The Impact of Windows and Daylight on Acute-Care Nurses' Physiological, Psychological, and Behavioral Health

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ABSTRACT

OBJECTIVE: To investigate the physiological and psychological effects of windows and daylight on registered nurses.

BACKGROUND: To date, evidence has indicated that appropriate environmental lighting with characteristics similar to natural light can improve mood, alertness, and performance. The restorative effects of windows also have been documented. Hospital workspaces generally lack windows and daylight, and the impact of the lack of windows and daylight on healthcare employees' well being has not been thoroughly investigated.

METHODS: Data were collected using multiple methods with a quasi-experimental approach (i.e., biological measurements, behavioral mapping, and analysis of archival data) in an acute-care nursing unit with two wards that have similar environmental and organizational conditions, and similar patient populations and acuity, but different availability of windows in the nursing stations.

RESULTS: Findings indicated that blood pressure ($p < 0.0001$) decreased and body temperature increased ($p = 0.03$). Blood oxygen saturation increased ($p = 0.02$), but the difference was clinically insignificant. Communication ($p < 0.0001$) and laughter ($p = 0.03$) both increased, and the subsidiary behavior indicators of sleepiness and deteriorated mood ($p = 0.02$) decreased. Heart rate ($p = 0.07$), caffeine intake ($p = 0.3$), self-reported sleepiness ($p = 0.09$), and the frequency of medication errors ($p = 0.14$) also decreased, but insignificantly.

CONCLUSIONS: The findings support evidence from laboratory and field settings of the benefits of windows and daylight. A possible micro-restorative effect of windows and daylight may result in lowered blood pressure and increased oxygen saturation and a positive effect on circadian rhythms (as suggested by body temperature) and morning sleepiness.

KEYWORDS: Critical care/intensive care, lighting, nursing, quality care, work environment

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The optimization of the physical environmental conditions for healthcare staff, especially nursing staff, may offer an opportunity to create high-performing work environments by helping staff to stay alert and productive. Environmental design that has restorative qualities and is supportive of sensitive tasks that demand focus helps caregivers work more effectively. Conversely, in working environments that are dark, monotone, and institutional, with inadequate external stimuli to help caregivers achieve their natural state of peak alertness and performance, caregivers have to struggle to stay wakeful and productive.

In healthcare settings, research has documented the positive benefits of healing environmental elements. Four major components—presence of nature, reduced noise and reduced crowding, soft and cyclical lighting, and availability of music—show benefits in healing environments, according to a literature review on adults and children by Sherman, Varni, Ulrich, and Malcarne (2005). One hospital study showed that certain physical design features (including natural lighting, live music, sufficient airflow, optimized layout, and homelike interiors) improved staff perception of the quality of their work life (Mroczek, Mikitarian, Vieira, & Rotarius, 2005). Among all the design features studied, the availability of apertures that bring in natural light triggered the highest positive response among hospital employees.

Windows that provide daylight and views of natural surroundings are a salient feature of the physical environment that promote occupant satisfaction and well being, as evidenced in corporate office, manufacturing, and healthcare settings. A study in a manufacturing company in southern Europe on 100 workers investigated the impact of windows, focusing on three components: sunlight, illumination, and views (Beale, Lawrence, Leather, & Pyrgas, 1998). The study found that the employees' intention to quit was significantly lowered if either sunlight or nature views were available. In addition, sunlight had a significant effect on job satisfaction, and nature views significantly lowered occupational stress. Another study on 333 Dutch office workers indicated that window views had a direct effect on reducing reported physical and psychological discomfort (Aries, Veitch, & Newsham, 2010).

Several studies have pointed out the quantitative benefits of presence versus absence of windows and daylight in healthcare settings, mainly on patients, and studies have addressed overall benefits on healthcare staff. The documented effects include decreased pain medication consumption and decreased pain medication costs (Walch, Rabin, Day, Williams, Choi, & Kang, 2005), increased antidepressant effects of prescribed medication (Benedetti, Colombo, Pontiggia, Bernasconi, Florita, & Smeraldi, 2003), and reduced duration of hospitalization in bipolar patients (Benedetti, Colombo, Barbini, Campori, & Smeraldi, 2001). Windows that provide views of nature are known for their restorative effects. For example, surgical patients assigned to rooms with a nature view had shorter lengths of post-operative time in the hospital compared with patients with a window view of a brick wall and had fewer complaints about their care as recorded by nurses (Ulrich, 1984).

Studies on medical staff indicate an improved perceived quality of the work environment in association with windows, sunlight, or views. Nurses exposed to exterior nature views have reported improved perceived alertness and reduced acute stress, whereas nurses with no view or non-nature views have reported deteriorated perceived alertness and increased acute stress (Pati, Harvey Jr., & Barach, 2008). A study on 141 nurses in Turkey reported higher job satisfaction and less occupational stress when exposed to daylight for more than 3 hours per day (Alimoglu & Donmez, 2005)

Lighting, natural or artificial, not only helps with visual tasks (Aries, Veitch, & Newsham, 1998) such as reading medication labels (Joseph, 2006), but it also affects physiological, psychological, and behavioral functions, according to laboratory research studies (e.g., Cajochen, 2007; Joseph, 2006).

In terms of biological factors, the intensity and the timing of light exposure can alter circadian rhythms and potentially improve the synchronization of the body clock, peak cognitive performance, and work activities in a process known as circadian realignment (Roberts, 2010). By altering circadian rhythms, light exposure can result in increased body temperature (Badia, Myers, Boecker, & Culpepper, 1991), decreased blood pressure (Myers & Badia, 1993; Boyce, 1997), and decreased heart rate (Smolders, de Kort, & Cluitmans, 2012).

In terms of psychological and behavioral factors, appropriate lighting can improve alertness, performance, mood, and social interaction through neuro-hormonal changes. Bright light exposure suppresses the secretion of melatonin—a hormone that governs alertness and sleepiness. Lighting is actually the most important environmental stimulus for humans with regard to alertness and sleepiness (Postolache & Oren, 2005; Crepeau, Bullough, Figueiro, Porter, & Rea, 2006; Cajochen, 2007).

Field studies on office workers have demonstrated the positive effects of lighting on alertness, performance, and mood. In a 2012 study, higher alertness and vitality were reported in highly illuminated conditions (1000 lx, compared with 200 lx), and higher physiological arousal (heart rate) and faster response times were found in a psychomotor vigilance task toward the end of the 1-hour exposure experiment (Smolders, de Kort, & Cluitmans, 2012). Individual performance is regulated by time awake, quality of light, prior sleep, and one's biological clock (Klerman, 2010, cited by National Space Biomedical Research Institute, 2010). In addition to timing, good lighting quality (spectrum and intensity) has been correlated with improved task performance (e.g., van Bommel & van den Beld, 2004; Joseph, 2006). Specifically, adequate lighting has been recognized as an essential factor for preventing errors by healthcare staff in medication rooms (Chaudhury, Mahmood, & Valente, 2009) and for potentially enhancing nursing care (Kamali & Abbas, 2012). Buchanan, Barker, Gibson, Jiang, and Pearson (1991) empirically tested three illumination levels and found significantly fewer errors in dispensing prescriptions in high-illumination environments (1500 lx) compared with low-illumination environments (450 lx).

