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Illuminating Circadian Rhythms with Human Centric Lighting

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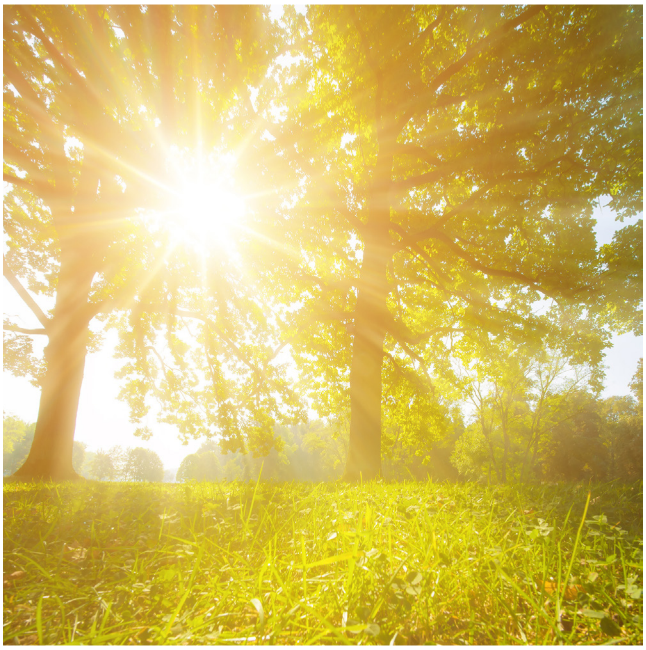
SUMMARY

Circadian rhythms, governing essential biological processes, are deeply intertwined with light cues, orchestrated by specialised retinal cells. Here we explore the vital role of circadian rhythms in health and well-being and emphasise the need for tailored lighting solutions. Novel metrics guide the design of circadian-friendly lighting, optimising environments for optimal function. Understanding light's influence unveils pathways to enhance alertness and mood. Integrating circadian wisdom into lighting schedules promises a brighter, healthier future.

INTRODUCTION

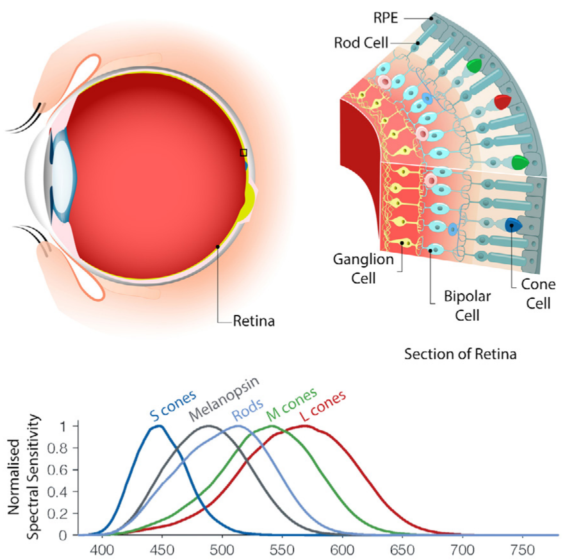
Circadian rhythms orchestrate essential biological processes, including body temperature regulation, hormone release, and sleep-wake patterns, profoundly influencing mood and cognitive performance[1]. Serotonin and melatonin, pivotal in regulating these rhythms, are affected by light cues[2], particularly through intrinsically photosensitive retinal ganglion cells (ipRGCs)[3].

This review delves into the intricate biology of light detection for circadian regulation, explores the importance of maintaining healthy circadian rhythms for overall well-being, and discusses how we can achieve this through artificial lighting.



From the moment life on Earth began around 3 billion years ago to the invention of the electric lightbulb 150 years ago, the sun has been the major source of the light cues that regulate our circadian rhythms.

UNDERSTANDING LIGHT DETECTION MECHANISMS



The human eye contains intrinsically photosensitive retinal ganglion cells (ipRGCs), containing melanopsin sensitive to 480nm light. These receive light information that keeps our biological clock on track.

Equipped with various photoreceptors, the human eye plays a crucial role in detecting light for circadian regulation. Beyond conventional rods and cones responsible for vision, ipRGCs are instrumental in synchronizing circadian rhythms and facilitating non-visual functions[4].

These ipRGCs, containing melanopsin sensitive to 480nm light, receive light information from both environmental cues and other photoreceptors, transmitting it to the biological clock via neuro-signalling pathways[4,5]. Such signalling intricacies regulate melatonin synthesis and metabolism, crucial for proper sleep-wake patterns[6,7].

