The Effect of Acute Sleep Deprivation and Fatigue in Cardiovascular Perfusion Students: A Mixed Methods Study

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Abstract: Sleep deprivation as a result of long working hours has been associated with an increased risk of adverse events in healthcare professions but not in cardiovascular perfusion. The purpose of this study is to investigate the impact of sleep deprivation on cardiovascular perfusion students. Testing with high-fidelity simulation after 24 hours of sleep deprivation allowed investigators to assess user competency and the effect of fatigue on performance. After informed consent, seven senior perfusion students were enrolled in the study (three declined to participate). The qualitative portion of the study included a focus group session, whereas the quantitative portion included administration of questionnaires, including the Epworth Sleepiness Scale (ESS) and the Stanford Sleepiness Scale (SSS), as well as clinical skills assessment using high-fidelity simulation. Subjects were assessed at three different intervals of sleep deprivation over a 24-hour period: baseline (6:00 AM), 12 hours (6:00 PM), 16 hours (10:00 PM), and 24 hours (6:00 AM) of wakefulness. During each scenario, normally monitored bypass parameters, including mean arterial pressure, activated clotting times, partial pressures of oxygen, partial pressures of carbon dioxide, and venous flow, were manipulated, and the subjects were required to return the parameters to normal levels. In addition, the scenario required calculation of the final protamine dose (using a dose–response curve) and detection of electrocardiography changes. Each task was varied at the different simulation sessions to decrease the effect of learning. Despite any lack of sleep, we hypothesized that, because of repetition, the times to complete the task would decrease at each session. We also hypothesized that the ESS and SSS scores would increase over time. We expected that the students would anticipate which tasks were being evaluated and would react more quickly. The average ESS scores progressively increased at each time period: baseline, 12 hours, 16 hours, and 24 hours. At 24 hours, the ESS and SSS scores were the greatest and the standard deviation was low, suggesting that fatigue affected all participants. During the clinical task evaluations, a “flattening effect” on the learning curve over time was observed. Tasks that required a higher level of cognition had prolonged completion times. Sleep deprivation significantly affects clinical performance as assessed with high-fidelity simulation. To optimize patient and clinician safety, it is important that the question of length of working time be investigated further. Keywords: fatigue, cardiopulmonary bypass, sleep loss, patient safety, education, acute sleep deprivation, perfusion students. JECT. 2012;44:116–125

Sleep deprivation among clinicians as a result of rigorous work schedules has been an ongoing problem in the healthcare field (1,2). Healthcare clinicians, especially residents, work longer and more continuous hours than is permitted in most other hazardous industries such as aviation and nuclear power (1,3). “Sleep loss” is a general term that encompasses both acute sleep deprivation (recent 24-hour complete sleep loss) and chronic partial sleep deprivation (<6 hours of sleep a night for at least 1 week) (4–8).

Extensive literature has shown that both acute sleep deprivation and fatigue markedly impair workplace performance, potentially putting clinicians at risk for making errors (8,9). Most experimental studies note performance deficits when clinicians obtain 4 hours of sleep or less (3). In a study by Papp et al. (4), residents across six specialties admitted to making mistakes (18 of 22), cutting corners (15 of 22), inefficiency (14 of 22), dozing on the job (eight of 22), and decrements in fine motor skills (seven of 22) when sleep-deprived. These effects

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The senior author has stated that authors have reported no material, financial, or other relationship with any healthcare-related business or other entity whose products or services are discussed in this paper.
are no surprise, because 24 hours of wakefulness has been found to produce psychomotor dysfunction equivalent to performance at a blood alcohol concentration of .10% (10,11). Many states in the United States have a blood alcohol limit conviction requirement of .08% for driving under the influence.

Like other healthcare professionals, cardiovascular perfusionists often work extended hours and, at times, during the night as a result of the unpredictable and often emergent nature of the job. As highly trained members of the cardiac surgical team, perfusionists must be available at all hours of the day and night to operate the heart–lung machine (HLM) in cases requiring cardiopulmonary bypass (CPB). At certain institutions, perfusionists must also provide 24-hour care for patients on ventilator assist devices and/or extracorporeal membrane oxygenation. These tasks can result in acute sleep deprivation of perfusionists.