Mood also can be improved by lighting (Scott, 2000). Mood and stimulation have been linked to the intensity level and color temperature of daylight (Begemann, van den Beld, & Tenner, 1997; van Bommel & van den Beld, 2004). Social interaction and frequency of communication, which negatively correlate with sleepiness (Kim et al., 2009), have been studied with respect to lighting. Exposure to light therapy has also been associated with reduced social withdrawal and reduced consumption of caffeinated drinks among patients with seasonal affective disorder (Kräuchi, Wirz-Justice, & Graw 1990). A study using real-time recording of daylight exposure, mood, and social interactions over a 20-day period found less conflict, more agreeableness, and improved mood among mildly seasonally depressed subjects compared with those exposed to bright light (aan het Rot, Moskowitz, & Young, 2008).

Studies that have found effects of lighting on interaction and interpersonal conflicts, as measured by the level of communication, amount of communication, number of conflicts, and performance appraisals in the workplace. A study on 72 female university students aged 18 to 25 showed that bright light increased the amount of general and intimate communication among friends (Gifford, 1988).

In general, daylight has also been found to be a more effective form of environmental lighting than electric lighting in boosting alertness and cognitive performance (Münch, Linhart, Borisuit, Jaeggi, & Scartezzini, 2012). Natural light provides high-intensity blue light (400–500 nm) in the morning. The wavelength smoothly transitions to orange-red light (600–700 nm) at sundown with minimal blue light intensity (Roberts, 2010). Human physiology has evolved by responding to this phenomenon. An effective light wavelength for a circadian response is mainly between 460 and 500 nm (Gaddy et al., 1993, as cited by Roberts, 2010). When indoor electric environmental lighting is not appropriate for our body's natural state, occupants will be trapped in "biological darkness" (Stevens & Rea, 2001).

Maximizing access to windows with views of nature and daylight may be a low-cost and easy way to increase the health and performance of nursing staff.

All of the above qualitative and quantitative evidence is derived from the fields of human biology and environmental psychology. The research was conducted in the laboratory or field, mainly not on healthcare workers or hospitalized patients, but it provides the background to objectively explore the restorative physiological and psychological effects of availability of windows and daylight on healthcare employees. Maximizing access to windows with views of nature and daylight may be a low-cost and easy way to increase the health and performance of nursing staff. We know that the performance and well being of healthcare providers is linked to patient satisfaction and perception of care (Rossberg, Melle, Opjordsmoen, & Friis, 2004). This study addresses the gap in the literature on frontline caregivers' work environment by objectively and subjectively measuring the physiological and psychological impacts of windows and daylight, as well as the effect of light on work performance (as measured by probability of errors). Based on the literature, the following hypotheses were tested:

Hypothesis 1: The presence of windows and daylight will improve physiological responses (e.g., decrease blood pressure and heart rate and increase oxygen saturation and body temperature) by realigning circadian rhythms.

Hypothesis 2: The presence of windows and daylight will reduce sleepiness and improve mood, as evidenced by subsidiary behaviors that represent deteriorated mood and sleepiness.

Hypothesis 3: The presence of windows and daylight will increase the frequency of communication and social interaction.

Hypothesis 4: The presence of windows and daylight will improve performance, as evidenced by reduced frequency of human-related medication errors.

Methods

Data were collected using multiple methods with a quasi-experimental approach (i.e., biological measurements, behavioral mapping, and analysis of archival data) in an acute-care nursing unit with two wards that have similar environmental and organizational conditions, and similar patient populations and acuity, but different availability of windows in the nursing stations.

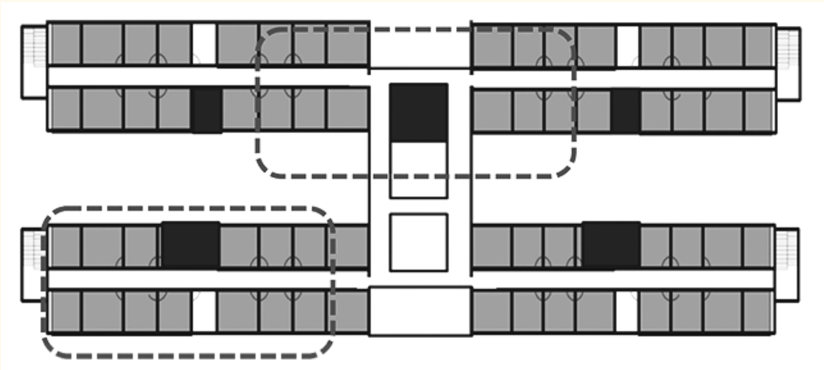
Setting

The study was carried out in two clusters of nurses' stations, located in the north and south wings of an 86-bed acute-nursing unit in a community hospital in Texas. The nurses' stations in the north ward have no access to daylight, where-

Figure 1. Windows and views in the north (left) and south (right) nurses' stations.

Figure 2. Facility floor plan.

Dark gray indicates nurses' stations; dotted line, the patient rooms accessed by the shadowed RNs (as adjusted by charge nurses); light gray, the patient rooms.



as the nurses' stations in the south ward have windows that face north and look out on portions of the hospital building, the sky, and a courtyard (see Figure 1). In terms of lighting quality, the windowed condition provides indirect daylight, which is not available in the windowless condition. In the windowless condition, T8 fluorescent ceiling-mounted lamps are the only sources of light available. In the windowed condition, the same electric lighting is available, in addition to daylight from a north-facing window.

The wards are mirrored in layout, with the same colors, finish materials, furniture, and equipment. Both wards are operated under the same management: one unit manager, one team leader, and charge nurses who were responsible for different shifts. Patient rooms are located on both sides of the corridors all along these two wings (double-loaded corridors, see Figure 2). Although abundant daylight was available through windows, no direct sunlight was available during the study period (summer months) due to the orientation of the windows, site obstructions surrounding the courtyard, and sun angle. Patients in this cardiac unit are continuously monitored using telemetry technology, and they require nursing care with technical skills beyond those of a basic medical/surgical nurse but do not require critical-care nursing. The patient population is similar across the units, with comparable acuity levels ($Mean_{windowless} = 3.2 \pm 0.06$, $Mean_{windowed} = 3.3 \pm 0.07$, $p = 0.16$) according to the standardized Patient Classification System for the hospital. Nurses rotate between the two stations.

Participants

Participants were selected from among day-shift registered nurses (RNs) in the hospital who rotate weekly between the north and south in-patient acute-care wards. Initially, 20 RNs were found to be potentially eligible for the study, all of whom agreed to participate; however, after changes in patient census and work schedules, 12 nurses remained eligible and were enrolled, all of whom completed the study. The participants, summarized in Table 1, did not know the variable

Table 1. Participant Demographics

		Frequency	Percentage
Gender	Female	10	83%
	Male	2	17%
	Total	**12**	**100%**
Age	20–29	4	33%
	30–39	1	8%
	40–49	4	33%
	50–59	3	25%
	Total	**12**	**100%**

of interest. This avoided any placebo effects as suggested by Ott and Longnecker (2008). The study was approved by the Institutional Review Board and Office of Research Compliance Staff of the Division of Research at the researchers' university, as well as the Institutional Review Board at the hospital.

