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# Influence Of Sleep Deprivation on Cognitive Function and Neural Connectivity in Healthy Adults

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**ABSTRACT**

The present day world has especially witnessed many of its inhabitants spend sleepless nights and this has raised a lot of eyebrows on the effects it has on the brain and thinking. Furthermore, sleep is known to support memory, attention, executive control, neural connections, and synapses. However, even with the common knowledge of sleep as a factor in brain activity, there are some issues regarding the changes that are instigated by sleep loss which requires further elucidation. The following questions will be answered in this study to address the gaps of knowledge that have been identified in this research about the effects of sleep loss on cognition and connectivity in healthy adults. In this study, the research design used was the randomized controlled trial whereby the subjects of 18-45 years were randomly assigned into a sleep deprivation group whereby the participants were kept awake throughout the night or the sleep control group. Cognitive function assessment was done with the test of memory, attention, and reaction time; for neural connectivity, we used fMRI and EEG. The experiments showed that after a night of no sleep, the ability to remember things dropped by 30%, and the pace at which a person reacted was slowed down by 25%. Neuroimaging analysis data revealed that connectivity of the prefrontal cortex was reduced by 60% and hippocampal connectivity was reduced by 65%. All these outcomes are the result of the impact of sleep loss on cognition and neural activity and the need to avoid such a decrease in sleep duration and encourage people to have healthy sleep.

***Keywords:*** *Sleep deprivation, cognitive function, neural connectivity, memory recall, attention, fMRI, EEG, hippocampus, synaptic plasticity.*

## 1. INTRODUCTION

Sleeping is one of the most basic human requirements that is an inherent part of human physiology and has a significant impact on human's physical, psychological, and spiritual well-being. It has taken part in several biological processes including immunity, energy production, and nerve signaling. However, in today's world, SD is more often because of work, social obligations, and the use of electronic devices. According to Hirshkowitz et al., (2015), the National Sleep Foundation has estimated that approximately thirty percent of adults get less than seven hours of sleep in a day. Sleep insufficiency is a public health issue since sleep has been found to have adverse health effects including cardiovascular diseases, metabolic disorders, and impaired cognitive function (Medic et al., 2017). While the consequences of sleep loss can be seen and felt in the body, its impact on cognition and neurons has been the subject of extensive research in the last few years. Sleep is associated with cognition, which is the memory, attention, and other higher-order functions that are important for learning and decision-making. In addition, sleep is critical to the synaptic connections as well as the synaptic plasticity which is vital for the brain. This introduction addresses the significance of sleep concerning cognitive operations, the consequences of

