Title: "The Impact of Shift-Accumulated Fatigue on Patient Care and Risk of Post-Shift Driving Collisions among 12-Hour Day and Night Shift Nurses"

Principal Investigator: Lois James, PhD

Co-Investigators: Stephen James, PhD, Marian Wilson, PhD, Kevin Stevens, RN, MSN, CHSE

Organization: Washington State University
Room 280 Lighty
Po Box 641060
Pullman, WA 99164-1060
Email: orso@wsu.edu

Project Dates: 05/01/2018 - 02/28/2021

Federal Project Officer: DENISE BURGESS
(301) 427-1318
denise.burgess@ahrq.hhs.gov

Acknowledgement of Agency Support: We would like to thank the Agency for Healthcare Research and Quality (AHRQ) for their support of this project.

Grant Award Number: R01 HS25965

1. Structured Abstract

Purpose: Evidence across industries links work-related fatigue with errors, accidents, and adverse long-term health outcomes. The purpose of this study was to determine the impact of shift-accumulated fatigue on patient care and driving safety.

Scope: This study provides objective evidence of the impact of shift work-related fatigue on patient and nurse safety, allowing us to make concrete recommendations regarding safe shift scheduling for day and night shift nurses—information that may help keep nurses safer, reduce preventable medical errors, and improve patient care.

Methods: This between-groups, repeated-measures quasi-experiment was conducted in the Washington State University (WSU) College of Nursing and Sleep and Performance Research Center. Fifty nurses working 12-hour day shifts and 50 nurses working 12-hour night shifts were recruited from Providence Medical Center. Participants reported to WSU for testing on two separate occasions—once immediately following their third consecutive 12-hour shift and once on their third consecutive day (72 hours) off work.

Results: We found that nurses were significantly more sleep restricted and subjectively sleepy following three consecutive shifts but were largely able to retain patient care competence and demonstrate driving safety. Night shift participants were significantly impaired on patient care skills, in particular the communication domain, compared to day shift participants. Furthermore, night shift participants had significantly greater lane deviation during the post-shift drive home, which is a key indicator of collision risk, demonstrating impaired driving safety.

Key Words: Nurses, Sleep, Fatigue, Performance, Patient Care, Safety, Shift Work

2. Purpose

Medical errors are the third leading cause of death in the United States. Recognizing this critical problem and the established connection between shift-worker fatigue and increased risk of making medical errors, the American Nursing Association (ANA) has stressed the importance of reducing fatigue and sleepiness in nurses. Among nurses, sleep deprivation and chronic fatigue associated with shift work have been linked to risk of patient care error and poorer quality patient care, as well as to occupational injury, increased burnout, and long-term health consequences. In fact, fatigue is such a concern in healthcare that The Joint Commission—a U.S.-based, independent, not-for-profit healthcare accrediting organization that focuses on enhancing quality of care and patient safety—identified drowsiness, fatigue, and sleep deprivation as hazards for both patient safety and healthcare workers' personal safety and well-being.

Longer shifts have grown popular due to greater flexibility in scheduling, continuity of patient care, and more days off per week. Yet, the risks to patients and nurses alike are overwhelming. For example, night shift nurses report more drowsiness driving home after shifts, and tragic instances of nurses and doctors falling asleep at the wheel reinforce the idea that the post-shift drive home is the most dangerous time of day for healthcare workers. When the Guardian Healthcare Professionals Network published an article about the dangers of healthcare professionals driving home after working night shifts, they indicated that 41% of the 1,135 doctors surveyed had fallen asleep while driving home post-shift. This prompted a flood of comments to the network with personal stories, such as "I crashed my car after a night shift and now have post-traumatic stress disorder," "Nurses are not allowed to sleep on their breaks – it is a sackable offence… I have fallen asleep at the wheel on quite a few occasions," "Sometimes I wonder how I'm still alive – who looks after healthcare employees?"

In addition to the immediate risks of fatigue to nurses and their patients, short sleep duration that is associated with shift work has been linked to cardiovascular disease, cancer, metabolic disease, and mental illness, such as depression and anxiety. A recently published NIOSH report revealed that healthcare practitioners are among the least likely to get sufficient sleep, with 40% receiving fewer than 7 hours per 24-hour period. Thus, almost half of healthcare practitioners are at increased risk of developing chronic disease.

In order to inform safe scheduling practices, quantitative estimates of the impact of cumulative 12-hour day versus 12-hour night shifts on nurses' safe practice relating to patient care and nurse safety risks while driving home are needed. Although prior studies using observational designs have identified risks associated with fatigue for both nurses and their patients, very little is understood about the nature of risks to nurses and their patients based on their work shift. In the midst of national demands to reduce the detrimental impact of fatigue on preventable medical errors, lawsuits against hospitals claiming nurses are being put at severe risk due to overwork, and the growing body of evidence linking fatigue, shift-work, and short sleep duration to chronic disease, the purpose of this project was to determine the impact of shift-accumulated fatigue on the spectrum of daily activities nurses engage in, from patient care to post-shift drive home.

3. Scope

This between-groups, repeated-measures quasi-experiment was conducted in the Washington State University (WSU) College of Nursing and Sleep and Performance Research Center. Fifty nurses working 12-hour day shifts and 50 nurses working 12-hour night shifts will be recruited from Providence Medical Center.

Participants reported to WSU for testing on two separate occasions—once immediately following their third consecutive 12-hour shift and once on their third consecutive day (72 hours) off work. Conditions were counterbalanced among participants to control for learning effects. Testing included a 10-minute Psychomotor Vigilance Task (PVT) to objectively measure their fatigue, the Karolinska Sleepiness Scale (KSS) to measure subjective sleepiness, 90 minutes of critical skills in our nursing simulation lab (including IV insertion, medication calculation, and quality of patient care), and a 20-minute drive in one of our driving simulators (to simulate a "post-shift" drive home). During testing, participants were fitted with functional near-infrared optical brain imaging and mobile eye gaze tracking devices to assess the impact of fatigue on cognitive workload and visual processing, respectively. Participants were also fitted with wrist actigraphs to objectively measure their sleep throughout the study. Please see the Methods section below for more details.