Procedure

The physiological and psychological effects of the presence of windows and daylight on RNs were assessed in a quasi-experimental study using a non-equivalent-groups crossover design that carefully controlled for personal, environmental, and organizational variables. More specifically, the same participants were studied under both conditions, with consistent work patterns and protocols. To control for work fatigue, only participants scheduled to work 2 days in a row each week were eligible, and observations were only on the second day of their shift. Environmental settings were controlled by conducting the study in areas with similar unit layouts, equipment, furniture, and finishes. Work protocol management, computer and charting systems, patient type and acuity, and nurse/patient ratios were similar in both conditions. Each participant was studied for a total of 16 hours through a shadowing procedure (8 hours per day in each treatment condition for 2 days). This procedure was introduced to the participants in the morning prior to the study, and participants maintained their daily activities while being shadowed by the researcher. They were given the option to ask the researcher to stop the observation process at any time for any reason, including the need for privacy or other needs that might benefit the participants or patients.

The order of windowed and windowless locations was randomly assigned by the charge nurses. Each observation day was dedicated to one nurse participant. Two observers (the principal investigator and a research assistant) conducted the onsite data collection after a set of pilot studies and inter-rater reliability assessments. Shadowing resulted in a total of 144 hours of behavioral mapping (across the 12 RNs) on work-related and subsidiary behavior related to sleepiness and mood. In addition, between the two observers, approximately 16 hours of pilot testing and reliability analysis were completed for light measurement and behavior observation. A total of 120 biological measurements were recorded. During the data recording, biological assessments (blood pressure, heart rate, temperature, and oxygen saturation) and subjective momentary sleepiness/alertness assessment were conducted at discrete hourly intervals. Behavioral cues were recorded in real time, and illumination levels were recorded every 5 minutes and averaged bi-hourly for analysis purposes.

In addition, archived data on human-related medication errors over a 3-year period (with more than 25,200 admissions) were collected for both nurse stations.

Study Design

The methods used to test the hypotheses in this study included physiological assessments (vital signs), behavioral mapping, momentary assessments, and records analysis. In addition, a digital light meter was used to measure horizontal illumination levels every 5 minutes during the observation and behavioral mapping period for each participant. The illumination measurement plane was set to remain at a constant distance from the participants' eyes.

Because each participant was repeatedly measured over time for the physiological assessments (vital signs), behavioral mapping, and momentary assessments, a mixed model was used to analyze the data. The dependent variables of interest were repeatedly measured for each subject. Bi-hourly measurements for all the response variables were paired for each individual in both conditions, and the patterns of the average daily measurements were analyzed in a mixed model to test the hypothesis of whether physiological psychological and behavioral responses were improved in the windowed condition compared with the windowless condition (one-directional hypothesis). The model was consistently tested for the treatment (i.e., the presence or absence of windows and daylight), time, gender, age, sleep duration, number of patients, average total light levels (lx), and daylight factor (indicating distance from window) as main effects, as well as for order of data collection and the interaction terms between time with treatment, average light, daylight factor, and average patient acuity as fixed variables. The final model included only the significant effects.

To account for the non-independence of the measurements, a subject ID was entered in the model as a random effect. The main independent variable of interest (presence or absence of window) was measured for each subject as each subject experienced both conditions. Other independent variables for individual subjects were time, sleep duration, number of patients, average total light levels, and daylight factor. Independent variables between subjects were gender and age. A non-parametric paired test was used to compare the frequency of human-related intravenous (IV) and non-IV medication errors in the windowed ward compared with the similar windowless ward while RNs were rotating frequently between the two.

Measures

Data were collected using multiple methods with a quasi-experimental approach (i.e., biological measurements, behavioral mapping, and analysis of archival data) in an acute-care nursing unit with two wards that have similar environmental and organizational conditions, and similar patient populations and acuity, but different availability of windows in the nursing stations. Measures representing the dependent variables include physiological, psychological, behavioral, and momentary ecological assessments. In addition to the documentation of the presence and absence of windows, the participants' total light exposure was measured.

Physiological Assessments

To measure physiological responses, the RNs' vital signs—blood pressure, heart rate, oxygen saturation level, and body temperature—were measured bi-hourly for every participant under both conditions using a Carescape™ V100 monitor from GE Healthcare (Fairfield, CT). The participants were seated during the measurements. To represent changes in blood pressure, systolic and diastolic blood pressure were combined to calculate mean arterial pressure (MAP) (Rogers et al., 2001).

Psychological and Behavioral Assessments

Frequency of communication and positive social interaction (measured by laughter), caffeine intake, illumination levels, and subsidiary behaviors related to coping with sleepiness were recorded every 5 minutes. Because the study was conducted in a similar fashion under the controlled and treated conditions, participants did not know that windows and daylight were the study's specific variables of interest, nor which variables and behavioral clues were recorded. Thus, the placebo effect, an unwanted favorable response to a condition, was avoided. The measurements were averaged bi-hourly and paired per participant and time of day for comparison.

Behavior observations from a total of 192 hours (24 days) were collected. After the data collection, 120 minutes of data from the beginning and end of the data collection period were eliminated because of frequent violation of the methodological consideration about deviation of actual measurement time from target measurement time. This deviation was a result of RNs' critical tasks at the beginning and end of shifts, as the research team was not supposed to interrupt tasks such as reporting, charting, medication administration, and communication to physician and patient. An allowable 30-minute deviation from target time was set in order to avoid interruption of critical tasks. Observations on the participants' frequency of communication and positive social interaction, caffeine intake, illumination levels received, location changes during the work routine, and subsidiary behaviors related to coping with sleepiness were recorded every 5 minutes using Noldus Behavior Mapping software and equipment (Olsen, Hutching, & Ehrenkrantz, 2000). A comparison of the measurements between the windowed and windowless conditions was made to determine whether the presence of windows and daylight increased communication and positive social interaction and reduced sleepiness-related subsidiary behavior. Given the assumption that RNs would be less sleepy and more alert in the windowed condition, we hypothesized that participants would communicate more frequently in the windowed condition compared with the windowless condition. The frequency of communication for each individual was compared between the windowed condition and windowless condition, both when participants were directly in the nurses' stations and when they were in various other locations.

If the presence of daylight improves mood and communication, the behavioral cues related to these variables should be improved. These subsidiary behaviors are psychological or physiological responses that are not directly related to the work task, but rather are behavioral manifestations that can interfere with tasks and lead to errors (Takanishi et al., 2010). These include behaviors related to monotony (stretching), sleepiness (yawning, sighing, and rubbing eyes), and habit (touching head). Laughter was also documented, as it is considered a manifestation of sociability, warmth, and approachability (Feagai, 2011; Palmer, 2005). The research team defined laughter as audible, chest moving, and occurring out of happiness or pleasure, and it was recorded each time that a positive conversation resulted in laughter.

If the presence of windows and daylight increases alertness, such improvement should be reflected in the RNs' related behavioral clues of sleepiness/alertness. Subsidiary behaviors related to overall sleepiness and deteriorated mood (yawning, sighing, singing and whistling, stretching trunk, touching forehead, and eye rubbing) were recorded via behavior observation. If alertness is improved by windows and daylight, the frequency of caffeine intake may decrease. To test this notion, the frequency of caffeine intake was monitored for each participant under both conditions (while participants were unaware of the measurement). To measure the intake of caffeinated beverages, the type of beverage in addition to the number of sips were recorded.

Momentary Ecological Assessment

In addition to observations of subsidiary behaviors related to sleepiness, visual momentary ecological assessment (Stone & Shiffman, 1994) was used by the RNs to document their bi-hourly subjective sleepiness. The format of the survey was borrowed from PedsQL™ Visual Analogue Scales (Varni, Seid, & Rode, 1999) and enabled participants to input their selection by choosing a number from 0 to 10 a maximum of five times daily. We hypothesized that the subjective sleepiness would be reduced in the windowed nurses' station compared with the windowless one, as daylight and windows are likely to increase the participant's alertness.

