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The Superpower of Sleep: Poor Sleep Quality Predicts Worse Executive Control Under Conditions of Stress

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The Superpower of Sleep: Poor Sleep Quality Predicts Worse Executive Control Under Conditions of Stress

A thesis submitted in partial fulfillment of the requirement for the degree of Bachelor of Science in Psychology from William & Mary

by

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ABSTRACT

Background: Over 60% of college students do not obtain the minimum recommended amount of sleep daily and over 54% experience above average levels of stress. Exposure to stress and poor sleep are each related to executive control, which is a set of cognitive abilities that are essential for daily functioning. Despite the prevalence of poor sleep and high stress, studies have rarely examined the joint impact of sleep and stress on executive control in students.

Objective: The purpose of this study was to examine whether the impairing effect of stress on executive control is stronger in individuals who obtain poor sleep.

Method: 76 undergraduate students recruited from William & Mary were randomly assigned to complete either a stress induction or a control task. Executive control was measured after the stress induction and control task. Self-reported sleep and actigraphy were tracked for a week prior to laboratory tasks.

Results: Sleep quality on the previous night did not predict executive control measured under control or stress conditions. Whereas average sleep quality did not predict executive control measured under control conditions, poor average sleep quality predicted worse executive control under conditions of stress.

Conclusion: Sleep quality impacts the extent to which executive control is impaired by stress. Due to the importance of executive control and the common experience of poor sleep and stress, specific interventions should focus on supporting students in obtaining sufficient sleep.

Keywords: Executive control, stress, sleep quality, college

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The Superpower of Sleep: Poor Sleep Quality Predicts Worse Executive Control Under Conditions of Stress

Despite the focus on the pandemics afflicting the world in the beginning of the 21st century, there is another epidemic that is hindering the functioning and success of millions of students. Unlike some of the other health challenges the globe faces, this epidemic has an easy solution which everyone already takes part in. The epidemic is poor sleep, and the solution appears simple: more sleep. Seven to nine hours of good quality nocturnal sleep is the recommendation for adults ages 18-64 (Hirshkowitz et al., 2015). Despite this feasible recommendation, the majority of college students do not obtain the recommended hours of nightly sleep. Eight hours or more of sleep is only reported by roughly 30% of college students while a quarter of college students report nightly sleep of fewer than six and a half hours (Lund et al., 2010).

Sleep is a repetitive state which is necessary for health and is critical for all of our daily functions (National Institute of Neurological Disorders and Stroke, 2023). For example, sleep is instrumental for good mental health and optimal immune system and cardiovascular system functioning (Huang et al., 2020; National Institute of Neurological Disorders and Stroke, 2023; Prather et al., 2012). In students, sleep's consistency, quality, and duration are responsible for about a fourth of students' academic achievements (Okano et al., 2019). College students who slept less than eight hours a night performed worse on their final exam than their peers who had at least eight or more hours of sleep per night for the five days during finals week (Scullin, 2019). A crucial factor in everything that we do and how our body functions is sleep.

One of the reasons that sleep has such wide-ranging implications is because sleep may impact executive control, which is a set of cognitive abilities that are essential for daily functioning (Diamond, 2013). It has been thought that there are three aspects to executive control: inhibition, updating, and shifting (Miyake et al., 2000). Executive control allows us to behave in ways that are socially acceptable, focus and prioritize tasks, be able to adjust to unanticipated changes, and to process and incorporate new information to existing knowledge (Diamond, 2013). Because of the many roles of executive control, better executive control has been associated with more positive outcomes (Blankenship et al., 2015). In the academic domain, better executive control is associated with better math and reading fluency, calculation, and reading comprehension (Blankenship et al., 2015). In the first year of college, low subjective executive control was associated with fewer credits earned (Baars et al., 2015). Better self-reported executive control was associated with higher grade point averages in college students (Knouse et al., 2014). Further, the association between academic success and executive control is stronger than the association between academic success and Intelligence Quotient scores (Siquara et al., 2018).

Although insufficient or excessive sleep duration has been linked to poorer executive control, sleep quality may be more impactful than quantity (Kohyama, 2021; Lo et al., 2016, Lücke et al., 2021). For example, primary, middle, and secondary school students who typically have poor sleep had better executive control if they obtained higher quality sleep the night before an assessment (Yu et al., 2022). In young adults, executive control improved as fewer interruptions occurred during sleep (Wilckens et al., 2014). With worse sleep quality the amount of space in the brain that the hippocampus occupies decreases faster than in those with better sleep quality (Fjell et al., 2020). Typical decision-making might also be impaired with poor sleep quality but not quantity. In emergency room nurses, those that had poor sleep quality reported more errors made while sleep quantity was not associated with errors made (Weaver et al., 2016).

One measure of sleep quality that has been closely linked to executive control is sleep efficiency. Sleep efficiency is calculated as a ratio of time spent sleeping and time spent in bed (Reed & Sacco, 2016). Sleep efficiency has been associated with a variety of forms of executive control such as inductive reasoning, response inhibition, and working memory (Boeve et al., 2022; Miyata et al., 2013; Pasula et al., 2018; Perez et al., 2020). Better sleep efficiency is also linked to improved inductive reasoning and response inhibition (Boeve et al., 2022; Perez et al., 2020). Better sleep efficiency the night before an assessment is associated with better working memory (Pasula et al., 2018). With a sleep efficiency of less than 85%, people had poorer scores on a measure of working memory (Miyata et al., 2013).

While sleep is an important factor in executive control in general, the context under which executive control is used is important to consider. In particular, stress is a contextual element that has been associated with executive control. Acute stress results in detriments to prefrontal cortex functioning and working memory (Gärtner et al., 2014). Exposure to induced acute stress was associated with reduced activity in the dorsolateral prefrontal cortex which is responsible for working memory (Qin et al., 2009). When participants were given hydrocortisone, an artificial hormone that mimics the natural hormone cortisol that is released during psychosocial stress, their working memory was impaired (Dickerson & Kemeny, 2004; National Cancer Institute, n.d.; Vaz et al., 2011). In individuals who read test instructions that made most people feel anxious, worse cognitive performance was found (Coy et al., 2011). Thus, evidence suggests that stress is a factor that is also associated with executive control. This is important to consider because stress is a ubiquitous experience and is particularly relevant to college students. In the span of a year, over half of students reported feeling above average levels of stress (American College Health Association, 2014). It was found that students ranked stress followed by sleep as the most cited causes for a decline in academic performance (American College Health Association, 2012).

While there is a wealth of knowledge and research on the factors of sleep, executive control, and stress, few consider these variables jointly using standardized, objective measures in a population of non-patient young adults. A substantial amount of research involving sleep and executive control has been conducted in older adults (Boeve et al., 2022; Cavuoto et al., 2016; Miyata et al., 2013). Although these studies can be helpful to theorize from, they may not necessarily translate directly into the sleep of non-patient young adults. In the present study, the sample consisted of undergraduate students, expanding the populations in which sleep, stress, and executive control have been studied. The purpose of the present study was to examine, in a sample of undergraduate students, whether the impairing effect of stress on executive control is stronger in individuals who obtain poor sleep.

Besides sleep and stress independently influencing executive control, insufficient sleep can aggravate stress, potentially compounding its impact on executive control (Shuttleworth & Foster, 2020). While sleep quantity did not affect cortisol levels following stress, good sleep quality compared to poor sleep quality was associated with lower cortisol levels (Bassett et al., 2015). Poor sleep has been associated with increased stress responses and inferior affective reactions (Williams et al., 2013).

When measuring cognitive performance in students, specific measures of executive control are not routinely used in favor of measures like final exam scores (Scullin, 2019). Although these studies are useful especially in studying young adults who are receiving an education, there are many limits to this kind of measure. While grades can be controlled for, there are many other variables introduced during final exam periods. Some individuals have their exams clustered affecting sleep while others may only have a couple exams, experiencing less stress. Moreover, many students do calculations around their final exam score to determine exactly how many points they must earn to receive a particular grade which could lead to some students scoring higher or lower depending on the final grade they are hoping for. Exam scores can also be impacted by exam schedules which increase study time and decrease usual academic demands. For these reasons, the present study used a standardized laboratory-based measure of executive control.

The present study used objective sleep measures since subjective sleep measures are not reliable predictors of executive control performance (Zavecz et al., 2020). While objective measures seem superior to subjective measures, not all objective measures are good predictors. In assessing function, sleep quantity is an inferior measure compared to sleep quality (Kohyama, 2021). There are accepted values of sleep measures that indicate poor or good sleep quality; sleep efficiency of at least 85% or greater is good sleep quality (Ohayon et al., 2017).

