

The Effect of Mild Sleep Deprivation on Students' Cognitive Function during Covid-19 Pandemic

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Abstract. The Covid-19 pandemic has altered students' sleep patterns due to increasing academic demands as a compromise to switching the learning mode from direct classroom interaction to online learning. As a result, some believed it would affect the quality of cognitive functions. We conducted one experiment involving ~200 undergraduate students to measure their inhibitory control – a segment of cognitive process that allows controlling the unnecessary but often striking impulses – under two conditions, i.e., sufficient sleep and lack of sleep. Participants were asked to record their regular sleeping hours a week before the measurement period to get the baseline condition. Lack of sleep condition was determined by taking only partitions (less than 85%) of the regular sleeping hours overnight. Inhibitory control was measured using the online version of Simon Task about 30 minutes after the participants woke up in the morning. We found no direct effect of sleep deprivation on the performance of the Simon Task. Participants performed the Simon Task comparably well between the Sleep Deprived and Sufficient Sleep conditions. However, sleep deprivation inhibited the learning process required to perform identical Simon Task on the subsequent measurement intake. Our finding demonstrates that despite no empirical evidence of the direct impact of sleep deprivation on cognitive function per se, it affects the covert learning process required to perform well in future assignments.

Keywords: coronavirus pandemic; inhibitory function; sleep deprivation; student

The Covid-19 pandemic has caused a rapid shift in human life globally. Day-to-day life has been disrupted, and the routine of daily life must change. Direct physical contact and interaction have been minimized to prevent the spread of the virus (Quaife et al., 2020). As a result, people have started using digital media as the primary communication tool. Many people admitted that they are experiencing a vast increase in online communication through digital media during the Covid-19 pandemic, such as text messages, voice calls, social media, and video calls (Nguyen et al., 2020). These unpredictable changes in communication were also observed in educational settings.

Life, in general, has also changed dramatically during the Covid-19 pandemic, especially for young adults. Increasing evidence has shown the inclination toward internet/online addiction among young adults, i.e. online video game (Cherkasova, 2020; Rahayu et al., 2021), binge online movies watching (Rahman & Arif, 2021), online shopping (Cassidy & Adair, 2021), etc as a compromise of restricted direct physical contacts or activities during Covid-19 pandemic.

The Covid-19 pandemic has forced higher education to switch from direct classroom activity to online learning, which some students found it challenging to adjust (Zis et al., 2021). Moreover, public concern was that the quality of learning was different between offline and online learning (e.g., Nambiar, 2020). Most teachers were not prepared with the e-learning methods, given the sudden urge to transform offline into online learning during the Pandemic. As a result, many teachers choose to increase take-home assignments for students (Rohman et al., 2020) to maintain the quality of the academic output. Anecdotal reports suggested that students might be experiencing sleep deprivation because of heavy academic workloads. In general, the Covid-19 lockdown has caused the quality and quantity of sleep to decrease across several demographic groups (Gupta et al., 2020). Many people experience delayed sleep schedules; this phenomenon is even more visible in younger people (Sinha et al., 2020). Therefore, further investigation regarding the effect of disruption on the sleeping pattern in students is required.

Many researchers have tried to investigate the effect of sleep deprivation in more general contexts. For instance, growing evidence showed that sleep deprivation was associated with an increased level of stress. A study by Hirotsu et al. (2015) supported the claim that sleep deprivation was associated with the disruption of neuroendocrine that might be responsible for the elevation of the cortisol level (Leprout et al., 1997). Cortisol hormone is triggering heightened stress levels. As the Covid-19 lockdown has caused many people to experience sleep disruption, a possible secondary effect is that people eventually become more anxious. A previous study found that stress and anxiety levels were also reported to increase during the Covid-19 pandemic (Mozza et al., 2020), including among students (Hamza et al., 2020).

To some extent, we suspected that sleep deprivation could also disrupt cognitive function. For instance, past literature has found that total sleep deprivation might have caused working memory impairment and decreased individual ability to control attention (Peng et al., 2020). In addition, long-term memory and an individual's ability to make decision-making were also found to be affected (Alhola & Polo-Kantola, 2007). However, the effect of sleep deprivation on another cognitive function -such as inhibitory control- during the Covid-19 Pandemic is undiscovered.

