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The Effects of Sleep Quality on Response Inhibition.

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Abstract

Night-time sleep is critical for waking cognition. The duration, quality, and architecture (the distribution of non-rapid eye movement (NREM) and rapid eye movement (REM) sleep) of sleep has been demonstrated to be linked to memory consolidation, emotional regulation, visual acuity, and other cognitive tasks essential to normative mental processes. Here, we investigate the relationship between response inhibition and sleep quality by comparing sleep measures and next day performance on an attention cognitive task; a measure of response inhibition. With a volunteer group of university students, we compared an experimental group that adjusted their sleep regimen according to sleep hygiene best practices to a control group without behavioral interventions. We used OURA rings to generate sleep index scores as measures of sleep quality. We hypothesized that 1) poor sleep quality would negatively impact attention task scores, 2) good sleep quality would positively impact attention scores and, 3) the experiment group would reflect higher frequency of positive moods based off a self-rated index. Our results suggest that the experiment group reported higher frequencies of positive moods, and that sleep quality is a positive predictor of performance on attention task scores, albeit an insignificant driver of attention task scores (*p*=0.44, CI: -0.103, 0.687). Instead, REM sleep is both a positive and significant driver of attention task scores (*p*=0.03, CI: 0.105, 0.614). Our findings suggest that the link between inhibitive emotional processing and REM sleep is one avenue to ensure altruistic behaviors between groups of people.

Keywords: sleep deprivation; cognition; response inhibition; attention; emotions

1. Introduction

Sleep is essential for a variety of cognitive functions (Zhao et al. 2018; Bocca et al. 2014). Sleep deprived individuals are more likely to engage in impulsive behaviors, impaired decision making, and demonstrate attenuated response inhibition (Anderson & Platten 2011; Chuah et al. 2006). An important part of executive functioning is inhibitory control; the ability to restrain oneself from inappropriate reactions in a given context (Zhao et al. 2018; Drummond et al. 2018). Sleep regulates the inhibitory effect on emotional reactivity (Van Peer et al. 2018; Yoo et al. 2007). Thus, the affective consequences of sleep deprivation extends beyond just the laboratory as the societal implications are felt daily in workplace environments where one is expected to maintain a standard of emotional restraint (Yoo et al. 2007; Anderson & Platten 2011). For example, performing tasks, such as driving, becomes difficult when one is unable to govern the appropriate reaction (Anderson & Platten 2011; Zhao et al. 2018).

Sleep plays a role in emotional processing (Stojanoski et al. 2019). Response inhibition is composed of two parts: The first part is described as paying attention to an incoming stimulus, while the latter component is inhibiting an output in response to that stimulus (Drummond et al. 2006). Response inhibition plays an important part in selective attention, it functions to ignore irrelevant stimuli that is in competition with the individual's goals

(Bocca et al. 2014; Diamond 2013). Sleep deprived individuals have been shown to experience greater difficulty in withholding inappropriate expressions towards negative stimuli (Drummond et al. 2006; Zhao et al. 2019). In addition, starting as early as childhood, the affective consequences of poor sleep quality has been linked to aggression, negatively impacting interpersonal relationships (Zhang et al. 2017; Schumacher et al. 2017; Anderson & Platten 2011).

Functionally, the prefrontal cortex, and specifically the amygdala, is a key driver of emotional processing by way of memory consolidation (Schumacher et al. 2017; Yoo et al. 2007; Walker 2009; Hashizume et al. 2019). Executive functioning is also dependent on the prefrontal cortex, suggesting that emotional processing and inhibitory control are intimately tied (Nilsson et al. 2005). Critically, sleep loss is associated with the diminished top-down effect over the amygdala, resulting in impaired inhibitory emotional processing, and consequently, expressing inappropriate responses (Yoo et al. 2007; Anderson & Platten 2011). The lack of sleep not only impairs its modulatory effect over emotions, but the deprivation results in a higher probability of reacting to adverse events (Yoo et al. 2007). Experimentally, this has been demonstrated in fMRI studies that show the amygdala exhibits greater activation than compared to non-sleep deprived individuals, with impulsive responses towards negative events (Yoo et al. 2007; Van Peer et al. 2018).

