slope of 35–40 ms per additional item in memory (Sternberg, 1966).

Depression, defined as persistent feelings of sadness or loss of interest that can interfere with daily function, was measured by Zung's Self-Rating Depression Scale (SDS). An index score of 49 or less on the SDS was considered to indicate no depression; a score of 50–59 defined mild to moderate depression; a score of 60–69 indicated moderate to severe depression; and an index score of 70 or greater was considered to classify severe depression (Zung, 1965).

Irritability, an emotional process characterized by a proneness to experiencing negative affective states such as anger, annoyance, and frustration (Barata, Holtzman, Cunningham, O'Connor, & Stewart, 2016), was measured by Zung's Affective Irritability Subscale (Zung, 1979). Cut-off scores for our study were not determined.

BMI was determined by measuring weight in kilograms and dividing the weight by the square of height in meters. Using CDC guidelines: below 18.5 is underweight, 18.5–24.9 is a healthy weight, 25.0–29.9 is overweight, and 30.0 or above is obese (CDC, 2017a).

Population description and sample selection plan

Participants were randomly selected from a pool of 300 Midwestern university students who volunteered within the first 2 weeks of the academic term. To avoid undue influence, course faculty did not recruit study participants. The researchers described their study, provided consent forms, and answered questions about the study. Participants were also informed that not everyone who consented to participate might be randomized for selection into the study. Inclusion criteria included age 18 to 30 years; ability to read, understand, and speak English; taking no medications; and having no diagnosed medical condition.

A power analysis was performed using Borenstein, Rothstein, and Cohen's (2001) “Power & Precision” software program to determine the needed sample size. The power calculation was based on using correlational and regression analyses. The possible effects of sleep on behavior were based on information gathered from similar published studies (Lindseth, Lindseth, & Thompson, 2013; Lupien, Gillin, & Hauger, 1999). Using a “medium” effect size with statistical power set at 0.80 and an alpha of 0.05, a sample of 70 participants was estimated as meeting statistical power. An oversampling of 14 (20%) additional participants were randomly selected for entry into the study to allow for possible attrition. Four participants withdrew from the study, primarily because of scheduling constraints. Of the 84 participants selected through a random drawing of names from a container, 80 completed the study.

Study protocols

Participants randomly selected from the pool of eligible and consenting volunteers met with the investigators the week after their selection for the study. Health assessments, demographic data, and anthropometric measurements were recorded for each participant, and study expectations and protocols were reviewed. Each week, participants verified they had followed study protocols and were reminded they could be dismissed from the study for non-compliance of study protocols.

During each of the study weeks, participants were assessed for height, weight, and health status. Sleep data recorded using actigraphy were downloaded for analysis on the last day of each study week. To ensure that participants' nutrient intakes met U.S. dietary guidelines, meals were provided for and eaten by all of the participants in the study dining room. This helped prevent unplanned effects that could result from poor nutritional intake. Between-meal snacks were also provided. Caffeine consumption was limited to 100 mg per day to avoid possible stimulating and confounding effects. Following the last night of sleep for the week, depression, irritability, and memory measures were completed in addition to recording each participant's sleep for the week. Laboratory test samples were also collected.

Both the University's Institutional Review Board and the U.S. Army Human Research Protections Office (the funding agency) approved the study protocols. Participants received a stipend of $25 per study week for their time and contribution to the body of scientific knowledge. They also agreed to adhere to prescribed study protocols but were assured their participation was voluntary and that refusing to participate would not carry any consequences. Participants were also assured that all study information was confidential and would be reported as aggregate data.

Study measures and methods

The research team prospectively collected data using study tools that had been psychometrically analyzed and validated by the original authors. Protocols were pilot-tested at the research site, and all instruments were confirmed to be reliable with a significance level of $p \leq 0.05$.

