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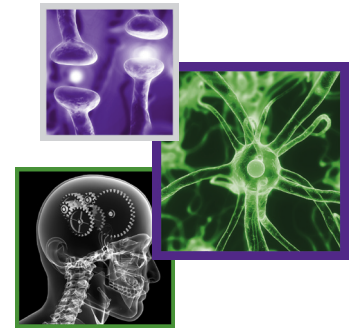
Neurodegenerative Disease Management



# Light, sleep and circadian rhythms in older adults with Alzheimer's disease and related dementias

Mariana G Figueiro

**Practice points**

- Light–dark patterns reaching the back of the eye set the timing of our biological clock, and synchronize us with the local time on Earth. Lack of synchrony, or circadian disruption, can lead to sleep disturbances, depression and anxiety, among other maladies.
- Older adults, including those with Alzheimer's disease and related dementias (ADRD), may exhibit reduced neuronal activity in the biological clock that governs circadian rhythms, along with reduced light reaching the back of the eye due to physiological changes in the aging eye.
- Lighting characteristics that are required to affect the circadian system are different from those that affect vision. The circadian system is a 'blue sky' detector and needs higher amounts of light than those required for visibility.
- Circadian sleep disorder leads to fragmented rest–activity patterns, resulting in more frequent naps during the daytime and reduced consolidated sleep at night, increased irritability and increased depressive symptoms.
- Older adults typically receive dim, constant light during waking hours. Light therapy, delivering high circadian stimulation during the day (circadian stimulus >0.3 or >400 lux at the eye of a bluish-white light) and low circadian stimulation during the evening (circadian stimulus <0.1 or <50 lux at the eye of a yellowish-white light), can help to deliver a robust light–dark pattern to residents. At a minimum, provide high light levels (e.g., sit residents outdoors or by windows) for at least 2 h in the morning to increase circadian stimulation in the morning. Residents should sleep in darkness, but nightlights delivering low, warm color lights, should be used to assist in navigation to the bathroom.
- Add new lighting delivering high circadian stimulation to spaces where residents spend the day, usually common or dining areas.

Alzheimer's disease and related dementias (ADRD) can cause sleep and behavioral problems that are problematic for ADRD patients and their family caregivers. Light therapy has shown promise as a nonpharmacological treatment, and preliminary studies demonstrate that timed light exposure can consolidate and improve nighttime sleep efficiency, increase daytime wakefulness and reduce evening agitation without the adverse effects of pharmacological solutions. Compliance with light treatment and the accurate measurement of light exposures during treatment, however, have presented barriers for the adoption of light therapy for ADRD. Recent research showing that the circadian system is maximally sensitive to short-wavelength light opens the way for the potential application of lower, more-targeted light intensities to maximize compliance and individualize light dose/timing in therapeutic settings.

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**KEYWORDS**
• ADRD • Alzheimer's disease • circadian rhythms • dementia •light • lighting • older adults • sleep

Light is not just for vision. Light reaching the retina contributes not only to visual perception but also to nonvisual responses, such as the resetting of the biological clock. Humans have a biological clock located in the suprachiasmatic nuclei (SCN) that generates and regulates circadian rhythms, which are biological rhythms that repeat themselves approximately every 24 h. These include cycles such as sleep–wake, body temperature, hormone production and alertness. The daily light–dark pattern reaching the retina is the main input to synchronize the biological clock to the solar day. If humans are not exposed to a sufficient amount of light of the right spectrum, for a sufficient amount of time, and with the right timing, the biological clock becomes desynchronized with the solar day and humans may experience decrements in physiological functions, neurobehavioral performance and sleep [1–4].

A person is more likely to experience a good night of sleep when the circadian and homeostatic systems, both of which influence the sleep–wake cycle, are aligned. Sleep pressure increases with time awake, contributing to high sleep need at night. The circadian system sends an alerting signal to the body during the day, counteracting the increase of sleep pressure with time awake and a sleeping signal during the night, promoting a consolidated night of sleep. The circadian clock consolidates sleep and wake periods in part by driving two 'gating' zones: the wake maintenance zone, which occurs approximately 2–3 h prior to habitual sleep onset, and the sleep maintenance zone, which occurs approximately 2–3 h prior to habitual wake onset, close to the minimum core body temperature [5,6].

Another very well-known circadian rhythm is the cycle of melatonin production. Melatonin is a hormone produced by the pineal gland at night and under conditions of darkness. For diurnal species, such as humans, melatonin signals that it is time to sleep [7]. The timing of melatonin onset in the evening, referred to as dim light melatonin onset (DLMO), occurs approximately 2 h prior to natural bedtimes, and is used as a marker of the circadian clock [8].

## Lighting characteristics affecting the circadian system

Lighting characteristics affecting the circadian system, as measured by acute melatonin suppression and phase shifting of DLMO, are different than those affecting visibility. Rods, cones and the intrinsically photosensitive retinal ganglion cells participate in circadian phototransduction, which is how the retina converts light signals into neural signals for the biological clock [9]. It is now known that lower levels of light, less than those originally demonstrated in the 1980s, can acutely suppress nighttime melatonin production and affect the timing of melatonin onset and offset; however, light levels needed to affect melatonin are still higher than those needed to affect vision [10,11]. For example, a warm color (correlated color temperature of 2700 K or lower) nightlight delivering 1 lux at the cornea will allow one to safely navigate in a space at night, but it will not suppress the hormone melatonin [11,12]. Humans are 'blue sky detectors'; the peak sensitivity for acute melatonin suppression and phase shifting of DLMO is close to 460 nm [13–15].

The effects of light on the circadian system vary over the course of the 24-h day. Morning light, given after the trough of core body temperature that typically occurs in the second half of the night, will advance the timing of sleep in the following cycle, while evening light, given prior to the trough of core body temperature, will delay the timing of sleep [8].

Photic history, or the amount of light received during the previous day, determines the effectiveness of light on acute melatonin suppression and on the phase shifting of the timing of DLMO [16–18]. For maximum results of light therapy, it is also important to accurately measure light exposures over the 24-h day, as opposed to taking just a 'snapshot' measurement of light exposure at one certain place and time [19,20]. The circadian system seems to keep track of light exposure, and therefore, knowing an individual's light exposure history over the past 24 h can help determine the best light prescription for the next 24 h [20].

## Sleep & circadian disruption in normal aging & ADRD patients

Between 40 and 70% of older adults suffer from sleep disturbances or disorders, which are especially prevalent among Alzheimer's disease and related dementias (ADRD) patients [21]. Older adults, in particular, those with ADRD, may exhibit reduced neuronal activity in the SCN, where the biological clock that governs circadian rhythms is located, along with reduced circadian rhythm amplitude due in part to the fact that at a molecular level, the SCN becomes

less responsive to light for entrainment [22]. It has been demonstrated that fractal activity patterns, which are robust in healthy physiological systems, are governed by the SCN and are significantly altered in those with dementia [23,24]. Additionally, when discussing the effects of light on the aging population, it is important to keep in mind that the first stage of phototransduction, when light signals are converted into neural signals, is negatively affected in this population: older adults have reduced optical transmission at short wavelengths [25,26]. Less light reaches the back of the eye due to lens thickening, and reduced light on the retina allows circadian rhythms to get out of sync [21,27]. In addition to less light reaching the back of the eye, efferent signals from the retina to the biological clock can also be reduced. For example, glaucoma has been associated with the degenerative loss of intrinsically photosensitive retinal ganglion cells, which is the main conduit of light signals from the retina to the SCN [28]. There are indications that those suffering from glaucoma with severe visual field defect, a condition whose incidence is associated with advancing age, suffer from higher rates of sleep disturbances, anxiety and depression [29]. Moreover, older adults, especially those with ADRD, typically lead a more sedentary indoor lifestyle, with less access to bright light during the day, potentially increasing the risk for circadian disruption [30–32]. Without exposure to a regular, daily pattern of light and dark, circadian rhythms can become irregular [33]. Circadian misalignment resulting from irregular light–dark patterns or from age-dependent changes in light sensitivity or in the circadian system response likely plays a role in poor sleep [27]. When the circadian system is disturbed, it can lead to poor sleep quality in older adults, even if they have no other significant health issues [34]. While sleep and circadian rhythms are closely related, disruption of sleep can occur independently of circadian rhythms disruptions. Light therapy may not be as effective, if effective at all, in treating these non-circadian sleep disturbances.

ADRD is the most common type of dementia diagnosed in older Americans. While individuals with ADRD can have similar sleep problems as healthy older adults, they tend to exhibit more random patterns of rest and activity rather than the consolidated patterns of healthy, older adults [35]. This lack of rest–activity pattern consolidation, along with related nocturnal wandering, is one of the main reasons why individuals with ADRD are transitioned from the home to more controlled environments.

In 2012 Figueiro *et al.* quantified circadian light exposure and activity levels of healthy older adults compared with older adults with ADRD during summer and winter months [36]. Circadian light exposures were measured using the Daysimeter, a calibrated, personal meter. Details about the operation of the Daysimeter are described elsewhere [19], but this device was designed to specifically measure light as it affects the circadian system. Each of the 16 healthy older adults and 21 ADRD patients wore a wrist Daysimeter [19] to measure light and activity levels for 1 week. Results of the quantitative study show that individuals with ADRD experienced lower circadian light levels, exhibited lower activity levels and had greater disruption to their rest–activity patterns than healthy older adults. The findings also show that people with ADRD experience lower levels of circadian light exposure and greater levels of rest–activity disruption during the winter than in summer. These results are consistent with earlier studies demonstrating that middle-aged adults are exposed to approximately 58 min of bright white light per day [31] while older adults in assisted living facilities were exposed to bright light for only 35 min per day [37]. Older adults with ADRD living in nursing homes experience as little as 2 min per day [38,39]. Given that current lighting in nursing homes and assisted living facilities is generally dim and constantly on, it is not surprising that sleep disturbances are common in this population [40].