Although acute sleep deprivation and fatigue have been widely studied in other medical specialties and clinical practice areas, discussion of this topic within the perfusion community has been lacking. In fact, only one study exists that directly examines the effect of sleep deprivation on perfusionists. Trew et al. (12) surveyed 445 perfusionists to elicit their opinions and experiences with fatigue and extended work hours. According to this survey, 6.7% have experienced a serious perfusion accident as a result of fatigue (12). In addition, 66% of respondents admitted to making minor errors on CPB as a result of fatigue, whereas 75.9% expressed concern that their clinical performance might be impaired when acutely sleep-deprived (12). According to these findings, perfusionists are vulnerable to job-induced sleep deprivation and fatigue, and patient safety may be jeopardized as a result.

At present, no study has investigated the effect of sleep deprivation on the performance of perfusionists. Designing a study with tasks realistic enough to simulate actual operating room (OR) conditions and experiences is a challenge (8,13). Consequently, reports of diminished performance among sleep-deprived clinicians have been scrutinized (13,14). Gold standard, prospective, randomized controlled studies using real patients to assess the relationship between fatigue and performance are not possible as a result of the potential risk posed to patients. However, with recent advances in high-fidelity computer simulation, researchers are now able to recreate high stress and routine clinical conditions and, therefore, draw parallels between simulator performance and clinical performance (13,15).

Using a mixed-methods approach involving a focus group discussion, subjective questionnaires, and the high-fidelity Orpheus cardiopulmonary bypass simulator (Ulco Technologies, Marrickville, New South Wales, Australia), this study sought to determine the effect of sleep deprivation on simulated clinical performance in perfusion students compared with their rested, baseline states.

**MATERIALS AND METHODS**

**Participants**

In October 2011, seven second-year Medical University of South Carolina (MUSC) cardiovascular perfusion (CVP) students were enrolled in the study under a protocol approved by the MUSC Institutional Review Board. All participants gave written informed consent. Each participant had similar experience with the Orpheus CPB simulator and had demonstrated baseline competencies using it.

**Focus Group Discussion**

Before baseline simulation testing at 6:00 AM, the study’s three investigators conducted a semistructured focus group interview to elicit participants’ attitudes and opinions regarding the effects of sleep deprivation during their CVP education. The discussion followed a set of four predetermined questions adapted from Papp et al.’s 2004 study (6) (Appendix A). Moderators took notes and kept time while guiding discussion, which lasted 30 minutes. The focus group session was later reviewed, and consistent themes were extracted. Thematic qualitative analysis was performed on these data.

**Quantitative Questionnaires**

After the focus group discussion, participants completed the Epworth Sleepiness Scale (ESS) and the Stanford Sleepiness Scale (SSS) to assess their self-perceived level of sleepiness (Appendix B). These questionnaires have been used in conjunction with “rested” performance assessments to establish interindividual baseline data (6,16–18).

The ESS questionnaire is a self-administered sleep propensity test that measures one’s likelihood of falling asleep during eight common, daily activities. ESS scores range from 0–24 and a sum score of 16 or greater indicates excessive daytime sleepiness (16). In contrast, the SSS questionnaire is a simple way to measure subjective sleepiness at a given time interval. Subjects rate their level of sleepiness on a 7-point, predetermined scale. Both questionnaires were administered before each simulation session.

**Simulated Cardiopulmonary Bypass Sessions**

**Sleep Conditions:** Participants received a normal night of rest before the first simulation session at 6:00 AM. By the last simulation session, subjects had been kept awake for a full 24 hours. An investigator remained with the participants at MUSC’s campus from 10:00 PM until 6:00 AM the next morning to ensure that participants remained awake, and subjects were asked to sign a waiver stating they were awake for the entire 24 hours. Participants were not allowed to consume caffeine or other stimulants during the study period.

