Mariana G. Figueiro, PhD

IF YOU KNOW SOMEONE with Alzheimer's disease (AD), you are probably aware of their relatively random patterns of rest and activity rather than the typical asleep-at-night and awake-during-the-daytime pattern. This aperiodic sleep/wake behavior can be very difficult for their caregivers who themselves want to follow a typical, 24-hour circadian pattern of rest and activity. Indeed, aperiodic sleep/wake behavior together with higher frequencies of disruptive or violent behavior are the most prevalent reasons for moving people with AD from their homes to more controlled living environments.[9]

How can light help consolidate sleep of AD patients? Clinical research has shown that bright white light exposure during the morning (at least 1000 photopic lux at the eye) [1,5,6,7,8] or in the evening[10] can improve nighttime sleep, increase daytime wakefulness, reduce evening agitation behavior and consolidate rest/activity patterns of people with AD. Studies looking into the effects of bright light exposure on rest/activity rhythms of persons with AD have been published as early as 1992[8,10], but in 1997 Eus van Someren published one of the most important papers describing the role of light in consolidating sleep/wake behavior in persons with AD.[12] He was able to show that bright light exposure during the daylight hours (1136 ± 89 lux at the eye from both daylight and fluorescent lighting) and dim light during nighttime hours were able to consolidate the rest/activity rhythms of persons with AD. Since then, a number of other studies have replicated his findings.[1,5,6]

Most recently, preliminary data from a study being conducted in Oregon, is suggesting that, like the study conducted by Eus van Someren, bright white light during the day has positive effects at consolidating sleep in persons with AD. (Eunice Noell-Waggoner, former chair of IESNA's Lighting for the Aged and Partially Sighted Committee is coordinating the project in conjunction with Dr. Philip Sloane from University of North Carolina Chapel Hill.)

What are alternatives to bright white light? As lighting professionals, we are all becoming more aware of the fact that the spectral sensitivity of the circadian system peaks at short wavelengths;[2,11] we like to say the human circadian system is a "blue sky" detector. Data from our laboratory[4] indicates that the strong response to blue light by the circadian system is, in part, the result of the blue versus yellow color opponent channel in the retina. This finding helps explain why blue light by itself is more effective at stimulating the circadian system than the same blue light combined with longer wavelengths to make white light. In terms of *photopic* illuminance, as much as 30 times more white light is needed than blue light to achieve the same circadian response (e.g., nocturnal melatonin suppression), in part because of color opponency.

> These most recent findings reinforce the inference that exposure to blue light in the early evening can consolidate sleep and increase the sleep efficiency in older adults, with or without AD

Integrating the findings from van Someren and colleagues[12] with those from Brainard et al. and Thapan et al., [2,11] we at the Lighting Research Center (LRC) applied blue light treatment to AD patients to see if it would improve sleep efficiency and consolidate their sleep at night.[3] The study was conducted for 30 days in a senior healthcare facility using four individuals diagnosed with mild to moderate levels of dementia. AD residents were exposed to blue light from an array of light emitting diodes (LEDs) (maximum wavelength= 470 nm) for 10 days in two-hour sessions (6:00 to 8:00 pm) just before the usual time they went to their bedrooms for the night. As a control, they were also exposed to light from an array of red light LEDs (maximum wavelength= 630 nm) for 10 days during the same two-hour time. The red-light exposure condition was introduced as a placebo control because narrow-band red light at this illuminance has been shown to be ineffective in activating the circadian system;[2,11] visually, however, it had similar brightness as the blue light. Thus, it was expected that only the blue light condition would be effective for activating the circadian system. Indeed, exposure to blue LEDs significantly increased nighttime sleep efficiency, which was defined in the studies as the amount of sleep during nighttime hours, and seemed to consolidate their sleep during the night, especially between midnight and 4:00 am (**Figure 1A**).

Based on these encouraging results, we went back to the same facility in 2004 and, using very similar protocol, we were able to replicate the findings from the 2002 study with AD subjects. This time, however, we expanded the research to include four residents without AD, all of whom had problems falling asleep at night. AD and non-AD residents were exposed to blue light from an array of blue LEDs (maximum wavelength= 470 nm) for 14 days in two-hour sessions (4:30 to 6:30 pm) (**Figure 2**). Again, as a control, they were also exposed to light from an array of red light LEDs (maximum wavelength= 630 nm) for 14 days during the same two-hour interval.