Moe *et al.* [41] determined whether disrupted sleep–wake cycles could predict impaired cognition by observing 78 ADRD patients and 38 healthy control participants in an overnight lab study. Participants did not have any reported sleep problems. A stronger relationship was found between cognition and sleep with the ADRD patients; in other words, they found a negative correlation between nighttime waking and cognitive performance. Cognitive function decreased with more time awake and longer rapid eye movement (REM) sleep latency, while more REM and slow-wave sleep were associated with better cognition.

These studies suggest that while circadian and sleep disturbances may be common in older adults, including those with ADRD, light, which is the strongest time giver for the circadian

system, has a potential to promote entrainment and improve sleep in this population. Therefore, light has the potential to become a powerful treatment for mitigating poor sleep quality frequently found in the older population, including those with dementia. Medications, often prescribed for sleep problems, have low effectiveness [42,43] and are associated with adverse effects, such as worsening confusion, falls and hip fractures [44–49]. A meta-analysis of sedative/hypnotic medications for older people with insomnia concluded that the benefits of sleep medication may not justify the increased risk [50]. Adverse side effects of light therapy may include eye strain and headaches [51] although other studies did not show any significant differences in side effects between light treatment and control experimental conditions [52]. The goal of this literature review is to identify studies that had used light as an intervention to improve sleep and behavior in patients diagnosed with ADRD.

## Light therapy for ADRD patients: a review of the literature

A search in Medline was performed in April–October 2016 and once again in December 2016 using the terms: Alzheimer's disease, dementia, light therapy, phototherapy, sleep and circadian rhythms. Studies from 1980 to 2016 that had used light as an intervention to improve sleep and/or behavior in ADRD patients were identified. The search yielded 305 results. After reading the abstracts, only those studies that discussed light as an intervention to reduce sleep disturbances and improve behavior (mood, depression and agitation) were selected, yielding a total of 25 articles. **Table 1** details these studies and a summary of their findings is discussed below.

Fetveit *et al.* [61] demonstrated that exposure to 2 h of bright light (6000–8000 lux at the cornea) in the morning for at least 2 weeks substantially improved the sleep efficiency of 11 older adults with dementia. Alessi *et al.* [67] showed that five consecutive days of 30-min exposure to sunlight, increased physical activity, structured bedtime and control of light and noise at night resulted in a significant decrease in daytime sleeping in intervention participants compared with controls. Further, they showed that intervention participants had increased participation in social and physical activities as well as social conversation.

Analyzing actigraph data, Van Someren *et al.* [55] found that increased illumination in the living environment of 22 ADRD patients increased the stability of their rest–activity rhythm following 4 weeks of treatment. A ceiling-mounted light fixture containing polychromatic light was installed in the common areas where the patients spent most of their waking time. Patients received an average of 1136 ± 89 lux at the cornea from the new lighting, although the amount of light received ranged from 790–2190 lux at the cornea depending on their position relative to a window. Bright light treatment was most effective in residents with relatively unimpaired vision, as opposed to those with severe visual deficits. Interdaily stability, which is a measure of the consistency in rest–activity patterns over the course of many days, increased (i.e., coupling of the rhythm to environmental time givers, such as mealtimes), indicating a more steadfast organization of the circadian rest–activity rhythm. This was the first field study demonstrating that unattended light during the daytime could improve rest–activity rhythms in ADRD patients.

Satlin *et al.* [53] examined whether evening light exposure (1500–2000 lux at the cornea) would improve sleep–wake patterns and reduce agitation in ADRD patients, and found an increase in circadian amplitude and improvement in intradaily variability (i.e., consolidated rest–activity patterns during the day) but not in interdaily stability (i.e., more consolidated rest–activity rhythms over the course of successive days). They also found that evening light exposure decreased nighttime activity and sundowning symptoms. Lyketsos *et al.* [58] administered 1 h of light (10,000 lux at the cornea) each morning for 2 weeks to ADRD patients with agitated behaviors and found that these individuals with agitated behaviors slept more hours at night, when exposed to bright light in the morning.

Mishima *et al.* [54] exposed 14 patients with dementia to 2 h of light (3000–5000 lux at the cornea measured at a distance of 1 meter) each morning for 4 consecutive weeks and observed a significant increase in nighttime sleep duration and a significant reduction in agitated behavior. In a later study, Mishima *et al.* [57] examined the therapeutic effects of 2 weeks of morning bright light (5000–8000 lux at the cornea) on rest–activity rhythm disorders in 12 patients with vascular dementia and ten ADRD patients. The 2 weeks of morning bright light induced a significant reduction in both nighttime activity and percentages of nighttime activity to total

activity compared with the pretreatment period, and compared with the dim light condition in the vascular dementia group, but not in the ADRD group.

Ancoli-Israel *et al.* [62] administered light (2500 lux at the cornea) for 2 h in the morning or the evening for ten consecutive days and found both groups of ADRD patients (those who received morning and those who received evening light) exhibited more consolidated sleep at night, as measured by average length of maximum nocturnal sleep bouts. Using the same dataset, Ancoli-Israel *et al.* [63] evaluated the effect of the lighting intervention on agitated behavior in these patients. Morning light delayed the acrophase of agitation by 1.63 h but there was no significant effect on observational ratings of agitation. Yamadera *et al.* [59] found that 4 weeks of morning bright light (3000 lux at the cornea) administered to 27 ADRD patients resulted in improved mental status scores, decreased percentage of daytime naps/naptime, increased percentage of nighttime sleep time and decreased percentage of nighttime awakenings.

Skjerve *et al.* [64] investigated sleep–wake rhythm disturbances and behavioral symptoms in subjects with severe dementia. Bright light treatment was given daily for 45 min in the morning to ten patients with severe dementia, sleep–wake rhythm disturbances and significant behavioral symptoms. Light treatment consisted of 5000–8000 lux at the cornea measured at a distance of 0.3–0.5 m. The patients' behavioral symptoms improved with treatment. No changes in sleep–wake measures were found, although an advance of the activity rhythm acrophase was identified during treatment. The results suggested that short-term bright light improves behavioral symptoms and certain aspects of activity rhythm disturbances, even in severely demented patients.

Dowling *et al.* [66] tested the effects of morning versus evening light, hypothesizing that morning bright light (≥2500 lux at the cornea) should result in the most improvement with a phase advance in the rest–activity rhythm of ADRD patients. Conversely, afternoon light exposure would phase delay the rhythm. No significant differences in actigraphy-based measures of nighttime sleep or daytime wake were found. However, both groups evidenced a significantly more stable rest–activity rhythm acrophase over the 10-week treatment period compared with the controls. The study concluded that 1 h of bright light exposure may provide sufficient additional input to the circadian pacemaker to facilitate entrainment to the 24-h day. When examining morning light therapy treatment, their results indicated that subjects with the most impaired rest–activity rhythm responded significantly and positively to the 1-h light intervention [65].

McCurry *et al.* [74] tested the effects of walking, light exposure and a combination intervention (walking, light and sleep education) on total wake time and subjective sleep quality in ADRD patients living in independent community settings. Participants in the walking, light and combination intervention showed significant improvements in total wake times and sleep efficiency, and the effect was larger in those who had greater adherence to the experimental protocol.

Sloane *et al.* [69] showed a statistically significant improvement in nighttime sleep with morning or all-day light (>2500 lux at the cornea), with greater improvement among persons with severe dementia. The authors claim that the effect size was greater than has been reported using prescription sleep medicines in long-term care populations. Using the same data set, Hickman *et al.* [68] showed that, compared with all day and evening light exposures, morning light had the greatest effect on both sexes. Depressive symptoms decreased in women and increased in men after morning light exposure.

To determine whether the progression of cognitive and noncognitive symptoms may be ameliorated by individual or combined long-term application of bright light and melatonin, Riemersma-van der Lek *et al.* [70] conducted a long-term, double-blind, placebo-controlled study with 189 elderly patients with dementia living in nursing homes. Light alone was found to attenuate both cognitive deterioration by as much as 5%, as determined by the Mini Mental Status Examination and the increase in functional limitations, as determined by the Activities of Daily Living Scale. Oral melatonin alone shortened sleep onset latency and increased sleep duration, but also increased withdrawn behavior. The light and melatonin treatment increased sleep efficiency and improved nocturnal restlessness, thus indicating that the adverse effect of melatonin on mood can be counteracted when administered as part of treatment with light for cognitive and noncognitive function.

However, not all studies to date have shown a positive effect of light on sleep disturbances or rest–activity rhythms of those with dementia.

