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Academy of Architecture for Health

AIA Knowledge Community

2020

Mission of the *Academy Journal*

As the official journal of the AIA Academy of Architecture for Health (AAH), this publication explores subjects of interest to AAH members and others involved in the fields of health care architecture, planning, design, and construction. The goal is to promote awareness, educational exchange, and advancement of the overall project delivery process, building products, and medical progress that affect all involved in those fields.

About AAH

AAH is one of 21 member communities of The American Institute of Architects (AIA). AAH is unique in the depth of its collaboration with professionals from all sectors of the health care community, including physicians, nurses, hospital administrators, facility planners, engineers, managers, health care educators, industry and government representatives, product manufacturers, health care contractors, specialty subcontractors, allied design professionals, and health care consultants.

AAH currently consists of approximately 7,000 members. Its mission is to provide knowledge which supports the design of healthy environments by creating education and networking opportunities for members of – and those touched by – the healthcare architectural profession.

Please visit our website at aia.org/aah for more about our activities. Please direct any inquiries to aah@aia.org.

Academy Journal editor

Regan Henry, RA, PhD, LEED AP, LSSBB

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About the journal

As we start the 23rd year of the Academy Journal, published by the AAH Knowledge Community, this edition includes articles that support the enhancement of the built environment for health care.
As the official publication of the Academy, the Journal publishes articles of particular interest to AIA members and the public involved in the fields of health care architecture, planning, design, research, and construction. The goal has always been to expand and promote awareness, educational exchange, and advancement of the overall project delivery process, building products, and medical progress that affects all involved in those fields.

Articles are submitted to, and reviewed by, an experienced, nationally diverse editorial review committee (ERC) of medical and architectural professionals. Over the years, the committee has reviewed hundreds of submissions, responded to writers' inquiries, and encouraged and assisted writers in achieving publication. In its over 20-year history, the Journal has provided valuable opportunities for new and seasoned authors from the architecture and health care professions, including architects, physicians, nurses, other health care providers, academics, research scientists, and students from the US and foreign countries.

Published articles have explored a broad range of medical topics, including research trends, the future of health care architecture, cardiac care, future and evolving technology, patient rooms and patient safety, lighting design for health care, psychology, workplace design, cancer care environments, emergency care, women's and children's care, and various health care project delivery methods.

We encourage graduates who have received health care research scholarships and others involved with research within the health care architecture field to submit their research to the Journal for publication consideration. We will continue to develop a cross-referenced article index and a broader base of writers and readers. The deadline for the 2021 call for papers is May 27, 2021.

Since the late 1990s, this free publication has expanded to include worldwide distribution. And we are proud to report that as our readership continues to grow, it also expands internationally. Readers have viewed the Journal online from the US, Canada, Europe, the Caribbean, Asia, Africa, India, and Saudi Arabia, just to name a few. The Journal is available to the 94,000 AIA members and the public on the AIA website at aia.org/aah.

Special thanks to AIA for its continued support and hard-working staff and to the many volunteers who have contributed to our growing and continued success including Doug Paul and Southern Ellis for their leadership on behalf of the AIA and AAH. I would especially like to thank the other members of the 2020 ERC: Donald L. Myers, AIA, NCARB; Angela Mazzi, AIA, ACHA, EDAC; Sharon Woodworth, FAIA, FACHA; Dale A. Anderson, AIA, NCARB, LEED AP BD+C, CSBA, EDAC, MBA, GGP, ACHA; and Erin Mcnamara, EDAC. As always, we appreciate your feedback, comments and suggestions by emailing aah@aia.org.

Letter from the editor

2020 has been a difficult year.

The COVID-19 global pandemic has impacted our lives in a profound way. Collectively, people have gained a new appreciation for the power of a virus and its potential impact to our hospitals, economy, and social networks. Our friends and colleagues in healthcare have been tested in a manner that will have meaningful consequences on the industry and what it means to dedicate one's life to care for another. Many of us have waited on news from scientists, cheered for progress, and followed FDA trials with great anticipation and awareness for the enormity of the pursuit. Never have I felt so appreciative of the people, networks, supply chains, and infrastructure that support our healthcare system.

As this journal goes to print, the dealth toll, in the United States, for COVID-19 stands around 300,000 and the first vials of vaccine are being administered to people on the frontline. There is great hope that we are at the beginning of the end of this saga, but still reeling from the exposed vulnerabilities to both the healthcare industry and society at large. We have learned so much and yet there is so much left to understand about the last ten months.

I look to 2021 and the years to follow as an opportunity to both celebrate our successes and learn from our missteps so that we are better and more prepared for future generations of frontline workers, patients in need, and vital equipment suppliers. There is great promise at the juncture between healthcare, design, and research. I applaud Orlando Maione for his vision to foster this journal and thank him for his many years of leadership and service as The Academy Journal Editor. We close out this year with an appreciation for the work accomplished and excitement for what is to come. I look forward to exploring with and learning from you in the years to come.

Cheers to a happy new year.

Regan Henry, RA, PhD, LEED AP, LSSBB
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Tailored lighting intervention to promote entrainment in myeloma transplant patients—A field study

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ABSTRACT

Light is the major synchronizer of circadian rhythms to the local position on Earth. Exposure to light at night and insufficient exposure to light early in the day has been linked with poor sleep and a host of health and behavioral problems. Myeloma patients spend two to three weeks inside their hospital rooms during transplantation, which can lead to circadian disruption due to low light levels typically found indoors. We performed a pilot study to determine whether circadian-effective light could promote entrainment in myeloma patients. We hypothesized that an increase in circadian entrainment would lead to reduced cancer-related fatigue, depression, and sleep problems. Fifty-five participants were randomly assigned to two lighting interventions that used freestanding luminaires to deliver either circadian-effective light (n=27) or circadian-ineffective light (n=28) throughout the hospital room between 7am and 10am during every day of hospitalization. Results showed an increase in nocturnal melatonin levels and an improvement in sleep in those receiving the circadian-effective (active) intervention. The present results suggest that light can be used to help myeloma transplant patients maintain circadian entrainment while hospitalized. Design guidelines and implementation tips to increase circadian stimulus in hospital rooms are also discussed.