In an evolutionary context, the resistance of negative emotions against sleep loss may serve as a way to prime the body to recognize negative stimuli at a quicker rate (Anderson & Platten 2011; Minkel et al. 2012; Walker 2009). In a study conducted by Van Peer et al. (2018), individuals who were sleep deprived, relative to a normal sleep control group, demonstrated attenuation of response inhibition during a simulated shooting task. Critically, from an evolutionary perspective, threat perception differed amongst sleep deprived and non-sleep deprived groups, with the former recognizing situations of threat quicker (Minkel et al. 2012). Sleep deprived individuals recognize environmental threats by preparing to react quicker and impulsively to potentially threatening stimuli by decreasing inhibitory control (Anderson & Platten 2011). This suggests that the body's response to sleep deprivation may have been adaptive since it is a universal response demonstrated by everybody (Anderson & Platten 2011).

In this study, we measured response inhibition by next day performance on an attention cognitive task in a group of university students (*n*=17) following a night's sleep. Response inhibition is measured by performance on an attention cognitive task. Use of OURA ring data measured sleep index, defined as a sleep score generated by considering a multitude of sleep metrics. Additionally, subjective reports of mood from sleep journals were collected and compared between experiment and control groups. We interrogate the sleep-to-inhibit hypothesis, an idea that hypothesizes that better sleep quality drives the capacity to behaviorally inhibit responses to stimuli. We tested the following predictions stemming from the sleep-to-inhibit hypothesis: 1) poor sleep quality would negatively impact attention task scores; 2) good sleep quality would positively impact attention scores; and 3) the experiment group would reflect higher frequency of positive moods based off a self-rated index.

2. Methods

2.1. Participants

A sample of students from the University of Toronto Mississauga participated in this study, which took place between the period of October 8, 2019 to October 29, 2019. The sample consisted of 17 adults, between the ages of 20-25 years old (13 females and 4 males). The participants were split into 4 groups, divided into categories Finch, Alpha, Omega, or Zebra. During the first week of the study, participants established a baseline by following their normal sleep routine. For the following 3 weeks, the 4 groups were split into 2 groups, experiment and control. Control and experiment groups alternated weekly. Sleep data from these groups was collected into an *Excel* spreadsheet. The attention task was administered October 21-25. We used the OURA ring to track sleep of the participants. The waterproof ceramic ring is connected via Bluetooth and transferred data to the participant's mobile device (Zambotti et al. 2017).

2.2. Experimental protocol

The control group was instructed to follow their regular sleep regime, while the experiment group adjusted their sleep routine to implement best practices of clinically recommended sleep guidelines (National Sleep Foundation, 2020). The experimental protocol entails guidelines for proper sleep hygiene, light hygiene, and circadian amplification.

Efficient sleep hygiene is defined as follows. Firstly, room temperature is set between 18-20 degrees Celsius, since cooler temperatures at night is an environmental cue that regulates the sleep circadian rhythm. The protocol had participants remove any stimulus in their sleep chambers during the evening, including electronics 1 hour before bed. If electronics were used, subjects were told to wear blue light blocking glasses. Secondly, participants were instructed to avoid any ingestion of caffeine after noon. For proper light hygiene, participants were required to receive a minimum of 30 minutes of natural sunlight a day. Experiment participants were instructed to refrain from any type of cool light during the evening. If lighting was necessary, participants used a warm-light candle, the Aukey Mini RGB Light, set on warm-light settings (180 lumens, 2700-6500 Kelvin) as a source of lighting.

Circadian amplification was the third component of the experiment protocol. This part of the experiment instructed participants to consistently wake up around dawn and go to bed around 10-11 PM. One hour before going to sleep, participants set an alarm that reminded them to unwind. Lastly, students were instructed not to perform any type of physical activity close to bedtime.