**Table 1. Summary of the studies described in this review.**

| Study (year) | Objective | Subjects | Diagnosis (type of dementia) | Methods/protocol |
|---|---|---|---|---|
| Satlin *et al.* (1992) | Test hypothesis that evening bright light pulses would improve sleep–wake patterns and reduce agitation in AD patients with severe sundowning and sleep disorders | 10 AD inpatients (1 female, 9 males; mean age = 70.1 years) with sundowning and sleep disturbances on veterans' hospital research ward. Those with substantial intercurrent medical illnesses and/or substantial cataracts excluded | DSM-III-R criteria for primary degenerative dementia and NINCDS-ADRDA criteria. All moderately to severely demented (mean ± SD MMSE = 0.6 ± 1.1) | Pilot study used open-treatment, uncontrolled design. After 1 week baseline measurements, ten subjects received 2 h/day exposure to bright light (19:00–21:00) for 1 week. Post-treatment lasted 1 week |
| Mishima *et al.* (1994) | Investigate effects of bright-light therapy on sleep time, behavior disorders and melatonin secretion on elderly people with dementia | 14 inpatients (mean age = 75 years, range = 61–83 years) with dementia showing sleep and behavior disorders from geriatric ward at a psychiatric hospital, 10 inpatients (mean age = 75 years, range = 65–81 years) from general ward of same hospital as control | Multi-infarct dementia or ADRD. The 14 experimental subjects met DSM-III criteria for insomnia disorder or sleep–wake schedule disorder | Daily light therapy for a 4-week period administered 09:00–11:00 Serum melatonin level measured for both the experimental and control groups. Blood for radioimmunoassay using double-antibody method was sampled at 00:00 and 12:00 on day before light therapy and during last week of light therapy |
| Van Someren *et al.* (1997) | Test hypothesis that enduring increase in daytime environmental illumination level improves rest–activity rhythm disturbances in dementia patients | 22 inpatients (7 females, 15 males; mean age = 79 ± 2 years) on psychogeriatric ward | Clinical diagnoses of AD (n = 16), multi-infarct dementia (n = 3), dementia with alcoholism (n = 2) or normal pressure hydrocephalus (n = 1) | Within-subjects field study. Ambient light and activity rhythms measured for 2 weeks prior to study (Baseline 1). Existing ceiling-mounted lighting fixtures replaced with new higher illuminance fixtures at night, prior to week 3 and ambient light and activity rhythms were measured for 1–2 more weeks (experimental). New lighting fixtures removed and existing light fixtures reinstalled during the night, and ambient light and activity rhythms were measured for 1–2 more weeks (baseline 2) |
| Colenda *et al.* (1997) | Examine entraining effects of phototherapy delivered by light visors on disturbed sleep patterns of community-dwelling AD patients | 5 community-dwelling subjects (mean age = 76.4 years) with AD and disturbed circadian rest–activity cycles as reported by primary caregivers | Subjects met 'research criteria' for AD. Mean MMSE = 16.4 | Pilot project used single subject design (28 days divided into three phases) with activity monitoring as primary outcome measure. Protocol consisted of 5-day baseline monitoring period (phase 1), followed by 10 consecutive days (phase 2) of phototherapy (2000 lux of full spectrum bright light) delivered by light visors for 2 h each morning (07:00–09:30), followed by 14 days (phase 3) of activity monitoring |

ABRS: Agitated Behavior Rating Scale; AD: Alzheimer's disease; ADRD: Alzheimer's disease and related dementias (and Alzheimer's-type dementia); Behave-AD: Behavioral Pathology in Alzheimer's Disease scale; BIMS: Brief Interview for Mental Status; CCT: Correlated color temperature; CDR: Clinical Dementia Rating; CMAI: Cohen-Mansfield Agitation Index; CSDD: Cornell Scale for Depression in Dementia; DSM: Diagnostic and Statistical Manual of Mental Disorders; GDS: Geriatric Depression Scale; IS: Interdaily stability; IV: Intradaily variability; K: Kelvin; L5: Least active 5-h period; LBD: Lewy body dementia; M10: Most active 10-h period; MD: Mixed dementia (AD and VD); MDS-COGS: Minimum Data Set Cognition Scale; MMSE: Mini-Mental State Examination; MOSES: Multi-Observational Scale for Elderly Subjects; NI-ADL: Nurse-informant adaptation; NINCDS-ADRDA: National Institute of Neurological and Communicative Disorders and Stroke and the Alzheimer's Disease and Related Disorders Association; NPI-Q: Neuropsychiatric Inventory; PGCARS: Philadelphia Geriatric Center Affect Rating Scale; PGCMS: Philadelphia Geriatric Center Morale Scale; PSQI: Pittsburgh Sleep Quality Index; RA: Relative amplitude; SD: Standard deviation; SDI: Sleep Disorders Inventory; SDQ: Sleep Disorders Questionnaire; SE: Sleep efficiency; SEM: Standard error of the mean; SOL: Sleep onset latency; TSD: Total sleep duration; VD: Vascular dementia.

| Lighting devices/levels | Measurement devices/outcome measures | Findings | Ref. |
|---|---|---|---|
| Light box with 3 U-shaped fluorescent bulbs (Philips FB40/CW; Philips Lighting, Eindhoven, The Netherlands), 1500–2000 lux | Devices: portable piezoelectric activity monitor with solid-state *ws:* during each study week, subjects rated by nurses for agitation, sleep–wake patterns, use of restraints and use of prescribed-as-needed medication | Clinical ratings of sleep–wakefulness on evening nursing shift improved with light treatment in 80% of subjects. Proportion of total daily activity occurring during the night decreased during the light-treatment week. Relative amplitude of the circadian locomotor activity rhythm, a measure of its stability, increased during the light-treatment week. Evening light exposure also decreased sundowning symptoms | [53] |
| Desktop light therapy device, full-spectrum fluorescent lamp, 3000–5000 lux at distance of 1 m | Devices: sleep diary<br>Outcomes: sleep–wake state and presence/absence of behavior disorders such as wandering, violent behavior, restlessness and other delirium-related abnormal behavior | 4 weeks of morning light therapy markedly improved sleep and behavior disorders in dementia group. Measurements of sleep time and serum melatonin values suggest sleep and behavior disorders in dementia group are related to decreases in the amplitude of sleep–wake rhythm and decreases in melatonin secretion. Morning light therapy significantly increased total and nocturnal sleep time, significantly decreasing daytime sleep time | [54] |
| Existing: ceiling-mounted luminaires with Philips TLD18W lamps (Philips Lighting, Eindhoven, The Netherlands)<br>Replacement: new luminaires with high-level white Philips TLD32W fluorescent lamps covered with UV-filtering Plexiglas diffusers<br>Baseline 1 levels: mean ± SEM = 436 ± 90 lux, range = 93–1417 lux<br>Experimental levels: 1136 ± 89 lux, 790–2190<br>Baseline 2 levels: 372 ± 65 lux, 110–1106 lux | Devices: BBC Goertz Metrawatt MX 4 and Gossen Mavolux digital lux-meters, wrist-worn actigraphs (The Netherlands Institute for Brain Research, Amsterdam, The Netherlands)<br>Outcomes: rest–activity (IS, IV, L5, M10, RA) and light exposure (weekly average light level [lux]) | During increased illumination, stability of rest–activity rhythm increased in subjects with intact vision, but not in visually impaired subject. IS was significantly higher during experimental phase than in combined baseline phases. IV was significantly lower during experimental phase than in both baseline phases. RA did not differ between the experimental phase and baseline phases, but an increase in RA was significantly associated with the presence of AD, absence of a severe visual deficit and a low change rate in day length | [55] |
| Bio-brite light visor (Bio-brite, Inc., MD, USA), 2000 lux | Devices: Actilume Activity Monitor (Ambulatory Monitoring, NY, USA), Gossen Multi-Pro Light Meter (Gossen Division, Berkey Marketing Co., NY, USA)<br>Outcomes: rest–activity data | Cosinor analyses found no consistent changes in acrophase, mesor or amplitude. Observed changes in acrophase were consistent with phase advancement of rest–activity cycle and biological intervention. Changes in number of nighttime awakenings were not found. One subject had significant increase in total sleep time, whereas another had significant decrease in total sleep time. Authors noted that perhaps light visors may be inadequate for providing light treatment | [56] |

**Table 1. Summary of the studies described in this review (cont.).**

| Study (year) | Objective | Subjects | Diagnosis (type of dementia) | Methods/protocol |
|---|---|---|---|---|
| Mishima *et al.* (1998) | Compare therapeutic effect of morning bright and dim light exposure on rest–activity rhythm disorders in patients with VD and ADRD | 12 subjects with VD (7 females, 5 males; mean age = 81 years) and 10 subjects with ADRD (6 females, 4 males; mean age = 78 years) | VD (mean MMSE = 8) and ADRD (mean MMSE = 9) | Randomized crossover study. Subjects exposed to 2 weeks of bright light (5000–8000 lux) and 2 weeks of dim light (300 lux) in the morning (09:00–11:00). Two-week treatment period occurred between pretreatment (1 week) and post-treatment (1 week) periods, with at least a 4-week interval between sessions. Continuous rest–activity monitoring performed at 1-min intervals throughout the study via actigraph worn on nondominant wrist |
| Lyketsos *et al.* (1999) | Test efficacy of bright light therapy for agitated behaviors in dementia patients | 15 subjects (14 females, 1 male; mean ± SD age = 80.8 ± 8.7 years) with dementia and agitated behaviors residing in a chronic care facility. Eight subjects completed study, seven completed at least 2 weeks. Subjects with major depressive episodes, delusions, hallucinations, manic syndrome, sleep–wake cycle disturbances or those bed-bound were excluded | DSM-IV criteria for dementia, scores >4 on Behave-AD scale | Randomized, controlled, crossover trial with two conditions. Subjects spent 4 weeks in each condition, with 1-week baseline and 1-week wash-out period between conditions. Bright light treatment administered for 1 h each morning using 10,000 lux full-spectrum lamp within 0.9 m of subject's face. Dim light (control) was dim, digital, low-frequency blinking light positioned in the middle of the active light treatment, with the 10,000 lux active light turned off |
| Yamadera *et al.* (2000) | Evaluate effects of bright light on cognition and circadian rhythm in ADRD | 27 adults (16 females, 11 males; mean age = 79.9 years). Subjects did not have 'physical problems' and received no medications | ADRD diagnosed via brain computed tomography, DSM-IV and NINCDS-ADRDA criteria. Severity of ADRD assessed via CDR | Single case design study consisting of 1-week adaptation session, 1-week pretreatment and 4-week treatment session with light (3000 lux) administered 09:00–11:00. In pretreatment session and again during week 4, actigram was recorded and MMSE was given. Subjects were divided into separate groups following CDR: questionably demented and mildly demented (QMD [n = 10]) and moderately and severely demented (MSD [n = 17]) |
| Ancoli-Israel *et al.* (2002) | Determine whether increased bright light exposure improves fragmented sleep patterns in nursing home residents with dementia | 77 nursing home residents (58 females, 19 males; mean ± SD age = 85.7 ± 7.3 years, range = 60–100). Most (80%) subjects not depressed according to GDS scores. Study excluded subjects who were bed-bound, deemed too ill, had severe visual impairments or were unable to communicate | Subjects described as severely demented by authors (mean ± SD MMSE = 12.8 ± 8.8; median MMSE = 9; MMSE <20 for 71% of subjects). No distinction made in respect to subjects' dementia types | Randomized control trial. Subjects completed baseline tests before experiment. Activity monitor worn on wrist 24 h before experiment and during entire 18-day protocol (3 days pretreatment, 10 days treatment, 5 days of post treatment). Subjects divided into four groups: morning bright light, evening bright light, evening dim red light (control) and daytime sleep restriction. Morning bright light, evening bright light and evening dim light groups were exposed to 2 h of light treatment every day for 10 days. Daytime sleep restriction group accompanied by staff to ensure compliance with 6 h sleep restriction. Morning and evening bright light groups exposed to 2500 lux at 09:30–11:30 and 17:30–19:30, respectively. Evening dim light group (control group) exposed to <50 lux of red light 17:30–19:30 |