Introduction to circadian rhythms

The 24-hour pattern of light and dark that accompanies Earth's axial rotation regulates the physiology and behavior of almost every living thing on the planet. For humans, light reaching the retinas is the primary exogenous (external) cue that synchronizes or entrains the body's endogenous (internal) master biological clock and thus our circadian rhythms to the solar day, essentially telling our bodies to do the right thing at the right time. Other secondary exogenous cues include social activity (Salgado-Delgado, Tapia Osorio, Saderi, & Escobar, 2011), meal times (Wehrens et al., 2017), and physical activity (Moreno et al., 2019), among others. Sleeping and waking, feeding and fasting, the regulation of core body temperature, blood pressure, and the secretion of hormones are just a few examples of circadian rhythms. The term "circadian," coined by biologist Franz Halberg (1959), is a blended word derived from the Latin circa ("about") and dies ("day").

Because the human circadian system free-runs at an average period of about 24.2 hours—slightly longer than the solar day—a daily cue of light and dark is required to advance the circadian system by about 10–15 minutes, thereby continually resetting the master biological clock to maintain circadian entrainment (Czeisler et al., 1981).

But what light gives, light can also take away. Exposure to light at the wrong time, or not receiving enough light at the right time, has become increasingly common since the advent of electric lighting over a century ago. Exposure to light at night, and even a complete reversal of the day-night pattern in the case of night-shift workers, are now facts of life in our 24-hour society. But exposure to light at night and insufficient exposure to light early in the day has been linked with poor sleep and a host of health and behavioral problems. Long-term disruption of the daily cycle of light and dark can lead to chronic disruption of the circadian system, which has been associated with metabolic dysregulation (leading to weight gain, obesity, and type 2 diabetes) (Depner, Stothard, & Wright, 2014), certain forms of cancer (Samuelsson, Bovbjerg, Roecklein, & Hall, 2018), depression (Germain & Kupfer, 2008), and other maladies (Abbott, Malkani, & Zee, 2018).

Lighting characteristics affecting the circadian clock

Four characteristics of light and light exposures play crucial roles in the circadian system's response.

1. The amount or level of light received at the eyes: "Is it bright or dim?"
   Early circadian research in animal (Sharma & Daan, 2002; Takahashi, DeCoursey, Bauman, & Menaker, 1984) and human (Boivin, Duffy, Kronauer, & Czeisler, 1994, 1996) models found that varying light levels at the eyes differentially affect the nighttime suppression of the hormone melatonin (the release of which prepares the body for sleep) and zeitgeber time, either advancing or delaying the timing of the

circadian system's 24-hour cycle. The greater the amount of light, the greater the melatonin suppression and the greater the advance/delay in zeitgeber time (A zeitgeber is an environmental synchronizing cue, like light, for example).

2. The spectral properties of the light experienced: "Is it warm (reddish) or cool (bluish)?" Because it has a peak spectral sensitivity that occurs around 460 nm (Brainard et al., 2001; Thapan, Arendt, & Skene, 2001), the human circadian system is maximally sensitive to short-wavelength ("bluish") light (e.g., 465–475 nm), which in turn is maximally effective for stimulating the circadian system. For the same photopic light level, a light source emitting greater short-wavelength light content will be more effective for activating the master biological clock than a light source emitting more long-wavelength ("reddish") light. Because light of all wavelengths evokes an alerting response at any time of day or night, long-wavelength light is especially useful for promoting alertness during the afternoon and evening without disrupting the circadian system (Figueiro, Bierman, Plitnick, & Rea, 2009; Plitnick, Figueiro, Wood, & Rea, 2010).

3. The timing and duration of light exposures: "When, and for how long, was I exposed to light?" Humans are more sensitive to light stimulus during the evening hours, at night, and in the early morning compared to the middle of the day (Figueiro, 2017; Jewett et al., 1997). Experiencing high levels of light later in the day and in the evening will delay the timing of the master biological clock, causing us to fall asleep later than our usual bedtime and leading us to sleep in or feel tired on waking the next day. Conversely, experiencing high levels of short-wavelength light early in the morning will advance the timing of the master biological clock, causing us to fall asleep earlier and wake up earlier the next day. Morning light will also reset the master biological clock, helping to entrain our circadian system to the solar day. Again, because the circadian system free-runs at a period that is generally longer than the 24-hour solar day, we need light early in the day to maintain regular bedtimes. Longer exposure durations are also more effective at suppressing melatonin (Nagare, Rea, Plitnick, & Figueiro, 2019).

4. A person's history of light exposures: "How much light have I received over the past 24 hours?" While it is well accepted that exposure to higher light levels results in greater melatonin suppression at night, research also shows that a one-day light exposure of 200 lux suppresses melatonin to a greater degree when it is preceded by three days of dim light (< 1 lux) compared to three days of the same 200-lux source (Smith, Schoen, & Czeisler, 2004). While the visual system's response to light is virtually instantaneous, the circadian system's response to light is cumulative (Figueiro, Nagare, & Price, 2018).

When appropriately specified according to these four characteristics, light exposures can be tailored to remedy symptoms of seasonal affective disorder (Golden et al., 2005), increase sleep efficiency in older adults (including those with Alzheimer's disease) (Fetveit, Skjerve, & Bjorvatn, 2003; Figueiro et al., 2014; Van Someren, Kessler, Mirmiran, & Swaab, 1997); promote circadian rhythmicity in premature infants (Rivkees, 2003); increase alertness at all times of day and night (Badia, Myers, Boecker, Culpepper, & Harsh, 1991; Cajochen et al., 2005; Cajochen, Zeitzer, Czeisler, & Dijk, 2000); and improve alertness and selected measures of performance (Sahin & Figueiro, 2013; Sahin, Wood, Plitnick, & Figueiro, 2014).

Light and myeloma transplant patients

Multiple myeloma (MM) patients undergoing autologous stem cell transplantation (ASCT) experience clinically significant negative sequelae that affect prognosis and survival as well as quality of life. These sequelae include increases in production of inflammatory cytokines, higher rates of neutropenic fever, and higher symptom burden (e.g., depression, pain). These symptoms are associated with circadian rhythm disruption (CRD), a disruption in naturally occurring 24-hour cycles of hormone secretion, temperature, and rest-activity. CRD increases production of pro-inflammatory cytokines, causing a cascade of negative side effects, including higher symptom burden and increased risk of neutropenic fever. CRD has been associated with decreased prognosis and survival.

