Lights Should Support Circadian Rhythms: Evidence-Based Scientific Consensus

Martin Moore-Ede (mme@circadian.com)
Circadian Light Research Center https://orcid.org/0000-0002-9557-0609
David E. Blask
Tulane University School of Medicine
Sean W. Cain
Monash University https://orcid.org/0000-0002-8385-1550
Anneke Heitmann
Circadian Light Research Center https://orcid.org/0000-0002-9560-2906
Randy J. Nelson
West Virginia University https://orcid.org/0000-0002-8194-4016

Research Article

Keywords: circadian, light, blue, health, cancer, diabetes, obesity, melatonin, spectral distribution, LED lights

Posted Date: January 19th, 2023

DOI: https://doi.org/10.21203/rs.3.rs-2481185/v1

Abstract

For over a hundred years, the lighting industry has primarily been driven by illumination aesthetics, energy efficiency and product cost with little consideration of the effects of light on health. The recent widespread replacement of traditional light sources by blue-enriched LED lights has heightened concerns about the disruption of the blue-sensitive human circadian system by these LED lights and their impact on the multiple health disorders linked to circadian disruption. Despite these health concerns, less than 0.5% of the lighting sold today modifies spectral content and intensity between day and night. We report that 248 scientists, with a total of 2,697 peer-reviewed publications on light and circadian clocks since 2008, reached consensus on 24 statements about the impact of light on circadian rhythms and health based on accumulated scientific evidence, including support for the widespread introduction of circadian lighting and warning labels on blue-enriched LED lights indicating that they “maybe harmful if used at night”.

Introduction

The timing, duration, intensity and spectral composition of ocular light exposure have a profound effect on circadian clocks and rhythmic physiological processes. For the first 10,000 generations of *Homo sapiens*, the contrast between bright daylight (10,000–100,000 lux) and nocturnal darkness (0.0001–0.1 lux) robustly entrained the human circadian timing system to the Earth’s 24-hour rotation [1]. However, for less than four generations over the past century, the natural 24-hour cycle of daylight and darkness at night has been replaced in the developed world by electric light. Approximately 90% of our time is now spent indoors [2] under electric light that is typically 100 times dimmer during the day than natural daylight and 1,000 times brighter after dusk than even the brightest moonlight.

The circadian disruption of the timing of physiological and biochemical processes that occurs in the absence of robust entrainment by light has been extensively studied over the past 50 years [1, 3]. Inadequate exposure to light during daytime hours and exposure to electric light at night have been associated with a wide range of health disorders [4–6]. By 2007, there was sufficient evidence for the World Health Organization (WHO) International Agency for Research on Cancer (IARC) [6] to classify night shift work with circadian disruption as a probable (group 2A) human carcinogen based on human epidemiological studies and research with animal models. Since then, a large number of studies have linked circadian disruption to the etiology of a wide range of health disorders, including obesity, diabetes, heart disease, reproductive and psychiatric disorders and certain endocrine-sensitive cancers, such as breast cancer and prostate cancer [5–9].

Since 2013, electric lighting has been transformed by the introduction of highly energy efficient LED (light-emitting diode) lights and the progressive regulatory-enforced phase outs of other less efficient light sources, including incandescent, halogen, CCFL, and fluorescent lights [10–12]. However, most LED lights optimize efficacy by utilizing a blue die, which increases the relative percentage of blue content in the white light spectrum compared to other sources of light [13]. Exposure to blue-enriched LED light in the evening and night hours raises significant health issues because the human circadian system is highly sensitive to blue light near the 480 nm peak sensitivity of the melanopic intrinsically photosensitive retinal ganglion cells (ipRGCs) in the human retina. Even small amounts of blue content in white LED light during nocturnal hours can cause circadian disruption and increase the risk of health disorders [14–15].

The obvious solution is to provide blue-rich light during the daytime to help entrain circadian rhythms and blue-depleted light at night to protect against circadian disruption [16]. However, the $100 billion/year lighting industry has been very slow to abandon the 24-hour unrestricted use of conventional blue-die LED light. Less than 0.5% of the lights sold today have any circadian supportive properties [17].