| Lighting devices/levels | Measurement devices/outcome measures | Findings | Ref. |
|---|---|---|---|
| 18 full-spectrum fluorescent tubes (Kohden Med, Inc., Tokyo, Japan), 5000–8000 lux | Devices: Actigraph (Ambulatory Monitoring Inc., NY, USA), illuminometer<br>Outcomes: rest–activity data | Bright light treatment induced significant reduction in nighttime activity and ratios of nighttime activity to total activity compared with the pretreatment period. Similar significant reductions from bright light compared with dim light condition in VD group but not in ADRD group | [57] |
| 10,000 lux full spectrum lamp placed within 0.9 m of subject's face | Devices: None specified<br>*Outcomes:* Sleep log for hours of sleep between 20:00 and 08:00; Behave-AD, CSDD; improvements in nocturnal sleep, depression and behavior | Subjects randomized to light treatment condition exhibited statistically significant improvement in nocturnal sleep, from a mean of 6.4 h/night to 8.1 h/night 4 weeks later ($p < 0.05$). Sleep in control condition did not improve significantly. No other significant differences observed between baseline and follow-up, nor between light treatment and control subjects on other outcome measures | [58] |
| 3000 lux, devices not specified | Devices: Mini-motion actigraph (Ambulatory Monitoring Inc., NY, USA)<br>Outcomes: Improved cognition by comparing CDR and MMSE scores and improved nighttime sleep in ADRD patients | Light treatment improved MMSE scores (especially in early stages of ADRD) and circadian rhythm disturbances (nap time percent, number of naps, sleep time in the night percent and number of awakenings in the night). Light treatment did not change CDR scores or improve severity of ADRD | [59] |
| Brite-Lite box (Apollo Light Systems, UT, USA) with cool white fluorescent lamps, ballast and reflector; placed 1 m from subject's head, within 45° visual field, often placed on top of TV. Morning and evening light treatment groups exposed to 2500 lux. Evening dim light group (control) exposed to <50 lux red light | Devices*:* Wrist-worn actigraphs (Actillume; Ambulatory Monitoring Inc., NY, USA) equipped with an accelerometer, microprocessor and 32-kb RAM, log-linear photometric transducer. Action3 software used to score sleep–wake data based on summing activity, maximum activity and light exposure<br>Outcomes*:* Sleep spread score. Sleep–wake data (sum and maximum activity) for 'day intervals' and 'night intervals'. Data only included if subjects showed significant pretreatment circadian activity rhythm | No significant improvements in nighttime sleep or daytime alertness, nor significant changes in activity rhythms, identified for any treatment group. Morning light treatment group, however, showed significant 1 h, 46 min delay in acrophase and increase in mesor between baseline and treatment week 2 | [60] |

**Table 1. Summary of the studies described in this review (cont.).**

| Study (year) | Objective | Subjects | Diagnosis (type of dementia) | Methods/protocol |
|---|---|---|---|---|
| Fetveit *et al.* (2003) | Evaluate effects of light treatment for nursing home patients with dementia and sleep disturbances | 11 nursing home residents (10 females, 1 male; mean ± SD age = 86.1 ± 8.9 years; range = 72–101). Sleep efficiency measured via actigraph <85%. No subject used hypnotics, antipsychotic or cholinesterase inhibitors as regular medication | Moderate to severe dementia (mean ± SD MMSE = 11.7 ± 4.2, range = 6–18; mean CDR score = 2.5 ± 0.5, range = 2–11). No probable depression identified (mean CSDD = 6.8 ± 2.7, range = 2–11) | Single case design study, subjects served as own control. Study consisted of one pretreatment period, immediately followed by one treatment period, each lasting 2 weeks, preceded by baseline period 8 months prior. For all three periods, of sleep registrations drawn from 7 consecutive days were used in analysis. Lighting equipment and research personnel in place for pretreatment and treatment periods, but lighting was energized during treatment period only. During treatment, residents were exposed to morning bright light (6000–8000 lux) for consecutive 2-h periods during breakfast time (08:00–11:00). Each seated patient had individual light box placed 60–70 cm from eye-level. Sleep–wake patterns were evaluated via nursing staff ratings and wrist-worn actigraphs |
| Ancoli-Israel *et al.* (2003) | Examine effect of light on sleep and circadian activity rhythms in patients with probable or possible AD | 92 nursing home residents (63 females, 29 males; mean ± SD age = 82.3 ± 7.6 years, range = 61-99 years). Subjects with recent or severe stroke or primary psychiatric disorder predating suspected onset of dementia were excluded | Subjects described as having 'probable or possible' AD (mean MMSE = 5.7). Evaluated using NINCDS-ADRDA criteria | Randomized, controlled, crossover trial with three periods: baseline (3 days), followed by treatment (10 days) and post-treatment follow-up (5 days). Wrist activity data collected throughout Treatment conditions included: morning bright light (09:30–11:30) for 30 subjects, morning dim red (09:30–11:30) for 31 subjects and evening bright light (17:30–19:30) for 31 subjects. Wrist-worn actigraphy data were used to calculate total sleep time, wake after sleep onset, percent sleep, percent wake, number of nighttime awakenings, average length of nighttime awakenings, number of daytime naps, duration of naps and length of time between naps. Computed sleep–wake activity statistics included the mean sleep or wake bout length, SD, min, max and 10, 25, 75 and 90 percentiles. Relationships between baseline vs treatment days 6–10 and treatment days 6–10 vs post-treatment follow-up were analyzed statistically |
| Ancoli-Israel *et al.* (2003) | Evaluate effect of bright light treatment on agitated behavior in large sample of patients with severe dementia. Expanded upon earlier pilot study | 92 nursing home residents (63 females, 29 males; mean ± SD age = 82.3 ± 7.6 years, range = 61–99 years). Subjects with recent or severe stroke or primary psychiatric disorder pre-dating suspected onset of dementia were excluded | Subjects described as having 'probable or possible' AD (mean MMSE = 5.7). Evaluated using NINCDS-ADRDA criteria | Randomized, controlled, crossover trial with three periods: baseline (3 days), followed by treatment (10 days) post-treatment follow-up (5 days). Wrist activity data were collected throughout. The three treatment conditions included: morning bright light (09:30–11:30) for 30 subjects, morning dim red (09:30–11:30) for 31 subjects and evening bright light (17:30–19:30) for 31 subjects. Subject agitation rated by trained research staff who observed subjects for 20 s every 15 min throughout the treatment period and by caregivers at one time point before and one time-point after treatment. Baseline agitation data were collected for 3 days, followed by 10 days of treatment (treatment days 1–5 and 6–10) and 5 days of post-treatment follow-up |

| Lighting devices/levels | Measurement devices/outcome measures | Findings | Ref. |
|---|---|---|---|
| Specially designed light box (ML-10000, Miljolys A/S, Norway), 6000–8000 lux at 60–70 cm distance | Devices: Actiwatch portable recorder (Cambridge Neurotechnoloy Ltd, England), sensitivity set to medium. Data collected in 1-min epochs<br>Outcomes: improved sleep metrics | Sleep improved substantially with bright light treatment, consistently among subjects. Waking time in nocturnal sleep was reduced by almost 2 h, SE improved 73-86%. Improvements were corroborated by nursing staff ratings | [61] |
| Brite-Lite boxes (Apollo Light Systems, UT, USA) with cool-white fluorescent, non-UV full spectrum light bulbs, 2500 lux, used for bright light conditions. Dim light condition used similarly configured red light box, <300 lux. Boxes were placed 1 m from subjects | Devices: Wrist-worn Actillume recorder (Ambulatory Monitoring Inc., Ardsley, NY, USA) used to measure activity and light exposure<br>Outcomes: improved sleep metrics | The three light treatments had no significant effect on sleep–wake activity, total sleep times, total wake times, observed bedtimes or final wake times. Increased bright light exposure (both morning and evening) consolidated nighttime sleep, but with no increase in TSD there were simply longer though fewer sleep episodes. Authors concluded light exposure benefits sleep and circadian rhythms with effects conferred to both patients and caregivers | [62] |
| Brite-Lite boxes (Apollo Light Systems, Orem, UT, USA) with cool-white fluorescent, non-UV full spectrum light bulbs, 2500 lux, used for bright light conditions. Dim light condition used similarly configured red light box, <300 lux. Boxes were placed 1 m from subjects | Devices: Light measured at eye-level via photometer to ensure correct light exposure<br>Outcomes: agitation assessed via CMAI and ABRS | Acrophase of agitation rhythm significantly delayed (1.63 h) by morning bright light treatment. Light treatment was associated with improved caregiver ratings but had little effect on observed agitation ratings | [63] |