2.3. Cognitive testing

Response inhibition was measured by performing an attention cognitive task for five days, similar to the Go or No Go (GnG) tasks commonly used, such as in Jin and colleagues (2015). GnG tasks present a commonly occurring go-stimulus coupled with a rarely occurring no-go-stimulus and is regarded to be an accurate measure of response inhibition (Cragg & Nation 2008). The participants completed a cognitive test online from the Harvard University Cognitive Task site; the Gradual Onset Continuous Performance Test (Test My Brain 2019, https://testmybrain.org/research_tools/). Once a test is completed, a score is generated according to the participant's performance. The cognitive test was administered the same time each day, between 9-10 AM, and performed 5 times a week, Monday through Friday.

The attention task was a 7-minute test that assesses sustained attention and the ability to inhibit responses. This tested the "Go-No-Go" action. The test required participants to pay attention to pictures that were displayed on the screen. These pictures consisted of city scenery and mountains. Participants were instructed to press the spacebar only when city scenes appeared. Conversely, the participant must withhold pressing the spacebar on mountainous scenes.

2.4. Data entry

During the experiment, each participant was required to fill out a sleep diary from the National Sleep Foundation twice a day; once in the morning and once in the evening (https://www.sleepfoundation.org/articles/nsf-official-sleep-diary). Three copies of the diary were printed, one for each week of study. These diaries allowed for subjective reports of the participant's sleep. The morning component of the diary consisted of answering 9 questions, including time of sleep onset and offset, length of sleep, how long it took to fall asleep, mood upon awakening, and any sleep disturbances. At the end of each day, subjects answered another 8 questions. This included ingestion of any caffeinated drinks, medications taken, naps, any exercise exceeding 20 minutes, and mood throughout the day. Additionally, alcohol ingestion, caffeine, or heavy meals approximately 2-3 hours before bed are noted. Finally, participants noted their bedtime routine in the hour before going to bed, such as reading a book, use of electronics, meditation, or any bathing.

Finally, each participant was instructed to input their data into an *Excel* spreadsheet. Along with the data from the sleep diary and attention task scores, the participants recorded the date, age, sex, group ID and experimental group. Additionally, experimental compliance to sleep hygiene protocol was indicated by a binary yes or no option in the data spreadsheet. Each subject also had to include data collected from the OURA ring. This included sleep index, total sleep time (TST), time in bed, REM (rapid eye movement), deep and light sleep, sleep efficiency, latency, timing, physical activity, and resting heart rate (RHR). The time spent in each sleep stage was converted into a proportion. These factors are generated by algorithms alongside fingertip pulse waveforms (Zambotti et al. 2017; Huotari et al. 2011).

2.5. Statistical analysis

Data were compared across both experiment and control groups using Pearson correlation coefficients, and linear mixed effects modeling through the *lme4* package in *R* version 1.2.1335. An alpha level of 0.05 was used in all analyses to determine statistical significance.

3. Results

When comparing sleep index to attention task scores for the experiment group, the scatterplots shows a greater correlation (*r*=0.39) (Fig. 1). Both the control and experimental groups demonstrate a positive linear correlation between sleep index and attention task scores - more so in the experiment group (Fig. 1a).