To address these concerns, we performed a pilot research study to determine whether circadian-effective light could promote entrainment (as measured by an increase in nighttime melatonin levels) in MM patients. For the purpose of this contribution, we limited our focus on the range of negative sequelae experienced by patients undergoing ASCT, and we hypothesized that an increase in circadian entrainment would lead to reductions in cancer-related fatigue, depression, and sleep problems among MM patients, both during and after ASCT hospitalization.

Methods and materials

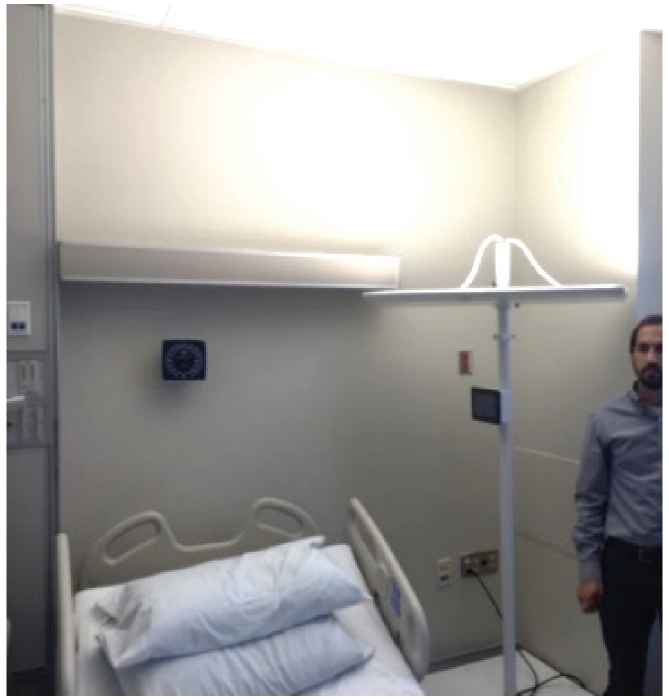
Tailored lighting intervention

Fifty-five participants were randomly assigned to two lighting interventions delivering either circadian-effective light (n=27) or circadian-ineffective light (n=28) throughout the participants' rooms from 7–10am daily during hospitalization. The circadian-effective light stimulus was specified following the Rea et al. model (Rea, Figueiro, Bullough, & Bierman, 2005). Following the model, the measured spectral irradiance at the cornea is first converted into circadian light (CL_A), which reflects the spectral sensitivity of the circadian system. CL_A is then transformed into a circadian stimulus (CS) value, which reflects the absolute sensitivity of the circadian system. Thus, CS is a measure of the effectiveness of the retinal light for stimulating the human circadian system, as measured by acute melatonin suppression, from threshold (CS = 0.1, or 10% melatonin suppression) to saturation (CS = 0.7, or 70% melatonin suppression). It is important to note that, strictly speaking, CL_A and CS characterize the spectral and absolute sensitivities of light-induced nocturnal melatonin suppression as regulated by the master biological clock. It is assumed, however, that CL_A and CS characterize the spectral and absolute sensitivities of the entire human circadian system because the biological clock plays a key role in regulating a wide variety of daily bodily functions, such as hormone production and sleep. For the purpose of the present study, it was assumed that the spectral and absolute sensitivities of nocturnal melatonin suppression are similar to those controlling light-induced changes of circadian timing and circadian entrainment.

Acuity Brands developed an experimental freestanding luminaire that used 3000 K, ambient "warm white" light to deliver either a CS of 0.3 for the circadian-effective ("active") bright white light (BWL) intervention (approximately 1000 lux at the participants' eye level) or a CS of 0.1 for the comparison ("inactive") dim white light (DWL) intervention (approximately < 50 lux at the participants' eye level). A warm light source was chosen for both interventions to make the space appear less institutional and more residential.

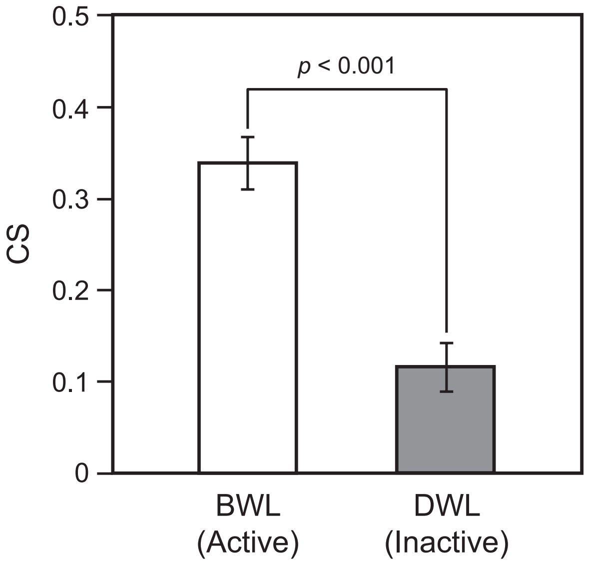
The interventions used ambient lighting to illuminate the entire room (Figure 1), rather than a light box, to reduce patient burden and promote compliance. The luminaires remained in the patients' hospital rooms for the duration of the study. They were pre-programmed to deliver the respective lighting interventions and turn on every morning from 7am to 10am. To ensure that the lighting intervention was successful, Daysimeters (Figueiro, Hamner, Bierman, & Rea, 2013), a type of light meter calibrated to measure CS, were placed behind the patient's bed and on the luminaire. The participants wore a third Daysimeter as a pendant during waking hours for their entire hospital stay. Figure 2 shows that, as hypothesized, those in the BWL intervention received significantly ($p < 0.001$) higher CS values than those in the DWL intervention.

FIGURE 1



The experimental luminaire used to deliver the BWL (active) and DWL (inactive) interventions in participants' rooms.

FIGURE 2



Mean CS values recorded by the bed Daysimeter when the lighting was programmed to be energized (7–10am). (The error bars represent standard deviation.)

