Published in final edited form as:

Clin Neuropsychol. 2015 ; 29(6): 863–875. doi:10.1080/13854046.2015.1096961.

Body Mass Index Moderates the Association between Sleep Quality and Vigilance on a Test of Inhibitory Control

Rachel Galioto^{1,2}, William V. Lechner³, Jonah Meister¹, Micah Wright¹, John Gunstad¹, and Mary Beth Spitznagel¹

¹Department of Psychological Sciences, Kent State University, Kent, OH, USA

²Department of Psychiatry, Rhode Island Hospital, Providence, RI, USA

³Center for Alcohol and Addiction Studies, Brown University, Providence, RI, USA

Abstract

Objective—Sleep problems are common among college students and related to numerous adverse outcomes including impaired cognitive performance. Obesity may confer an elevated risk of cognitive deficits with poor sleep given its relationship with poorer sleep quality and impaired cognition. This study examined whether the relationship between reduced sleep quality and poorer vigilance and inhibitory control were moderated by elevated body mass index (BMI).

Method—Participants were 85 college students who completed a computerized task of inhibitory control that required vigilance (go/no-go [GNG] task) and the Pittsburgh Sleep Quality Index, a measure of sleep quality.

Results—Poor sleep quality was observed in 63.5% of the sample and was related to more omission errors on the GNG task and increased BMI. Results further revealed that BMI moderated the relationship between sleep quality and performance on the GNG task such that individuals in the severely obese range of BMI had more omission errors with poorer sleep quality, while there was no association between sleep and GNG performance among normal weight and overweight individuals.

Conclusions—These findings highlight the likely contribution of obesity to decreased vigilance with poor sleep. Future research is needed to confirm these findings using objective measures of sleep quality (e.g., actigraphy, polysomnography).

Keywords

Sleep quality; College students; Vigilance; Obesity; Cognition

Insufficient sleep is common among college students, including short duration, irregular sleep schedules, and reduced sleep quality (e.g., Chang & Chen, 2014; Lund, Reider, Whiting, & Prichard, 2010; Vargus, Flores, & Robles, 2014). The effects of sleep

Address Correspondence to: Rachel Galioto, Department of Psychiatry, Rhode Island Hospital, 110 Lockwood St., Providence, RI 02903, USA. rachel_wiedemann@brown.edu.

DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

disturbances in this population are substantial, such as increased risk of mental illness (Byrd et al., 2014), impaired social relationships (Carney, Edinger, Meyer, Lindman, & Istre, 2006), and reduced academic performance (Curcio, Ferrara, & De Gennaro, 2006; Gaultney, 2010).

Not surprisingly, sleep problems are also related to worse cognitive performance. Experimental studies have demonstrated a link between sleep deprivation and restriction and poorer performance on measures of attention and executive functions. For example, one study in college students demonstrated that following 24 h of sleep deprivation, participants in a sleep-deprived condition performed more poorly on a critical reasoning task compared to non-sleep-deprived individuals (Pilcher & Waters, 1997). In another study, chronic sleep restriction (i.e., <6 h) was correlated with reduced vigilance, working memory, and processing speed (Van Dongen, Maislin, Mullington, & Dinges, 2003). Recent work found that restricted sleep (approximately 3 h of sleep) was related to greater propensity toward impulsive risk-taking behavior (Rossa, Smith, Allan, & Sullivan, 2014).

In addition to experimentally manipulated sleep deprivation paradigms, observational studies have also demonstrated a link between inadequate, irregular, and disrupted sleep and cognition. Students who obtain proper and consistent sleep are better academic performers (Curcio et al., 2006; Kelly, Kelly, & Clanton, 2001), and research demonstrates associations between low sleep quality and quantity with reduced attention and executive control (Dahl, 1996; Jones & Harrison, 2001; Vriend et al., 2012) and a link between sleep loss and reduced learning (Curcio et al., 2006). Recent work in healthy young adults revealed a positive correlation between subjective sleep quality and performance on indices of attention and executive function (Benitez & Gunstad, 2012). Additionally, one study among undergraduate students demonstrated that poorer self-reported sleep quality was associated with less cognitive control over negative stimuli (Vanderlind et al., 2014).

The mechanism for reduced cognitive function with poor sleep is not fully clear, but in light of experimental and observational research linking disrupted sleep to attention and executive functions, a vulnerability of the prefrontal cortex has been suggested as the underlying neuroanatomical substrate involved (Curcio et al., 2006). In a study with adolescents, poorer sleep quality was related to decreased activation in the dorsolateral prefrontal cortex during a response inhibition task which was related to poorer vigilance and greater decision-making complacency (Telzer, Fuligni, Lieberman, & Galván, 2013). Similarly in adults, 24 h sleep deprivation was associated with a decline in sustained task-related activation in the prefrontal cortex (Chuah, Venkatraman, Dinges, & Chee, 2006).