Using this innovative design, our Specific Aims were to:

Aim 1: Measure the within-participant impact of shift-accumulated fatigue on nursing simulation critical skills. We analyzed the difference in nursing simulation test outcomes between the same participants following three consecutive 12-hour shifts ("work condition") compared to following three consecutive days off ("rest condition"). PVT, KSS, and actigraphy were used to assess fatigue, sleepiness, and sleep differences during these test times. We expected significant fatigue-related deterioration in critical skills during the work condition compared to during the rest condition.

Aim 2: Measure the between-participant impact of day vs. night shifts on nursing simulation critical skills. We analyzed the difference in nursing simulation test outcomes between nurses working the day shift (07:00-19:00) and nurses working the night shift (19:00-07:00). PVT, KSS, and actigraphy were used to assess fatigue, sleepiness, and sleep differences between day and night shift nurses. We expected significant fatigue-related deterioration in critical skills from night shift compared to day shift nurses.

Aim 3: Quantify the risk of collisions to nurses driving home post shift. We measured known predictors of collisions, such as lane deviation and braking latency as well as any collisions in the driving simulator. We expected that nurses working the night shift would be at greater risk for driving collisions than nurses working the day shift. Furthermore, we expected that nurses would be at greater risk of collision following three shifts compared to when tested during their time off. Finally, we expected a significant interaction between shift and condition, whereby night shift nurses during their work condition would be at the greatest risk of collision.

The American Nursing Association's position statement stresses the importance of reducing fatigue and sleepiness in nurses due to their extreme negative consequences. Shift regulations for physicians have been in place since 1987 due to the patient safety effects of physician fatigue, yet there are *still* no national work-hour policies for nurses. This study provides objective evidence of the impact of shift work-related fatigue on patient and nurse safety. This is translational research that could lead to regulations on safe working hours for nurses.

4. Methods

Study design

We employed a mixed, repeated-measures (post shift vs. time off), between-groups (12-hour day vs. 12-hour night shift) design. Participants (N=100) came to the lab on two occasions – once immediately after their third consecutive 12-hour shift ("work" condition) and once at the same time of day on their third consecutive day off ("rest" condition). Order of testing was randomized to avoid learning effects.

Testing occurred at the same time of day for each condition to control for circadian factors. Shift patterns at Providence were 07:00-19:00 for days and 19:00-07:00 for nights. Thus, day shift nurses were tested between approximately 19:30-21:30 on both testing days, and night shift nurses were tested between approximately 07:30-09:30 on both testing days. Equal numbers of participants from 12-hour day (n=50) and 12-hour night (n=50) shifts were recruited to facilitate a between-groups analysis based on shift type. Known confounds were controlled for (e.g., gender, age, years of experience, children in the home, etc.) as we tested the impact of shift-accumulated fatigue on nurse and patient safety outcomes; please see the analytic plan for details.

Our rationale for comparing 12-hour day versus 12-hour night shifts was to get the strongest test effect while investigating a highly popular shift schedule that is worked by approximately 65% of the nursing workforce. Our rationale for testing nurses immediately after their third consecutive shift was because this is frequently their final shift in a work week, arguably when they had the most shift-accumulated fatigue that they were likely to have. Similarly, our rationale for testing nurses again on their third consecutive day off was that this was their penultimate day off, resulting in them being rested but still allowing them time to recover (post testing) so they could get sufficient sleep before returning to work.

Sample and Setting

Fifty nurses working the 12-hour day shift and 50 nurses working the 12-hour night shift were recruited from Providence Medical Center. Due to the COVID-19 pandemic, data collection concluded slightly earlier than intended, resulting in a final sample of 94 participants. Table 1 describes the sample characteristics.

Table 1
Sample Characteristics by Shift Type

	Night Shift (*n* = 49)	Day Shift (*n* = 44)	All (*n* = 94*)
Age (*SD*)	34.14 (9.14)	37.96 (9.59)	35.93 (9.52)
Female (%)	87.76	95.18	89.36
Non-White** (%)	14.29	9.09	11.70
Bachelor’s Degree (%)	69.39	77.27	73.40
Patient Focus (%)			
Neonatal	20.41	13.64	17.02
Pediatric	30.61	40.91	35.11
Adult / Geriatric	48.98	45.45	47.87

Note. *SD* = standard deviation. All variables were determined by self-report. *One nurse arrived for one test session after a night shift and the other test session after a day shift. **Non-White (%) includes Hispanic White.

Our recruitment plan was coordinated with Providence and included posting flyers, posting on Providence websites and social media sites, announcements at staff meetings, and word-of-mouth notice via Dr. Wilson, who had frequent contact with Providence nurses.

To promote volunteering, we paid nurses overtime for study consenting at the hospital and the full amount of time between getting off shift and completing testing in our lab on two separate occasions (approximately 6 hours in total of reimbursed time). Furthermore, to ensure nurse safety, on "work" condition testing days, we arranged Uber rides for participants for the duration of the day. This included a trip from home to work, from work to WSU, and from WSU back to home. This was necessary to avoid placing participants at increased risk for collisions following what amounted to a 14.5-hour shift (their regular 12-hour shift in the hospital, travel time to the WSU, and approximately 2 hours of testing at WSU).

All testing occurred at WSU. The patient care portion of testing occurred in our state-of-the-art nursing simulation lab equipped with three fully functioning simulation suites, including control rooms and observation rooms. The simulation lab contains 10 Human Patient Simulators ranging from high fidelity (sweat, bleed, cry) to medium fidelity and can imitate patients of all ages and genders. Each manikin is capable of providing patient care feedback to the nurse as if it were a human patient. They are also capable of Foley, chest tube, ET tube, and IV insertion. Nurses can give IV medications as well as give oral medications to these manikins. They can be hooked up to telemetry and provide feedback in code situations on CPR skills. The manikins can go into cardiac arrest or demonstrate respiratory distress and a variety of other patient responses to ensure a realistic patient care experience. The driving portion of testing occurred in the world renowned Sleep and Performance Research Center (SPRC), which includes HD driving simulators, in a light- and sound-controlled environment, with custom developed driving metrics for quantifying risk of collision. The SPRC is a coalition of basic and applied research laboratories aiming to understand the neurobiology of sleep and sleep loss and the effect of sleep loss on metabolism, immune function, cognitive performance, and behavior, all with the aim of ensuring adequate, recuperative sleep and/or mitigating the effects of inadequate sleep. Our mission statement is to be the leader in research on sleep and biological rhythms and their impact on performance and health by integrating from the molecular level to real-world operations.

