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Individuals' Cognitive Functions in Numerical Stroop Test Is Associated with Their Sleep disturbance and Cognitive Disability

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ABSTRACT

Introduction: Poor sleep quality can lead to negative effects on cognitive performance. However, the association between sleep quality and person's ability to inhibit a habitual response has not been investigated yet. In this study, the relationship between sleep quality and cognitive function with subjects' performance in numerical Stroop test (NST) was investigated.

Methods: 21 male and female volunteers underwent NST. Sleep quality and cognitive function were evaluated using Pittsburgh sleep quality and cognitive disabilities index questionnaires, respectively. Finally, the correlation between sleep quality and cognitive disability indices with NST parameters was measured.

Results: Unfavorable sleep quality and cognitive disability were significantly correlated with decreased the reaction time of subjects in NST. In addition, a significant correlation was observed between lower sleep quality and cognitive disability.

Conclusion: It is concluded that poor sleep quality reduces the ability to inhibit a habitual response. In addition, poor sleep quality increases individuals' impulsive decisions. Furthermore, cognitive performance is negatively influenced by poor sleep quality.

Keywords: sleep quality, Pittsburgh questionnaire, cognitive disability questionnaire, numerical Stroop test.

INTRODUCTION

Sleep is one of the important physiological events playing a crucial role in maintaining the physical and mental health (1). Sleep is characterized by a remarkable decrease in consciousness and a significant reduction in responding to sensory stimuli, which can be quickly reversible (2). Sleep is associated with complex alteration in physiology of different systems and affects almost all physical and mental functions (3). During sleep, the organism body take actions necessary to maintain brain function and body health. Neurogenesis and synaptogenesis occur during different stages of sleep (3). Sleep also plays an important role in removing the harmful substances accumulated surrounding brain neurons during the wakefulness (4). In fact, the production and flow of cerebrospinal fluid increases dramatically during sleep and somehow washes and removes toxic substances such as beta amyloid from brain tissue (4). Having sustained and effective cognitive functions including learning, consolidating new memories, attention, language, reasoning, creativity and decision making is dependent on sleep (5).

The brain neuronal activity undergoes remarkable changes during both non-rapid eye movement and rapid eye movement stages of sleep (6). Thus, sleep is expected to play an important role in brain-related functions (6). Normally, healthy adults need 7 to 9 h and elderly individuals require 8 to 9 hours of night sleep (7). Missing even one hour from normal sleep duration causes poor sleep quality. Poor sleep quality implies a reduction in both normal duration or quality of sleep (8).

Multiple factors can cause or contribute to poor sleep quality including severe life stress, illness, psychological or physical injuries, as well as environmental parameters such as sound, light, and low or high ambient temperature (9). People with Inadequate sleep undergo impairment of cognitive functions so that they exhibit reduced performance in analytical and logical reasoning (10). They also need more time for responding to environmental stimuli and show a weak performance in tasks engaging sustained attention (11). Poor sleep quality leads to enhancement of sleep pressure and weakens the executive function of the individuals (12). Then, poor sleep quality exposes the people at risk when they are doing their everyday activities that require high attention, such as driving (10).

Although a growing body of research supports the link between sleep and cognitive function, however the association between sleep quality and person's ability to inhibit a habitual response has not been evaluated. Therefore, in this study, we investigated the relationship between sleep quality and cognitive function with subjects' performance in numerical Stroop test (NST) by measuring the error rate, missing rate, and reaction time.

MATERIALS AND METHODS

Participants

21 volunteers (10 males and 11 females) aged 22 to 36 years old, right-handed, healthy, and without any chronic or acute background diseases, participated in this study. They had normal or corrected vision, reported no substance abuse issues, including drug or alcohol addiction, and were not taking any medications aside from dietary supplements. Additional details regarding the demographic information of the participants are provided in Table 1. The ethical considerations of this research were reviewed and approved by the Ethics Committee of Tarbiat Modares University (code: IR.MODARES.REC.1401.085).

