ORIGINAL ARTICLE

The Effects of Health Care Providers Night Shift on Cerebral Oxygen Saturation and its Relationship to Cognitive Function

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Background: In-training physicians frequently experience acute periods of sleep deprivation due to the extended durations of on-call shifts. To safeguard the well-being of residents, ensure patient safety, and optimize their performance, it becomes imperative to thoroughly assess and evaluate the cerebral function of in-training physicians subsequent to their shifts.

Objective: To elucidate the effects of the nightshifts on regional cerebral oxygen saturation ($rScO_2$) and cognitive function of 50 in-training pediatricians.

Materials and Methods: The $rScO_2$ was monitored using Near-infrared spectroscopy at specific intervals, pre-on-call (H0), post-call (H16), 24-hours from pre-on-call (H24), and 48-hours from pre-on-call (H48). All physicians continued their duties without a post-call day. The mathematical tests were performed at H0, H16, H24, and H48, while the Montreal cognitive assessment (MoCA) test was conducted at H0 and H24.

Results: The mean $rScO_2$ at post-call at 65.8±5.3% and 24-hours from pre-on-call at 64.6±6.4%, were significantly declined from pre-on-call at 68.2±5.6% ($p<0.001$), and then returned to baseline at 48-hours from pre-on-call at 68.9±5.5%. The mathematical test scores were not different. The mean MoCA score was significantly decreased at 24-hours from pre-on-call at H0 with 28.4±1.4 to H24 with 27.7±1.8 ($p<0.001$).

Conclusion: The 16-hours nightshifts and continuous working among residents might cause a transient reduction of $rScO_2$, which could lead to decreased cognitive function scores. Understanding the effects of stress, fatigue, and sleep deprivation on the cognitive performance of medical residents not only benefits each individual resident, but also promotes a culture of continuous improvement and excellence in medical education.

Keywords: Cerebral oxygen saturation; In-training physicians; Sleep deprivation; Work-hours; Cognitive function

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Due to long working hours and demanding responsibilities, physician-in-training programs are perpetually exposed to high levels of stress and fatigue. The intensive nature of medical residency frequently results in sleep disruption and deprivation, which impair cognitive ability and decision-making capabilities[1]. One common cause of sleep deprivation included work-related factors[2].

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In healthcare professionals, they experience work-related stress such as time pressure, high expectations, low tolerance for errors, and night-time on-call work[3]. Previous studies have focused on simulating clinical tasks[4], attention and monitoring tasks[5], and cognitive task performance. The overall results have shown that sleep deprivation was inversely related to neurocognitive performance[4]. Lack of sleep from night-time on-call work is a problem for healthcare workers. The impact of 24-hour on-call shifts has been studied from different perspectives. It can negatively affect those workers psychologically, physiologically, and reduce cognitive performance[6,7]. Sleep deprivation is a key factor of cognitive performance variability, which includes both errors of omission such as failure to respond to a stimulus in a timely manner, and errors of commission such as responses when no stimulus is present or to the erroneous stimulus[8].

In the past decade, near-infrared spectroscopy (NIRS) has gained widespread adoption as a valuable tool. It provides information on the regional oxygen saturation (rSO_2) of monitored organs by calculating a regional oxygenation value of deeper tissues. The obtained rSO_2 displays a balance between brain oxygen supply and demand that is as accurate as invasive techniques[9,10]. Regional cerebral oxygen saturation ($rScO_2$) monitoring is applicable in both children and adults. In patients with head trauma, $rScO_2$ monitoring has been reported as accurate enough to detect early changes in cerebral blood flow[11]. Studies showed good correlation between the $rScO_2$ and cognitive function in patients[12-14]. The $rScO_2$ monitoring has been shown to decrease the risk of cerebral ischemia, resulting in less cognitive decline and a shorter hospital stay in patients undergoing major abdominal surgery[12]. A prior study reported the association between cerebral oxygenation and cognitive function measured by the Mini-Mental State Examination in chronic kidney disease patients. That study demonstrated that $rScO_2$ level was independently associated with estimated glomerular filtration rate and the cognitive function had significantly positive correlation with $rScO_2$ ($r=0.624$, $p<0.001$)[13]. Additionally, functional NIRS variations were associated with changes in mental workload during computer-based piloting activities in volunteers[14]. There was a study involving fifteen healthy physicians with one night on-call. Acute sleep deprivation altered the cardiovascular autonomic response to gravitational stimulus[15].