Inhibitory control is a part of the cognitive function responsible for resisting the temptation to give an impulsive or inappropriate response toward certain stimuli (Tiego et al., 2018). In the learning context, inhibitory control plays a huge role in academic success. For example, an experimental study found that inhibition control, measured using a modified Stroop Task, could predict students' grades at the university (Visu-Petra et al., 2011).

Nevertheless, some previous literature on the effect of sleep deprivation on inhibitory control still varies. Among university students, sleep deprivation did not affect inhibitory function measured using the Stroop Task (Patrick et al., 2017). Meanwhile,

several studies showed different evidence. For example, there is a significant increase in potentially high-risk behavior and impulsivity among young adults who experience insufficient sleep (Rossa et al., 2014). Thus, impulsivity affects an individual ability to resist temptation, in other words: the inhibitory control itself. Another study using structural MRI supported chemical changes in several brain areas indicating disruption response inhibition performance after an individual experienced sleep deprivation (Zhao et al., 2018).

In this research, we try to investigate the effect of sleep deprivation on students' inhibitory control during the Covid-19 pandemic lockdown. In addition, we want to look further at whether there was any difference in students' inhibitory control when they had sufficient sleep and when they experienced mild sleep deprivation. We used an online version of the Simon Task—a tool for measuring inhibition control, which our participants in their own homes can access.

Methods

Sample

We performed a priori power analysis to ensure that the ideal number of participants guaranteed sufficient statistical strength. First, the power analysis's effect size (d) was determined using Cohen's (1988) classification. Taking account of the ($d = .50$) effect size with $(1 - \beta)$ at .90 and α at .05 level, we conclude that 180 participants were sufficient to get adequate statistical power. Next, 200 undergraduate students from Universitas Gadjah Mada were recruited for this study. The informed written consent was obtained according to procedures approved by the ethics committee of the Faculty of Psychology at the University Gadjah Mada, Yogyakarta. The students participated in this study in exchange for course credit.

Procedure

A week before the experiment began, the participants were asked to fill out a daily journal in which they reported their sleep duration every day of that week. Each participant answered these questions below in regards to their daily sleep duration, i.e.: (i) their actual time to go to bed, (ii) what time they fell asleep (predicted), and (iii) what time they woke up in the morning. Based on these questions, we could collect the total sleep time, i.e., the gap between point (c) to (a), and the total time on the bed, i.e., the gap between point (b) to (a). In this study, we calculated the total sleep time per day over a week to get the average sleep time acting as the baseline in this study.

Previous studies (dos Santos Silva et al., 2015; Lohsoonthorn et al., 2013) suggested that average sleeping time refers to the use of a minimal 85% of average sleep duration in a week (i.e., the baseline). Our current study used it as the reference for manipulating the

Sufficient Sleep (SS) condition. Meanwhile, sleeping time below 85% of the average sleep duration in a week was used as the reference for manipulating the Deprived Sleep (DS) condition. A within-subject reverse counterbalancing was used in this study. We split the participants into two separate groups. One hundred four participants were placed into the first experimental group, while 96 participants were put into the second experimental group. Those in the first group would be given a Deprived Sleep (DS) manipulation following the Sufficient Sleep (SS) manipulation. There were three days between the delivery of two manipulations. The second group's order was reversed, as shown in Table 1. The reason for choosing a within-subject design with reversed order (split by half participants) was to keep individual differences such as personality, intelligence, etc. which were not our variables of interest but might be influencing the dependent variable, i.e. inhibitory control.

Table 1.
The Order of Experimental Manipulation

Groups	Week 1	Week 2	
		First Intake	Second Intake
1st (N=104)	self-report (baseline)	sleep-deprived condition	sufficient sleep condition
2nd (N=96)	Self-report (baseline)	sufficient sleep condition	sleep-deprived condition

On each day of the experiment, the participants should have reported when they went to bed and to woke up in the morning. Subsequently, they were asked to perform the inhibition control using Simon Task (Simon & Rudell, 1967), which was built using the OpenSesame 3.3.4 program (Mathôt et al., 2012). The Simon Task instruction has been written on the online program therefore there participants could administer the test by themselves. The experiment program was delivered via the JATOS server. Therefore, it could be accessed by each participant through their PC or Laptop browser.