**Table 1. Summary of the studies described in this review (cont.).**

| Study (year) | Objective | Subjects | Diagnosis (type of dementia) | Methods/protocol |
|---|---|---|---|---|
| Skjerve *et al.* (2004) | Determine whether short-term bright light treatment improves behavioral symptoms and activity acrophase in subjects with severe dementia | 10 psychogeriatric patients (7 males, 3 females; mean age = 79.4 years, range = 65–87 years) with severe dementia, sleep–wake rhythm disturbances and significant behavioral symptoms. Subjects with terminal disease, confined-to-bed and moderate-to-severe visual impairment or blindness were excluded | AD or VD according to ICD-10 criteria. Median MMSE = 0, CDR = 3 (severe dementia) | Open clinical trial, within-subjects field study before and after design. Study included three periods: pretreatment (2 weeks), treatment (4 weeks) and post-treatment (2 weeks). Bright light treatment administered daily for 45 min during breakfast (08:00–10:00). Nurse attended each subject to ensure they faced light with open eyes at prescribed distance of 0.3–0.5 m. Actigraphy data collected for 6 weeks (weeks 2–7) of study period and clinical ratings were collected and scored. Measured aspects of sleep–wake disturbances included: daytime sleep, difficulty falling asleep, night-time wakefulness and early morning awakening |
| Dowling *et al.* (2005) | Determine effectiveness of morning light treatment on circadian disruption measures in institutionalized patients with severe AD | 46 long-term nursing facility residents (36 females, 10 males; mean ± SD age = 84 ± 10 years, range = 60–98 years) diagnosed with AD. Subjects experienced rest–activity disruptions (i.e., insomnia, frequent nighttime awakenings, wandering at night, unusually early morning awakenings, sundowning and excessive daytime sleepiness). Subjects with other neurological diagnoses, who could not perceive light or who regularly took valerian, melatonin or sleeping pills were excluded | Diagnosis of AD according to NINCDS-ADRDA criteria. Mean ± SD MMSE = 6.7 ± 6.8, median MMSE = 5, MMSE range= 0–23 | Randomized control study in two nursing homes. The 12-week study included three periods: baseline (1 week), light intervention (10 weeks) and post-intervention (1 week). Study had two phases in which subjects were randomly divided into two groups per phase phase I compared morning bright light treatment (experimental) with normal room lighting (control) conditions. Phase 2 compared bright light treatment in morning vs afternoon. Morning bright light treatment administered for 1 h (09:30–10:30) during weekdays for 10 weeks. Afternoon bright light treatment time not specified Bright light treatment was primarily daylight (either outdoors or indoor space with abundant windows and light) supplemented by light boxes, when necessary, to ensure subject exposure to >2500 lux in gaze direction. Control group exposed to 150–200 lux indoor light. Rest–activity data recorded via dominant-wrist-worn activity monitor for 6 days and 7 nights during baseline and for 5 days and 5 nights during the last week of intervention |
| Dowling *et al.* (2005) | Determine effectiveness of timed light treatment on circadian disruption measures in institutionalized patients with AD | 70 long-term care residents (57 females, 13 males; mean ± SD age = 84 ± 10 years, range = 58–98 years) diagnosed with AD. Subjects with other neurological diagnoses, who could not perceive light or who regularly took valerian, melatonin or sleeping pills were excluded | Diagnosis of AD according to NINCDS-ADRDA criteria. Mean MMSE ± SD = 7 ± 7, range = 0–23 | Randomized control study in two nursing homes. The 11-week study included two periods: baseline (1 week) and light intervention (10 weeks). Study had two phases in which subjects were randomly divided into two groups per phase. Phase 1 compared morning bright light treatment (experimental) with normal room lighting (control) conditions. Phase 2 compared bright light treatment in morning vs afternoon. Morning bright light treatment administered for 1 h (09:30–10:30) and afternoon light treatment administered for 1 h (15:30–16:30), both treatments during weekdays for 10 weeks. Bright light treatment was primarily daylight (either outdoors or indoor space with abundant windows and light) supplemented by light boxes, when necessary, to ensure subject exposure to >2500 lux in gaze direction. Rest–activity data recorded via dominant-wrist-worn activity monitor for 6 days and 7 nights during baseline and for 4 days and 5 nights during the last week of intervention |

| Lighting devices/levels | Measurement devices/outcome measures | Findings | Ref. |
|---|---|---|---|
| Philips HF 3301 lamp (Philips Lighting, Eindhoven, The Netherlands), 5000–8000 lux, at 0.3–0.5 m distance | Devices: Actiwatch (Cambridge Neurotechnology Ltd, UK)<br>Outcomes: agitation assessed via CMAI and BEHAVE-AD; actigraphy data (mesor, acrophase, IS, IV, RA and SE); and improvement in activity rhythm disturbances and behavioral symptoms | Behavioral symptoms improved with treatment as shown by CMAI and BEHAVE-AD. No changes in sleep–wake measures were found, but there was an advance of the activity rhythm acrophase during treatment. These results suggest that short-term light treatment improves behavioral symptoms and aspects of activity rhythm disturbances even in severely demented subjects | [64] |
| Brite-Lite IV (Apollo Light Systems, UT, USA) providing 10,000 lux at 26 in and 2500 lux at 4 ft Control group exposed to 150–200 lux | Devices: Cal LIGHT 400 calibrated light meter (MI, USA), Actiwatch activity monitor (AW-64, Mini Mitter Co. Inc., OR, USA). Actigraphy data analyzed with Actiware Sleep, v.3.2, software (Philips Respironics, PA, USA)<br>Outcomes: nighttime sleep parameters included SE, nighttime sleep time, nighttime wake time, number of nighttime awakenings, daytime wake time. Circadian parameters included IS, IV, L5, M10, RA | Morning light treatment did not improve rest–activity rhythms or sleep measures in experimental group compared to the control group. Subjects with most disrupted rest–activity rhythms responded positively to the morning bright light treatment | [65] |
| Brite-Lite box Brite-Lite IV (Apollo Light Systems, UT, USA) providing 10,000 lux at 26 in and 2500 lux at 4 ft Control group exposed to 150–200 lux | Devices: Cal LIGHT 400 calibrated light meter (MI, USA), Actiwatch activity monitor (AW-64, Mini Mitter Co. Inc., OR, USA). Actigraphy data analyzed with Actiware Sleep, v.3.2, software (Philips Respironics, Murraysvile, PA, USA).<br>Outcomes: nighttime sleep parameters included SE, nighttime sleep time, nighttime wake time, number of nighttime awakenings, daytime wake time | Administration of 1 h bright light treatment did not improve sleep–wake or rest–activity measures compared to experimental control group, regardless of whether light was administered in the morning or afternoon. Subjects in either experimental light condition evidenced a significantly more stable rest–activity rhythm acrophase over the 10-week treatment period compared to control subjects who tended toward phase delay | [66] |

**Table 1. Summary of the studies described in this review (cont.).**

| Study (year) | Objective | Subjects | Diagnosis (type of dementia) | Methods/protocol |
|---|---|---|---|---|
| Alessi *et al.* (2005) | Test multidimensional, non-pharmacological intervention to improve abnormal sleep–wake patterns in nursing home residents | 118 nursing home residents (91 females, 27 males; mean age = 86.9 years). Subjects who were acutely ill, in contact isolation or completely bed-bound were excluded | No dementia diagnosis specified. Mean ± SD MMSE = 11.9 ± 9.2 for intervention group, 10.6 ± 10.0 for control group | Randomized control trial with 62 subjects receiving intervention and 56 receiving usual care (control). All subjects underwent 3-day baseline assessment of wrist actigraphy, behavioral observations (daytime sleep and participation in social and physical activities and social conversation), and bedside noise and light monitoring at baseline, repeated at follow-up. Assessment periods also included 1 night of pulse oximetry. Intervention occurred on 5 consecutive days (08:00–20:00) and included encouragement of subjects to decrease daytime in-bed time, ≥30 min daily sunlight exposure, increased physical activity, structured bedtime routine and decreased night-time noise and light |
| Hickman *et al.* (2007) | Assess effect of ambient light treatment on depressive symptoms in persons with dementia | 66 psychiatric patients and dementia-specific care facility residents with dementia (31 females, 35 males; 91% aged ≥65 years, mean and range not reported). Subjects with certain eye diseases (e.g., moderate/severe macular degeneration or absence of lens) and bipolar disorder were excluded | 68% of subjects diagnosed with severe to very severe dementia following MDS-COGS criteria, 32% had mild to moderate dementia. MMSE and consensus conference (between the principal investigator and the site coordinator) used to assess four subjects for whom MDS-COGS data could not be obtained | Cluster-unit crossover intervention trial with four lighting conditions: morning bright light (07:00–11:00), evening bright light (16:00–20:00), all day bright light (07:00–20:00) and standard light (07:00–20:00). Each lighting condition provided for multiple 3-week treatment periods in predetermined sequence, with data collection occurring in week 3 |
| Sloane *et al.* (2007) | Determine whether high-level ambient light in public areas of long-term care facilities will improve sleep–wake and circadian rhythms of persons with dementia | 66 psychiatric patients and dementia-specific care facility residents with dementia (31 females, 35 males; mean age: 79 years, 91% aged ≥65 years). Subjects with proliferative diabetic retinopathy, moderate or severe macular degeneration or absence of a natural or artificial lens in either eye were excluded | Moderate to severe dementia, diagnostic criteria not specified | Cluster-unit crossover intervention trial with four lighting conditions: morning bright light (07:00–11:00), evening bright light (16:00–20:00), all day bright light (07:00–20:00) and standard light (07:00–20:00). Each lighting condition provided for multiple 3-week treatment periods in predetermined sequence, with data collection occurring in week 3 |

