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A Polysomnographic Study of Effects of Sleep Deprivation on Novice and Senior Surgeons during Simulated Vitreoretinal Surgery

Marina Roizenblatt, MD, PhD,[1,2,3] *Peter L. Gehlbach, MD, PhD,*[3] *Vitor D.G. Marin, MD,*[1]
Arnaldo Roizenblatt, MD,[1] *Vinicius S. Saraiva, MD, PhD,*[1,2] *Mauricio H. Nakanami, MD,*[1]
Luciana C. Noia, MD, PhD,[1] *Sung E.Song Watanabe, MD, PhD,*[1] *Erika S. Yasaki, MD,*[1]
Renato M. Passos, MD, PhD,[1,2] *Octaviano Magalhães Junior, MD, PhD,*[1] *Rodrigo A.B. Fernandes, MD, PhD,*[1]
Francisco R. Stefanini, MD,[1] *Rafael Caiado, MD, PhD,*[1] *Kim Jiramongkolchai, MD,*[4] *Michel E. Farah, MD, PhD,*[1,2]
Rubens Belfort Junior, MD, PhD,[1,2] *Mauricio Maia, MD, PhD*[1,2]

Purpose: To assess the impact of a 3-hour polysomnography (PSG)-recorded night of sleep deprivation on next-morning simulated microsurgical skills among vitreoretinal (VR) surgeons with different levels of surgical experience and associate the sleep parameters obtained by PSG with Eyesi-generated performance.

Design: Self-controlled cohort study.

Participants: Eleven junior VR surgery fellows with < 2 years of surgical experience and 11 senior surgeons with > 10 years of surgical practice.

Methods: Surgical performance was assessed at 7AM after a 3-hour sleep-deprived night using the Eyesi simulator and compared with each subject's baseline performance.

Main Outcome Measures: Changes in Eyesi-generated score (0–700, worst to best), time for task completion (minutes), tremor-specific score (0–100, worst to best), and out-of-tolerance tremor percentage. Polysomnography was recorded during sleep deprivation.

Results: Novice surgeons had worse simulated surgical performance after sleep deprivation compared with self-controlled baseline dexterity in the total score (559.1 ± 39.3 vs. 593.8 ± 31.7; $P = 0.041$), time for task completion (13.59 ± 3.87 minutes vs. 10.96 ± 1.95 minutes; $P = 0.027$), tremor-specific score (53.8 ± 19.7 vs. 70.0 ± 15.3; $P = 0.031$), and out-of-tolerance tremor ($37.7\% \pm 11.9\%$ vs. $28.0\% \pm 9.2\%$; $P = 0.031$), whereas no performance differences were detected in those parameters among the senior surgeons before and after sleep deprivation ($P \geq 0.05$). Time for task completion increased by 26% ($P = 0.048$) in the post–sleep deprivation simulation sessions for all participants with a high apnea–hypopnea index (AHI) and by 37% ($P = 0.008$) among surgeons with fragmented sleep compared with those with normal AHI and < 10 arousals per hour, respectively. Fragmented sleep was the only polysomnographic parameter associated with a worse Eyesi-generated score, with a 10% ($P = 0.005$) decrease the following morning.

Conclusions: This study detected impaired simulated surgical dexterity among novice surgeons after acute sleep deprivation, whereas senior surgeons maintained their surgical performance, suggesting that the impact of poor sleep quality on surgical skills is offset by increased experience. When considering the 2 study groups together, sleep fragmentation and AHI were associated with jeopardized surgical performance after sleep deprivation.

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Sleep disturbance and deprivation negatively impact a surgeon's physical and psychological intraoperative state, and this can potentially affect performance and subsequent patient outcomes.[1] The impact of excessive work hours and sleep deprivation on education experienced under the apprenticeship model has been studied and remains somewhat controversial.[2] However, objective, quantitative, and controlled data on the effects of short or poor-quality sleep on the surgical performance of in-training physicians remain sparse.

Although it seems intuitive that sleep deprivation should impair human function and concentration and therefore

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compromise microsurgical skills, some studies present contradictory findings.[3–5] Accordingly, prior work has hypothesized that increased surgical experience may diminish the role that poor perioperative sleep quality plays in surgical performance.[6–8] Given the implications of sleep deprivation on surgical performance and safety and the obvious means by which these risks are mitigated, assessment of sleep deprivation and poor sleep patterns in microsurgeons justifies further study.

