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Original Article

The Effect of Acute Sleep Deprivation on Temporal Processing and Frequency Resolution in Normal Healthy Adults

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OBJECTIVE: The study aimed at evaluating the impact of 24 hours of sleep deprivation on temporal processing and frequency resolution in normal individuals with no history of neurological and psychological deficits.

MATERIALS and METHODS: Sixteen individuals with normal hearing were included in the study. Temporal modulated transfer function, gap detection test, duration discrimination test, and pitch discrimination test were carried out in all of the individuals with a baseline evaluation, followed by an intra- test evaluation after 24 hours of sleep deprivation.

RESULTS: The mean gap detection test values were elevated in sleep deprivation conditions as compared to the baseline condition. The temporal modulation transfer function scores were also increased in the sleep deprivation condition when compared to the baseline condition. Individuals performed poorly for the duration discrimination test and pitch discrimination test in the sleep-deprived condition. All tests showed statistical significance between the two conditions, with $p<0.005$.

DISCUSSION: The reduced scores may be due to the effects of sleep deprivation on working memory, arousal, attention, concentration, and also reduced metabolism in the frontal lobe.

CONCLUSION: This could indicate that sleep deprivation also affects central auditory processing, since temporal processing and frequency resolution form the neurobiological basis of central auditory processing. Hence, it can be put forth that an acute period of 24 hours of sleep deprivation was sufficient to significantly worsen temporal processing and frequency resolution abilities.

KEY WORDS: Hearing, threshold, pure-tone, pitch, duration

INTRODUCTION

Behaviorally, sleep can be understood as a reduced response to external stimulation, increased reaction time, elevated arousal threshold, lack of mobility or slight mobility with slow eye movements, and a state of impaired cognitive function and as a reversible unconscious state. For human survival, sleep is important. Sleep plays a vital role in memory and learning. Modern lifestyle modifications, like increased stress, may affect the sleep pattern, resulting in poor quality of sleep. Reduction in the duration of sleep has tremendous effect on bodily functions, including the digestive, endocrine, vascular, immune, and nervous systems. The nature of sleep behavior is also believed to have an effect on psychiatric functions, like cognition, mood, and behavior. Sleep deprivation thus affects the overall health status of the individual [1, 2].

Reduction in sleep has negative effects on the immune, metabolic, and endocrine systems [3]. Sleep deprivation also increases blood pressure in healthy adults [4]. Mood is reported to be affected in sleep-disordered individuals [5]. Cumulative sleepiness, mood disturbances, and decrements in psychomotor vigilance performance were said to be present in individuals who were sleep restricted for a week of at least 4-5 hours per night [6]. Poor sleep quality also impairs cognitive performance in older adults [7]. Sleep deprivation of 24 hours significantly reduced the overall level of accuracy in dichotic temporal order judgment and increased the threshold from 57.61 ms to 73.93 ms, a reduction in temporal resolution of 28.3% [8].

Though the impact of sleep deprivation has been studied extensively in various experimental studies involving animals [9] to human imaging f-MRI studies [10], there has been limited research on the impact of sleep deprivation on temporal processing and frequency resolution. Therefore, the aim of the current study was to evaluate the impact of 24 hours of sleep deprivation on temporal processing and frequency resolution in clinically normal individuals.

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MATERIALS and METHODS

Participants

As per the inclusion criteria, 16 individuals with normal hearing, good physical and psychological health, and good sleeping habits were included in the study. Individuals with sleep disorders, neurological problems, or any positive medical or family history or on any medication within 1 day preceding the initial testing or on the day of sleep deprivation testing were excluded from the study. The study included 8 males (50%) and 8 females (50%) with a mean age (±standard deviation) of 20.06 (±2.43) years. The participants did not smoke or consume any medications, stimulants, caffeine, or alcohol 24 hours prior to the sleep deprivation test and the baseline test sessions. Ethics committee approval was received for this study from the ethics committee of Institutional ethics committee, Kasturba medical college, Mangalore. Informed consent was obtained from all subjects in prior.

Procedure

An initial pure tone audiometry, with air conduction (250-8000 Hz) and bone conduction (250-4000 Hz) testing followed by tympanometry, was done in all of the participants to ensure normal hearing sensitivity (thresholds <15 dBHL) and normal middle ear functioning ('A' type tympanogram). A calibrated GSI-61 audiometer and calibrated GSI-tympstar immittance meter were used for obtaining pure tone thresholds and middle ear status, respectively.