Study procedures

As nurses volunteered to participate, we screened for eligibility. This included hospital level "fit-to-work" clearance as well as requiring that all participants were "healthy sleepers." Specifically, during screening we excluded participants with known sleep disorders. We anticipated that this would result in a more conservative estimate of the impact of shift work on risks to nurses and their patients and reduce the risk of selection bias (e.g., nurses volunteering because they wanted to gain insight into their poor sleep). All screening was conducted via telephone by the study coordinator, who has extensive experience screening participants for laboratory-based studies, following a screening protocol. When eligible participants were identified, they were randomly assigned to either "work" condition first, or "rest" condition first and were scheduled for testing days (with at least 4 weeks between testing days to try and reduce learning effects). Approximately 1 week prior to participants' first testing day, they came to WSU for consenting, taking a brief demographic questionnaire, taking some basic health measures (e.g., BMI), and receiving a wrist actigraph for monitoring their sleep (for 7 consecutive days immediately prior to testing). The same actigraph was assigned to each participant 1 week prior to their second test day.

Testing included a 10-minute Psychomotor Vigilance Task (PVT) to measure nurses' objective level of fatigue and the Karolinska Sleepiness Scale (KSS), which takes less than a minute to complete. This was followed by approximately 90 minutes of critical skills in our nursing simulation lab: First, we fitted participants with fNIR devices and mobile eye tracking devices, ensured that they were comfortable and unobtrusive to participants, and conducted an orientation to the simulation lab (including where all supplies that they may need are kept, ensuring that they can easily read charts and patient monitoring screens, etc.) Then, participants were given time to prepare for the simulation, including reviewing patient labs, receiving and reviewing a prior nurse shift report, and asking any clarifying questions they had. Following this preparation phase, the critical skills scenario began, in which quality of patient care was monitored and evaluated. Participants were then tested on medication calculations (four consecutive questions). Finally, participants were debriefed to ensure that they were comfortable with all testing they received.

Upon completion of the critical skills testing, participants completed a 20-minute drive in one of our driving simulators (to simulate a "post-shift" drive home). During testing participants were escorted from task to task and closely monitored by research assistants, under the guidance of the study coordinator and the research team. At the conclusion of testing, participants returned their actigraphs, had fNIR and mobile eye tracking devices removed, were debriefed, and were discharged from the study. On participants "work" condition test days, they were taken home in an Uber to ensure their safety (given the increased risk of collision we may have exposed them to).

Measures

Critical Skills Simulation: The patient care simulation scenario was developed to incorporate a variety of nursing care skills, such as IV insertion, vital signs, and medication administration, as well as patient deterioration to assess nursing care with regards to "failure to rescue," Foley insertion, documentation, and physical assessment. Quality of patient care was measured using the Creighton Competency Evaluation Instrument. This tool has been tested for validity and reliability in both the simulation and clinical environment to assess nursing care. It encompasses Assessment, Communication, Clinical Judgment, and Patient Safety. Scoring involves a checklist of items summed and scaled to a percentage, for which 100% denotes a perfect score.

Medication calculation: Participants were asked to mentally calculate medication dosages using a timed task delivered via Qualtrics. Calculation reaction time (measured in milliseconds from accessing the question to answering it) and errors (measured by comparison to correct calculation via dummy variables for which 1=error and 0=no error) were assessed. The calculations were feasible without a calculator and represented a critical skill that nurses are required to perform on a frequent basis.

Psychomotor Vigilance Task (PVT): We tested nurses on a 10-minute Psychomotor Vigilance Task (PVT, Pulsar model 2.0.5.9, Philadelphia, PA). The PVT is a well-validated and simple reaction-time task with high stimulus density. It measures participants' ability to sustain attention and is one of the most widely used objective research measures of fatigue. During each PVT, participants were asked to watch for a number counter to appear on a computer screen, then press the keyboard space bar as quickly as possible. The number appeared at random intervals from 2 to 11 seconds. Once it appeared, the number on screen counted up, from zero, in milliseconds until the spacebar was pressed. Objective fatigue was measured by increased reaction time between on-screen appearance of the stimuli and pressing the keyboard space bar.

Karolinska Sleepiness Scale (KSS): The KSS is a brief, single-item, well-validated self-report assessment of subjective sleepiness on a scale from 1 (extremely alert) to 9 (extremely sleepy; fighting sleep). It is widely used in sleep research for capturing "in-the-moment" sleepiness.

Wrist Actigraphy: Participants were fitted with wrist actigraphs for 7 consecutive days immediately preceding each test day to measure their sleep. Actigraphy is a well-validated, non-invasive method for monitoring rest/activity cycles by using three-axis accelerometers to monitor a person's movement continuously. Actigraphy has an accuracy rate of 92% compared to polysomnography, which is the gold standard of sleep measurement. These watch-sized devices record data in 1-minute increments throughout the day. The wrist actigraph used for this research was the ReadiBand® (model 04, Fatigue Science, Vancouver, BC).

Functional near infrared (fNIR) optical brain imaging: Cognitive workload was measured using fNIR spectroscopy, an optical brain monitoring technology that provides an ambulatory, non-invasive measure of cerebral hemodynamics within the prefrontal cortex in response to sensory, motor, or cognitive activation. Cognitive workload was operationalized as changes in blood oxygenation associated with the cerebral hemodynamic response, for which oxy-hemoglobin (HbO_2) converts to deoxy-hemoglobin (HbR) during neural activity as a function of changes in light absorption for HbO_2 and HbR at peak wavelengths in the 730-nm and 850-nm range. The use of fNIR devices in this study allowed us to determine the impact of shift-accumulated fatigue on nurses' cognitive capacity as they engaged in a range of activities that are expected of them on a daily basis.

