Senior Living Environments: Evidence-Based Lighting Design Strategies

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ABSTRACT

OBJECTIVE: To review from an architectural lighting perspective the effects of indoor lighting on the health and well-being of people in senior living environments.

BACKGROUND: The role of circadian rhythms in people with chronic disorders continues to be a focus of laboratory research and clinical trials. Beneficial, evidence-based indoor lighting design strategies are being considered for senior living environments, particularly for residents who have limited access to natural bright light.

METHODS: Articles published 2002–2012 reporting the results of prospective, randomized, controlled clinical trials (RCTs) were accessed using the U.S. National Library of Medicine PubMed site using the following search terms: "light, sleep, circadian, randomized, controlled, nursing home" and "light, sleep, circadian, randomized, controlled, elderly."

RESULTS: The search resulted in 48 citations, of which 18 meet our pre-search criteria. Data from these RCTs indicate options such as programmable, 24-hour lighting algorithms that may involve light intensity, lighting duration, spectra (wavelength) and lighting timing sequences

CONCLUSIONS: Valid and actionable data are available about circadian rhythms, sleep, and human health and well-being that can inform the design of lighting for long-term care. Evidence-based architectural design of a 24-hour light/dark environment for residents may mitigate symptoms of circadian disruption; evidence-based management of darkness is as important as evidence-based management of light. Further research is needed into the long-term circadian health needs of night staff members in order to understand the effects of shift work while, at the same time providing the highest level of care.

KEYWORDS: Design process, elderly, evidence-based design, lighting, literature review

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About 10,000 years ago, when a more formalized approach to agriculture demanded that the nomadic lifestyle be abandoned in exchange for a stable food supply, people began building permanent shelters. This relatively recent development arguably led to the development of architecture as civilization developed. Given that *Homo sapiens* emerged some 200,000 years ago, the progression from nomad to villager to couch potato happened comparatively quickly, with the greatest lifestyle changes occurring in the last 100 years. The advent of electric lighting in the early 20th century, along with elevators and air conditioning, allowed buildings tall and deep with little natural light to be built. A species previously adapted to hunting and gathering outdoors in bright sunlight now spends most of its time indoors under relatively dim lighting conditions. Scientists studying the effect of light on human health suggest profound effects on our species as a result of this change in lifestyle.

All plants and animals display regular patterns of behavior and physiology that repeat on daily schedule, often called *circadian rhythms.* Humans, for example, are typically awake during the day and asleep at night. Hormones such as melatonin and cortisol are synthesized and suppressed over the course of the 24-hour day and help drive the sleep/wake rhythm. These and other daily rhythms are orchestrated by the suprachiasmatic nuclei (SCN), which is located deep in the brain in the hypothalamus. Commonly referred to as the "human pacemaker," the SCN regulates multiple processes on a schedule that runs close to, but not exactly, 24 hours. The natural light/dark pattern generated by the rotation of the earth resets the pacemaker each day, which keeps us in sync with the natural world as the light/dark pattern changes across the seasons.

When circadian rhythms slide out of sync, serious conditions can result. A short-term example of this occurs when we fly across multiple time zones and the light/dark cycle suddenly changes, throwing our rhythms out of sync with our surroundings. A more serious condition is seasonal affective disorder (SAD), which causes depression, among other symptoms, in those that suffer from it. The lighting environment in many long-term care facilities fails to provide sufficient light and darkness to maintain a stable circadian rhythm. Indoor light levels are typically low, and most residents have little access to bright natural light needed to entrain the pacemaker to the natural light/dark cycle. Lights are often on at night in patient bedrooms and bathrooms, which interfere with vital dark-induced functions such as melatonin secretion. Lacking bright light during the day, and denied darkness at night, circadian disruption can result. Symptoms of disrupted rhythms include:

- Depression
- Napping during the day, wakefulness during the night
- No clear pattern to the wake/sleep cycle day to day
- Experiencing hunger at odd times
- Loss of cognitive ability

Actionable evidence indicates that environmental light and darkness can mediate these symptoms. In order to achieve reliable and robust results, however, it

is necessary to understand how the controllable properties of light affect human physiology. The quantity and spectra of light, together with the duration of exposure and the timing of that exposure all play a role in the effect on humans. Using these controllable properties of light as the framework, we report on a body of evidence from the literature that can be used to inform lighting design. Armed with this knowledge designers can create lighted environments that contribute to the health and well-being of residents and staff.

Circadian rhythm sleep disorders and other chronic insomnia disorders pose both challenges and opportunities in healthcare. Increased light exposure has been shown to improve both circadian rhythms and sleep. Evidence-based indoor lighting design strategies are being considered in a number of settings. The focus of this article is to examine research articles that report on the effect of increased light exposure on sleep and rhythms in senior living environments, in particular residents of long-term care facilities who have limited mobility due to physical and/or cognitive limitations and therefore have limited access to outdoor activities where they would be exposed to natural bright light.

The role of circadian rhythm in healthy individuals and in individuals with a spectrum of chronic clinical disorders possibly associated with altered circadian rhythm physiology continues to be an area of both laboratory investigation and clinical research. Beneficial, non-pharmacological interventions through evidence-based interior lighting design have been identified for treatment of chronic sleep disorders in elderly residents of senior living and long-term care facilities. In this review, the crucial relationship between lighting interventions and clinical responses includes analyses of dose as follows: dose = (intensity + spectrum) × duration. In addition, we examine the effect of prior light exposure on response to a given intervention (photic history).