Since the main justification by the lighting industry for ignoring the health hazards of blue-die LED light is the claim that circadian science is not yet mature, we tested this assumption by surveying the leading scientists in this field. We sought to determine if a scientific consensus can be documented between currently active scientists, which would clarify the core findings of circadian lighting science, and the evidence-based conclusions that can currently be reached from this science.

Methods

Survey Population:

A search of PubMed with the terms “circadian” + “light” identified 10,002 peer-reviewed scientific articles published between April 1, 2008 and April 1, 2022 by 29,455 unique authors. We identified all the authors out of this sample who had published four or more peer-reviewed articles, and we built an email list of 2,154 authors using their most recent identifiable email addresses on academic and publisher websites. A total of 1,156 (53.7%) of these scientific authors received and opened an email invitation to participate in the Scientific Consensus Survey on Circadian Light, and 248 (21.5%) of the recipients completed the survey (21.5%).

The 248 respondents had published an average of 11 (median: 7; range: 4–68) peer-reviewed articles that met the “circadian” + “light” criterion in the 2008–2022 study period. A total of 111 of the respondents (44.8%) were based in North America, 96 (38.7%) were based in Europe, 17 (6.9%) were based in South America, 12 (4.8%) were based in Australia/New Zealand, 10 (4.0%) were based in Asia, and the remaining 2 (0.8%) were based in Africa. The publications of each of the 248 respondents were reviewed to classify the respondents’ primary research models: human research (studies including human subjects and human-related reviews and translational research) and nonhuman research (studies including mammalian, other vertebrate species, invertebrates, plants and cellular/molecular systems). There were 103 researchers who predominantly performed human research and 145 researchers who performed non-human research only. Subgroup comparisons of the frequencies of the response options for each statement were conducted using chi-square tests.

Survey Design

Forty statements were developed for testing by the authors of this article. Thirty were potential factual conclusions summarizing the scientific literature with the following response options: 1) Don’t Know, 2) No Evidence, 3) Limited Evidence, 4) Good Evidence or 5) Well-Established. Five were potential practical advice conclusions about lighting with the same set of response options. The five remaining statements were potential expert policy statements based on the scientific literature with the following response options: 1) Don’t Know, 2) Strongly Disagree, 3) Disagree, 4) Agree or 5) Strongly Agree.

Definition of Consensus

In a large and diverse group of scientists addressing complex scientific questions, achieving unanimous agreement is not feasible or expected. In Delphi health policy consensus studies, where there are several rounds of feedback between participants enabling participants to change their minds and refine their answers based on new data and the judgments of their peers, 70–75% agreement is often accepted as consensus [18–19]. In this single iteration survey, with no opportunity to revise answers based on feedback from other participants, we defined a consensus as when two-thirds of the respondents (66.7%) supported the statement. The responses “Good Evidence” and “Well-Established” were combined for evidence-based statements, and “Agree” and “Strongly Agree” were combined for expert policy statements. The “Don’t Know” option on each tested statement allowed scientists to abstain from the evaluation of the strength of evidence on specific topics with which they were not familiar and therefore to be excluded from the consensus calculation on those topics.

Results

Consensus was reached on 24 out of the 40 test statements, listed in Table 1.

The first set of consensus statements related to the role of regular exposure to bright light during the day (daylight or bright indoor electric light) in enhancing the robust entrainment of circadian rhythms and maintaining health. There was strong consensus that robust circadian rhythms are important for health (95.1%) and that disrupting circadian rhythms can cause ill health (98.4%). There was also consensus that increasing daytime light intensity indoors within the normal indoor intensity range of 50 to 500 lux enhances circadian entrainment and strengthens circadian rhythms (70.5%), improves daytime alertness and reduces sleepiness (74.7%). The majority (59.1%) of respondents indicated there was “good evidence” or it was “well established” that increasing indoor daytime light intensity enhances sleep at night, but this did not reach the two-thirds consensus level.