Light Measurement

A digital light meter, model 401025 by EXTECH Instruments (Nashua, NH), was used to measure horizontal illumination levels (light levels on the work surface) every 5 minutes (or earlier if participants changed location).

The illumination measurement plane was set to remain at a consistent distance from the participants' eyes (average height). If the participants were seated, the measurement plane would be at 30 inches (76.2 cm), which represents the height of the workstation. If participants were standing, the measurement plane was set at 40 inches (101.6 cm), a typical height for a standing counter (Waggener, personal communication, 2011).

Because it was not possible to use a tape measure at all times while shadowing the participants, the observers created anatomical markers (using a tape measure) to keep the measurement plane consistent and be able to rapidly measure lighting at the correct height. The observers used a unified method to measure lighting. The methods were practiced before the study began. In these experiments, we ensured that the light measurement would be taken in a way such that the reader was not shadowed by an object or by observers' or participants' bodies. Therefore, the observers held the reader away from their bodies. The light meter was held stationary for at least 2 seconds (counting "one one-thousand, two one-thousand") in a horizontal position before reading the digits shown on the screen.

The positive impact of windows and daylight on RNs was tested using physiological assessments (vital signs), behavioral mapping, and records analysis.

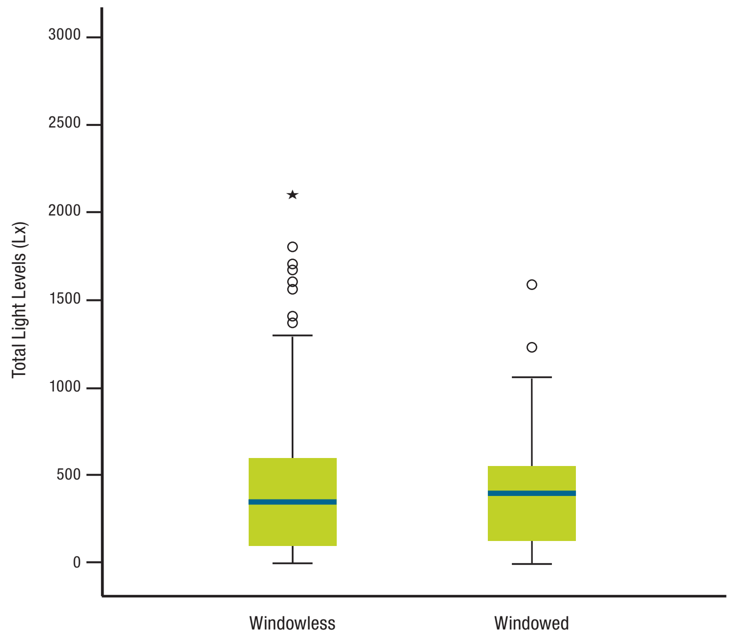
Records Analysis

Furthermore, records of IV and non-IV medication errors in all existing categories were studied for the windowed (design case) and windowless (reference case) wards from January 1, 2009, to December 31, 2011 (including more than 20,000 patient admissions). This includes the 3 full years of medical records data available to the hospital following a switch in the medical records system. The medication errors included incidents with and without harm, both of which were included in the analysis. A comparison was made of whether the windowed ward had lower numbers of human-related medication errors than the windowless ward. Following the notion that alertness would be improved in the windowed nurses' station, we hypothesized that the human-related medication errors would be less frequent in the windowed ward compared with the similar windowless ward while RNs were rotating frequently between the two.

Results

The positive impact of windows and daylight on RNs was tested using physiological assessments (vital signs), behavioral mapping, and records analysis. In terms of light intensity, the total average daily light exposure for RNs, based on a repeated measurement taken every 5 minutes during the 24 days of shadowing, was nearly the same in the windowless condition (765 ± 192) and the windowed condition (672 ± 148), with no statistical difference ($F = 0.59$, $p = 0.44$). The outliers indicate the instances when the RNs left their unit to an area with natural lighting (Figure 3). When assigned to the windowless station, RNs left the ward for other areas more often than when they were working in the windowed station. These instances are plotted as outliers, as the destinations included a daylight atrium or outdoors that provided considerably higher light levels.

Figure 3. Average light exposure for RNs during nursing care.



Physiological Responses

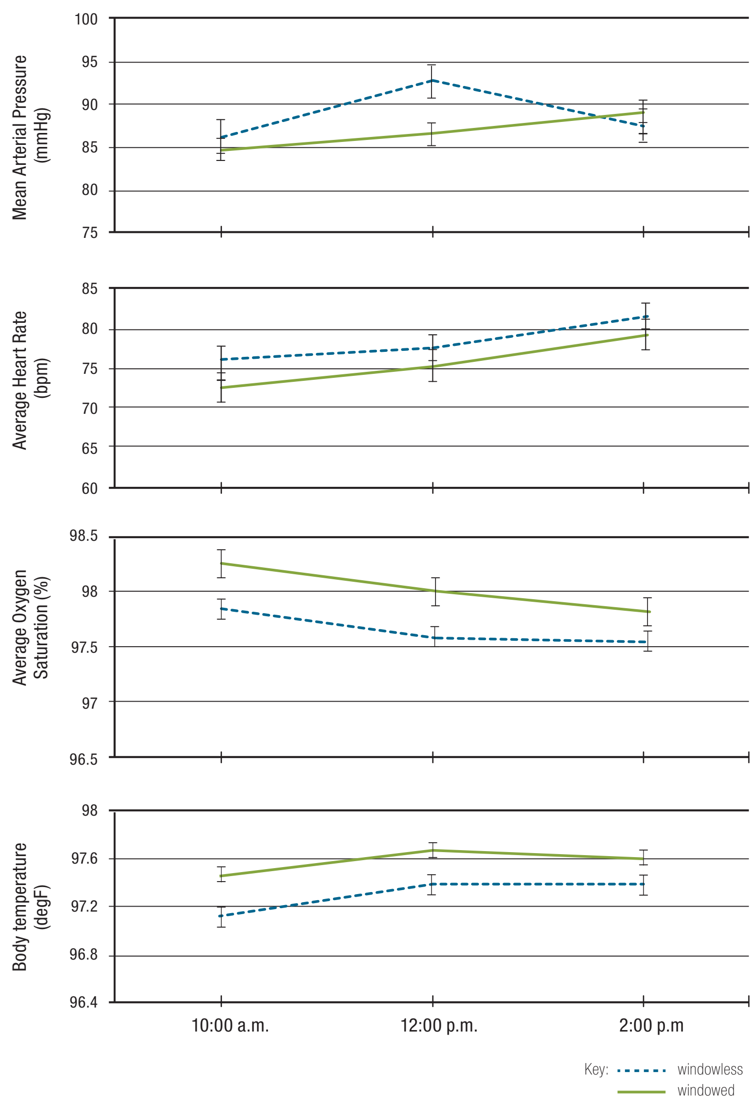
If the presence of windows has restorative effects and the availability of daylight improves neuro-hormonal mechanisms resulting in the adjustment of the body's circadian rhythms, the RNs' biological assessment should indicate the improvements. The RNs' vital signs—blood pressure, heart rate, oxygen saturation level, and body temperature—were measured bi-hourly, once in the windowless condition (control) and once in the windowed condition (design). (Table 3, in the "Discussion," below, summarizes the findings.)