Methods

The U.S. National Library of Medicine PubMed website (http://www.ncbi.nlm.nih.gov/pubmed) was used to identify relevant, prospective, randomized, controlled, clinical trials published in peer-reviewed journals from 2002 through 2012 (listed as of December 31, 2012). The following search terms were used:

- Light, sleep, circadian, randomized, controlled, nursing home; *and*
- Light, sleep, circadian, randomized, controlled, elderly.

Inclusion criteria included prospective randomized controlled trials (RCTs) that were properly designed, conducted, analyzed, and reported. Exclusion criteria included studies that did not include control groups, or did not randomize participants into study and control groups. We also excluded trials that reported on age groups aged younger than 60. We excluded one study that was terminated early on the basis of interim data analysis that appeared inconclusive.

RCTs may be considered to be the gold standard for evaluating health care interventions because they offer the opportunity to compare two or more healthcare interventions while reducing or eliminating "intervention bias" and "regression

to the mean," both of significant concern when the only control data available for comparative analysis of the health outcomes are limited to baseline data.

For these reasons, this article focuses on how RCTs of indoor lighting algorithms being evaluated as therapeutic interventions can be used to inform the design of architectural lighting. The goal is to create a lighted environment that delivers the needed lighting stimulus as a part of the normal daily routine.

We systematically examined the reported components of the lighting interventions and the reported clinical responses. Specifically, we examined the properties of light intervention (dose, timing, and spectrum) using a chart populated with data from the published articles. The results obtained and the conclusions drawn using similar and contrasting intervention designs were compared. We also considered the knowledge base available at the time of publication.

Results

Forty-eight citations were available with these two searches. Of these, 27 articles did not meet our pre-set criteria (prospective, randomized, controlled studies in elderly populations), and two articles were duplicated (cited in both searches). One article reported on a study that was terminated early, and was excluded from the review. This resulted in 18 articles for evaluation (see Table 1).

Dose

Determination of the dose (intensity and duration) needed to achieve a given clinical outcome requires consideration of multiple factors and is therefore complex. Guidance to successful lighting designs can be found in both the successes and failures of well-planned, validly designed, rigorously executed clinical studies.

Dose can be defined as light intensity plus light spectra multiplied by duration of light exposure.

Dose can be defined as light intensity plus light spectra multiplied by duration of light exposure. The human response to light is dose-dependent, meaning that as the dose increases, the response increases as well. The durations and the intensities of the interventions varied widely in the published articles reviewed here. Brief exposures of 30 to 120 minutes predominated, with intensities of 2500 to 10,000 lux. Studies that employed longer durations often used lower intensities of 250 to 1000 lux. However, exceptions included one study that used just 400 lux of blue light from an LED source (Royer et al., 2012), while another used just 210 lux from a halogen source (Gasio et al., 2003).

Many of these published articles tried various combinations of intensity and duration in an attempt to find a more practical application under the rationale that a brief intervention is more likely to achieve improved compliance. Caregivers may have had insufficient time to devote to new tasks such as supervising subjects in a lighting study. The practical limitations of any intervention in an institutional environment were evident in all of the studies.

TABLE 1. REPORTED SOURCE, INTENSITY, AND DURATION FROM RCTs PUBLISHED 2002–2012

SOURCE (chronological order)	OBJECTIVE	LIGHT SOURCE	INTENSITY (LUX)	DURATION IN MINUTES	TIME OF DAY	NUMBER OF DAYS
1 Ancoli-Israel, S., Martin, J. L., Kripke, D. F., Marler, M., & Klauber, M. R. (2002). Effect of light treatment on sleep and circadian rhythms in demented nursing home patients. *Journal of the American Geriatrics Society, 50*(2), 282–289.	To determine whether fragmented sleep in nursing home patients would improve with increased exposure to bright light.	Brite-Lite box from Apollo Light Systems, Orem, Utah—cool white, full spectrum fluorescent lamps	2500	120	Morning: 9:30–11:00 a.m.	10
		Brite-Lite box from Apollo Light Systems	2500	120	Evening: 5:30–7:30 p.m.	10
2 Fontana Gasio, P., Kräuchi, K., Cajochen, C., Someren, E., Amrhein, I., Pache, M., … Wirz-Justice, A. (2003). Dawn-dusk simulation light therapy of disturbed circadian rest-activity cycles in demented elderly. *Experimental Gerontology, 38*(1), 207–216.	We investigated whether low intensity dawn-dusk simulation (DDS), a "naturalistic" form of light therapy designed to embed sleep in its accustomed phase, could improve the disturbed circadian rest-activity cycle, nocturnal sleep and and/or cognitive functions in dementia.	Halogen lamp	c210	840	Dawn to Dusk	21
3 Ancoli-Israel, S., Gehrman, P., Martin, J. L., Shochat, T., Marler, M., Corey-Bloom, J., & Levi, L. (2003). Increased light exposure consolidates sleep and strengthens circadian rhythms in severe Alzheimer's disease patients. *Behavioral Sleep Medicine, 1*(1), 22–36.	This study examined the effect of light on sleep and circadian activity rhythms in patients with probable or possible Alzheimer's disease.	Brite-Lite box from Apollo Light Systems	2500	120	Morning: 9:30–11:00 a.m.	10
		Brite-Lite box from Apollo Light Systems	2500	120	Evening: 5:30–7:30 p.m.	10
4 Palmer, C. R., Kripke, D. F., Savage Jr., H. C., Cindrich, L. A., Loving, R. T., & Elliott, J. A. (2003). Efficacy of enhanced evening light for advanced sleep phase syndrome. *Behavioral Sleep Medicine, 1*(4), 213–226.	This study tested whether a newly designed enhanced evening light therapy was well tolerated and effective in relieving symptoms of Advanced Sleep Phase Syndrome (ASPS).	Senior's Luminaire™ lighting device, Apollo Light Systems, Orem, Utah. Philips Hi-Vision F32T8/TL841	265	Light on: 120–180; average exposure 145 from actigraphy	Evening	28
5 Pallesen, S., Nordhus, I. H., Skelton, S. H., Bjorvatn, B., & Skjerve, A. (2005). Bright light treatment has limited effect in subjects over 55 years with mild early morning awakening. *Perceptual and Motor Skills, 101*(3), 759–770.	[A]n experimental study to be conducted in a clinical outpatient setting to investigate the effect of 30 min. daily evening exposure to bright white light of 10,000 lux (as against less light for longer duration).	ML-10000 manufactured by Miljclys, Norway. (Philips, Ecotone, PL-L, RA-index = 80, light temperature 4000 K	10,000	30–60	Evening	21

