Abstract

Objectives: Lighting is one of the environmental factors which can improve patient sleep in healthcare environments. Many research studies have been published on this topic, but due to the high degree of variation in study designs and results, the implications have been difficult to interpret. This review aims to consolidate studies on the impact of bright light exposure on sleep in order to present the most effective lighting conditions and characteristics that can be further applied and researched in future healthcare environments.

Methods: We searched multiple databases for peer-reviewed articles focused on the impact of light on sleep or sleep-related outcomes in healthcare settings. We provided detailed analysis of the direct links between light and sleep, and a more cursory analysis of links between light and sleep-related factors, from 34 articles which met our inclusion criteria.

Results: The current state of the literature includes evidence on how various durations and intensities of morning, mid-day, and evening bright light exposure, as well as whole-day light exposure interventions can improve specific aspects of sleep, as well as sleep-related outcomes. The lighting interventions differed in all attributes (illuminance levels, exposure time, exposure duration, and spectral qualities), but showed promising results in improving patients' sleep.

Conclusions: Higher illuminance levels of short-term morning bright light exposure, up to 2 hours of moderate morning exposures, up to 4 hours of moderate evening exposure, and whole-day low exposures to lower illuminance levels can improve patient sleep outcomes. Based on new findings on the mechanism through which light impacts sleep, future studies should be more specific about the spectral qualities of light sources.

Introduction

Impaired sleep is associated with negative outcomes such as higher risk of death, depression, anxiety, poorer quality of life, decreased memory and concentration, cognitive decline, impaired immune function, mood disorders, greater rates of falls and injuries, and increased healthcare costs (Joshi, 2008; Sloane, Williams, Mitchell, Preisser, Wood, Barrick, Hickman, Gill, Connell, Edinger, & Zimmerman, 2007). The negative consequences of poor sleep are particularly problematic for patients in hospitals and long term care facilities whose health is already compromised. While healthcare facilities are meant to be places to cure and heal patients, they are often not very sleep-friendly, and this can negatively affect patient health and wellness. Review of existing literature shows that many environmental factors, such as light, noise, air quality, and room temperature, as well as the layout and furniture of the room, can affect patient sleep (DuBose & Hadi, 2016). This review focuses specifically on the impact of lighting on sleep outcomes of patients in healthcare settings.

The 24-hour sleep/wake cycle in our body is sustained by an integration of the endogenous pacemaker with a range of exogenous cues, called zeitgebers (Hood, Bruck, & Kennedy, 2004). Light is the most powerful of the zeitgebers influencing the regulation of the endogenous pacemakers and entrainment of human circadian rhythms (Hood et al., 2004; Sloane et al., 2007). Besides rods and cones, a third photoreceptor in the retina, the intrinsically photosensitive retinal ganglion cells (ipRGCs), sends signals directly to the biological clock. The ipRGCs are sensitive to short-wavelength light, and require a greater magnitude of white light to activate the circadian system compared to the level and spectrum required for activating the visual system. The timing and duration of light exposure also significantly affect entrainment of the circadian rhythm (Hanford & Figueiro, 2013).

We systematically reviewed the existing literature to understand how the use of light can improve patient sleep in healthcare settings. The main focus of the paper is on research that explores the impact of light on sleep, but we also discuss research on the effectiveness of light in regulating rest/activity, circadian rhythm, and hormonal changes, which are the mechanisms through which the sleep/wake cycle is regulated. Sleep is the ultimate outcome of interest, but it is a downstream result of internal mechanisms that are influenced, in part, by environmental light.

Aims

The purpose of this study is to consolidate and evaluate the research studies on the effectiveness of lighting interventions on sleep and sleep-related physiological aspects (e.g., circadian or rest-activity rhythm) of patients in healthcare settings. Primary outcomes of interest in the study are direct quantitative measures of sleep (duration, efficiency, timing, consolidation) and secondary outcomes of interest are related to physiological markers closely linked to sleep (e.g., circadian or rest activity rhythm, melatonin, and serotonin). A strong body of literature has linked circadian rhythmicity and secretion of hormones such as melatonin and serotonin to sleep (Mishima, Okawa, Hishikawa, Hozumi, Hori, & Takahashi, 1994; Mishima, Okawa, Shimizu, & Hishikawa, 2001; Okawa, Mishima, Hishikawa, Hozumi, Hori, & Takahashi, 1991; Ursin, 2002). The research suggests that sleep can be improved by more regulated circadian rhythms and an increase in melatonin and serotonin levels. Therefore, the current review also sought studies that evaluated the effect of light interventions on these secondary outcomes of interest (circadian or rest-activity rhythm, melatonin, or serotonin) since they are indicators of potential impact on sleep as well.

This literature review seeks to determine whether sufficient evidence exists to specify optimal lighting conditions to significantly improve patients' sleep in order to establish lighting benchmarks that can be used in future for improving lighting environments of hospitals. It also aims to identify gaps in the existing literature in order to provide clear directions for the future light and sleep studies which can further enrich our understanding of the effectiveness of those benchmarks.

Methodology

We searched *Medline, CINAHL, PsycINFO,* and the *Web of Science* for references in peer-reviewed journals published between January 1990 and April 2016 that pertained to light, illumination, or phototherapy targeting healthcare patient populations with the aim of improving sleep or sleep-related physiological factors (e.g., circadian or rest-activity rhythm, melatonin, or serotonin). In this paper, we use "sleep-related factors" as a term for physiological mechanisms or processes which affect human sleep. The search applied combinations of the various search terms relevant to outcomes of interest such as "outcome assessment," "sleep disorders," "circadian rhythm," "melatonin," "serotonin," "light," "illumination," "phototherapy," "residential facilities" and "hospitals" (Table 1). In addition, we searched for secondary references from acquired papers and review articles.