The impact of both night prior and average sleep on various forms of executive control have been studied. After not sleeping for a night, it takes four days to recover to typical brain functioning (Kitamura et al., 2016). In college students, the more time spent sleeping the seven days leading up to the test and the night before the test, the better memory capacity was (Phan et al., 2019). For the three nights prior, inconsistent sleep was associated with poor attention (Whiting & Murdock, 2016). Individuals who have a better night of sleep than usual, have better cognitive functioning while cognitive functioning suffers in individuals who typically have good sleep and have above average sleep quality the night prior (Yu et al., 2022). On the night prior when individuals obtain a level of sleep quantity that is closer to recommended levels, they have improved cognitive functioning (Wild et al., 2018). Average sleep efficiency over a week is associated with inductive reasoning performance (Perez et al., 2020). Recent research suggests that both average sleep quality and prior night sleep quality are important for executive control performance (Lo et al., 2016).

Although it has not been extensively investigated, it may be that poor sleep quality in non-patient undergraduate students is particularly detrimental to executive control when executive control is employed in conditions of acute stress. This is important to investigate because this may help explain the many negative implications of poor sleep. In light of current research, it is hypothesized that poor average sleep quality leading up to the day of executive control task performance and poor sleep quality the night prior to the day of executive control task performance will predict worse executive control under conditions of acute stress.

Method

Participants

A total of 106 participants were recruited from the William & Mary undergraduate student population. Participants (*N* = 76) who received an Actiwatch as part of their participation in the parent study were included in the current study. Participants ranged in age from 18 to 26 (*M* = 18.92, *SD* = 1.28). The sample was 41% male, 54% female, 1% other, and 4% did not respond. The sample was composed of 46% White/Caucasian, 11% Black/African American/African, 21% Asian/Asian American, 3% Latino/Hispanic, 16% multiracial, and 4% did not respond. Participants family's household income ranged from $25,000 or less to $300,001 or more (*Mdn* = 120,001 - $150,000; demographics by condition table A1). One participant was excluded from analyses due to missing data on their executive control task (n-back 2). Two participants were excluded from analyses using sleep quality on the night prior as they did not have sleep data from the night prior to the session. Thus, 73 participants were included in analyses using the measure of night prior sleep efficiency and 75 participants were included in analyses using the average sleep efficiency measure. Participants received credit for college courses for participating. William & Mary's Institutional Review Board granted approval on 8/17/2021.

Materials

Neutral Videos

During the session, participants watched a five-minute and 30-minute neutral video to obtain physiological data (not included in the present study).

Trier Social Stress Test

Stress was induced with a variation of the Trier Social Stress Test (TSST), which was designed to elicit social evaluative threat (Kirschbaum et al., 1993). The stress induction was administered to participants who were randomly assigned to the experimental group. This test involved inducing stress for the participant through instructing them that they will be completing tasks where they will be evaluated socially. The variation used in this experiment instructed participants that they were about to complete a speech task and an arithmetic task. The speech task involved presenting a five-minute speech on why they were the best candidate for a vacant position regardless of job details. Participants were told that the experimenter would be evaluating them as if they were a hiring manager and their speech would be filmed and shown to a panel of their peers to be evaluated. In the arithmetic task, participants were asked to count backwards aloud from 2083 in increments of 17 for five minutes. If they miscalculated the experimenter would point out their mistake by saying “error, 2083” and the participant would have to start all over again. When the arithmetic task was introduced, participants were told that most students at William & Mary do fairly well on this task.

The control version of this task, referred to as the Placebo TSST, involved the participant standing and speaking out loud for five minutes about a book, movie, or recent trip that they took (Het et al., 2009). The experimenter told the participant that no one would be able to see or hear them and left the room. For the arithmetic task, the research assistant instructed the participant to count aloud in increments of 15 starting from 0 and then left the participant alone to complete this task (Het et al., 2009).

Measures

Koala Sleep Daily Diary

Participants received a daily sleep diary each morning at 5:30 a.m. Participants did not have to complete the survey at 5:30 a.m. but were asked to complete the survey as soon as they woke up. The questions asked each morning were about time zone, watch removal, naps, time got into bed, if used electronics in bed, time tried to sleep, time woke up, time got out of bed, sleep quality rating (1 very good – 4 very bad), caffeine consumption, exercise, and stress experiences (stressful, desirable, impact, control, coping strategy, goal of strategy, effectiveness of strategy). The daily diary reports of time zone, watch removal, naps, time got into bed, time tried to sleep, time woke up, and time got out of bed were the only data used in the present study. These variables were compared to the Actiwatch actigraphy. Actigraphy data that was marked as sleep when the participant indicated they had removed the watch or were napping was removed. Additionally, data that was in stark conflict to the daily sleep diary were manually excluded from the actigraphy.

N-back Task

One of the facets of executive control, working memory, includes being able to obtain information and manipulate it to incorporate additional details (Diamond, 2013). The measure of executive control used in this study was the n-back task with an n of two. The n-back task has been continually shown to be an acceptable measure of working memory (a component of executive control; Frost et al., 2021). The n-back measures working memory through accuracy. In the n-back task, participants are shown a series of words. Participants must indicate whether the current word that they see matches the word that they saw two words ago. The working memory task is updated, meaning that with each new word that appears, participants must adjust the words they remember to be able to match the current word to the word that was shown two words ago (figure 1). For example, when the participant sees the fourth word, they must indicate whether it is a match or not to the second word by pressing either a button labeled match or a button labeled not a match. When the sixth word is shown they must indicate whether it is a match or not to the fourth word. The n-back task was completed a total of 3 times. Prior to each n-back, practice trials had to be passed with a score of 90% or higher. The first n-back (n-back 0) test trials lasted for two minutes. The purpose of n-back 0 was for the participant to learn the task. The second n-back (n-back 1) and third n-back (n-back 2) test trials each lasted for six minutes and consisted of 120 trials. N-back 1 was completed prior to the stress or control induction and n-back 2 was completed following the stress or control induction. Within each of the n-back trials there were twenty words in each block, six total blocks of words, and two blocks of each neutral, positive, and negative words.

Wrist Actigraphy

The Philips Respironics Actiwatch 2 actigraphy device recorded participants' sleep and physical activity using an accelerometer at an epoch length of 15 seconds on an activity logging mode.

The Actiwatch 2 data was analyzed using Philips Actiware Software version 6.1.2.1. Actigraphy data was manually edited through evaluating the daily diary reports examining watch removal, naps, time tried to sleep, and time woke up. Consistent with current research only nocturnal sleep was assessed and data marked as sleep that was outside of the sleep time reported by the participant was excluded (Lo et al., 2016). The measure of sleep quality obtained from the Actiwatch was sleep efficiency. Sleep efficiency was calculated as a percentage of how long the participant spent asleep divided by how long the participant spent in bed. For best health, sleep efficiency should be at least 85% (National Sleep Foundation, 2020). Sleep quality was evaluated using sleep efficiency on the night prior to the day the executive control task was performed. Sleep efficiency was also examined during the seven nights leading up to the day the executive control task was performed (including data that didn't have a full week of data, with a minimum of four days of data). The Actiwatch 2 has been shown to be an effective sleep tracking device. The Actiwatch has been validated in comparison to polysomnography (lab sleep study) which is considered the best assessment of sleep (Meltzer et al., 2012). The Actiwatch 2 is found to be both specific and sensitive to sleep measures (Meltzer et al., 2012). Although it is not statistically significant the Actiwatch 2 does underestimate (less than 1% difference) sleep efficiency (Meltzer et al., 2012).

Procedure

Participants came in for a brief initial session seven to ten days prior to their second in-person session. In this initial session, participants completed informed consent and based on watch availability, were given an Actiwatch. Participants wore an Actiwatch for seven to ten days prior to their second session to obtain objective sleep data. Participants also completed daily sleep diaries for the days prior to their second study session.

When participants arrived for the second study session, they had physiological measuring equipment placed on their torso and hand (not included in the present study). Participants watched neutral videos to obtain baseline physiological data, and then completed an n-back task. The first n-back task participants completed was labeled n-back 0. N-back 0 had a duration of two minutes. The purpose of n-back 0 was for participants to learn how the task worked. Prior to condition assignment, participants completed an n-back task. Participants were then randomly assigned to either the control or experimental group. Research assistants did not look at the randomization file until right before either the stress or control induction so that there would be no changes in behavior which might make the participant feel more comfortable and mitigate the stress induction. Participants then completed the stress induction or control task, followed by an n-back task. For the last task of the session, participants watched a 30-minute neutral video sitting the entire time. At the end of the session, all participants received a referral sheet listing local and national mental health resources.

