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New research in the light and health field is expanding the possibilities for LED lighting in healthcare environments

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Introduction

There are two major problems with residents in all senior health care facilities: poor sleep quality and falls. Lighting may contribute to these two major problems as we discovered in our study of a senior health care facility. Schuyler Ridge Residential Health Care facility is a modern, not-for-profit, skilled nursing facility located in Clifton Park, New York. The 74,000 square-foot facility houses three 40-bed living units and has capacity for 120 live-in residents. Each living unit has its own nursing station. Through discussions with the nursing staff and administrators at Schuyler Ridge, opportunities were identified for lighting improvement to help mitigate poor sleep quality, and possibly, falls.

The lighting fixtures and controls were not well located in the resident bedrooms. One switch near the bed controlled a wall-mounted luminaire containing two-T8 fluorescent lamps, located over the resident's bed. The switch was hard for the residents to locate and switch at night because it was not illuminated and was usually placed out of reach from the bed. Although not all of the residents can get out of bed without help, many of them get up to use the bathroom at night. Staff noted that most falls occur when the residents are getting in and out of bed unattended. One reason for these falls may be the fact that the light switches are usually out of reach from the bed and residents attempt to reach the bathroom in the dark. Another switch was located on the wall adjacent to the door to the resident's room. This switch controlled a 9-watt, twin-tube compact fluorescent lamp housed within the wall mounted luminaire. Staff members turned these lights on at night to perform mandatory checks on the residents. Although this was a low-wattage lamp, its location above the heads of the sleeping resident often awakened them during the mandatory checks.

Ironically, in addition to disruptions to sleep caused by staff activating a fluorescent lamp over the patients' head at night, residents did not have easy access to light bright enough to activate the circadian system (e.g., daylight) during the day (Rea et al., 2002). Constant, dim, retinal illumination may lead to disruption of the circadian system and thereby causing sleep disturbances, particularly among the oldest members of our society (Skene and Swaab, 2003).

Two different approaches to the lighting were undertaken, both aimed at improving the residents' sleep quality. First, a custom fixture containing blue light-emitting diodes (LEDs) was designed and used as a light treatment device in the common dining room to help consolidate sleep and increase sleep efficiency of resident volunteers. Second, the lighting in some of the bedrooms was redesigned to replace, during nighttime, the existing fluorescent lighting above the bed with arrays of amber LEDs activated by motion sensors. The redesign may also have had a positive impact for reducing falls.

Background

Chronic sleep disturbances are experienced by 40% to 70% of the oldest people in the population, over 65 years (Van Someren, 2000). In general, this group of adults tends to go to bed early and wake at an earlier time of day than younger adults. Frequent nocturnal awakenings, difficulty falling asleep, and an increased number of naps during the day are also more common in the oldest adults. Sleep disturbances are associated with decreased physical health, including increased cardiovascular problems, disruption of endocrine functions, and decline of immune functions (Van Cauter et al., 1998).

Disruption of the circadian system is one important reason why sleep disturbances increase among elderly adults. Light incident on the retina is the most important stimulus to the circadian system, synchronizing and consolidating rest/activity patterns in concert with the solar day. Much higher light levels are needed to stimulate the circadian system than the visual system. Indeed, white light in excess of 100 to 200 lux at the eye (500 to 1000 lux on a horizontal surface) for 6.5 hours was shown to reliably stimulate the circadian system of normal young subjects, measured in terms of nocturnal melatonin suppression (Zeitzer et al., 2000). Older adults are exposed to less retinal illumination than younger people due to optical changes in the eye as well as to changes in their daily routine. Short wavelength light, which maximally stimulates the circadian system, can be attenuated by more than 80% in normal older adults relative to young adults due to changes in pupil size (senile meiosis) and changes in the crystalline lens (both increased density and scatter)(Weale, 1991; Charman, 2003). Those with cataracts will be much more affected (Nadler et al., 1990). The impact of low light levels on circadian regulation and sleep may be further compounded by age-related neurological changes in the circadian system (Skene and Swaab, 2003). Moreover, older adults lead more sedentary lives, rarely leaving indoor living environments without access to daylight. Residents of some senior housing facilities might be exposed to light greater than 1000 lux for no more than a half hour each day (Sanchez et al., 1993). Logically then, low retinal illuminances for the circadian system are expected to be associated with the sleep disturbances commonly found among the elderly.