Demographic and health data

Demographic and anthropometric data were collected for the study. The demographic data included the participants' ethnicity, age, gender, and educational levels. Anthropometric measurements were taken using a wall-mounted height board to measure height and a balance-beam scale to weigh each participant on the first and last days of each study week. The Quetelet Index (kg/m^2) (height-to-weight ratio) was used to determine BMI.

Baseline health assessments identified conditions that might affect study outcomes, such as endocrine, cardiac, respiratory, metabolic, gastrointestinal, urinary, sensory, integumentary, and neurological disorders. A diagnosis of a medical or psychological condition was an exclusion criterion for the study.

Biochemical/lab test samples were drawn and analyzed for possible relationships between sleep and glucose, cortisol, and serotonin levels. Serum glucose samples were drawn; and salivary cortisol samples were taken using side cheek swabs. Because morning cortisol levels are considered a reliable biological marker of adrenocortical activity (Pruessner et al., 1997), salivary cortisol samples were taken in the morning. Trained/certified medical personnel performed the lab sampling and testing, following CLIA (Clinical Laboratory Improvement Act) standards to enhance the reliability and validity of the test results.

Sleep measurements

Sleep time and efficiency were measured using the ActiGraph Actiwatch Spectrum® Sleep Watch, and sleep quality was measured using the PSQI. Assessments were recorded at the end of each study week.

Actiwatch devices had a reliability coefficient of 0.92 and a validity of 0.99 (Tryon, 2005). ACT Millennium Graphs Interactive Software (Version 2 K3.0) was used to analyze the actigraph sleep data. Participants wore the Actiwatches® continuously during the study, and the devices recorded the following data: minutes of sleep, as the total number of minutes slept in a study week; and sleep efficiency, as the number of minutes slept per night, divided by the total length of time spent in bed after "lights off" (Royal Philips; Bend, OR).

Participants completed the **PSQI** each week (Buysse, Reynolds 3rd, Monk, Berman, & Kupfer, 1989; Luyster et al., 2016), using a Likert scale for the 19 items, which yielded seven component scores with a range of 0 (good sleep efficiency) to 5 (poor sleep efficiency). Summing all seven scores gave a global sleep score for each participant (Buysse et al., 1989). A PSQI score > 5 indicates poor sleep efficiency (Shirvastava et al., 2014). The test–retest reliability of this questionnaire was reported as $r = 0.85$ over 4 weeks (Buysse et al., 1989).

Neurobehavioral measurements

This study measured working memory using the Sternberg Item Recognition Test (Sternberg, 1966). As noted, participant depression and irritability were also measured using the SDS.

The **Sternberg** test has been used to test both short-term and working memory. A set of two, four, or six digits is presented to participants on a computer screen, followed by presentation of a single digit. Participants were asked if the single digit was part of the original set of numbers, and the more rapid the response (in milliseconds), the better the score. In the current study, error rates were also recorded. This tool has reported test–retest reliability coefficients as high as 0.95 in short-term memory studies (Sternberg, 1966).

The **SDS** contains 20 scored items related to the most common characteristics of depression. In completing the SDS, participants described their depression for the past 24 h with scores ranging from 1 (least depressed) to 4 (most depressed) (Zung, 1965, 1986). An index score was derived by dividing the patients' total sum on the 20 items by the maximum score of 80. The resulting decimal is multiplied by 100. The lower the score, the less reported anxiety; likewise, the higher the score, the more reported anxiety. Score cutoffs for no, mild–moderate, moderate–severe, and severe depression are defined above. In a study of depression measurements of 415 undergraduate students, the Zung SDS had a reliability alpha of 0.85 (Campbell, Maynard, Roberti, & Emmanuel, 2012).