THE SIGNIFICANCE OF MAINTAINING HEALTHY CIRCADIAN RHYTHMS

Recent research underscores the pivotal role of circadian rhythms in human health and well-being. Dysfunctional circadian patterns, often stemming from environmental factors like artificial lighting, have been linked to a spectrum of disorders ranging from sleep disturbances and depression to more severe conditions like cardiovascular diseases and cancer[8]. Even subtle changes in the light environment can disrupt circadian synchrony, emphasising the need for optimising lighting conditions to support circadian health[9].

Tailoring lighting parameters such as intensity and colour temperature has shown promising results in mitigating daytime fatigue, enhancing alertness, and improving overall performance[10, 11]. Such interventions are particularly beneficial in environments lacking natural light[12] and spaces that are occupied for most of the day, as recognized by the International WELL Building Standard, which promotes human-centric lighting for enhanced productivity and well-being in office buildings and schools.

Use of artificial lighting can disrupt our circadian rhythm, causing issues.

Lighting that compliments circadian rhythm can increase well-being.

DEVELOPING METRICS FOR CIRCADIAN FRIENDLY LIGHTING

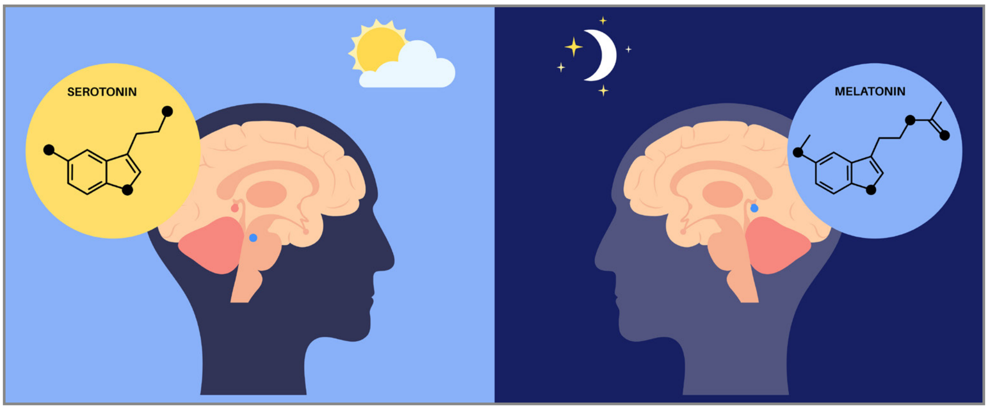
Traditional metrics like Lux and CRI, designed for vision-based photoreceptors, fall short in capturing the circadian effects of lighting. To address this gap, novel metrics such as 'α-opic radiances' and the Melanopic/Photopic ratio have been standardised, providing a more accurate assessment of lighting's impact on circadian processes[13,14]. Adhering to these guidelines is crucial for designing lighting systems that effectively stimulate ipRGCs while promoting optimal circadian function[15].

EXPLORING LIGHT'S INFLUENCE ON CIRCADIAN REGULATION

Studies highlight the profound influence of light intensity and wavelength on circadian rhythms and cognitive performance. Exposure to high-intensity white light (>1000 lux) during the day enhances alertness and cognitive functions[15]. Additionally, short-wavelength (blue) dominant light has been shown to influence alertness, particularly when delivered in the morning[15]. Understanding these nuances is essential for optimising lighting environments to support circadian health and cognitive well-being[16].

UTILISING HIGH LIGHT

In an average office, a mix of electric light and daylight provides illumination ranging from 300 to 500 lux, while the noon sun blazes at a dazzling 100,000 lux[17]. Alertness tends to rise with light intensity, peaking around 1000 lux. However, the relationship isn't straightforward; 100 lux typically triggers a 50% alertness response, with higher levels showing diminishing returns. Studies suggest that exposure to 1000 lux during the day can mitigate sleep loss effects[18]. When well-rested, some research indicates that even as low as 75 lux can reach a saturation point for alertness[19], but this is not common among working individuals!



Exposure to blue light enhances Serotonin production, which is a precursor to Melatonin. However, prolonged blue light exposure can significantly inhibit Melotonin production.

OPTIMISING SHORT-WAVELENGTH DOMINANT LIGHTING

The spectral range of 450 – 500nm, characterised by short-wavelength light, holds significant biological implications. Blue light, with a peak sensitivity at 480nm for ipRGCs, plays a pivotal role in enhancing serotonin production, the precursor to melatonin[4]. Studies have shown acute suppression of melatonin at 460nm, intensifying with higher blue photon density[8,20]. Investigating these effects primarily through artificial blue light exposure and differing light colour temperatures has revealed noteworthy outcomes.