Temporal processing and frequency resolution abilities were tested using four tests: temporal modulated transfer function test, gap detection test, duration discrimination test, and pitch discrimination test. The tests were done on all subjects bilaterally. Initial baseline evaluation was carried out, followed by an intra-test evaluation 24 hours after the sleep deprivation. The testing was done using matrix laboratories (MATLAB) software (version 7), while the stimulus was presented using a calibrated Grason-Stadler (GSI-61) audiometer through telephonics dynamic headphone (TDH)-39 headphones. The stimuli for the tests were presented at the subject's most comfortable level using the transformed up-down procedure. Since the threshold had to be estimated to a point of 70% in the psychometric function curve, a 2-up 1-down procedure was used. Gap detection test and temporal modulated transfer function test were carried out using 2-alternate forced choice method, and duration discrimination test and pitch discrimination test were carried out using 3-alternate forced choice method.

Gap Detection Test

For the gap detection test to be carried out, first, the noise bands are filtered from the output of the broadband (0-5000 Hz) of constant spectrum level noise generated by means of a digital filter, which permits extremely sharper filter skirts. A narrow band noise with 2000 Hz center frequency, 250-ms duration, and varying gaps (0, 2, 5, 10, 15, 20, 25, 30, and 40) inserted at 125 ms of the noise duration was presented along with the standard narrow band noise of 2000 Hz center frequency of 250-ms duration without any gap, at 40 dBHL, in 2-alternate forced choice fashion, and the threshold for gap detection was obtained.

The gap detection test was scored based on the smallest gap detected by the participants by indicating the appropriate interval of noise that contains the gap. The subject just has to indicate whether it was the first or the second interval that contained the gap.

Temporal Modulated Transfer Function

The temporal modulated transfer function addresses the ability to detect the presence of amplitude modulation in a sound. A narrow band noise of 2000 Hz center frequency amplitude modulated at 8 Hz with varying modulation depth (0%-100%) and 250-ms duration was presented along with standard narrow band noise of 2000 Hz center frequency of 250-ms duration without any modulation, at 40 dBHL, using 2-alternate forced choice method. The subject was instructed to indicate which noise interval was modulated, and the threshold of modulation was detected.

The temporal modulated transfer function was scored based on the smallest level or depth of modulation that the participants were able to identify. The participants had to indicate if the modulation was present in the first or the second interval.

Duration Discrimination Test

Duration discrimination test is the ability to detect a change in the duration of auditory stimuli. As per the 3-alternate forced choice method employed for this task, 3 successive narrow band noises of 250 ms were presented, which had the same power spectrum but differed only in duration. One of them had a longer duration, and rest of the two had the standard duration of 250 ms; the subjects were asked to indicate which sound had a longer duration. The minimum difference in duration that the subjects were able to perceive was calculated.

The task was scored based on the smallest change in the duration that was identified by the participants. The subjects had to indicate whether the first, second, or third interval was longer than the other two, which were of standard interval.

Pitch Discrimination Test

Pitch discrimination test as described as the ability to detect change in pitch of the auditory stimuli. As per the 3-alternate forced-choice method employed for this task, 3 successive 3000 Hz pure tones of 250 ms were presented, which had same power spectrum but differed only in pitch. One of them had a higher frequency, and rest of the two had the standard center frequency of 3000 Hz. The minimum difference in the pitch that the subjects were able to identify due to the change in frequency of the variable tone was calculated.

The task was scored based on the smallest change in the pitch that was identified by the participants. The subjects had to indicate whether the first, second, or third interval had the higher pitch than the other two, which were of standard frequency.

Statistical Analysis

The effect of 24 hours of sleep deprivation on temporal processing and frequency resolution was studied using Student's paired-t test.

RESULTS

The effect of 24 hours of sleep deprivation on temporal processing and frequency resolution was studied using student's paired t-test. The statistical analysis showed a significant difference in gap detec-

Table 1. Mean and standard deviation of gap detection test

		Mean	Std. Deviation
Pair 1	Gap Detection Test. Deprived	4.5184	0.65288
	Gap Detection Test. Baseline	3.6226	0.50426

Table 2. Mean and standard deviation of pitch discrimination test

		Mean	Std. Deviation
Pair 1	Pitch Discrimination Test. Deprived	10.463E2	3.93028
	Pitch Discrimination Test. Baseline	55.3925	7.68611