Experimental procedure

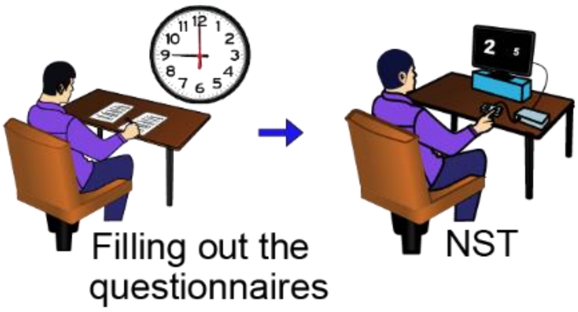

Figure 1. Experimental design

Subjects attended the lab at around 9 a.m. They first completed an informed consent form and then filled out a demographic information table, the Pittsburgh sleep quality index questionnaire, and a cognitive disability questionnaire, respectively. Then, a 10-min numerical Stroop test (NST), performed according to a method described later (Figure 1).

Pittsburgh sleep quality questionnaire

The Pittsburgh sleep quality index was developed by researchers at the University of Pittsburgh in 1989 (13). This questionnaire assesses sleep quality by evaluating seven components related to individuals' sleep over the past month (13). These components include subjective sleep quality, sleep latency, sleep duration, habitual sleep efficiency, sleep disturbances, use of sleeping medication, and daytime dysfunction (13). Participants answered the questions on a Likert scale ranging from 0 to 3. The total score from the seven components ranges from 0 to 21 and the higher the sleep quality score, the lower the sleep quality. In other words, a score of 21 indicates the worst sleep quality and zero indicates the best sleep quality. This questionnaire has a reliability of 0.83 and has demonstrated high validity in multiple studies. The Persian version of the Pittsburgh sleep quality questionnaire has shown acceptable reliability and validity in the Iranian population (14).

Cognitive disability questionnaire

Nejati developed this questionnaire in 2013, which comprises 30 items structured into seven components: memory, cognitive control and selective attention, decision-making, planning, sustained attention, social cognition, and cognitive flexibility (15). It assesses cognitive disability using a five-point Likert scale ranging from 1 (never) to 5 (always), with higher scores indicating deteriorating cognitive ability. In the Iranian population, the cognitive disability questionnaire has a reliability of 0.83 and has been used in numerous studies (16).

Numerical Stroop Test (NST)

The NST was used to evaluate cognitive processes as well as the ability to suppress automatic or habitual reactions. Participants in each trial viewed two single-digit numbers on a 16-inch screen situated about 80 centimeters away from their eyes. In each trial, a hashtag symbol was first displayed for 700 ms, followed by a blank screen for 500 ms. Subsequently, a pair of numbers was displayed in white against a black background for 800 ms, which was followed by another 500 ms blank screen. Afterwards, the next trial immediately commenced (17) (Figure 2). The digits ranged from 1 to 9 and were displayed in the Arial font. Participants were instructed to use a keypad to select the number with the greater value, irrespective of its size, using their right index finger. The side on which the larger number appeared was counterbalanced. The distance between each pair of numbers varied from 1 to 3. The number pairs were presented in three conditions: congruent, where the numerically larger number was physically larger (56 points) than the other digit (32 points); neutral, where both digits were of the same physical size (44 points) but differed numerically; and incongruent, where the numerically larger digit was smaller in physical size. The total number of trials was 252, with an equal distribution across numerical distances and congruency conditions. The trial order was pseudo-randomized. The task was divided into two sessions of 126 trials each, with a 5-min rest period between sessions to minimize mental fatigue and prevent dominating alpha waves.

The following variables were assessed in this test: Error rate: It reflects the percentage of total trials in which the participant provided incorrect responses by selecting a number with a lower value. Reaction time: This parameter represents the average time elapsed between the onset of presenting the numbers and pressing the left or right key. Missing rate: This indicates the percentage of total trials in which the participant failed to press either the left or right key following the presentation of the stimuli.

Statistical analysis

Statistical analysis was performed using GraphPad Prism (version 8, GraphPad Software, Boston, Massachusetts USA). Linear regression was performed to assess the correlation between variables, and the Pearson correlation coefficient was measured to determine the degree of their association. $p<0.05$ was regarded as the threshold for statistical significance.