**Simulation Environment:** Clinical performance was evaluated using the high-fidelity Orpheus perfusion simulator at MUSC’s high-fidelity CVP simulation facility.
The Orpheus system is composed of a hydraulic simulator linked to a controlling computer. The hydraulic component replicates the patient’s physiologic circulation and can be connected to an actual HLM as well as the facility’s monitoring screens to display real-time hemodynamic data (19). The simulator also incorporates a blood-gas analyzer with a touch-screen monitor that displays gas flow and fraction of inspired oxygen, arterial and venous blood gases, activated clotting time, and allows for drug administration. The Orpheus realistically recreates bypass conditions and, therefore, has wide applications for perfusionists.

The mock OR used for this study consisted of an operating table with sterile blue drapes and a patient mannequin to mask the hydraulic simulator. It also had overhead surgical lights and two monitoring screens that displayed real-time mean arterial and central venous pressures, electrocardiography (EKG) waveforms, and temperature (Figure 1). Perfusion equipment used in the OR included the Sarns 8000 HLM (Terumo, Ann Arbor, MI) and the Hemotherm Dual-Reservoir Cooler/Heater (Soma Technology, Inc., Bloomington, CT). A standard institutional MUSC paper CPB recording chart, pen, and calculator were provided. During simulation testing, auditory alarms and alerts on the HLM were preset to the facility’s default values. Participants were instructed to maintain normothermic conditions. Safety devices such as level sensors and a bubble detector were not used.

Conduct of Simulated Cases

Each simulator session took 7 minutes and was conducted by the study’s three investigators. One investigator acted as the surgeon, handling appropriate surgical instruments and giving subjects verbal instructions and cues for surgical timing according to a script for verbal commands at predetermined time points using a digital stopwatch. The remaining two investigators kept time to ensure interrater reliability and triggered prescripted events on the simulator using the control computer. Subjects served as their own controls and were assessed at four defined intervals over a 24-hour period: baseline (6:00 AM), 12 hours (6:00 PM), 16 hours (10:00 PM), and 24 hours (6:00 AM) of continuous wakefulness. Before each simulation session, participants were given 5 minutes to complete the ESS and SSS questionnaires. At this time, they were also presented with a detailed patient history and an adult surgery protocol with which they were familiar. Subjects were then individually brought into the simulation OR and instructed to conduct a normal bypass run.

The participants were instructed to initiate CPB, and a timer was set to 7 minutes. At each 1-minute interval, an investigator rapidly manipulated one of the following parameters—mean arterial pressure, partial pressures of oxygen, decreased venous return, ventricular fibrillation, and protamine dosage calculation. Performance was assessed based on the subject’s response time to initiation of corrective action. Subjects were given 2 minutes to react to each change such that five “events” were inserted into a 7-minute test period. Desired parameters were administered before the study and are routinely used for adult surgery protocols, so the subjects were familiar with the values before the study (Table 1). If no action was taken during this time, subjects were assigned a maximum score of “120 seconds” on that particular task. Similar tasks were

Figure 1. Medical University of South Carolina’s high-fidelity simulation center operating room with the heart–lung machine and related equipment (left). The control center and Orpheus cardiopulmonary bypass simulator trainer screen (right).
RESULTS

The participants’ demographic information is displayed in Table 2. No participant had previously been medically diagnosed with a sleep disorder.

Focus Group Discussion

Transcripts of the focus group were analyzed by means of thematic qualitative analysis. The epistemological paradigm being followed during the thematic analysis was based in phenomenology. After initial reading and analysis of the transcription, proto-themes were developed and then expanded. From the proto-themes, qualitative themes were isolated and are presented subsequently.

Job Performance

Participants agreed that their perfusion training and clinical workload has led to chronic sleep loss and fatigue. Although some claimed to be “conditioned to it,” other participants said that doing two cases per day for a week while on clinical rotations was very tiring. Demands of call in addition to pumping scheduled cases also contributed to participants’ fatigue. As a result, participants mentioned that they have been “so tired that they don’t remember routine things” such as whether or not they “fed their dog that morning.” Two of the seven participants admitted to experiencing “micro sleep” while on pump and being concerned about committing dangerous errors during these lapses in concentration. Participants also said that their formal learning was impaired when having to do a case in the morning and attend class in the afternoon. Subjects described themselves as running on “autopilot” and “spacing out” during these times.