Table 3. Mean and standard deviation of temporal modulated transfer function

		Mean	Std. Deviation
Pair 1	Temporal Modulated Transfer Function. Deprived	-34.5625	10.36641
	Temporal Modulated Transfer Function. Baseline	-42.0625	9.49715

Table 4. Mean and standard deviation of pitch discrimination test

		Mean	Std. Deviation
Pair 1	Pitch Discrimination Test. Deprived	33.0199	9.71819
	Pitch Discrimination Test. Baseline	84.5338	14.45456

tion test, temporal modulated transfer function, duration discrimination test, and the pitch discrimination test between the baseline conditions and the sleep deprivation conditions. The mean gap detection test values were elevated in the sleep deprivation condition (4.51±0.652) compared to the baseline condition (3.62±0.504), with t=5.002 and p=0.001. The temporal modulated transfer function scores were also increased in the sleep deprivation condition (-34.5625±10.366) relative to the baseline condition (-42.06±9.50), with t=2.388 and p=0.031. The sleep deprivation reduced the scores of the duration discrimination test (55.39±0.686) and pitch discrimination test (84.53±14.455) compared to the baseline condition scores of duration discrimination test and pitch discrimination test (104.63±23.930), with t=3.084 and p=0.008 and (109.96±21.718) with t=4.450 and p=0.001, respectively. All tests employed showed statistical significance, with p<0.005. The mean and standard deviation of the gap detection test, duration discrimination test, temporal modulated transfer function, and pitch discrimination test are provided in Tables 1-4.

DISCUSSION

The results of the present study revealed poor performances of normal hearing participants for the temporal processing and frequency resolution tests. The reduced scores may be the result of the effects of sleep deprivation on working memory, arousal, learning, attention, and concentration and reduced metabolism in the frontal lobe. This could indicate that sleep deprivation also affects central auditory processing, since temporal processing and frequency resolution form the neurobiological basis of central auditory processing [11]. Impairment of neurobiological functions affects memory, attention, concentration, reaction time, stimulus perception, and behavioral regulation, which are critical for the processing of auditory information. There are also the negative effects of extended wakefulness on central auditory processing following sleep deprivation. Metabolic activation studies [12] using attention and working memory tasks in humans suggest that a network between posterior association cortices and the prefrontal cortex are linked to these behaviors. Though, subcortical structures, such as the thalamus and the tectum, play an important role, cortical structures are thought to support attention. It was suggested that nocturnal sleep periods that are reduced by as little as 1.3 to 1.5 hours for 1 night results in a reduction of daytime alertness by as much as 32% [1].

Reduced scores in the gap detection test due to sleep deprivation were also reported [13]. Sleep deprivation thus impacts several functions associated with prefrontal cortex activity [14], which is important for the perception of auditory temporal resolution [8]. Hence, it is reasonable to postulate that sleep deprivation may impair central auditory processing through circuits involving the prefrontal cortex. Working memory, learning, attention, and arousal were reported to be affected in sleep-deprived individuals [15, 16]. Sleep deprivation in humans was also found to influence different components of attention non-selectively, through mechanisms that might either affect the centrencephalic structures maintaining vigilance or ubiquitously perturb neuronal function [17]. The results of a study showed that acute sleep deprivation alters the neurophysiology of the frontal and the temporal lobes [18]. The metabolism in the frontal lobe was reduced in findings reported in 2006 [19]. The findings in various studies indicate that the effect of sleep deprivation on the frontal lobe primarily involves reduced speech and language expression and perception, and reduced ability of creative processes, paying attention, and concentration. On the other hand, the effect on the temporal lobe was reported to be manifested as changes in the auditory abilities both affecting the perception and processing of auditory information as well as altering mood and behavior and impairing auditory memory.

Central auditory processing involves attention and concentration, which form the neurological basis of central auditory processing. In the views of a neuropsychological perspective, language tasks involving attention and higher level processing, such as reading comprehension, were affected by sleep deprivation [20].

In conclusion, an acute period of 24 hours of sleep deprivation was sufficient to significantly worsen temporal processing and frequency resolution in neurologically and psychologically healthy adults. Clinicians should take proper care in diagnosing a patient if sleep deprivation is a factor that lies overshadowed by other associated problems, like vertigo and weakness, which are usually missed in the case history.

Ethics Committee Approval: Ethics committee approval was received for this study from the Institutional Ethics Committee of Kasturba medical college, Mangalore.

Informed Consent: Written informed consent was obtained from the patients who participated in this study.

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