Sleep problems are particularly acute in persons with Alzheimer's disease (AD). Their sleep patterns are similar to those of non-demented patients, but the symptoms are much more frequent and tend to be more severe, making the care for those with AD very difficult (Ancoli-Israel et al., 1997). Fragmented sleep/wake patterns are the major reason that persons with AD are institutionalized. Bright light exposure during the day has already been shown to help regulate the rest/activity rhythms of persons with AD (Van Someren et al., 1997). Further, light exposure in the evening can delay the circadian clock and help older adults sleep better at night and be more awake during the day (Murphy and Campbell, 1996). Figueiro et al. (2002) was able to show that persons with AD increased sleep efficiency and exhibited more consolidated sleep from midnight to 04:00 after early evening exposures to light from blue light-emitting diodes (LEDs).

In addition to reductions in retinal illumination, the quality of the retinal image is also compromised in older adults, possibly contributing to falls. Age-dependent changes in the crystalline lens lead, in particular, to poorer spatial vision. As the crystalline lens ages it becomes less clear and scattered light reduces spatial resolution, not only reducing visual acuity but also elevating contrast thresholds for all spatial frequencies (Nadler et al., 1990). Under low light levels even high contrast objects, such as door frames and objects on the floor, can go undetected, leading to disorientation and falls (De Boer et al., 2004).

Neural changes also become problematic for the oldest people in our population. Gibson (1966) describes a number of higher-order perceptual phenomena that can be compromised in seniors. In particular, an inability to orient oneself with respect to the environment becomes more common with aging. This neural weakness is confounded and amplified by optical changes in the eye (reduced retinal illuminance and spatial resolution) and, together, may contribute significantly to the increased incidence of falls found in older people.

Methods

A four-week study was conducted during March and April 2004 at the Schuyler Ridge Residential Health Care facility. The experiment was approved by Rensselaer's Institutional Review Board (IRB) and consent forms were signed by the caregivers, family members, and patients.

Blue light treatment

Four residents with AD and four non-AD residents, all experiencing sleeping problems, participated in the sleep study. Patients followed their normal routine except they were brought to a dining room for two hours between 16:30 and 18:30 hours. Dinner was typically served between 17:00 and 17:30 hours. The room was illuminated to approximately 300 lux on the table by ceiling luminaires containing fluorescent lamps. Two to three experimenters interacted with the subjects during the two-hour evening sessions. Subjects were taken to their rooms to sleep for the night, around 20:00 hours, as usual.

During the first two weeks, two subjects with AD and two subjects without dementia were exposed to custom-designed tabletop luminaires containing red LEDs (λ_{max} = 640 nm) every evening for 14 days, while the other two subjects with AD and two subjects without dementia were exposed to tabletop luminaires containing blue LEDs (λ_{max} = 470 nm) (Figures 1a and 1b). The LEDs for this aspect of the study were donated by Nichia America Corp. These luminaires produced approximately 30 lx of blue light or red light at the cornea of the patients; however, illuminance at the cornea could not be rigidly controlled due to voluntary movements, changes in sitting positions, and absences from the room due to unrelated clinical conditions. The red-light exposure condition was introduced as a placebo control because red light at this illuminance has been shown to be ineffective in activating the circadian system (Brainard et al., 2001; Thapan et al., 2001). Thus, it was expected that only the blue light condition would be effective for activating the circadian system. After the first two weeks, the subjects were not exposed to light treatment for 10 days, after which the second phase of the experiment began, again running for two weeks. During the 10-day break period, subjects were not requested to stay in the dining room after dinner. Subjects who were exposed to red light in the first phase were exposed to blue light in the second phase of the experiment, and vice versa.

Figures 1a and 1b: Light fixture with blue LEDs on (above) and experimental setup (below).

Tympanic temperatures and observations of sleep were obtained from nurses during the last four nights of both two-week exposure periods. Originally, the nurses were asked to measure tympanic temperatures and record observations of sleep every two hours throughout the last 96 hours (four days) of the two-week exposure periods. However, a complete set of data was not obtained; many daytime and evening observations and measurements were simply not collected. Moreover, many of the nighttime tympanic temperature measurements were not obtained due to the sleeping positions of the subjects. Furthermore, one AD subject and one non-AD subject were not able to conclude the study for medical reasons. Therefore, only nighttime observation data at 00:00, 02:00, 04:00 and 06:00 were complete and, thus, analyzed for three subjects in the AD group and three subjects in the non-AD group.