The following study designs were included throughout the search process: randomized controlled, quasi-randomized controlled, controlled before-and-after, historically controlled, cohort studies, and case-control studies. Excluded throughout the search process were studies that reported neither the original research nor environmental factors of interest (i.e., light, illumination, and phototherapy) in relation to outcomes of interest, studies with duplicate hits, and studies published in languages other than English.

INSERT TABLE 1

Search Outcome

The search strategy produced 988 papers (Table 1). After applying the inclusion and exclusion criteria to the titles and abstracts from the first screening, we excluded 910 articles. We retrieved the full texts of the remaining 78 articles. The second screening of the full texts led to the removal of 50 additional articles. Thus, 962 articles were excluded. By screening the review papers caught through the screening process, 8 more articles were identified and added to the final set (Figure 1). The final set included 34 articles, of which three of them, report on the same study with minor changes in study population and outcomes (Arne. Fetveit & Bjorvatn, 2004; A. Fetveit & Bjorvatn, 2005; Arne Fetveit, Skjerve, & Bjorvatn, 2003).

INSERT FIGURE 1

Data Abstraction and Synthesis

From the final 34 papers, the following data were extracted and inserted into a table including the setting, the population, the mean age, the sample size, lighting intervention or exposure, intervention characteristics, the outcome measure, and the finding (Table 2).

Results

Organization of Heterogeneous Findings

Studies included in our review investigated the impact of light on a variety of patient sleep measures including sleep quality, total sleep time, nocturnal sleep time, diurnal sleep time, nocturnal wake time, awakenings, daytime wake time, sleep efficiency, sleep onset time, sleep disturbances, and daytime sleepiness. In a less detailed manner, we also reviewed and reported studies that investigated the impact of light on sleep-related factors, including rest/activity measures, circadian rhythmicity, and sleep hormones such as melatonin and serotonin .

The timing of lighting interventions applied in these studies fall into several categories such as morning, mid-day, evening, whole-day, and tailored dynamic lighting systems. They also vary immensely in duration of exposure, length of the lighting intervention study, illuminance and spectral qualities. Additionally, there is great variability in the level of detail provided about spectral quality and light source. We reported the the highest level of detail available in the source documents, which in many cases is very limited. To deal with the heterogeneity of these studies, we have organized the findings by the different sleep outcomes, and within this category further grouped the studies by type of lighting intervention. Each section begins with the overall impact and is followed by specific findings (and lighting descriptions) from the articles. A summary of findings is presented in Tables 2; Overall conclusions from the full body of literature are discussed at the end of the review.

Impact of Light on Sleep

Impact of light on sleep quality.

Sleep quality is usually measured through different self-reported questionnaires such as Pittsburgh Sleep Quality Index (PSQI), Richards-Campbell Sleep Questionnaire (RCSQ), General Sleep Disturbance Scale (GSDS), and Sleep Timing and Sleep Quality Sleep Questionnaire (STSQS). Although all of these measurement methods evaluate the quality of sleep on a numerical measure, with higher scores indicating worse sleep, it is not possible to map them onto each other as the questions and scales of the studies vary. The current review identified that 30 minutes of full-spectrum morning bright light (10,000 lux) exposure, and tailored lighting systems (66 to 324 lux, white 9325k CCT) can improve the quality of patient sleep measured by self-reported questionnaires.

Morning bright light exposure can improve sleep quality. Based on the literature review, various types of morning bright light therapies can improve the quality of patients' sleep. Twenty-four older adults in a nursing home were exposed to 30 minutes of 10,000 lux full spectrum light every morning over the course of a month. The mean scores of the PSQI global sleep quality measure decreased from 12.87 (out of a maximum of 21) at the beginning of the intervention to 3.95 after therapy, and were still markedly lower than baseline (4.87) at the one month follow-up ($p<0.001$) (Akyar & Akdemir, 2013). In a study with 30 mothers of low-birth-weight infants staying in a neonatal intensive care unit, those mothers treated with 30-minutes of 8,000 lux blue-green light (wavelengths 470–525 nm) delivered through light visors fixed close to the eye during the first waking hour for 3 weeks reported improved sleep quality measured by General Sleep Disturbance Scale, but this was not significantly different from the results of the control group (Lee, Aycock, & Moloney, 2013).

Tailored dynamic whole-day light systems (6:00 a.m. to 6:00 p.m.) can improve sleep quality. Tailored light systems create a dynamic lighting schema with changing light attributes (illuminance and spectral qualities) throughout the course of a day. Twelve consecutive patients with liver cirrhosis were randomized to either a room with controlled lighting, delivering blue-enriched light in the morning and less intense, red-enriched light in the evening, or to identical rooms with a standard wall-mounted lighting system. There was no significant improvement on any of the sleep quality measures (PSQI, STSQS and sleep diaries); the authors noted that patients had severe circadian rhythm disturbances when the study began and suggested this could possibly limit the opportunity for impact (De Rui, Middleton, Sticca, Gatta, Amodio, Skene, & Montagnese, 2015). On the other hand, another study showed significant improvement in sleep quality of 14 patients with Alzheimer's disease and related dementia using a tailored lighting system. This tailored lighting system delivered moderate light levels from a high correlated color-temperature white light source (9,325 k) for 4 weeks. The lighting system was turned on at the residents' waking time (between 6-8 a.m.) and switched off at 6 p.m. The mean light level at the baseline was 66 lux at the cornea, compared to 324 lux during the intervention. The mean score of global PSQI index was significantly reduced during the intervention compared to baseline (8.7 to 4.1, p=0.01) (M. Figueiro, Plitnick, Lok, Jones, Higgins, Hornick, & Rea, 2014).

