Original Article / *Özgün Makale*

DOI: 10.4274/tjsm.galenos.2023.95967

Journal of Turkish Sleep Medicine 2023;10:216-220

Effect of 24-hour Sleep Deprivation on Visual Reactivity in Healthcare Professionals

Sağlık Çalışanlarında 24 Saatlik Uyku Deprivasyonun Vizüel Reaktivite Üzerine Olan Etkisi

Nevroz Ünlü, Çiğdem Deniz*, Talip Asil**

University of Health Sciences Turkey, Kanuni Sultan Süleyman Training and Research Hospital, Clinic of Neurology, İstanbul, Turkey
**Tekirdağ Namık Kemal University Faculty of Medicine, Department of Neurology, Tekirdağ, Turkey*
***Memorial Hizmet Hospital, Clinic of Neurology, İstanbul, Turkey*

Abstract

Objective: The effects of sleep deprivation on cerebral metabolism and blood flow have been investigated using different methods. To evaluate cerebral blood flow (CBF) changes and reactivity using transcranial Doppler (TCD) sonography in response to visual stimulation before and after sleep deprivation.

Materials and Methods: The study included twenty healthcare professionals. For each cerebral hemisphere, the flow velocities of the two posterior cerebral arteries (PCA) were measured using TCD with eyes closed before and after sleep deprivation. Again, before and after sleep deprivation, visual stimulation was given with eyes open and flow velocity in PCA was recorded. The visual reactivity value was calculated for the right and left hemispheres before and after sleep deprivation. Reactivity is calculated as relative changes in blood flow velocity [ΔBFv = 100*(Vs-Vr)/Vr].

Results: It was found that CBF velocity increased significantly in response to visual stimulus before and after sleep deprivation in the right and left hemispheres ($p<0.001$).

In both hemispheres, CBF velocities measured after sleep deprivation without visual stimulus increased compared with those measured before sleep deprivation, but this increase showed statistical significance only for the right hemisphere ($p=0.008$). It was observed that the visual reactivity value calculated after sleep deprivation from the right and left hemispheres significantly decreased compared with that before sleep deprivation ($p<0.001$).

Conclusion: We found that visual reactivity values in healthcare professionals were significantly reduced after sleep deprivation. This decrease in visual reactivity value may cause decreased attention and prolongation of reaction time in healthcare professionals.

Keywords: Cerebral reactivity, sleep deprivation, posterior cerebral artery, visual stimulation

Öz

Amaç: Bu çalışmada uyku deprivasyonu öncesi ve sonrası görsel uyarıya yanıtla oluşan, serebral kan akım (CBF) hızı değişikliklerini ve reaktiviteyi transkranial Doppler sonografi (TCD) ile değerlendirmeyi amaçladık.

Gereç ve Yöntem: Çalışmaya, 20 sağlık çalışanı alındı. Her bir hemisfer için, uyku deprivasyonu öncesi ve sonrası, gözler kapalı konumda iken TCD ile her iki posterior serebral arterden (PCA) akım hızlarına bakıldı. Ve yine uyku deprivasyonu öncesi ve sonrası, gözler açıkken, görsel uyarı verildi ve PCA'daki akım hızları kaydedildi. Ayrıca sağ ve sol hemisfer için uyku deprivasyonu öncesi ve sonrası vizüel reaktivite değeri hesaplandı. Reaktivite, göreceli kan akım hızı değişiklikleri [ΔBFv = 100*(Vs-Vr)/Vr VR] olarak hesaplandı. Vr; minimum hızı gösterir (gözler kapalı, uyaran yok) ve Vs; maksimum hızı gösterir (gözler açık, uyaran var).