Table 1
Statements on which consensus was reached

CONSENSUS STATEMENTS	%
Robust circadian rhythms are important for maintaining good health.	95.1
Disrupting circadian rhythms can cause ill-health.	98.4
Regular daily exposure to daylight enhances circadian entrainment and strengthens circadian rhythms.	95.1
Regular daily exposure to daylight can enhance sleep at night.	86.4
Increasing indoor light intensity during daytime[a]:	
… can enhance circadian entrainment and strengthen circadian rhythms	70.5
… can improve daytime alertness and reduce sleepiness	74.6
Increasing indoor light intensity at night[b]:	
… increases the disruption of circadian rhythms	90.6
… increases the suppression of nocturnal melatonin production	94.6
Repetitive and prolonged exposure to light at night bright enough to cause circadian disruption:	
… increases the risk of breast cancer in women	67.6
… increases the risk of obesity and diabetes	74.7
… increases the risk of sleep disorders	87.4
Human Sensitivity to Blue Wavelengths	
The sensitivity peak of the ipRGC melanopic receptors in the human retina is approximately 480nm in the blue part of the visible spectrum.	97.2
The most potent wavelengths for circadian entrainment are 460–495 nm blue light near to the sensitivity peak of the ipRGC melanopic receptors.	92.7
Blue-enriched (460-495nm) light in the evening (during the three hours before bedtime)[c]	
… disrupts nocturnal sleep more than blue-depleted light at the same intensity.	70.3
… phase delays the circadian system more than blue-depleted light at the same intensity.	75.5
… disrupts circadian rhythms more than blue-depleted light at the same intensity.	70.1
Exposure to 460-495nm blue light at night:	
… suppresses melatonin production	90.6
… disrupts circadian rhythms	84.8

CONSENSUS STATEMENTS	%
PRACTICAL APPLICATIONS	
Light used in the evening (during the three hours before bedtime) should have as little blue content as practically possible	82.5
The risk of circadian disruption during the three hours before bedtime can be reduced either by 1) dimming indoor lighting which may compromise the ability to perform visual work tasks, or 2) reducing the blue content of indoor lighting maintained at the intensity required for visual tasks	72.0
EXPERT OPINION	
The blue content of light entering the eyes is much more important in determining circadian health outcomes than the correlated color temperature (CCT) of the light source.	86.7
Increasing the energy efficiency of lights is desirable, but not if it increases the risks of causing circadian disruption and serious illness.	93.2
LED lights with high 460-495nm blue content should carry the warning label “maybe harmful if used at night”	79.1
There is now sufficient evidence to support the widespread introduction of circadian lighting that adjusts light intensity and blue content across day and night to maintain robust circadian entrainment and health	85.9
There is significant variation in individual sensitivity to light, therefore circadian lighting should be optimized where possible using personalized solutions.	90.6
a. Assume a range of normal indoor light intensities of 50–500 desktop lux, and assume comparable prior light exposure history	
b. Assume a range of normal indoor light intensities of 50–500 lux, and assume comparable prior light history	
c. Assume light bright enough (300–500 desktop lux) to read a fine-print book	

The second set of consensus statements related to the impact of electric light at night. There was strong consensus that increasing indoor light intensity at night increases the disruption of circadian rhythms (90.6%) and increases the suppression of nocturnal melatonin production (94.6%). There was also consensus that repetitive and prolonged exposure to light at night bright enough to cause circadian disruption increases the risk of breast cancer in women (67.6%), obesity and diabetes (74.7%), and sleep disorders (87.4%). The majority of respondents agreed that there was good support (“good evidence” or “well established”) that repetitive and prolonged exposure to light at night that was bright enough to cause circadian disruption increases cardiovascular disease (60.7%) and depression (60.8%), but these did not reach the two-thirds consensus level.

The third set of consensus statements related to the impact of the blue wavelengths in white illumination on the human circadian system. There was strong consensus that “the sensitivity peak of the ipRGC melanopic receptors in the human retina is approximately 480 nm in the blue part of the visible spectrum”

(97.2%) and that “the most potent wavelengths for circadian entrainment are 460–495 nm blue light near to the sensitivity peak of the ipRGC melanopic receptors” (92.7%).