Darkening light levels in rooms, as a part of multicomponent intervention, may improve sleep quality. A multifactorial cohort study examined the effect of a sleep protocol intervention with several sleep hygiene measures, including a light control measure, defined as providing darkened light levels in rooms according to patient preference. The intervention group experienced better RCSQ sleep quality (p=0.001) compared to the baseline. However, the difference between the intervention and control group results was not significant (LaReau, Benson, Watcharotone, & Manguba, 2008).

Impact of light on total sleep time (TST).

Total sleep time is the cumulative amount of sleep time in sleep episodes occurring at any time of the day or night (total sleep episodes less the wake time). Based on results of literature review, 2 hours of full-spectrum 3,000-5,000 lux of morning light exposure, constant whole-day (*6:00 a.m. to 9:00 p.m.*) bright light exposure of 1,000 lux, and a tailored dynamic whole-day

(*6:00 a.m. to 10:00 p.m.*) lighting system (324 lux mean light level and CCT of 9,325 K) can increase total sleep time by 30, 10, and 29 minutes respectively.

Morning bright light therapy may increase total sleep time. The effect of morning bright light exposure (3,000-5,000 lux, 9-11 a.m., for 4 weeks) on the sleep of fourteen elderly patients with dementia and sleep disorders at a psychiatric hospital was compared to ten control elderly patients from the general ward of the same hospital. Total sleep time of the elderly patients with dementia was significantly shorter than that of the control group (7.1 vs. 8.2 hours) at baseline and increased significantly to 7.6 hours during the intervention(Mishima et al., 1994). Other studies of morning bright light therapy with shorter durations of light exposure (1 hour of >2,500 lux full-spectrum light for 10 weeks on elderly Alzheimer's patients and 30 minutes of 8,000 lux blue-green or red light for three weeks on mothers of low-birth-weight infants) did not find significant improvements in TST (Glenna A. Dowling, Burr, Van Someren, Hubbard, Luxenberg, Mastick, & Cooper, 2008; Lee et al., 2013).

Evening bright light therapy, as a part of multicomponent intervention, may increase total sleep time. Our review captured only one study on the impact of evening light exposure on total sleep time. This study added evening bright light therapy (2,000-3,000 lux, from 6-10 p.m., delivered through ceiling lights) as part of a multicomponent sleep hygiene program to improve sleep in delirious older adults of a Geriatric Monitoring Unit (GMU). Data from nurse-collected, hourly patient sleep logs showed significant improvements in TST at discharge compared to the baseline period (7.7 hours vs. 7.1 hours, $p<0.01$) (Chong, Tan, Tay, Wong, & Ancoli-Israel, 2013). Authors explained how evening bright light exposure can be beneficial in elderly with advanced sleep phase syndrome based on previous studies. However, because this was a multicomponent intervention it is not clear whether the effect was from evening bright light therapy or results of other interventions in the sleep hygiene program. Another multicomponent study that includes a component of light intervention such as darkening light levels at nights did not observe significant improvements in TST (LaReau et al., 2008).

Tailored dynamic whole-day light systems (6:00 a.m. to 6:00 p.m.) can increase total sleep time. Tailored and whole-day light exposure is a promising intervention for improving TST. In the study mentioned earlier, during four weeks of a tailored lighting system (324 lux mean light level and CCT of 9325 k, from first thing in the morning (6 -8 a.m. to 6 p.m.), the mean total sleep time was significantly longer compared to the baseline (460 minutes vs. 431 minutes, $p=0.03$)(M. Figueiro et al., 2014). The much shorter study (average of 8.5 days) of a full day dynamic lighting system (maximum 500 lux in gaze direction from 6:00 a.m. to 10:30 p.m. ; blue enriched in morning (6,500 K) and red-enriched in afternoon/evening (3,000 K)) did not show significant improvements in total sleep duration for the severely ill cirrhosis patients they studied (De Rui et al., 2015).

Constant whole-day bright light (1,000 lux from 6:00 a.m. to 9:00 p.m.) can increase total sleep time. Another well-randomized and blinded controlled trial explored the effect of long-term (15 months) treatment with daily supplementation of light and/or melatonin on sleep of demented elderly residents of assisted care facilities. The 12 facilities were randomly assigned to one of the two light conditions (whole-day exposure to an average 1,000 lux bright light or to an average 300 lux dim light between 9 a.m. to 6 p.m. and participants were assigned a daily intake of either melatonin or placebo one hour before sleep. Bright light treatment significantly increased sleep duration by 10 minutes (2%) per year ($p=0.04$) (Riemersma-van Der Lek, Swaab, Twisk, Hol, Hoogendijk, & Van Someren, 2008). Melatonin-only treatment even more significantly increased total sleep duration (27 minutes or 6%, $p=0.004$), but the combined treatment (light and melatonin) did not show significant improvements.

Impact of light on nocturnal sleep time.

Another sleep variable of interest is the duration of sleep that occurs during the night. The current review identified that 2 hours of full-spectrum 3,000-5,000 lux and 1 hour of 10,000 lux morning bright light exposure can increase nocturnal sleep time by 1 hour and 1.7 hours, respectively.