| Lighting devices/levels | Measurement devices/outcome measures | Findings | Ref. |
|---|---|---|---|
| Sunlight exposure ≥10,000 lux daily, verified via handheld light meter placed at eye level facing sun | Devices: Actillume wrist actigraph and Action3 software (Minimotionlogger; Ambulatory Monitoring, Inc., NY, USA) \|Bedside monitor (Augmentech, Inc., PA, USA) for noise and light levels. Ohmeda Biox 3700 pulse oximeter (CO, USA) with fingertip sensor Outcomes: improved nighttime sleep, reduced daytime sleep, increased participation in social and physical activities and social conversation | Only effect on nighttime sleep was a moderate decrease in mean duration of awakenings, with no significant effects on nighttime sleep percentage or number of awakenings, for intervention subjects. Intervention subjects also saw a significant decrease in daytime sleeping, as well as increased participation in social and physical activities as well as social conversation. The authors recommended consideration of nonpharmacological interventions for managing sleep–wake patterns among nursing home residents. | [67] |
| High-level, low-glare ambient lighting system. Bright conditions delivered mean light intensities ranging 2535–2638 lux. Standard condition delivered mean light intensities ranging 591–617 lux | Devices: digital handheld light meter (placement and manufacturer not specified) Outcomes: subjects' mood assessed via CSDD in week 3 of each treatment period | Significant differences between male and female subjects identified in CSDD scores in response to all bright light conditions. Morning bright light condition associated with depressive symptoms that were lowest for women and highest for men. Authors concluded that unit-level ambient light treatment is not effective for improving depressive symptoms in persons with dementia, and instead recommended individual intervention | [68] |
| High-level, low-glare ambient lighting system. Bright conditions delivered mean ± SD light levels ranging from 2495 ± 179 lux to 2641 ± 259 lux between two facilities. Standard condition delivered mean ± SD light level of 606 ± 179 lux | Devices: digital handheld light meter (positioned away from subject, ≅4 ft above floor, pointed toward ceiling; manufacturer not specified). Actiwatch-L (Mini Mitter Inc., OR, USA) Outcomes: nighttime sleep measures, daytime sleepiness measures, circadian rhythm measures (mesor, amplitude, IV, IS) | Nighttime sleep significantly increased for subjects in morning bright light and all day bright light. Morning bright light advanced phase by 29 min, and evening bright light delayed phase by 15 min. No other significant effects were observed, and strength of activity–rest patterns was not influenced by any treatment condition | [69] |

**Table 1. Summary of the studies described in this review (cont.).**

| Study (year) | Objective | Subjects | Diagnosis (type of dementia) | Methods/protocol |
|---|---|---|---|---|
| Riemersma-van der Lek *et al.* (2008) | Determine effect of long-term bright light exposure and orally administered melatonin treatment on cognitive and noncognitive symptoms in residential patients with dementia | 189 elder-care residents (170 females, 19 males; mean ± SD age = 85.8 ± 5.5 years (SD 5.5 years) of 12 group care facilities. Residents using monoamine oxidase inhibitors, long-term use of NSAIDs, with severe liver or kidney dysfunction, and aphakia were excluded | Clinical diagnoses followed DSM-IV and NINCDS-ADRDA criteria. 120 (63%) subjects had probable AD, 20 (11%) had VD, and 24 (13%) were diagnosed with other types of dementia (dementia due to multiple etiologies [n = 9], frontal-type dementia [n = 3], LBD [n = 2], Parkinson's disease [n = 2], Wernicke-Korsakoff syndrome [n = 1], and unspecified dementia [n = 7]). 17 (8%) subjects did not meet criteria for dementia | Long-term (1999-2004), double-blind, placebo-controlled, 2 × 2 factorial randomized trial. In addition to light and placebos, subjects administered 2.5 mg melatonin supplements (Terafarm, Brielle, Netherlands). Subjects were tracked for up to 3.5 yr (mean ± SD duration = 15 ± 12 months). Subjects randomly assigned to 4 groups and exposed to 4 conditions: light only (49 subjects), melatonin only (46 subjects), both light and melatonin (49 subjects), and neither light nor melatonin (45 subjects). Subjects exposed to bright light received it in common living rooms between 09:00 and 18:00. Melatonin (95 subjects) or placebo (94 subjects) administered 1 h before bedtime. Subjects asked to wear activity monitor for 2 weeks. Data sets examined via mixed-effect regression analysis |
| Dowling *et al.* (2008) | Test whether addition of melatonin to bright-light therapy improves effectiveness of treatments for circadian disruption in institutionalized AD patients | 50 long-term care residents with circadian disruption and AD diagnosis (43 females, 7 males; mean ± SD age = 86 ± 8 years, range = 60–100 years). Circadian disruptions included insomnia, frequent nighttime awakenings and wandering, unusually early morning awakenings, sundowning and excessive daytime sleepiness. Study excluded subjects with other neurological diagnoses and those regularly administered valerian, melatonin or sleeping pills | Diagnosis of probable AD according to NINCDS-ADRDA criteria. Study reported mean ± SD MMSE score = 9.3 ± 7.9 (no significant differences between subjects) | Randomized, controlled trial. Subjects divided into three groups: bright light plus evening melatonin (LM, 16 subjects), bright light plus evening placebo (LP, 17 subjects) and usual indoor light only (control, 17 subjects) 11-week study included 1-week baseline data collection period and 10-week bright light intervention period. LM and LP groups received bright light (>2500 lux) in gaze direction 9:30–10:30 on weekdays, and were administered 5 mg melatonin (LM) or placebo (LP) at 17:00–18:00, with bedtime at 20:00. During intervention, subjects in experimental groups were exposed bright light outdoors or indoors in space with plentiful natural light. When light boxes supplemented ambient light, as needed, subjects were seated at tables facing the light boxes situated 30–34 in from their eyes. The control group received usual indoor light (150–200 lux) |

| Lighting devices/levels | Measurement devices/outcome measures | Findings | Ref. |
|---|---|---|---|
| Ceiling-mounted Philips TLD 840 and 940 fluorescent tubes (Philips Lighting, Eindhoven, The Netherlands) fitted with Plexiglas diffusers.<br>Bright light exposure targeted at ≅1000 lux, control lighting targeted at ≅300 lux | Devices: Actiwatch (Cambridge Neurotechnology, Cambridge, England). Mixed-effect regression analysis performed with MLwiN 2.0 software (Centre for Multilevel Modelling, University of Bristol, Bristol, UK), and SPSS 14.0 (IBM Corp., Armonk, NY, USA) employed for T-tests, chi-squared tests, and logistic regressions<br>Outcomes: actigraphy data analyzed for SE, SOL and TSD sleep measures. Standardized scales for cognitive (MMSE, CSDD, PGCMS) and noncognitive (PGCARS, MOSES, NPI-Q, CMAI), symptoms, limitations of activities of daily living (NI-ADL), and adverse effects assessed every 6 months | Bright light exposure reduced subjects' cognitive deterioration (as measured via MMSE) by relative measure of 5% while also improving CSDD scores for depressive symptoms by 19%. Bright light also slowed increase in functional limitations over time by 53%. Melatonin reduced SOL by 19% and increased TSD by 6%. Melatonin had an adverse effects, however, on PGCARS scores (both positive and negative affects). The melatonin-only condition increased withdrawn behavior (as measured via MOSES). Bright light combined with melatonin treatment (as measured via CMAI) reduced aggressive behavior by 9%, increased SE by 3.5% and improved nocturnal restlessness by 9%. Authors concluded that light provides modest benefit for some cognitive and noncognitive dementia symptoms, and recommended that melatonin be used only in combination with light to reduce its adverse effects on mood | [70] |
| Bright light administered via APOLLO Brite Lite IV boxes (Orem, UT, USA) to supplement daylight, as needed. Light boxes delivered 10,000 lux at 26 in and 2500 lux at 48 in. Control group exposed to indoor lighting only (range = 150–200 lux) | Devices: rest–activity data collected via wrist-worn Actiwatch activity monitor (AW-64; Mini Mitter Co., Inc., OR, USA). The actigraphy data were analyzed using Actiware Sleep Version 3.2 Statistical analyses performed using SPSS V.14.0 0 (IBM Corp., Armonk, NY, USA). Cal LIGHT 400 light (Cooke Corp., MI, USA) meters used to monitor exposures in gaze direction of each subject at least once per treatment<br>Outcomes: sleep–wake measures and rest–activity measures, both parametric (amplitude, acrophase, goodness of fit to $R^2$) and nonparametric (IS, IV, L5, M10, amplitude, relative amplitude) | Authors found no significant difference in intervention doses received by LM and LP groups. Daytime sleep decreased for the LM group (66 min) and increased for both LP and control groups by 25 and 50 min, respectively. The groups showed significant differences between baseline and post intervention in respect to several rest–activity variables. The LM group, specifically, showed significantly better results for parametric and nonparametric amplitude, goodness of fit to $R^2$ and M10. Both LM and LP groups phase advanced (63 min and 34 min, respectively) and control group phase delayed (21 min), but these results were not statistically significant. In general, LM group had improvements in daytime somnolence, nighttime sleep, daytime activity and sleep ratio. Authors concluded that light treatment plus melatonin, and not light treatment alone, improved subject performance in sleep–wake and rest–activity measures | [71] |