Irritability was measured using an affective irritability subscale from the SDS (Sakamoto, Kijima, Tomoda, & Kambara, 1998; Zung, 1965). The reviewer asked 20 questions, with responses rated from 1 (least irritable) to 4 (most irritable). An index score is derived by dividing the patients' total sum on the 20 items by the maximum score of 80. The resulting decimal is multiplied by 100. The lower the score, the less reported anxiety; likewise, the higher the score, the more reported anxiety. A score of 45 or above indicates anxiety. A reliability coefficient of 0.86 was determined in previous studies with a similar study sample (Lindseth & Petros, 2016).

Data entry and analysis

Frequencies were measured and recorded from the demographic and anthropometric measures. Participants removed their Actiwatches® on the final day of each study week, and the collected data were downloaded for analysis. Each participant's minutes of sleep and sleep efficiency ratios were recorded from the sleep actigraphs. Upon completion of the study, the sleep data were analyzed and compared to participants' self-recorded sleep records. Working memory, irritability, and depression measures were recorded. Final sleep measurements were calibrated to determine the impact of participant sleep on memory scores. Serotonin, serum glucose, and salivary cortisol lab measures were also recorded, as was health status. Study data were entered and analyzed using the SPSS statistical program. Participant demographic, neurobehavioral, biochemical lab results, and sleep data were analyzed using correlational and regression analyses. The statistical significance was set at $p < .05$.

Partial correlations are presented in the tables to show the effect of each individual variable as it was entered into the equation while controlling for the other independent variables. The cumulative R^2 is shown for each variable as it was entered into the equation, along with the corresponding R^2 change value. The last column of the table displays the standardized beta coefficients that explain the relative weights of the independent variables as they were entered into the regression equation while controlling for the other independent variables in the equation.

Results

Demographic characteristics

Demographics of the 80 randomly selected participants included 68 Caucasians, one Native American, five Hispanic Americans, four Asian Americans, and two African American participants. The mean age of the participants was 20.7 years (standard deviation [*SD*] = 2.0). They averaged 13.9 years of education (*SD* = 1.0) with an average BMI of 24.4 (*SD* = 3.9). Age and years of education were not significantly related to neurobehavioral variables.

Sleep, neurobehavioral, and lab test correlations

Upon completion of each study week, sleep actigraphs were used to quantify the sleep hours and minutes and sleep efficiency ratios for the participants. The PSQI sleep-quality data were correlated with the cognitive, behavioral, lab test, and sleep results. Decreased sleep efficiency was significantly associated with increased irritability ($r = -0.30$, $p < .001$), increased depression ($r = -0.40$, $p < .01$), and increased BMI ($r = -0.32$, $p < .01$). In addition, participants who had poorer PSQI sleep quality had significantly increased depression ($r = 0.41$, $p < .001$) and increased irritability ($r = 0.29$, $p < .01$). None of the biochemical lab values were significantly associated with time slept per night or sleep efficiency (Table 1).

Relationships among neurobehavioral, lab data, and sleep measures

To determine if sleep affected cognitive memory, depression, or irritability, three regression models were constructed with BMI, cortisol, serotonin, glucose, sleep efficiency, and PSQI sleep quality as independent variables. The variables were entered into regression equations based on their significance levels in previous studies. The anthropometric variable (BMI) was entered into the equation first. Next, the physiological lab variables (cortisol, serotonin, and glucose) were entered into the cognition/sleep, depression/sleep, and irritability/sleep models, respectively. Finally, the sleep efficiency and PSQI sleep-quality variables were entered. Then cognition, depression, or irritability scores were entered as the dependent variables.

The effects of sleep were significantly associated with irritability (Table 2). The strongest predictors for the effects of sleep on irritability were poor PSQI sleep quality ($\beta = 0.36$; $p < .0001$), poor sleep efficiency ($\beta = -0.27$; $p = .01$), and increased BMI ($\beta = 0.21$, $p \leq .05$). Results of the regression analysis indicated that these variables accounted for 28% of the variance in predicting increased levels of irritability.