Morning bright light therapy can improve nighttime sleep time. A before-and-after study on the effect of 2-hour full-spectrum morning bright light exposure (3,000-5,000 lux, 9-11 a.m., for 4 weeks) on the sleep of elderly patients with dementia showed a significant increase in mean nocturnal sleep time after light therapy compared to baseline (6.7 vs. 5.7 hours) (Mishima et al., 1994). Another randomized controlled trial on demented patients in a chronic care facility found that 1-hour morning exposure of 10,000 lux light for 4 weeks significantly increased nocturnal sleep time (6.4 to 8.1 hours) compared to the control group with exposure to dim light (illuminance levels unspecified) (Lyketsos, Veiel, Baker, & Steele, 1999). A separate series of studies included in this review, however, did not find any significant increase in nocturnal sleep time of Alzheimer's patients in long-term care facilities as a result of 10 weeks of 1 hour of morning light exposure of >2,500 lux (Glenna A. Dowling, Hubbard, Mastick, Luxenberg, Burr, & Van Someren, 2005; G. A. Dowling, Mastick, Hubbard, Luxenberg, & Burr, 2005).

Impact of light on diurnal sleep time.

Daytime sleep has a different structure than nighttime sleep and is not as restorative (Evans & French, 1995). Because daytime sleep may shorten the duration of more restorative night time sleep, light exposure that decreases daytime sleep can help preserve nocturnal sleep.

The current review identified that a 2-hour light exposure of 3,000-5,000 lux and 1-hour morning exposure of >2,500 lux, in conjunction with an evening dose of melatonin, significantly decreased the diurnal sleep duration by 18 and 66 minutes respectively.

Morning bright light therapy can reduce diurnal sleep time. In the aforementioned Mishima et al (1994) study, 2-hour bright light exposure of 3,000-5,000 lux for 4 weeks showed a significant decrease in daytime sleep of demented patients compared to baseline (1 vs. 1.3 hours), in addition to the improvements found in total sleep time and nocturnal sleep time (Mishima et al., 1994). Another randomized controlled trial showed that 1-hour daily morning bright light exposure (9:30-10:30 a.m., >2,500 lux in gaze direction for 10 weeks) plus an evening dose of melatonin, significantly decreased patients' daytime sleep (249 minutes vs. 315 baseline) compared to the control group (150-200 lux), significantly improving the ratio of day/night sleep from 0.7 at baseline to 0.53 post treatment (Glenna A. Dowling et al., 2008). However, it is important to note that the lighting intervention was combined with evening intake of melatonin so it is not possible to attribute the result entirely to the lighting intervention.

Evening bright light therapy may reduce diurnal sleep time. Elderly residents of eight community homes completed a quasi-randomized controlled trial, which assessed the impact of a multicomponent, non-pharmacological protocol on sleep. The protocol included evening bright light exposure (5-8 p.m.) for up to 2 hours of approximately 1,467 lux full-spectrum bright light, in addition to other sleep hygiene strategies. After the intervention was implemented, residents were less frequently observed sleeping during the day (from 22.1 percent of observations at baseline to 13.8 percent during the intervention), ($p<0.001$), but this was not corroborated with the actigraphy data (Ouslander, Connell, Bliwise, Endeshaw, Griffiths, & Schnelle, 2006). Again, since this was a multicomponent intervention it is not certain that the decrease in diurnal sleep was due to the evening bright light therapy.

Impact of light on nocturnal awakenings.

The current review identified that two hours of morning bright light exposure of 6,000-8,000 lux can reduce total nocturnal wake time, early morning awakenings, and wake after sleep onset time. Four hours of mid-day bright light exposure of 2,500 lux can reduce the awake times. Four hours of bright light exposure of 2,000-3,000 lux in the evening, as a part of a multicomponent program, may also reduce the number of awakenings. Whole-day exposure to an average 1,000 lux bright light combined with melatonin treatment may decrease the duration of awakenings.

Morning bright light exposure can reduce the duration of early morning and nighttime awakenings. Two hours of morning bright light exposure (6,000-8,000 lux, between 8-11 a.m., for 2 weeks) was significantly associated with reduced early morning awakening time (0:16 pretreatment to 0:01 during treatment), reduced total nocturnal wake time (3:24 hour pretreatment to 1:40 hour during treatment), and wake after sleep onset time (1:49 pretreatment to 1:23 treatment) of demented patients in nursing homes (Arne. Fetveit & Bjorvatn, 2004; A. Fetveit & Bjorvatn, 2005; Arne Fetveit et al., 2003). Other studies on morning bright light exposures with shorter duration (one hour of light for ten weeks, >2,500 lux) did not show significant changes in number of nighttime awakenings or total time awake at night (Glenna A. Dowling et al., 2005; G. A. Dowling et al., 2005).

Mid-day light exposure can reduce the number of nocturnal awakenings. In a cohort study, 4 hours of mid-day bright light exposure (2,500 lux; 10 a.m.- 12 p.m. and 2-4 p.m. for 4 weeks) significantly decreased mean value of nocturnal awake times in the elderly residents with insomnia compared to the baseline (5.57 times vs. 7.96 times) measured by actigraphy (Mishima et al., 2001). Other studies with afternoon light exposure (>2,500 lux between 3:30-4:30 p.m. for 4 weeks) did not show significant changes in nighttime wake times (G. A. Dowling et al., 2005).

Evening bright light exposure may reduce the number of nocturnal awakenings. Four hours of evening bright light exposure (2,000-3,000 lux; 6-10 p.m.), as a part of a multicomponent program during the full length of patient stay, was significantly associated with fewer number of observed nocturnal awakenings (0.6 versus 0.7; $p < 0.05$) in 228 delirious older adults (Chong et al., 2013).

Limiting light exposure during nighttime may reduce awakenings. In a study of nursing home residents, the number of changes in light levels at night was significantly associated with awakenings. A light change was recorded if there was approximately a 10 lux change in light level (Schnelle, Alessi, Al-Samarrai, Fricker, & Ouslander, 1999). Other multicomponent sleep hygiene protocols with light interventions, such as darkened light level at nights, did not show any significant changes in awakenings (LaReau et al., 2008).