In the Simon Task, participants were given verbal instructions that were either congruent or incongruent with the visual stimulus. For example, in the incongruent condition, the instruction to press the RIGHT key (i.e., by flashing the word "RIGHT" on the computer screen) was displayed on the left side of the screen. The participants were asked to give the correct response as fast as possible. We recorded their correct answers and the reaction time of their responses.

We calculated each of students sleeping baseline on Week 1 (see Table 1) and informed each student to follow the sleeping duration instruction given by email on each condition, i.e. either for sufficient-sleep condition or deprived-sleep condition, according to their sleeping arrangement based on the experiment study design (see Table 1). Before

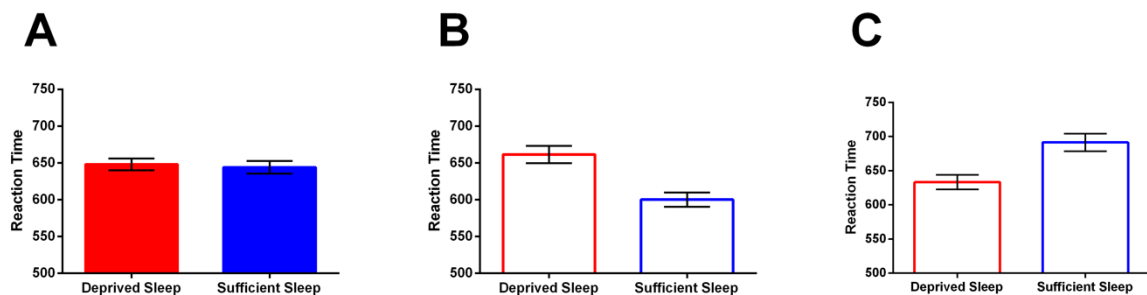
commencing the Simon Task, students were asked to report the time they went to bed and woke up in the morning to check whether they followed the experimenter's instruction.

Results

Overall, there was no significant difference between participants' reaction time when they lacked sleep and when they had enough sleep before completing the control inhibition task when we collapsed all the data ($W = 10420.5$, $p = .65$; Figure 1A). In addition, the participants performed the task with above 95% accuracy. It indicated that participants did the task well despite the difference in hours they spent in bed the night before (i.e. sufficient vs deprived sleep). However, after we split the data based on their group, we found there was a significant difference in participants' reaction time during Sufficient Sleep (SS) and Deprived Sleep (DS) conditions, either in the 1st Group ($W = 4196$, $p = .001$; Figure 1B) or in the 2nd Group ($W = 638$, $p = .001$; Figure 1C) due to the order of data intake. In addition, the average reaction time in the first Intake tended to be longer than in the second Intake (Please see Table 1 for reference to the order or data collection intake). It means that participants have learned how to perform the task on a subsequent day (i.e. second data intake), as indicated by the faster reaction time required to complete the task.

Figure 1.

Reaction Time during Simon Task Across the Group

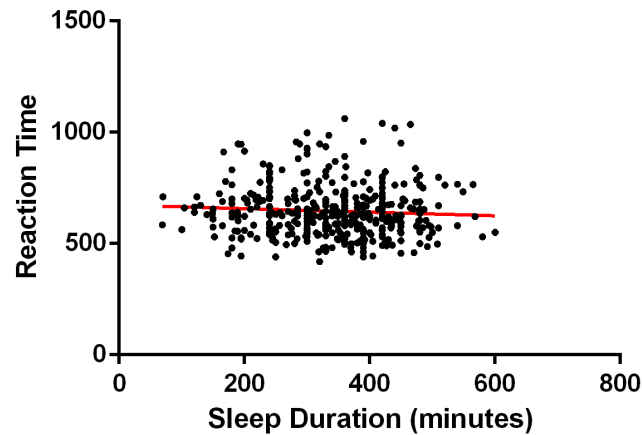


Note: (A) No significant difference was observed between both experimental groups. However, a significant difference was observed in (B) the 1st group—Deprived Sleep first ($M = 662$ ms) followed by Sufficient Sleep condition ($M = 607$ ms). A similar pattern was also visible in (C) the 2nd group—Sufficient Sleep ($M = 694$ ms) followed by Deprived Sleep ($M = 636$ ms) condition.

