Lighting for Health: LEDs in the New Age of Illumination

The proliferation of electric lighting was a hallmark of the 20th century, providing widespread access to light virtually anywhere, at any time of day. In the same way, the 21st century may become the age of lighting for physiological well-being—often referred to with the familiar catchphrase light and health. Recent research has greatly advanced the understanding that light not only enables vision, but is also a critical signal to our biological systems, affecting circadian rhythms, pupillary response, alertness, and more. However, applying early research findings to widespread lighting practices must be done with great caution, if it is ready to be done at all. After all, light as a drug is much different from light as a commodity.

A recent article in the journal *Trends in Neurosciences* argued for a cautious and informed approach when attempting to translate scientific studies to engineering practice and policymaking. In *Measuring and Using Light in the Melanopsin Age*,[1] a diverse group of fourteen leading researchers explored the current state of knowledge on nonvisual photoreception, which is centered on the photopigment melanopsin, and how it can be applied in the field today. This article is an important statement, providing a firm viewpoint from authors at 11 different institutions.

Humans are exposed to a substantial amount of electric lighting, all of which has some effect on our physiology—regardless of the type of source. Now there is a rapidly expanding amount of information on light and health, which is leading to a rapidly expanding number of questions on exactly how we should light architectural spaces. Often, uncertainty surrounds the role of LEDs. This largely stems from the timing of LED technology's quick rise to prominence in the lighting world and the outlook for its future. With LEDs there is greater ability to tailor lighting systems to meet both visual and nonvisual needs, which is presenting many new opportunities. At the same time, there is potential for poorly engineered products—including LEDs and other types of light sources—or poorly implemented lighting systems to cause harm.

Current Science and Limitations

The non-image-forming response to light is wide ranging, including circadian, neuroendocrine, pupillary, behavioral, and other physiological effects. Specific outcomes include the daily resetting of circadian clocks (a process called entrainment), as well as acute effects like pupil constriction, increasing alertness, and melatonin suppression. Light has been shown to be an effective clinical treatment for a variety of conditions, such as Seasonal Affective Disorder (SAD), but also plays an important role in maintaining daily physiological function. Importantly, the non-image-forming photoreceptor system in our eyes is different from our visual system. Although it shares some of the same photoreceptors, it has its own unique spectral and temporal response to light stimuli. This is one of the reasons traditional measures of lighting quantity, such as illuminance, do not accurately quantify the nonvisual effect of a lighting stimulus.

In the past two decades, much has been learned about the sensitivity of the nonvisual photoreceptor system. Most notably, intrinsically photosensitive retinal ganglion cells (ipRGCs) were identified, as was the spectral sensitivity of melanopsin, the photopigment they contain. The ipRGCs have peak sensitivity to blue light—which is thus important for light and health—but the total response of the nonvisual photoreceptive system is a composite of input from the ipRGCs, rod photoreceptors, and cone photoreceptors. This composite response can change based on the spectrum, intensity, and temporal pattern of the light, as well as the light-exposure history and circadian adaptation state of the individual, which is one reason why characterizing nonvisual photoreception with a single spectral weighting function has remained elusive.

LEDs and Nonvisual Photoreception

LEDs are often associated with light and health—either positively or negatively—for several reasons. LEDs came to prominence just as knowledge of nonvisual photoreception was emerging, and the rates of adoption suggest that LEDs will soon be in widespread use in architectural applications. This combination has provided an opportunity to develop and evaluate best practices for nonvisual stimulation. Additionally, LEDs offer superior flexibility in terms of spectrum, intensity, directionality, and controllability, compared to most conventional light sources, and all of these characteristics are important factors in designing a system for nonvisual impact—particularly the ability to tune LED spectrum.

Sometimes the unique relative spectral power distribution of LEDs causes worry, simply because it looks different from other, more familiar, light sources. Although most LED light sources have a blue "pump" that may result in more energy per unit illuminance at a specific wavelength, photoreceptors do not process individual wavelengths. Rather, photoreceptors integrate information over a range of wavelengths—the very principle that the triphosphor fluorescent lamp, for example, was designed to exploit. Thus, an important consideration is that LEDs emit no more short-wavelength (blue) energy than other sources *at the same correlated color temperature* (CCT).[2] That is, even though most LEDs have a peak in their

1 Lucas et al. 2014. Measuring and Using Light in the Melanopsin Age. Trends in Neurosciences 37(1). 1–9.

2 This can be mathematically evaluated, and occurs because CCT calculations emission around 450 nm, in order to have the same CCT they emit less energy than other comparable-CCT light sources in the regions above and below 450 nm. LEDs are not inherently more hazardous (or beneficial) to human health than any other light source.