Results

Across the entire sample, average sleep efficiency ranged from 61.09 to 91.40 with an average of 81.66 (*SD* = 5.40) (table 1). Night prior sleep efficiency ranged from 52.20 to 94.04 with an average of 81.35 (*SD* = 9.08) (table 1). In the control condition, average sleep quality ranged from 73.30 to 91.23 with an average of 83.16 (*SD = 3.71)* (table 2) and night prior sleep efficiency ranged from 53.16 to 94.04 with an average of 82.66 (*SD* = 8.05*)* (table 2). In the stress condition, average sleep quality ranged from 61.09 to 91.40 with an average of 79.99 (*SD* = 6.46) (table 2) and night prior sleep efficiency ranged from 52.20 to 93.21 with an average of 79.81 (*SD* = 10.06) (table 2). For best health, sleep efficiency should be at least 85% (National Sleep Foundation, 2020).

Executive control was measured by the number of errors on the n-back task. In the whole sample, n-back 2 errors ranged from 2 to 42 with an average of 12.83 (*SD = 9.00)* (table 1). In the control condition, n-back 2 errors ranged from 3 to 36 with an average of 12.75 (*SD* = 8.79) (table 2). In the stress condition n-back 2 errors ranged from 2 to 42 with an average of 12.94 (*SD* = 9.32) (table 2).

See tables for correlations among study variables across the entire sample (table 3) and by condition (table 4). The main regression analyses examined sleep as a predictor of executive control (n-back 2) with condition as the moderator. There was a significant interaction between average sleep quality and condition predicting executive control (table 5, figure 2). Whereas average sleep quality did not predict executive control measured under control conditions b = .27, SE = .36, $t(75) = .76$, $p = .451$, poor average sleep quality predicted worse executive control under conditions of stress b = -.82, *SE* = .22, $t(75) = -3.73$, $p < .001$ (table 5). When controlling for night prior sleep, the interaction between average sleep quality and condition predicting executive control remained significant (table 6). The interaction between night prior sleep quality and condition predicting executive control was non-significant (table 7, figure 3). There was a non-significant interaction between night prior sleep quality and condition predicting executive control when controlling for average sleep (table 8).

Discussion

Most college students do not obtain sufficient sleep and frequently experience stress (American College Health Association, 2014; Lund et al., 2010). This is problematic due to the effects of sleep and stress on executive control (Gärtner et al., 2014; Wilckens et al., 2014). Considering the prevalence and associations between sleep, stress, and executive control, the purpose of this study was to examine whether the impairing effect of stress on executive control is stronger in individuals who obtain poor sleep quality. Through regression analyses, sleep was examined as a predictor of executive control with condition as the moderator. Contrary to hypotheses, we did not find that the relationship between prior night sleep quality and executive control was significantly stronger when executive control was measured under stress. Consistent with hypotheses, the relationship between average sleep quality and executive control was significantly stronger when executive control was measured under stress. Whereas average sleep quality was not associated with executive control measured under control conditions, poor average sleep quality predicted worse executive control under conditions of stress.

As hypothesized, our results indicate that poor average sleep quality predicts poor executive control following an acute stress induction. This finding extends previous research by showing that stress and sleep quality jointly impact executive control rather than independently (Gärtner et al., 2014; Ochab et al., 2021; Scullin, 2019). In particular, previous research showing that sleep quality impacts executive control has measured executive control under standard lab conditions (Lo et al., 2016; Perez et al., 2020). Although the present study does not establish a causal relation, our results indicate that sleep may be particularly important to cognitive functioning during times of stress. This is important because executive control is important for so many abilities and has many health implications (Blankenship et al., 2015; Diamond, 2013).

The non-significant finding for night prior sleep in the stress condition was surprising due to the opposition to previous research. Changes in cognition were similar in individuals who had two nights of sleep deprivation and those who over two weeks sleep between four to six hours nightly (Van Dongen et al., 2003). In people who are chronically getting insufficient sleep, if they obtain one night of good sleep, they experience improvements because they are getting back to their baseline of cognitive function instead of operating in a state of diminished functioning (Wild et al., 2018).

Although effects in the control condition were not the focus of the present study, the non-significant findings in the control condition for both night prior and average sleep were unexpected in light of recent research. Both night prior sleep and average sleep are related to executive control measured under standard non-stressful conditions (Perez et al., 2020; Wild et al., 2018). Some possible explanations for the non-significant results are that the task was too easy to observe an effect and we did not control for individual differences that may be obscuring an effect. In older adults, sleep quality is only associated with working memory when the individual has a high cognitive load (Rana et al., 2018). Some individuals with a specific gene mutation can obtain fewer hours of sleep but still acquire equivalent amounts of specific sleep stages as individuals with a longer sleep duration (Pellegrino et al., 2014). Research has found that some factors such as fluid intelligence, dieting and bilingualism can also impact working memory (Blasiman & Was, 2018).

Limitations

While significant results were found for poor average sleep quality predicting worse executive control under conditions of stress, generalizability of results is difficult due to the demographics of the sample. The age range of the sample was very restricted, and racial sample demographics were uneven to national distributions in United States universities (National Center for Education Statistics, 2022). The median income range for this study population was over double the national median household income (Guzman, 2018). Future investigations should aim for demographically representative samples for more generalizable study results.

Future Directions

Although speculative, results of the present study have potential implications for health and academic performance of college students. The majority of college students may be impeding their academic performance due to experiencing stress and obtaining insufficient sleep (American College Health Association, 2014; Lund et al., 2010; Okano et al., 2019). For example, through executive control, poor sleep may contribute to worse academic performance when assessments are taken in stressful conditions (e.g., final exams; Shuttleworth & Foster, 2020). This study's extension of current research is important due to the implications for behavioral modification interventions which could improve functioning and academic success during a stressful time in the lives of young adults (American College Health Association, 2014; Lund et al., 2010; Okano et al., 2019). Poor sleep, through executive control, may also contribute to negative health outcomes by impairing a person's ability to regulate thoughts, emotions, and behaviors when exposed to stressful life events (Bolden et al., 2019).

This result could serve as the foundation for exploring the relationships between sleep, stress, and psychopathology. Poor executive control has been associated with anxiety, depression, eating disorders, suicide attempts, and unsafe drinking behaviors (Bolden et al., 2019; Ciszewski et al., 2020; Healy et al., 2018; Parada et al., 2012; Saffer & Klonsky, 2017). In adults with generalized anxiety disorder, the extent of symptoms assessed by a professional predicted worse performance on an inhibition task measuring executive control (Hallion et al., 2017). In individuals with anxiety, executive control prior to an intervention can give an estimate on how much a patient might improve from an intervention to reduce emotional struggles (Healy et al., 2018). Combining this body of research with results of the present study, suggests that future research may want to examine whether poor sleep quality through executive control contributes to psychopathology.

Building upon the link between executive control and psychopathology, executive control under stress has also been associated with psychopathology (Bolden et al., 2019; Pe et al., 2016). College students experience more symptoms of depression as they have worse affective updating (linked to working memory) while feeling intense stress (Pe et al., 2016). College students who experience impairment in executive control resulting from induced stress, are more likely to have depression symptoms during a later stressful academic period (Quinn & Joormann, 2015). These findings are more directly applicable to results of the present study because we measured executive control under conditions of acute stress. Thus, future research may want to focus on whether poor sleep quality is associated with executive control, which then relates to psychopathology risk.

As our results showed, poor average sleep quality predicts poorer executive control under stress; therefore, interventions to increase sleep could improve psychopathology (Bolden et al., 2019). Typical sleep efficiency is associated with the extent to which an individual experiences the signs of depression (Bolden et al., 2019). Executive control may be the mechanism through which sleep can predict psychological disorders (Bolden et al., 2019). Thus, when an individual has poor sleep quality, they may be less able to effectively regulate their responses to stress, placing them at heightened risk for psychopathology. This is important because almost 50% of college students reported moderate levels of stress and roughly 30% of college students reported high levels of stress in the past 30 days (American College Health Association, 2022). The proportion of college students meeting the criteria for one mental health disorder rose about 20% from 2013 to 2020 (Lipson et al., 2022). While executive control is critical for daily functioning, the repercussions of impaired executive control resulting from stress can impact more than just functioning and can lead to psychopathology (Quinn & Joormann, 2015). Therefore, future research exploring the effect of sleep on the relationship between executive control under stress and psychopathology is imperative.

In addition to future research investigating the relationships between stress and sleep with outcomes like psychopathology, future research should also assess interventions to improve sleep as behavioral modifications to potentially improve executive control. These results suggest that improving average sleep quality could be an effective intervention to improve performance in college students as they are typically under stress during their schooling (American College Health Association, 2014). Future research can build upon these findings to optimize success in college students considering poor sleep and stress are prevalent (American College Health Association, 2014; Lund et al., 2010; Okano et al., 2019).