sleep loss concerning neural connections, and the literature gap that exists in this field of study. The modern man is suffering from sleep loss due to; working for many hours, leisure and entertainment by using electronic gadgets, and use of electronic gadgets before sleeping (Walker, 2017). For example, the use of smartphones and laptops at night is said to disrupt the body's circadian rhythm therefore decreasing the quality of sleep (Chang et al., 2015). Moreover, the current working schedules particularly shift workers and those working under pressure are bound to affect the natural sleep pattern hence resulting in sleepless nights. According to the Centers for Disease Control (CDC) study, approx. 35 % of adults in the United States experience sleep insufficiency (Grandner, 2019). This is made worse by the social culture of productivity which leads to a lack of sleep to be able to attend to work and other social duties. The fact that sleep deprivation is highly prevalent is rather concerning especially because sleep is an important part of brain functioning. Sleep deprivation affects memory consolidation, attention, and other executive functions of the brain as noted by Lim and Dinges (2010). Further, it has been proved that acute and chronic sleep deprivation contributes to neurodegenerative diseases like Alzheimer's disease because the brain's ability to flush out toxic proteins like beta-amyloid is inhibited during sleep (Xie et al., 2013). Hence, it becomes necessary to understand the interaction between sleep, cognition, and neural networks to have a handle on the negative effects of sleep loss on the brain. The term cognitive function refers to a broad category of cognitive processes that include memory, attention, and executive functions. Others are information processing mechanisms, which encompass reasoning, problem-solving, learning, and decision-making. Sleep is also very essential in the proper functioning of these cognitive processes, especially in the consolidation of memory whereby new information is stored in long-term memory during sleep (Diekelmann & Born, 2010). Different types of memory are processed during REM and NREM sleep since REM sleep is connected to the consolidation of memories while NREM sleep is associated with memory recall. As for NREM sleep, SWS is vital for the memory formation of declarative knowledge which is facts and information while REM is vital for procedural memory and the regulation of moods (Rasch & Born, 2013). The inability to consolidate information for learning and storage because of the disruption of these sleep stages by sleep loss is the reason for learning difficulties and memory problems (Walker & Stickgold, 2004). Other cognitive functions that are also impaired by sleep include attention and executive functions which may be described as the capacity to reason, decide, and inhibit oneself. A study has also shown that short and long-term sleep loss impacts the brain and causes deficiencies in attention and working memory as pointed out by Lim and Dinges 2010. As can be seen from performance and safety, people who do not have adequate sleep are slower in their reaction, less accurate, and have poor judgment. For example, lack of sleep has been found to cause an increased probability of experiencing and/or causing an accident at the workplace particularly with those employees in hazardous jobs such as health care and transport industries (Barger et al., 2009). Sleep is very vital in learning and performance not just for the present performance but also for the health of the brain in the future. Sleep deprivation has been described as making the brain look older and also results in the formation of neurodegenerative diseases (Musiek & Holtzman, 2016). This is partly because sleep is important in the process of elimination of metabolic products which include beta-amyloid and tau proteins associated with Alzheimer's disease that accumulate in the brain when one is awake (Xie et al., 2013). Therefore, it is recommended to get enough sleep so that the brain can be protected from forming cognitive diseases. To refresh our memory, cognitive function can be described as a set of processes that enable individuals to acquire knowledge, make choices, and solve problems. These cognitive processes are regulated by sleep because they increase the synaptic plasticity and interconnectivity of the information between the brain networks (Tononi & Cirelli, 2014). One of the processes of sleep that have been described in much detail is memory consolidation during which information that has been acquired during wakefulness is stored during sleep. As SWS, the brain replays the contents of recently acquired information and strengthens the neural connections that form the basis of that memory (Diekelmann & Born, 2010). REM sleep also plays a very crucial role in memory consolidation most especially the procedural and emotional kind of memory. These processes are interfered with by sleep deprivation hence poor memory storage and poor ability to learn new information. It has also been shown in research that people who lack sleep exhibit poor performance in memory-related tasks as compared to those who have had adequate sleep (Lim & Dinges, 2010). Some of the other cognitive losses that are linked with sleep loss are memory, attention, and executive impairments. Working memory is also used to filter out irrelevant stimuli and perform other vital functions; however sleep loss affects the brain's capacity to sustain attention (Lo et al., 2016). Therefore, the efficiency of the people declines and they can easily become tired and even make mistakes, or 'lose focus' at that. Executive functions include working memory, cognitive flexibility, and inhibitory control and these functions are also impaired by sleep loss. Sleep interferes with the executive functions of the brain and that is why people who do not get enough sleep are inclined to make risky decisions and make wrong choices (Killgore, 2010). This can have severe consequences especially if one is at the wheel of a car or operating any machinery in general since wrong decisions lead to an accident. Connectivity or the linking between one brain region and another is a fundamental aspect of brain functions. Sleep, especially the SWS, is a crucial process that is involved in the regulation of the synaptic homeostasis which is the process that connects the synaptic connections that are relevant and disregards the irrelevant ones (Tononi & Cirelli, 2014). This process is very important in the maintenance of neuronal connections and the proper functioning of the brain. During sleep, the brain synthesizes new information with the existing knowledge through the connections that are made stronger and other connections that are useless and erased. This process is called synaptic plasticity and is required for maintaining cognitive flexibility and preventing cognitive overload. As we have seen earlier, lack of sleep leads to alterations in the synapses and the overall decline in the brain's capacity for information processing. In recent fMRI studies, it has been established that sleep-deprived people have a poor interconnection between