Personal Life

Personal Well-Being: Perfusion students reported the negative impact of sleep loss on their personal health. One participant reported being medically diagnosed with “chronic fatigue” while in perfusion school and was seeing a physician to cope with this matter. Moreover, some noted weight loss resulting from their busy clinical schedules. Others said they frequently “grabbed food on the go” and ate unhealthy “convenience food,” leading to weight gain. Most participants did not have the energy or motivation to exercise after pumping a case and being awake at early hours. More importantly, perfusion students’ physical health appears to be at risk. Participants mentioned sometimes “having difficulty driving home after cases” and “feeling unsafe driving home” as a result of their level of sleepiness; some did not remember driving home.

Personal Relationships: Several participants commented that relationships with family and friends suffered as a result of sleep deprivation as a result of the demands of their training. Two participants in this study had children, one was married, and five had significant others at the time of the study. All participants agreed that acute sleep deprivation negatively affected their moods. As one subject described, fatigue from a rigorous work schedule made her “irritable with people” and “put my nerves on edge.” One subject mentioned the need to “vent a lot” because of tiredness, long hours, and resultant stress, whereas others expressed that they were usually “too tired to engage in conversation at all.” Some subjects could not “remember the last time [they] spoke with family.”

Those participants with children felt as though they could not adequately fulfill their parental duties as a result

<table>
<thead>
<tr>
<th>Table 1. Desired parameters used for the simulation sessions.</th>
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<tr>
<td>Heparin dose</td>
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<td>Protamine dose</td>
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<td>Cardioplegia</td>
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<td>Desired temperature</td>
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<td>Cardioplegia pressures</td>
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<td>Desired hematocrit</td>
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<td>Bypass parameters</td>
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HDR, heparin dose response; CPS, cardioplegia; CABG, coronary artery bypass graft; ACT, activated clotting time; PO2, partial pressures of oxygen; PCO2, partial pressure of carbon dioxide.

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<th>Table 2. Demographic table.</th>
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<td>Characteristic</td>
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<tr>
<td>Gender</td>
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<tr>
<td>Male</td>
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<td>Female</td>
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<td>Marital status</td>
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<td>Single</td>
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<td>Children</td>
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<td>Age in mean years (standard deviation)</td>
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EFFECT OF ACUTE SLEEP DEPRIVATION AND FATIGUE
of long work hours and sleepiness at the end of their workdays. In particular, one participant mentioned that I “couldn’t take the kids to the park to play because I was not sure when I [would] be done with work for the day.” Another said that she could not spend much time with her child because she had to get to bed so early every night to be rested for the next day’s case. This participant reported that she had to make her child’s bedtime earlier because they were going to bed at earlier times. A participant expressed difficulty in feeling like a “happy mom” when she is chronically tired and stressed. Instead of using leisure time on the weekend to spend time with family and significant others, participants had to use this time to “catch up on sleep.”

**Quantitative Questionnaires**

All participants completed the ESS and SSS questionnaires before each of the four simulation sessions. The ESS scores revealed that five of seven (71%) participants scored above “16” at the time of the third simulation session (10:00 PM), a score that necessitates clinical intervention. At 24 hours of wakefulness, six participants had cumulative scores of “24,” which is the maximum obtainable score, indicating a high propensity for falling asleep. In fact, mean ESS scores (mean, 15.8; range, 1–24) of the participants were only slightly less than mean scores in patients diagnosed with narcolepsy (mean, 17.5; range, 13–23) (16). Scores from the SSS questionnaire provided complementary data. The results of the SSS tend to increase in participants’ subjective rated sleepiness (Figure 2). From baseline to 12 hours of wakefulness, it appears the participants rated similar levels of sleepiness. This may be related to individual differences in wakefulness at 6:00 AM vs. 6:00 PM. By the last testing session, six participants rated themselves as functioning in a state of sleep with SSS scores of 7. Three of the participants felt sleepier at baseline (6:00 AM) than at 12 hours of wakefulness (6:00 PM). The ESS mean scores also increased over time (Figure 3). At 16 and 24 hours of wakefulness, the mean score was above 16, which is considered “extreme sleepiness.” This illustrates that the subjects felt the effects of acute sleep deprivation on their ability to doze given multiple different situations. The standard deviation at 24 hours was ±4 showing the extent of the trend across participants.