The effects of sleep on depression also were significant (Table 3; $p < .01$). The strongest predictors for the effects of sleep on depression were poor PSQI sleep quality ($\beta = 0.29$; $p = .003$), decreased sleep efficiency ($\beta = -0.33$; $p = .001$), and higher BMI ($\beta = 0.28$, $p = .006$). Results of the regression analysis showed that these variables accounted for 34% of the variance in predicting increased levels of depression.

The independent variables were entered into the cognitive memory regression equation in the following order: BMI, glucose, PSQI sleep quality, and sleep efficiency. As shown in Table 4, there was a non-significant ($p > .05$) hierarchical regression on the effects of sleep on cognitive memory.

Discussion

Sleep quality, irritability, and depression

In our study, significant predictors for increased depression and irritability resulted when participants had poor PSQI sleep quality, poor sleep efficiency, and higher BMI's. These findings were consistent with those of other studies (Celik et al., 2018; Cunningham et al., 2015; Gobin et al., 2015; Lukowski & Milojevich, 2015). Poor sleep quality was identified as a complaint affecting up to half of college students in a systematic review of sleep and depression of college students (Dinis & Bragança, 2018). Also, in a study of 445 college students, a decrease in sleep quality led to a more than three-fold increase in the risk of depression (Celik et al., 2018); and in the Gobin et al. (2015) study of 154 undergraduate students there was a relationship between poor sleep quality and depressive symptoms, anxiety and disturbed mood (irritability). In Lukowski and Milojevich (2015), university students completed questionnaires designed to assess sleep quality and temperament. An association between poor sleep quality and increased negative temperament was found. The relationship between poor sleep quality is not just restricted to depression but has also been associated with major depression to include next-day suicidal ideation (Littlewood et al., 2019). Thus, the importance of promoting good sleep quality in young adults because of the serious consequences related to depression and higher risk of suicide.

The age ranges in these previous studies were broader than those in our study. For example, Cunningham et al. (2015) and Liu et al. (2013) studied participants ages 18 to 75 years and Roberts and Duong (2014) included participants ages 18 to 64 years. In a prospective study of 3134 adolescents ages 12–18 years, Roberts and Duong found a significant relationship of poor sleep quality and depression. Their participants in the 18–19–year age group were similar in age to the young adults in our study. Given that most of the studies we identified in the literature had participants up to age 75 years, more research should be focused on high-risk young adult groups who tend to have higher levels of suicidality (CDC, 2017b).

We also controlled for the educational levels of our participants, who were required to be in their third semester of study. This criterion was included to ensure a limited effect of total years of education on study outcomes.

Sleep and BMI

In our study, higher BMI levels correlated significantly with poorer sleep efficiency scores. While some studies have noted significant relationships among decreased sleep or poor sleep and higher BMI levels (Beccuti & Pannain, 2011; Krističević et al., 2018; Quick et al., 2016;

Table 1
Sleep, cognition, depression, irritability and physiological intercorrelations.

Variable	Sleep efficiency	Sleep time	PSQI sleep quality	Depression	Irritability	Working memory	Serotonin	Cortisol	Glucose	BMI
Sleep efficiency	1.0									
Sleep time	−0.05	1.0								
PSQI sleep quality	−0.22	0.03	1.0							
Depression	−0.40***	0.12	0.41**	1.0						
Irritability	−0.30***	0.04	0.29**	0.81**	1.0					
Working memory	0.20	−0.11	−0.21	−0.07	−0.02	1.0				
Serotonin	0.04	−0.12	0.07	0.10	0.08	0.06	1.0			
Cortisol	−0.15	0.06	−0.14	0.10	−0.06	0.04	0.00	1.0		
Glucose	−0.13	0.02	0.16	0.10	−0.04	−0.11	−0.05	0.11	1.0	
BMI	−0.32***	−0.04	0.14	0.38**	0.29**	0.07	−0.20	0.15	0.18	1.0

Note: (n = 80).
* $p \leq .05$.
** $p \leq .01$.
*** $p \leq .001$.