Mobile eye gaze tracking: Participants' visual scanning patterns were measured using mobile eye-gaze tracking devices. These devices are designed to record participants' natural gaze behavior in real time in a broad range of applications with considerable robustness, mobility, and ease of use. They are unobtrusive, are a similar weight to sight-correction glasses, and come with a lightweight smart recorder that supports real-time data access and control via a wireless connection. They can be used by participants who wear contact lenses. The use of mobile eye gaze tracking devices in this study allowed us to determine whether shift-accumulated fatigue affects nurses' ability to visually process information that is critical to their day-to-day activities.

Driving simulation: The WSU Sleep and Performance Research Center is equipped with two high-fidelity MPRI PatrolSimIV driving training simulators that enable us to collect all of the commonly measured parameters used in simulator-based driving research. The simulators capture data on variables such as collisions, speed, lane-keeping, frequency of braking, steering control, accelerator release time, time to collision, accelerator-to-braking transition time, and minimum acceleration. Each of these is thought to be affected by driver fatigue. Data are sampled at 72 Hz. The scenario we used in this research is a 20-minute drive in a rural setting. During the scenario, participants are randomly presented with unexpected events, such as a pedestrian or dog running in front of their vehicle, the driver ahead braking suddenly, or a speeding vehicle roaring past. Performance during this drive is based on embedded metrics for driving consistency (e.g., lane deviation, braking latency, and collisions).

Data management

Data was stored on a secure server at WSU. To guard against loss, all data was backed up regularly. Scanned study forms were archived with the PI and stored in a secure location at WSU. All study data was de-identified by assigning each participant a unique study identification number (SID) that was included on all study forms and in the actigraphy, simulation, and PVT data files. This SID was used to link multiple forms completed by the participant. A crosswalk database was maintained that links the SID to each participant's name and other identifying information required. This database was password protected and kept in a secure location with restricted access. De-identified data were merged in Excel via SID and imported to SPSS for analysis.

Study Hypotheses and Analytical Approach

Specific Aim 1: Measure the within-participant impact of shift-accumulated fatigue on nursing simulation critical skills

To determine whether nurses were significantly impaired following three consecutive 12-hour shifts (during their "work condition") compared to their third consecutive day off (during their "rest condition"), we measured differences in critical skills performance on a range of simulated tasks. These included response to a quality of patient care scenario and medication calculation. In addition, PVT and KSS scores were used to assess objective fatigue and subjective sleepiness differences during these test times, and actigraphy data were used to assess sleep during the work week and time off. We tested the following research hypotheses:

H_1: Participants will perform worse on the quality of patient care scenario during their work condition than during their rest condition

H_2: Participants will take longer to calculate medications during their work condition than during their rest condition

H_3: Participants will make more medication calculation errors during their work condition than during their rest condition

H_4: Participants' objective levels of fatigue (measured by PVT) will be greater during their work condition than during their rest condition

H_5: Participants' subjective sleepiness (measured by KSS) will be greater during their work condition than during their rest condition

H_6: Participants' sleep restriction (measured by actigraphy) will be greater during their work condition than during their rest condition

H_7: Participants' cognitive capacity (measured by fNIR) will be depleted during their work condition compared to during their rest condition

H_8: Participants' visual processing (measured by mobile eye gaze tracking) will be impaired during their work condition compared to during their rest condition

Specific Aim 2: Measure the between-participant impact of day vs. night shifts on nursing simulation critical skills

To determine whether night shift work significantly impairs competency on nursing simulation critical skills, we compared the performance of nurses working the day shift (07:00-19:00) compared to nurses working the night shift (19:00-07:00) on patient-care test outcomes. Differences in fatigue (as measured by PVT) and sleep (as measured by actigraphy) were examined between day and night shift nurses. We tested the following research hypotheses:

H_1: Participants working the 12-hour night shift will perform worse on the quality of patient care scenario than participants working the 12-hour day shift

H_2: Participants working the 12-hour night shift will take longer to calculate medications than participants working the 12-hour day shift

H_3: Participants working the 12-hour night shift will make more medication calculation errors than participants working the 12-hour day shift

H_4: Participants working the 12-hour night shift will have depleted cognitive capacity (measured by fNIR) than participants working the 12-hour day shift

H_5: Participants working the 12-hour night shift will have impaired visual processing (measured by mobile eye gaze tracking) than participants working the 12-hour day shift

Specific Aim 3: Quantify the risk of collision for nurses driving home post shift

To quantify this risk, we measured known predictors of collisions, such as lane deviation and braking latency, as well as collisions in the driving simulator. We tested the following research hypotheses:

H_1: Participants will have greater lane deviation during their work condition than during their rest condition
H_2: Participants will have greater braking latency during their work condition than during their rest condition
H_3: Participants will have more collisions during their work condition than during their rest condition
H_4: Participants working the 12-hour night shift will have greater lane deviation than participants working the 12-hour day shift
H_5: Participants working the 12-hour night shift will have more braking latency than participants working the 12-hour day shift
H_6: Participants working the 12-hour night shift will have more collisions than participants working the 12-hour day shift

We used multi-level-modeling (MLM) with adjustments for multiple comparisons to analyze each specific aim. This analytical technique accounts for clustering of observations around participants and partitions variance accordingly, reducing the risk of type-I errors by avoiding violating the assumption of independence among observations. It was used as an alternative to repeated-measures Analysis of Variance (ANOVA), which has greater difficulty coping with missing data than MLM. IBM SPSS (v. 24.0.0.0, New York, NY) was used for all statistical analysis. Separate models were conducted for each of the outcome variables.

Limitations
Several study limitations need to be addressed that may influence the generalizability of results. First, Spokane, WA, has limited racial and ethnic diversity (approximately 90% of the population is White). As expected from this homogeneity, over 90% of our research participants were White. Our sample also had limited gender diversity; over 90% were women. Second, although simulation is a valuable tool for use as a proxy for patient care, it is still an artificial environment, without some of the inherent risks and stresses of actual patient care. Similarly, with our use of driving simulation, participants know they are not in real danger, so they might not be as motivated to not fall asleep, for example, at the wheel. That said, in situations where real measures are unsafe (for example driving), we argue that simulation provides the most realistic and valid alternate measure.