The impact of poor concentration and motor deficits may be amplified in technically demanding microsurgical fields, such as vitreoretinal (VR) surgery.[9,10] Presently, the literature lacks quantitative studies that objectively evaluate performance in a realistic VR surgical environment after an objectively administered sleep-deprived night, as recorded by polysomnography (PSG). Given the high-precision demands of VR surgery and the current availability of realistic simulators that record performance,[11–13] VR microsurgery may represent an ideal opportunity to analyze the impact of sleep deprivation on high-precision clinical skills.

Here, we present a performance study in which the Eyesi surgical simulator (VRmagic) used for posterior segment teaching tasks objectively quantified the performance of in-training and senior VR surgeons. The groups comprised surgeons with < 2 years and > 10 years of surgical experience, respectively. Skills were evaluated at baseline before sleep deprivation and after a night of PSG-controlled and PSG-characterized sleep deprivation. The primary goal was to assess whether sleep deprivation affected surgical dexterity based on surgical experience. A secondary objective was to assess whether known sleep parameters obtained by PSG had an impact on Eyesi performance data.

Methods

Study Design and Participants

Junior VR fellows with < 2 years of surgical experience and senior surgeons with > 10 years of surgical practice were recruited at the Ophthalmology Department, Universidade Federal de São Paulo, São Paulo, Brazil, for this self-controlled cohort study from January 2020 to February 2022. All participants provided written informed consent, the Ethics in Research Committee approved the study, and the research was conducted in accordance with the Declaration of Helsinki. Participants were excluded if they took medications that could affect surgical performance or were diagnosed with potentially performance-affecting chronic diseases. Considering the learning curve, junior participants were required to have prior experience with the Eyesi simulator for a minimum of 12 hours before being recruited into the study. Because no senior surgeons had significant prior experience with the simulator, they received a standardized oral orientation and a live hands-on demonstration before performing the tasks, followed by continuous feedback from the dry-laboratory staff (M.R.) throughout the study to minimize the learning curve. Due to the known association of age and body mass index with fine motor behaviors and sleep patterns, these variables were also analyzed. According to previous studies, obesity and increasing age are correlated with low hand grip strength, which is a predictor of hand dexterity.[14,15] Furthermore, sleep duration tends to decrease with increasing age and body mass index.[16,17]

Polysomnographic Recording

Sleep patterns were recorded using Somnologica 3.2 (Embla Co.), and sleep deprivation was defined as 3 hours spent in bed.[18–20] The following parameters were assessed: total time in bed (TTB), the time from lights out until sleep offset; total sleep time, the time from sleep onset to sleep offset; sleep efficiency percentage (total sleep time/TTB); sleep latency, the time between lights out and the first epoch scored as sleep; rapid eye movement latency, the time from sleep onset to the first epoch of rapid eye movement sleep; and arousals, the abrupt shift of electroencephalographic frequency exceeding 16 Hz, lasting longer than 3 seconds, and preceded by 10 seconds of stable sleep.

Sleep fragmentation is characterized by repeated arousals during the sleep period. Apnea was defined as the absence of nasal airflow for at least 10 seconds, whereas hypopnea was defined as a nasal airflow decrease of > 30% for at least 10 seconds followed by an arousal or a desaturation event.[21] Desaturation was defined as a 4% decrease in oxygen saturation from the average saturation in the preceding 120 seconds lasting for at least 10 seconds. The apnea−hypopnea index (AHI) was defined as the number of such respiratory events per hour of the total sleep time.[22] According to the American Academy of Sleep Medicine Scoring Manual, the following normal sleep parameters have been established: < 10 arousals per hour and an AHI of < 5.

Study Protocol

The Eyesi simulator and PSG were used as performance tests to quantitatively assess surgical dexterity and sleep pattern, respectively. Participants were instructed not to ingest caffeinated beverages or medications 24 hours before the simulation. On day 1, each participant's baseline performance was established. For this purpose, surgeons completed a course specifically designed for this study. All volunteers were instructed to sleep for at least 8 hours during the 24 hours preceding the baseline performance assessment. The performance outcomes assessed by the Eyesi platform were surgical score (0−700, worst to best), tremor-specific score (0−100, worst to best), out-of-tolerance tremor (percentage), and simulation completion time (minutes).