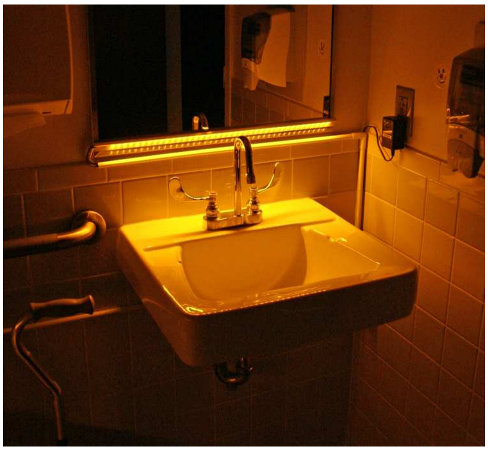
Bedroom and bathroom lighting redesign

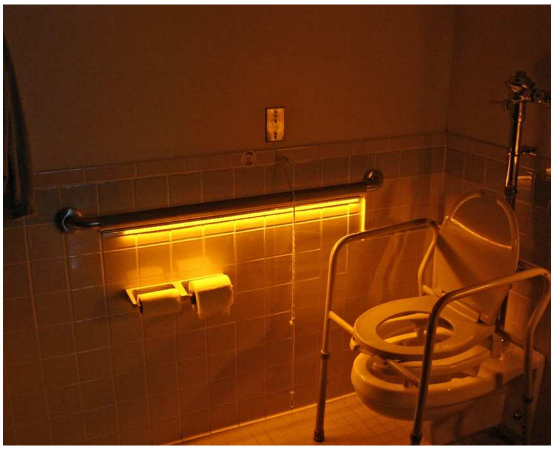
New lighting was installed in the bedrooms and bathrooms of four residents. Two of the residents were independently mobile with the use of a walker and mobility of the other two was restricted to a wheel chair. These four residents did not participate in the sleep study using blue LEDs.

Combination photosensor- and motion sensor-controlled amber LEDs were installed in the residents' bedrooms and bathrooms to provide lighting at night. The amber LEDs for this aspect of the study were part of the LINEARlight Flex system donated by OSRAM SYLVANIA/OSRAM Opto Semiconductors and came mounted on a flexible circuit board with adhesive tape on the back for installation. Amber was selected from the various color choices because it gives enough light to see and is the closest in color to the very familiar incandescent light source. Three arrays of LEDs were used; under the bed, around the bathroom doorframes, and behind the handrail and under the mirror in the bathroom. In the dark, each LED array was slowly ramped up to full-on by its own passive infrared (PIR) motion sensor when motion was detected; the array was turned off after three minutes if no motion was detected. A photosensor ensured that the motion sensor could not be activated when daylight entered the windows or the fluorescent lights were on.

Figures 2a and 2b: Amber LEDs installed under bed (left) and around doorway (right). Note: photosensors were disconnected for the photos.

The PIR motion sensor located under the bed was positioned to detect foot motion along the floor, as the staff entered the room and as the resident lowered his/her feet from the bed onto the floor. The LED array under the bed provided general, low-level ambient light in the bedroom at night; illuminance levels between 10 and 15 lux were measured on the floor next to the bed. The PIR motion sensor that controlled the array of LEDs placed around the bathroom door frame was located at the kickboard adjacent to the bathroom door frame, and was oriented to respond to foot motion approaching the bathroom door. The LED array framing the bathroom door not only contributed to the low, ambient illumination in the bedroom at night, it also provided perceptual information to the residents about the location of the bathroom as well as a strong sense of spatial orientation (i.e., vertical and horizontal cues). These lights contributed approximately 2 to 10 lux on the floor near the door and when standing at the door frame, 10.5 lux was measured at the plane of the cornea. The array of LEDs in the bathroom was activated by a PIR motion sensor located under the sink and provided 5 to 10 lux at the center of the bathroom floor and about 2 to 4 lux at the cornea when standing at the sink.





Figures 3a and 3b: Amber LEDs installed at sink (left) and toilet (right) areas.