There is also a strong link between poor sleep and obesity in adolescents and young adults (Gangwisch, Malaspina, Boden-Albala, & Heymsfield, 2005; Gupta, Mueller, Chan, & Meininger, 2002; Vargas et al., 2014; Yeh & Brown, 2014). A number of longitudinal studies have demonstrated that chronic sleep restriction predicts subsequent weight gain and obesity (e.g., Chaput, Després, Bouchard, & Tremblay, 2008; Gangwisch, Malaspina, Boden-Albala, & Heymsfield, 2005; Hasler et al., 2004). Possible mechanisms for this relationship may include alterations in neuroendocrine and metabolic hormones, glucoregulation, and waking behavior such as physical inactivity and poorer dietary patterns (as reviewed by Magee,

Huang, Iverson, & Caputi, 2010). Research has demonstrated that poor sleep quality alters hormones involved in energy balance regulation and appetite control which could lead to increased food intake (Al-Disi et al., 2010; Gonnissen, Hursel, Rutters, Martens, & Westerterp-Plantenga, 2013).

The strong link between poor sleep and obesity is particularly concerning given that obesity is also independently related to cognitive deficits, particularly in the areas of attention, executive function (such as response inhibition, working memory, planning, and ability to shift and maintain cognitive set), and memory (Fergenbaum et al., 2009; Gunstad, Paul, Cohen, Tate, & Gordon, 2006; Gunstad et al., 2007; Nilsson & Nilsson, 2009; Sabia, Kivimaki, Shipley, Marmot, & Singh-Manoux, 2009). Moreover, recent work demonstrates a link between obesity and slower reaction time on a task of inhibitory control requiring vigilance, even among otherwise healthy young adults (Calvo, Galioto, Gunstad, & Spitznagel, 2014; Maayan, Hoogendoorn, Sweat, & Convit, 2011), and reduced prefrontal cortex volume, specifically in the orbitofrontal aspect, has been observed in obese but otherwise healthy young adults, as well (Maayan et al., 2011). Although these findings in healthy young samples suggest a cognitive vulnerability that is independently associated with obesity, health factors and medical comorbidities of obesity, including sleep apnea and type 2 diabetes (Bray, 2004), psychiatric conditions (Mansur, Brietzke, & McIntyre, 2015), physical inactivity, and poorer dietary patterns (Liang, Matheson, Kaye, & Boutelle, 2014), may be a more common presentation for individuals with obesity, and may exacerbate susceptibility to cognitive dysfunction.

Although poorer cognition (especially attention/executive function) is linked to both sleep quality and obesity, prior work has not investigated if there is an additive or interactive effect of these two problems on cognition. Such an effect could result from altered activity in the prefrontal cortex related to both disrupted sleep (Curcio et al., 2006) and obesity (Maayan et al., 2011). To examine this question, this study investigated the relationship between subjective sleep quality and performance on a task of inhibitory control that required vigilance in a sample of healthy young adults, and whether or not this relationship is moderated by body mass index (BMI). It was predicted that poorer subjective sleep quality would be related to decreased performance on indices of inhibitory control and that these relationships would be more robust with increasing BMI. In addition, it is possible that obesity-related medical conditions such as sleep apnea and vascular problems could lead to both poorer sleep and cognitive performance. For this reason, exploratory analyses were conducted to examine specific sleep symptoms to explore possible underlying causes that may contribute to these relationships.

MATERIALS AND METHODS

Participants

The sample included 85 college students recruited through advertisements. Obese and overweight individuals were oversampled, to ensure representation across BMI groups. Prospective participants were excluded if they had a past or present diagnosis of sleep apnea, diabetes, neurological disorder or injury, head injury with loss of consciousness exceeding 10 min, severe psychiatric illness (Diagnostic and Statistical Manual of Mental Disorders—

4th Edition, Text Revision (DSM-IV-TR) defined), alcohol or drug dependence (DSM-IV-TR defined), learning disorder or developmental disability (DSM-IV-TR defined), or visual or auditory impairment that precluded computerized neurocognitive testing.

Procedures

All study procedures were approved by the local Institutional Review Board and informed consent was obtained prior to participation in the study. As part of a larger study, participants were screened by telephone for inclusion/exclusion criteria. During the session, participants completed cognitive testing and questionnaires. Height and weight measurements were taken by research staff while participants were wearing their street clothes, having removed shoes and outer wear. BMI was calculated according to the standard metric formula ($BMI = \text{weight (kg)}/\text{height (m)}^2$).

Measures

Subjective sleep quality—The Pittsburgh Sleep Quality Index (PSQI; Buysse, Reynolds, Monk, Berman, & Kupfer, 1989) is an 18-item self-report questionnaire assessing sleep during the past month. Responses yield seven component scores (e.g., sleep latency, disturbances, duration, etc.) which range from 0 to 3 and are totaled for a global sleep quality score ranging from 0 to 21; higher scores reflect poorer sleep quality. A score of 5 or greater is considered to indicate poor quality of sleep. In addition to the overall score, one of the PSQI items includes 10 components assessing various sleep problems (e.g., cannot get to sleep within 30 min, cough or snore loudly, have pain), which provide a more qualitative description of sleep problems and which are scored on a 0–3 scale. For this study, the scores for each of these items were used in addition to the global PSQI score.

Medical and psychological history—Participants completed a questionnaire assessing demographic information including age, sex, and ethnicity. Participants were also asked to fill out a medical form to ensure consistency in their report at screening of any medical exclusionary criteria. No participants were excluded based on this information.