To ensure their well-being, patient safety, and optimal performance, it is essential to assess and evaluate the cerebral function of resident physicians following a call. To the authors' knowledge, there have been no studies reporting the effects of in-training physicians' work hours on $rScO_2$. The primary objective of the present study was to establish the values of $rScO_2$ and cognitive function in healthy pediatric residents after post call shifts. Additionally, the study aimed to determine the duration required for these effects to return to baseline levels once normal sleep patterns were resumed.

Materials and Methods

Recruitment

The present study was conducted at a pediatric department in a tertiary care academic center, which is a regional referral center in Thailand. The prospective study was conducted with all in-training pediatric physicians. Potential participants were excluded if they had current sleep disorders including obstructive sleep apnea, hypoventilation or insomnia, medical problems, or psychological problems thought to interfere with the study. The study was approved by the Committee on Human Rights Related to Research Involving Human Subjects, Faculty of Medicine Ramathibodi Hospital, Mahidol University (COA. MURA2020/590). All participants provided written informed consent prior to enrolment in the study.

Measurement and outcomes

$rScO_2$ measurement

The $rScO_2$ was monitored using two-channel continuous wave NIRS device INVOS 5100 (Somanetics, Troy, MI), where two adhesive sensors were placed on the forehead of the participants. Sensors were fixed with an opaque elastic bandage to shield the optodes from ambient light. The sensor contains two diodes, emitting near-infrared light at two different wavelengths that are absorbed by hemoglobin at 730 and 810 nm. Light travels from the sensor's light-emitting diode to either a proximal or distal detector, so the two depths of light penetration enable the device to subtract surface data and calculate a regional oxygenation value for deeper tissue. The probing depth of NIRS light penetrating the cerebral region is 2 to 3 cm[16]. Prior to measurement, participants were asked to sit in a chair for at least ten minutes to minimize the effect of postural change, and then the $rScO_2$ sensors were attached to their foreheads. The $rScO_2$ was gathered every two seconds and recorded on the device. The stable value was measured in each participant as a surrogate measure for $rScO_2$. The values for the two probes were averaged at each time point and used to calculate the mean $rScO_2$ level.

Cognitive assessment

The Montreal Cognitive Assessment (MoCA) is a bedside clinical evaluation tool for mild cognitive impairment. The MoCA cognitive test evaluates cognitive domains such as attention, executive functions, memory, language, visuoconstructional skills, conceptual thinking, calculations, and orientation. The total possible score is 30 points, and a score of 26 or above is considered to be normal. The Thai version of MoCA was used in the present study. Cronbach's alpha coefficient was 0.74, Pearson's correlation coefficient was 0.91, sensitivity was 70%, and specificity was 95%[17,18].

Mathematical assessment

Calculation skills are critical for physicians, particularly those specializing in pediatrics. The majority of a pediatrician's work involves accurate measurements, for the purpose of performing dosage calculations. Prior study indicated that specific areas of the brain, namely the bilateral intraparietal and prefrontal areas, are systematically activated during the perception and execution of numerical calculations[19]. To assess participants' calculation ability, the authors used a Grade 10 mathematics assessment derived from standard student textbooks. This test encompassed four broad domains, numbers and operations, algebra, geometry and measurement, and data analysis, probability, and statistics. Participants could achieve a maximum score of ten points on this assessment.

Study protocol

Baseline characteristics and sleep patterns were collected. The $rScO_2$ was monitored the pre-on-call time at 4 pm (H0), the time at 8 am the next morning (H16), the time at 4 pm, 24-hours from pre-on-call time (H24), and the time at 4 pm, 48-hours from pre-on-call time (H48). The mathematical test was performed at H0, H16, H24, and H48, and the MoCA test was only performed at H0 and H24 to minimize the practice effect of repeated measuring. Blood pressure and heart rate were monitored during the study.