Outcome measures

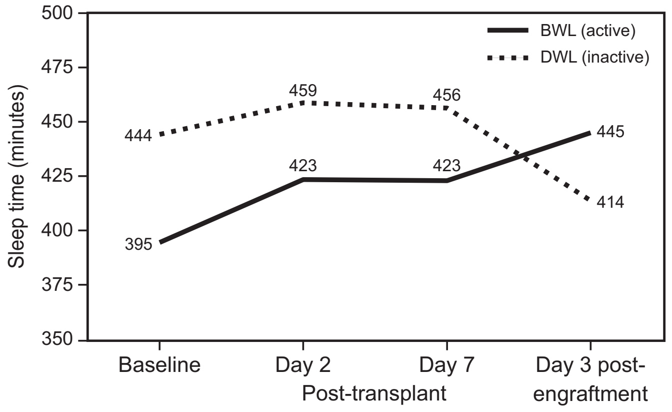
Outcome measures were assessed prior to hospitalization (baseline), on days 2 and 7 post-transplant, and on day 3 of engraftment (i.e., when the body accepts the transplanted stem cells). Day 3 of engraftment is usually the day before discharge from the hospital. We collected 24-hour actigraphy data to obtain objective measures of sleep; nighttime urine to obtain 6-sulfatoxymelatonin (6-SMT), a melatonin metabolite; and questionnaire data on participants' depression and cancer-related fatigue. Only those outcomes that yielded statistically significant (or nearly significant) results from the lighting interventions are reported below, thus excluding the participants' statistically nonsignificant subjective assessments of depression and cancer-related fatigue.

Results

Sleep

At baseline, the participants in the BWL (active) intervention reported shorter (but statistically nonsignificant) sleep time than those in the DWL (inactive) intervention. The sleep time of those in the BWL (active) intervention steadily lengthened over the course of the study, however, while the sleep time of participants in the DWL (inactive) intervention plateaued from days 2 through 7 and actually decreased by day 3 of engraftment compared to baseline. This was reflected in a nearly significant ($F_{4,120}$ = 2.31; p = 0.063) lighting intervention × assessment time (baseline vs. day 3 of engraftment) interaction for sleep time (Figure 3). Overall, sleep time decreased through time in participants who received the DWL (inactive) intervention, while it increased in those who received the BWL (active) intervention.

FIGURE 3



Sleep time in minutes at baseline (before hospitalization), day 2 after transplant, day 7 after transplant, and day 3 of engraftment (generally the day before discharge from the hospital). Sleep time decreased in those exposed to the DWL (inactive) intervention, while it increased in those exposed to the BWL (active) intervention.

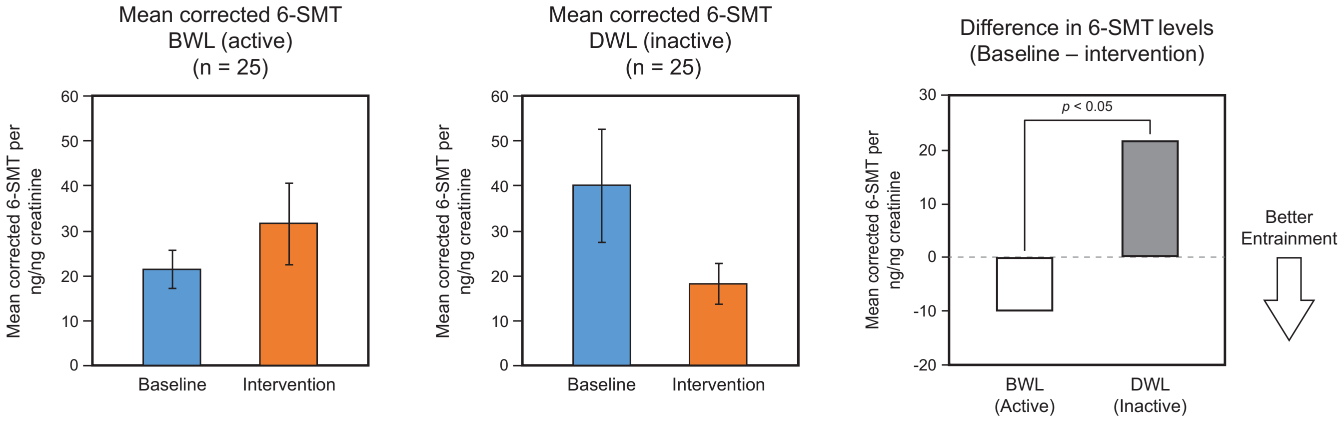
Creatinine-corrected urinary melatonin-sulfate (6-sulfatoxymelatonin, 6-SMT)

There was a steep decline in 6-SMT levels for patients in the DWL (inactive) intervention, while 6-SMT levels for participants in the BWL (active) intervention were slightly higher, suggesting that the latter intervention maintained circadian entrainment during hospitalization. Due to the small sample size, the lighting intervention × assessment time interaction for 6-SMT levels approached significance ($F_{1,47}$ = 3.92; p = 0.054) but was not adequately powered to reach significance at the 0.05 level (Figure 4). The difference between baseline and intervention was significantly greater ($p < 0.05$) after exposure to the BWL (active) intervention than after exposure to the DWL (inactive) intervention.

Discussion

The results reported here suggest that implementing a robust light-dark pattern in hospital rooms can promote circadian entrainment and improve sleep in MM patients. Given that improved sleep has been linked to a series of health benefits, the active lighting intervention employed in this study could be an important first step in improving patient health, especially among patients who are hospitalized for extended stays, such as those receiving ASCT or those being treated for stroke or traumatic brain injury in rehabilitation units.

FIGURE 4



Mean-corrected 6-SMT levels, which increased in those receiving the BWL (active) intervention and decreased in those receiving the DWL (inactive) intervention. (The error bars represent standard deviation.)

Although it was not confirmed by the present study, providing ambient circadian-effective light in hospital rooms has been shown to reduce symptoms resulting from disruption of the circadian system that are commonly experienced by hospitalized and survivor cancer patients, including cancer-related fatigue (Ancoli-Israel et al., 2012; Johnson et al., 2018; Redd et al., 2014) and depression (Desautels, Savard, Ivers, Savard, & Caplette-Gingras, 2018; Sun et al., 2014). Previous studies have also shown that bright white light delivered by light box (Litebook) reduced cancer-related fatigue and improved sleep efficiency among cancer survivors following completion of their treatment and release from the hospital (Wu et al., 2018).

These results should be interpreted in the context of a few important study limitations. Perhaps most importantly, the study is preliminary and was conducted with a small sample size. In our preliminary data, we observed a marginally significant (p = 0.059) lighting intervention × assessment time interaction for melatonin. The effect size for this interaction is f^2 = 0.09, which is midway between a "small" and "moderate" effect size using the Cohen (1988) characterization. Moreover, since the results do not include post-hospitalization assessments, it is not yet known whether circadian-effective light delivered during hospitalization affects cancer treatment symptoms during the post-transplant period. Larger clinical trials measuring immune function biomarkers should be performed to extend these preliminary results.