5. Results

For ease of presentation and interpretation, results are presented by specific aim and research hypothesis:

<u>*Specific Aim 1*</u>: Measure the within-participant impact of shift-accumulated fatigue on nursing simulation critical skills

H_1: Participants will perform worse on the quality of patient care scenario during their work condition than during their rest condition

Participants overall Creighton's scores were 83.11% (SD=13.78%) and overall subscores were 90.32% (SD=18.15%) for assessment, 82.26% (SD=24.44%) for communication, 88.52% (SD=15.95%) for clinical judgment, and 74.53% (SD=20.72%) for patient safety. This indicates that nurses had a fairly high degree of competence overall, with some individual variability. Very little difference was observed in Creighton's scores between work and rest conditions, and no significant differences were revealed with multi-level modeling (at the 0.05 level of significance). This indicates that nurses were able to maintain competence in assessment, communication, clinical judgment, and patient safety within a patient care scenario after three consecutive 12-hour work shifts. This research hypothesis is not supported, as consecutive 12-hour shifts did not appear to degrade nurses' patient care skills.

H_2: Participants will take longer to calculate medications during their work condition than during their rest condition

Participants' overall reaction times for calculating medications was 25.41 seconds (SD=9.51). This did not differ significantly between work (25.42) and rest (25.41) conditions, indicating that nurses speed in calculating medications is not impaired by consecutive 12-hour shifts. This research hypothesis is not supported.

H_3: Participants will make more medication calculation errors during their work condition than during their rest condition

Overall, participants made medication calculation errors 26% of the time. Although nurses tended to make more errors during their work condition than their rest condition (27% vs. 25%), this difference was not statistically significant, indicating that accuracy in calculating medications is not impaired by consecutive 12-hour shifts. This research hypothesis is not supported.

H_4: Participants' objective levels of fatigue (measured by PVT) will be greater during their work condition than during their rest condition

Participants' average reaction time during PVT testing was 299.35 milliseconds (SD=36.03). No significant difference was observed in PVT scores between work and rest conditions, indicating that participants were not impaired by fatigue due to consecutive 12-hour shifts. This research hypothesis is not supported.

H_5: Participants' subjective sleepiness (measured by KSS) will be greater during their work condition than during their rest condition

KSS scores were 4 (out of 9) overall across participants. When testing during their work condition, participants tended to have higher subjective sleepiness (5 vs. 3 out of 9). When tested with multi-level modelling, this difference was found to be statistically significant (f=67.02; df=1, 360; $p<.001$). Thus, this research hypothesis is supported, indicating that working consecutive 12-hour shifts results in increased subjective sleepiness for nurses. Figure 1 below illustrates this difference.

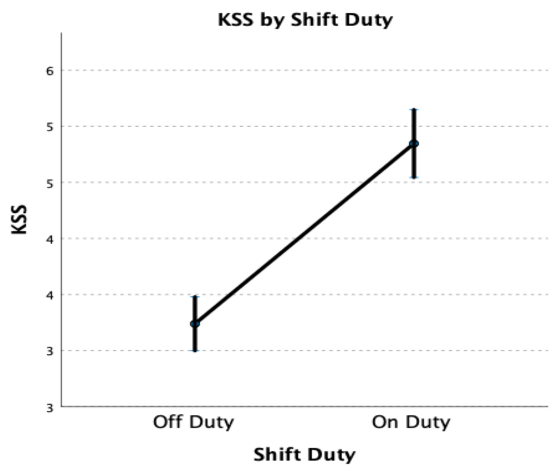

Figure 1. KSS scores for participants during rest condition (off duty) compared to work condition (on duty)

H_6: Participants' sleep restriction (measured by actigraphy) will be greater during their work condition than during their rest condition

Nurses slept on average 7.14 hours per 24 hours during the study. The main effect of condition was significant (*f*=97.85; *df*=1, 161; p<.001 [b=2.53; CI=2.04-3.02]), whereby nurses slept on average 8.10 hours (SD=2.09) per 24 hours during their rest period and 6.21 hours (SD=1.70) per 24 hours during their work period. This indicates that working consecutive 12-hour shifts does result in sleep restriction, supporting this research hypothesis. Figure 2 below depicts sleep quantity across consecutive shifts for both work and rest conditions, also separated by day and night shifts (specific aim 2).

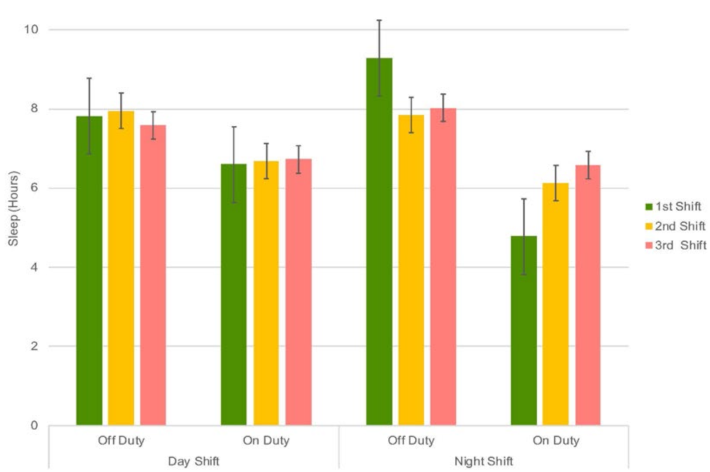

Figure 2. Sleep quantity of day and night shift nurses across the three consecutive on-duty vs. off-duty days.