To optimize functioning and well-being, possible interventions to improve sleep should be investigated. An avenue that sleep could be improved is through napping. Due to constraints around course schedules, students do not have much autonomy when it comes to the time they need to wake up. Around the age of 18-19 is when bedtimes are the latest potentially due to hormone changes, exacerbating insufficient sleep due to mandated wake up times (Fischer et al., 2017; Roenneberg et al., 2004). Research supports the idea that napping could help to mitigate the deficits of poor nocturnal sleep on executive control (Cousins et al., 2021; Lau et al., 2015; Mednick et al., 2003). Cognitive functioning in young adults improved when they napped (Cousins et al., 2021; Lau et al., 2015; Mednick et al., 2003). Napping could improve executive control through the increased oxygen to the dorsolateral prefrontal cortex of the brain that occurs during rapid-eye movement sleep (REM) (Kubota et al., 2011; Qin et al., 2009; Reichert et al., 2014). Napping could improve executive control due to increased oxygen to brain regions responsible for working memory (Kubota et al., 2011).

In addition to napping, increasing exercise could be examined as another intervention to improve poor sleep. It has been shown that executive control may be improved with exercise through sleep efficiency (Wilckens et al., 2018). As many colleges have a health center, a recreation or exercise center, and complete orientation, providing college students with more information and resources is not an arduous addition. Sleep education courses through the health or wellness center could be advertised or pamphlets publicizing these courses distributed during new student orientation. Another resource on many college campuses that could contribute to this undertaking is the recreation/exercise center. It has been shown that exercise may counteract some of the impairments in cognition that result from poor sleep (Sewell et al., 2021). Not only could the recreation/exercise center provide a facility for this intervention to take place, but they could assist with educating students on this issue.

While napping and exercise are behaviors that could be increased to improve poor sleep, a behavior that could be reduced to improve poor sleep is caffeine consumption. Consuming caffeine in the morning was associated with worse sleep efficiency than those taking a placebo (Landolt et al., 1995). In addition to impacting sleep quality, caffeine is associated with increased stress (Magalhães et al., 2021). Incorporating the results of this study with current research, reducing caffeine could not only improve sleep quality, but also decrease stress, therefore improving cognitive functioning (Landolt et al., 1995; Magalhães et al., 2021).

Due to the common experiences of poor sleep and stress, continued study into factors that improve sleep quality and decrease stress should be prioritized as this study showed that poor average sleep quality predicted worse executive control under stress. Given the breadth of impacts of deficient sleep, a deeper understanding of these relationships is vital for improving the lives of many individuals.

Conclusion

The majority of undergraduate students report poor sleep and stress (American College Health Association, 2014; Lund et al., 2010). Poor sleep and stress have both been shown to impact executive control which is vital for daily functioning (Diamond, 2013; Gärtner et al., 2014; Wilckens et al., 2014). The present study showed average sleep quality predicts executive control under stress. Future investigations should apply these findings to other areas such as psychopathology as executive control may be the mechanism through which sleep can predict psychological disorders (Bolden et al., 2019). This finding has potential implications for optimizing college student wellness through behavior modification interventions. Future studies should examine the role of napping (specifically napping with REM sleep) and exercise to buffer the impacts of poor sleep on executive control (Lau et al., 2015; Mednick et al., 2003; Reichert et al., 2014; Sewell et al., 2021; Wilckens et al., 2014). Due to the impact of sleep quality on executive control under stress and to support students in achieving academic success and well-being, future research should examine implications for psychopathology and interventions to buffer impacts of poor sleep and stress on executive control.

Tables and Figures

Table 1

Descriptive Statistics for Study Variables

Variable	*N*	*Min*	*Max*	*M*	*SD*
N-back 2 Errors	102	2.00	42.00	12.83	9.00
N-back 1 Errors	101	2.00	48.00	14.06	7.77
Average Sleep Efficiency	76	61.09	91.40	81.66	5.40
Night Prior Sleep Efficiency	74	52.20	94.04	81.35	9.08
Valid N	71				

Table 2

Descriptive Statistics by Condition

Condition	*N*	*Min*	*Max*	*M*	*SD*
Control					
N-back 2 Errors	55	3.00	36.00	12.75	8.79
N-back 1 Errors	52	2.00	48.00	13.87	8.99
Average Sleep Efficiency	40	73.30	91.23	83.16	3.71
Night Prior Sleep Efficiency	40	53.16	94.04	82.66	8.05
Valid N	38				
Stress					
N-back 2 Errors	47	2.00	42.00	12.94	9.32
N-back 1 Errors	49	3.00	36.00	14.27	6.30
Average Sleep Efficiency	36	61.09	91.40	79.99	6.46
Night Prior Sleep Efficiency	34	52.20	93.21	79.81	10.06
Valid N	33				

Table 3

Zero-Order Correlations Among Variables

Variable	*N-back 1 Errors*	*N-back 2 Errors*	*NP Sleep*	*AVG Sleep*
N-back 1 Errors	-	.667**	.155	-.171
N-back 2 Errors	.667**	-	-.134	-.309**
NP Sleep	.155	-.134	-	.357**
AVG Sleep	-.171	-.309**	.357**	-

Note. AVG Sleep = Average Sleep Efficiency. NP Sleep = Night Prior Sleep Efficiency.

** $p < 0.01$ level (2-tailed).

Table 4

Correlations for Study Variables by Condition

Condition	***N-back 1 Errors***	***N-back 2 Errors***	***NP Sleep***	***AVG Sleep***
Control				
N-back 1 Errors	-	.704**	.164	.069
N-back 2 Errors	.704**	-	.070	.119
NP Sleep	.164	.070	-	.328*
AVG Sleep	.069	.119	.328*	-
Stress				
N-back 1 Errors	-	.643**	.186	-.400*
N-back 2 Errors	.643**	-	-.292	-.559**
NP Sleep	.186	-.292	-	.336
AVG Sleep	-.400*	-.559**	.336	-

Note. AVG Sleep = Average Sleep Efficiency. NP Sleep = Night Prior Sleep Efficiency.

*$p < 0.05$ (2-tailed). ** $p < 0.01$ level (2-tailed).

Table 5

Moderator Analysis: Average Sleep Efficiency

Model	***Coefficient***	***SE***	***t***	***p***	***CILL***	***CIUL***
Constant	12.11	1.43	8.49	.000	9.27	14.96
AVG Sleep	.27	.36	.76	.451	-.44	.99
Condition	.28	2.04	.14	.892	-3.79	4.35
AVG Sleep x Condition	-1.09	.42	-2.59	.012	-1.93	-.25
Condition	**Effect**	**SE**	***t***	***p***		
Control	.27	.36	.76	.451		
Stress	-.82	.22	-3.73	.000		

Note. AVG Sleep = Average Sleep Efficiency. NP Sleep = Night Prior Sleep Efficiency. Average sleep efficiency was mean centered prior to analysis.

Table 6

Moderator Analysis: Average Sleep Efficiency Controlling for Night Prior Sleep Efficiency

Model	***Coefficient***	***SE***	***t***	***p***	***LLCI***	***ULCI***
Constant	16.00	9.72	1.65	.104	-3.39	35.40
AVG Sleep	.31	.37	.82	.415	-.44	1.05
Condition	.10	2.11	.05	.960	-4.10	4.31
AVG Sleep x Condition	-1.10	.43	-2.56	.013	-1.95	-.24
NP Sleep	.05	.12	-.40	.687	-.28	.19
Condition	**Effect**	**SE**	***t***	***P***		
Control	.31	.37	.82	.415		
Stress	-.79	.23	-3.44	.001		

Note. AVG Sleep = Average Sleep Efficiency. NP Sleep = Night Prior Sleep Efficiency. Average sleep efficiency was mean centered prior to analysis.

Table 7

Moderator Analysis: Night Prior Sleep Efficiency

Model	***Coefficient***	***SE***	***t***	***p***	***LLCI***	***ULCI***
Constant	12.42	1.45	8.59	.000	9.53	15.30
NP Sleep	.07	.18	.42	.678	-.28	.43
Condition	.86	2.15	.40	.692	-3.43	5.14
NP Sleep x Condition	-.36	.24	-1.49	.141	-.83	.12
Condition	**Effect**	**SE**	***t***	***p***		
Control	.07	.18	.42	.678		
Stress	-.28	.16	-1.78	.080		

Note. AVG Sleep = Average Sleep Efficiency. NP Sleep = Night Prior Sleep Efficiency. Night prior sleep efficiency was mean centered prior to analysis.