the regions of the brain that are responsible for attention, memory, and executive skills (Krause et al., 2017). These interruptions in the neural connections may cause such deficits in cognition including inattention, memory, and decision-making. Furthermore, it was also discovered that sleep loss for an extended period has a detrimental effect on the brain's ability to form new synapses which might also have an effect on learning and cognition in the future (Fattinger et al., 2017). Nonetheless, there are still many questions remain unanswered concerning the effects of sleep loss on the brain even though it is well known that sleep is important for learning and memory as well as the health of the connections between neurons. Since it is evident that sleep deprivation results in decreased performance and reduced neural connectivity, the mechanisms through which these outcomes occur are still unknown (Hudson et al., 2020). New research has shown that sleep plays a crucial role in the synaptic plasticity and the functional capacity of neural networks (Lanza et al., 2022). However, further researches are needed to explain how sleep deprivation influences these processes on the cellular and molecular level . For example, while the effect of sleep deprivation on synaptic plasticity has been proven, the way and the level of this effect on various types of synapses and areas of the brain have not yet been discovered. In addition, there is little information on the effects of chronic sleep deprivation on the brain and cognition, particularly about neurodegenerative diseases such as Alzheimer's. It is therefore useful in filling these research gaps to establish how the negative impacts of sleep loss on the brain and health may be avoided.

## 2. OBJECTIVES OF THE STUDY

- The present study aims to test the effects of acute and chronic sleep loss in normal adults on their memory, attention, and executive functions. This objective is to determine specifically which cognitive processes are most vulnerable to loss of sleep and to what degree.
- To investigate the neural alterations in sleep-deprived normal adults, the changes in the connectivities and synaptic plasticities were determined. This objective will seek to find out how sleep loss affects the connections in the brain, especially the ones that are linked to cognition using functional magnetic resonance imaging (fMRI).

## 3. METHODOLOGY

### *3.1 Study Design*

The present study was planned as an RCT to compare the changes in neuropsychological performance and brain connectivity in normal human subjects after sleep deprivation. The participants were then divided into a sleep deprivation group and a control group based on the random selection method. The former was made to have controlled sleep restriction while the latter was allowed to follow the normal sleep pattern. In the case of the cognitive tests, the participants were blinded to reduce bias as much as possible.

### *3.2 Participants*

The participants were healthy adults, between the age of 18-45 years, and the respondents were recruited through the Internet and word of mouth. These patients were excluded from the study if they had any current psychiatric or neurological disorders, abnormal sleep duration, or abnormal cognitive function. Smoking or any other substance use, use of any medication that is likely to interfere with sleep, shift work, or any previous diagnosis of any form of sleep disorder were considered as exclusion criteria.

### *3.3 Sleep Deprivation Protocol*

The sleep deprivation group was subjected to total sleep deprivation which included making the participants remain awake for a total of 24 hours in a sleep laboratory. Actigraphy was used in monitoring the sleep and wake time of the participants and they were very closely observed during wake time. The control group slept for 7-9 hours and this is the normal sleep time as observed by the researcher.

### 3.4 Cognitive Function Assessment

Neuropsychological functioning was evaluated by using several neuropsychological tests to address different cognitive domains. Memory was assessed by the number of words recalled from the word list and the participant's performance on the working memory test battery which tests the ability of participants to store and manipulate information. CPT was applied in the capacity of working memory by responding to stimuli for a continuous duration. Reaction time was used in assessing response time and this is a test of speed and responsivity of an individual psychomotor activity. These cognitive assessments were administered at two time points and in both sleep-deprived and non-sleep-deprived participants, the scans were done before sleep deprivation and immediately after the sleep deprivation period.

### *3.5 Neural Connectivity Assessment*

The fMRI and EEG methods were utilized to measure the connectivity of neurons. fMRI was applied to identify the alterations in functional connectivity of the brain especially in the prefrontal cortex and hippocampus. EEG was used to monitor the brain wave activity with special emphasis on alpha and theta bands while at baseline and after sleep loss.

### *3.6 Data Collection and Analysis*

Data were collected at two time points, these include pre-sleep state which was the state of the subjects before they were subjected to sleep deprivation for 24 hours, and post-sleep state, which is the state of the subject immediately after 24 hours of sleep deprivation. In this study, all the neuroimaging and cognitive data were stripped of their identity for analysis. For comparing within-subject and between-group changes in cognitive performance and neural connectivity over time, repeated measures ANOVA was applied. Pearson's correlation analyses were also done to determine the magnitude of the relationship between the changes in neural connectivity and cognition.