There was also consensus that “blue-enriched (460–495 nm) light in the evening (during the three hours before bedtime) disrupts nocturnal sleep more (70.3%), phase delays the circadian system more (75.5%) and disrupts circadian rhythms more (70.1%) than blue-depleted light at the same intensity. There was also strong consensus that exposure to 460–495 nm blue light at night suppresses melatonin production (90.6%) and disrupts circadian rhythms” (84.9%).

The fourth set of consensus statements related to the practical application of circadian science to lighting. There was consensus that “light used in the evening (during the three hours before bedtime) should have as little blue content as practically possible” (82.5%) and that “the risk of circadian disruption during the three hours before bedtime can be reduced either by 1) dimming indoor lighting which may compromise the ability to perform visual work tasks, or 2) reducing the blue content of indoor lighting maintained at the intensity required for visual tasks” (72.0%).

The participants were also asked their expert opinion about the implications of circadian science for the design and implementation of lighting. There was consensus that “the blue content of light entering the eyes is much more important in determining circadian health outcomes than the correlated color temperature (CCT) of the light source” (86.7%) and “increasing the energy efficiency of lights is desirable, but not if it increases the risks of causing circadian disruption and serious illness (93.2%).

Summarizing their expert opinion, there was consensus that “there is now sufficient evidence to support the widespread introduction of circadian lighting that adjusts light intensity and blue content across day and night to maintain robust circadian entrainment and health (85.9%), and “LED lights with high 460-495nm blue content should carry the warning label “maybe harmful if used at night” (79.1%). They also reached consensus that “there is significant variation in individual sensitivity to light, therefore circadian lighting should be optimized where possible using personalized solutions” (90.6%).

Table 2
Statements on which consensus (support by two-thirds of the respondents) was not reached

NO CONSENSUS	%
Increasing indoor light intensity during daytime[d]	
… can enhance sleep at night	59.9
Repetitive and prolonged exposure to light at night bright enough to cause circadian disruption:	
… increases the risk of prostate cancer in men	42.4
... increases the risk of cardiovascular disease	60.7
… increases the risk of depression	60.8
Increasing the 460-495nm blue content of indoor light during daytime[e]	
… can enhance circadian entrainment	62.6
… can enhance sleep at night.	47.2
Repetitive and prolonged exposure to 460-495nm blue-enriched light during nocturnal hours[f]	
… increases the risk of breast cancer in women.	47.5
… increases the risk of prostate cancer in men.	32.9
… increases insulin resistance and may impair glucose tolerance.	50.6
… increases the risk of cardiovascular disease.	43.9
… increases the likelihood of depression	45.8
… increases the risk of sleep disorders	65.4
PRACTICAL APPLICATIONS	
Light used during overnight shifts should have as little blue content as practically possible.	54.9
Using bright blue-enriched light during overnight shifts may increase alertness, but the risks of causing circadian disruption and serious illness are severe.	56.4
Lighting with high blue content during the day and minimal blue content during the evening and night protects the health of workers in 24/7 workplaces	50.8
d. Assume a range of normal indoor light intensities of 50–500 desktop lux, and assume comparable prior light exposure history	
e. Assume a IES standard indoor light intensity of 300 desktop lux in a room without windows, Assume comparable prior light history	

NO CONSENSUS	%
Increasing indoor light intensity during daytime[d]	
f. Assume IES standard lighting of 300–500 desktop lux required to perform normal work tasks	

Table 2 lists the test statements for which two-thirds (66.6%) consensus was not reached. Comparisons between the response frequencies of the two subgroups - respondents whose research was all or partly human research and respondents who did not do any human research - showed that there was overall good agreement between the two subgroups, with significant differences being found in the evaluation of only four of the forty statements. Three of these statements are as follows:

- Increasing indoor light intensity at night increases the suppression of nocturnal melatonin production
- Exposure to 460–495 nm blue light at night suppresses melatonin production
- There is significant variation in individual sensitivity to light; therefore, circadian lighting should be optimized where possible using personalized solutions.

had a higher consensus score in the human than in the nonhuman researchers (but reached consensus in both subgroups).