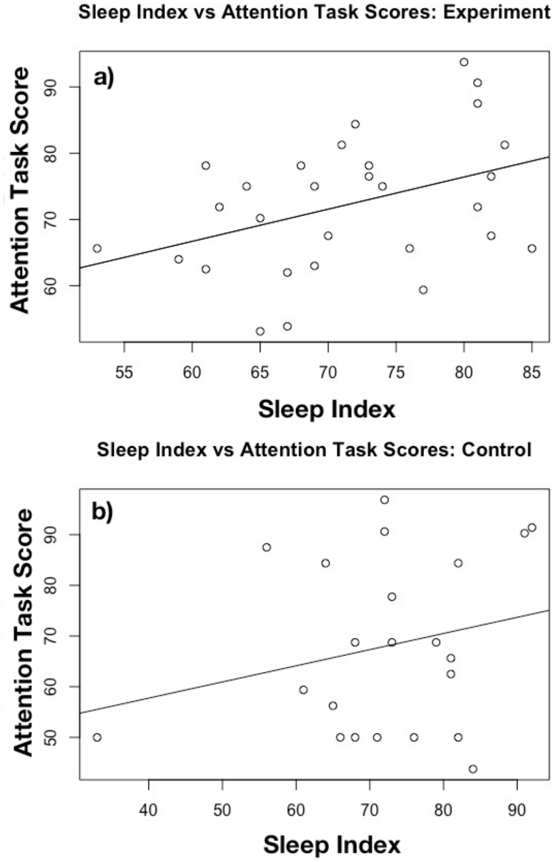

Figure 1. Scatterplots with best-fit lines comparing sleep index (x-axis) to attention task scores (y-axis). Correlation coefficient (r): Experiment r=0.39 (a), Control r=0.24 (b).

Table 1 demonstrates the estimate coefficients, standard errors, *p*-values and confidence intervals for each fixed effect. The only factor that is not only significant, but a positive predictor of performance on attention task scores, is REM sleep (*p*=0.03, Confidence Interval (CI): 0.108, 0.614).

Table 1. Estimate coefficients (β), standard error (SE), p-values (p), and 95% confidence interval (CI) for each fixed effect is displayed. Significance level = 0.05.

Fixed Effects	***β***	***SE***	***p***	***CI***
REM	0.33	0.15	0.03	(0.108, 0.614)
Sleep Index	0.15	0.20	0.44	(-0.103, 0.687)
Deep	-0.06	0.12	0.59	(-0.488, 0.120)
TST	0.12	0.19	0.53	(-0.164, 0.662)
RHR	-0.10	0.15	0.47	(-0.522, 0.067)
Experiment Group	0.05	0.11	0.65	(-0.151, 0.465)

Figure 2 displays mood frequencies between the experiment group and the control group. Frequency of positive mood indices were higher in the experiment group than in the control group (Fig. 2). Also, the experiment group displayed a higher frequency than the control group for negative mood indices (Fig. 2).

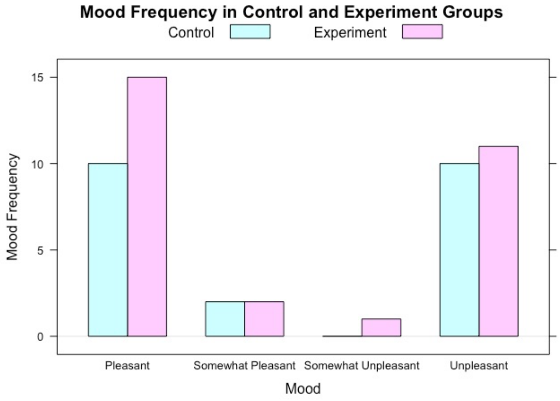

Figure 2. Bar graph comparing the mood frequencies in both control and experiment groups. A total of four mood categories were recorded (x-axis).

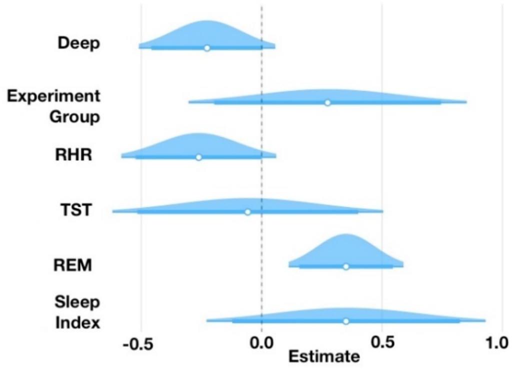

Figure 3. Attention graph using linear mixed effects. Fixed effects such as sleep index, REM, TST, RHR, and deep sleep are used as a function of attention task scores (the response variable), while controlling for Group ID variance. The reference category is the control group.

Figure 3 and Table 1 demonstrate that although the experiment group, TST, and sleep index are positive predictors of higher attention task scores, they are insignificant. The only factor that is a significant positive predictor of attention task scores is REM sleep (*p*=0.03, CI: 0.108, 0.614).