Cognitive test—The Automated Neuropsychological Assessment Metrics-4 (ANAM4) is a computerized cognitive battery which assesses multiple areas of cognition (www.vistalifesciences.com). The ANAM tasks use both practice sessions and alternate forms, which is an established standard for reducing practice effects in cognitive testing (Beglinger et al., 2005). This study examined performance on the go/no-go (GNG) task which is a measure of inhibitory control requiring vigilance. In this task, participants are presented with a series of rapidly flashing X's and O's and are instructed to click when X appears, but refrain from clicking when O appears. Mean reaction time, omission errors (missing X), and commission errors (clicking O) were examined in this study. Participants first complete a practice session lasting 20–30 s followed by the actual testing session which lasts two minutes.

Statistical analyses

Outlier analyses were conducted and scatterplots were examined with univariate outliers defined as >3 *SD* from the mean. Bivariate correlations were conducted to examine the

relationship among demographic variables, sleep, cognitive function, and BMI. Moderation analyses using a multiple linear regression model were performed separately for each GNG variable (reaction time, omissions, commissions) to determine whether BMI moderated the relationship between sleep quality and GNG indices. Exploratory moderation analyses were also conducted to examine whether BMI moderated the relationship between specific sleep symptoms or sleep duration and GNG indices. For each regression, the PSQI and BMI were entered into the first block and a PSQI by BMI interaction term was entered into the second block. The dependent variable was the GNG variable of interest. In order to interpret the interactions, simple slope analysis was conducted (e.g., Cohen, Cohen, West, & Aiken, 2003; Preacher, Curran, & Bauer, 2006), examining the relationship between sleep quality and the cognitive variables at the mean and one standard deviation above and below the mean for BMI.

RESULTS

Characteristics of the sample

Participants were on average 21.07 ($SD = 2.48$) years old and were 57.6% female. Racial make-up was 69.4% Caucasian, 23.5% African American, 2.4% Asian American, 1.2% Latin American, and 3.5% other. Average BMI was 29.41 ($SD = 7.98$). Of the sample, 41.2% were normal weight (BMI ranging from 18.5 to 24.9), 12.9% were overweight (BMI ranging from 25 to 29.9), and 45.9% were obese (BMI ≥ 30).

Average PSQI scores were 5.84 ($SD = 2.88$). Of the sample, 63.5% reported poor sleep quality, based on the PSQI > 5 cutoff. Participants reported on average sleeping 8.05 h ($SD = 1.05$; range = 5–10) per night during the past month. The most common reasons for poor sleep reported on the PSQI were waking up in the middle of the night or early morning, not being able to fall asleep within thirty minutes, and having to get up to use the bathroom. Table 1 presents PSQI item scores.

Preliminary data analyses and data screening

Univariate outliers for all BMI, PSQI, and cognitive variables were examined using histograms and descriptive statistics. There were no outliers identified for these variables. Multivariate outliers were examined using scatterplots; no multivariate outliers were identified.

Bivariate correlations examined the association between demographic factors and primary outcome variables to minimize possible confound. Independent samples *t*-tests revealed no differences between sexes for BMI, PSQI, or any of the cognitive variables. Age was not significantly associated with the PSQI or any of the cognitive variables. There was a significant association between age and BMI ($r = .27, p < .05$). Ethnicity was related to commission errors ($r = -.28, p < .01$); there was no relationship between ethnicity and PSQI, BMI, or any of the cognitive variables. Ethnicity was entered as a covariate into all regression models.

Bivariate correlations among sleep, cognitive function, and BMI

Bivariate correlations examined the relationship between PSQI and cognitive function. Poorer sleep quality was associated with more omission errors ($r = .26, p < .05$) on the GNG task; there were no significant associations between sleep quality and any other cognitive test. PSQI was also associated with BMI ($r = .22, p < .05$) such that poorer sleep quality was associated with higher BMI. Full results are provided in Table 2.

Bivariate correlations were then used to clarify the relationship between aspects of the PSQI and BMI to help clarify these results. Higher BMI was related to poorer sleep quality related to coughing or snoring, feeling too hot, pain, and fewer hours of actual sleep. Greater omission errors were related to poorer sleep quality due to not breathing comfortably and coughing or snoring loudly. See Table 1.

BMI moderates the association between sleep quality and vigilance

Reaction time—The first model predicting reaction time using ethnicity, PSQI, and BMI was not significant, $F(3, 81) = 1.07, p = .37$. The second model, which included the BMI $\times$ PSQI interaction term, was also not significant, $F(4, 80) = .83, p = .51$.

Omission errors—The first model predicting omission errors using ethnicity, PSQI, and BMI was not significant, $F(3, 81) = 2.67, p = .05$. However, with the addition of the BMI $\times$ PSQI interaction term, the final model was significant, $F(4, 80) = 4.25, p < .01$, and accounted for an additional 8.5% of variance over the previous model, $F(1, 80) = 8.00, p < .01$. The interaction term was a significant predictor in the final model ($\beta = 1.9287, t = 2.88, p < .01$) as were PSQI ($\beta = -1.401, t = -2.44, p = .02$) and BMI ($\beta = -.532, t = -2.04, p = .04$). See Table 3.