Blood Pressure

The findings from the mixed model analysis showed that MAP, a measurement for blood pressure combining systolic and diastolic pressure, was significantly lower (see Table 3) when the RNs worked at the windowed location (94.6 ± 3.0 versus 86.9 ± 3.0; estimate = 7.65, $p < 0.0001$).

The data indicated that age, gender, and order also had a significant effect on MAP. The higher the RN's age, the higher the MAP (p values reported in the Table per age group). Female nurses had significantly lower MAP than did male nurses ($p = 0.046$). No other variable had an effect on MAP.

Figure 4. Bi-hourly measurements of vital signs.



Heart Rate

Heart rate was not significantly reduced (p = 0.067) when the RNs worked in the ward with windows and daylight (78.39 ± 2.8) compared with the windowless ward (75.7 ± 2.8). Further study of the data showed that time has a significant effect (p = 0.002) on heart rate. Heart rate increased over time; therefore, the mean heart rate had an upward trend (see Figure 4). No other variables affected heart rate.

Oxygen Saturation

Oxygen saturation was significantly higher ($p = 0.016$, estimate = –0.0371) when the RNs worked in the windowed ward (97.02 ± 0.2) compared with the windowless (97.39 ± 0.2) ward. Age was a significant predictor for oxygen saturation; the higher the RNs' age, the lower the oxygen saturation level (p-values are presented in the table per age group) as expected in human physiology. Male nurses had lower oxygen saturation than female nurses. The graph showed a downward trend in oxygen saturation over time (see Figure 4); however, time did not have a significant effect. No other variable had any effect on oxygen saturation. It is notable that the windows were fixed and not operable. Therefore, fresh air was not provided at the treatment condition, and both wards were ventilated with the same mechanical system.

Body Temperature

Body temperature (a marker of body circadian rhythm), although still within the normal range, was significantly higher ($p = 0.026$, estimate = –0.28) when RNs worked in the ward with windows and daylight (97.58°F ± 0.16) compared with the windowless ward (97.30°F ± 0.16). Further observations showed that, except for the treatment presence and absence of windows, no other variable had any effect on body temperature.

Psychological and Behavioral Responses

Psychological and behavioral responses recorded were communication and positive interaction, as well as indicators of deteriorated mood and sleepiness.

Communication and Positive Interaction

Communication was measured both based on quantity and quality. Frequency of occurrence of communication was recorded. In addition, positive social interaction (communication followed by laughter) was recorded.

Communication in the nursing stations by the RNs significantly increased (p < 0.0001) when they worked in the ward with windows and daylight (21.61 ± 1.5) as compared with the windowless ward (13.11 ± 1.5).

Frequency of communication. Communication in the nursing stations by the RNs significantly increased ($p < 0.0001$) when they worked in the ward with windows and daylight (21.61 ± 1.5) as compared with the windowless ward (13.11 ± 1.5). The presence of the window resulted in eight more occurrences of communication per RN participant (parameter estimate of 10.26). No other variable had an effect on communication.

Figure 5 displays the locations where communications occurred when the RNs worked in the two wards. The vertical axis shows the total number of communications in each ward during the 192-hour shadowing of individual RNs in the unit. The graph shows a major shift in the frequency of communication in the nurses' station, which is interestingly the location of the window (independent variable). The total frequency of communication was similar in the reference case and design case in all other areas; however, frequency of communication outside

Figure 5. Nurses' communication.

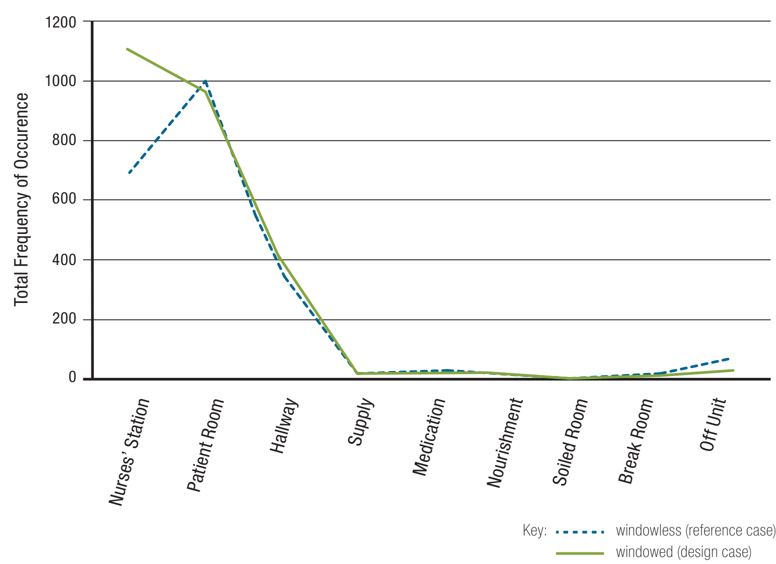
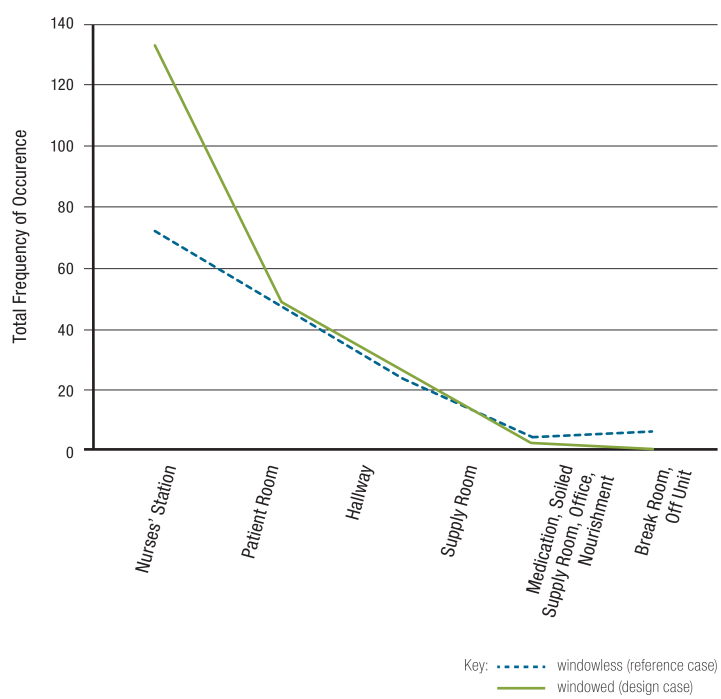


Figure 6. Positive sociability and approachability.



the assigned work unit (in the hospital entrance, adjacent work units, or break areas) was higher in the windowless location than in the windowed condition. It is notable that the break area for both wards is the same. The break area is windowless, shared between the two wards, and located in the middle of the floor plan at an equal distance from the two studied wards.

Frequency of laughter. The increase in the average occurrence of laughter in the windowed nursing station was higher (4.67 ± 0.96) than the windowless station (1.96 ± 0.96) significantly (p = 0.028, estimate = –2.71). No other variable had an effect on the occurrence of laughter.

Figure 6 displays the total frequency of laughter during the shadowing of individual RNs plotted by location. Consistent with the findings in the previous section about communication, the occurrence of positive interactions resulting in laughter was similar in different locations, except in the nurses' stations, where the presence of windows varied. The occurrence of positive conversation (e.g., a compliment or positive humor) followed by laughter in patient rooms was quite similar in both the windowed and windowless wards.

The occurrence of subsidiary behavior indicators of sleepiness and deteriorated mood in the windowed condition was less than in the windowless condition (2.89 ± 0.96 vs. 5.25 ± 0.96, estimate = 2.36).