Statistical analysis

No similar studies were available for power analysis for the present study. The authors collected data from all pediatric residents in the authors' department. The Kolmogorov-Smirnov test was used to check the normality of the data distribution. Parametric continuous variables were described as mean and standard deviation (SD). Categorical variables were expressed as number of patients and percentage. The student's t-test and Mann-Whitney U test were used to compare continuous variables. Categorical variables were analyzed using Fisher's exact test. Mean $rScO_2$, MoCA score and mathematic score were compared by using the repeated measures ANOVA. Continuous variables were presented as mean±SD or 95% confidence intervals (CI) for normally distributed data or median (range) for abnormally distributed data. Categorical variables were presented as numbers (percentage). A p-value less than 0.05 was considered significant. Statistical analyses were performed using the IBM SPSS Statistics, version 26.0 (IBM Corp., Armonk, NY, USA).

Table 1. Demographic data of the studied pediatricians

Baseline characteristics	n=50
Age (year), mean [SD]	28.6 [1.6]
Female; n (%)	46 (92.0)
BMI (kg/m^2), mean [SD]	20.8 [1.8]
Underlying; n (%)	
No underlying disease	41 (82.0)
Allergic rhinitis	9 (18.0)
Average sleep time in 1 week (hours/day), mean [SD]	6.1 [1.1]
Average work hour (hours/day), mean [SD]	10.5 [1.9]
Caffeine intake: at least 1 cup/day; n (%)	36 (72.0)

SD=standard deviation; BMI=body mass index

Results

Baseline characteristic

The enrollment data and demographics of 50 participants included in the present study are summarized in Table 1. Obstructive sleep apnea was a factor in the exclusion of one pediatric resident. The mean age and BMI were 28.65 (SD 1.6) years and 20.80 (SD 1.8), respectively. Forty-six participants were female (92%). Eighty-two percent were healthy and 18% were allergic rhinitis. The mean sleep duration was 6.08±1.05 hours per day, with 28% reported short sleep duration of less than five hours, in the previous one week of study. The results showed that 72% of participants consumed at least one caffeinated beverage per day, with 4% consumed three cups of coffee per day.

Effects of nightshift work hours on the $rScO_2$ level

The participants had an average nightshift active work duration of 12 (±2) hours. Importantly, none of the participants took naps or slept during the day following their nightshift work. The results revealed a significant decrease in the mean of $rScO_2$ level between pre-on-call time (H0) and H16 at 68.2±5.6 versus 65.8±5.3% ($p<0.001$). Moreover, the $rScO_2$ levels reached their lowest point at the time of 24-hours from pre-on-call time (H24) at 68.2±5.6 versus 64.6±6.4% ($p<0.001$). However, there was no significant difference in the $rScO_2$ level between baseline (H0) and at the time of 48-hours from pre-on-call time (H48) (Figure 1).

Effects of nightshift work hours on the cognitive functions and mathematical test

The mean MoCA score was statistically significantly decreased from 28.4±1.4 at H0 to 27.7±1.8 at H24 ($p<0.001$) (Figure 2). The means of the mathematic scores remained consistent across

Table 2. The variable data associated with cognitive impairment

	CI (n=7); median (range)	No CI (n=43); median (range)	p-value
Baseline $rScO_2$ (H0) (%)	69 (67, 70)	68 (65, 73)	0.72
Difference of $rScO_2$ at H16 from H0 (%)	−2 (−6, 0)	−3 (−5, 0)	0.66
Difference of $rScO_2$ at H24 from H0 (%)	−6 (−12, −4)	−2 (−4, 0)	0.02*
Average sleep time in 1 week (hours/day)	5 (4, 6)	6 (6, 7)	0.07
Total sleep time during on-call duty (hours)	4 (3, 4)	4 (3, 5)	0.57

CI=cognitive impairment group (participants who achieve a MoCA score of 25 or lower); $rScO_2$=cerebral oxygen saturation; H0=pre on-call; H16=16-hours from pre on-call time; H24=24-hours from pre on-call time

* Statistically significant difference

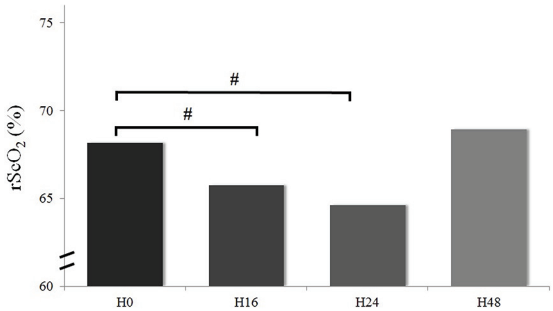

Figure 1. The effects of nightshifts work hours on the $rScO_2$ level.