Whole-day light exposure (morning to evening) may reduce the duration of nocturnal awakenings. In the Riemersma-van et el (2008) study mentioned earlier, whole-day exposure to an average 1,000 lux bright light from 9 a.m. to 6 p.m. for the full length of stay, combined with melatonin treatment, reduced the average duration of individual brief nocturnal awakenings by 0.53 minutes per year or a relative 12% (0.85 to 0.21; p=0.01) (Riemersma-van Der Lek et al., 2008).

Impact of light on daytime wake times.

Morning bright light exposure may increase daytime wake time. Morning bright light exposure (4,000 lux; 1-2 hours; between 9:30 to 11:30 a.m.; for the full length of stay) was applied to six elderly demented residents of two nursing homes. During the bright light period, the percentage of wake in daytime significantly increased in three subjects (Koyama, Matsubara, & Nakano, 1999). However, due to the small sample size of the study and inconsistent results, the findings may not be generalizable. Another study on the impact of morning light exposure on daytime wake times did not find any significant results (Glenna A. Dowling et al., 2005).

Impact of light on sleep efficiency.

Sleep efficiency is the ratio of total nocturnal sleep time to the total amount of time spent in bed. The current review identified that two hours of morning bright light exposure (6,000-8,000 lux), a tailored lighting system with bluish-white light (324 lux; morning to evening), and long-term whole-day bright light treatment (1,000 lux, morning to evening), when combined with melatonin intake, can improve sleep efficiency by 12.7%, 4% and 3.46%.

Morning bright light exposure can improve sleep efficiency. Morning bright light exposure has been shown to be very effective in improving sleep efficiency. Two hours of morning bright light exposure (6,000-8,000 lux between 8-11 a.m. for two weeks) improved the sleep efficiency of demented patients in nursing homes. Sleep efficiency remained significantly higher for more than 4 weeks post-treatment (85.6% immediately following treatment vs. 72.9% baseline, p = 0.006; 77.5% 4 weeks after treatment vs. 72.9% baseline, p=0.049) (Arne. Fetveit & Bjorvatn, 2004; A. Fetveit & Bjorvatn, 2005; Arne Fetveit et al., 2003). In the Koyama et al (1999) study of the effects of morning bright light exposure (1-2 hours of 4,000 lux light between 9:30 a.m. and 12 p.m. for the full length of stay) on six demented patients in a nursing home, the percentage of sleep during lights-out (sleep efficiency) significantly increased in three subjects. However, the sample was small and results were not consistent across all 6 participants (Koyama et al., 1999).

Evening light exposure can improve sleep efficiency. A sample of 3 Alzheimer's disease (AD) residents and 3 non-AD residents with sleep complaints participated in a study where they were exposed to 30 lux of blue or red light at the cornea for 2 weeks between 4:30-6:30 p.m. Non-AD subjects were found asleep during the night more often after exposure to blue light compared to when exposed to red light (89.5% of the time versus 67% of the time). A similar trend was observed with the AD patients, but it was not significant (M. G. Figueiro, 2008). This study suggested the effectiveness of narrowband blue light in improving sleep, but the sample was very small and bigger study samples might result in different findings.

Tailored whole-day light systems (morning to evening) may improve total sleep efficiency. In the Figueiro et al (2014) study, a tailored lighting system which delivered moderate levels of bluish-white light (324 lux; between 6-8 a.m. and 6 p.m.) was associated with better sleep efficiency scores during the intervention compared to baseline (84% vs. 80%, p=0.03) (M. Figueiro et al., 2014). Long-term whole-day bright light treatment (1,000 lux, 9 a.m. -6 p.m., for an average of 15 months), combined with melatonin intake, significantly increased sleep efficiency of elderly residents of an assisted care facility by 3.46% (p=0.01) compared to the control condition with dim light (300 lux) (Riemersma-van Der Lek et al., 2008).

Impact of light on sleep onset latency.

Sleep onset latency is the time that it takes to transition from full wakefulness to sleep;

bright morning light has been shown to improve latency.

Morning bright light exposure can improve sleep latency. Morning bright light exposure can shift the sleep onset time earlier and reduce sleep onset latency (the amount of time to fall asleep). In Fetveit's study of 11 demented patients in a nursing home, 2 hours of morning bright light exposure (6,000-8,000 lux, between 8 and 11 a.m. for 2 weeks) was associated with a significant reduction of one hour in sleep onset latency (01:17 pretreatment to 00:17 treatment) (A. Fetveit & Bjorvatn, 2005; Arne Fetveit et al., 2003). Another study also found that sleep onset latency remained significantly reduced up to 12 weeks post-treatment (Arne. Fetveit & Bjorvatn, 2004). In the Koyama et al study of effects of morning bright light exposure (1-2 hours of 4,000 lux light between 9:30 a.m.– 12 p.m.) with six demented patients, sleep onset advanced to earlier in the evening in three subjects during the bright light treatment period, but the sample was small and results were not consistent across all 6 participants (Koyama et al., 1999).

Impact of light on sleep disturbances.

The current review identified that 2 hours of evening light exposure of 1,500-2,000 lux can reduce clinical rating of sleep disturbances.

Morning bright light exposure may reduce sleep disturbances. A recent study examined the impact of morning bright light therapy (30 minutes of 10,000 lux, 9:30-10:00 a.m., 3 times per week for a 4-week period) on sleep disruptions of 32 elderly residents of a long-term care facility. There was no significant difference between mean scores of sleep disruptions between the intervention and the control group (Wu, Sung, Lee, & Smith, 2015).