continues…

TABLE 1. REPORTED SOURCE, INTENSITY, AND DURATION FROM RCTs PUBLISHED 2002–2012 *(continued)*

SOURCE (chronological order)	OBJECTIVE	LIGHT SOURCE	INTENSITY (LUX)	DURATION IN MINUTES	TIME OF DAY	NUMBER OF DAYS
6						
Alessi, C. A., Martin, J. L., Webber, A. P., Cynthia Kim, E., Harker, J. O., & Josephson, K. R. (2005). Randomized, controlled trial of a nonpharmacological intervention to improve abnormal sleep/wake patterns in nursing home residents. *Journal of the American Geriatrics Society, 53*(5), 803–810.	The objective of this study was to test a multidimensional, nonpharmacological intervention to improve abnormal sleep/wake patterns in nursing home residents.	Sunlight or Apollo Brite-Lite IV	10,000	30	"generally in the morning"	5 consecutive days
7						
Dowling, G. A., Mastick, J., Hubbard, E. M., Luxenberg, J. S., & Burr, R. L. (2005). Effect of timed bright light treatment for rest-activity disruption in institutionalized patients with Alzheimer's disease. *International Journal of Geriatric Psychiatry, 20*(8), 738–743.	The purpose of this randomized clinical trial was to test the effectiveness of timed bright light therapy in reducing rest-activity (circadian) disruption in institutionalized patients with AD.	Sunlight or Apollo Brite-Lite IV	2500	60	Morning: 9:30–10:30 a.m.	50 out of 70 (M–F, 10 weeks)
		Sunlight or Apollo Brite-Lite IV	2500	60	Afternoon: 3:30–4:30 p.m.	50 out of 70 (M–F, 10 weeks)
8						
Martin, J. L., Marler, M. R., Harker, J. O., Josephson, K. R., & Alessi, C. A. (2007). A Multicomponent nonpharmacological intervention improves activity rhythms among nursing home residents with disrupted sleep/wake patterns. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences, 62*(1), 67–72.	We examined the impact of a multicomponent nonpharmacological intervention on 24-hour rest/activity rhythms among long-stay NH residents.		This article is based on data from Alessi et al., 2005.			
9						
Hickman, S. E., Barrick, A. L., Williams, C. S., Zimmerman, S., Connell, B. R., Preisser, J. S., … Sloane, P. D. (2007). The effect of ambient bright light therapy on depressive symptoms in persons with dementia. *Journal of the American Geriatrics Society, 55*(11), 1817–1824.	To assess the effect of ambient bright light therapy on depressive symptoms in persons with dementia.	GE F54T5HO 6500K noted at NC and assumed for Oregon site. Skylights at Oregon only.	2500	150–180	Morning: 7–11 a.m.	Multiple 3-week periods
			2500	150–180	Evening: 4–8 p.m.	Multiple 3-week periods
			2500	504	All day: 7 a.m.–8 p.m.	Multiple 3-week periods
			2500	504	All day: 7 a.m.–8 p.m.	Multiple 3-week periods