Table 2
Hierarchical regression for sleep effects on irritability.

Predictor variables	Partial correlation	R^2	R^2 change	Beta coefficients	Sig.
BMI	0.23	0.08	0.08	0.21*	0.05
Cortisol	−0.12	0.10	0.02	−0.12	0.24
Sleep efficiency	−0.28	0.15	0.05	−0.27**	0.01
PSQI sleep quality	0.39	0.28	0.13	0.36***	0.0001

R^2 = 0.28, F(4,75) = 7.25, p = .0001.
* $p \leq .05$.
** $p \leq .01$.
*** $p \leq .001$.

Table 3
Hierarchical regression for sleep effects on depression.

Predictor variables	Partial correlation	R^2	R^2 Change	Beta coefficients	Sig.
BMI	0.31	0.14	0.14	0.28**	0.006
Serotonin	0.16	0.17	0.03	0.13	0.17
Sleep efficiency	−0.36	0.26	0.09	−0.33***	0.001
PSQI sleep quality	0.33	0.34	0.08	0.29**	0.003

R^2 = 0.34, F(4,75) = 9.71, $p \leq .001$.
* $p \leq .05$.
** $p \leq .01$.
*** $p \leq .001$.

Table 4
Hierarchical regression for sleep effects on cognition.

Predictor variables	Partial correlation	R^2	R^2 Change	Beta coefficients	Sig.
PSQI sleep quality	−0.21	0.04	0.04	−0.21	0.07
Sleep efficiency	0.24	0.06	−0.02	0.13	0.24
BMI	0.29	0.08	0.02	0.17	0.16
Glucose	0.30	0.09	−0.01	−0.09	0.46

R^2 = 0.04, F(4,76) = 0.85, p = .07.
Significance: $p \leq 0.05$.

Vargas et al., 2014), other studies examining the relationship of body weight and its effect on sleep had results similar to those in our study (Hargens et al., 2013; Liu et al., 2013; Smith et al., 2014). The analyses in our study also showed that increased BMI's in healthy young adults were tied to reduce sleep quality and significantly increased depression and irritability. In another study of college students, increased body weight was associated with irritability and perceptions of more serious sleep-related conditions such as sleep-apnea. Thus, the researchers suggested weight management as a preventive measure (Smith et al., 2014). These results help support the importance of maintaining a healthy BMI to enhance good-quality sleep and sleep efficiency outcomes.

Sleep time, irritability, and depression

We found no significant associations of time slept with irritability or depression. This result contrasts with those of other studies (Gobin et al., 2015; Wallace et al., 2017; Zhang et al., 2018). Shokri-Kojori et al. (2018), for example, reported decreased mood (irritability) levels following sleep deprivation. Published findings indicate a bidirectional association of sleep time and depressed mood among college students (Carskadon, Sharkey, Knopick, & McGeary, 2012); however, our results differed from this conclusion. Also, the exact amount of sleep reduction found in studies was not well associated with depressive symptoms (Gobin et al., 2015).

Sleep and memory

We also found no significant associations of cognitive memory with sleep time, sleep efficiency, or PSQI sleep quality. Our results are not consistent with those of del Angel et al. (2015), who used auditory and visual cognition testing to assess 13 undergraduate students after a sleep reduction of sleeping only 4 h a night for 5 days. They found a decrease in memory on the fifth day of sleep reduction. Of interest and consistent with our study results, in another study of 12 students whose sleep was reduced to 4 h for one night, accuracy and speed task performance did not change significantly (Gosselin et al., 2017). Also, in a different study of 22 adults (ages 21–30 years) randomly assigned to 4 or 8 h of sleep for 9 nights, participants ages 18–30 years who had less sleep (only 4 h of sleep) showed no change in working memory (Casement, Broussard, Mullinton, & Press, 2006). This is similar to our findings. Because the tasks in these studies involved different cognitive processes, decreased sleep times may vary in their effects on different memory skills. It is also noteworthy that previous studies did not have a common set point for sleep reduction, timing, or length of study. Further research is needed to establish the associations of specific cognitive testing and sleep time.