Table 8

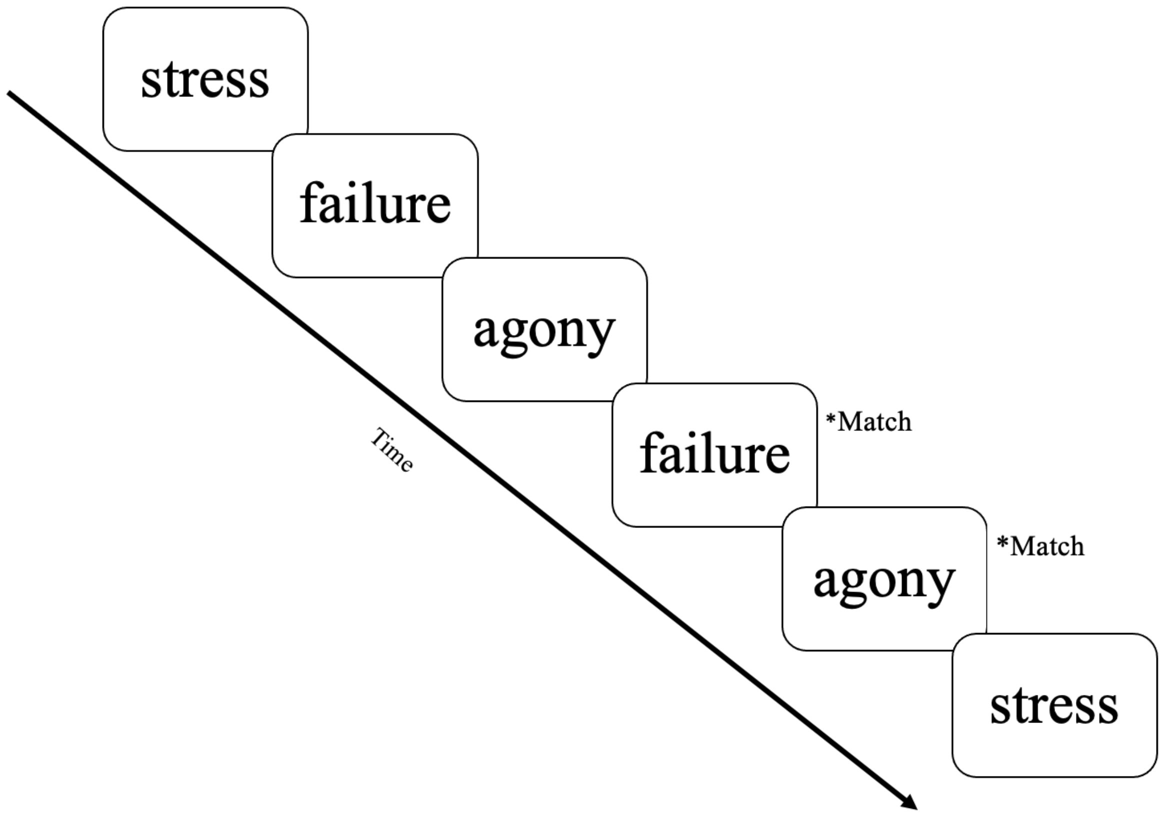
Moderator Analysis: Night Prior Sleep Efficiency Controlling for Average Sleep Efficiency

Model	***Coefficient***	***SE***	***t***	***p***	***LLCI***	***ULCI***
Constant	52.64	17.27	3.05	.003	18.18	87.10
NP Sleep	.15	.18	.84	.404	-.20	.50
Condition	-.47	2.16	-.22	.828	-4.78	3.84
NP Sleep x Condition	-.32	.23	-1.39	.170	-.79	.14
AVG Sleep	-.48	.21	-2.34	.022	-.90	-.07
Condition	**Effect**	**SE**	***t***	***P***		
Control	.15	.18	.84	.404		
Stress	-.17	.16	-1.09	.280		

Note. AVG Sleep = Average Sleep Efficiency. NP Sleep = Night Prior Sleep Efficiency. Night prior sleep efficiency was mean centered prior to analysis.

Figure 1

Example of N-back Task (2-back)



Note. This figure is an example of the n-back (2-back). Participants identify whether the current word that they see matches the word they saw two-words back. Each word was presented for 500 milliseconds with a 2,500-millisecond interval between each word.

Figure 2

N-back 2 Errors by Average Sleep Efficiency

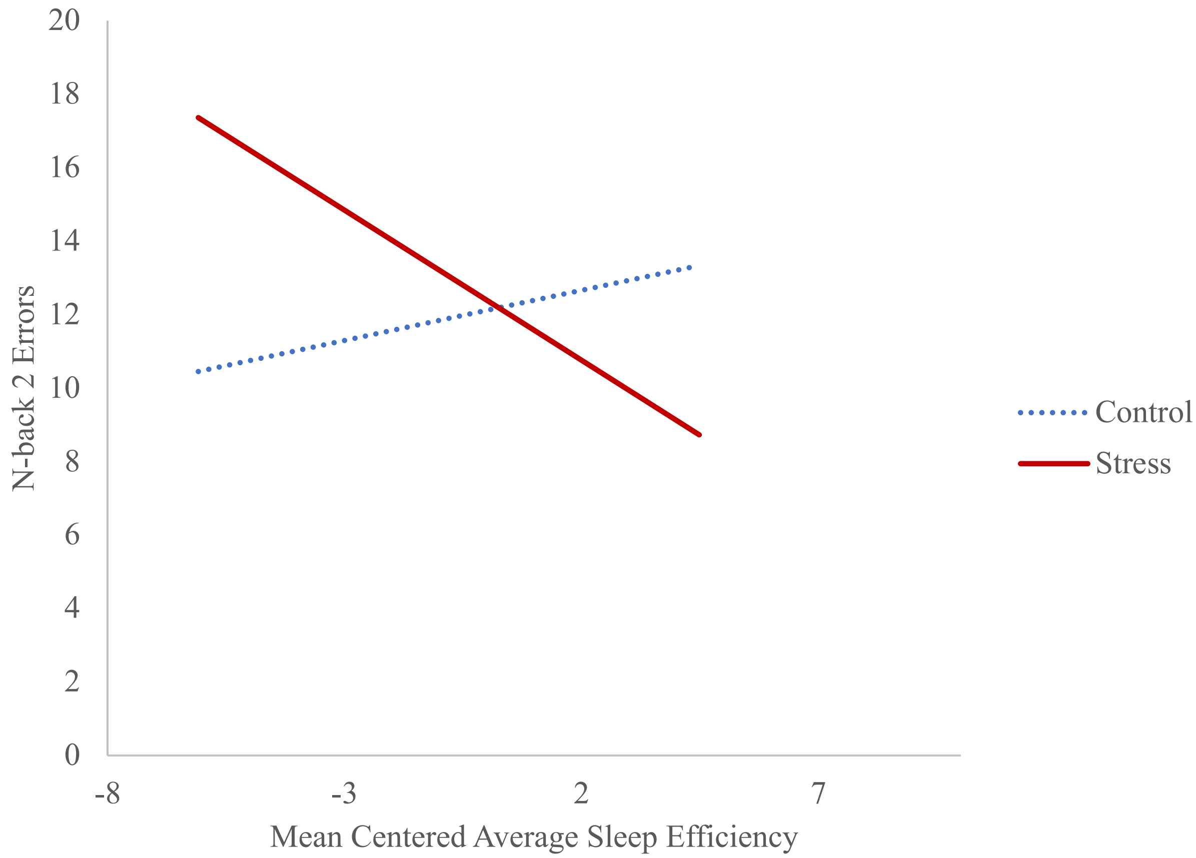
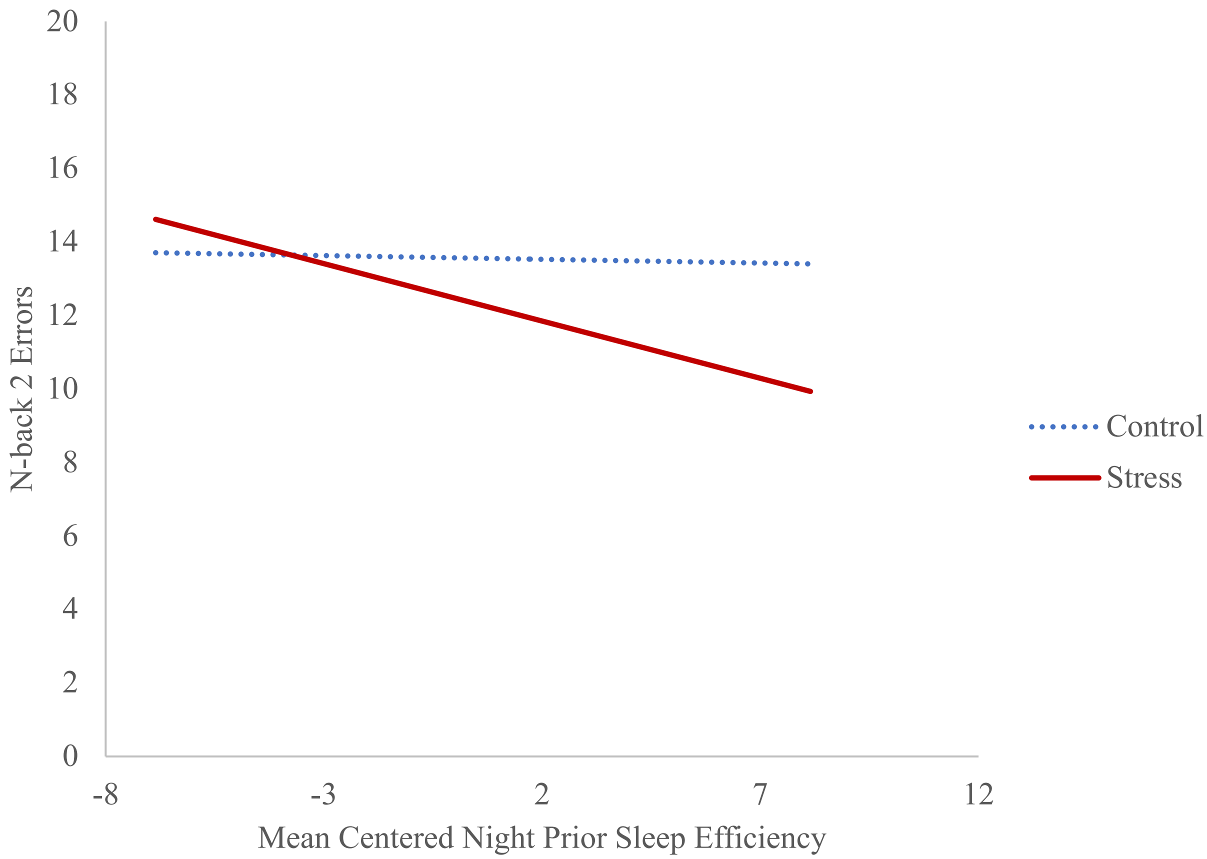