**Table 1. Summary of the studies described in this review (cont.).**

| Study (year) | Objective | Subjects | Diagnosis (type of dementia) | Methods/protocol |
|---|---|---|---|---|
| Burns *et al.* (2009) | Assess effects of light treatment on agitation and sleep in people with dementia | 48 residents of nursing homes specializing in care of patients with dementia and behavioral disturbances (32 females, 16 males; mean age = 82.5 years [placebo group], 84.5 years [treatment group]). Inclusion criteria were diagnosis of dementia, sleep disruption at least 2 nights/week, and presence of at least 1 agitated behavior. Subjects with cataracts excluded | Diagnosis of dementia according to WHO Organic Mental Disorders ICD-10 criteria. Subjects included those with AD (n = 21), VD (n = 16), LBD (n = 6) and MD (n = 5) | Single center randomized controlled trial. Subjects randomly assigned to standard light (n = 26) and light treatment (n = 22) groups. In study's first (baseline) week, subject diagnoses were confirmed by research team, and subjects given physical and eye examination. Subjects wore actigraphs during baseline week, then removed them for treatment period (weeks 2 and 3). Treatment consisted of exposure to either full-spectrum light at 10,000 lux (treatment) or standard fluorescent tube light at 100 lux (control) for 2 h between 10:00 and 12:00. Follow-up assessments conducted on week 4 (immediate post-treatment, subjects again wearing actigraph) and again on week 8 (one month post treatment, without actigraph). Subjects were assessed according to outcome measures at baseline and in weeks 4 and 8 |
| van Hoof *et al.* (2009) | Assess effects of prolonged exposure to low-level light from a high-CCT source on behavior and circadian rhythmicity of institutionalized older adults with dementia | 22 psychogeriatric day care ward residents (17 females, 5 males; mean ± SD age = 88.2 ± 5.5 years) | Clinical diagnoses of probable AD (n = 5), VD (n = 12), MX (n =4), and LBD (n =1) | Cross-over design field study, subjects randomly divided into 2 groups. During each of the two light interventions, assessments were made using the Dutch Behaviour Observation Scale for Intramural Psychogeriatrics, tympanic temperature, and illumination levels. The lighting equipment was switched on at baseline conditions each morning at 07:30 and allowed to gradually reach at least 500 lux horizontal by 08:00, when subjects arrived. The amount of light was gradually lowered at 18:00 in order to reach a level of 50 lux at 18:30 as subjects were leaving. The lighting installed during the first intervention had a CCT of 17,000 K and 2700 K during the second intervention |

| Lighting devices/levels | Measurement devices/outcome measures | Findings | Ref. |
|---|---|---|---|
| Full spectrum light at 10,000 lux (treatment) or standard fluorescent tube light at 100 lux (control). No additional specifications provided | Devices: Actiwatch (Cambridge Neurotechnology Ltd, Cambridge, UK).<br>Outcomes: behavioral measures included CMAI (primary) along with MMSE, CSDD, Crichton Royal Behavior Rating Scale and Manchester and Oxford Universities Scale for the Assessment of Dementia as secondary outcome measures. Sleep–wake and activity–rest outcome measures included sleep charts (maintained by nursing staff in 30-min blocks), and actigraph measures (sleep duration, diurnal phase, amplitude, M10 and L5) | Authors identified limited evidence of reduced agitation and improved sleep in the treatment group. They also noted that light treatment may be more effective in the winter months and may have deleterious effects on subjects in the summer. Authors concluded that bright light therapy may provide an alternative to drug therapy for people with dementia who are experiencing agitated behaviors | [72] |
| 2 ceiling-mounted luminaires, each containing 6 fluorescent tubes (MASTER TL5 HO ActiViva Active 54W 1SL) emitting 17,000 K and 4 tubes (MASTER TL5 HO 54 W/827 UNP) emitting 2700 K. All devices Philips Lighting, (Eindhoven, The Netherlands) | Devices: Light simulation tool Radiance version 3.9. Braun 4520 (Braun GmbH, Frankfurt, DE) ear thermometer to measure tympanic temperature as a marker of circadian rhythm. Minolta Chroma Meter XY-DC (Konica Minolta, Inc., Tokyo, JP) to measure CCT<br>Outcomes: lighting intervention effects assessed via Dutch Behaviour Observation Scale for Intramural Psychogeriatrics. Tympanic temperature measurements | Tested lighting interventions produced no significant improvements in circadian rhythmicity, behavior or tympanic temperature range. 17,000 K light intervention resulted in worsened observed behavior that may have resulted from visual discomfort, according to authors | [73] |

**Table 1. Summary of the studies described in this review (cont.).**

| Study (year) | Objective | Subjects | Diagnosis (type of dementia) | Methods/protocol |
|---|---|---|---|---|
| McCurry *et al.* (2011) | Test effects of exercise (walking), light exposure and combination of exercise and light exposure on sleep quality in people with AD | 132 subjects with AD and their caregivers. Eligible subjects had ≥2 sleep problems/ week (SDI), <32 score on sleep apnea subscale of SDQ, probable or possible AD, ability to walk across a room and caregiver who could monitor sleep and implement treatment recommendation. Subjects agreed to no changes in sedating medication over 2-month treatment plan. Potentially eligible subjects wore wrist-worn actigraphs for 1 week, those whose wake time averaged 1 h/night invited to participate in study. Subjects with visual impairment, medical contraindication with bright light exposure and prior diagnosed sleep disorder excluded | Probable or possible AD, as conformed by medical records or subjects' primary care physician | Randomized controlled trial with blinded assessors. Assessments conducted at baseline, and 2 months (post-treatment) and 6 months after baseline. Subjects randomized into 4 treatment groups: walking (n = 32); light (n = 34); and combination walking, light and guided sleep education (Nighttime Insomnia Treatment and Education in AD [NITE-AD], n = 33) and cControl (n = 33). Walking, light and lontrol groups participated in three at-home training visits (weeks 1, 2 and 8), receiving phone calls to reinforce caregiver completion of daily logs. NITE-AD group participated in 6 home training visits (4-weekly, 2 bi-weekly). All subjects received basic sleep hygiene guidelines. Walking group used self-paced walking program with a goal of 30 continuous min/day. Light group used light box for 1 h/day providing 2500 lux at eye of white light. Light group subjects permitted to do other activities while in treatment. Caregivers were encouraged to reduce light levels at night. NITE-AD group was asked to follow individualized sleep schedule, walk for 30 continuous min/day and receive 1 h/day of light. Control group did not change schedules and had nondirected contact with trainers. Subjects in Walking and Control groups used wrist-worn actigraphs for 1 week at each assessment period. Subjects in the light and NITE-AD groups wore actigraph around neck |
| Figueiro *et al.* (2014) | Investigate effectiveness of tailored lighting intervention for individuals with ADRD living in nursing homes | 14 subjects (9 females, 5 males; mean age = 86.9 ± 4.4 years) with mild to moderate dementia. Subjects with major organ failure, major illness, history of head injury, use of psychotropic medicine, obstructing cataracts, macular degeneration, blindness or uncontrolled generalized disorders excluded | Mild-to-moderate dementia, based on DSM-IV criteria | Single case design study. Low-level 'bluish-white' lighting designed to deliver high circadian stimulation during the day time was installed in subjects' rooms for 4 weeks<br>Measures of sleep quality, depression and agitation collected using standardized questionnaires at baseline, at the end of the 4-week lighting intervention, and 4 weeks after the lighting intervention was removed |
| Sloane *et al.* (2014) | Evaluate effects of innovative blue–white light therapy on home-dwelling persons with dementia and their caregivers | 17 pairs of home-dwelling subjects with dementia (11 females, 6 males; age ≥65 years) and their caregivers (13 females, 4 males; age ≥18 years). Those with sleep apnea, history of photosensitivity dermatitis, progressive retinal disease, permanently dilated pupil or moderate-to-severe macular degeneration were excluded | Diagnosis of dementia documented by a physician (precise diagnosis was not required) | Randomized clinical controlled trial with crossover. Subjects with dementia received blue–white light and control yellow–white light for 6 weeks separated by a 4-week washout. Because subjective data were collected four-times within a crossover design, six effects were estimated: period effect, effect of the intervention compared to the usual light (the lighting at baseline), effect of the control condition compared to the usual light, carryover for the intervention condition and carryover for the control condition and the intervention condition minus the control condition effect, which is the effect of primary interest |

| Lighting devices/levels | Measurement devices/outcome measures | Findings | Ref. |
|---|---|---|---|
| SunRay light box (SunBox Co., MD, USA) administered 2500 lux for 1 h/day before bedtime | Devices: wrist-worn Micro Mini Motionlogger actigraph with Action4 data analysis software (Ambulatory Monitoring Inc., NY, USA). Micro Light Sensor actigraph worn as necklace (Ambulatory Monitoring Inc., NY, USA) to monitor light exposure Outcomes: questionnaires were SDI, SDQ, Sleep Apnea section, the Self-Administered Comorbidity Questionnaire, MMSE, CSDD. Objective sleep outcomes were total wake time at night measured with actigraphy, and subjective sleep outcomes were SDI scores completed by caregiver. Covariate measures were CSDD, SDQ, MMSE. Treatment adherence ensured by daily activity and light exposure logs, actigraphy. Treatment satisfaction was 6-month follow-up assessment by caregiver | All intervention groups showed increased sleep at night; hence, walking and light (alone or in combination) were effective non-pharmacological strategies to improve sleep quality in AD patients. 115 subjects completed treatment, 100 subjects completed 6-month follow-up assessment. Each intervention (active) group had significantly lower total wake time at night compared to control group. Compared to control group, Walking group subjects slept + 33.1 min/night, Light group subjects slept + 39.0 min/night and the NITE-AD group slept + 39.8 min/night. No significant differences were found in total wake time change scores in the three active groups. No significant difference in SDI scores for any of the groups. At 6 months, no significant difference existed between any of the groups for either the objective or subjective outcome measures. Sleep improvements were not sustained due to decreased treatment adherence, authors observed | [74] |
| Two GE fluorescent lamps (GE Lighting, OH, USA), CCT = 9325 K | Devices: Daysimeter (Lighting Research Center, Rensselaer Polytechnic Institute, NY, USA) Outcomes: objective measures of sleep, rest–activity patterns and circadian disruption | Lighting intervention significantly decreased PSQI global sleep scores, and increased TSD and SE. Intervention also increased phasor magnitude (a measure of the 24-h resonance between light–dark and rest–activity patterns), suggesting an increase in circadian entrainment. Depression scores (as measured by CSDD and CMAI) were also significantly reduced | [75] |
| Intervention light was blue–white compact fluorescent light bulb (Philips Lighting, Eindhoven, The Netherlands), 13,000 K. Control lighting was yellow–white compact fluorescent bulb (Philips Lighting, Eindhoven, The Netherlands), 2700 K | Devices: Daysimeter (Lighting Research Center, Rensselaer Polytechnic Institute, NY, USA) Outcomes: TSD, SOL, SE and number of sleep bouts | 6 weeks of modest doses of blue–white light appeared to improve sleep in caregivers but not in persons with dementia | [76] |