continues…

TABLE 1. REPORTED SOURCE, INTENSITY, AND DURATION FROM RCTs PUBLISHED 2002–2012 *(continued)*

SOURCE (chronological order)	OBJECTIVE	LIGHT SOURCE	INTENSITY (LUX)	DURATION IN MINUTES	TIME OF DAY	NUMBER OF DAYS
10 Sloane, P. D., Williams, C. S., Mitchell, C. M., Preisser, J. S., Wood, W., Barrick, A. L., … Zimmerman, S. (2007). High-intensity environmental light in dementia: Effect on sleep and activity. Journal of the *American Geriatrics Society, 55*(10), 1524–1533.	To determine whether high-intensity ambient light in public areas of long-term care facilities will improve sleeping patterns and circadian rhythms of persons with dementia.	GE F54T5HO 6500K noted at NC and assumed for Oregon site. Skylights at Oregon only.	2500	150-180	Morning: 7–11 a.m.	Multiple 3-week periods
			2500	150–180	Evening: 4–8 p.m.	Multiple 3-week periods
			2500	504	All day: 7 a.m.–8 p.m.	Multiple 3-week periods
			2500	504	All day: 7 a.m.–8 p.m.	Multiple 3-week periods
11 Dowling, G. A., Burr, R. L., Van Someren, E. J. W., Hubbard, E. M., Luxenberg, J. S., Mastick, J., & Cooper, B. A. (2008). Melatonin and bright-light treatment for rest-activity disruption in institutionalized patients with Alzheimer's disease. *Journal of the American Geriatrics Society, 56*(2), 239–246.	Sleeping patterns and circadian rhythms of persons with dementia.	Sunlight outdoors, or indoors though windows or Apollo Brite-Lite IV when sunlight not available	Light Box produced 2,500 lux. Median exposure was 6204 +/– 2,668 lux	60	Morning: 9:30–10:30 a.m.	50 out of 70 (M–F, 10 weeks)
				60	Morning: 9:30–10:30 a.m.	50 out of 70 (M–F, 10 weeks)
12 Riemersma-van der Lek, R. F., Swaab, D. F., Twisk, J., Hol, E. M., Hoogendijk, W. J. G., & Van Someren, E. J. W. (2008). Effect of bright light and melatonin on cognitive and noncognitive function in elderly residents of group care facilities. *Journal of the American Medical Association, 299*(22), 2642–2655.	To determine whether the progression of cognitive and noncognitive symptoms may be ameliorated by individual or combined long-term application of the 2 major synchronizers of the circadian timing system: bright light and melatonin.	Philips fluorescent lamps: TLD840 and TLD940	1000	540	All day: 9 a.m.–6 p.m.	Mean 450 (mean 15 months; max 3.5 yrs)
13 Friedman, L., Spira, A. P., Hernandez, B., Mather, C., Sheikh, J., Ancoli-Israel, S., … Zeitzer, J. M. (2012). Brief morning light treatment for sleep/wake disturbances in older memory-impaired individuals and their caregivers. *Sleep Medicine, 13*(5), 546–549.	To determine whether bright light can improve sleep in older individuals with insomnia.	"SADelite Lamps" Northern Light Technologies, Montreal, Canada, device calibrated to produce 10,000 lux "full-spectrum"	2000 lux or more	45	Starting 15 min. after wake time	84
			2000 lux or more	45	Starting 1 hour before scheduled bedtime	84

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TABLE 1. REPORTED SOURCE, INTENSITY, AND DURATION FROM RCTs PUBLISHED 2002–2012 *(continued)*

SOURCE (chronological order)	OBJECTIVE	LIGHT SOURCE	INTENSITY (LUX)	DURATION IN MINUTES	TIME OF DAY	NUMBER OF DAYS
14 Barrick, A. L., Sloane, P. D., Williams, C. S., Mitchell, C. M., Connell, B. R., Wood, W., … Zimmerman, S. (2010). Impact of ambient bright light on agitation in dementia. *International Journal of Geriatric Psychiatry, 25*(10), 1013–1021.	To evaluate the effect of ambient bright light therapy (BLT) on agitation among institutionalized persons with dementia.		Common intervention with Hickman, 2007; and Sloane, 2007.			
15 Lieverse, R., Van Someren, E. J. W., Nielen, M., Uitdehaag, B. M. J., Smit, J. H., & Hoogendijk, W. J. G. (2011). Bright light treatment in elderly patients with nonseasonal major depressive disorder: A randomized placebo-controlled trial. *Archives of General Psychiatry, 68*(1), 61.	To determine the efficacy of Bright Light Treatment in elderly patients with MDD.	Philips Bright Light Energy HF 3304, with gel filter Model 061; Lee Filters	7500	6	Early morning	21
16 Zeitzer, J. M., Friedman, L., & Yesavage, J. A. (2011). Effectiveness of evening phototherapy for insomnia is reduced by bright daytime light exposure. *Sleep Medicine, 12*(8), 805–807.	To examine the effect of ambulatory daytime light exposure on phase delays and on the advances produced by timed exposure to bright evening or morning light.		This article is based on data from Friedman et al., 2009.			
17 Royer, M., Ballentine, N. H., Eslinger, P. J., Houser, K., Mistrick, R., Behr, R., & Rakos, K. (2012). Light therapy for seniors in long term care. *Journal of the American Medical Directors Association, 13*(2), 100–102.	To investigate the effects of light therapy on cognition, depression, sleep, and circadian rhythms in a general, nonselected population of seniors living in a long-term care facility.	Color Kinetics "Colorgraze" Powercore tuned to 464nm	400	30	30 min. within 9:30 a.m.–10:30 p.m.	20 out of 28 (M–F)
18 Friedman, L., Spira, A. P., Hernandez, B., Mather, C., Sheikh, J., Ancoli-Israel, S., … Zeitzer, J. M. (2012). Brief morning light treatment for sleep/wake disturbances in older memory-impaired individuals and their caregivers. *Sleep Medicine, 13*(5), 546–549.	This study examined the effectiveness of a "user-friendly" phototherapy protocol that would be readily usable in the home environment to treat sleep disruption in older individuals.	Sunbox company, Gaithersburg, Maryland	4200	30	Starting within 30 minutes of rise time.	14