Sleep and biochemical lab data

In our study participant sleep times showed no association with serotonin, glucose, or cortisol levels. Similarly, there were no significant relationships between BMI and time slept per night. This result contrasts with those of Quick et al. (2016), who noted a significantly higher BMI with shorter sleep duration.

According to Fernstrom (2012), fluctuations in serum serotonin levels are a precursor to sleep disturbances. Low serotonin levels can also result in increased irritable behaviors, which may be a secondary consequence of poorer sleep (Born & Wagner, 2009; Markus et al., 2005). Although Ferrar Jr., Bisson, and French (1995) have suggested that increased serotonin levels may induce sleep, our study showed no significant relationships of serotonin with sleep time, sleep efficiency, or PSQI sleep-quality scores. In some patients, low serotonin may result in increased depression (Cowen & Browning, 2015).

We also found no effect of poor sleep times on cortisol levels, similar to the results of Klinenberg et al. (2013), who reported no change in morning cortisol levels with sleep restriction. Omisade et al. (2010), however, found reduced morning cortisol levels and increased afternoon cortisol levels with decreased sleep. Our definition of decreased sleep was < 6 h per night, whereas Omisade et al. (2010) restricted sleep to 3 h per night for their study. Physiologically, these changes may be explained by fluctuations in cortisol levels arising from circadian rhythm shifts or sleep interruptions (Klinenberg et al., 2013; Omisade et al., 2010).

Limitations

Sleep times and sleep efficiency measures were recorded and calculated with actigraph sleep watches, but polysomnography might produce more reliable sleep recordings (Marino et al., 2013). However, given that the purpose of our study was to investigate free-living participants in a non-laboratory setting, we felt that Actiwatches® could achieve sufficient accuracy for our analyses.

Some of the results with our lab measures suggest conclusions that differ from those of other studies (Gobin et al., 2015; Wallace et al., 2017; Zhang et al., 2018). Lack of repeated sampling of lab values also may also be a limitation of our study because values can change throughout the day (Omisade et al., 2010).

Conclusion and implications

Our study revealed significant associations between decreased sleep efficiency, poorer PSQI sleep quality, increased BMI, and increased depression and irritability. Although we found that poor sleep efficiency had significant neurobehavioral effects (irritability and depressed performance) in healthy individuals, the literature reports mixed results for correlations of sleep time and sleep efficiency with physiological outcomes in similar populations (CDC, 2018; Haba-Rubio et al., 2015). Our analyses showed an association of increased BMI levels with reduced sleep quality and significantly increased depression and irritability. Poor sleep quality and efficiency and decreased sleep quantity were also significantly related to increased risk for conditions such as poor glucose metabolism, and type 2 diabetes (Bruno et al., 2013; Cappuccio, D'Elia, Strazzullo, & Miller, 2010), further validating the importance of maintaining a healthy BMI. However, we found no significant associations between amount of sleep and neurobehavioral measures. Overall, consistent with our results, sleep quality rather than sleep quantity in young adults seems to be key to maintaining good mental and physical health (Vargas et al., 2014; Wallace et al., 2017).

Of concern is that sleep deprivation is becoming more common, and some findings indicate that lack of sleep can have negative neurobehavioral and physiological implications. Further study is warranted given the conflicting results in the literature coupled with our findings on the impact of sleep time and sleep efficiency and the clinical implications. Clinical applications include the need for healthcare providers to offer more education and encouragement to college-age students about the importance of getting good-quality sleep. Interventions to improve and promote sleep should be implemented to support the adoption of good sleep routines. We recommend challenging faculty, particularly in health-related professions (such as nursing, counseling, and social work), to stress the importance of sleep to new college students during orientation sessions.

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