RESULTS

Considering that the subjects' who participated in our study had relatively different indices of sleep quality and cognitive ability, therefore, in this study, we examined the relationship between indices of sleep quality and cognitive disabilities with the parameters related to the NST, including error rate, missing rate, and reaction time. The results showed that the analysis of linear

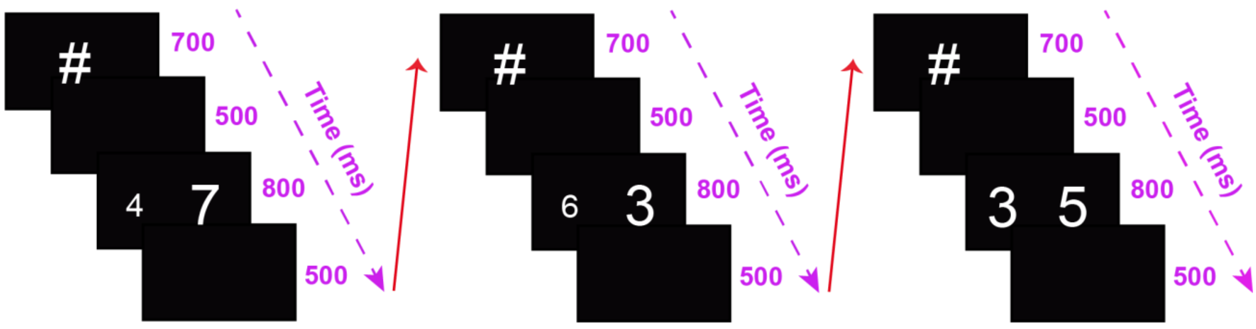

Figure 2. The timing protocol for displaying the numbers during the trials of NST.

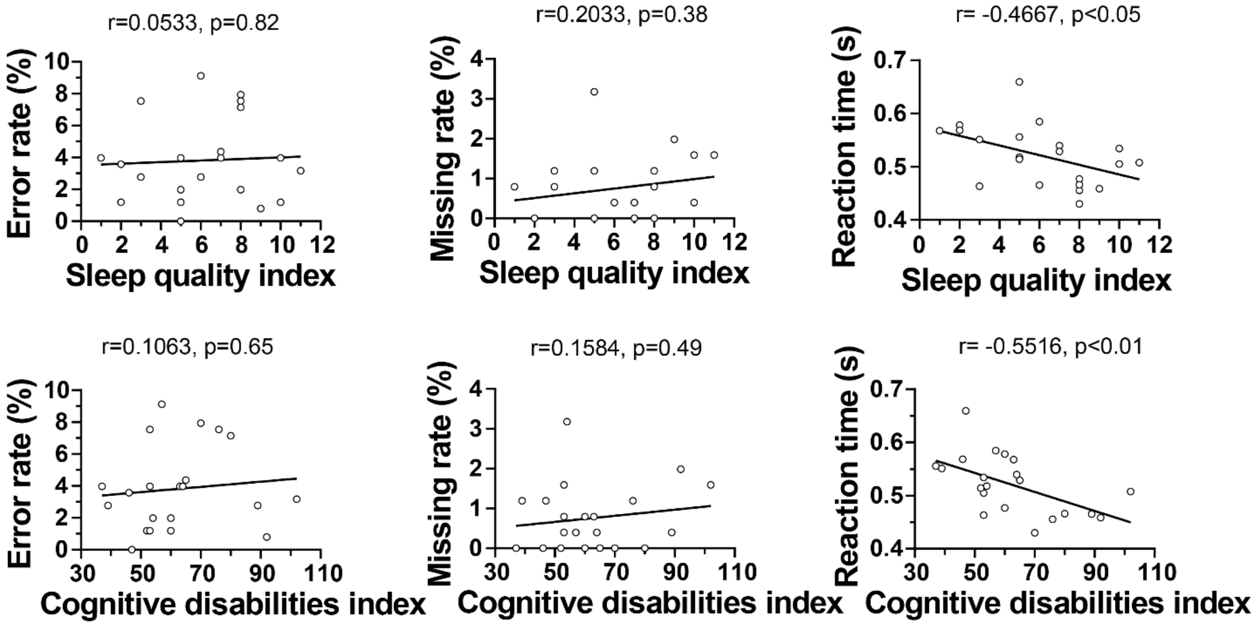

Figure 3. Correlation between sleep quality & cognitive disabilities indices with subjects' performance in NST.