Analysis of simple slopes revealed that for participants with BMI 1SD above the mean, poorer sleep quality was associated with GNG omission errors ($\beta = .527, t = 3.58, p < .01$); however, the relationship between sleep quality and GNG omission errors was not significant for those with average, or 1SD below the mean BMI ($\beta = .116, t = 1.04, p = .30$ and $\beta = -.296, t = -1.41, p = .16$, respectively).

In order to clarify the contributors to the interaction between BMI and sleep quality on omission errors, a number of post hoc moderation analyses were conducted which examined specific sleep-related problems. Interaction terms were created by multiplying BMI by the score for each specific sleep symptom (e.g., difficulty breathing, coughing/snoring loudly, etc.). For all analyses, ethnicity, BMI and the specific problem was entered into the first block and the BMI by sleep difficulty interaction terms was entered into the second block. For brevity, only the final block which includes the interaction term is reported. The final block was significant for breathing difficulty, $F(4, 80) = 11.13, p < .001$, accounting for an additional 13.9% of variance over the first model, $F(1, 80) = 17.15, p < .001$, with both the interaction term ($\beta = 1.894, t = 4.14, p < .001$) and breathing difficulty ($\beta = -4.409, t = 1.42, p = .003$) being significant predictors in the final model. The final block was also significant for coughing or snoring loudly, $F(4, 80) = 2.97, p = .02$, accounting for an additional 4.3% of variance over the first model, $F(1, 80) = 3.92, p = .05$ which neared significance, with

the interaction term nearing significance in the final model ($\beta = 1.19$, $t = 1.98$, $p = .05$). The final block was significant for being too cold, $F(4, 80) = 6.71$, $p < .001$, accounting for an additional 11.4% of the variance over the previous block, with the interaction term ($\beta = 1.526$, $t = 3.48$, $p < .01$), and being too cold ($\beta = -1.123$, $t = -2.65$, $p = .01$) being significant in the final model. Results were not significant for difficulty getting to sleep within thirty minutes, waking up in the middle of the night or early morning, getting up to use the bathroom, feeling too hot, bad dreams, or having pain.

Commission errors—The first model predicting commission errors using ethnicity, PSQI, and BMI was significant, $F(3, 81) = 3.02$, $p = .03$. The second model, which included the BMI $\times$ PSQI interaction term was also significant, $F(4, 80) = 2.57$, $p = .04$. However, ethnicity was the only significant predictor in the final model ($\beta = -.287$, $t = -2.64$, $p = .01$).

BMI does not moderate the association between sleep duration and cognitive function

Reaction time—The first model predicting reaction time using ethnicity, sleep duration, and BMI was not significant, $F(3, 81) = .95$, $p = .42$. The second model, which included the BMI $\times$ sleep duration interaction term was also not significant, $F(4, 80) = .90$, $p = .47$.

Omission errors—The first model predicting omission errors using ethnicity, sleep duration, and BMI was not significant, $F(3, 81) = 1.18$, $p = .32$. The second model, which included the BMI $\times$ sleep duration interaction term was also not significant, $F(4, 80) = .98$, $p = .43$.

Commission errors—The first model predicting commission errors using ethnicity, sleep duration, and BMI was not significant, $F(3, 81) = 2.49$, $p = .07$. The second model, which included the BMI $\times$ sleep duration interaction term, was also not significant, $F(4, 80) = 1.87$, $p = .12$.

DISCUSSION

This study examined the influence of BMI on the relationship between subjective sleep quality and a test of inhibitory control requiring vigilance in a sample of healthy college students. It was hypothesized that BMI would moderate this relationship such that individuals with elevated BMI would experience greater decrements in performance with reduced sleep quality. Results demonstrated that BMI moderated the relationship between poor sleep quality and omission errors on the GNG task, as individuals in the severely obese range demonstrated more omission errors with poorer sleep quality. Post hoc analyses indicated that the specific sleep symptoms that BMI moderated were difficulty breathing, coughing or snoring loudly, and feeling too cold. Several aspects of these findings warrant further discussion.

Consistent with the previous literature (Assaad, Costanian, Haddad, & Tannous, 2014; Lund et al., 2010; Vargas et al., 2014), high rates of poor sleep quality (63.5%; PSQI > 5) were observed in this study. This is significant given research that demonstrates a strong link between poor sleep quality and health consequences such as fatigue, sleepiness, anxiety, and depression (Pilcher, Ginter, & Sadowsky, 1997; Vargas et al., 2014). Also similar to previous

research (Benitez & Gunstad, 2012), we demonstrated a detrimental effect of poor sleep quality on cognition among healthy college students.

The novel finding of this study is that elevated BMI contributed to reduced vigilance in the context of poor sleep. Specifically, we found that for individuals with BMI in the severely obese range, poorer sleep quality was related to poorer vigilance on an inhibitory control task; in contrast, there was no effect of poor sleep quality on inhibitory control for overweight or normal weight individuals. Although causality cannot be fully determined from this study, the finding that poor sleep quality was related to reduced vigilance for obese individuals, while this was not the case for individuals who were overweight or of a healthy weight, suggests a possibility that obesity increases the risk for cognitive deficits associated with reduced sleep.