On day 2, the participant's surgical performance was evaluated after the sleep-deprived night. The minimal interval between the 2 days of analysis (baseline vs. sleep-deprived night) was 1 week, and subjects were again instructed to sleep for at least 8 hours during the 24 hours before the study night. The night in which the PSG was recorded for all participants started at 12AM and ended at 3AM (3 hours of TTB), and all surgical simulations were carried out the following morning beginning at 7AM. Each participant's performance metrics were again recorded using the Eyesi software. The simulation course was completed once before and then after sleep deprivation to avoid statistical noise in the dexterity results, and surgeon grading sheets were reviewed for statistical analysis at the end of the protocol.

Statistical Analysis

Considering the lack of research in this field, sample size calculation was based on a pilot study of 5 participants. With a sample size of 11 participants, a 30-point modification in the Eyesi-generated score after sleep restriction was detected, with a power of 80% at a 5% significance level. Statistics were performed using SPSS version 22.0 (IBM).

Regarding the demographic descriptive statistics, comparisons between proportions were performed using the Fisher exact test; the independent Student t test was used to compare means. Normality of data distributions was analyzed via the

Table 1. Demographic Descriptive Statistics of 11 Novice Surgeons and 11 Senior Surgeons Stratified by Subgroup

	Groups Based on Expertise Level		
	Novice Surgeons (n = *11*)	*Senior Surgeons* (n = *11*)	***P* Value***
Male, n (%)	6 (54.5)	8 (72.7)	0.66
Age (yrs)			< 0.001
Mean ± SD	29.27 ± 1.42	45.73 ± 5.33	
Median (minimum to maximum)	30 (27−32)	46 (36−57)	
Surgical practice time (yrs)			< 0.001
Mean ± SD	1.09 ± 0.30	15.45 ± 4.48	
Median (minimum to maximum)	1.00 (1.00−2.00)	15.00 (10.00−24.00)	
BMI (kg/m^2)			0.29
Mean ± SD	23.52 ± 3.12	24.90 ± 2.89	
Median (minimum to maximum)	24.30 (19.00−28.70)	25.70 (20.10−28.70)	

BMI = body mass index; SD = standard deviation.
*Fisher exact test or independent sample *t* test.

Kolmogorov−Smirnov test. Difference in simulated surgical performance before and after sleep deprivation was analyzed using mixed-effect linear regression after Bonferroni correction for multiple comparisons. Comparison of the mean data generated by Eyesi simulator modification after sleep deprivation according to the PSG sleep parameters was performed using the nonparametric Mann−Whitney *U* test and the Kruskal−Wallis test. Relative variation (delta) was calculated as the difference between the Eyesi-generated data before and after sleep restriction; the obtained value was divided by the data obtained before sleep deprivation. The level of significance was preset at 5% ($P < 0.05$).

Results

Demographic parameters of the 11 novice surgeons and 11 senior surgeons stratified by subgroup are summarized in Table 1. The Eyesi-generated data before and after sleep deprivation (Table 2) showed that novice surgeons had worse simulated surgical performance in the total score, task completion time, tremor-specific score, and out-of-tolerance tremor after sleep deprivation. In contrast, no differences were detected in these parameters in the senior group before and after sleep deprivation.

Considering the 2 study groups together, our analysis indicated a 26% ($P = 0.048$) increase in the relative delta of task completion time after sleep deprivation for participants who had a high AHI (≥ 5 respiratory events per h) compared with those with a normal AHI (< 5 respiratory events per h) (Fig 1). Similarly, the relative delta of the task completion time after sleep deprivation increased by 37% ($P = 0.008$) for surgeons who had fragmented sleep, represented by a high number of arousals per hour (Fig 2). Furthermore, a fragmented night's sleep was the only polysomnographic parameter associated with worse total surgical performance on the following day, represented by a decrease of 10% ($P = 0.005$) in the Eyesi-generated total score for all participants (Fig 3).