Bulgular: Sağ ve sol hemisferde uyku deprivasyonu öncesi ve sonrası görsel uyarıya yanıtta, CBF hızlarının anlamlı olarak arttığı görülmştür ($p<0,001$). Her iki hemisferde de vizüel uyaran olmadan uyku yoksunluğu sonrasında ölçülen CBF hızları, uyku yoksunluğu öncesine göre artmıştır, ancak bu artış sadece sağ hemisfer için istatistiksel anlamlılık göstermiştir ($p=0,008$). Sağ ve sol hemisferden uyku deprivasyonu sonrası hesaplanan vizüel reaktivite değerinin, uyku deprivasyonu öncesi değere göre anlamlı düştüğü görülmüştür ($p<0,001$).

Sonuç: Sağlık çalışanlarında görsel reaktivite değerlerinin uyku yoksunluğundan sonra önemli ölçüde azaldığını bulduk. Görsel reaktivite değerindeki bu azalma, sağlık çalışanlarında dikkatin azalmasına ve reaksiyon süresinin uzamasına neden olabilecektir.

Anahtar Kelimeler: Serebral reaktivite, uyku deprivasyonu, posterior serebral arter, görsel uyarı

Address for Correspondence/Yazışma Adresi: Lec, Çiğdem Deniz MD, Tekirdağ Namık Kemal University Faculty of Medicine, Department of Neurology, Tekirdağ, Turkey
Phone: +90 505 390 29 81 **E-mail:** teriyaki9@hotmail.com **ORCID-ID:** orcid.org/0000-0003-1325-4328
Received/Geliş Tarihi: 01.11.2022 **Accepted/Kabul Tarihi:** 21.01.2023

Introduction

The activity and rest periods of human life are variable. For survival, an individual needs sleep to work and perform daily activities. Waking and sleeping periods change in a cyclical (circadian) rhythm. Neglect of sleep can lead to disturbances in various systems of the body. Modern society often makes it necessary to increase productivity at the expense of insomnia. However, research has shown that long- term sleep deprivation or chronic short sleep causes a decrease in cognitive functions which may lead to reduced productivity (1-4).

Prolonged sleep deprivation causes loss of several basic cognitive abilities, such as attention, as well as complex cognitive functions such as fluent speech, logical thinking, and decision-making ability (5). Sleep deprivation causes a general decrease in cerebral blood flow (CBF) and metabolism, as well as a more pronounced decrease in high cortical functions (6). Previous studies have shown that suppression of sleep also causes decreased visual attention (7).

Vasodilation and an increase in blood flow velocity occur in the cerebral arteries in response to the metabolic demand, which increases as a result of the activation of the cerebral cortex (8). Using transcranial Doppler (TCD) sonography, it is possible to observe the changes in blood flow velocity in the cerebral arteries, as well as in the CBF with visual and motor stimulation (8,9). TCD can also show the relationship between neuronal activation and metabolic requirement by enabling continuous recording of blood flow velocity changes from the posterior cerebral artery (PCA) using visual stimulation (10).

In this study, we aimed to evaluate changes in CBF velocity and reactivity caused by the response to visual stimulation before and after sleep deprivation using TCD.

Materials and Methods

Upon the approval of the ethics committee, 20 healthcare professionals were included in this study to evaluate the changes in CBF and reactivity caused by the response to visual stimulation before and after sleep deprivation between May 1st 2010 and August 1st 2010. Approval was obtained from the Ethics Committee of Trakya University (decision no: 10-07, date: 28.05.2009). All participants gave their written informed consent to participate in the study. Healthcare professionals were evaluated twice, before and after a 24-hour sleep deprivation. 24-hour sleep deprivation was evaluated by recruiting healthcare professionals who are working 24-hour shifts, meaning, who are awake for 24 hours. Getting at least 8 hours of sleep before 24-hour sleep deprivation was taken as an inclusion criterion. The study included healthy young males who are aged 20 to 40 of age with no history of chronic illness, sleeep disorder and visual disturbances, and with normal physical and neurologic examinations.