While we are still learning about the benefits of lighting design for the circadian system, the present research and the work of others in the field clearly show that avoiding disturbance from light at night and creating a robust light-dark pattern can stimulate the circadian system, promote daytime alertness, and yield benefits for health and well-being. Despite the study's limitations, our findings nonetheless demonstrate that this easy-to-deliver, low-cost intervention improves sleep and circadian entrainment among MM bone marrow transplant patients during hospitalization.

Implementation tips

A patient's stay in the hospital can range from a day to a few months. No matter the duration, lighting in a patient's room can positively impact the patient's psychological and physiological recovery. In addition to providing good visibility, low glare, and good color rendering, lighting for patient rooms should be designed to promote circadian entrainment by delivering high CS during the day and low CS in the evening to increase patients' sleep times and improve their sleep quality.

Circadian-effective lighting for designers and manufacturers

Circadian-effective lighting to promote circadian entrainment requires designers to create a CS schedule that, at a minimum, delivers a pattern of bright light during the day and dim light in the evening. Although not necessarily required, the CS schedule can mimic the spectral properties and illuminance levels that are provided by the daily solar cycle. As indicated in the UL Design Guidelines (Underwriters Laboratories Inc., 2019), the circadian-effective lighting design process includes six essential steps:

Step 1: Establish a circadian-effective lighting design criterion (e.g., CS = 0.3).

Step 2: Select a luminaire type (e.g., direct/indirect).

Step 3: Select a light source (e.g., 3000 K LED).

Step 4: Perform photometrically realistic software (e.g., AGi32) calculations for the building space.

Step 5: Calculate CS from the vertical illuminance (measured at the eye) and the light source's spectral power distribution (SPD).

Step 6: Determine whether the lighting system meets the circadian-effective lighting design criterion; repeat steps 2–6 if necessary.

The space's occupants are the most important considerations in circadian-effective lighting design and the establishment of a design criterion CS for step 1. One important thing to consider is the occupants' ages. Age-related changes to the eye can render CS prescriptions for elementary school students inappropriate for office workers or seniors in eldercare environments. It is also very important to take into account where, when, and how the occupants use the space. Because hospital beds can be angled to position patients upright (viewing the wall and windows) or fully reclined (viewing the ceiling), room lighting should accommodate both patient orientations. It is thus very important that lighting systems can provide appropriate CS levels without glare of direct views of luminaires in both positions. When specifying CS for patient rooms, it is recommended that illuminance be measured at the patients' eyes while sitting up at a 45° tilt and while laying down looking straight up at the ceiling (Figure 5). Establishing these parameters helps designers determine appropriate CS exposures and the timing of their delivery.

FIGURE 5

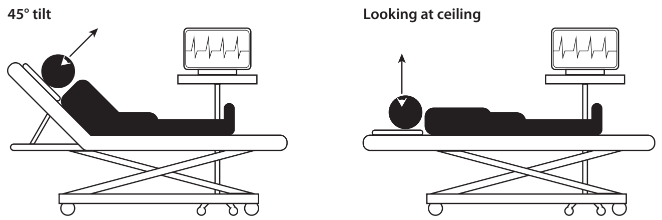


Figure 5: Light measurements in hospital rooms may need to be taken at 45° or 90° (horizontal) to account for patients' orientation(s) in bed.

As shown in Figure 6, several major lighting characteristics that are encompassed by design steps 2 and 3 contribute to how well the system can deliver the criterion CS:

- The light source's spectral power distribution (SPD), which represents the radiant power emitted by a light source as a function of wavelength, is crucial for circadian lighting design. Higher short-wavelength content generally delivers greater CS values for the same amount of photopic (lux) light at the eye.
- Vertical illuminance levels, or light at the occupants' eyes.
- The light source's intensity distribution, whether from a single luminaire or multiple luminaires, will determine how the light is distributed into the room and ultimately to the eye and work plane.
- Duration of exposure plays an important role in how the circadian system responds to a given light source. It should be noted that CS > 0.3 is based on a 1-hour exposure.

Once the fundamentals of occupant(s) and lighting characteristics are taken into account, the lighting design can be extended to incorporate information about the room to accomplish the aims of step 4. Lighting design software and manufacturers' published photometric data files (IES, or *.ies) are especially valuable tools for step 5, as they permit simulated predictions of luminaire performance, CS delivery, lighting power density (LPD), and energy usage.

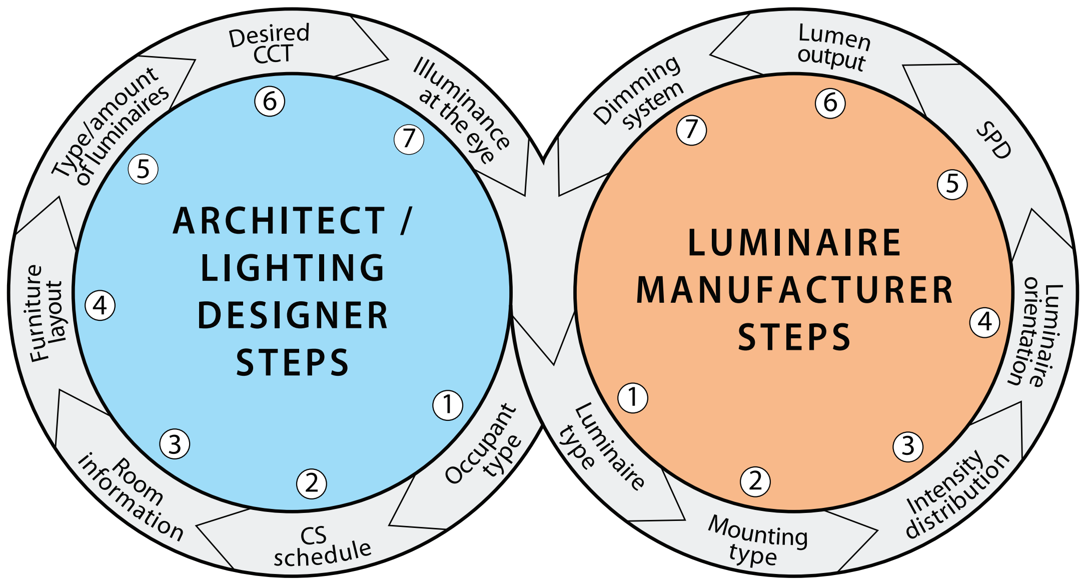
Finally, when you reach step 6, it is important to avoid viewing the design process as a hard-and-fast series of steps that inevitably lead to the desired outcome. Successful designs actually grow from a dynamic interchange between architects, lighting designers, and manufacturers, all of whom fit together as important pieces of the puzzle. And like all designs, several iterations may be required, with input from all of these actors, to achieve optimal CS performance. If your design does not meet the criterion CS, try altering one of the components from the diagram in Figure 6. Keep in mind that the design must meet all visual criteria established by organizations such as the Illuminating Engineering Society.