Sleepiness and Mood

Sleepiness and mood were assessed in three ways, observed behavioral indicators, observed frequency of caffeine intake, and participants' self-reported subjective momentary assessment.

Figure 7. Comparison of caffeinated and non-caffeinated liquid intake.

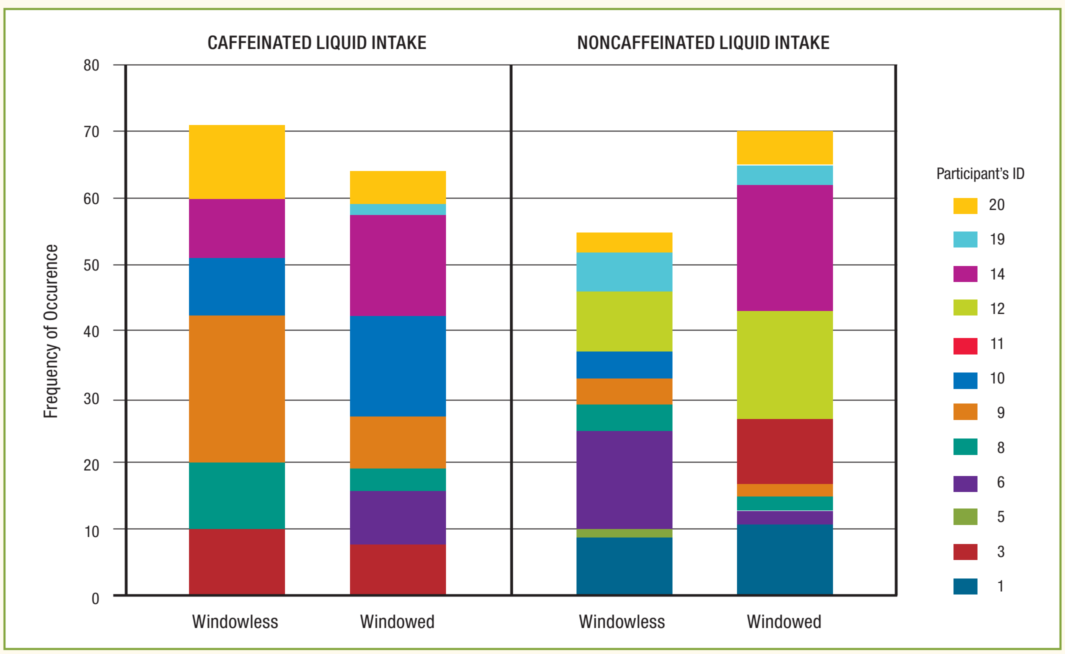


Table 2. Mixed Model Analysis for Windowed and Windowless Conditions (measured bi-hourly at 8:00 a.m., 10:00 a.m., and 12:00 p.m.)

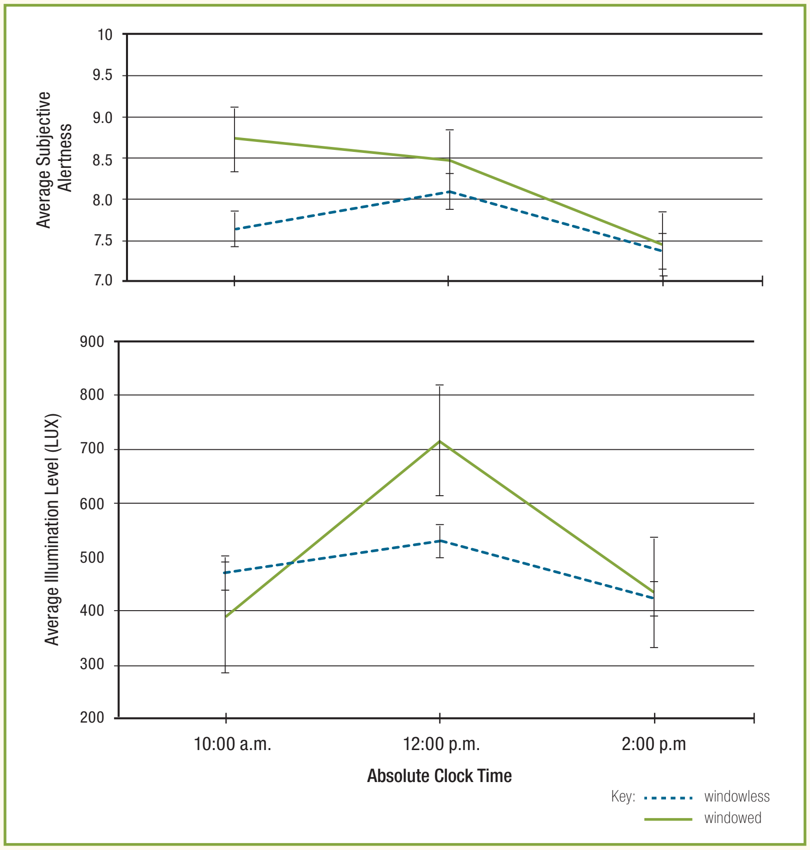
Effect		Mean Arterial Pressure (Blood Pressure)		Heart Rate		Blood Oxygen Saturation		Body Temperature		Frequency of Communication (in Nurse Station)		Frequency of Laughter (in Nurse Station)		Subjective Momentary Sleepiness		Frequency of Subsidiary Behavior (Sleepiness & Mood)	
		Estimate (St. Error)	Sig.	Estimate (St. Error)	Sig.	Estimate (St. Error)	Sig.	Estimate (St. Error)	Sig.	Estimate (St. Error)	Sig.	Estimate (St. Error)	Sig.	Estimate (St. Error)	Sig.	Estimate (St. Error)	Sig.
Intercept		109.76 (6.4)	0.000	79.07 (2.97)	0.000	95.29 (.41)	0.000	97.64 (0.19)	0.000	19.58 (1.97)	0.000	4.85 (1.26)	0.001	2.33 (0.53)	0.001	3.25 (1.93)	0.002
Time (Ref 2:00 p.m.)	10:00 a.m.			−6.13 (1.67)	0.001									−0.77 (0.32)	0.019	1.71 (1.56)	
	12:00 a.m.			−4.00 (1.67)	0.134									−0.86 (0.32)	0.009	2.12 (1.56)	
Treatment (Ref Windowed)	Windowless	7.65 (1.94)	0.000	2.69 (1.66)	0.067	−0.37 (0.17)	0.016	−0.28 (0.14)	0.026	−8.5 (1.79)	0.000	−2.71 (1.19)	0.028	0.52 (0.37)	0.095	3.84 (1.71)	0.023
Gender (Ref Male)	Female	−12.41 (5.13)	0.045			1.56 (0.32)	0.002										
Age Group (Ref 50–59)	20–29	−15.88 (4.97)	0.015			1.81 (0.31)	0.001										
	30–39	−20.57 (7.25)	0.025			1.17 (0.45)	0.036										
	40–49	−10.86 (4.97)	0.065			2.30 (0.31)	0.000										
Order (Ref 2)	level 1	−8.46 (1.94)	0.000														
Sleep Duration																	
Number of Patients																	
Illumination																	
Daylight Factor																	

Behavioral indicators of sleepiness and deteriorated mood. The findings showed that the treatment had a significant direct effect on the occurrence of subsidiary behavior ($p = 0.023$). The occurrence of subsidiary behavior indicators of sleepiness and deteriorated mood in the windowed condition was less than in the windowless condition (2.89 ± 0.96 vs. 5.25 ± 0.96, estimate = 2.36). Further study of the data indicated that although the total occurrence of subsidiary behavior per participant per day significantly decreased by 46% (*t*-test, $p = 0.03$), the mixed model did not pick up a significant effect for the treatment variable (presence or absence of windows).