H_7: Participants' cognitive capacity (measured by fNIR) will be depleted during their work condition compared to during their rest condition

Patient care scenarios were categorized into two phases, pre patient decline and post patient decline, to determine whether greater cognitive effort was required to cope with the scenario deteriorating. T-test results indicated that there was a significant difference between left dorso-lateral pre-frontal cortex HBR concentration levels in the two phases of the simulation t(244.89)=-4.002, p<.001 (Pre/Post), such that HBR concentration is significantly lower pre decline (m=-.54, SD=2.59) than post decline (m=.44, SD=1.53). Generalized linear mixed model analysis confirmed this significant relationship (*F*=15.96, 1, p<.001). Left anterior-medial pre-frontal cortex HBR concentration levels were significantly different across the two phases of the simulation t(257.60)=-3.115, p=.002, such that HBR concentration was significantly lower pre decline (m=-.58, SD=2.71) than post decline (m=.26, SD=1.75). Generalized linear mixed model results confirmed the findings from the t-test (*F*=9.65, 1, p=.002). Right dorso-lateral pre-frontal cortex HBR concentration levels were significantly different across the two phases of simulation t(278.74)=-2.228, p=.027. Pre-decline levels were significantly lower for HBR (m=-.48, SD=2.42) than in post-decline simulation tasks (m=.04, SD=1.67). Study condition (work vs. rest), however, had no significant impact on any fNIRS measures, indicating that working consecutive 12-hour shifts does not impair brain function related to oxygenated blood flow. This research hypothesis is not supported.

H_8: Participants' visual processing (measured by mobile eye gaze tracking) will be impaired during their work condition compared to during their rest condition

Eye gaze tracking data yielded a large quantity of data, in which we attempted to identify different patterns of visual processing based on work versus rest condition. Preliminary analysis has not uncovered any predictable differences, or even patterns, but we continue to explore this data due to the rich context it may provide into different visual processing styles.

Specific Aim 2: Measure the between-participant impact of day vs. night shifts on nursing simulation critical skills

H_1: Participants working the 12-hour night shift will perform worse on the quality of patient care scenario than participants working the 12-hour day shift

Night shift nurses' overall Creighton's scores were 81.36% (SD=14.2%) compared to day shift nurses' scores of 84.63% (SD=13.56%). This difference was statistically significant (*f*=4.23; *df*=1, 345; p<.05), supporting this research hypothesis and indicating that nurses working 12- hour night shifts performed worse on patient care scenarios than did nurses working 12-hour day shifts. Figure 3 below illustrates this difference.

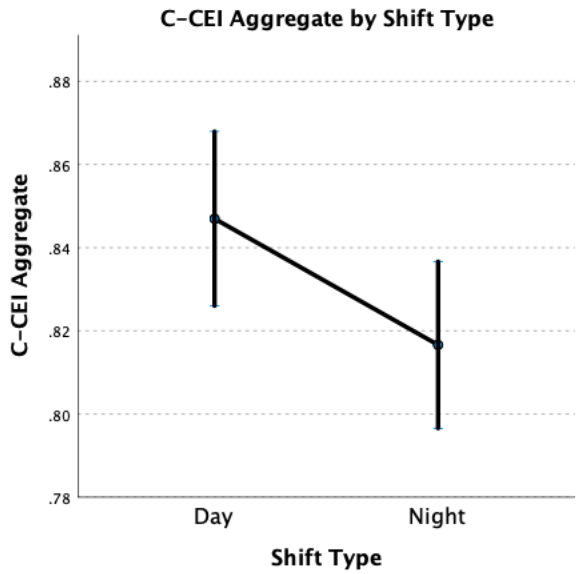

Figure 3. Overall Creighton's scores for day vs night shift nurses

When the various sub-scores were examined, the area where deteriorating appeared to be most evident was "communication" ($F = 4.244$, $p = .042$), such that day nurses had higher scores (74.80%) than night nurses (62.00%). This suggests that night nurses may not as effectively communicate verbally with the patient or doctor or in writing to other nurses through documentation.

H_2: Participants working the 12-hour night shift will take longer to calculate medications than participants working the 12-hour day shift

Reaction times for calculating medications were roughly equivalent for day shift (25.20 seconds) and night shift (25.60 seconds) nurses, indicating that medication calculation speed does not differ significantly between shift types. This research hypothesis is not supported.

H_3: Participants working the 12-hour night shift will make more medication calculation errors than participants working the 12-hour day shift

Error rates for medication calculating were actually higher among day shift than night shift nurses (29% vs 23%, respectively), although this was not a statistically significant difference. This research hypothesis is not supported.

H_4: Participants' objective levels of fatigue (measured by PVT) will be greater for night shift nurses than day shift nurses

No significant difference was observed in PVT scores between day and night shift nurses. This research hypothesis is not supported.

H_5: Participants' subjective sleepiness (measured by KSS) will be greater for night shift nurses than day shift nurses

No significant difference was observed in KSS scores between day and night shift nurses. This research hypothesis is not supported.

H_6: Participants' sleep restriction (measured by actigraphy) will be greater during their work condition than during their rest condition

Although there was not a significant main effect of shift type on sleep quantity among participants, there was a strong effect of shift on "predicted cognitive effectiveness," which is calculated based on 1) time since last sleep period; 2) quantity of sleep in the previous 72 hours; and 3) time of day to account for circadian effects. Predicted cognitive effectiveness scores are categorized into "risk zones" that have been equated to risk from blood alcohol content impairment. A score of >90 is in the "very low risk" zone, with an equivalent blood alcohol content of 0, and a score of 81-90 is considered "low risk," still with an equivalent blood alcohol content of 0. A score of 71-80, however, is in the "elevated risk" zone, with an equivalent blood alcohol content of 0.05, and a score of 61-70 is in the "high risk" zone (blood alcohol content equivalent of 0.08). Finally, a score of 60 or less is considered "very high risk," with an equivalent blood alcohol content of 0.11.

Across the study, nurses' predicted cognitive effectiveness scores were on average 86.15 (SD=10.99). Overall, night shift nurses had lower predicted cognitive effectiveness scores (M=82.66, SD=12.65) than day shift nurses (M=90.36, SD=6.43). This main effect was statistically significant (f=25.22; df=1, 161; p<.001). These data show that predicted cognitive effectiveness scores are substantially lower for night nurses than day nurses across the board. When predicted cognitive effectiveness scores are broken down by hour of shift, however, a more extreme pattern of findings emerges (illustrated in Figure 4).