Evening bright light exposure can reduce sleep disturbances. Evening bright light therapy has been shown to improve the rest-activity rhythm of inpatients with Alzheimer's disease and disturbed sleep. In this before-and-after study, ten patients were exposed to 2 hours of evening (7:00 - 9:00 p.m.) bright light (1,500-2,000 lux) for a week. The mean score of sleep-wakefulness disturbances of all patients, as rated by nurses, decreased from 6.2 at baseline to 3.0 during the treatment and 2.3 post-treatment ($p < 0.05$) (Satlin, Volicer, Ross, Herz, & Campbell, 1992).

Impact of light on daytime sleepiness.

Morning bright light exposure can reduce daytime sleepiness. Ten elderly patients with sleep disturbances were studied before and after exposure to approximately 8,000 lux bright light for 1 hour during their lunch time (11:30 a.m. to 12:30 p.m.) over 3 weeks. Three weeks before the study and 3 weeks after the study, subjects had their lunch under approximately 1,000 lux light exposure. During the light exposure, nurse-rated drowsiness in the afternoon decreased significantly (from 1.5 baseline to 1.3 after exposure on a 0-4 scale; $p=0.01$) (Kobayashi, Fukuda, Kohsaka, Sasamoto, Sakakibara, Koyama, Nakamura, & Koyama, 2001). Other lighting solutions such as dynamic whole-day lighting systems and shorter light durations (30 minutes of morning bluish bright light exposure of 400 lux for 4 weeks) did not improve self-reported daytime sleepiness measures (De Rui et al., 2015; Royer, Ballentine, Eslinger, Houser, Mistrick, Behr, & Rakos, 2012).

Impact of Light on Sleep-related Physiological Markers

Although our review focuses primarily on studies which reported improvements in sleep measures by light, it also includes studies which have measured changes in sleep-related factors, such as rest/activity measures, circadian rhythmicity, and sleep hormones in association with light. Detailed analysis of the connections between these sleep-related factors and direct sleep outcomes is not in the scope of this paper, but we summarize here the lighting interventions which demonstrate significant impacts on any of these factors. A more detailed summary of these studies is listed in table 3. The rest/activity rhythm and circadian measures explained here are nighttime activity level, mean activity level during the 10 most active hours (M10), mean activity level (mesor), resonance between light–dark and rest–activity patterns across 24 hours (phasor magnitude), time of the peak activity (acrophase), difference between activity peaks and troughs (amplitude), number and duration of sleep bouts, fragmentation of rest-activity rhythm (intra-daily variability or IV), stability of the rest-activity rhythm (inter-daily stability or IS), the rest/activity rhythm α parameter (relative width of peak and trough), and rhythmicity of the circadian rhythm. Hormonal changes related to sleep are also measured.

Morning light exposure.

Two hours of morning bright light therapy of 6,000-8,000 lux significantly reduced the mean value of nighttime activity and mean value of mesor compared to pretreatment levels in dementia patients (A. Fetveit & Bjorvatn, 2005; Arne Fetveit et al., 2003). Another 2 hour morning bright light intervention on dementia patients using 5,000-8,000 lux also showed significant reduction in nighttime activity counts per day, as well as a reduction of the ratio of nighttime activity to total activity, compared to the pretreatment period and the dim light control condition (300 lux) for patients with vascular dementia (Mishima, Hishikawa, & Okawa, 1998). Morning light exposure of shorter duration (one hour, >2,500 lux), combined with melatonin intake, also significantly increased M10 in Alzheimer’s patients compared to baseline. It also significantly increased the amplitude of the rest–activity rhythm, compared to the morning bright light plus placebo and control groups with usual indoor light. In addition, nonparametric measure of amplitude also significantly improved for the light and melatonin group compared to the light and placebo group. Rest-activity rhythm, indicated by an improvement in the goodness of fit (R2) of the data to a traditional cosinor model, also improved significantly when compared to the control group (Glenna A. Dowling et al., 2008). Another study with 2 hour bright light exposure on demented patients (2,500 lux) showed that increased exposure to morning bright light was significantly associated with an increased mean activity level and a delayed acrophase from baseline to treatment (Ancoli-Israel, Martin, Kripke, Marler, & Klauber, 2002). On the contrary, acrophase was significantly advanced by 45 minutes of morning bright exposure of 5,000-8,000 lux in demented patients (Skjerve, Holsten, Aarsland, Bjorvatn, Nygaard, & Johansen, 2004). It was also significantly advanced by morning bright light exposure (1-2 hours; 2,500 lux) in another group of demented patients (Sloane et al., 2007).

Evening light exposure.

Evening exposure to bright light (2,500 lux) for 1-2 hours produced a significant phase delay in acrophase for patients with dementia (Sloane et al., 2007). It also significantly increased amplitude of the rhythm, decreased the mean score of intra-daily variability, and decreased the mean percent of nocturnal activity in Alzheimer’s patients where they were exposed to 1,500-2,000 lux for 2 hours (Satlin et al., 1992). In another study on Alzheimer’s patients, 2 hours of 2,500 lux evening light exposure improved the rhythmicity of the circadian rhythm, measured by the increase of the F statistic of the fit of the 5-parameter model (Ancoli-Israel, Gehrman, Martin, Shochat, Marler, Corey-Bloom, & Levi, 2003). Longer duration of evening light exposure (4 hours 2,000-3,000 lux) significantly increased length of the first sleep bout and number of sleep bouts at discharge in patients with delirium (Chong et al., 2013).

Mid-day light exposure.