Individuals younger than 20 years and older than 40 years, females, and those with a previous sleep disorder, history of psychiatric or organic illness, visual impairment, and those who smoked more than ten cigarettes and consumed more than five cups of coffee per day were excluded from the study. The healthcare professionals who participated in the study were informed that no medication that could affect the central nervous system should be taken 24 hours before the procedure, and, smoking should be stopped at least half an hour before and coffee should not be consumed at least 6 hours before the procedure.

The participants were placed in a quiet room, relaxed and in a lying position with 2-MHz TCD (Multi-Dop X4/CD8, DWL Elektronische Systeme GmbH, Sipplingen) probes being placed on the bilateral temporal bone with an elastic headband and the temporal bone at a depth of 60-70 mm. Probes were fixed by finding P2 branches of two PCAs. Whether the artery was a PCA was proved according to the increase in blood flow velocity in response to visual stimulation. The participants were asked to follow the testers fingertips for 20 seconds with the eyes open, and then to keep their eyes closed for 20 seconds. This 40 second period was repeated a total of 10 times. The time at which the visual stimulation began was indicated by an acoustic signal every 20 seconds.

For each cerebral hemisphere, the flow velocities of the two PCAs were measured using TCD at different times, before and after sleep deprivation, with eyes closed. Again, before and after sleep deprivation, visual stimulation was given with eyes open, and flow velocity in the PCAs was recorded. The visual reactivity value was calculated for the right and left hemispheres before and after sleep deprivation. Reactivity is calculated as relative changes in blood flow velocity. [$\Delta BFv = 100*(Vs-Vr)/ Vr$ Vr; indicates minimum velocity (eyes closed, stimulus off) and Vs; indicates maximum velocity (eyes open, stimulus on)] (10).

Statistical Analysis

The statistical analysis of the data was performed using the SPSS 11.5 software. Descriptive statistics (mean, standard deviation, median, lowest, highest, frequency and ratio values) were used for the data. Nonparametric tests were used for the measurements obtained. Wilcoxon signed-rank test was used for repeated measurements. P values less than 0.05 were considered as statistically significant.

Results

Twenty healthcare professionals were included in this study to evaluate the changes in CBF velocity and reactivity in response to visual stimulation before and after sleep deprivation. The average age of the participants was 31.3±4.7 years, and all were male.

It was found that the CBF velocity increased significantly in response to visual stimulus before and after sleep deprivation in the right and left hemispheres ($p<0.001$) (Table 1).

In both hemispheres, CBF velocities measured after sleep deprivation without visual stimulus increased compared to before sleep deprivation, but this increase showed statistical significance only for the right hemisphere ($p=0.008$). Under visual stimulus in both hemispheres, there was no statistically significant difference in CBF velocities before and after sleep deprivation (Table 1).

It was observed that the visual reactivity value calculated after sleep deprivation from the right and left hemispheres significantly decreased compared to before sleep deprivation ($p<0.001$) (Table 2).

Table 1. Blood flow velocity before and after sleep deprivation					
PCA flow velocity	**After sleep deprivation**	**p**	**Before sleep deprivation**	**p**	**p**
Right hemisphere PCA Vr (stimulus off)	28.4±7.32	p<0.001	22.6±6.5	p<0.001	p=0.008
Right hemisphere PCA Vs (stimulus on)	37±10.4		37.7±9.5		p=0.22
Left hemisphere PCA Vr (stimulus off)	29.5±8.07	p<0.001	25.9±8.3	p<0.001	p>0.05
Left hemisphere PCA Vs (stimulus on)	39.9±10.6		40.3±9.8		p>0.05
Vr; minumum velocity cm/sec (eyes closed, stimilus off), Vs; maximum velocity cm/sec (eyesopen, stimulus on). P value of <0.05 was considered as statistically significant. PCA: Posterior cerebral arteries					

Discussion

In our study, CBF velocities in the right and left hemispheres increased significantly in response to visual stimuli before and after sleep deprivation (p<0.001). In both hemispheres, CBF velocities measured after sleep deprivation without visual stimuli increased compared to before sleep deprivation, but this increase showed statistical significance only for the right hemisphere (p=0.008). There was no statistically significant difference in CBF velocity before and after sleep deprivation under visual stimulus in both hemispheres (Table 1). In addition, visual reactivity values in the right and left hemispheres calculated after sleep deprivation were significantly decreased compared to the values obtained before sleep deprivation (p<0.001) (Table 2).