**Statistical Analysis**

Two researchers measured reaction time for participants. Interobserver variability was assessed through a correlation coefficient using linear regression between activity times recorded by the two researchers. The interobserver activity time correlations were high ($R^2 = .97$) showing sufficient reproducibility between the two researchers and thus an average of the two times was taken for analysis purposes. Univariate analyses included descriptive statistics such as means and standard deviations. A univariate repeated-measures analysis of variance (ANOVA) was used to test the equality of means among the various time points by task. Three time points (12 hours, 16 hours, and 24 hours) were compared to baseline as well as to each other: 12 hours vs. 16 hours, 12 hours vs. 24 hours, and 16 hours vs. 12 hours. For tasks 2 and 3, separate models were run with and without the two outliers, although results of the regression and ANOVA did not differ significantly, except for task 2, which was no longer significant in the trend regression analysis. Thus, the outliers were included in analyses. Multivariate linear regression with repeated measures was performed for each task independently to compare baseline time in seconds with the three time points (in seconds) at 12 hours, 16 hours, and 24 hours. All analyses were conducted using SAS 9.3 (Cary, NC) and Microsoft Excel 2010 (Microsoft, Redmond, WA). Statistical significance was considered at $p$ values <.05.
Analysis of Variance and Regression of Task Performance

The mean completion times for each task are presented in Table 3. Significant differences were found for baseline vs. 12 hours in tasks 3, 4, and 5 ($p = .004$, $p = .043$, and $p = .004$, respectively), baseline vs. 16 hours in tasks 3 and 5 ($p = .001$ and $p = .004$, respectively), and baseline vs. 24 hours in tasks 3 and 5 ($p < .001$ and $p = .001$, respectively) by repeated-measures ANOVA (Figures 4–6). Also significantly different were time points 16 hours vs. 24 hours ($p = .02$) in task 1 (Figure 7). Means in task 2 were borderline significantly different when comparing 12 hours with 24 hours ($p = .076$) and 16 hours to 24 hours ($p = .099$) (Figure 8).

For task 1, the reaction times were significantly faster at time point 16 hours compared with baseline when adjusted for the other time points in the model; time points 12 and

Table 3. Mean completion times for the five tasks (baseline, 12 hours, 16 hours, and 24 hours wakefulness).

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<tr>
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<th>Reaction times</th>
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<tr>
<td></td>
<td>Time 1 (µ ± SD)</td>
<td>Time 2 (µ ± SD)</td>
<td>Time 3 (µ ± SD)</td>
<td>Time 4 (µ ± SD)</td>
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<tr>
<td>Task 1: pO2 decrease</td>
<td>80.6 (72.3)</td>
<td>73.5 (65.0)</td>
<td>39.1 (19.6)</td>
<td>64.5 (30.5)</td>
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<tr>
<td>Task 2: decrease venous return</td>
<td>19.1 (24.2)</td>
<td>13.4 (5.7)</td>
<td>11.9 (4.3)</td>
<td>8.6 (3.5)</td>
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<tr>
<td>Task 3: pCO2 decrease</td>
<td>237.8 (4.4)</td>
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<tr>
<td>Task 4: protamine dosage calc.</td>
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<td>103.7 (21.6)</td>
<td>1120.6 (40.7)</td>
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<tr>
<td>Task 5: Decrease MAP</td>
<td>91.3 (36.2)</td>
<td>22.6 (18.5)</td>
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*p values of < .05 were considered statistically significant.