Discussion

In this prospective, interventional, and self-controlled study, we compared simulated surgical dexterity, before and after sleep deprivation, between novice and experienced surgeons. Methodologically, this study conducted "gold standard" polysomnographic sleep evaluations to establish quantitative PSG sleep parameters that were then correlated with standardized surgical performance data as measured by the Eyesi simulator. The overall performance of junior surgeons was negatively affected by sleep deprivation. They were also slower in completing the course tasks, and their rate of tremor was increased, whereas in senior surgeons, dexterity remained unchanged after sleep deprivation.

Detailed analysis of patterns of sleep deprivation revealed that both junior and senior surgeons who had fragmented sleep with > 10 arousals per hour had a 10% decrease in the total surgical score and a 37% increase in task completion time on the following day. Task completion time also increased among surgeons with a high AHI; in this group, the increase in the relative delta time was 26%. To the best of our knowledge, no previous studies have analyzed the objective sleep parameters obtained by PSG and compared them with quantitative performance data generated in a simulated surgical environment.

Schlosser et al[7] previously reported a difference in subjective alertness based on experience level and concluded that experienced surgeons felt significantly less sleepy compared with junior residents and interns in the postcall condition. Similarly, O'Brien et al[23] showed that the odds of an orthopedic surgeon making an error on a validated individual software test were 51% lower for attending surgeons than for residents, without an observed difference between fellows and residents. The same chance of error would decrease by 5% for every 1-year increase in participant experience. Lehmann et al[5] found no differences in the sleep-deprived condition between residents and medical students, suggesting that only a large difference in surgical expertise could provide surgeons with significant mechanisms for adapting to sleep deprivation.

An analogous conclusion was obtained by Whelehan et al,[24] who interestingly determined in a systematic review that the technical skills of "sleepy" surgeons were affected negatively and that sleep deprivation was likely to impact all levels of surgical training except for attending surgeons. Therefore, there is growing evidence that more

Table 2. Eyesi-Generated Data Before and After Sleep Deprivation

	Sleep Deprivation		
	*Before**	*After**	**P Value**[†]
Novice surgeons			
Eyesi-generated score	593.8 (31.7)	559.1 (39.3)	0.041
Intraocular time for task completion,minimum	10.96 (1.95)	13.59 (3.87)	0.027
Tremor-specific score	70.0 (15.3)	53.8 (19.7)	0.031
Tremor out of tolerance, %	28.0 (9.2)	37.7 (11.9)	0.031
Senior surgeons			
Eyesi-generated score	548.4 (54.9)	538.2 (44.7)	0.549
Intraocular time for task completion, minimum	16.4 (3.41)	17.58 (5.72)	0.323
Tremor-specific score	44.7 (25.4)	43.3 (15.2)	0.846
Tremor out of tolerance, %	42.4 (15.7)	43.8 (8.9)	0.747

*Data are expressed as mean (standard deviation).
[†] Mixed-effect linear regression.

experienced surgeons can compensate for sleep deprivation with learned strategies to minimize dexterity errors when exposed to adverse situations that would otherwise result in fatigue-related decreases in technical skill. A unique strength of this potentially validating study is an objective polysomnographic analysis of sleep and a correlative analysis with validated and quantitative surgical performance data.

Regarding the relationship between sleep arousals detected by PSG analysis and the performance change measured by the Eyesi simulator before and after sleep deprivation, participants who had fragmented sleep had decreased hand dexterity and increased task completion time. Sleep fragmentation is defined as multiple arousals or awakenings throughout the sleep cycle that lead to breaks in sleep continuity, and PSG is considered the gold standard examination to assess this sleep disorder.[21] Similar to sleep deprivation, sleep fragmentation also results in reduced TTB, so both conditions can potentially compromise cognitive status and psychomotor performance on the days after disturbed sleep. According to Bonnet and Arand,[25] reaction time is a typical task component that is sensitive to sleep loss.