Consistent with our previous study,[3] AD subjects slept better between midnight and 4:00 am after exposure to blue light than after exposure to red light. Overall, nighttime sleep efficiency was statistically significantly higher after blue light exposure than after red light exposure. AD subjects were found asleep 67 percent of the time after blue-light exposure but only 54 percent of the time after red-light exposure (**Figure 1B**).

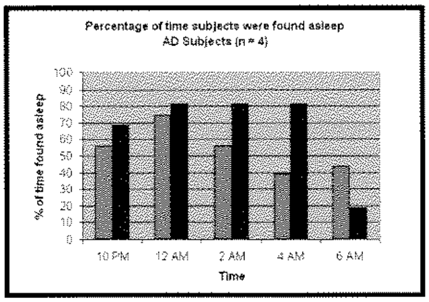

Figure 1A: Percentage of time the AD subjects were found asleep following either red or blue light exposures (approximately 30 photopic lux at the eye). Subjects consistently slept better between midnight and 4:00 am following blue-light exposure than after red-light exposure.[3]

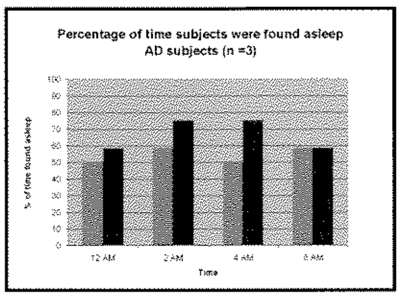

Figure 1B: Percentage of time the AD subjects were found asleep following either red or blue light exposures (30 photopic lux at the eye). Subjects consistently slept better between midnight and 4:00 am following blue-light exposure than after red-light exposure. Note: one AD resident was not able to complete the study for medical reasons.

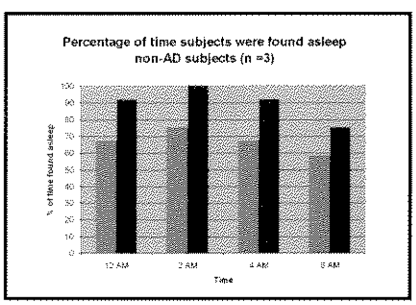

Figure 1C: Percentage of time the non-AD subjects were found asleep following either red or blue light exposures (30 photopic lux at the eye). Subjects consistently slept better between midnight and 6:00 am following blue-light exposure than after red-light exposure. Note: one non-AD resident was not able to complete the study for medical reasons.

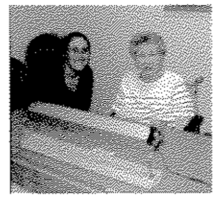

Figure 2: Experimental set up and picture of tabletop luminaire built by the LRC.

Non-AD patients also showed statistically significant more sleep between midnight and 6:00 am after exposure to blue light than after exposure to red light. These non-AD subjects were found asleep 90 percent of the time after blue-light exposure but only 67 percent of the time after red-light exposure (**Figure 1C**).

What could these findings mean to older adults and their caregivers? It was very encouraging to be able to replicate our earlier work[3] and to expand that work to include poorly sleeping non-AD subjects, who also showed strong responses to blue light exposure for increasing sleep consolidation and efficiency. It should also be noted that the observed sleep patterns were consistent with the anecdotal comments collected from the non-AD subjects. Those subjects without dementia 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). Together, these most recent findings reinforce the inference that exposure to blue light in the early evening can consolidate sleep and increase the sleep efficiency in older adults, with or without AD.

These findings also 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. High levels of white light during the day can clearly consolidate sleep at night, but when high levels of white light cannot be incorporated into the space due to energy codes or installation barriers, blue light from portable luminaires may be a better solution, serving as another "layer of light." Indeed, we believe that there is a great potential for manufacturers to develop new, cost-effective products using blue LEDs that will promote and facilitate compliance to blue light treatment.

Ultimately, however, the relative effectiveness of high levels of white light or of dim blue light will depend upon the willingness of older people to comply with one or the other light treatment. The issue of compliance still needs to be resolved with further research. Nevertheless, we strongly urge the lighting community to begin to think in terms of "circadian light per watt" rather than "traditional lumens per watt" if we are to provide the most energy efficient, and healthy, lighting systems in senior facilities.

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