One statement:

- Repetitive and prolonged exposure to light at night bright enough to cause circadian disruption increases the risk of cardiovascular disease in the non-human research subgroup.

obtained slightly more support (and reached the consensus criterion in the nonhuman research subgroup).

Discussion

Among the 248 scientist participants with multiple peer-reviewed publications in the circadian light field, there was strong consensus that "*there is now sufficient evidence to support the widespread introduction of circadian lighting that adjusts light intensity and blue content across day and night to maintain robust circadian entrainment and health*". This conclusion was supported by consensus on 23 other specific statements about the disruptive effects on circadian rhythms and health of especially blue-enriched light at night and the lack of adequate light during the day. These scientific experts also agreed that "*LED lights with high 460–495 nm blue content should carry the warning label "maybe harmful if used at night*"

Blue-enriched LED lights have gained dominance in the lighting market because they can provide 100–200 lumens per watt energy efficient lighting compared to 5 lumens/watt for incandescent and 50–60 lumens/watt for fluorescent lights [16]. This breakthrough invention in lighting using gallium nitride (GaN) crystals was recognized by the 2014 Nobel Prize for Physics awarded to three Japanese scientists, Isamu Akasaki, Hiroshi Amano and Shuji Nakamura [13]. Blue-enriched LEDs have grown from less than 1% market share in 2013 to greater than 80% market share in 2022, aided by government policies and utility rebates that incentivize the replacement of traditional lighting with LEDs to achieve energy savings and further promoted by regulatory bans on incandescent, halogen and fluorescent lighting [10–12].

Over a similar timeframe, substantial evidence has accumulated that unrestricted use of blue-enriched LED lights may be hazardous to human health. The circadian clocks that regulate the timing of physiological processes, with molecular mechanisms defined by the 2017 Nobel Prize in Physiology or Medicine winners Jeffrey Hall, Michael Rosbash and Michael Young [20], are uniquely sensitive to blue light [21]. This is because the melanopic intrinsically photosensitive retinal ganglion cells (ipRGCs) that entrain circadian clocks to the environmental light dark cycle have a peak sensitivity to ~ 480 nm blue light [22]. Even small amounts of blue content in white LED light during nocturnal hours can cause circadian disruption and increase the risk of health disorders [15]. Exposure to electric light at night has been associated with obesity, diabetes, cardiovascular disease, and certain cancers, including breast and prostate cancer. Multiple scientific panels of the WHO International Agency for Research on Cancer (IARC) (23], American Medical Association [8] and NIH National Toxicology Program [9] have determined that exposure to light at night and insufficient light during the day increase the risk of breast cancer and other disorders.

We undertook this consensus survey because the lighting industry has been very slow to introduce circadian lighting, claiming that the science is not sufficiently mature and that there is more research to be done. Academic opinions can vary widely in any new field, and there is a temptation for the lighting industry to pick the message they want to hear. Therefore, it is preferable to test whether there is a consensus across the broad community of scientists in the circadian field. The population we invited to participate in the Consensus Survey were all active scientists who have published four or more peer-reviewed articles identified in a PubMed search with the terms “circadian” + “light” since 2008 (i.e. after the first report of the WHO IARC carcinogenic findings [6]) and for whom we were able to identify an email address. There was no preselection of potential participants other than by these criteria. However, scientists who have changed employment so their email address was out of date, who were not corresponding authors with their email address published in their articles, or who were not sufficiently familiar with the English language in which the survey was conducted may be underrepresented in the sample.

Failure to reach two-thirds consensus on the other 15 tested statements does not mean they are not factually correct. For 8 of these statements, the majority (50.6–65.4%) of respondents ranked them as “good evidence/well established”, but a sufficient fraction of respondents ranked them as having “limited evidence” to bring the overall consensus below the two-thirds (66.6%) support criterion. In this group of active scientists engaged in seeking funding for their research, there may be a bias towards a more conservative “limited evidence” answer, which justifies the need for more research. Another possible reason is a lack of familiarity with the recent literature on a specific issue since PubMed citations with the terms "circadian" + "light" currently exceed 1,000/year.