The mechanism for this association may be a result of already compromised cognition in obese individuals (Fergenbaum et al., 2009; Gunstad et al., 2006, 2007; Nilsson & Nilsson, 2009; Sabia et al., 2009), which could result in reduced cognitive resilience in the presence of poor sleep. Of note, the current findings are observed among otherwise very healthy young adults—the sample excluded individuals with medical diseases that contribute to reduced sleep (e.g., sleep apnea) or cognitive difficulties (e.g., type 2 diabetes). Therefore, the relationships observed in this study do not appear to be the product of a disease state on cognition. However, it is possible that undiagnosed or subclinical conditions could have contributed. For example, although self-report of sleep apnea was an exclusionary criteria for this study, bivariate correlations revealed a strong relationship between the PSQI item for coughing or snoring loudly and BMI, though overall report of this problem was low in the sample. In addition, post hoc moderation analyses indicated that elevated BMI moderated the relationship between omission errors and difficulty breathing, coughing or snoring loudly, and feeling too cold, which may suggest a contribution of possible undiagnosed sleep apnea or decreased blood flow/vascular problems. Elevated BMI was also related to pain and fewer hours of sleep which are both known to negatively affect cognition. Impaired glucoregulation may also be a contributor given recent research that demonstrated that even in healthy young adults without diabetes, higher fasting glucose levels were related to poorer performance on a test of inhibitory control (greater GNG commission errors) (Hawkins, Gunstad, Calvo, & Spitznagel, in press). It is also possible that this finding reflects the cumulative effects of the cognitive vulnerability of the prefrontal cortex associated with both disrupted sleep and obesity (Curcio et al., 2006; Maayen et al., 2011).

The implications of these findings are substantial given high rates of both obesity (Morrell, Lofgren, Burke, & Reilly, 2012) and sleep problems (e.g., Vargas et al., 2014) among college students, but would likely generalize to other adult populations as well. Overall, findings highlight the importance of adequate sleep quality, particularly among obese individuals. Obesity is linked to a higher rate of sleep problems (Chen et al., 2014). This problem may be perpetuated by difficulty losing weight, as poor sleep among obese individuals is associated with decreased efficacy of weight loss interventions (Sawamoto et al., 2014; Valrie, Bond, Lutes, Carraway, & Collier, 2014). Given the current results, it is possible that the connection between poor sleep and reduced weight loss outcomes is related

to poorer cognition, thus contributing to a cycle exacerbating the challenge of weight loss for obese individuals.

The high prevalence of obesity (Fryar, Carroll, & Ogden, 2014) makes it likely that the clinical neuropsychologist will encounter patients with obesity on a regular basis. Comorbidities between obesity and medical conditions linked to cognitive impairment, including cardiovascular risk factors, type 2 diabetes, and sleep apnea (Awad, Gagnon, & Messier, 2004; Elias, Goodell, & Dore, 2012; Kielb, Ancoli-Israel, Rebok, & Spira, 2012), further increase the likelihood of the neuropsychologist encountering an individual with obesity in clinical practice. Additionally, our sample of older adolescents represents an age group with increased susceptibility for traumatic brain injury (TBI; Faul, Xu, Wald, & Coronado, 2010). Research suggests that not only are individuals with obesity at risk for greater severity of TBI (Tagliaferri, Compagnone, Yoganandan, & Gennarelli, 2009), but that nearly half of individuals with TBI demonstrate weight gain following the injury (Crenn et al., 2014). Incorporating findings from this study into practice, the neuropsychologist should be attentive to the role that sleep quality may play in the cognition of patients with obesity, with the understanding that poor sleep quality may be a contributor to an individual's cognitive profile and that recommendations for improving sleep may be of particular importance for these patients.

This study must be viewed in light of a number of limitations. First, sleep quality was measured using a self-report questionnaire. Although the PSQI has been used extensively in college student populations, there is the possibility for error and bias in all self-report measures. Future studies should re-examine these relationships using objective measures, such as polysomnography or actigraphy. Additionally, cross-sectional methodology limits our ability to draw conclusions about directionality among these relationships alternative models could be examined. Perhaps poor sleep and impaired inhibitory control actually drive increased BMI; future research should clarify the nature of these relationships using longitudinal designs. Additionally, although it is reasonable to suspect that poor sleep exacerbates cognitive dysfunction in obese persons, there may also be other variables (e.g., depression) which are contributing to both poor sleep and reduced cognition. Future studies should examine the possible contribution of such variables. Finally, although exclusionary criteria included self-reported diagnosis of sleep apnea, it is possible that even in this young, otherwise healthy sample, undiagnosed or subclinical sleep apnea or vascular problems are present and contributing to these findings. Future work should focus on the possible involvement of sleep apnea.

In summary, we examined the relationships among BMI, sleep quality, and inhibitory control. We found reduced vigilance in the context of poor sleep quality for severely obese individuals, but not individuals who were normal weight or overweight. Such findings highlight the possibility that severe obesity may confer a particular risk of decrements in attention with poor sleep quality. Future research is needed to clarify these relationships using objective measures of sleep quality.