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Figure 4. Task 3: partial pressures of oxygen (pCO2) decrease. Mean and standard deviations (seconds) are presented for the four simulation sessions. Group means were compared at baseline with the three simulation sessions and also between each simulation by repeated-measures analysis of variance. *p values of < .05 were considered statistically significant.

Figure 5. Task 4: protamine dosage calculation. Mean and standard deviations (seconds) are presented for the four simulation sessions. Group means were compared at baseline with the three simulation sessions and also between each simulation by repeated-measures analysis of variance. *p values of < .05 were considered statistically significant.

Figure 6. Task 5: decrease mean arterial pressure. Mean and standard deviations (seconds) are presented for the four simulation sessions. Group means were compared at baseline with the three simulation sessions and also between each simulation by repeated-measures analysis of variance. *p values of < .05 were considered statistically significant.
16 hours were significantly faster for task 2 in the adjusted model. For task 3, only the 24-hour time point was significantly faster, whereas the 12-hour time point was significantly slower compared with baseline for task 4. Time points 16 and 24 hours were significantly faster for 16 and 24 hours compared with baseline (Figure 9).

DISCUSSION

Published literature linking acute sleep deprivation and performance in medical personnel first appeared in 1971 when Friedman et al. (1) reported that post-call residents made more errors interpreting EKG results compared with rested residents. Since then, sleep deprivation in residents has been extensively studied in the laboratory setting, producing indisputable evidence that lack of sleep impedes known human performance factors such as behavior (i.e., mood), cognition, and vigilance (2,6). Data regarding clinical performance, however, have been less conclusive as a result of the difficulty of devising such studies, yet recent advances in computer simulation has allowed investigators to replicate more closely OR conditions and, therefore, examine the relationship between sleep loss and task-related performance (13).

Using a mixed-methods approach involving simulation, qualitative questionnaires, and a focus group discussion, the current study demonstrated that cardiovascular perfusion students are affected by sleep deprivation. Perfusion students acknowledged that sleep deprivation has been a common trend in their training experience, affecting their learning and education, clinical performance, and personal lives. Several students admitted to experiencing episodes of involuntary micro sleep while on CPB as a result of fatigue, and they expressed concern that they may have committed an error during this time. This finding corroborates those of Trew et al.’s 2011 (12) survey in which three-fourths of practicing perfusionists admitted to experiencing micro sleep while on CPB. Two-thirds of surveyed perfusionists also admitted to making an error as a result of impaired abilities attributable to fatigue, and 6.7% reported perfusion accidents associated with fatigue (12).

Another common observation was the detrimental impact of acute sleep deprivation on the personal health and well-being of perfusion students. Previous literature has consistently noted a significant association between fatigue and worsened mood, which was also evidenced in our study. Nearly all of the students reported heightened levels of stress, shortened tolerance for friends and family, and increased irritability, putting a toll on their relationships. Additionally, sleep loss posed a serious risk to the students’ physical health. Many students reported feeling unsafe driving home after a long day or after a night on call. This concern is echoed in other healthcare fields in which there has been a growing body of research examining the effect of fatigue on motor vehicle accidents and near misses. In a study by Steele et al. (20), collision rates among emergency medicine physicians were found to be 8% with near crashes as high as 58%. With respect to perfusion, Trew et al. (12) found a reported 6.9% of automobile accidents attributed to extended work hours and fatigue and 44.4% of perfusionists experienced near miss automobile accidents.
The quantitative aspects of this study reinforce and strengthen the aforementioned qualitative findings. The quantitative results obtained from assessment of reaction times during performance of clinically relevant tasks using simulation highlight the negative impact that acute sleep deprivation had on perfusion students. Significant differences in reaction times were found between baseline values and 12-hour, 16-hour, and 24-hour values as well as between 16 hours and 24 hours. These results support the early findings of Taffinder et al. (21) in which surgical residents were slower and committed more errors in a simulated laparoscopic surgery with increasing sleep loss. Similar findings are supported in a more recent study by Grantcharov et al. (22) in which surgical residents made more errors and were less efficient after a night on call compared with their rested performances.