Figure 3

N-back 2 Errors by Night Prior Sleep Efficiency



References

American College Health Association. (2012). *American College Health Association-National College Health Assessment II: Reference Group Executive Summary Fall 2011. https://www.acha.org/documents/ncha/ACHA-NCHA-II_ReferenceGroup_ExecutiveSummary_Fall2011.pdf*

American College Health Association. (2014). *American College Health Association-National College Health Assessment II: Reference Group Executive Summary Spring 2014.* https://www.acha.org/documents/ncha/ACHA-NCHA-II_ReferenceGroup_ExecutiveSummary_Spring2014.pdf

American College Health Association. (2022). *American College Health Association-National College Health Assessment III: Reference Group Executive Summary Fall 2021. https://www.acha.org/documents/ncha/NCHA-III_FALL_2021_REFERENCE_GROUP_EXECUTIVE_SUMMARY.pdf*

Baars, M. A. E., Nije Bijvank, M., Tonnaer, G. H., & Jolles, J. (2015). Self-report measures of executive functioning are a determinant of academic performance in first-year students at a university of applied sciences. *Frontiers in Psychology, 6*, 1131. https://doi.org/10.3389/fpsyg.2015.01131

Bassett, S. M., Lupis, S. B., Gianferante, D., Rohleder, N., & Wolf, J. M. (2015). Sleep quality but not sleep quantity effects on cortisol responses to acute psychosocial stress. *Stress, 18*(6), 638-644. https://doi.org/10.3109/10253890.2015.1087503

Blankenship, T. L., O'Neill, M., Ross, A., & Bell, M. A. (2015). Working memory and recollection contribute to academic achievement. *Learning and Individual Differences, 43*, 164-169. https://doi.org/10.1016/j.lindif.2015.08.020

Blasiman, R. N., & Was, C. A. (2018). Why is working memory performance unstable? A review of 21 factors. *Europe's Journal of Psychology, 14*(1), 188-231. https://doi.org/10.5964/ejop.v14i1.1472

Boeve, A., Halpin, A., Michaud, S., Fagan, M., & MacAulay, R. K. (2022). Specific sleep health domains as predictors of executive function in older adults. *The Journal of Neuropsychiatry and Clinical Neurosciences*, appi. neuropsych. 21040112.

Bolden, J., Gilmore-Kern, J., & Fillauer, J. P. (2019). Associations among sleep problems, executive dysfunctions, and attention-deficit/hyperactivity disorder symptom domains in college students. *Journal of American College Health, 67*(4), 320-327. https://doi.org/10.1080/07448481.2018.1481070

Cavuoto, M. G., Ong, B., Pike, K. E., Nicholas, C. L., Bei, B., & Kinsella, G. J. (2016). Objective but not subjective sleep predicts memory in community-dwelling older adults. *Journal of Sleep Research, 25*(4), 475-485.

Ciszewski, S., Flood, K. E., Proctor, C. J., & Best, L. A. (2020). Exploring the relationship between disordered eating and executive function in a non-clinical sample. *Perceptual and Motor Skills, 127*(6), 1033-1050. https://doi.org/10.1177/0031512520937569

Cousins, J. N., Leong, R. L. F., Jamaluddin, S. A., Ng, A. S. C., Ong, J. L., & Chee, M. W. L. (2021). Splitting sleep between the night and a daytime nap reduces homeostatic sleep pressure and enhances long-term memory. *Scientific Reports, 11*(1), 5275. https://doi.org/10.1038/s41598-021-84625-8

Coy, B., O'Brien, W. H., Tabaczynski, T., Northern, J., & Carels, R. (2011). Associations between evaluation anxiety, cognitive interference and performance on working memory tasks. *Applied Cognitive Psychology, 25*(5), 823-832. https://doi.org/10.1002/acp.1765

Diamond, A. (2013). Executive functions. *Annual Review of Psychology, 64*(1), 135-168. https://doi.org/10.1146/annurev-psych-113011-143750

Dickerson, S. S., & Kemeny, M. E. (2004). Acute stressors and cortisol responses: A theoretical integration and synthesis of laboratory research. *Psychological Bulletin, 130*(3), 355-391. https://doi.org/10.1037/0033-2909.130.3.355

Fischer, D., Lombardi, D. A., Marucci-Wellman, H., & Roenneberg, T. (2017). Chronotypes in the US - influence of age and sex. *PloS One, 12*(6), e0178782. https://doi.org/10.1371/journal.pone.0178782

Fjell, A. M., Sorensen, O., Amlien, I. K., Bartrés-Faz, D., Bros, D. M., Buchmann, N., Kietzmann, T. C., Kievit, R., Zsoldos, E., & Walhovd, K. B. (2020). Self-reported sleep relates to hippocampal atrophy across the adult lifespan: Results from the lifebrain consortium. *Sleep, 43*(5), 1. https://doi.org/10.1093/sleep/zsz280

Frost, A., Moussaoui, S., Kaur, J., Aziz, S., Fukuda, K., & Niemeier, M. (2021). Is the n-back task a measure of unstructured working memory capacity? towards understanding its connection to other working memory tasks. *Acta Psychologica, 219*, 103398. https://doi.org/10.1016/j.actpsy.2021.103398

Gärtner, M., Rohde-Liebenau, L., Grimm, S., & Bajbouj, M. (2014). Working memory-related frontal theta activity is decreased under acute stress. *Psychoneuroendocrinology, 43*, 105-113. https://doi.org/10.1016/j.psyneuen.2014.02.009

Guzman, G. G. (2018). *Household Income: 2017* [Infographic]. Census.gov. https://www.census.gov/content/dam/Census/library/publications/2018/acs/acsbr17-01.pdf

Hallion, L. S., Tolin, D. F., Assaf, M., Goethe, J., & Diefenbach, G. J. (2017). Cognitive control in generalized anxiety disorder: Relation of inhibition impairments to worry and anxiety severity. *Cognitive Therapy and Research, 41*(4), 610-618. https://doi.org/10.1007/s10608-017-9832-2

Healy, K. L., Oei, T. P., & Shaw, S. (2018). Effectiveness of a questionnaire measure of executive function in predicting treatment outcomes for anxiety and depression following CBT. *Scientific Journal of Depression and Anxiety, 2*(1), 1-9.