Advances in spectral engineering have enabled the development of blue-depleted LED lights for nocturnal use and 480 nm blue-enriched LED lights for daytime without significantly compromising color or energy efficiency [16]. This means there is little excuse not to use lighting, which modifies blue content and intensity over the day-night cycle. Recent demonstrations of significant returns on investments in circadian lighting, such as a 43% reduction in elderly falls and reduced depression and agitation in nursing homes [24, 25] and improvement of sleep and reduction of delirium in intensive care patients [26, 27], will help transition circadian lighting from a "nice to have" to a "must have".

References

1. Moore-Ede MC., Sulzman FM., and Fuller CA. *The Clocks That Time Us: Physiology of the Circadian Timing System.* Cambridge, MA: Harvard University Press; 1982.
2. Klepeis NE, Nelson WC, Ott WR, *et al*. The National Human Activity Pattern Survey (NHAPS): a resource for assessing exposure to environmental pollutants. *J Expo Anal Environ Epidemiol* 2001; **11**: 231-252.
3. Bedrosian TA, Fonken LK, & Nelson RJ. Endocrine Effects of Circadian Disruption. *Annu. Rev. Physiol.* 2016; **78**: 1.1–1.23.
4. Blask DE, Dauchy RT, Brainard GC, & Hanifin JP. Circadian Stage-Dependent Inhibition of Human Breast Cancer Metabolism and Growth by the Nocturnal Melatonin Signal: Consequences of Its Disruption by Light at Night in Rats and Women. Integrative Cancer Therapies. 2009; **8:** 347–353.
5. Kim M, Vu TH, Maas MB, *et al.* Light at night in older age is associated with obesity, diabetes, and hypertension. Preprint 2022; https://academic.oup.com/sleep/advance-article/doi/10.1093/sleep/zsac130/6608953?login=true)
6. Burns AC, Windred DP, Rutter MK *et al*. Low daytime light and bright night-time light are associated with psychiatric disorders: an objective light study in >85,000 UK Biobank participants. Preprint 2022; https://www.medrxiv.org/content/10.1101/2022.10.16.22280934v1.full.pdf
7. Straif K, Baan R, Grosse Y, *et al.* Carcinogenicity of shift-work, painting, and fire-fighting. *Lancet Oncol 2007;* **8:** 1065-1066.
8. Stevens RG. Brainard GC, Blask DE, *et al*. Adverse health effects of nighttime lighting: comments on American Medical Association policy statement. *Am. J. Prev. Med*. 2013; **45**: 343–346.
9. U.S. National Toxicology Program. NTP Cancer hazard assessment report on night shift work and light at night. National Toxicology Program, U.S. Department of Health and Human Services. 2021; https://ntp.niehs.nih.gov/ntp/results/pubs/cancer_assessment/lanfinal20210400_508.pdf
10. U.S. Department of Energy 2022-05-09 Energy Conservation Program: Definitions for General Service Lamps; Final rule. 2022; https://www.regulations.gov/document/EERE-2021-BT-STD-0012-0022