Although sleep restriction intuitively impairs neurocognitive processes, current evidence does not provide compelling grounds for drawing uniform conclusions about a quantifiable impact on surgical outcomes. The evidence is

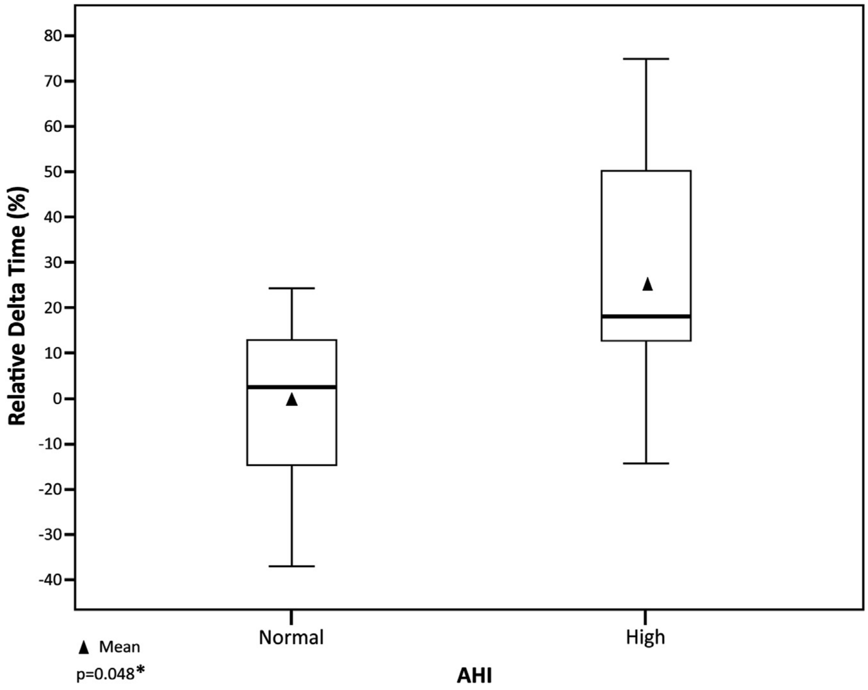

Figure 1. The relationship between the apnea−hypopnea index (AHI) and intraocular time for task completion before and after sleep deprivation for all participants. *Mann−Whitney *U* test.

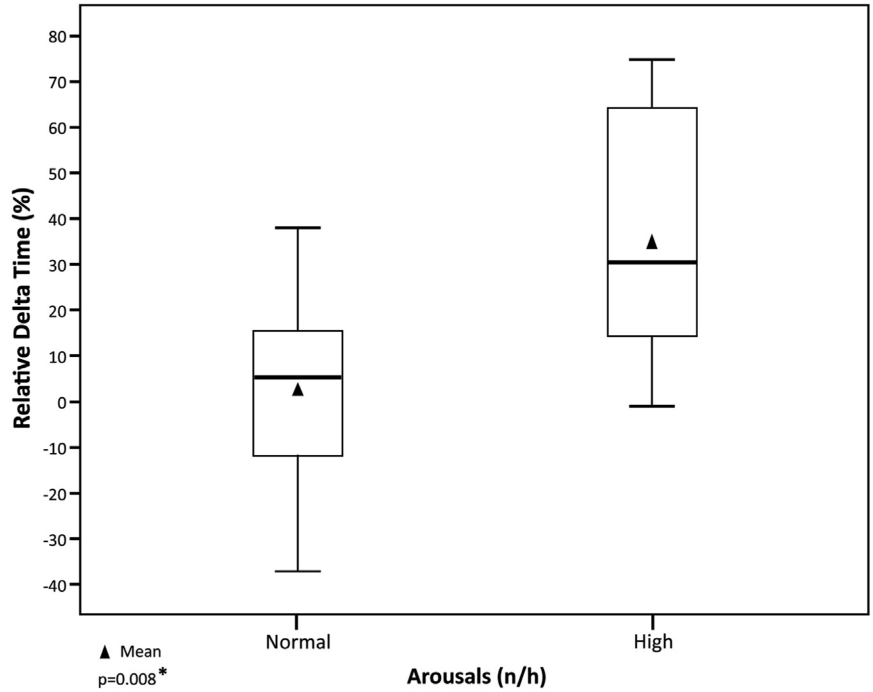

Figure 2. The relationship between sleep fragmentation, represented by arousals per hour of sleep, and intraocular time for task completion before and after sleep deprivation for all participants. *Mann—Whitney *U* test. n/h = arousals per hour of sleep.

mixed in support of the negative impact, the lack of impact, or even the positive impact of acute sleep restriction on the quality of surgical performance.[26] The main limitation in a systematic review concerns the heterogeneity in previous studies regarding the following factors: performance metrics used to assess surgical skills, extent of acute sleep restriction, presence of