Het, S., Rohleder, N., Schoofs, D., Kirschbaum, C., & Wolf, O. T. (2009). Neuroendocrine and psychometric evaluation of a placebo version of the 'Trier social stress test'. *Psychoneuroendocrinology, 34*(7), 1075-1086. https://doi.org/10.1016/j.psyneuen.2009.02.008

Hirshkowitz, M., Whiton, K., Albert, S. M., Alessi, C., Bruni, O., DonCarlos, L., Hazen, N., Herman, J., Adams Hillard, P. J., Katz, E. S., Kheirandish-Gozal, L., Neubauer, D. N., O'Donnell, A. E., Ohayon, M., Peever, J., Rawding, R., Sachdeva, R. C., Setters, B., Vitiello, M. V., & Ware, J. C. (2015). National sleep foundation's updated sleep duration recommendations: Final report. *Sleep Health, 1*(4), 233-243. https://doi.org/10.1016/j.sleh.2015.10.004

Huang, T., Mariani, S., & Redline, S. (2020). Sleep irregularity and risk of cardiovascular events: The multi-ethnic study of atherosclerosis. *Journal of the American College of Cardiology, 75*(9), 991-999. https://doi.org/10.1016/j.jacc.2019.12.054

Kirschbaum, C., Pirke, K., & Hellhammer, D. H. (1993). The "trier social stress test": A tool for investigating psychobiological stress responses in a laboratory setting. *Neuropsychobiology, 28*, 76-81. https://doi.org/10.1159/000119004

Kitamura, S., Katayose, Y., Nakazaki, K., Motomura, Y., Oba, K., Katsunuma, R., Terasawa, Y., Enomoto, M., Moriguchi, Y., Hida, A., & Mishima, K. (2016). Estimating individual optimal sleep duration and potential sleep debt. *Scientific Reports, 6*(1), 35812. https://doi.org/10.1038/srep35812

Knouse, L. E., Feldman, G., & Blevins, E. J. (2014). Executive functioning difficulties as predictors of academic performance: Examining the role of grade goals. *Learning and Individual Differences, 36*, 19-26. https://doi.org/10.1016/j.lindif.2014.07.001

Kohyama, J. (2021). Which is more important for health: Sleep quantity or sleep quality? *Children (Basel), 8*(7), 542. https://doi.org/10.3390/children8070542

Kubota, Y., Takasu, N. N., Horita, S., Kondo, M., Shimizu, M., Okada, T., Wakamura, T., & Toichi, M. (2011). Dorsolateral prefrontal cortical oxygenation during REM sleep in humans. *Brain Research, 1389*, 83-92. https://doi.org/10.1016/j.brainres.2011.02.061

Landolt, H., Werth, E., Borbély, A. A., & Dijk, D. (1995). Caffeine intake (200 mg) in the morning affects human sleep and EEG power spectra at night. *Brain Research, 675*(1), 67-74. https://doi.org/10.1016/0006-8993(95)00040-W

Lau, E. Y. Y., Wong, M. L., Lau, K. N. T., Hui, F. W. Y., & Tseng, C. (2015). Rapid-eye-movement-sleep (REM) associated enhancement of working memory performance after a daytime nap. *PLoS One, 10*(5), e0125752.

Lipson, S. K., Zhou, S., Abelson, S., Heinze, J., Jirsa, M., Morigney, J., Patterson, A., Singh, M., & Eisenberg, D. (2022). Trends in college student mental health and help-seeking by race/ethnicity: Findings from the national healthy minds study, 2013–2021. *Journal of Affective Disorders, 306*, 138-147. https://doi.org/10.1016/j.jad.2022.03.038

Lo, J. C., Groeger, J. A., Cheng, G. H., Dijk, D., & Chee, M. W. L. (2016). Self-reported sleep duration and cognitive performance in older adults: A systematic review and meta-analysis. *Sleep Medicine, 17*, 87-98. https://doi.org/10.1016/j.sleep.2015.08.021

Lücke, A., Wrzus, C., Gerstorf, D., Kunzmann, U., Katzorreck, M., & Schilling, O. (2021). Sleep and working memory: Short-term links in daily life and long-term associations. *Innovation in Aging, 5*, 329. https://doi.org/10.1093/geroni/igab046.1280

Lund, H. G., Reider, B. D., Whiting, A. B., & Prichard, J. R. (2010). Sleep patterns and predictors of disturbed sleep in a large population of college students. *Journal of Adolescent Health, 46*(2), 124-132. https://doi.org/10.1016/j.jadohealth.2009.06.016

Magalhães, R., Picó-Pérez, M., Esteves, M., Vieira, R., Castanho, T. C., Amorim, L., Sousa, M., Coelho, A., Fernandes, H. M., Cabral, J., Moreira, P. S., & Sousa, N. (2021). Habitual coffee drinkers display a distinct pattern of brain functional connectivity. *Molecular Psychiatry, 26*(11), 6589-6598. https://doi.org/10.1038/s41380-021-01075-4

Mednick, S., Nakayama, K., & Stickgold, R. (2003). Sleep-dependent learning: A nap is as good as a night. *Nature Neuroscience, 6*(7), 697-698. https://doi.org/10.1038/nn1078

Meltzer, L. J., Walsh, C. M., Traylor, J., & Westin, A. M. L. (2012). Direct comparison of two new actigraphs and polysomnography in children and adolescents. *Sleep, 35*(1), 159-166. https://doi.org/10.5665/sleep.1608

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., & Wager, T. D. (2000). The unity and diversity of executive functions and their contributions to complex “frontal lobe” tasks: A latent variable analysis. *Cognitive Psychology, 41*(1), 49-100.

Miyata, S., Noda, A., Iwamoto, K., Kawano, N., Okuda, M., & Ozaki, N. (2013). Poor sleep quality impairs cognitive performance in older adults. *Journal of Sleep Research, 22*(5), 535-541.

National Cancer Institute. (n.d.). Therapeutic Hydrocortisone (Code C555). *In NCIthesaurus.* Retrieved April 16, 2023, from https://ncithesaurus.nci.nih.gov/ncitbrowser/ConceptReport.jsp?dictionary=NCI_Thesaurus&ns=ncit&code=C555.

National Center for Education Statistics. (2022, May). *Postbaccalaureate Enrollment*. U.S. Department of Education, Institute of Education Sciences https://nces.ed.gov/programs/coe/indicator/chb

National Institute of Neurological Disorders and Stroke. (2023, March 17). *Brain Basics: Understanding Sleep.* https://www.ninds.nih.gov/health-information/public-education/brain-basics/brain-basics-understanding-sleep

National Sleep Foundation. (2020, October 28). *What is Sleep Quality?* https://www.thensf.org/what-is-sleep-quality/#:~:text=People%20with%20good%20sleep%20quality,more%20for%20optimal%20health%20benefits.

Ochab, J. K., Szwed, J., Oleś, K., Bereś, A., Chialvo, D. R., Domagalik, A., Fąfrowicz, M., Ogińska, H., Gudowska-Nowak, E., Marek, T., & Nowak, M. A. (2021). Observing changes in human functioning during induced sleep deficiency and recovery periods. *PloS One, 16*(9), e0255771. https://doi.org/10.1371/journal.pone.0255771

Ohayon, M., Wickwire, E. M., Hirshkowitz, M., Albert, S. M., Avidan, A., Daly, F. J., Dauvilliers, Y., Ferri, R., Fung, C., Gozal, D., Hazen, N., Krystal, A., Lichstein, K., Mallampalli, M., Plazzi, G., Rawding, R., Scheer, F. A., Somers, V., & Vitiello, M. V. (2017). National sleep foundation's sleep quality recommendations: First report.

Okano, K., Kaczmarzyk, J. R., Dave, N., Gabrieli, J. D. E., & Grossman, J. C. (2019). Sleep quality, duration, and consistency are associated with better academic performance in college students. *NPJ Science of Learning, 4*(1), 1-5. https://doi.org/10.1038/s41539-019-0055-z

Parada, M., Corral, M., Mota, N., Crego, A., Rodríguez Holguín, S., & Cadaveira, F. (2012). Executive functioning and alcohol binge drinking in university students. *Addictive Behaviors, 37*(2), 167-172. https://doi.org/10.1016/j.addbeh.2011.09.015

Pasula, E., Manoussakis, J., Anderson, C., & Drummond, S. (2018). Night-to-night sleep variability versus delta power: Effects on working memory in younger and older adults. Paper presented at the *Journal of Sleep Research, 27*

Pe, M. L., Brose, A., Gotlib, I. H., & Kuppens, P. (2016). Affective updating ability and stressful events interact to prospectively predict increases in depressive symptoms over time. *Emotion, 16*(1), 73-82. https://doi.org/10.1037/emo0000097

Pellegrino, R., Kavakli, I. H., Goel, N., Cardinale, C. J., Dinges, D. F., Kuna, S. T., Maislin, G., Van Dongen, H., P.A., Tufik, S., Hogenesch, J. B., Hakonarson, H., & Pack, A. I. (2014). A novel BHLHE41 variant is associated with short sleep and resistance to sleep deprivation in humans. *Sleep, 37*(8), 1327-1336. https://doi.org/10.5665/sleep.3924

Perez, E., Dzierzewski, J. M., Aiken-Morgan, A. T., McCrae, C. S., Buman, M. P., Giacobbi, P. R., Roberts, B. L., & Marsiske, M. (2020). Anxiety and executive functions in mid-to-late life: The moderating role of sleep. *Aging & Mental Health, 24*(9), 1459-1465.