References

- Al-Disi D, Al-Daghri N, Khanam L, Al-Othman A, Al-Saif M, Sabico S, Chrousos G. Subjective sleep duration and quality influence diet composition and circulating adipocytokines and ghrelin levels in teen-age girls. *Endocrine Journal*. 2010; 57:915–923. [PubMed: 20733266]
- Assaad S, Costanian C, Haddad G, Tannous F. Sleep patterns and disorders among university students in Lebanon. *Journal of Research in Health Science*. 2014; 14:198–204.
- Awad N, Gagnon M, Messier C. The relationship between impaired glucose tolerance, type 2 diabetes, and cognitive function. *Journal of Clinical and Experimental Neuropsychology*. 2004; 26:1044–1080. [PubMed: 15590460]
- Beglinger LJ, Gaydos B, Tangphao-Daniels O, Duff K, Kareken DA, Crawford J, ... Siemers ER. Practice effects and the use of alternate forms in serial neuropsychological testing. *Archives of Clinical Neuropsychology*. 2005; 20:517–529. [PubMed: 15896564]
- Benitez A, Gunstad J. Poor sleep quality diminishes cognitive functioning independent of depression and anxiety in healthy young adults. *The Clinical Neuropsychologist*. 2012; 26:214–223. [PubMed: 22335237]
- Bray GA. Medical consequences of obesity. *The Journal of Clinical Endocrinology & Metabolism*. 2004; 89:2583–2589. [PubMed: 15181027]
- Buysse DJ, Reynolds CF 3rd, Monk TH, Berman SR, Kupfer DJ. The Pittsburgh sleep quality index: A new instrument for psychiatric practice and research. *Psychiatry Research*. 1989; 28:193–213. [PubMed: 2748771]
- Byrd K, Gelaye B, Tadessea MG, Williams MA, Lemma S, Berhanec Y. Sleep disturbances and common mental disorders in college students. *Health Behavior and Policy Review*. 2014; 1:229–237. [PubMed: 25309939]
- Calvo D, Galioto R, Gunstad J, Spitznagel MB. Uncontrolled eating is associated with reduced executive functioning. *Clinical Obesity*. 2014; 4:172–179. [PubMed: 25826773]
- Carney CE, Edinger JD, Meyer B, Lindman L, Istre T. Daily activities and sleep quality in college students. *Chronobiology International*. 2006; 23:623–637. [PubMed: 16753946]
- Chang SP, Chen YH. Relationships between sleep quality, physical fitness and body mass index in college freshmen. *Journal of Sports Medicine and Physical Fitness*. 2014 [Epub ahead of print].
- Chaput JP, Després JP, Bouchard C, Tremblay A. The association between sleep duration and weight gain in adults: A 6-year prospective study from the Quebec Family Study. *Sleep*. 2008; 31:517–523. [PubMed: 18457239]
- Chen X, Pensuksan WC, Lohsoonthorn V, Lertmaharit S, Gelaye B, Williams MA. Obstructive sleep apnea and multiple anthropometric indices of general obesity and abdominal obesity among young adults. *International Journal of Social Science Studies*. 2014; 2:89–99. [PubMed: 25530977]
- Chuah YML, Venkatraman V, Dinges DF, Chee MWL. The neural basis of interindividual variability in inhibitory efficiency after sleep deprivation. *Journal of Neuroscience*. 2006; 26:7156–7162. [PubMed: 16822972]
- Cohen, J., Cohen, P., West, SG., Aiken, LS. *Applied multiple regression/correlation analysis for the behavioral sciences*. 3. Hillsdale, MI: Erlbaum; 2003.
- Crenn P, Hamchaoui S, Bourget-Massari A, Hanachi M, Melchior JC, Azouvi P. Changes in weight after traumatic brain injury in adult patients: A longitudinal study. *Clinical Nutrition*. 2014; 33:348–353. [PubMed: 23810396]
- Curcio G, Ferrara M, De Gennaro L. Sleep loss, learning capacity, and academic performance. *Sleep Medicine Reviews*. 2006; 10:323–337. [PubMed: 16564189]
- Dahl RE. The impact of inadequate sleep on children's daytime cognitive function. *Seminars in Pediatric Neurology*. 1996; 3:44–50. [PubMed: 8795841]
- Elias MF, Goodell AL, Dore GA. Hypertension and cognitive functioning: A perspective in historical context. *Hypertension*. 2012; 60:260–268. [PubMed: 22753214]
- Faul, M., Xu, L., Wald, MM., Coronado, VG. *Traumatic brain injury in the United States: Emergency department visits, hospitalizations and deaths 2002–2006*. Atlanta, GA: Centers for Disease Control and Prevention, National Center for Injury Prevention and Control; 2010.