Before-and-after surveys for residents and staff were developed to evaluate the bedroom and bathroom lighting. Staff members read and completed the surveys themselves, while residents had the questions read to them by an experimenter. The after survey was conducted two weeks after installation. Seventeen night staff members completed the survey about the pre-existing lighting conditions and sixteen completed surveys about the LED lighting. The four residents whose rooms had the LEDs were interviewed before and after the LEDs were installed.

Results

Blue light treatment

Overall, and as expected, non-AD subjects slept significantly better than AD subjects after blue light exposure (p = 0.007).

Non-AD subjects

Non-AD patients slept better between midnight and 06:00 after exposure to blue light than after exposure to red light. A one tail student's t-test compared the percentage of time subjects spent asleep between midnight and 06:00 hours after blue light exposure compared to red light exposure. Overall, nighttime sleep efficiency was significantly higher after blue light exposure than after red light exposure (p = 0.0003). Non-AD subjects were found asleep 89.5% of the time after blue light exposure and 67% of the time after red light exposure. Figure 4 shows the percentage of time non-AD subjects were found asleep between midnight and 06:00.

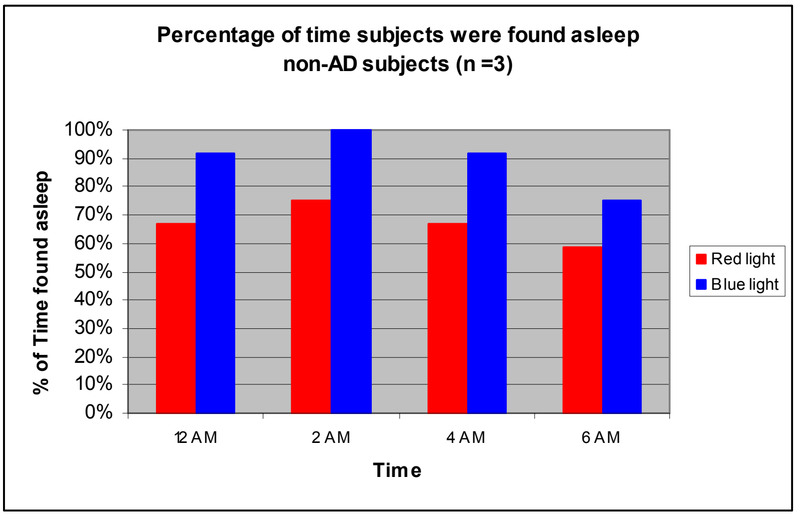


Figure 4: Percentage of time non-AD subjects were found asleep between midnight and 06:00.

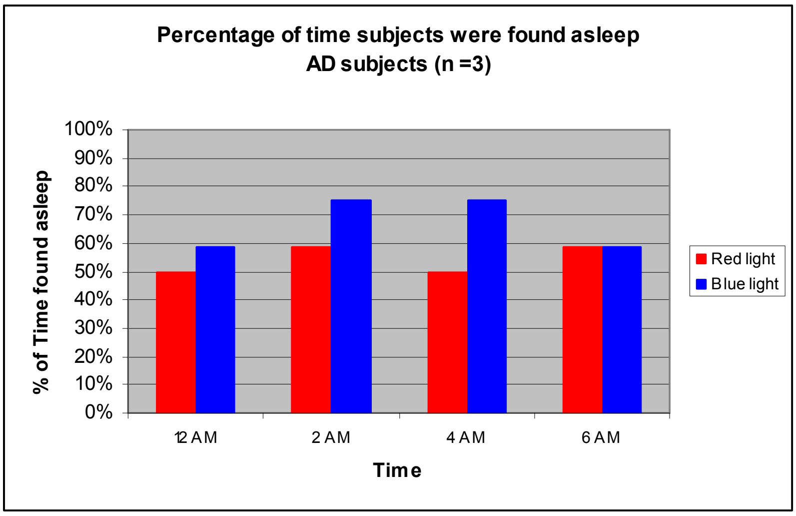


Figure 5: Percentage of time AD subjects were found asleep between midnight and 06:00.

AD subjects

Consistent with Figueiro et al. (2002), AD subjects also slept better between midnight and 06:00 after exposure to blue light than after exposure to red light. A one tail student's t-test compared the percentage of time subjects spent asleep between midnight and 06:00 hours after blue light exposure compared to red light exposure. Overall, nighttime sleep efficiency was significantly higher after blue light exposure than after red light exposure ($p = 0.03$). AD subjects were found asleep 67% of time after blue light exposure and 54% of the time after red light exposure. Figure 5 shows the percentage of time AD subjects were found asleep between midnight and 06:00.