**Table 1. Summary of the studies described in this review (cont.).**

| Study (year) | Objective | Subjects | Diagnosis (type of dementia) | Methods/protocol |
|---|---|---|---|---|
| Figueiro *et al.* (2016) | Evaluate the effectiveness of a self-luminous light table designed to provide high circadian light stimulation during daytime hours for regulating circadian rhythms and improving sleep and behavior outcomes in nursing home residents with ADRD | 6 subjects (4 females,2 males; mean ± SD age: 84 ± 8.6 years) living in a nursing home | ADRD with associated moderate impairment (mean ± SD BIMS score = 5.3 ± 1.9) | Single-case design study. Activity–rest patterns and light–dark exposures measured for entirety of baseline (1 week), lighting intervention (4 weeks) and post-intervention (4 weeks) periods The lighting intervention was placed on a timer and activated between 07:00 and 18:00. Subjects sat at the table for all meals, and subjects remained seated at the table for most of the day. Measures of sleep quality, depression and agitation collected using standardized questionnaires at baseline, at the end of the 4-week lighting intervention, and 4 weeks after the lighting intervention was removed (three questionnaire sessions in total) |

In the study by Ancoli-Israel *et al.* [60], bright light exposure (2500 lux at the cornea) did not produce significant improvement in nighttime sleep and daytime alertness. The authors suggested that these negative results were due to the subjects' level of dementia. They did, however, find that increasing the exposure to morning light made the circadian rhythm of rest–activity significantly more robust in this population. Dowling *et al.* [71] found no effect of light treatment alone on nighttime sleep, daytime wake or rest–activity rhythms, but were able to demonstrate an increase in daytime wakefulness and activity levels with concurrent administration of oral melatonin. Sloane *et al.* [76] showed a positive effect of a tailored light treatment (bluish white light, correlated color temperature = 13,000 K) designed to deliver 400 lux at the cornea, in self-reported sleep in caregivers of ADRD patients living at home, but not in sleep and behavior of the patients themselves. Van Hoof *et al.* [73] did not find a significant effect on behavior and tympanic temperature rhythms in dementia patients after they were exposed to 500 lux at the cornea of a 17,000 K light source. Burns *et al.* [72] exposed dementia patients to either 10,000 lux at the cornea (treatment condition) or 100 lux at the cornea (control) of light for four consecutive weeks and measured agitation and depression scores as well as actigraphy. Results showed very little effect of light treatment on agitation and depression and only a slight indication that sleep was improved, especially in the winter months. Colenda *et al.* [56] used light visors to deliver 2000 lux of light at the cornea each morning for 10 days to community-dwelling AD patients and found no consistent biological effect of the light treatment on sleep, noting that perhaps light visors may be an inadequate means of providing light treatment.

Given that not all of the published studies yielded positive outcomes, it is not surprising that a Cochrane review conducted in 2002, which included only five studies that met their inclusion criteria (relevant, randomized controlled trials in which bright light treatment was compared with a control group for the effect on managing sleep, behavioral, mood or cognitive disturbances), concluded that there was not enough evidence to assess the value of light treatment for people with dementia [78]. A recent Cochrane review conducted in 2014 included eight studies that met their inclusion criteria and that had available data for their analyses. Authors, again, concluded that there is not enough evidence to justify the use of light therapy to improve sleep and behavior in ADRD patients [79].

One explanation for the mixed results may be that current light therapy approaches for sleep disturbances in older adults are not formalized in terms of amount, spectrum, timing, distribution and duration, leading, in some cases, to a weakening of the therapeutic effects of light. In fact, Forbes *et al.* in their latest Cochrane review [79] analyzed studies that used a variety of light therapy approaches. None of the studies

| Lighting devices/levels | Measurement devices/outcome measures | Findings | Ref. |
|---|---|---|---|
| Custom-designed self-luminous LED light table (Lighting Research Center, Rensselaer Polytechnic Institute, NY, USA) delivering 1190 lux perpendicular to plane of table surface and 2780 lux at table's center | Devices: custom-designed self-luminous light table and Daysimeter (Lighting Research Center, Rensselaer Polytechnic Institute, NY, USA).<br>Outcomes: questionnaires were PSQI, CSDD and CMAI. Objective measures of sleep, rest–activity patterns, light–dark exposures and circadian stimulus | Percent sleep significantly increased during the intervention weeks. Compared to baseline, light exposure significantly reduced depression (CSDD) and agitation (CMAI) scores, which remained significantly lower after postintervention compared to baseline, suggesting a carryover effect of the lighting intervention. PSQI scores suggested improved sleep quality compared to baseline, but difference did not reach statistical significance | [77] |

included in their analyses controlled or measured the actual light dose received by participants. Pooling data from these studies where the various light delivery methods were used without any control of how much light subjects were actually being exposed to during the intervention may have affected the outcomes of their analyses. This is an important point to consider, because in studies where carefully controlled light stimulus was delivered, a positive impact of light on sleep quality of those with ADRD was in fact found [75,80]. Another possibility for these mixed results is the variation in care between the various facilities. While light–dark patterns are important for circadian entrainment, which in turn is important for good sleep quality, many other factors (e.g., activity and feeding times) may affect behavior in this population.

In general, the only formalized recommendations for light treatment (amount, spectrum, timing and duration) are those used to treat symptoms of seasonal affective disorder (SAD). Sufferers of SAD are expected to be exposed to 10,000 lux at the cornea of white light for 30 min or 2500 lux at the cornea of the same white light for 2 h. Those recommendations were developed based on studies conducted by Lewy *et al.* [10] nearly 30 years ago, when the knowledge of nonvisual effects of light on circadian regulation was very limited. While this recommendation has been successful in treating symptoms of SAD, clinicians often find that patients have a difficult time complying with the recommendations because the high light levels of white light can be very uncomfortable, resulting in squinting and gaze aversion. Since much more is now known about the retinal phototransduction mechanisms that drive the circadian system, there is a much higher likelihood that more modest and more comfortable light doses can be used as a reliable, nonpharmacological treatment for circadian sleep disturbances so commonly found in those with ADRD. In fact, Figueiro *et al.* [75] recently showed a positive effect of a more comfortable lighting intervention designed to maximally affect the circadian system in ADRD patients living in long-term care facilities, and even more recently demonstrated that innovative delivery methods can be employed to ensure patients' compliance with such interventions [77]. The same principle can be used in any population suffering from circadian sleep disorders. It is important to note, however, that light therapy may not be as effective – or may not be effective at all – at treating noncircadian sleep disorders, such as insomnia, also commonly experienced by older adults.

## Future perspective

Although there is not a complete understanding of the effects of light on the aging circadian system outside laboratory conditions, it is clear that a distinct, repeated pattern of light and dark is needed to help maintain the synchrony between the aging circadian system and the solar day. [81] With that in mind, it is important to design

separate lighting systems for daytime and nighttime activities. Lighting in the built environment should provide high circadian light stimulation during the day and low circadian stimulation at night, good visual performance (e.g., reading) during waking hours and low-level nightlights that enable safe navigation through the space and that minimize sleep disruption.

During daytime hours, light levels in indoor environments should be high enough to activate the circadian system. This can be accomplished with the use of daylight or electric lighting systems. Care should be taken to avoid introducing glare in the space. The combination of high levels of 'cool' light sources (a minimum of 400–600 lux at the cornea and CCT >5000 K) during the day and 'warm' light sources (no more than 80–100 lux at the cornea; CCT <2800 K) in the evening promotes circadian entrainment better than current lighting system designs (i.e., constant dim light). As detailed in Figueiro [81], the cool light source at that light level for a 1-h duration will provide good circadian stimulation. A similar lighting specification was shown to improve restless behavior in patients with dementia [82].

In addition to impacting the aging circadian system, light can also impact the aging perceptual system. Sight and visibility are important for good perception; therefore, it is important to provide light that will support the perceptual system. At night, light levels should be dim and allow for safe navigation, especially in bedrooms and bathrooms [81,83–85]. It is also important to encourage older people to increase their exposure to light–dark patterns as part of their wellness program. Daylight can be added into the home environment, especially in long-term care settings, by adding skylights, clerestory windows and sunrooms.

Future clinical research should focus on testing these new lighting schemes that are designed to specifically deliver a strong daytime circadian stimulation to ADRD patients. But, it is imperative that the light doses that subjects are receiving be measured. It is also important to point out that light therapy that promotes better sleep may not only improve the quality of life for those with ADRD and their caregivers, but it may also have an important clinical relevance. Recent research suggests that sleep quantity and quality may be directly linked to ADRD [86,87]; other more recent studies suggest that cortical responses are reduced with accrued sleep debt [88], which is common in those who suffer from circadian misalignment. Therefore, studies should be designed to remove barriers to the use of effective nonpharmacological therapies that increase sleep efficiency. Finally, when assessing the effect of light on sleep and behavior in ADRD patients, it is important to also consider other environmental factors and comorbidities (e.g., ophthalmological diseases [89]) and other therapies, such as cognitive behavior therapy and exercise [74]. Future studies should investigate whether light can be more effective at treating sleep and behavior disturbances if combined with some of these other therapies.

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