11. California AB 2208 Kalra Assembly. Fluorescent lamps: sale and distribution: prohibition. 2022; https://legiscan.com/CA/rollcall/AB2208/id/1201402
12. European Union 2018; https://ec.europa.eu/info/news/new-lightbulb-rules-will-enable-household-energy-savings-and-help-reduce-ghg-emissions-2018-aug-31_en
13. Gibney E, Nobel for blue LED that revolutionized lighting. *Nature.* 2014; **514**: 152–153.
14. Zielinska-Dabkowska KM. Make lighting healthier. *Nature.* 2018; **553**: 274-276.
15. Cain SW, McGlashan EM, Vidafar P, *et al*. Evening home lighting adversely impacts the circadian system and sleep. *Scientific Reports.* 2020; **10:** 19110.
16. Moore-Ede MC. LEDs must spectrally balance illumination, circadian health, productivity, and energy efficiency. LED Magazine 2021 https://www.ledsmagazine.com/lighting-health-wellbeing/article/14199941/ideal-led-lighting-must-balance-multiple-objectives-magazine
17. DataBridge, *Global Circadian Rhythm Lighting Market – Industry Trends and Forecast to 2028. 2021;* https://www.databridgemarketresearch.com/reports/global-circadian-rhythm-lighting-market
18. de Raaff CAL, Gorter-Stam MAW, de Vries N, *et al.* Perioperative management of obstructive sleep apnea in bariatric surgery: a consensus guideline. *Surg Obes Relat Dis. 2017:* **13**: 1095-1109.
19. Barrios M, Guilera G, Nuno L, & Gomez-Benito J. Consensus in the delphi method: What makes a decision change? *Technological Forecasting and Social Change*. 2021; **163**: 120484.
20. Van Laake LW, Luscher TF, Young ME. The circadian clock in cardiovascular regulation and disease: Lessons from the Nobel Prize in Physiology or Medicine 2017. *European Heart Journal*, 2018; **39**: 2326–2329.
21. Moore-Ede MC, Heitmann A, & Guttkuhn R. Circadian potency spectrum with extended exposure to polychromatic white LED light under workplace conditions. *J Biol Rhythms* 2020; **35**: 405–415.
22. Bailes HJ & Lucas R.J. Human melanopsin forms a pigment maximally sensitive to blue light (λ_{max} ~479 nm) supporting activation of $G_{q/11}$ and $G_{i/o}$ signalling cascades. *Proc R Soc B.* 2013; **280**: 20122987.
23. International Agency for Research on Cancer. *Working Group on the Evaluation of Carcinogenic Risks to Humans: Shift work. Painting, Firefighting, and Shiftwork* 2010; **98**: 563-764.
24. Grant LK, St. Hilaire MA, Heller JP *et al*. Impact of Upgraded Lighting on Falls in Care Home Residents. JAMDA 2022; Preprint https://doi.org/10.1016/j.jamda.2022.06.013
25. Figueiro MG, Plitnick BA, Lok A. *et al.* 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*. 2014; **9**: 1527–1537.
26. Engwall M, Fridh I, Jutengren G, *et al.* The effect of cycled lighting in the intensive care unit on sleep, activity and physiological parameters: A pilot study. *Intensive & Critical Care Nursing*. 2017; **41**: 26–32.
27. Simons, K.S. Laheij RJF, van den Boogaard M *et al.* Dynamic light application therapy to reduce the incidence and duration of delirium in intensive-care patients: a randomized controlled study. *Lancet*

Respir Med. 2016; **4**: 194-202.

Declarations

ACKNOWLEDGMENTS:

We thank R. Guttkuhn for assistance with the analysis of the PubMed database, P Jones, M. Laungani, and A. Godkhindi for assistance with the graphical design of the online consensus survey, and B. Harrison for helpful discussions.

Funding: Fees for using the QuestionPro survey website and partial costs of compiling the email database were provided by Korrus Inc.

Author contributions: MME conceived the idea and designed the study. DEB, SWC, RJH and AH contributed to the wording and selection of test statements. MME and AH analyzed the survey responses MME drafted, and DEB, SWC, RJH and AH edited the manuscript.

COMPETING INTERESTS:

MME & AH are inventors on patents US9827440B2, CN105265025B, EP2982224B1, JP6391669B2, CA2908659A1, KR101986700B1, AU2018241062A1 and patent application PCT/US2019/041728 that are assigned to Korrus Inc. that disclose circadian optimized spectrally engineered light sources, including day and night LEDs. MME received compensation from and holds equity in Korrus Inc. and CIRCADIAN. SWC is an inventor on a provisional patent on a circadian lighting system (WO2021102504A1) and is co-Founder and co-Director of Circadian Health Innovations, a circadian wearables company. None of the remaining authors declare any commercial or financial relationships that could be construed as a potential conflict of interest.

ORCID

Martin Moore-Ede 0000-0002-9557-0609

Sean W. Cain 0000-0002-8385-1550

Anneke Heitmann 0000-0002-9560-2906

Randy J. Nelson 0000-0002-8194-4016