Although a 2700 K LED lamp emits about the same amount of blue energy as an incandescent lamp, it is also important to recognize that LED lamps can be engineered to emit light at any desired CCT. Further, while most commercially available LED products have similar spectral output, it would be possible to engineer the relative spectral power distribution to provide maximum benefit if there was a way to effectively and accurately determine the spectrum needed for any given physiological or behavioral benefit. Further, color-tunable products are relatively easily achieved using LED technology, which can offer greater flexibility for changing nonvisual efficacy based on the time of day. At this point, the challenge is identifying exactly what spectral content is the most beneficial—something which is quite possibly application, time-of-day, and user dependent.

Implementing Light and Health Solutions

In many ways, this new age of light and health is a direct reaction to the previous century's transition to illuminated interiors. Now that so much time is spent indoors, there is a need to control the luminous environment to promote health (and avoid harm). However, many architectural spaces serve multiple purposes and have many different users. What may be beneficial for an occupant during the day may be harmful for an occupant at night, and may vary significantly between individuals in a given space. Even more complicated is the need to balance the desire for alertness with preservation of normal circadian rhythms among night-shift medical staff, for example. Therefore, even if a prescription for effective nonvisual stimulation is developed, implementing the solution may not be straightforward, especially if there are users with different histories and needs occupying the space at the same time.

As the authors of *Measuring and Using Light in the Melanopsin Age* state, "Simple prescriptions are as likely to do harm as good, and even experts may have divergent ideas about best practice under some situations." That said, lighting practitioners may choose to follow some basic guidance provided by the authors: if minimizing nonvisual response is a goal, the amount of light reaching the eye—especially short-wavelength (blue) radiation—should be limited; if activating nonvisual responses is a goal, increasing short-wavelength radiation and total illuminance levels at the eye should be the focus. Understanding when to apply each scenario should be the role and responsibility of the specifier. There are many details to be considered, but few definitive answers to important questions about the effect of light level, spectrum, or otherwise customized solutions on different users or user groups.

Future Development

In the early days of understanding the human visual system, there were dueling theories of color vision: trichromacy and opponent channels. It was not until decades later that scientists were able to decipher that the two theories were complementary, rather than mutually exclusive. It is difficult to say exactly where things are in the maturation of understanding nonvisual photoreception, but it is likely that numerous theories that exist today will continue to be refined, and may even converge. An important question to ask is whether sticking with the status quo is more acceptable than altering design practice based on early research findings, especially when either approach may be determined in the future to be detrimental to health and wellbeing.

While the science may still be building, the lighting industry is already seeing LED products marketed for their health benefits. This is not unique to the technology though, as "full-spectrum" incandescent and fluorescent lamps have been marketed for decades, but there is unprecedented momentum to address light and health thanks to the customizability of LEDs. Specifiers and consumers must understand that no lighting product is a panacea; in fact, any benefit derived is dependent on the proper use of the product. Further, it is possible that no benefit is achieved, or worse, that harm is done. Like many health questions, there is no easy answer. One thing is for certain, however: the lighting industry cannot ignore nonvisual needs indefinitely.

Conclusion

Lighting systems are conventionally designed to meet the task performance needs of users, with comfort, aesthetics, and energy consumption also being important considerations. Thanks to recent scientific advancement, it is clear that nonvisual needs should also be considered, but there remains much to be discovered before widespread implementation of nonvisually-effective solutions is possible. While today's LEDs are generally no more beneficial or dangerous to human health than other, similar light sources, they have the potential to be carefully tuned to meet the diversifying demands placed on lighting systems.

rely on the CIE 1931 Color Matching Functions, one of which covers the blue region of visible light—mainly between 420 nm and 500 nm. This concept is also very important in understanding Blue Light Hazard (i.e., light-induced retinal damage), which is explored in a DOE SSL fact sheet, Optical Safety of LEDs, available at http://www.ssl.energy.gov/factsheets.html.

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