Following exposure to 460nm light, reductions in evening sleepiness and reaction times were observed, alongside notable differences in EEG readings, thermoregulation, and heart rate compared to 550/555nm light treatments[21,22]. Conversely, studies have demonstrated reduced melatonin suppression by filtering out short-wavelength light (<530nm or <480nm) during nighttime light exposure[23,24,25]. Remarkably, blue light (1 h at 40 lux) outperformed a caffeine dose of 240mg in tests measuring accuracy under distracting conditions. Combining both blue light and caffeine yielded the fastest reaction times, indicating an additive effect[26].

Variations in lighting colour temperatures (CCT) have shown comparable effects, where blue-enriched sources create higher colour temperatures. Notably, exposure to very high 17,000K CCT lighting resulted in subjective improvements in alertness, mood, performance, and reduced evening fatigue and irritability compared to 4000K lighting[11]. Additionally, low-level delivery of 6500K light (40 lux for 2hrs) in the evening induced melatonin suppression and enhanced alertness[27]. However, studies suggest that while high CCT light exposure induces alertness, to improve reaction time it requires coupling with higher light intensity exposure[15].

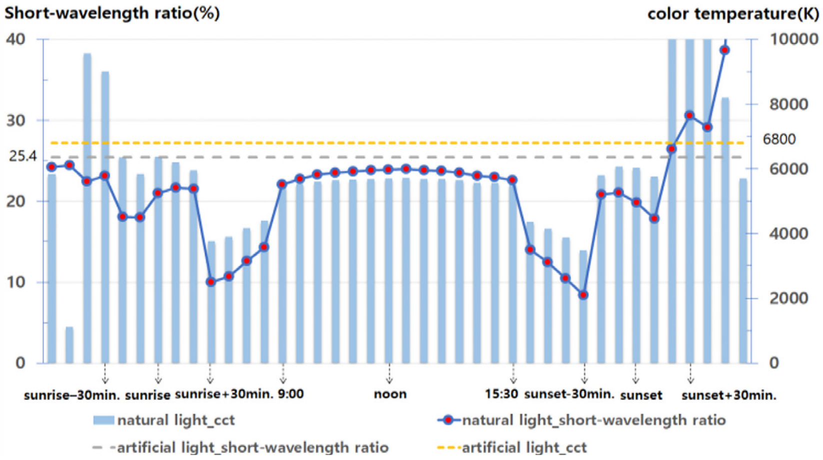


Figure: Properties of the colour temperature and short-wavelength ratio of artificial light and natural light measured in Korea. Note that the increased colour temperatures before sunrise + 30 mins and after sunset -30 mins are discounted as noise. Reproduced from Geon-Woo et al (2019).

Timing plays a crucial role in the delivery of short-wavelength dominant light. Blue light poses risks to proper melatonin cycling if delivered in the evening or at night[28,29]. Whereas, daytime exposure to blue light has been linked to positive effects on physical health, including circadian rhythm resetting, mood enhancement, and cognitive performance improvement, offering relief from Seasonal Affective Disorder[8]. Furthermore, the benefits of short-wave dominant lighting on alertness and reaction time surpass those of higher intensity white light when delivered during periods of heightened homeostatic sleep drive, typically in the afternoon[15]. This aligns with the natural progression of daylight, which peaks in colour temperature around 5500K between 9am and 3pm, with gradual changes on either side from a baseline of ~3500K (see Figure above).

INTEGRATING CIRCADIAN EFFECTS INTO LIGHTING SCHEDULES

Studies to replicate natural daylight's colour temperature and short-wavelength ratio into lighting schedules have been limited but promising. A four-channel LED light with varying colour temperatures to mimic natural daylight properties, resulting in increased melatonin concentrations in rat subjects compared to standard artificial lighting without colour shifts[30].

Lighting schedules closely mirroring the colour temperature and intensity progression of natural daylight, albeit with adjusted maximums due to age-related visual changes have been implemented in nursing homes to help reduce the symptoms of dementia[31].

CONCLUDING THOUGHTS ON CIRCADIAN LIGHTING

Illuminating the biology of light detection for circadian regulation underscores the intricate relationship between light exposure and human health. Numerous studies investigating the effects of light stimuli on individuals have underscored the significant influence of light intensity and colour on alertness and mood. While most studies have been conducted under controlled conditions with limited sample sizes, there is ample evidence supporting the alignment of artificial lighting with natural daylight rhythms.

Still, further research is warranted to explore the benefits of a holistic tailored lighting regimes on health and productivity. But evidence shows that by leveraging insights into light's influence on circadian rhythms and developing tailored lighting solutions, we can optimise environments to promote better sleep, mood, and cognitive performance, ultimately enhancing overall well-being[32].

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