- Fergenbaum JH, Bruce S, Lou W, Hanley AJ, Greenwood C, Young TK. Obesity and lowered cognitive performance in a Canadian First Nations population. *Obesity*. 2009; 17:1957–1963. [PubMed: 19478788]
- Fryar, CD., Carroll, MD., Ogden, CL. Prevalence of overweight, obesity, and extreme obesity among adults: United States 1960–1962 through 2011–2012. 2014. Retrieved from http://www.cdc.gov/nchs/data/hestat/obesity_adult_11_12/obesity_adult_11_12.htm
- Gangwisch JE, Malaspina D, Boden-Albala B, Heymsfield SB. Inadequate sleep as a risk factor for obesity: Analyses of the NHANES I. *Sleep*. 2005; 28:1289–1296. [PubMed: 16295214]
- Gaultney JF. The prevalence of sleep disorders in college students: Impact on academic performance. *Journal of American College Health*. 2010; 59:91–97. [PubMed: 20864434]
- Gonnissen HK, Hursel R, Rutters F, Martens EA, Westerterp-Plantenga MS. Effects of sleep fragmentation on appetite and related hormone concentrations over 24 h in healthy men. *British Journal of Nutrition*. 2013; 109:748–756. [PubMed: 22682471]
- Gunstad J, Paul RH, Cohen RA, Tate DF, Gordon E. Obesity is associated with memory deficits in young and middle-aged adults. *Eating and Weight Disorders—Studies on Anorexia, Bulimia and Obesity*. 2006; 11:e15–e19.
- Gunstad J, Paul RH, Cohen RA, Tate DF, Spitznagel MB, Gordon E. Elevated body mass index is associated with executive dysfunction in otherwise healthy adults. *Comprehensive Psychiatry*. 2007; 48:57–61. [PubMed: 17145283]
- Gupta NK, Mueller WH, Chan W, Meininger JC. Is obesity associated with poor sleep quality in adolescents? *American Journal of Human Biology*. 2002; 14:762–768. [PubMed: 12400037]
- Hasler G, Buysse DJ, Klaghofer R, Gamma A, Ajdacic V, Eich D, ... Angst J. The association between short sleep duration and obesity in young adults: A 13-year prospective study. *Sleep*. 2004; 27:661–666. [PubMed: 15283000]
- Hawkins ML, Gunstad J, Calvo D, Spitznagel MB. Higher fasting glucose is associated with poorer cognition among otherwise healthy young adults. *Health Psychology*. (in press).
- Jones K, Harrison Y. Frontal lobe function, sleep loss and fragmented sleep. *Sleep Medicine Reviews*. 2001; 5:463–475. [PubMed: 12531154]
- Kelly WE, Kelly KE, Clanton RC. The relationship between sleep length and grade-point average among college students. *College Student Journal*. 2001; 35:84–86.
- Kielb SA, Ancoli-Israel S, Rebok GW, Spira AP. Cognition in obstructive sleep apnea-hypopnea syndrome (OSAS): Current clinical knowledge and the impact of treatment. *Neuromolecular Medicine*. 2012; 14:180–193. [PubMed: 22569877]
- Liang J, Matheson BE, Kaye WH, Boutelle KN. Neurocognitive correlates of obesity and obesity-related behaviors in children and adolescents. *International Journal of Obesity*. 2014; 38:494–506. [PubMed: 23913029]
- Lund HG, Reider BD, Whiting AB, Prichard JR. Sleep patterns and predictors of disturbed sleep in a large population of college students. *Journal of Adolescent Health*. 2010; 46:124–132. [PubMed: 20113918]
- Maayan L, Hoogendoorn C, Sweat V, Convit A. Disinhibited eating in obese adolescents is associated with orbitofrontal volume reductions and executive dysfunction. *Obesity*. 2011; 19:1382–1387. [PubMed: 21350433]
- Magee CA, Huang X, Iverson DC, Caputi P. Examining the pathways linking chronic sleep restriction to obesity. *Journal of Obesity*. 2010; 2010:821710. [PubMed: 20798899]
- Mansur RB, Brietzke E, McIntyre RS. Is there a “metabolic-mood syndrome”? A review of the relationship between obesity and mood disorders. *Neuroscience and Biobehavioral Reviews*. 2015; 52:89–104. [PubMed: 25579847]
- Morrell JS, Lofgren IE, Burke JD, Reilly RA. Metabolic syndrome, obesity, and related risk factors among college men and women. *Journal of the American College of Health*. 2012; 60:82–89.
- Nilsson LG, Nilsson E. Overweight and cognition. *Scandinavian Journal of Psychology*. 2009; 50:660–667. [PubMed: 19930267]
- Pilcher JJ, Ginter DR, Sadowsky B. Sleep quality versus sleep quantity: Relationships between sleep and measures of health, well-being and sleepiness in college students. *Journal of Psychosomatic Research*. 1997; 42:583–596. [PubMed: 9226606]