Caffeine intake. Caffeine intake was not significantly reduced ($p = 0.275$) when nurses worked in the windowed ward compared with the windowless ward. No variable had an effect on caffeine intake.

Other observations of the data indicated that caffeine intake had an insignificant reduction of 10% in the windowed nurses' station compared with the windowless station; meanwhile, intake of decaffeinated drinks (water, ice, or fruit juice) increased by 10%, again insignificantly (Figure 7), keeping the overall liquid intake (for thirst) the same. Although the observation showed interesting

Figure 8. Bi-hourly subjective momentary alertness (top graph) and average total illumination levels (bottom graph) in windowed and windowless conditions.



trends, the hypothesis regarding significant reduction of caffeine intake was not supported.

Subjective momentary assessment of sleepiness. The observed reduction in the bi-hourly ecological momentary assessment of sleepiness in RNs was not significant (p = 0.094). Other observation of the data indicated that time of day was a significant predictor of sleepiness (Table 2). The estimated means indicated that sleepiness consistently increased over time. Figure 8 displays subjective alertness (subjective sleepiness subtracted from 10) under the windowed and windowless conditions. This shows that the reduction in sleepiness and increase in alertness provided by windows and daylight is significant in the morning and the effect of the treatment is reduced over time.

Further study of the data showed that variability between subjects in reporting sleepiness was very high, as indicated by a residual variability of 2.20. Figure 8 also displays the bi-hourly average total illumination levels that nurses were exposed to during the day in the windowless and windowed conditions. The total average illumination in the windowed condition was higher than that in the windowless condition but had considerable variation during the day.

Medication Errors

In the past 3 years, a total of 23 medication errors were reported in the entire unit (Figure 9). The yearly probabilities of error, adjusted per each patient room for

Figure 9. Non-IV and IV medication error rates between 2009 and 2011 (adjusted per patient room per year).

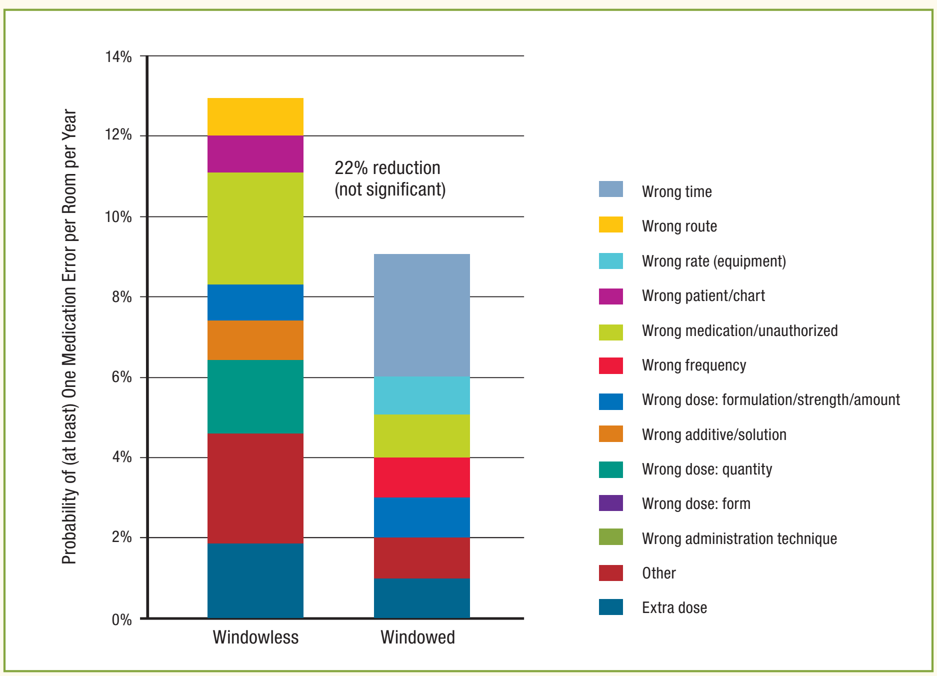


Table 3. Summary of Findings

HYPOTHESIS	FINDINGS
1: The presence of windows and daylight will improve physiological responses (decrease blood pressure and heart rate and increase oxygen saturation and body temperature) by realigning circadian rhythms.	The reduction of mean arterial pressure, combination of systolic and diastolic, ($p < 0.0001$) was significant. The increase of temperature (0.026) was significant. The increase in blood oxygen saturation was significant ($p = 0.016$) but the change was clinically trivial. The reduction of heart rate was not significant ($p = 0.067$).
2: The presence of windows and daylight will reduce sleepiness and improve mood, as evidenced by subsidiary behaviors that represent deteriorated mood and sleepiness.	The frequency of subsidiary behaviors that indicate sleepiness and deteriorated mood was significant ($p = 0.023$). Self-assessed sleepiness was not significant ($p = 0.095$).
3: The presence of windows and daylight will increase the frequency of communication and social interaction.	Increased frequency of communication ($p < 0.0001$) and positive social interaction (measured by communication followed by laughter) in nurse station was significant ($p= 0.028$).
4: The presence of windows and daylight will improve performance, as evidenced by reduced frequency of human-related medication errors.	The decrease in medical errors was not significant ($p = 0.14$).

the windowless and windowed ward, were 11.6% and 9.0%, respectively, showing a 22% lower probability of error in the windowed ward; however, further analysis using a non-parametric paired test on the occurrence of IV and non-IV medication errors in the windowed ward compared with the windowless ward showed that the reduction was not significant (sum rank of 38 negative ranks to 17 positive ranks, $z = -1.10$, $df = 13$, $p = 0.14$).

Discussion

This study compared the physiological and behavioral responses of day-shift RNs when providing direct patient care, as measured once in a windowed nurse station and once in a windowless nurse station in an acute-care unit. Table 3 summarizes the findings. The findings showed that four out of five of all the nurses' vital signs improved significantly when they were stationed in the nurses' station with windows and daylight. Overall, daily MAP decreased significantly. Both oxygen saturation and body temperature increased significantly. The amount of increase in oxygen saturation is clinically trivial (less than one unit), but it still hints at a possibility of improvement in nurses. Heart rate showed an insignificant reduction.

Physiological Outcomes

The lowered blood pressure may be explained by availability of daylight, which, according to Walch et al. (2005), has stress-reducing effects. Another important element may be the presence of windows and an outside view, which, according to Ulrich (1984), has healing effects. A pleasant window view has a "micro-restorative" effect, providing the opportunity of "brief respite to one's directed attention" (Kaplan, 1993, p. 196).

The oxygen saturation increase in the windowed condition seemed to be fairly consistent. One explanation may be tied to the sense of happiness and freshness that windows and daylight bring to the windowed nurses' station compared with the windowless one. This may have stimulated deep breathing, which results in increased oxygen saturation (Bernardi et al., 1998). More research is needed to unravel the effect of windows and daylight on employees' oxygen saturation. Another explanation may be the stress-reducing effects of windows. For example, a study by Standley and Moore (1995) showed that the stress-reducing effect of music improved oxygen saturation in infants. This explanation will direct attention back to the "micro-restorative" (Kaplan, 1993, p. 196) effect of windows and its possible effect on oxygen saturation, similar to the effect on heart rate described above. The effect of age on the oxygen saturation is expected as supported by evidence (Genes, Chandra, Ellis, & Baumlin, 2013; Moraes et al., 2014).