Regression to the mean inherently occurs with repeated measures on the same subject, thereby introducing random error (23). In our study, the students completed the same five tasks, although in varying orders, in four serial time points. The reaction times of the three observations following the baseline simulation were not as extreme as that of the baseline, and thus we could assume the follow-up experiment reaction times were more accurately representative of the subjects’ true mean reaction time than the baseline simulation. We believe this may be the result of the repetition of tasks, although they were altered at each time point.

Whether these decrements in performance translate into critical errors and compromised patient care is unknown. In this study, we unexpectedly found that the participants made clinically relevant errors that could potentially affect patient care. During the four simulation sessions, the reservoir was drained a total of five times, and drug calculation errors were made 16 times. However, we cannot infer poor outcomes from these experiences because safety devices are available and widely used.

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Regression to the mean inherently occurs with repeated measures on the same subject, thereby introducing random error (23). In our study, the students completed the same five tasks, although in varying orders, in four serial time points. The reaction times of the three observations following the baseline simulation were not as extreme as that of the baseline, and thus we could assume the follow-up experiment reaction times were more accurately representative of the subjects’ true mean reaction time than the baseline simulation. We believe this may be the result of the repetition of tasks, although they were altered at each time point.

Whether these decrements in performance translate into critical errors and compromised patient care is unknown. In this study, we unexpectedly found that the participants made clinically relevant errors that could potentially affect patient care. During the four simulation sessions, the reservoir was drained a total of five times, and drug calculation errors were made 16 times. However, we cannot infer poor outcomes from these experiences because safety devices are available and widely used.
detectors, bubble detectors, etc.) but were not in place during this study. Moreover, organizational safety theories anticipate that very few complications would result in patient injury as a result of the teamwork model that is present in the healthcare system (6,24).

This study has several limitations. First, our study used tests of insufficient duration to expose performance deterioration (7,11,25). Many studies have documented that tasks of longer duration are most susceptible to the effects of acute sleep deprivation (3,10,26). Although pump runs typically exceed 1 hour, our simulation testing sessions lasted only 7 minutes, which may not represent a realistic clinical scenario. Participants might have been able to make a concerted mental effort for that short amount of time, but their performance could have deteriorated to a greater extent had the testing period been more representative of a normal CPB run.

Second, our study population was small and homogeneous. At the time of the study, participants were still relatively inexperienced, although all were on similar levels clinically. This lack of experience makes it difficult to extrapolate our results to the broader community of seasoned, practicing perfusionists. Some people become “conditioned” to a state of acute sleep deprivation so that their performance is unaffected, whereas others are more sensitive to sleep deprivation. This inherent variety makes it challenging to present uniform results and recommendations for the profession.

Lack of stimulant use was restricted for the participants. The authors wanted to get true baseline responses without the interaction of stimulants. However, this may not reflect real-life situations and therefore may affect some of the responsiveness of the participants.

Lastly, as a result of the nature of the simulation laboratory, in which most of the equipment is donated; safety devices were not used during the study because they were not available. The authors realize a majority of institutions use these devices; however, some institutions do not. The authors had to use what training equipment was available in this study, recognizing the limitations of not using safety devices in the conduct of the study.

In conclusion, acute sleep deprivation and fatigue appear to negatively impact perfusion students’ performance on simulated tasks, increases the likelihood of dozing during multiple activities, and increases self-assessed sleepiness. Our unintentional discovery of medical errors associated with sleep deprivation in interns (7,11,25). Although pump runs typically exceed 1 hour, our simulation testing sessions lasted only 7 minutes, which may not represent a realistic clinical scenario. Participants might have been able to make a concerted mental effort for that short amount of time, but their performance could have deteriorated to a greater extent had the testing period been more representative of a normal CPB run.

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In conclusion, acute sleep deprivation and fatigue appear to negatively impact perfusion students’ performance on simulated tasks, increases the likelihood of dozing during multiple activities, and increases self-assessed sleepiness. Our unintentional discovery of medical errors also raises concern. As to now acute sleep loss may affect performance and decision making. The evidence of self-rated sleepiness along with delayed response times found in the simulated bypass scenarios should raise concern of all perfusionists regarding extended work hours. Lastly, further research needs to be conducted with respect to acute sleep deprivation and fatigue and how it relates to practicing clinical perfusionists.