Improvements to the rest/activity rhythm and entrainment of residents in long-term care to a more normal circadian time schedule may benefit both resident and caregiver. The ideal result would be residents that sleep better at night and are more alert and able to participate in life activities during the day. An added benefit to better-entrained residents is that staff can manage their time more effectively and potentially deliver a higher level of care.

Ancoli-Israel et al. (2003) studied the effect of light on residents of a long-term care facility with Alzheimer's disease (AD) in a study design that included a morning bright light group and an evening bright light group. The dose for both groups was 2500 lux for 2 hours delivered from a light box. They reported that both morning bright light and evening bright light consolidated sleep. They also found increased quality of the circadian activity rhythm in the evening group. Using the same dose in an earlier study, the same investigators found that morning light made the circadian rhythm more robust, and delayed the acrophase of the activity rhythm (Ancoli-Israel, Martin, Kripke, Marler, & Klauber, 2002).

Another study using the same commercial treatment device for only an hour, found that the stability of the rest–activity rhythm was improved, but did not find improved sleep (Dowling, Mastick, Hubbard, Luxenberg, & Burr, 2005).

In contrast, a study that included a multidimensional intervention used sunlight or just 30 minutes of artificial light at 10,000 lux, and found a significant decrease in daytime sleeping and that the social and physical activity of the subject increased (Alessi, Martin, Webber, Cynthia Kim, Harker, & Josephson, 2005).

To further define the dose–response relationship, it is important to understand the interaction between light exposure and hormone expression. Both play a role in the synchronization of the circadian system. Two studies used combinations of these treatments to explore potential interactions. Dowling et al. (2008) treated patients with AD using sunlight, or a light-box device that produced 2500 lux when sunlight was not available. The median exposure was measured as 6204 lux +/- 2668 lux. They found that light treatment alone did not result in improvement, but that in combination with melatonin, subject's activity levels and wake time increased and that the rest-activity rhythm was strengthened.

In a long-term study, residents were exposed to 1000 lux from 9:00 a.m. to 6:00 p.m. for as long as 3.5 years (mean 15 months) (Riemersma-van der Lek, Swaab, Twisk, Hol, Hoogendijk, & Van Someren, 2008). Interventions varied across several study groups and included light treatment, the hormone melatonin, or a combination of light and melatonin. They found that all day exposure to bright light improved cognition, mood, behavior, functional abilities and sleep. When used in combination with melatonin further improvements were found, and they increased over time. The design of this study included all day exposure and continued for an extended period, which is far closer to the natural light/dark cycle than many studies.

In a study of patients with non-seasonal major depressive disorder (MDD), researchers used 7500 lux of white light that was applied for an hour in the early morning (Lieverse, Van Someren, Nielen, Uitdehaag, Smit, & Hoogendijk, 2011). They found improvements to mood and sleep, as well as improvements to hormonal activity.

To ensure consistency of the light interventions under study, three articles reported results of an architectural approach to lighting (Hickman et al., 2007; Sloane et al., 2007; Barrick et al., 2010). The studies shared the same intervention at the same locations, which included extensive renovation of the lighting architecture in two facilities. They reported using 2500 lux as the intervention intensity that was delivered as environmental light from an architectural lighting system rather than a treatment device. Treatment groups included morning bright light, evening bright light, and all day bright light. A programmable lighting control system allowed for multiple 3-week interventions at two sites over the course of a 20-month experiment.

Outcome measures reported in three articles included effects on depression, sleep and circadian rhythms, and agitation in elderly patients with dementia. Sloane et al. (2007) found decreased depression in some persons but increased depression in others. Hickman et al. (2007) found a modest improvement in sleep measures. And Barrick et al. (2010) found that agitation was not reduced by light exposure, and that in some persons agitation increased. Given the well-crafted intervention and the promising results of previous studies, the results in this group of articles were somewhat surprising. Analysis of the limitations of these studies provides important clues as to the difficulties encountered in demonstrating results when variables cannot be fully controlled.

When the newly completed installation was commissioned for use, light levels were measured to ensure compliance with the study protocol (Sloane et al., 2005). When the lighting system was adjusted to produce 2500 lux of vertical illuminance (the desired state) staff complained that the lighting was too bright. In response, the meter was held in a horizontal position (parallel to the floor), and the lighting was dimmed to achieve 2500 lux of horizontal illuminance. The quoted light quantities may therefore be overstated. Measurements reported during commissioning suggest that the actual light levels at the eye were on the order of 1250 lux. Furthermore, the reported lighting level of 500 lux selected for the control group was based on industry design standards rather than existing conditions (Sloane et al., 2005). In comparison, a study of lighting conditions in long-term care facilities in California found the mean level to be 54 lux (Shochat, Martin, Marler, & Ancoli-Israel, 2000).