Our observations of a significantly increased body temperature in the morning are consistent with those of Turner, Van Someren, and Mainster (2010), who noted that morning sunlight increases vigilance and core body temperature. Increased body temperature may be related to increased performance (Wright, Hull, & Czeisler, 2002). More specifically, Wright et al. (2002) explain that regardless of the circadian phase, even an increase of about 0.27°F in body temperature has been associated with enhanced memory and cognitive performance. Therefore, further study is suggested to trace the effect of the availability of natural light in healthcare workspaces on caregivers' memory and cognitive performance.

Psychological and Behavioral Outcomes

Psychological and behavioral outcomes, including communication and laughter, sleepiness and mood are discussed below.

Communication and Laughter

Both psychological and behavioral outcomes that measured communication and positive sociability showed significant improvements. When working in the windowed nurses' station, RNs communicated significantly more frequently than when they were working in the windowless nurses' station. When the communication data were analyzed by location over the course of the workday, the findings showed that the increase in communication occurred when the participating RN was in the nurses' station where the window and daylight were available and did not change in any other nursing areas in the unit. Although only communication by the participating RN was recorded, the positive effect of the window on other RNs in the room may have played a role in increased communication.

The increase in positive sociability, as measured by the occurrence of frequent laughter, was also significant. Another interesting observation and lesson learned was that an all-day observation per participant in all care areas may not be necessary, as the trends are similar over time and the change actually occurred only in the nurses' station where the window was located. In most cases, the greatest effect was visible in the morning (10:00 a.m. measurement).

Sleepiness

Of the three means of measurement—subsidiary behavior, caffeine intake, and momentary self-assessment—only one showed significant improvement. The results from behavior mapping indicated that the reduction in subsidiary behavioral cues of mood and sleepiness was significantly lower in the windowed nursing stations. The anecdotal observations of the researchers during shadowing was that self-assessment of sleepiness was highly dependent on stressful or emotional events.

Therefore, no conclusion can be made in terms of reduced momentary self-reported sleepiness or caffeine intake in the windowed ward. For self-reported sleepiness, the variability between subjects in reporting sleepiness was very high, as indicated by a residual variability of 2.2. Therefore, given the subjective type of measurement (self-evaluation, which may be confounded by daily events and emotions), we recommend the use of the same methodology with a larger sample size to overcome the effect of individual differences and study the effect of subjective sleepiness in a statistical analysis. No other variable had an effect on sleepiness.

An optimized study design for future research to capture the effects of windows would involve a larger sample size in a given time interval in the nurses' station where the window is located as opposed to long hours shadowing in all nursing areas. Given the time effect on sleepiness and the fact that sleepiness was significantly reduced in the morning and not the afternoon, it may be a good strategy for future research to conduct behavior observation during morning hours when time-affected sleepiness and fatigue are not as prevalent. Another explanation for this may be the varying amount of daylight over time. The total daylight level in the windowed station was higher in the morning but dropped one below the baseline (total electric light levels) for the windowless station in the afternoon.

Because evidence in other settings has shown that lighting therapy reduced caffeine use, increased social interaction, and reduced sleepiness (Kräuchi et al., 1990) for depressed patients, further research is needed to investigate the effect of windows and natural light on behavior and caffeine use in healthy workers and caregivers. If increased exposure to quality lighting in the workplace reduces sleepiness, and therefore caffeine intake by workers, such an environmental design strategy may have a positive impact on employees' health.

Medication Errors

The patient/nurse ratio and patient acuity and type were similar between the two patient wards, but the frequency of errors for patients in the ward with the windowed nurse station was one-fifth that in the windowless ward during the 3 years of data reviewed. However, the result was not statistically significant because of the low number of overall errors. Only 23 medication errors were reported and documented in the 3 years prior to our study. Although the hypothesis failed, we suggest future research on medication errors using longer durations to compensate for the small number of occurrences. Because errors are underreported (Koohestani & Baghcheghi, 2009), we estimate that the actual number of errors may be more than twice the numbers reported. Evidence indicates that only 25% (Mayo & Duncan, 2004) to 47% (Blegen et al., 2004) of medication errors may actually be reported by nurses. Common underlying reasons for missed reports are fear of supervisor or coworker pressure or belief that the incident was not important enough to report (Mayo & Duncan, 2004). Risk-free and blame-free reporting and improved documentation procedures for nurses can help with the reliability of data sources and therefore contribute to future research on improving environments for nurses.

Limitations

This research study was conducted in a controlled setting. However, as with other field research, it was not possible to control for all existing variables. Although the furniture, interior finishes, information technology, workload, patient type, patient acuity, and equipment were similar in the two nurses' stations (windowed and windowless), the seating arrangements differed, which may have affected the rate of communication.

Lighting design in clinical workplaces should emphasize not only the minimum light intensity for clear vision but also the biological need to adjust workers' circadian functions to improve performance.

Both nurses' stations were in double-loaded corridors with similar patient rooms in form and arrangement. However, the windowless nurses' station was located in the middle of the ward, and the one with windows was centered in the left side of the corridor. This arrangement could have impacted the nurses' walking distance. However, this factor was controlled to a great extent by charge nurses who made random room assignments.

The observation portion of the study in which the researcher shadowed the participant in the windowed and windowless stations measuring subsidiary behavior, communication, and positive sociability was not researcher-blind. However, the collection of the other data was blind, including biological data, participant self-reporting of sleepiness, and medical records. This excluded possible researcher bias.

Conclusion

Evidence from a laboratory setting has confirmed that lighting designed with characteristics similar to those of sunlight improves circadian adjustments through neuro-hormonal effects, as expressed by elevated mood, alertness, vigilance, and cognitive function (Czeisler et al., 1986, Postolache & Oren, 2005; Kent et al., 2010). From a psychological perspective, the availability of windows and daylight results in respite and mental restoration (Kaplan, 1993) and has been shown to have stress-reducing effects (Walch et al., 2005) on various populations. Overall, our findings support evidence from field and laboratory research on the positive effects of windows on acute-care RNs.

Implications for Practice

- The presence of windows and daylight may have psychological, psychological, and behavioral benefits related to circadian rhythms (evidenced by temperature), communication, and positive sociability on RNs working a day shift.

- Because alertness is connected to both staff and patient safety, maximizing access to daylight and providing quality lighting design in nursing areas may be an opportunity to improve safety though environmental design and enable staff to manage sleepiness and stay alert.

- The best source of lighting for human health is daylight. Past studies have shown that, under similar conditions, daylight may have significantly greater effects than incandescent and fluorescent light on circadian adjustments. Therefore, although maximizing the availability of daylight should be one of the main goals for clinical workspace design, optimizing electric lighting to support circadian rhythms is an important goal given the limited presence of natural daylight.

- Lighting design in clinical workplaces should emphasize not only the minimum light intensity for clear vision but also the biological need to adjust workers' circadian functions to improve performance.

- What Steven and Rea (2001) refer to as "biological darkness" occurs when indoor lighting is not adjusted for the human body's biological needs, resulting in circadian disruption with serious consequences on health and performance. Therefore, the physical environment in which the caregivers work on critical tasks should be designed to support a high-performing and healthy clinical staff.

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