Putting it all together

The varied intricacy and difficulty of visual tasks performed in patient rooms also call for varying lighting specifications. Generally, the higher the light level, the faster the visual system can convert optical stimuli into usable information (Chan et al., 2012). For tasks involving objects that are very small or have low contrast with their environment, high horizontal illuminance (measured on the workplane) levels (> 1000 lux) are required. For tasks involving larger objects or those that have suitable contrast with the environment, where increased light levels provide diminishing returns, low-level ambient lighting (100–200 lux) is acceptable (Chan et al., 2012).

Glare caused by electric lighting, daylight, reflective surfaces, and other sources can be avoided by selecting the appropriate luminaires and making interior design changes within the space. Indirect light sources can be

FIGURE 6



	ARCHITECT / LIGHTING DESIGNER STEPS		MANUFACTURER STEPS
①	Occupant type is the most important factor when determining the lighting for circadian design.	①	The type of luminaire will determine the effectiveness of getting the desired CS at the eye.
②	Create a 24-hour CS schedule that promotes circadian entrainment. CS should be ≥ 0.3 during the day (or at least for 3 hours in the morning) and < 0.1 starting 2 hours prior to bedtime.	②	Luminaires can be plugged into an outlet or mounted to the ceiling, walls, or furniture. Creating layers of light can provide the desired aesthetics, task illumination, and circadian-effective light.
③	Information about the size of the room, ceiling height, and material and surface reflectances will aid in determining what type of luminaires are needed and how light will interact with the space.	③	Intensity distribution provides an idea of how light will be distributed in the space.
④	Furniture layout can determine the occupant's field of view and allow for strategic placement of luminaires. If the occupant's location is not known, opt to maintain the same vertical CS levels throughout the entire space.	④	Luminaires can be classified as direct, indirect, direct/indirect, semi-direct, or semi-indirect.
⑤	Determine what type and how many luminaires are needed in the space based on room dimensions, and the luminaire's intensity distribution and lumen output.	⑤	Light sources rated as having the same CCT usually have different SPDs, and therefore will result in different CS. Always use the SPD (not the CCT) and light level at the eye to calculate CS.
⑥	CCT impacts the atmosphere of a space by providing a warm or cool feel, but for circadian-effective light, you will need to use the SPD provided by the manufacturer or measured in the space.	⑥	Lumen output helps determine how many luminaires will be needed to achieve the target CS. High lumen output luminaires will help reach the target CS with fewer luminaires, but may cause glare.
⑦	CS is calculated using vertical illuminance and the light source's SPD. To modulate CS during the day, either use a tunable system that changes the SPD and light level or simply use a dimmer to reduce evening light exposure.	⑦	Separate lighting switches, dimming controls, and/or a color-tunable system helps with achieving the target CS, which is higher during the day (especially in the morning) and lower in the evening and at night.

Summary of considerations that designers and manufacturers need to account for when designing for the circadian system.

used to avoid glare while still meeting visual and circadian requirements, and other sources of glare can be reduced or eliminated by selecting nonreflective finishes for surfaces, altering window locations, and using window blinds. Finally, color rendering is another important consideration for luminaire selection, as accurate color perception is crucial for caregivers' patient diagnoses.

Patient room lighting that provides a robust 24-hour light-dark pattern can have profound positive effects on patient recovery. Lighting for patient rooms should be designed to promote circadian entrainment, providing high CS during the day and low CS in the evening, in order to increase patients' sleep times and improve their sleep quality. Nighttime lighting should be conducive to patient sleep while also accommodating visiting families and permitting caregivers to perform their tasks. Circadian lighting schemes have been shown to be effective for improving sleep in hospital ICU patients (Engwall, Fridh, Johansson, Bergbom, & Lindahl, 2015).

Due to the nature of the population, their temporary removal from the familiar surroundings of home, and the dynamic nature of the hospital environment, circadian rhythm disruption is not uncommon among hospital patients. The patient's health conditions (e.g., psychiatric and neurodegenerative diseases) can also lead to circadian rhythm disruption, as can critical illness generally (Oldham, Lee, & Desan, 2016). Environmental influences such as ambient lighting in patient rooms can also disrupt the circadian system. A study conducted in three intensive care units found that patients typically sleep for only about 6 hours over a given 24-hour period, with only half of that sleep time occurring at night (Gabor et al., 2003). Improving and increasing nighttime sleep by promoting entrainment of a patient's circadian rhythm to a robust light-dark cycle can lead to improved health outcomes (Engwall et al., 2015).

The recommended lighting pattern (Table 1 and Figure 7) for patients over the course of the day begins with a CS of 0.3 in the morning for at least 3 hours, drops to a CS of 0.2 for the midafternoon, and then drops once again to a CS of 0.1 in the late afternoon through the evening until bedtime. After bedtime, room lighting should be turned off, and nightlights should be added to permit safe navigation. This schedule can be accomplished using lighting designs that employ either static or tunable CCT systems.

TABLE 1

Time of day	CS
7–10am	0.3
10–11am	0.3 → 0.2
11am–4pm	0.2
4–5pm	0.2 → 0.1
5pm–end of day	0.1

Recommended lighting pattern for hospital patient rooms to promote circadian entrainment.

FIGURE 7

Figure 7: Simulations of hospital room lighting delivering high CS in the morning (left), medium CS in the afternoon (middle), and low CS in the evening (right).