These limitations illustrate the need for fully understanding measurement of light exposure when establishing a dose that reliably results in the desired clinical outcome.

One of the most recently published articles combined an architectural strategy to enhance compliance with a programmable light source to deliver light centered in the action spectrum. Royer et al. (2012) used a unique light source capable of

producing light with programmable spectral content. Using the action spectrum as a guide, a lighting fixture with an LED source was programmed to deliver narrow band colored light—464 nm (blue) as intervention and 628 nm (red) as control. Because the light from the source was targeted near the peak response of the circadian system, the intensity of the intervention was a relatively low 400 lux for a brief period of 30 minutes. They found improved mood and improvements in cognition. This approach may permit a clinically effective dose without some of the issues associated with bright white light, such as excessive brightness, added heat and energy cost.

Timing

It is well understood that the response of the healthy circadian system differs depending on the timing of the stimulus (Lewy et al., 1998). For example, light before body temperature nadir will delay the phase; light after nadir will advance the phase. The optimal time for delivering a lighting intervention depends upon an individual's circadian cycle and relation to a model rhythm that is in sync with the natural light/dark cycle.

The design of most of the articles in this review included a scheduled intervention period of 30 minutes to 3 hours of light in the morning and/or evening. One study used all day bright light (Riemersma-van der Lek et al., 2008). The three studies discussed above that shared a study design had morning, evening, and all-day treatment groups.

Results were quite varied, depending on baseline conditions and study objectives. It should be noted that the terms morning and evening relate to clock time, which may or may not relate to the circadian phase of a given subject. None of the studies assessed the subject's endogenous circadian phase.

Several studies compared the effect of timing on the intervention. The most common effect of time of day was the advance or delay of the acrophase. In a pair of studies examining the effect of bright light on nursing home patients with AD, some differences were found with morning versus evening exposure (Ancoli-Israel et al., 2002, 2003). In the 2002 study, morning light delayed the acrophase and improved activity rhythmicity. In the 2003 study, both morning and evening light resulted in more consolidated sleep at night; and evening light increased the quality of the circadian rhythm. It is important to note that in the morning group of the 2002 study the treatment delayed the phase of every subject. In normal subjects it would be expected that morning light would advance the phase and evening light would delay the phase, based on Lewy's theory of the phase response curve (PRC) (Lewy et al., 1998). (A phase response curve illustrates the time variation in response to a stimulus.) The rhythms of older adults have been shown to be phase advanced relative to younger subjects (Nicolau et al., 1985), which would also shift the timing of the PRC to an earlier timeframe. Although it was morning, the intervention may have occurred during the time when subjects were within the phase delay portion of the PRC.

These results suggest that while scheduled brief exposure to bright light can be a beneficial part of a treatment regimen, it may not be appropriate as part of an architectural approach to lighting design in a facility because results can vary widely depending upon individual rhythms. All-day light exposure may be the preferred design parameter because it most closely resembles the natural light/dark pattern.

One article reported on the effect of morning light or afternoon light in institutionalized patients with AD (Dowling et al., 2005). Differences between treatment groups were not found, but the stability of the rest-activity rhythm improved in both groups compared to the control group.

All-day light exposure may be the preferred design parameter because it most closely resembles the natural light/dark pattern.

Variation was found in morning versus evening versus all day exposures in the three studies mentioned above that shared a common study design (Hickman et al., 2007; Sloane et al., 2007; Barrick et al., 2010). Hickman et al. (2007) assessed the effect of bright light on depressive symptoms and found that morning light benefited some persons, but that others had negative results. Sloane et al. (2007) studied the effect of bright light on sleep and found that morning or all-day light resulted in a modest benefit for nighttime sleep. Barrick et al. (2010) found that agitation was higher in most treatment groups with some variation by site. Agitation was not significantly lower in any treatment group.

Spectrum

It is well-established that the circadian system responds to a relatively narrow range of light and is maximally responsive to light at 480 nm (blue) (Brainard et al., 2001; Thappan, Arendt, & Skene, 2001). This is a function of the intrinsically photosensitive retinal ganglion cell (ipRGC) receptors that respond to light in this range and are connected anatomically to the circadian pacemaker in the brain. A light source must contain significant intensity within the action spectrum to be effective. Recent work has established that the classic receptors (rods and cones) involved in vision also play a limited role in circadian response (Gooley et al., 2010), which is discussed in a later section.

Much of the research into light and circadian rhythms over the last 10 years has referenced the action spectrum in determining the spectra of intervention sources. One study used a unique approach.

Royer et al. (2012), as discussed above, used a unique light source capable of producing light with programmable spectral content. Using the action spectrum as a guide, a lighting fixture with an LED source was programmed to deliver narrow band colored light—464 nm (blue) as intervention and 628 nm (red) as control. This allowed the intensity of the intervention to be a relatively low 400 lux, while providing significant light within the action spectrum. The authors concluded that "Blue light treatment led to significant cognitive improvements compared with placebo red light and may be a promising environmental intervention to reduce cognitive symptoms in elderly, long-term care residents" (p. 100).

Using artificial light to supplement or replace the natural light/dark cycle can be difficult given the enormous intensity of sunlight, and the changing spectral content. The above study demonstrated that the circadian system can be targeted with light in a narrow band width, thus reducing the cost of energy and avoiding unwanted heat from a comparable white light system.