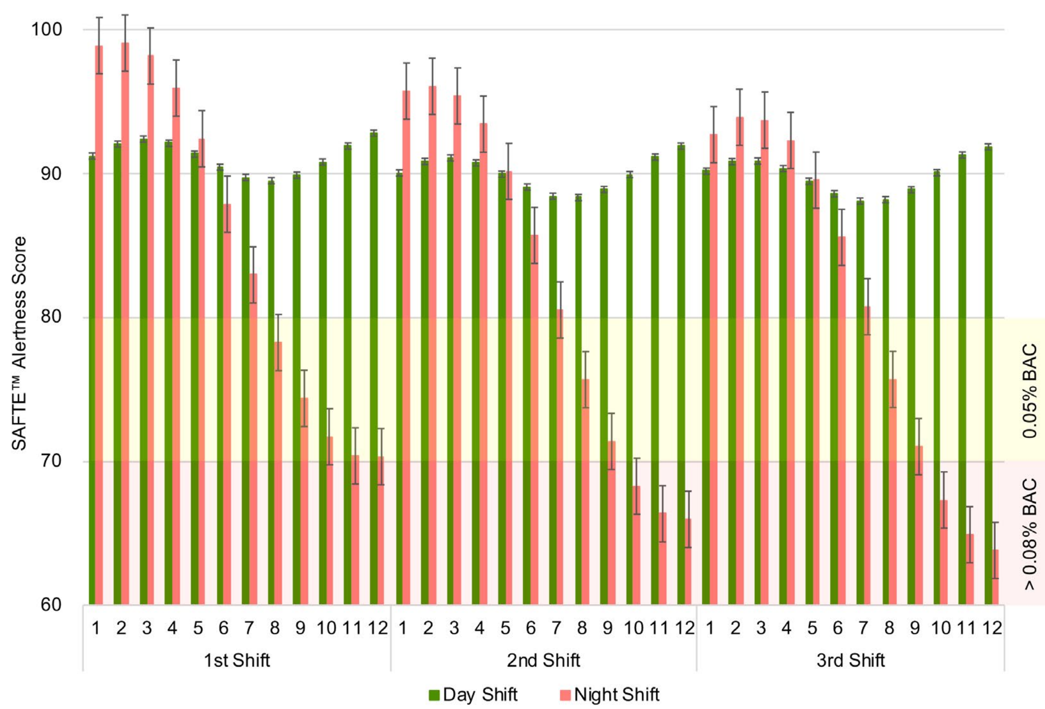

Figure 4. Mean predicted cognitive effectiveness scores by hour for day and night shift nurses across three consecutive 12-hour shifts

While night shift nurses are on duty, their predicted cognitive effectiveness scores drop significantly *every hour worked* across a 12-hour shift. Figure 3 demonstrates this decline (night shift nurses are represented in red). This decline is not observed for day shift nurses (represented in green), who tend to fluctuate in cognitive effectiveness across their shifts. Night shift nurses by hour 8 of their shift are on average in the "elevated risk zone" of <80 (the equivalent of a 0.05 blood alcohol content). By hour 10 of their second and third shifts, they are on average <70, which is "high risk" and the equivalent of legally drunk (0.08 blood alcohol content). As indicated in Figure 3 above, some night shift nurses are dropping below 60, which is the equivalent of a 0.11 blood alcohol content with "very high" risk of accident, error, and injury. Day shift nurses do not tend to drop below the high 80s, demonstrating the extreme difference in day vs. night shift work for nurses and especially for those working past the 10-hour mark.

H_7: Participants working the 12-hour night shift will have depleted cognitive capacity (measured by fNIR) than participants working the 12-hour day shift

Shift type (day vs. night) had no significant impact on any fNIRS measures, indicating that brain function related to oxygenated blood flow is not impaired by shift. This research hypothesis is not supported.

H_8: Participants working the 12-hour night shift will have impaired visual processing (measured by mobile eye gaze tracking) than participants working the 12-hour day shift

Eye gaze tracking data yielded a large quantity of data, in which we attempted to identify different patterns of visual processing for day vs. night shift nurses. Preliminary analysis has not uncovered any predictable differences, or even patterns, but we continue to explore this data, due to the rich context it may provide into different visual processing styles.

Specific Aim 3: Quantify the risk of collision for nurses driving home post shift

H_1: Participants will have greater lane deviation during their work condition than during their rest condition

Although participants had a trend of greater lane deviation during their work condition than during their rest condition, this did not reach significance at the 0.05 alpha level (f=2.45, df=1, 1588; p=.12). Thus, this hypothesis is not supported.

H_2: Participants will have greater braking latency during their work condition than during their rest condition

No significant differences in braking latency based on work versus rest conditions were observed, indicating that working consecutive 12-hour shifts did not impair braking latency. Thus, this hypothesis was not supported.

H_3: Participants will have more collisions during their work condition than during their rest condition

Approximately 10% of participants had a collision in the driving simulator during their work condition compared to 9% during their rest condition. This difference was not statistically significant; thus, this research hypothesis was not supported.

H_4: Participants working the 12-hour night shift will have greater lane deviation than participants working the 12-hour day shift

Multi-level models revealed that participants working the 12-hour night shift did have significantly greater lane deviation than participants working the 12-hour day shift (f=5.40; df=1, 1588; p<.05). This research hypothesis is supported, indicating that night shift nurses are at greater risk for collision than day shift nurses. This is illustrated in Figure 5 below.