References

Abbott, S. M., Malkani, R. G., & Zee, P. C. (2018). Circadian disruption and human health: A bidirectional relationship. *European Journal of Neuroscience, 51(1)*, 567-583. doi:10.1111/ejn.14298

Ancoli-Israel, S., Rissling, M., Neikrug, A., Trofimenko, V., Natarajan, L., Parker, B. A., . . . Liu, L. (2012). Light treatment prevents fatigue in women undergoing chemotherapy for breast cancer. *Support Care Cancer*, 20(6), 1211-1219. doi:10.1007/s00520-011-1203-z

Badia, P., Myers, B., Boecker, M., Culpepper, J., & Harsh, J. R. (1991). Bright light effects on body temperature, alertness, EEG and behavior. *Physiology and Behavior, 50(3)*, 583-588. doi:10.1016/0031-9384(91)90549-4

Boivin, D. B., Duffy, J. F., Kronauer, R. E., & Czeisler, C. A. (1994). Sensitivity of the human circadian pacemaker to moderately bright light. *Journal of Biological Rhythms*, 9(3-4), 315-331. doi:10.1177/074873049400900311

Boivin, D. B., Duffy, J. F., Kronauer, R. E., & Czeisler, C. A. (1996). Dose-response relationships for resetting of human circadian clock by light. *Nature*, 379(6565), 540-542. doi:10.1038/379540a0

Brainard, G. C., Hanifin, J. P., Greeson, J. M., Byrne, B., Glickman, G., Gerner, E., & Rollag, M. D. (2001). Action spectrum for melatonin regulation in humans: Evidence for a novel circadian photoreceptor. *Journal of Neuroscience*, 21(16), 6405-6412. doi:10.1523/JNEUROSCI.21-16-06405.2001

Cajochen, C., Munch, M., Kobialka, S., Krauchi, K., Steiner, R., Oelhafen, P., . . . Wirz-Justice, A. (2005). High sensitivity of human melatonin, alertness, thermoregulation, and heart rate to short wavelength light. *Journal of Clinical Endocrinology and Metabolism*, 90(3), 1311-1316. doi:10.1210/jc.2004-0957

Cajochen, C., Zeitzer, J. M., Czeisler, C. A., & Dijk, D. J. (2000). Dose-response relationship for light intensity and ocular and electroencephalographic correlates of human alertness. *Behavioural Brain Research*, 115(1), 75-83. doi:10.1016/s0166-4328(00)00236-9

Chan, M. C., Spieth, P. M., Quinn, K., Parotto, M., Zhang, H., & Slutsky, A. S. (2012). Circadian rhythms: From basic mechanisms to the intensive care unit. Critical Care Medicine, 40(1), 246-253. doi:10.1097/CCM.0b013e31822f0abe

Cohen, J. (1988). Statistical Power Analysis for the Behavioral Sciences (2nd ed.). Hillsdale, NJ: L. Erlbaum Associates.

Czeisler, C. A., Richardson, G. S., Coleman, R. M., Zimmerman, J. C., Moore-Ede, M. C., Dement, W. C., & Weitzman, E. D. (1981). Chronotherapy: Resetting the circadian clocks of patients with delayed sleep phase insomnia. *Sleep*, 4(1), 1-21. doi:10.1093/sleep/4.1.1

Depner, C. M., Stothard, E. R., & Wright, K. P. (2014). Metabolic consequences of sleep and circadian disorders. *Current Diabetes Reports*, 14(7), 507. doi:10.1007/s11892-014-0507-z

Desautels, C., Savard, J., Ivers, H., Savard, M.-H., & Caplette-Gingras, A. (2018). Treatment of depressive symptoms in patients with breast cancer: A randomized controlled trial comparing cognitive therapy and bright light therapy. *Health Psychology*, 37(1), 1-13. doi:10.1037/hea0000539

Engwall, M., Fridh, I., Johansson, L., Bergbom, I., & Lindahl, B. (2015). Lighting, sleep and circadian rhythm: An intervention study in the intensive care unit. *Intensive and Critical Care Nursing*, *31(6)*, 325-335. doi:10.1016/j.iccn.2015.07.001

Fetveit, A., Skjerve, A., & Bjorvatn, B. (2003). Bright light treatment improves sleep in institutionalised elderly—An open trial. *International Journal of Geriatric Psychiatry, 18(6)*, 520-526. doi:10.1002/gps.852

Figueiro, M. G. (2017). Disruption of circadian rhythms by light during day and night. *Current Sleep Medicine Reports*, 3(2), 76-84. doi:10.1007/s40675-017-0069-0

Figueiro, M. G., Bierman, A., Plitnick, B., & Rea, M. S. (2009). Preliminary evidence that both blue and red light can induce alertness at night. *BMC Neuroscience, 10,* 105. doi:10.1186/1471-2202-10-105

Figueiro, M. G., Hamner, R., Bierman, A., & Rea, M. S. (2013). Comparisons of three practical field devices used to measure personal light exposures and activity levels. *Lighting Research & Technology*, *45(4)*, 421-434. doi:10.1177/1477153512450453

Figueiro, M. G., Nagare, R., & Price, L. L. A. (2018). Non-visual effects of light: How to use light to promote circadian entrainment and elicit alertness. *Lighting Research & Technology, 50(1)*, 38-62. doi:10.1177/1477153517721598

Figueiro, M. G., Plitnick, B. A., Lok, A., Jones, G. E., Higgins, P., Hornick, T. R., & Rea, M. S. (2014). Tailored lighting intervention improves measures of sleep, depression, and agitation in persons with Alzheimer's disease and related dementia living in long-term care facilities. *Clinical Interventions in Aging, 9,* 1527-1537. doi:10.2147/CIA.S68557

Gabor, J. Y., Cooper, A. B., Crombach, S. A., Lee, B., Kadikar, N., Bettger, H. E., & Hanly, P. J. (2003). Contribution of the intensive care unit environment to sleep disruption in mechanically ventilated patients and healthy subjects. *American Journal of Respiratory and Critical Care Medicine, 167(5)*, 708-715. doi:10.1164/rccm.2201090

Germain, A., & Kupfer, D. J. (2008). Circadian rhythm disturbances in depression. *Human Psychopharmacology, 23(7)*, 571-585. doi:10.1002/hup.964

Golden, R. N., Gaynes, B. N., Ekstrom, R. D., Hamer, R. M., Jacobsen, F., Suppes, T., . . . Nemeroff, C. B. (2005). The efficacy of light therapy in the treatment of mood disorders: A review and meta-analysis of the evidence. *American Journal of Psychiatry, 162(4)*, 656-662. doi:10.1176/appi.ajp.162.4.656

Halberg, F. (1959). [Physiologic 24-hour periodicity; General and procedural considerations with reference to the adrenal cycle]. *Internationale Zeitschrift für Vitaminforschung. Beiheft., 10,* 225-296.