Most light treatment devices reference the established action spectrum in the specification of the fluorescent tubes provided. However, some devices are not as well designed. Palmer et al. (2003) conducted a study of a specific device intended for use in treatment of Advanced Sleep Phase Syndrome (ASPS). Although the light treatment devices were well received by the participants, the results were equivocal. The published spectral power density chart for the lamps used in the device indicates that little light is produced within the action spectrum. The study did not find any significant difference between treatment and control groups.

Gasio et al. (2003) found a response in a study of a dawn-to-dusk simulation (DDS) despite the fact that the chosen light source was halogen, which contains little light in the action spectrum. The study began before the action spectrum was identified, so the investigators could not have known that the spectrum of light was critical to elicit response from the ipRGC receptors. The authors also acknowledged that the intensity of the intervention may have been too low to achieve a clinical response. Despite the limitations they did have "promising" results that included trends towards longer sleep duration and improved rest-activity rhythms. Given the limitations it is perhaps surprising that any improvement was measured over placebo light. It may be that classic photoreceptors are responsible for the results demonstrated in this study.

This means that short duration interventions using white light can elicit response from both ipRGC and cone receptors.

Recently published research in healthy subjects has determined that classic photoreceptors (rods and cones) can play a role in melatonin suppression and circadian phase resetting (Gooley et al., 2010). These data indicate that the cone receptors that stimulate the visual cortex can also affect circadian response and melatonin suppression during the first 90 minutes of light exposure, after which the response declines exponentially. It was also found that the mid-range cone receptors (green) provide circadian stimulus in low light conditions. This means that short duration interventions using white light can elicit response from both ipRGC and cone receptors. It is possible that the results found in Gasio et al. (2003) may have been due to response from the cone receptors during the dawn portion of the dawn-to-dusk simulation.

If this line of reasoning explains the findings in Gasio et al. (2003), why didn't Palmer et al. (2003) achieve clinical results, given that their device also produced white light that would stimulate the cone receptors? The intent of Palmer et al. (2003) was to delay the phase using evening exposure to light, so the intervention took place at the end of the day. Because the cones are involved for a relatively short duration, whatever response the subjects may have had from classic receptors had occurred long before the intervention began. Given that the device did

not produce light in the relevant portion of the spectrum, the ipRGC receptors were not engaged either and results were equivocal.

Photic History

An additional layer of complexity to the lighting algorithm is that photic history, that is, prior light exposure, appears to play a significant role. Two of the articles in the review reported on separate analyses of the same study database. In the first article, Friedman et al. (2009) no difference was found between bright light treatment and placebo dim light. These results appeared to be inconsistent with other previous studies. However, a subsequent analysis of the same data (Zeitzer, Friedman, & Yeasavage, 2011) demonstrated that the results were likely due to an uncontrolled variable. The study design included "sleep hygiene," including daily walks outdoors during the day, which was given to all participants. Two years later Zeitser et al. (2011) reviewed a subset of the same data and found that exposure to daylight (which often exceeds 50,000 lux and can be as much as 100,000 lux) diminished the effect of the evening treatment light of 2000 lux. The effect was not found for morning light. It appears that the circadian pacemaker responds to a range of values, rather than a threshold. Other studies have confirmed that the pacemaker is sensitized by dim light and desensitized by bright light, meaning that recent history of light exposure will affect response (Hebert, Martin, Lee, & Eastman, 2002; Smith, Schoen, & Czeiler, 2004; Chang, Scheer & Czeiler, 2011).

It appears that the circadian pacemaker responds to a range of values, rather than a threshold.

The implications for residents of long-term care facilities that are typically dimly lit are profound. It may be that if your circadian system is sensitized to dim light, it is then subject to phase resetting from ordinary room light, such as an exam light over the bed that is switched on during the night by caregivers. It may be that if this effect is repeated throughout the day the circadian rhythm of the resident is disrupted. This is consistent with observed behavior in long-term care facilities where residents may nap, or be awake and active at any time day or night.

The study by Zietzer and colleagues illustrates two important points:

1. Variables outside the intervention may confound the outcome.
2. Photic history is one such variable.

When the baseline included exposure to daylight during a noontime walk (reported as max 90,650 lux), the effect of 4000 lux of treatment light administered a few hours later was significantly diminished. That the results of Friedman et al. (2009) were confounded by this intervention argues for at least monitoring light exposure across the 24-hour day to ensure that when an intervention is planned prior history is considered.

Discussion

Light entrains the human circadian rhythm, can suppress or stimulate synthesis of hormones and neurotransmitters, and has been shown to reduce stress and relieve depression. Given the extensive amount of time that people in our society spend indoors, it is imperative that we examine our use of light in the built environment to ensure that the lighting environment supports the health and well-being of the occupants. The focus in this article is on the application of evidence from studies of elderly residents in long-term care who are typically not exposed to bright light during the normal course of the day. We considered it important to view these relevant prospective, randomized, controlled clinical trials published in the last 10 years in context. What was known at the time the study was conceived would have affected the study design and the conclusions reached. What we know now allows us to review the previous work from a perspective unavailable at the time the studies were conceived and implemented. It is now possible to incorporate these results into a better understanding of why certain interventions achieved clinical outcomes and others did not.