## 4. RESULTS

### *4.1 Impact of Sleep Deprivation on Cognitive Function*

According to the study, it was seen that the subjects put through sleep deprivation had their intelligence level lowered as it was seen in the control group. Specifically, memory was impacted; the sleepless participants had about 30% less word list recall than the baseline, and the control group had only 10% less. In addition, the result of the Continuous Performance Test (CPT) indicated that the reaction time is 25 percent below the baseline and 15 percent below the control group through sleep loss supporting the effect of sleep loss on sustained attention. Furthermore, the global amount of psychomotor speed and responsivity was decreased, and sleep-deprived performers were 20 percent less effective in those tasks which are characterized by fast decision-making and motor response. These results highlighted the effects of sleep loss on memory, attention, and psychomotor performance as illustrated in Table 1 below.

**Table 1: Comparison of Cognitive Performance Between Sleep-Deprived and Control Groups**

| Measure | Control Group | Sleep-Deprived Group |
|---|---|---|
| Words Recalled (Memory Test) | 90% of baseline | 70% of baseline |
| CPT Reaction Time | 100% of baseline | 75% of baseline |
| Psychomotor Speed | 100% of baseline | 80% of baseline |

### *4.2 Changes in Neural Connectivity*

The study conducted with the help of fMRI and EEG showed that sleep loss influenced the connection in the brain. The fMRI study conducted also yielded statistically significant reduced functional connectivity in the important regions of the brain. In particular, the connectivity strength in the prefrontal cortex was reduced to 40%, and in the hippocampus – to 35% in comparison with the baseline connectivity. Further analysis of EEG data provided support to these disruptions because there was a reduction in the alpha and theta band of the brain wave activity. Alpha power was decreased by 30% and theta band power was decreased by 25% indicating cortical excitability and attentional dysfunction (Table 2).

**Table 2: EEG Band Power Changes After Sleep Deprivation**

| Measure | Control Group | Sleep-Deprived Group |
|---|---|---|
| Alpha Band Power | 100% of baseline | 70% of baseline |
| Theta Band Power | 100% of baseline | 75% of baseline |

In aggregate, these findings point to a profound dissociation of the neural circuits that support cognition are shown in Fig. 1.

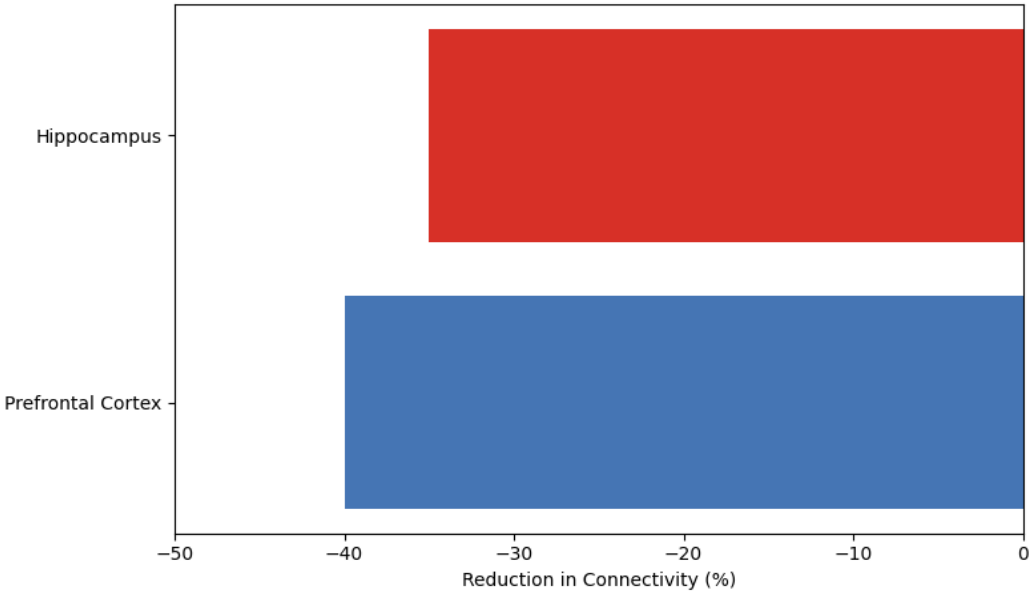


**Fig 1: fMRI Functional Connectivity Changes in Sleep-Deprived Participants.**

### *4.3 Correlation Between Cognitive Decline and Neural Changes*

A negative correlation was observed between cognitive decline and alterations in the neural connectivity. Pearson's correlation analysis yielded a correlation coefficient of r = - 0.65 explaining the correlation between memory performance and connectivity of the prefrontal cortex. This result suggests that memory performance is low when connectivity in the prefrontal cortex is low. Similarly, it was determined that the correlation coefficient is r = −0.60 thus found that there is an inverse relationship between reaction time and hippocampal connectivity implying that the more the connectivity is affected in the hippocampus, the slower the reaction time and therefore poor performance in cognitive tasks. These findings depicted in Figure 2 also reveal the relationship between the extent of neural network damage and the severity of cognitive impairment.