TCD is a technique that noninvasively measures alters in CBF velocity in the main cerebral arteries during a given stimulus with high temporal resolution. Alters in CBF velocity have been reported to correlate with changes in CBF in the basal cerebral arteries if the arterial diameter remains constant (11,12). In fact, flowmetry studies with TCD have demonstrated the presence of visually evoked CBF velocity responses (13). It has been shown that subjects looking at an inverted checkerboard, commonly used as a visual stimulus, caused an 18% increase in blood flow velocity in the PCA, which supplies blood to the visual cortex (14). In general, the increased metabolic demands of cerebral activation cause dilation of arterioles and a consequent increase in the flow velocity of basal cerebral arteries (15-17). Increased regional cerebral metabolism in the occipital cortex due to visual stimulation has also been demonstrated by positron emission tomography (PET) studies (18). In our study, it was observed that flow velocities in the right and left hemispheres increased significantly in response to visual stimuli before and after sleep deprivation (p<0.001) (Table 1).

Using PET, Thomas et al. (19) demonstrated that total metabolism reduced after short-time sleep deprivation, with further decreases in the thalamus, prefrontal and posterior parietal cortices. Similar to PET studies, multiple studies of acute sleep deprivation on attention using functional magnetic resonance imaging (fMRI) have also reported reduced activation in prefrontal regions (20). However, findings from fMRI studies specifically for the thalamus are controversial. Some fMRI studies on attention and sleep deprivation have reported increased thalamic activation after sleep loss, while others have not.

Table 2. Reactivity values before and after sleep deprivation		
Vissual reactivity		**p**
Reactivity in right hemisphere before sleep deprivation	69.9±25.1	p<0.001
Reactivity in right hemisphere after sleep deprivation	29.9±11	
Reactivity in left hemisphere before sleep deprivation	61.8±26.4	p=0.006
Reactivity in left hemisphere after sleep deprivation	36.5±14.7	
P value of <0.05 was considered as statistically significant		

A recent meta-analysis of 11 studies assessing sleep deprivation using fMRI showed that brain activation in regions including the bilateral intraparietal sulcus, bilateral insula, right prefrontal cortex, medial frontal cortex and right parahippocampal gyrus was significantly decreased after sleep deprivation compared to rested wakefulness, while it was increased only in the bilateral thalamus (20). In other words, it has also been reported that sleep deprivation may cause regional changes in the brain, i.e. decreased activity in the anterior brain but increased activity in the posterior brain, and decreased default network and thalamocortical connectivity but increased interhemispheric connectivity (21).

The thalamus is crucial in maintaining wakefulness and vigilant attention (22-24). Previous behavioural reports have shown that alertness and vigilant attention are reduced after sleep deprivation (25). The observation of increased rather than decreased thalamic activity with decreased alertness and vigilant attention after sleep deprivation could be interpreted as an increased effort of thalamic activation to compensate for the dysfunction of the fronto-parietal attention network after sleep loss (19). Studies have found that thalamic activation is greater in sleep deprivation than in rested wakefulness, and task difficulty in rested wakefulness is relation with increases in thalamic activation, but not in sleep deprivation (19). In conclusion, increased thalamic activation after sleep deprivation may demonstrate a complex interaction between the arousing effects of sleep loss and the arousing effects of task performance on thalamic activity (20). It has also been shown that cognitive performance is maintained at an acceptable level as a result of prolonged sleep deprivation and that this compensation mechanism is more pronounced in the right

cerebral hemisphere, according to Drummond and Brown (26), and Drummond et al. (27). Consistent with the above, our study showed an increase in blood flow after sleep deprivation in the absence of visual stimuli compared to before sleep deprivation in both hemispheres, but this was significant in the right hemisphere (Table 1).