Data are presented as mean±SD

$rScO_2$=cerebral oxygen saturation; H0=pre-on-call time; H16=16-hours from pre-on-call time; H24=24-hours from pre-on-call time; H48=48-hours from pre on-call time

Statistically significant difference

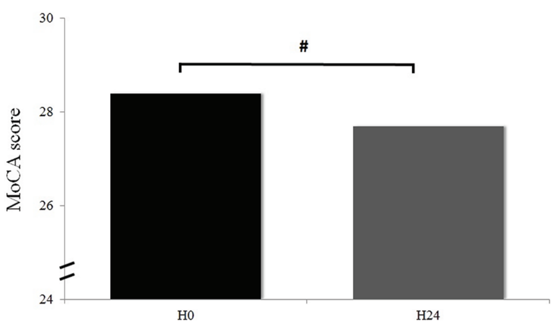

Figure 2. The effects of nightshift work hours on the cognitive function.

Data are presented as mean±SD

H0=pre-on-call time; H24=24-hours from pre-on-call time

Statistically significant difference

all time points with scores of 9.4, 9.3, 9.5, and 9.4 at H0, H16, H24, and H48, respectively, from a total score of 10.

Relationship between $rScO_2$ and cognitive function

The present study found seven out of 50 participants achieved a MoCA score of 25 or less, indicating cognitive impairment. Moreover, all participants displayed impairment in at least one test in the memory domain, with 57% affected in the attention domain, 29% in the language domain, and 14% in the visuospatial domain. Further analysis revealed that participants with a MoCA score of 25 or less exhibited a significant reduction in the $rScO_2$ level between H0 and H24 at –6 (–12, –4) versus –2 (–4, 0) (p=0.02) (Table 2). However, no significant differences in mathematical test scores were discovered between all-time points with H0 at 9.4, H16 at 9.3, H24 at 9.5, and H48 at 9.4 from a total score of 10.

Discussion

Medical education and training can be challenging and demanding, especially for in-training physicians who are responsible for patient care. The demanding workload, coupled with long hours, especially during post-call duties, can profoundly impact the health and quality of life of these individuals. Sleep deprivation resulting from extended work hours has long been a concerning issue within the health care profession. A prior study established that a quarter of trainees in the United States work more than 80 hours per week, with an average of 60 hours per week[20]. In the present study, the authors focused on pediatric residents, who typically worked 10 to 12 hours per day and were required to undertake at least two nightshifts per week. These nightshifts were often lengthy, spanning 24 to 36 hours, and occasionally even longer. These situations are more common in developing countries, where the demand for medical services is high, but the number of in-training physicians is limited[21]. To the authors knowledge, the present study represents the first attempt to investigate the impact of work hours on the $rScO_2$ and cognitive function of in-training physicians. The present study findings revealed that over 50% of the participants reported sleeping for fewer than seven hours per night before an on-call shift and less than four hours during night call.

Consequently, most of these physicians experienced acute sleep deprivation on top of chronic sleep deficits. These findings aligned with the research of Yasin et al., which reported a high prevalence of sleep deprivation, excessive daytime sleep, tiredness, and perceptions of inadequate sleep among young doctors[22]. Furthermore, a recent study showed the effect of sleep deprivation on executive function and impaired HPA-axis function[1]. These findings highlight the critical importance of addressing the issue of sleep deprivation among medical professionals to safeguard their cognitive abilities and overall well-being.

The main results of the present study revealed a significant decrease in mean $rScO_2$ values immediately after on-call duties (H16) and 8-hours post-call duties (H24). However, these $rScO_2$ values returned to normal levels after participants had adequate sleep. It is well established that cerebral autoregulation maintains cerebral oxygen delivery in the case of stable arterial oxygen content. All participants in the present study were healthy and free of any medical conditions that could impair cerebral perfusion, such as hypotension, tachycardia, bradycardia, anemia, or dehydration at the time of study. Therefore, the authors hypothesized that the declines in $rScO_2$ might correlate with increased oxygen consumption due to an increased neuron metabolism. A plausible explanation for this finding according to a previous study demonstrated that 36 hours of total sleep deprivation led to a significant increase in activation of task-positive areas in the bilateral insular cortex. This information suggests that when the brain is awake following sleep deprivation, it requires additional compensatory resources to maintain the task performance[23]. Therefore, the present study provides evidence that acute sleep deprivation resulting from on-call duties adversely affects $rScO_2$, possibly due to increased neuron activity. These findings contribute to a better understanding of the physiological changes in the brain during acute sleep deprivation and underscore the importance of addressing sleep-related issues among health care providers to ensure optimal cognitive functioning and overall health. The implementation of policies that restrict the maximum number of work hours or mandate adequate rest periods between shifts can reduce the negative effects of sleep deprivation. It is worth noting that the National Academy of Medicine recommended a decade ago that any reduction in the work hours of in-training physicians should be accompanied by an investment in resources to support sufficient staffing and infrastructure[24,25].