- Pilcher JJ, Walters AS. How sleep deprivation affects psychological variables related to college students' cognitive performance. *Journal of the American College of Health*. 1997; 46:121–126.
- Preacher KJ, Curran PJ, Bauer DJ. Computational tools for probing interactions in multiple linear regression, multilevel modeling, and latent curve analysis. *Journal of Educational and Behavioral Statistics*. 2006; 31:437–448.
- Rossa KR, Smith SS, Allan AC, Sullivan KA. The effects of sleep restriction on executive inhibitory control and affect in young adults. *Journal of Adolescent Health*. 2014; 55:287–292. [PubMed: 24602612]
- Sabia S, Kivimaki M, Shipley MJ, Marmot MG, Singh-Manoux A. Body mass index over the adult life course and cognition in late midlife: The Whitehall II Cohort Study. *American Journal of Clinical Nutrition*. 2009; 89:601–607. [PubMed: 19073790]
- Sawamoto R, Nozaki T, Furukawa T, Tanahashi T, Morita C, Hata T, ... Sudo N. Higher sleep fragmentation predicts a lower magnitude of weight loss in overweight and obese women participating in a weight-loss intervention. *Nutrition & Diabetes*. 2014; 4:e144. [PubMed: 25347608]
- Tagliaferri F, Compagnone C, Yoganandan N, Gennarelli TA. Traumatic brain injury after frontal crashes: Relationship with body mass index. *The Journal of Trauma: Injury, Infection, and Critical Care*. 2009; 66:727–729.
- Telzer EH, Fuligni AJ, Lieberman MD, Galván A. The effects of poor quality sleep on brain function and risk taking in adolescence. *NeuroImage*. 2013; 71:275–283. [PubMed: 23376698]
- Valrie CR, Bond K, Lutes LD, Carraway M, Collier DN. Relationship of sleep quality, baseline weight status, and weight-loss responsiveness in obese adolescents in an immersion treatment program. *Sleep Medicine*. 2014; 16:432–434. [PubMed: 25701536]
- Van Dongen HP, Maislin G, Mullington JM, Dinges DF. The cumulative cost of additional wakefulness: dose-response effects on neurobehavioral functions and sleep physiology from chronic sleep restriction and total sleep deprivation. *Sleep*. 2003; 26:117–126. [PubMed: 12683469]
- Vanderlind WM, Beevers CG, Sherman SM, Trujillo LT, McGeary JE, Matthews MD, ... Schnyer DM. Sleep and sadness: Exploring the relation among sleep, cognitive control, and depressive symptoms in young adults. *Sleep Medicine*. 2014; 15:144–149. [PubMed: 24332565]
- Vargas PA, Flores M, Robles E. Sleep quality and body mass index in college students: The role of sleep disturbances. *Journal of American College Health*. 2014; 62:534–541. [PubMed: 24933244]
- Vriend JL, Davidson FD, Corkum PV, Rusak B, McLaughlin EN, Chambers CT. Sleep quantity and quality in relation to daytime functioning in children. *Children's Health Care*. 2012; 41:204–222.
- Yeh SS, Brown RF. Disordered eating partly mediates the relationship between poor sleep quality and high body mass index. *Eating Behaviors*. 2014; 15:291–297. [PubMed: 24854821]

Table 1

Symptom scores from the Pittsburgh Sleep Quality Inventory and correlation with body mass index and cognitive variables ($n = 85$)

PSQI item	Mean (SD)	BMI	RT	Omissions	Commissions
Cannot get to sleep within 30 min	1.25 (1.15)	.16	.14	.13	.14
Wake up in the middle of night/early morning	1.79 (1.05)	-.14	-.21	-.05	-.06
Have to get up to use the bathroom	1.21 (1.15)	.02	-.10	.14	.02
Cannot breathe comfortably	.21 (.62)	.17	-.11	.45**	-.07
Cough or snore loudly	.51 (1.00)	.23*	.13	.26*	<.01
Feel too cold	.74 (.93)	.10	.04	-.17	-.08
Feel too hot	1.16 (1.01)	.22*	.09	.21	-.06
Have bad dreams	.64 (.74)	.16	.05	.19	-.14
Have pain	.45 (.72)	.23*	.03	.11	-.20
Sleep duration	8.05 (1.05)	-.22*	-.09	-.01	.04

Abbreviations: *SD*—Standard deviation, *BMI*—Body mass index, *PSQI*—Pittsburgh Sleep Quality Index, *RT*—Reaction time.

* $p < .05$;

** $p < .001$

Table 2Bivariate correlations among cognitive function and sleep quality, and body mass index ($n = 85$)

	PSQI	BMI
Reaction time	.12	.18
Hits	-.26 [*]	-.15
Omissions	.26 [*]	.20
Commissions	.15	.14
Body mass index	.22 [*]	—

Abbreviations: BMI—Body mass index, PSQI—Pittsburgh Sleep Quality Index.

^{*}
 $p < .05$.

Table 3

Hierarchical linear regression predicting go/no-go omission errors

Variable	<i>B</i>	<i>SE B</i>	β	<i>R</i> ²
Block 1				.090 *
Ethnicity	−.01	.14	−.008	
PSQI	.16	.07	.228 *	
BMI	.04	.03	.154	
Block 2				.085 **
Ethnicity	−.08	.14	−.063	
PSQI	−.96	.39	−1.40 *	
BMI	−.13	.06	−.532 *	
PSQI × BMI	.04	.01	1.928 **	

Notes: Block one refers to the model which includes ethnicity, BMI, and PSQI scores. Block 2 refers to the model which includes all variables in block one as well as the PSQI by BMI interaction term. Total $F(4, 80)$ for the final model = 4.25**, Adjusted $R^2 = .13$.

Abbreviations: PSQI—Pittsburgh Sleep Quality Index, BMI—Body Mass Index; lower score for omission errors reflects better performance.

* $p < .05$;

** $p < .01$ (two-tailed).