Exposure to 4 hours of bright light (2,500 lux) in two sessions (morning and afternoon) significantly increased mean value of melatonin parameters AMP (the difference between peak and low values) and ACUn (total melatonin level measured from 4 hours before to 8 hours after bedtime) in elderly residents with insomnia compared to the baseline (Mishima et al., 2001).

Whole-day light exposure: Long-term daily treatment with morning to evening bright light (1,000 lux), combined with melatonin intake, significantly improved nocturnal restlessness (minutes per hour containing any activity during the most restful 5 hour period of the average 24-hour pattern) in elderly residents (Riemersma-van Der Lek et al., 2008). Another multicomponent intervention exposed participants to >20,000 lux of direct sunlight for at least 30 minutes between the hours of 9 a.m. and 5 p.m., shifted the timing of the mesor significantly earlier and changed the α parameter of the rest/activity rhythm in elderly residents from baseline to follow-up compared to the control group when controlling for age and disease severity (Martin, Marler, Harker, Josephson, & Alessi, 2007). Exposure to a tailored lighting system which delivered moderate light levels (324 lux) and was illuminated between waking time and evening changed the phasor magnitude significantly between baseline and treatment in Alzheimer's patients (M. Figueiro et al., 2014). Another study with whole-day bright light exposure (1,136 lux) on Alzheimer's patients also showed significantly lowered intra-daily variability and increased inter-daily stability (Van Someren, Kessler, Mirmiran, & Swaab, 1997).

INSERT TABLE 2

Various Light Exposure Conditions Associated with Significant Sleep Uutcomes

The result of our analysis shows that, out of 34 studies under review, 14 studies investigated the impact of light on sleep outcomes, 10 studies on sleep-related outcomes, and 10 studies on both sleep and sleep-related outcomes. Among 24 studies on sleep outcomes, 16 studies were associated with statistically significant results. For 20 studies on sleep-related outcomes, 13 studies showed statistically significant results. Figure 2 illustrates an overview of illumance (lux) and the time/duration of exposure of the lighting interventions of the 16 studies that showed significant results in sleep outcomes. Since one study (Schnelle et al., 1999) did not specify illuminance and timing/duration of light at all, it was excluded from Figure 2. Figure 3 illustrates the overview of the lighting interventions of the 13 studies that showed significant results in sleep-related outcomes. Eight studies appear on both figures since they reported significant findings on sleep and sleep-related outcomes. In studies comparing outcomes between lighting intervention and control groups, we considered the impact of lighting intervention significant if the outcomes were significantly different between the intervention and control groups.

By charting the illuminance level and timing of all the interventions which were found to have positive impact on sleep, we can draw some overall conclusions. Studies using higher illuminance levels had an impact despite shorter light exposure durations in comparison with the studies using lower illuminance levels. Light conditions (1, 10 in Figure 2) with high illuminance levels (≥10,000 lux) were effective even with short-term exposure (30 to 60 minutes), light conditions (4, 5, 6, 9, 11) with medium illuminance levels (3,000-10,000 lux) were effective with relatively longer exposure (1-2 hours). Lighting conditions (2, 3, 7, 8, 12, 13, 14, 16) with lower illuminance levels (≤ 3,000 lux) tended to have even longer exposure (1 to 4 hours or whole-day). It seems that the appropriate duration of light exposure depends on the illumination level to be effective in sleep outcomes.

For those with significant results in sleep measures, as shown in Figure 2, the timing of light exposure also varied. Our analysis shows that, out of those significant 16 studies on sleep measures, patients were exposed to light during morning in nine studies (1, 3, 4, 5, 6, 9, 10, 11, 16a), during the afternoon (4pm to 8pm) in one study (7), during both morning and afternoon in one study (12), during evening in three studies (2, 14, 16b), and over the cross of the whole-day in three studies (8, 13, 16c). Although a majority of studies with significant results (9 of 16 studies) implemented morning light, there is evidence from the other studies that this is not the only time of day when light exposure can improve sleep.

For lighting interventions that improved sleep-related outcomes, the same relations between duration of light exposure and illuminance levels can be observed (Figure 3). However, studies included in this review did not find significant improvements on sleep-related outcomes by short-term exposures to higher levels of illuminance (≥10,000 lux).

Illuminance and spectral qualities are important attributes of lighting environments, which not only determine the visual experience of patients but also impact circadian rhythmicity and therefore patients' sleep, yet most of the articles did not provide detailed information about the lighting intervention's spectra qualities. Out of the whole pool of studies evaluated, only one article provided the spectral power distribution of the lighting (M. Figueiro et al., 2014), 2 articles provided the peak wavelength of the lighting (Lee et al., 2013; Royer et al., 2012) 4 articles provided the color temperature, 10 articles provide miminal information such as full-spectrum, white, or cool white and the remaining 18 articles either provided no information at all about the quality of the lighting. Future studies in lighting need to clearly identify and present light's spectral qualities under investigation in publication and to consider its effect during study. With the efforts, future research will help us identify appropriate spectural qualities of light that can improve sleep and sleep-related outcomes. Another important aspect of lighting studies was the duration of the study, which varied from as short as 5 days to long-term covering the full length of patient stay. The majority of studies included in this review took place in nursing homes or long-term care facilities which facilitate such longer-term studies.

INSERT FIGURE 2

Discussion

Patient sleep in healthcare environments is easily disrupted. Based on results of the literature review, light interventions in healthcare settings can improve subjective measures of sleep quality, increase total sleep time by 10 to 36 minutes, increase nocturnal sleep time by 1 to 1.7 hours, decrease the duration of daytime sleep by 18 to 66 minutes, decrease the number and duration of awakenings, increase sleep efficiency by 3.46% to 12.7%, reduce sleep onset latency by 1 hour, decrease sleep disturbances by 3.2 times and decrease afternoon sleepiness. These myriad improvements in patient sleep outcomes by lighting interventions emphasize the importance of lighting systems in healthcare environments, yet the inconsistency of findings points to the need for further investigation of these systems.