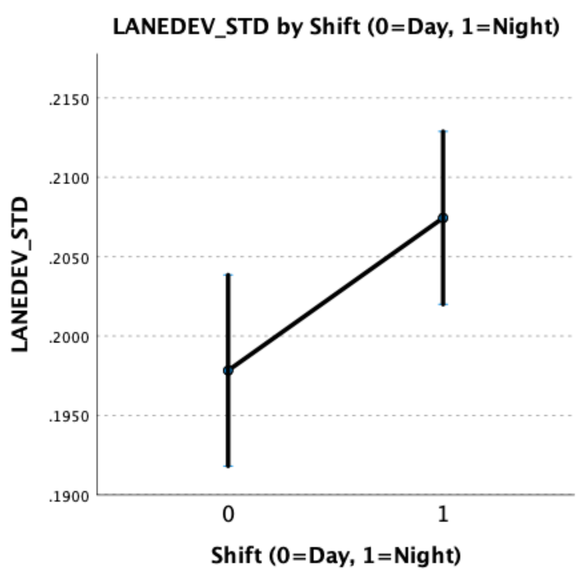

Figure 5. Lane deviation by participant work shift

H_5: Participants working the 12-hour night shift will have more braking latency than participants working the 12-hour day shift

No significant differences in braking latency based on day versus night shift were observed. Thus, this hypothesis was not supported.

H_6: Participants working the 12-hour night shift will have more collisions than participants working the 12-hour day shift

Day shift participants had collisions in 7% of drives compared to night shift participants, who had collisions in 11% of drives. Despite being what appears to be a meaningful or clinical difference, this difference did not quite meet the 0.05 alpha threshold of significant, so we urge caution in inferring generalizability.

Summary and Recommendations

We found that nurses were significantly more sleep restricted and subjectively sleepy following three consecutive shifts, despite maintaining relatively high levels of patient care. This was more pronounced for night shift nurses than for day shift nurses. Of particular note, the deterioration in predicted cognitive effectiveness scores across consecutive night shifts was extreme (displayed in figure 4), with nurses consistently falling into the high-risk category by the end of a 12-hour night shift.

This means that, by the end of a 12-hour night shift, nurses are the predicted equivalent of being legally drunk (>0.08 blood alcohol content)—with potentially significant implications for both patient care and nurse safety during their post-shift drive home. This pattern was not observed for day shift nurses, who were able to maintain good predicted cognitive effectiveness throughout their shifts.

Our findings have implications for shift length, shift timing, and overtime allocation. With regards to shift length, the drop in nurses' cognitive effectiveness from "low risk" to "elevated risk" (0.05 blood alcohol content) tended to occur at the 8-hour point, and the drop from "elevated risk" to "high risk" (>0.08 blood alcohol content) tended to occur at the 10-hour point —particularly across second and third consecutive shifts. Hospitals should consider the risks to patients and nurses alike of shifts greater than 8 hours in length.

Shift timing is also a critical consideration. On-duty night shift nurses tend to be in the high-risk category 2 hours prior to the conclusion of their shift, and off-duty day shift nurses at the same time of day are in the very-low-risk zone. On the other hand, day shift nurses 2 hours from the conclusion of their shift are still in the very-low-risk zone, as are off-duty night shift nurses. As indicated above, the difference in predicted cognitive effectiveness between night shift nurses nearing the end of a shift and day shift nurses approaching the start of a shift is extreme, whereas the difference in predicted cognitive effectiveness between day shift nurses nearing the end of a shift and night shift nurses approaching the start of a shift is minimal. This could impact staffing decisions about when to start and end shifts. Based on our data, it might be safer to begin and end a shift 1 hour earlier (6am-6pm or 6pm-6am in our case). Although shift length would be unchanged (and presumably sleep quantity relatively unaffected), the slight difference in circadian disruption might affect the cognitive effectiveness of night shift nurses and result in less risk to nurses and patients alike.

Finally, our predicted cognitive effectiveness results have potential implications for decisions about overtime hours. Based on our predicted cognitive effectiveness findings, it appears to be safer to bring a day shift nurse in early than to hold a night shift nurse over. Hospitals should consider the capacity of their nurses to handle additional shift hours before assigning them.

Although participants did not tend to differ significantly in their patient care skills during either the patient care scenario or the simulated drive home, several significant differences were observed between night and day shift participants. Night shift participants were significantly impaired on patient care skills, in particular the communication domain, compared to day shift participants.

In the development of interventions that mitigate the effects of fatigue on nursing competence and performance, researchers and clinicians should consider variation in both communication skills and predicted cognitive effectiveness as potential areas of focus. Interpersonal communication interventions that specifically target night shift nurses may prove fruitful. For example, the Situation, Background, Assessment, and Recommendation (SBAR) technique has been offered as a tool to improve patient safety by facilitating communication among physicians and nurses and could be adapted to compensate for the cognitive deficits of night nurses. Identifying possible sources of individual differences in predicted cognitive effectiveness—such as administrative practices or chronotype—could also facilitate the design or specificity of interventions. Last, given the increases in sleepiness we observed for all nurses regardless of shift type, interventions around sleep hygiene, fatigue countermeasures, or fatigue risk management could be useful avenues for risk mitigation among nurses working consecutive shifts.

Regarding nurse safety, night shift participants had significantly greater lane deviation during the post-shift drive home, which is a key indicator of collision risk, demonstrating impaired driving safety. Policies to prevent post-shift accidents, such as car services, carpooling, or pre-drive napping, should be considered to prevent collision risk.

6. List of Publications and Products

List of published/accepted manuscripts arising from this study:

1. James, L., James, S., Wilson, M., Brown, N., Dotson, E., Edwards, C., Butterfield, P. Sleep health and predicted cognitive effectiveness of nurses working 12-hour shifts: an observational study. *International Journal of Nursing Studies*, 112:103667 (2020).

2. Wilson, M., Brown, N., James, L., James, S., Stevens, K., Butterfield, P. Psychometric evaluation of the Creighton Competency Evaluation Instrument in a population of working nurses Journal of Nursing Measurement. *Journal of Nursing Measurement*, in press.

3. Bigand, T., Dakup, P., Hansen, D., Wilson, M., Thomas, B., James, S., James, L., Gaddameedhi, S. Relationships between Cortisol, Sleep, Stress, and Mood among Night Shift Nurses. WIN Conference, 2021.

List of manuscripts under development or review arising from this study:

1. James, L., James, S., Wilson, M., Brown, N. The impact of cumulative 12-hour day vs. night shifts on nurse safety during a simulated “drive home” post-shift

2. James, L., James, S., Dotson, E. Nurses’ oxygenated blood flow in the pre-frontal cortex during a simulated patient care scenario