Nutrition and blood flow in the brain, are provided by neurovascular coupling (NVC), which is determined as the adjustment of local CBF in accordance with the underlying cortical neural activity (8). NVC includes a complex interaction between activated neurons, astrocytes, and microvascular endothelial and smooth muscle cells. These may involve alterations in neuronal activation, dysfunction of astrocytes, and/or changes in production of vasodilator mediators by microvascular endothelial cells (28). Cerebrovascular reactivty (CVR) measurement can indicate the capacity of cerebral blood vessels to respond to neuronal metabolic stimuli, hence NVC, and is commonly used to assess cerebrovascular function (29). As a result, decreased CVR may cause inadequate energy supply, especially in regions with increased energy demand (30). Jackson et al. (7) evaluated 27 hours of sleep deprivation with electoencephalography and revealed performance deficits in visual tasks. In the study by Lee et al. (31), P300 latency was prolonged and amplitude was decreased during 38 hours of sleep deprivation; this was shown to cause impairment in cognitive performance in terms of alertness and reaction time. In a recent study using TCD and functional near-infrared spectroscopy, it was shown that 24 hours of sleep deprivation impaired maintenance of attention and slowed reaction time without profound changes in cognitive areas such as working memory, visual memory and short-term visual information matching (28). In our study, in which we evaluated the posterior circulation system, a significant decrease in reactivity in response to visual stimuli was observed in both hemispheres after sleep deprivation (Table 2). This may result in decreased attention and prolonged reaction time.

Numerous studies have indicated the disruptive neurobehavioural effects of sleep deprivation on attention, working memory and other cognitive tasks; these effects are manifested in the form of psychomotor slowing, increased neglect and application errors, and decreased learning of cognitive task (25,32). It is inevitable that this situation will affect people who work in shifts or are exposed to long working hours, and of course health professionals more. Shift work is associated with deep synchronisation of circadian rhythm (33). As the circadian rhythm reduces daytime sleepiness, sleep time between consecutive night shifts may be further reduced. When this reduced sleep duration is added to the circadian dysfunction associated with the night shift, the impact of reduced sleep duration on cognitive function in healthacre professionals will be of concern. Sleep deprivation and misalignment of circadian phase will also be associated with slow reaction time, frequent loss of attention and increased error rates when performing tasks (34).

Study Limitations

The fact that the subject group in our study consisted of healthcare professionals of similar age, male gender and without a history of previous illness is important in terms of ensuring the homogeneity of the group. On the other hand, the small number of healthcare professionals and the inability to perform cognitive tests can be considered as limitations of our study.

Conclusion

In our study, CBF velocities in the right and left hemispheres increased significantly in response to visual stimuli before and after sleep deprivation. In both hemispheres, CBF velocities measured after sleep deprivation without visual stimuli increased compared to before sleep deprivation, but this increase was more pronounced in the right hemisphere, suggesting that the compensation mechanism after sleep deprivation is more effective in the right hemisphere. We also found that visual reactivity values in healthcare professionals were significantly reduced after sleep deprivation. This decrease in visual reactivity value may cause decreased attention and prolongation of reaction time in healthcare professionals.

Acknowledgements: We would like to thank Bengü Altunan who edited the English text.

Ethics

Ethics Committee Approval: Approval was obtained from the Ethics Committee of Trakya University (decision no: 10-07, date: 28.05.2009).

Informed Consent: All participants gave their written informed consent to participate in the study.

Peer-review: Externally peer-reviewed.