According to a meta-analysis of laboratory-based sleep loss studies, the average cognitive performance of healthy young adults who are sleep deprived, both short- or long-term, is –1.3 SD or more below the mean[26]. Additionally, the authors discovered that the MoCA score decreased significantly following a night on-call in the present study. The findings corroborate the findings of previous studies that examined the detrimental effect of long on-call hours on performance and cognitive functioning[27,28]. Furthermore, the authors examined the relationship between the reduction in $rScO_2$ and MoCA scores. Similarly to the previous study's finding, the present study finding indicated that participants with cognitive impairment had lower $rScO_2$ levels[12,13].

Improving the quality of life for in-training physicians is crucial for their health and the delivery of high-quality healthcare. Medical education institutions can play a pivotal role by implementing policy changes in post-call shift practices. These changes should encompass addressing sleep deprivation, bolstering support structures, fostering work-life balance, enhancing patient handoffs, prioritizing ongoing education, and granting access to wellness programs. These modifications will not only improve the overall experience of in-training physicians, but also contribute significantly to the development of well-rounded and resilient healthcare professionals. By prioritizing the health and well-being of those in training, medical education institutions can improve patient care and the health care system as a whole.

The present study has limitations. First, the exclusive focus on pediatricians may restrict the generalizability of the findings to other medical specialties. Different specialties may involve distinct work tasks, daily routines, rest periods before night shifts, and workloads during these shifts. Second, the authors administered the Thai version of the MoCA test twice in the study, which may have introduced practice effects. The interval between the two tests was 24 hours, which is short compared to other studies that used different forms of the MoCA test with intervals ranging from two weeks to five years[29]. A previous study concluded that using the alternative forms of MoCA for brief periods of time (60 minutes to one month) might eliminate the possibility of practice effects[30]. However, the authors did not have access to an alternate form of the MoCA test in Thai. Nevertheless, the present study results still demonstrated a significant decline in MoCA scores at the 24-hours after pre-on-call time, providing support for the impact of acute sleep deprivation. Despite these limitations, the present study carries significant implications for the enhancement of in-training physicians' programs. The findings highlight the importance of critically evaluating work-hour restrictions and innovations in medical education to prevent excessive work hours and sleep deprivation among medical professionals, particularly in countries like Thailand. Thereby, the authors can effectively mitigate the adverse consequences of sleep deprivation and fatigue on patient care and safety. Overall, implementing strategies to ensure adequate rest reduces both acute and chronic sleep deprivation and can lead to improved cognitive functioning and overall performance among healthcare providers.

Conclusion

The current practice of continuous 24-hour working shifts in residency training programs can lead to a reduction in the $rScO_2$, which might impair cognitive function. Work-hour restrictions should be considered as an innovation in the residency training programs to avoid excessive hours of work and to mitigate the effects of sleep deprivation and fatigue on patient care and safety. Understanding the effects of stress, fatigue, and sleep deprivation on the cognitive performance of in-training physicians holds significant benefits, not only for the well-being of in-training physicians but also for fostering a culture of continuous improvement and excellence in medical training. A large multicenter study on resident work hours' impact on patient safety and resident burnout needs to be conducted.

What is already known on this topic?

Physician-in-training programs experience chronic stress and fatigue due to long working hours and demanding responsibilities, leading to sleep disruption and deprivation that often impairs cognitive ability and decision-making.

What does this study add?

Continuous 24-hour working shifts in residency training programs may reduce $rScO_2$, potentially impairing cognitive function. Implementing work-hour restrictions is crucial as an innovative measure to prevent excessive work hours and address the impact of sleep deprivation and fatigue on patient care and safety.

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Conflicts of interest

The authors declare no conflicts of interest.

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