4. Discussion

This study made the following three predictions: 1) poor sleep quality would negatively impact attention task scores, 2) good sleep quality would positively impact inhibition scores and 3) the experiment group would reflect higher frequencies of positive mood indices off a self-rated index. Table 1 suggests that although sleep index is a positive predictor of higher attention task scores, it is not a significant driver of attention task scores (*p*=0.44, CI: -0.103, 0.687). Instead, our results suggest that REM is both a positive and significant predictor of attention task scores (*p*=0.03, CI: 0.108, 0.614). Although insignificant, the results showed that the experiment group, and TST are positive predictors of higher performance on attention task scores (Table 1). These results support previous work that shows that sleep is critical for essential cognitive functions such as response inhibition (Bocca et al. 2014; Chuah et al. 2006; Anderson & Platten 2011; Byun et al. 2018; Yoo et al. 2007).

The results show that the experiment group reported greater frequency of positive mood indices (Fig. 2). The prefrontal cortex of the amygdala is sensitive to sleep loss, which is an important element in inhibitory emotive processing. Additionally, REM sleep is crucial for emotional regulation, and it helps to govern sound emotional responses during waking hours (Nishida et al. 2009). Mean REM sleep for the experiment group (0.27) is greater than the control group (0.25), and this may be one explanation as to why members of the experiment group reported higher frequency of positive moods. A Wilcoxon ranked sum test, however, reveals an insignificant difference in REM sleep between the two groups (*p*=0.73, CI: -0.050, 0.040). Our findings concur with Nishida and colleagues (2009).

There may have been other factors not taken into consideration. For instance, Song & colleagues (2019) state that chronotype has an influence on response inhibition; particularly amongst evening type individuals. Evening types (ET) had later peak times in performance during the day, compared to morning types (MT) (Song et al. 2019). Therefore, it would not make sense to let the ET group perform an attention task in the morning, when they had higher subjective reports of sleepiness, experiencing overall more difficulty (Song et al. 2019).

The study had several limitations. Lack of compliance during the experiment was the most noteworthy, as not all subjects ascribed to the experiment protocol. Thus, their data was omitted. It was ultimately up to the subject to carry out the correct experimental protocol instructions while honestly indicating experimental compliance during the data entry process into Excel. In addition, the study consisted of a small sample size, which is an inaccurate representation of the whole population. Similarly, the sample size exhibited disproportionality between sexes (male and female). This may have yielded inaccurate data with respect to sex. The duration of the study is also a limitation. The experiment group did not have substantial time to establish a baseline following the experimental protocol. The abrupt change in participants' sleeping routine may explain why the experiment group reported higher negative mood indices (Fig. 2). Medication and caffeine ingestion may have also been limitations. For example, medications such as antidepressants can promote more sleep in some individuals. Although there were binary tabs to indicate whether the subject was taking medications or caffeinated drinks, the type was not documented. This prompts assumptions that may not entirely be correct. Likewise, the experiment design was not entirely inclusive. For an example, if a subject was experiencing a sleeping disorder, it was not accounted for.

From an evolutionary perspective, our findings suggest that during periods of susceptibility following a poor night's sleep, impulsive responses towards potentially threatening stimuli are favored. In high stake scenarios, there is a bias towards disinhibited responses despite what the outcome may be. This could have meant the difference between being safe or in harm in ancestral states. Given that one of the main functions of REM sleep is emotional consolidation, response inhibition may have helped to facilitate the most appropriate outputs that are in the best interests of these groups.

5. Conclusion

In conclusion, this study highlights the essential cognitive significance associated with sleep. Sleep is the body's way of improving both behavioral and cognitive performance. As seen in the study, better behavioral performance on response inhibition is contingent on obtaining REM sleep. In evolutionary terms, the human body's response to sleep deprivation on response inhibition may be the body's way of preparing the individual to become more impulsive by reacting to threat stimuli quicker. Neural pathways favored impulsive reactions following a poor night's sleep, instead of calculated decision making. Conversely, sufficient REM sleep encourages tolerability between groups of people by facilitating appropriate inhibited outputs. Given that *Homo sapiens* are largely social, inhibited responses may have been one way to encourage prosociality between groups of people, since REM sleep regulates emotional processing.

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