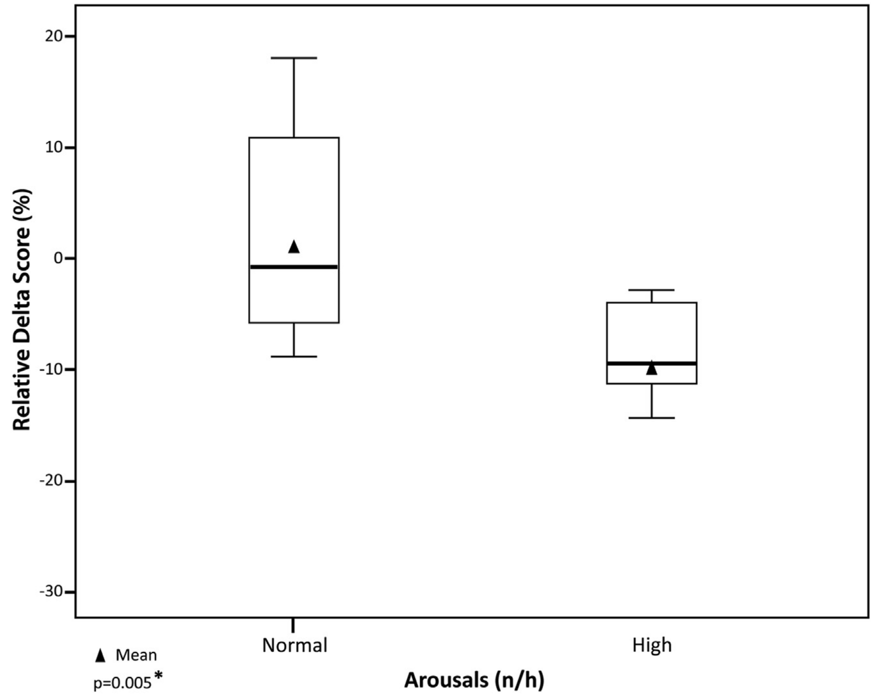

Figure 3. The relationship between sleep fragmentation, represented by arousals per hour of sleep, and Eyesi score before and after sleep deprivation for all participants. *Mann—Whitney *U* test. n/h = arousals per hour of sleep.

chronic sleep restriction, time of day due to circadian desynchronization, expertise level, and task demands.

In full consideration, it is not yet predictable as to which sleep circumstance predisposes to detrimental effects on safety in the setting of surgical care of patients.[27,28] To address these limitations, the current study standardized these variables by adopting a preestablished task sequence from the Eyesi simulator, a realistic virtual-reality surgical platform with strong validity evidence.[10,11,29] Surgical assessment was performed at the same time in the morning for all participants in the 2 study groups. To objectively analyze sleep deprivation, we adopted a 3-hour PSG-recorded night preceded by TTB of at least 8 hours during the 24 hours before the baseline performance assessment.

Djonlagic et al[30] showed that there is a clear minimal requirement for sleep continuity to establish optimal memory consolidation. The group also found a correlation between overnight deterioration and AHI. It is well recognized that apnea and hypopnea lead to impaired daytime functioning in various neuropsychological and affective domains because of disruption of sleep architecture and intermittent hypoxemia. The most common abnormalities are executive dysfunction and impaired vigilance.[31] A meta-analysis of the effects of obstructive sleep apnea syndrome on neuropsychological functioning showed that fine motor coordination was more sensitive to respiratory events than were tests of fine motor speed or visual perception.[32]

The current study complements the aforementioned meta-analysis data and presents a numeric scale for performance evaluation. Devita et al[33] reported a decreased cognitive profile of patients with obstructive sleep apnea syndrome and slowing of the motor component of their responses. Verstraeten et al[34] stated that motor slowness among those with respiratory sleep disorders derived from daily sleepiness or nonrestorative sleep had a substantial impact on daily activities by worsening cognitive efficiency. The current study extended those findings and demonstrated that a longer time is required for fine motor task completion in a simulated surgical environment among subjects with high AHI. It is worth mentioning that breathing cessations due to apnea or hypopnea are often followed by arousals, leading to sleep fragmentation and, thus, impaired sleep quality.[35]