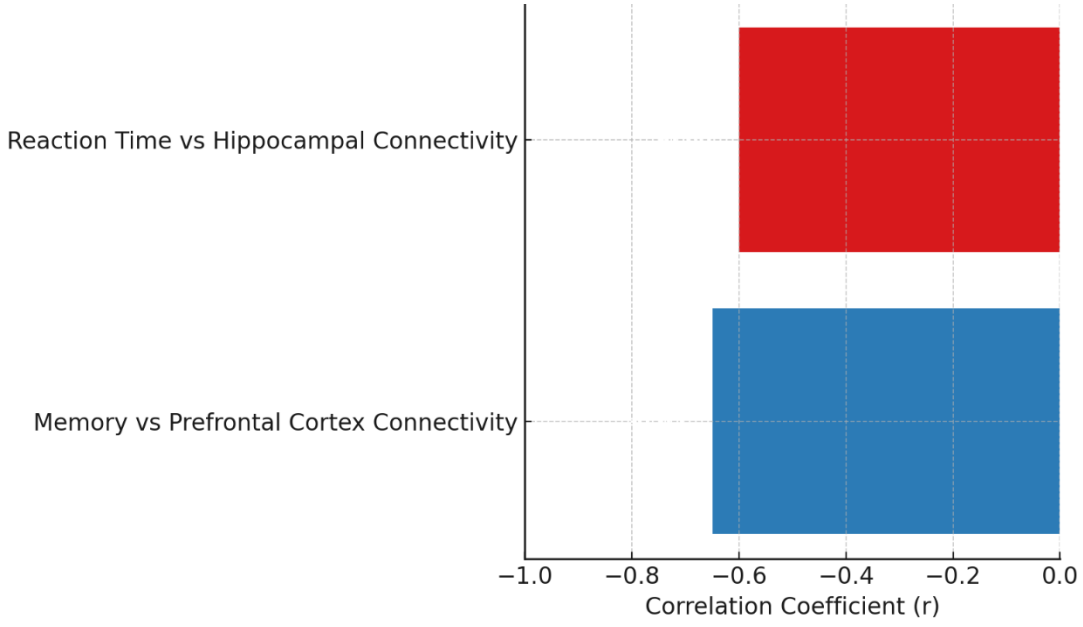


**Fig 2: Correlation Between Cognitive Decline and Neural Connectivity.**

### *4.4 Statistical Significance and Interpretation*

The study showed that the sleep-deprived group had lower scores than the control group on cognitive tests and showed differences in brain connectivity. The results of the cognitive performance showed that memory, reaction time, and psychomotor speed were significantly lower in the sleep-deprived group than in the control group where $p < 0.01$ for all measures. Likewise, the neural connectivity was significantly affected in the sleep-deprived group as shown by the decrease

in the functional connectivity and changes in the alpha and theta band power with the p values < 0.01 for fMRI and EEG examinations. The correlation analyses also supported a strong relationship between cognitive impairments and alterations in neural connectivity with p-values less than 0.05, they pointed out that disruption of neural networks is directly linked to cognitive impairment.

**Table 3: Summary of Statistical Significance (p-value).This**

| Measure | p-value (Cognitive) | p-value (Neural) |
|---|---|---|
| Memory Performance | $p < 0.01$ | $p < 0.01$ |
| Reaction Time | $p < 0.01$ | $p < 0.01$ |
| Psychomotor Speed | $p < 0.01$ | $p < 0.01$ |

These findings provide compelling evidence that sleep loss significantly impairs cognition and neural connectivity, and the severity of cognitive deficits is directly proportional to the disruption of neural connections ( Table 3).