ACKNOWLEDGMENTS

We thank the Medical University of South Carolina’s Cardiovascular Perfusion graduating class of 2012 for participation in this study.

REFERENCES

APPENDIX A: FOCUS GROUP QUESTIONS

1. Describe your personal experiences with sleep loss and fatigue during medical training.
2. Has sleep loss and fatigue affected you personally during your perfusion training? If so, how?
3. What strategies or countermeasures have you used in dealing with the effects of sleep loss and fatigue?
4. How could circumstances be changed to reduce sleep loss and fatigue in your training program?

APPENDIX B: QUALITATIVE QUESTIONNAIRES

Epworth Sleepiness Scale

0 = No chance of dozing
1 = Slight chance of dozing
2 = Moderate chance of dozing
3 = High chance of dozing

<table>
<thead>
<tr>
<th>SITUATION</th>
<th>CHANCE OF DOZING</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sitting and reading</td>
<td>_____</td>
</tr>
<tr>
<td>Watching TV</td>
<td>_____</td>
</tr>
<tr>
<td>Sitting inactive in a public place (e.g. a theater or a meeting)</td>
<td>_____</td>
</tr>
<tr>
<td>As a passenger in a car for an hour without a break</td>
<td>_____</td>
</tr>
<tr>
<td>Lying down to rest in the afternoon when circumstances permit</td>
<td>_____</td>
</tr>
<tr>
<td>Sitting and talking to someone</td>
<td>_____</td>
</tr>
<tr>
<td>Sitting quietly after a lunch without alcohol</td>
<td>_____</td>
</tr>
<tr>
<td>In a car, while stopped for a few minutes in traffic</td>
<td>_____</td>
</tr>
</tbody>
</table>

Stanford Sleepiness Scale

<table>
<thead>
<tr>
<th>DEGREE OF SLEEPINESS</th>
<th>SCALE RATING</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feeling active, vital, alert, or wide awake</td>
<td>1</td>
</tr>
<tr>
<td>Functioning at high levels, but not at peak; able to concentrate</td>
<td>2</td>
</tr>
<tr>
<td>Awake, but relaxed; responsive but not fully alert</td>
<td>3</td>
</tr>
<tr>
<td>Somewhat foggy, let down</td>
<td>4</td>
</tr>
<tr>
<td>Foggy; losing interest in remaining awake; slowed down</td>
<td>5</td>
</tr>
<tr>
<td>Sleepy, woozy, fighting sleep; prefer to lie down</td>
<td>6</td>
</tr>
<tr>
<td>No longer fighting sleep, sleep onset soon; having dream-like thoughts</td>
<td>7</td>
</tr>
<tr>
<td>Asleep</td>
<td>X</td>
</tr>
</tbody>
</table>

APPENDIX C: SIMULATION SCHEDULE OF EVENTS

SESSION #1: 6:00 AM
1 min: pO2 Decrease
2 min: Decrease Venous Return
3 min: Ventricular Fibrillation
4 min: Protamine Dosage Calculation
5 min: Decrease Mean Arterial Pressure

SESSION #2: 6:00 PM
1 min: Decrease Venous Return
2 min: Decrease Mean Arterial Pressure
3 min: Ventricular Fibrillation
4 min: pO2 Decrease
5 min: Protamine Dosage Calculation

SESSION #3: 10:00 PM
1 min: Decrease Mean Arterial Pressure
2 min: pO2 Decrease
3 min: Ventricular Fibrillation
4 min: Protamine Dosage Calculation
5 min: Decrease Venous Return

SESSION #4: 6:00 AM
1 min: Ventricular Fibrillation
2 min: Decrease Venous Return
3 min: Decrease Mean Arterial Pressure
4 min: Protamine Dosage Calculation
5 min: pO2 Decrease