regression and the calculation of Pearson's correlation coefficient showed a direct relationship between indices of sleep quality and cognitive disabilities with the parameters of error rate and missing rate, but in none of these cases, this relationship was not significant ($r=0.0533$, $p=0.82$ for error rate, $r=0.2033$, $p=0.38$ for missing rate in sleep quality; $r=0.1063$, $p=0.65$ for error rate, $r=0.1584$, $p=0.49$ for missing rate in cognitive disability; Figure 3). However, a significant correlation was observed between indices of sleep quality and cognitive disabilities with reaction time. In other words, subjects with poor sleep quality and more cognitive disabilities had a shorter reaction time. It seems that the participants answer quickly with impatience ($r= -0.4667$, $p<0.05$ for reaction time in sleep quality; $r= -0.5516$, $p<0.01$ for reaction time in cognitive disability; Figure 3).

Then, examining the relationship between sleep quality and cognitive disabilities indices showed a direct and significant relationship ($r=0.5296$, $p<0.05$; Figure 4).

DISCUSSION

The results of this study indicated that participants who had poor sleep quality had impaired cognitive performance and lower ability to inhibit habitual responses. Numerous studies have consistently demonstrated a decline in cognitive functions following inadequate sleep. Working

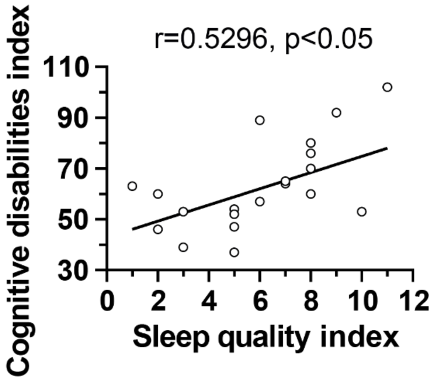

Figure 4. Correlation between sleep quality & cognitive disabilities indices.

memory, episodic memory, and associative memory are negatively affected by inadequate sleep (18, 19). Furthermore, increased fatigue resulting from inadequate sleep impairs alertness and attention (18). Moreover, inadequate sleep extends its influence to various cognitive domains, including logical reasoning, social judgment and decision-making (19, 20). Previous studies have shown that inadequate sleep, attention becomes highly unstable and irregular, leading to variable performance in attention-related tests (18). However, overall individuals' performance in attention tests decreases following inadequate sleep as a result of increased sleep pressure and decreased alertness (18, 19). Generally, the overall duration of wakefulness following inadequate sleep can predict the extent of attention disruption (18).

Interestingly, our study showed that poor sleep quality decreased reaction time in the NST. Although this result may seem unexpected at first, it can be justified according to previous findings. In a fMRI study, Venkatraman et al. (2007) reported that the right nucleus accumbens was more activated following taking the riskier choices in a gambling task following inadequate sleep compared to a normal sleep condition, indicating an elevated expectation of the higher reward after taking the decision (21, 22). In addition, the insular and orbitofrontal cortices were less activated following losses, indicating a reduced response to losses (22). Olson et al. (2016) and Killgore et al. (2006) observed that sleep-deprived individuals performing the Iowa Gambling Task exhibit impulsive behaviors, making riskier decisions more easily and considering short-term rather than long-term benefits (23, 24). In another study, Mullin et al. (2013) observed heightened activity in the ventral striatum and decreased deactivation in the medial prefrontal cortex during the winning in a monetary reward task following inadequate sleep compared to a normal sleep state (22). Together, these findings suggest that the value of reward and punishment is not accurately represented in neuronal activities following inadequate sleep, leading to impulsive and erroneous decisions (18). This may explain the decreased reaction time observed in sleep-deprived subjects (25).

CONCLUSION

In conclusion, this study documented relationships between sleep quality with ability to inhibit a habitual response and cognitive performance. Therefore, optimizing the duration and quality of sleep plays an important role in increasing cognitive performance and reducing habitual response.

DECLARATIONS

The author declares no conflicts of interest.

ACKNOWLEDGMENT

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