Bedroom and bathroom lighting redesign

Figure 6 shows the results of the survey regarding the bedroom and bathroom lighting. No statistical tests were planned and none are reported.

Before Installation Surveys – Staff	Yes	No	N/A
Do you turn on the room lights for performing checks on the residents at night?	100%	0%	0%
When checking on the residents at night, are they likely to wake up?	94%	6%	0%
Do the residents find the room lights uncomfortably bright at night?	82%	0%	18%
Before Installation Surveys – Residents			
Does the staff turning on the lights at night wake you up?	83%	0%	17%
Do you find the overhead lighting bright or glaring at night?	91%	0%	9%
Is it difficult to find or reach the lighting controls at night?	83%	8%	9%
After Installation Surveys – Staff			
There is enough light for performing checks on residents during the night.	81%	19%	0%
The (colored) lighting is useful.	93%	0%	7%
There is enough light in the bathroom without having to turn on overhead lighting.	62%	38%	0%
It is convenient to have the lighting on a motion sensor.	100%	0%	0%
After Installation Surveys – Residents			
Does the colored light wake you up at night when the nurses come in?	0%	100%	0%
Is the colored light uncomfortable at night if you get up to go to the bathroom?	0%	100%	0%
Do you like the colored light?	100%	0%	0%

Figure 6: Survey results

The results of the survey show highly positive responses from both the staff and the residents to the amber LED arrays, except for the staff responses to the bathroom lighting who suggested that the bathroom lighting was too dim. Indeed, in confirmation of these responses, the bathroom did appear too dim to the experimenters as well. Again, light levels in the bathroom floor were between 5 and 10 lux at the center of the bathroom.

Discussion

Blue light treatment

The positive effects of blue light exposure, though significant in both groups, were smaller in the AD subject group than the in the non-AD subject group. This finding was expected based on the fact that AD subjects have more fragmented sleep patterns than healthy older adults and because compliance with the experimental protocol was more difficult for the AD subjects than for the non-AD subjects. It should be noted that the impacts of blue light exposure obtained with the AD subjects in this experiment were smaller than those obtained in the previous study (Figueiro et al., 2002). This may be because two out of four subjects in the previous study were in much earlier stages of AD and compliance to the light exposure protocol was greater in the earlier study.

Unlike the results obtained in this study, most of the AD subjects were found awake at 06:00 in the Figueiro et al. (2002) study. This suggests that the sleep consolidation obtained in the present study was not as robust as that obtained in the first study. An explanation for this discrepancy may be, as mentioned above, the uncertainty of the light exposure in this study compared to the earlier study. Another reason might be that light exposure in the present study was administered at an earlier time in the evening (i.e., 16:30 to 18:30 instead of 18:00 to 20:00) which might not be as effective to the circadian system.

The observed sleep patterns were also consistent with the anecdotal comments collected from the non-AD subjects. These subjects consistently noted that the blue light, unlike the red light, improved their sleep. Although perhaps obvious, we were careful to explain the expected outcome of the experiment only *after* all data were collected.

In total, the findings from this study again reinforce the inference that exposure to blue light in the early evening can consolidate sleep and increase sleep efficiency. Not only were the present data consistent with the earlier results obtained from AD subjects (Figueiro et al., 2002), but blue light was even more effective for non-AD subjects who had expressed problems with sleeping. These consistencies seem to clearly support the broader inference that light, as it impacts the circadian system, is fundamentally important to consider in the design and operation of senior housing.

Bedroom and bathroom lighting redesign

Although it was obviously impossible to monitor falls in the bedrooms and bathrooms, the results of the survey from both staff and residents indicated a very positive response to the amber LED arrays controlled by motion sensors. The surveys unambiguously showed that staff and residents much preferred the new lighting system to the existing fluorescent system, largely because the new system minimized disruptions to sleep. The new LED lighting systems in the bedrooms not only reduced residents' sleep disturbances, but they also reduced discomfort caused by turning on room lights at night. Its impact on falls will need to be examined in a subsequent study, but the logic of the lighting design in this regard seems compelling.

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