Although this research was adequately powered to detect the deterioration of surgical performance, the small sample size should be considered a potential limitation. Future studies with an increased sample size would allow for a more precise description of the effects of sleep deprivation on surgical performance. In addition, the current findings pertain to acute sleep interruption, and alternate findings might result in studies of task performance after chronic sleep deprivation or after an arduous week of work. Furthermore, impaired surgical dexterity after sleep deprivation was measured in a simulator setting. Inherent limitations in extrapolating simulator data to real-world application include but are not limited to the differing complexity of the anatomy for a given disease, familiarity with the procedure, response variability to treatment that is inherent in medical science, and others. Further surgeon variables that have not been controlled and have the potential to contribute to differences in performance among novice versus senior surgeons after sleep deprivation include age, prior sleep quality, previous experience with the simulator, degree of acclimation to sleep deprivation, and the individual level of stress felt by each surgeon during procedures.

With the aforementioned limitations considered, there could be ethical issues related to conducting this research in a clinical setting with intentionally sleep-deprived surgeons. Therefore, the simulator is both a means to provide quantifiable and comparable data and a means of ethical study of this important question. Therefore, the notable significance of this study is that it is the first in the medical literature in which PSG sleep parameters were correlated with objective data obtained from the simulated surgical performances of sleep-deprived VR surgeons with different levels of surgical expertise. The results of this study serve as a signal that further study is merited and may have important implications in the practice of VR and general microsurgery.

In summary, the current study detected simulated surgical dexterity impairment among novice VR surgeons with acute sleep deprivation. In addition to diminished overall performance, the task completion time was longer, and the tremor rate was higher in the morning after a sleep-deprived night. In contrast, senior VR surgeons maintained their surgical dexterity, suggesting that the impact of sleep deprivation on surgical skills seems to be, in part, offset by increased experience. Importantly, sleep fragmentation and a high AHI were associated with impaired surgical dexterity after 1 night of controlled sleep deprivation in all surgeons. These findings suggest further critical analysis of the impact of sleep deprivation and sleep fragmentation on performance in microsurgical specialties at all levels of experience, with the greatest implications potentially being for trainee and junior surgeons.

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Footnotes and Disclosures

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[1] Department of Ophthalmology, Universidade Federal de São Paulo, São Paulo, Brazil.

[2] Vision Institute, Instituto Paulista de Estudos e Pesquisas em Oftalmologia (IPEPO), Universidade Federal de São Paulo, São Paulo, Brazil.

[3] The Wilmer Eye Institute, Johns Hopkins University School of Medicine, Baltimore, Maryland.

[4] Kaiser Permanente Medical Group, McLean, Virginia.

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HUMAN SUBJECTS: Human subjects were included in this study.

All participants provided written informed consent, the Ethics in Research Committee approved the study, and the research was conducted in accordance with the Helsinki Declaration.

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Author Contributions:

Conception and design: Roizenblatt, Gehlbach, Marin, Roizenblatt, Saraiva, Nakanami, Noia, Watanabe, Yasaki, Passos, Magalhães Junior, Fernandes, Stefanini, Caiado, Jiramongkolchai, Farah, Belfort Junior, Maia.

Data collection: Roizenblatt, Gehlbach, Marin, Roizenblatt, Saraiva, Nakanami, Noia, Watanabe, Yasaki, Passos, Magalhães Junior, Fernandes, Stefanini, Caiado, Jiramongkolchai, Farah, Belfort Junior, Maia.

Analysis and interpretation: Roizenblatt, Gehlbach, Marin, Roizenblatt, Saraiva, Nakanami, Noia, Watanabe, Yasaki, Passos, Magalhães Junior, Fernandes, Stefanini, Caiado, Jiramongkolchai, Farah, Belfort Junior, Maia.

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Abbreviations and Acronyms:

AHI = apnea−hypopnea index; **PSG** = polysomnography; **TTB** = total time in bed; **VR** = vitreoretinal.

Keywords:

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Correspondence:

Marina Roizenblatt, MD, PhD, Department of Ophthalmology, Administrative Office, Universidade Federal de São Paulo, 821 Botucatu Street, 1st floor, São Paulo 04023-062, Brazil. E-mail: maroizenb@gmail.com.

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