Further analysis was performed to check whether there is a correlation between the amount of sleep and participants' reaction time. Based on this analysis, we found no correlation between participants' reaction time on Simon Task and the amount of participants' sleep ($R = -.89$, $p = .75$; Figure 2). This result implied that participants' inhibitory control had no relation to the amount of their sleep per se.

Figure 2.

Correlation between Participants' Reaction Time with the Amount of Sleep They Had

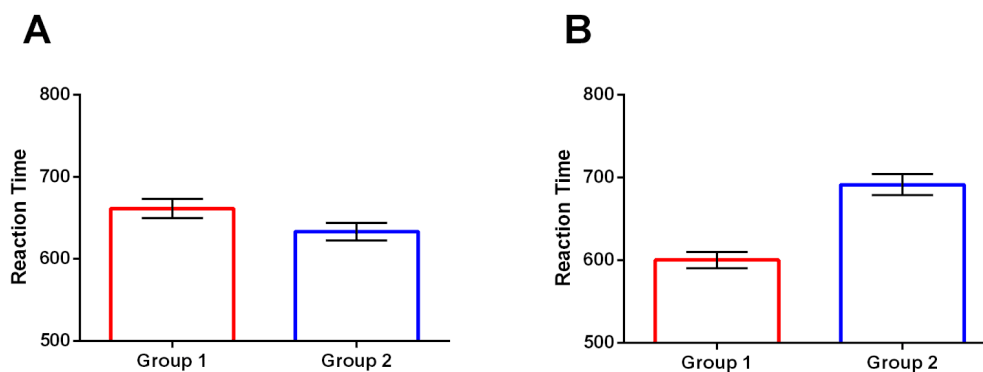


Note: A significant correlation was not observed.

Next, we also checked whether there were any differences in the participants' reaction time in Deprived Sleep (DS) and Sufficient Sleep (SS) conditions between the 1st and 2nd groups. Based on this analysis, no significant difference was observed between the 1st and 2nd Group of Deprived Sleep (DS) conditions ($U = 5706$, $p = .081$; Figure 3A). Therefore, it indicated that the manipulation order did not affect participants in this condition. However, we found a significant difference in reaction time between the 1st and 2nd Group of Sufficient Sleep (SS) conditions ($U = 2639$, $p < .001$; Figure 3B). Therefore, it is possible that the order effect interfered with our data on the Sufficient Sleep (SS) condition but not the Deprived Sleep (DS) condition.

Figure 3.

Reaction Time during Simone Task Across the Condition



Note: (A) a significant difference was not observed in the Deprived Sleep (DS) condition, while this pattern was not found in (B) the Sufficient Sleep (SS) condition. Please note that the order of Intake for the 1st Group is DS-SS; meanwhile, the order of the 2nd Group is SS-DS.

From the beginning, slower reaction time on the subsequent Intake (i.e. second intake) relative to the prior Intake (i.e. first intake) could be interpreted as evidence of learning. The differential reaction time on the Sufficient Sleep (SS) condition (Figure 3B) indicated that the learning occurred as a function of the intake order. Conversely, no difference in reaction time on the Deprived Sleep (DS) condition (Figure 3A) can be interpreted as no learning has occurred. In other words, our participants did not engage optimum learning during the Deprived Sleep (DS) condition relative to the Sufficient Sleep (SS) on the prior Intake (i.e., 1st Intake), which in turn affects the performance on the subsequent Intake (i.e., 2nd Intake). We further examined the reaction time of the 1st Intake and found a significant difference ($U = 2034, p < .001$) between Deprived Sleep (DS) and Sufficient Sleep (SS) Conditions.

Discussion

Our finding does not demonstrate the relation between sleeping patterns and individual inhibitory control. Using Simon Task, our data indicates that participants did not show performance differences when they experienced a lack of sleep as compared with when they had enough sleep. This finding contradicts past studies highlighting the importance of sleep for optimum individual inhibitory function (Wilckens et al., 2014; Labelle et al., 2015).