Authorship Contributions

Surgical and Medical Practices: N.Ü., Ç.D., T.A., Concept: N.Ü., Ç.D., T.A., Design: N.Ü., Ç.D., T.A., Data Collection or Processing: N.Ü., Ç.D., Analysis or Interpretation: N.Ü., Ç.D., T.A., Literature Search: N.Ü., Ç.D., Writing: N.Ü., Ç.D.

Conflict of Interest: No conflict of interest was declared by the authors.

Financial Disclosure: The authors declared that this study received no financial support.

References

1. Alkadhi K, Zagaar M, Alhaider I, Salim S, Aleisa A. Neurobiological consequences of sleep deprivation. Curr Neuropharmacol 2013;11:231-49.
2. Virtanen I, Kalleinen N, Urrila AS, Leppänen C, Polo-Kantola P. Cardiac autonomic changes after 40 hours of total sleep deprivation in women. Sleep Med 2015;16:250-7.
3. He J, Hsuchou H, He Y, Kastin AJ, Wang Y, Pan W. Sleep restriction impairs blood-brain barrier function. J Neurosci 2014;34:14697-706.
4. Ko CH, Fang YW, Tsai LL, Hsieh S. The effect of experimental sleep fragmentation on error monitoring. Biol Psychol 2015;104:163-72.
5. Kendall AP, Kautz MA, Russo MB, Killgore WD. Effects of sleep deprivation on lateral visual attention. Int J Neurosci 2006;116:1125-38.