Phan, D., Chan, C., Pan, R., Yang, N., Hsu, H., Ting, H., Lai, K. R., & Lin, K. (2019). Investigating the effect of daily sleep on memory capacity in college students. *Technology and Health Care, 27*(2), 183-194. https://doi.org/10.3233/THC-181350

Prather, A. A., Hall, M., Fury, J. M., Ross, D. C., Muldoon, M. F., Cohen, S., & Marsland, A. L. (2012). Sleep and antibody response to hepatitis B vaccination. *Sleep, 35*(8), 1063-1069. https://doi.org/10.5665/sleep.1990

Qin, S., Hermans, E. J., van Marle, H. J. F., Luo, J., & Fernández, G. (2009). Acute psychological stress reduces working memory-related activity in the dorsolateral prefrontal cortex. *Biological Psychiatry, 66*(1), 25-32. https://doi.org/10.1016/j.biopsych.2009.03.006

Quinn, M. E., & Joormann, J. (2015). Control when it counts: Change in executive control under stress predicts depression symptoms. *Emotion, 15*(4), 522-530. https://doi.org/10.1037/emo0000089

Rana, B. K., Panizzon, M. S., Franz, C. E., Spoon, K. M., Jacobson, K. C., Xian, H., Ancoli-Israel, S., Lyons, M., & Kremen, W. S. (2018). Association of sleep quality on memory-related executive functions in middle age. *Journal of the International Neuropsychological Society, 24*(1), 67-76. https://doi.org/10.1017/S1355617717000637

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

Reichert, C. F., Maire, M., Gabel, V., Hofstetter, M., Viola, A. U., Kolodyazhniy, V., Strobel, W., Goetz, T., Bachmann, V., Landolt, H., Cajochen, C., & Schmidt, C. (2014). The circadian regulation of sleep: Impact of a functional ADA-polymorphism and its association to working memory improvements. *PLoS One, 9*(12), e113734. https://doi.org/10.1371/journal.pone.0113734

Roenneberg, T., Kuehnle, T., Pramstaller, P. P., Ricken, J., Havel, M., Guth, A., & Merrow, M. (2004). A marker for the end of adolescence. *Current Biology, 14*(24), R1038-R1039. https://doi.org/10.1016/j.cub.2004.11.039

Saffer, B. Y., & Klonsky, E. D. (2017). The relationship of self-reported executive functioning to suicide ideation and attempts: Findings from a large U.S.-based online sample. *Archives of Suicide Research, 21*(4), 577-594. https://doi.org/10.1080/13811118.2016.1211042

Scullin, M. K. (2019). The eight hour sleep challenge during final exams week. *Teaching of Psychology, 46*(1), 55-63. https://doi.org/10.1177/0098628318816142

Sewell, K. R., Erickson, K. I., Rainey-Smith, S. R., Peiffer, J. J., Sohrabi, H. R., & Brown, B. M. (2021). Relationships between physical activity, sleep and cognitive function: A narrative review. *Neuroscience & Biobehavioral Reviews, 130*, 369-378.

Shuttleworth, S., & Foster, R. G. (2020). Sleep and stress. *Interface Focus, 10*(3), 20200016. https://doi.org/10.1098/rsfs.2020.0016

Siquara, G. M., Lima, C. d. S., & Abreu, N. (2018). Working memory and intelligence quotient: Which best predicts on school achievement? *Psico: Revista Semestral do Instituto De Psicologia Da PUC Rio Grande do Sul, Brasil, 49*(4), 365-374. https://doi.org/10.15448/1980-8623.2018.4.27943

Van Dongen, H. P. A., Maislin, G., Mullington, J. M., & Dinges, D. F. (2003). The cumulative cost of additional wakefulness: Dose-response effects on neurobehavioral functions and sleep physiology from chronic sleep restriction and total sleep deprivation. *Sleep: Journal* *of Sleep and Sleep Disorders Research, 26*, 117-126. https://doi.org/10.1093/sleep/26.2.117

Vaz, L. J., Pradella-Hallinan, M., Bueno, O. F. A., & Pompéia, S. (2011). Acute glucocorticoid effects on the multicomponent model of working memory. *Human Psychopharmacology, 26*(7), 477-487. https://doi.org/10.1002/hup.1230

Weaver, A. L., Stutzman, S. E., Supnet, C., & Olson, D. M. (2016). Sleep quality, but not quantity, is associated with self-perceived minor error rates among emergency department nurses. *International Emergency Nursing, 25*, 48-52. https://doi.org/10.1016/j.ienj.2015.08.003

Whiting, W. L., & Murdock, K. K. (2016). Emerging adults' sleep patterns and attentional capture: The pivotal role of consistency. *Cognitive Processing, 17*(2), 155-162. https://doi.org/10.1007/s10339-016-0754-9

Wilckens, K. A., Erickson, K. I., & Wheeler, M. E. (2018). Physical activity and cognition: A mediating role of efficient sleep. *Behavioral Sleep Medicine, 16*(6), 569-586. https://doi.org/10.1080/15402002.2016.1253013

Wilckens, K. A., Woo, S. G., Kirk, A. R., Erickson, K. I., & Wheeler, M. E. (2014). Role of sleep continuity and total sleep time in executive function across the adult lifespan. *Psychology and Aging, 29*(3), 658-665. https://doi.org/10.1037/a0037234

Wild, C. J., Nichols, E. S., Battista, M. E., Stojanoski, B., & Owen, A. M. (2018). Dissociable effects of self-reported daily sleep duration on high-level cognitive abilities. *Sleep, 41*(12), 1. https://doi.org/10.1093/sleep/zsy182

Williams, P. G., Cribbet, M. R., Rau, H. K., Gunn, H. E., & Czajkowski, L. A. (2013). The effects of poor sleep on cognitive, affective, and physiological responses to a laboratory stressor. *Annals of Behavioral Medicine, 46*(1), 40-51. https://doi.org/10.1007/s12160-013-9482-x

Yu, D., Goncalves, C., Yang, P., Geldhof, G. J., Michaelson, L., Ni, Y., & Lerner, R. M. (2022). Does prior night's sleep impact next day's executive functioning? it depends on an individual's average sleep quality. *Journal for Person-Oriented Research, 8*(1), 10. –23. https://doi.org/10.17505/jpor.2022.24218

Zavecz, Z., Nagy, T., Galkó, A., Nemeth, D., & Janacsek, K. (2020). The relationship between subjective sleep quality and cognitive performance in healthy young adults: Evidence from three empirical studies. *Scientific Reports, 10*(1), 4855–4855. https://doi.org/10.1038/s41598-020-61627-6

APPENDIX

Table A1

Sociodemographic Characteristics of Sample and Conditions

Baseline Characteristic	Control		Stress		Full Sample	
	n	%	n	%	n	%
Age						
18	16	39%	15	43%	31	41%
19	12	29%	15	43%	27	36%
20	8	20%	2	6%	10	13%
21	2	5%	1	3%	3	4%
22	1	2%	0	0%	1	1%
26	1	2%	0	0%	1	1%
No Response	1	2%	2	6%	3	4%
Gender						
Male	21	51%	10	29%	31	41%
Female	18	44%	23	66%	41	54%
Other	1	2%	0	0%	1	1%
No Response	1	2%	2	6%	3	4%
Race						
White/Caucasian	22	54%	13	37%	35	46%
Black/African American/African	4	10%	4	11%	8	11%
Asian/Asian American	6	15%	10	29%	16	21%
Latino/Hispanic	1	2%	1	3%	2	3%

Table A1 (continued)

Baseline Characteristic	Control		Stress		Full Sample	
	n	%	n	%	n	%
Race						
American Indian/Native American/Alaska Native	0	0%	0	0%	0	0%
Middle Eastern/Arab	0	0%	0	0%	0	0%
Native Hawaiian/Pacific Islander	0	0%	0	0%	0	0%
Multiracial	7	17%	5	14%	12	16%
No Response	1	2%	2	6%	3	4%
Academic Year						
Freshman	21	51%	22	63%	43	57%
Sophomore	12	29%	10	29%	22	29%
Junior	5	12%	0	0%	5	7%
Senior	2	5%	1	3%	3	4%
No Response	1	2%	2	6%	3	4%
Family's Household Income						
$25,000 or less	3	7%	2	6%	5	7%
$25,001 - $40,000	3	7%	3	9%	6	8%
$40,001-$70,000	2	5%	3	9%	5	7%
$70,001 - $90,000	2	5%	3	9%	5	7%
$90,001 - 120,000	4	10%	3	9%	7	9%
$120,001 - $150,000	6	15%	2	6%	8	11%

Table A1 (continued)

Baseline Characteristic	Control		Stress		Full Sample	
	n	%	n	%	n	%
Family's Household Income						
$150,001 - $200,000	7	17%	6	17%	13	17%
$200,001 - $300,000	6	15%	6	17%	12	16%
$300,001 or more	6	15%	3	9%	9	12%
No Response	2	5%	4	11%	6	8%