Jewett, M. E., Rimmer, D. W., Duffy, J. F., Klerman, E. B., Kronauer, R. E., & Czeisler, C. A. (1997). Human circadian pacemaker is sensitive to light throughout subjective day without evidence of transients. *American Journal of Physiology, 273*(5 PT 2), R1800-1809. doi:10.1152/ajpregu.1997.273.5.r1800

Johnson, J. A., Garland, S. N., Carlson, L. E., Savard, J., Simpson, J. S. A., Ancoli-Israel, S., & Campbell, T. S. (2018). Bright light therapy improves cancer-related fatigue in cancer survivors: A randomized controlled trial. *Journal of Cancer Survivorship*, *12(2)*, 206-215. doi:10.1007/s11764-017-0659-3

Moreno, J. P., Crowley, S. J., Alfano, C. A., Hannay, K. M., Thompson, D., & Baranowski, T. (2019). Potential circadian and circannual rhythm contributions to the obesity epidemic in elementary school age children. *International Journal of Behavioral Nutrition and Physical Activity, 16(1)*, 25. doi:10.1186/s12966-019-0784-7

Nagare, R., Rea, M. S., Plitnick, B., & Figueiro, M. G. (2019). Nocturnal melatonin suppression by adolescents and adults for different levels, spectra, and durations of light exposure. *Journal of Biological Rhythms, 34(2),* 178-194. doi:10.1177/0748730419828056

Oldham, M. A., Lee, H. B., & Desan, P. H. (2016). Circadian Rhythm Disruption in the Critically Ill: An Opportunity for Improving Outcomes. *Critical Care Medicine, 44(1)*, 207-217. doi:10.1097/CCM.0000000000001282

Plitnick, B., Figueiro, M. G., Wood, B., & Rea, M. S. (2010). The effects of red and blue light on alertness and mood at night. *Lighting Research & Technology, 42(4)*, 449-458. doi:10.1177/1477153509360887

Rea, M. S., Figueiro, M. G., Bullough, J. D., & Bierman, A. (2005). A model of phototransduction by the human circadian system. *Brain Research Reviews, 50(2)*, 213-228. doi:10.1016/j.brainresrev.2005.07.002

Redd, W. H., Valdimarsdottir, H., Wu, L. M., Winkel, G., Byrne, E. E., Beltre, M. A., . . . Ancoli-Israel, S. (2014). Systematic light exposure in the treatment of cancer-related fatigue: A preliminary study. *Psychooncology, 23(12)*, 1431-1434. doi:10.1002/pon.3553

Rivkees, S. A. (2003). Developing circadian rhythmicity in infants. *Pediatrics*, 112(3), 373-381. doi:10.1542/peds.112.2.373

Sahin, L., & Figueiro, M. G. (2013). Alerting effects of short-wavelength (blue) and long-wavelength (red) lights in the afternoon. *Physiology and Behavior, 116-117*, 1-7. doi:10.1016/j.physbeh.2013.03.014

Sahin, L., Wood, B., Plitnick, B., & Figueiro, M. G. (2014). Daytime light exposure: Effects on biomarkers, measures of alertness, and performance. *Behavioural Brain Research, 274*, 176-185. doi:10.1016/j.bbr.2014.08.017

Salgado-Delgado, R., Tapia Osorio, A., Saderi, N., & Escobar, C. (2011). Disruption of circadian rhythms: A crucial factor in the etiology of depression. *Depression Research and Treatment, 2011*, 839743-839743. doi:10.1155/2011/839743

Samuelsson, L. B., Bovbjerg, D. H., Roecklein, K. A., & Hall, M. H. (2018). Sleep and circadian disruption and incident breast cancer risk: An evidence-based and theoretical review. *Neuroscience and Biobehavioral Reviews, 84*, 35-48. doi:10.1016/j.neubiorev.2017.10.011

Sharma, V. K., & Daan, S. (2002). Circadian phase and period responses to light stimuli in two nocturnal rodents. *Chronobiology International, 19(4),* 659-670. doi:10.1081/cbi-120005389

Smith, K. A., Schoen, M. W., & Czeisler, C. A. (2004). Adaptation of human pineal melatonin suppression by recent photic history. *Journal of Clinical Endocrinology and Metabolism, 89(7),* 3610-3614. doi:10.1210/jc.2003-032100

Sun, J.-L., Wu, S.-C., Chang, L.-I., Chiou, J.-F., Chou, P.-L., & Lin, C.-C. (2014). The relationship between light exposure and sleep, fatigue, and depression in cancer outpatients: Test of the mediating effect. *Cancer Nursing, 37(5)*, 382-390. doi:10.1097/ncc.0000000000000106

Takahashi, J. S., DeCoursey, P. J., Bauman, L., & Menaker, M. (1984). Spectral sensitivity of a novel photoreceptive system mediating entrainment of mammalian circadian rhythms. *Nature, 308*, 186-188.

Thapan, K., Arendt, J., & Skene, D. J. (2001). An action spectrum for melatonin suppression: Evidence for a novel non-rod, non-cone photoreceptor system in humans. *The Journal of Physiology, 535,* 261-267. doi:10.1111/j.1469-7793.2001.t01-1-00261.x

Underwriters Laboratories Inc. (2019). Design Guideline for Promoting Circadian Entrainment with Light for Day-Active People, Design Guideline 24480, Edition 1. Retrieved from shopulstandards.com/ProductDetail.aspx?productId=UL24480_1_D_20191219

Van Someren, E. J. W., Kessler, A., Mirmiran, M., & Swaab, D. F. (1997). Indirect bright light improves circadian rest-activity rhythm disturbances in demented patients. *Biological Psychiatry, 41(9)*, 955-963. doi:10.1016/S0006-3223(97)89928-3

Wehrens, S. M. T., Christou, S., Isherwood, C., Middleton, B., Gibbs, M. A., Archer, S. N., . . . Johnston, J. D. (2017). Meal timing regulates the human circadian system. *Current Biology, 27(12)*, 1768-1775.e1763. doi:10.1016/j.cub.2017.04.059

Wu, L. M., Amidi, A., Valdimarsdottir, H., Ancoli-Israel, S., Liu, L., Winkel, G., . . . Redd, W. H. (2018). The effect of systematic light exposure on sleep in a mixed group of fatigued cancer survivors. *Journal of Clinical Sleep Medicine, 14(01),* 31-39. doi:10.5664/jcsm.6874

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