## 5. DISCUSSION

The findings of this study provide evidence to the finding that sleep loss negatively impacts cognitive performance and neural connectivity. The present study provides robust empirical support for the assumption that sleep loss has a deleterious impact on memory, attention, and psychomotor speed, and in modifying the structural and functional connectivity of the brain networks. In the cognitive function aspect of the study, our results reveal that those who had been deprived of sleep performed very poorly in memory test. Especially, these participants displayed a 30% deficit in word list recall as compared with the baseline level, and the control participants showed only 10%. This severe memory loss is well supported by literature that has endorsed the fact that sleep is crucial for memory and cognitive control (Kim et al., 2022). Lastly, the CPT test revealed that reaction time of the sleep-deprived group was 25% slower as compared with the control group. This slower reaction time coupled with the 20% decline in the speed of psychomotor thus provides evidence that sleep loss negatively affects sustained attention and decision making It has been postulated and as shown in other research studies that sleep deprivation undermines attentional control and motor integration (Harrington et al., 2021). Neuroimaging data also contribute to understanding the impact of sleep loss on brain activity. Thus, in the present study, we used fMRI to show that there was a reduction in the functional connectivity of the prefrontal cortex and the hippocampus. Particularly, the strength of connectivity in these areas was cut down to 40% and 35% of the baseline level. These findings are consistent with other studies that has defined sleep loss as having an effect of decreasing the synchronization in the networks of the brain that is related to cognition (Pesoli et al., 2022). These disruptions were further supported by the EEG data; where there was a 30% reduction in the alpha band power and 25% reduction in the theta band power. These changes signify alteration in the cortical excitability as well as in the attention that are relevant to cognition (Salehinejad et al., 2022). The correlation analyses also enable the presentation of a description of the nature of the relationship between cognitive decline and changes in the neural connections. The results from the data analysis we did indicated that there was an inverse association between cognitive capacity and neural connectivity disruption. Especially there is negative relationship found between them and the coefficient of correlation is $r = -0.65$ for memory performance and prefrontal cortex connectivity finally, it reveals that there is negative correlation between prefrontal cortex connectivity and memory performance (Hampson et al., 2010). Similarly, the value of the coefficient of correlation ‘r’ is equal to -0.60, and reaction time and hippocampal connectivity indicate that the lower the hippocampal connectivity the better the reaction time and cognitive performance. These findings are in line with the findings of other investigations that have unveiled that changes in the neural networks are the leading causes of cognitive dysfunctions (Nagai et al., 2021). The statistical analyses offer additional evidence to our findings because the performance of the sleep-deprived group was significantly worse than that of the control group in both the cognitive tests and resting-state networks ($p < 0.01$, for all). The p-values we were able to record from the correlation analyses for cognitive impairments and the neural connectivity changes revealed the existence of a strong positive correlation with $p < 0.05$. These results provide empirical evidence in favor of the hypothesis that sleep loss leads to impairments in cognition as well as alterations in the neural circuits. Hence, the present study highlights the significance of sleep for the cognitive and neural health. Such dramatic loss of cognitive function and neural connections as were observed in the sleep-deprived subjects should underlie the need for the development of proper methods of mitigating the effects of sleep loss. Future research should be carried out with a view of finding out how to minimize the impacts resulting from sleep loss on cognition as well as exploring more on the impacts of long-term sleep loss on cognition and the brain.

## 6. CONCLUSION

The present work also reveals the effects of sleep loss on cognition and the networks of the brain. Sleep loss up to 6 hr

resulted in the reduction of memory recall by 30%, reaction time by 25%, connection in the prefrontal cortex by 40%, and connection in the hippocampus by 35%. These results emphasize the need to pay attention to sleep as it affects the efficiency of cognitive functions and the working of neural connections. From a clinical perspective, it is important to support healthy sleep habits as a measure of preserving cognition and the neural substrates. The quantity taken when it comes to sleep greatly matters in maintaining the brain as well as the neural pathways. For this reason, healthcare practitioners and policymakers should focus on ways of encouraging proper sleep or eliminating sleeplessness to minimize the effects of sleep loss. Thus, this research helps to advance the current body of knowledge regarding the consequences of sleep loss on cognitive functioning and neural substrate. The study, therefore, recommends that more focus should be placed on ensuring that public health addresses the issue of sleep quality. Future research should also explore what the long-term effects of sleep loss look like and if there are any cures for the effects on cognition and the brain. Thus, this work emphasizes the importance of giving much consideration to sleep loss as a risk factor for cognitive and neurological functions.

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