However, the effect of sleep on control inhibition is not always direct. For example, a previous study suggested that the increase of deprived sleep on the inhibitory control measured by the Standard Stroop Test has resulted from several nights of sleep deprivation (Patrick et al., 2017). Moreover, there is also a possibility that our participants are more resistant to the effect of sleep deprivation. A previous study demonstrated that young adults are less prone to the impact of sleep deprivation in a short period (Almklov et al., 2015).

The human brain can readjust itself from certain external stimuli, commonly termed "brain plasticity." This ability tends to be at its peak during young adulthood and starts to decrease as we get older (Pauwels et al., 2018). Young adults, especially students, usually had to study until late at night to be successful academically. As a result, sometimes, they had to reduce their sleeping duration. Moreover, pandemics have forced many students to perform their daily activities at home, making it harder to separate personal and academic life. Those unable to cope with the situation might end up feeling stressed. This pattern may later contribute to sleep deprivation since good sleep indicators such as Rapid Eye Movement (REM) sleep, sleep efficiency, and slow-wave sleep decrease among people experiencing psychosocial stress (Kim & Dimsdale, 2007).

Although sleep deprivation, to some extent, may cause brain damage (Zhao et al., 2017), brain plasticity may help young adults overcome short-term sleep deprivation's adverse effects. After all, the human brain is still developing during this age (Arain et al.,

2013). On the other hand, brain plasticity also supports the learning process (Mateos-Aparicio & Rodríguez-Moreno, 2019), including adapting to the negative effect of insufficient sleep. However, a direct examination is required to get a clearer understanding of whether individuals' brain plasticity is related to the resistance to the effect of sleep deprivation, specifically on inhibitory control as a part of executive function.

In addition, we also took further analysis to check the participants' performance within each experimental group. Although there was no "bad consequence" of deprived sleep per se, we found people had less optimum learning when the sleep-deprived condition was placed on the prior Intake. The Simon Task has been found to be vulnerable to practice effect (Iani et al., 2009; D'Ascenzo et al., 2020). This effect, however, almost disappears during the sleep-deprived state, indicating that the learning process when people lack sleep will not have a direct impact but rather a longer-term effect as it will prevent future performance.

There has been another research procedure that provides more accurate data and less error margin regarding sleeping habits, such as the utilization of biometrics measurement, i.e. polysomnography (Marino et.al, 2013) and heart rate variability (Stein & Pu, 2012). However, during the Covid-19 pandemic, any research methodology which involves direct physical contact was restricted. Therefore, the above-mentioned measurement procedure might not be an ideal option. Nevertheless, our experimental paradigm can be combined with a more objective and tractable methodology in the future to attain stronger evidence.

Conclusion

In conclusion, although our study does not provide the direct influence of sleeping patterns, i.e. deprived vs sufficient sleep, on the individual inhibitory control per se, it is suggested that sleep deprivation can inhibit the learning process, therefore, affecting students' long-term performance. We conducted a within-subjects study design with reversed order sleeping habit manipulation, i.e. sufficient sleep and deprived-sleep conditions. Following the sleep pattern as instructed by the experimenter, each of the participants was given Simon Task to measure inhibitory control. While there was no performance difference on the Simon Task per se between sufficient-sleep and deprived-sleep conditions, we observed the deteriorated learning performance as a function of the sequential learning in the group that was under deprived-sleep condition and followed by the sufficient-sleep condition. Hence, our study suggested that deprived-sleep condition affects the learning process despite no evidence of impaired performance per se on cognitive tasks.

Recommendations

Our study indicates that healthy sleeping habit is necessary for an effective long-term learning process. Despite of overwhelming academic workload, students must have enough quality of life to preserve their future learning capacity. In addition, schools and teachers should adjust students' academic demands to improve school mental health.

Declaration

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Author's contribution

GL conceived the study, analyzed the data, and wrote the manuscript. SFJ analyzed the data and wrote the manuscript. AN & BA conducted the experiments and collected data.

Conflict of interests

The authors declare not to have any competing interests related to this work.

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