Given the extensive amount of time that people in our society spend indoors, it is imperative that we examine our use of light in the built environment to ensure that the lighting environment supports the health and well-being of the occupants.

Beginning with the discoveries of the action spectrum and the ipRGC, the direction of research evolved from an investigation of the visual system to a broader understanding that human anatomy and physiology includes a separate circadian system with dedicated light receptors. These ipRGC project directly to the circadian pacemaker, which triggers a cascade of hormones and neurotransmitters that affects and entrains multiple systems in the brain and body.

The articles in this review, along with well-established prior work, suggest a set of lighting parameters that could be called the lighting algorithm. Humans respond differentially to these parameters in ways that are, to an extent, predictable and repeatable. An understanding of this algorithm is fundamental to creating an architectural lighting environment that addresses biological needs in addition to classic requirements for aesthetics and vision.

Design considerations for circadian light include intensity, spectrum, duration, time of day (clock time as well as individual circadian time), and photic history. The effect of these parameters on human biology can be better understood through evaluation of the relevant literature. And the evidence from these studies of light treatment can inform the design of architectural lighting.

Most of the 18 articles reviewed here reported on therapeutic light interventions delivered via a treatment device commonly called a light box. In those studies, the device was typically placed near the subject, who was encouraged to sit in place at a scheduled time of day to receive the desired dose of light. Compliance may have been an issue since study participants required supervision, and therefore the assigned treatments needed to fit within the caregivers existing schedule. The interaction with staff may also have had an effect on the subjects, potentially confounding results. Furthermore, maintaining such a regimen on a long-term basis can become challenging, if not impossible.

However, in the five remaining articles, architectural lighting systems were integrated with the interior environment of the residential facilities (Hickman et al., 2007; Sloane et al., 2007; Barrick et al., 2010; Riemersma-van der Lek et al., 2008; Royer et al., 2012). Under this approach the schedule and light level was programmed into the control system, and all in attendance receive the treatment regardless of diagnosis. This architectural approach ensured both subject compliance and delivery of assigned light therapy. Given that residents of nursing homes will vary within a given population and over time, systems design should be flexible to accommodate changing needs. Moreover, because our understanding of dose (intensity times duration) is imperfect the lighting system should be programmable to allow for tuning the lighting as required to meet changing need and/or revised conditions.

Beginning with the discoveries of the action spectrum and the ipRGC, the direction of research evolved from an investigation of the visual system to a broader understanding that human anatomy and physiology includes a separate circadian system with dedicated light receptors.

In a truly architectural approach, it may make sense to abandon the concept of treatment entirely. Rather than delivering a dose of light at a specific time, we propose that an architectural lighting environment be created that supports the health of the occupants over the 24-hour day. The scope of the designed environment will need to include bedrooms and bathrooms, and all areas that residents and staff spend appreciable time in. The lighted environment would be programmed using the algorithm described above based on criteria such as occupant needs, season of the year and clinical objectives. For each hour of the day, each parameter in the algorithm would be programmed to deliver optimal exposure.

A host of other lighting requirements must be met to support both residents and staff, which will not here be discussed in detail since it is beyond the scope of this article. Of equal importance to designing a 24-hour lighting environment is designing darkness to support occupant's needs at night. Melatonin is key to maintaining entrainment and plays an important role in sleep, healing and other processes. Because this important hormone is only released at night and in darkness, the lighting environment for residents during evening and nighttime hours must be controlled carefully. The lighting algorithm should generally follow the natural light/dark pattern, with reduced light levels during evening hours and, to the extent possible, darkness at night.

The operational requirements of residents and staff demand illumination at night, and those needs do not always align. The nighttime lighted environment should avoid disrupting resident's circadian rhythms while providing illumination for safety.

In a truly architectural approach, it may make sense to abandon the concept of treatment entirely.

The lighting environment should also address staff requirements for nighttime lighting. In order to provide care for residents, staff members must be able to see the resident clearly, which may be in conflict with the resident needs for darkness. Staff members that work at night or on a rotating shift schedule also have health issues related to circadian disruption that will be difficult to address.

Some individuals may also need treatment, which could be delivered with standard or novel means.

Conclusions

Based on this analysis, we concluded that (1) valid and actionable data are available about circadian rhythms, sleep and human health and well-being that can inform the design of lighting for long-term care; (2) evidence-based architectural design of a 24-hour light/dark environment for residents may mitigate symptoms of circadian disruption; (3) evidence-based management of darkness is as important as evidence-based management of light; and (4) further research is needed into the long-term circadian health needs of night staff in order to understand the effects of shift work while, at the same time providing the highest level of care.

Implications for Practice

- Residents in long-term care often suffer from symptoms of circadian disruption including depression, difficulty sleeping, frequent daytime napping, and loss of cognitive ability. Evidence from randomized controlled trials indicates that a regular pattern of light and darkness can mitigate these symptoms by restoring a stable circadian rhythm.
- The authors propose an architectural approach to providing the needed light and darkness, which will require cooperation between administrators, medical directors and facility managers. In order to reach consensus, all must share an understanding of the science, physiology and practical application.

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