6. Tomasi D, Wang RL, Telang F, Boronikolas V, Jayne MC, Wang GJ, Fowler JS, Volkow ND. Impairment of attentional networks after 1 night of sleep deprivation. Cereb Cortex 2009;19:233-40.
7. Jackson ML, Croft RJ, Owens K, Pierce RJ, Kennedy GA, Crewther D, Howard ME. The effect of acute sleep deprivation on visual evoked potentials in professional drivers. Sleep 2008;31:1261-9.
8. Aaslid R. Visually evoked dynamic blood flow response of the human cerebral circulation. Stroke 1987;18:771-5.
9. Uzuner N, Yalcinbaş O, Gücüyener D, Ozdemir G. Hand gripping effect on cerebral blood flow in normal subjects. Eur J Ultrasound 2000;11:147-50.
10. Uzuner N, Ak I, Gücüyener D, Asil T, Vardareli E, Ozdemir G. Cerebral hemodynamic patterns with technetium Tc 99m exametazime single photon emission computed tomography and transcranial Doppler sonography: a validation study using visual stimulation. J Ultrasound Med 2002;21:955-9.
11. Deppe M, Ringelstein EB, Knecht S. The investigation of functional brain lateralization by transcranial Doppler sonography. Neuroimage 2004;21:1124-46.
12. Serrador JM, Picot PA, Rutt BK, Shoemaker JK, Bondar RL. MRI measures of middle cerebral artery diameter in conscious humans during simulated orthostasis. Stroke 2000;31:1672-8.
13. Willie CK, Colino FL, Bailey DM, Tzeng YC, Binsted G, Jones LW, Haykowsky MJ, Bellapart J, Ogoh S, Smith KJ, Smirl JD, Day TA, Lucas SJ, Eller LK, Ainslie PN. Utility of transcranial Doppler ultrasound for the integrative assessment of cerebrovascular function. J Neurosci Methods 2011;196:221-37.
14. Fabjan A, Musizza B, Bajrović FF, Zaletel M, Strucl M. The effect of the cold pressor test on a visually evoked cerebral blood flow velocity response. Ultrasound Med Biol 2012;38:13-20.
15. Droste DW, Harders AG, Rastogi E. Two transcranial Doppler studies on blood flow velocity in both middle cerebral arteries during rest and the performance of cognitive tasks. Neuropsychologia 1989;27:1221-30.
16. Knecht S, Deppe M, Bäcker M, Ringelstein EB, Henningsen H. Regional cerebral blood flow increases during preparation for and processing of sensory stimuli. Exp Brain Res 1997;116:309-14.
17. Becker VU, Hansen HC, Brewitt U, Thie A. Visually evoked cerebral blood flow velocity changes in different states of brain dysfunction. Stroke 1996;27:446-9.
18. Wiedensohler R, Kuchta J, Aschoff A, Harders A, Klug N. Visually evoked changes of blood flow velocity and pulsatility index in the posterior cerebral arteries: a transcranial Doppler study. Zentralbl Neurochir 2004;65:13-7.
19. Thomas M, Sing H, Belenky G, Holcomb H, Mayberg H, Dannals R, Wagner H, Thorne D, Popp K, Rowland L, Welsh A, Balwinski S, Redmond D. Neural basis of alertness and cognitive performance impairments during sleepiness. I. Effects of 24 h of sleep deprivation on waking human regional brain activity. J Sleep Res 2000;9:335-52.
20. Ma N, Dinges DF, Basner M, Rao H. How acute total sleep loss affects the attending brain: a meta-analysis of neuroimaging studies. Sleep 2015;38:233-40.
21. Zhou F, Huang M, Gu L, Hong S, Jiang J, Zeng X, Gong H. Regional cerebral hypoperfusion after acute sleep deprivation: A STROBE-compliant study of arterial spin labeling fMRI. Medicine (Baltimore) 2019;98:e14008.
22. Luria AR. The working brain. Harmondsworth, England: Penguin Books 1973.
23. Schiff ND. Central thalamic contributions to arousal regulation and neurological disorders of consciousness. Ann N Y Acad Sci 2008;1129:105-18.
24. Parasuraman R, Warm JS, See JE. Brain systems of vigilance. In: Parasuraman R, ed. The attentive brain. Cambridge, MA: MIT Press 1998;221-256.
25. Lim J, Dinges DF. Sleep deprivation and vigilant attention. Ann N Y Acad Sci 2008;1129:305-22.
26. Drummond SP, Brown GG. The effects of total sleep deprivation on cerebral responses to cognitive performance. Neuropsychopharmacology 2001;25:S68-73.
27. Drummond SP, Gillin JC, Brown GG. Increased cerebral response during a divided attention task following sleep deprivation. J Sleep Res 2001;10:85-92.
28. Csipo T, Lipecz A, Owens C, Mukli P, Perry JW, Tarantini S, Balasubramanian P, Nyúl-Tóth Á, Yabluchanska V, Sorond FA, Kellawan JM, Purebl G, Sonntag WE, Csiszar A, Ungvari Z, Yabluchanskiy A. Sleep deprivation impairs cognitive performance, alters task-associated cerebral blood flow and decreases cortical neurovascular coupling-related hemodynamic responses. Sci Rep 2021;11:20994.
29. Kisler K, Nelson AR, Montagne A, Zlokovic BV. Cerebral blood flow regulation and neurovascular dysfunction in Alzheimer disease. Nat Rev Neurosci 2017;18:419-34.
30. Smoliński Ł, Litwin T, Kruk K, Skowrońska M, Kurkowska-Jastrzębska I, Członkowska A. Cerebrovascular reactivity and disease activity in relapsing-remitting multiple sclerosis. Adv Clin Exp Med 2020;29:183-8.
31. Lee HJ, Kim L, Suh KY. Cognitive deterioration and changes of P300 during total sleep deprivation. Psychiatry Clin Neurosci 2003;57:490-6.
32. Durmer JS, Dinges DF. Neurocognitive consequences of sleep deprivation. Semin Neurol 2005;25:117-29.
33. Kuhn G. Circadian rhythm, shift work, and emergency medicine. Ann Emerg Med 2001;37:88-98.
34. Hirsch Allen AJ, Park JE, Adhami N, Sirounis D, Tholin H, Dodek P, Rogers AE, Ayas N. Impact of work schedules on sleep duration of critical care nurses. Am J Crit Care 2014;23:290-5.