A combination of different aspects of lighting such as timing of exposure (morning, mid-day, evening), duration of exposure (30 minutes to whole-day), illuminance (324 to higher than 10,000 lux) and spectural qualities determined effectiveness of lighting interventions in the reviewed studies. Short-term exposure (30 to 60 minutes) of high illuminance levels (≥10,000 lux), relatively long-term exposure (1-2 hours) of medium illuminance levels (3,000-10,000 lux) and long-term exposure (1 to 4 hours or whole-day) to lower illuminance (≤ 3,000 lux), all can improve measures of patient sleep.

The evidence surrounding the impact of light on sleep-related factors is unequivocally positive, pointing to the high potential for effectively impacting the outcome of sleep which is exceedingly meaningful to the patient experience. Although our literature review confirmed the effectiveness of light for improving patients' sleep outcomes, the lack of consistent measurements and outcomes throughout the reviewed studies makes it difficult to compare different lighting conditions and evaluate their relative effectiveness. In our review, we were able to identify and highlight a range of effective lighting conditions that can improve patients sleep. However, there is a broad heterogeneity regarding characteristics of subjects, settings, and care conditions associated with each effective light condition and also a broad diversity regarding sleep variables, measurement methods and tools. Although this diversity does not allow us to make specific recommendations about the best possible lighting option to improve patient sleep in hospitals, the finding of our literature review enables us to present a set of effective lighting conditions that can be implemented in developing alternative lighting systems and be tested through rigorous studies.

The majority of the studies that investigated the direct impact of light on sleep measures in healthcare facilities are focused on elderly patients. Only one of the 34 studies in our sample looked at non-elderly patients (mothers of low-weight infants in NICU; average age 26.6 years) (Lee et al., 2013). Many of these studies (19 out of our sample of 34 studies) have been done on sample groups of elderly patients who suffer from Alzheimer's disease or related dementia. Aging itself is associated with sleep disturbances, and neurodegenerative diseases such as Alzheimer's intensify sleep problems. The current literature review revealed that although this population may make a suitable target for sleep studies, the unique aspects of this population make it difficult to generalize the findings to other populations, such as healthier young patients in a hospital inpatient unit. More studies are needed to test the impact of lighting exposure in a hospital environment on improving sleep of younger adults, as well as cognitively intact older adults.

The mechanism for delivering the lighting interventions in the studies in this review include natural light exposure, light box, florescent lamps, LED luminaires, and light visors. Twelve studies of the 34 studies delivered light through light boxes located in the middle of the rooms. Other solutions included wall-mounted, ceiling-mounted, or desktop lights. Light boxes are more prevalent in lighting intervention studies, compared with more permanent architectural light fixtures such as wall or ceiling-mounted light sources. Temporarily installing ceiling- or wall-mounted lighting interventions in healthcare settings is not an easy task because it requires changing the patient room environment and replacing the existing electrical equipment, which can be time-consuming, costly, and disruptive of common care routines. However, overhead lighting, enhance the quality of the lighting studies through creating a more realistic lighting environment in the study setting and therefore, provides better opportunities for translating the study findings to real-world lighting solutions. For this matter, future lighting studies should consider using lighting apparatus which are more typical of a healthcare settings rather than light boxes.

Another common aspect of studies included in this literature review was the long intervention period, often lasting for several weeks. The study duration varied from one week to 5 years. This may confirm the suitability of implementing lighting interventions for improving sleep outcome for patients in long-term healthcare settings. It does not, however, include interventional studies with lighting interventions for shorter than a week, which is a more typical length of stay for patients in inpatient units. Patients in acute care units are critically ill and more susceptible to the unfavorable atmosphere in hospitals. They have shorter lengths of stay during which a lighting intervention could be employed since they often transfer from one unit to another, depending on their acute conditions. Acute care patients have more frequent sleep deprivation and sleep disruption compared to patients on a general ward (BaHammam, 2006; Chan, Spieth, Quinn, Parotto, Zhang, & Slutsky, 2012). Even if patients spend only 3 nights in a unit, the daily exposure of light could possibly impact their nighttime sleep, yet the current state of knowledge about the impact of light on patients' sleep in hospitals does not extend to lighting interventions for short stay patients. Future research should investigate the potential to improve patient sleep in acute care settings through lighting interventions.

Research into the biological mechanism through which light impacts sleep has advanced over the last decade and helps to connect the relevance of the research on sleep-related factors to sleep itself. Advances in understanding light and lighting technology have expanded our ability to both produce a great variety of lighting solutions and measure various aspects of that lighting. Most of the studies identified by this review do not provide sufficient detail about the lighting sources employed to understand their mechanisms for action and why they did or did not produce significant impacts. To be most helpful to the science of light and sleep, future studies should document the qualities of the lighting that are most important for influencing the sleep-wake rhythms, such as the spectral qualities and level of light that hits the cornea, as opposed to merely the ambient overall lighting levels (M. Figueiro et al., 2014; M. S. Rea, Bierman, Figueiro, & Bullough, 2008; Mark S. Rea, Figueiro, Bierman, & Bullough, 2010). We will certainly learn more over time about how light works and how it affects sleep through the brain, and capturing these important details about lighting interventions will allow researchers to interpret studies based on emerging science. Most importantly, by discovering the right combination of lighting factors that are most effective at supporting good patient sleep conditions we can translate these findings into clear recommendations for designing healthcare environments.

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None

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