Response to the 2016 AMA Report on LED Lighting

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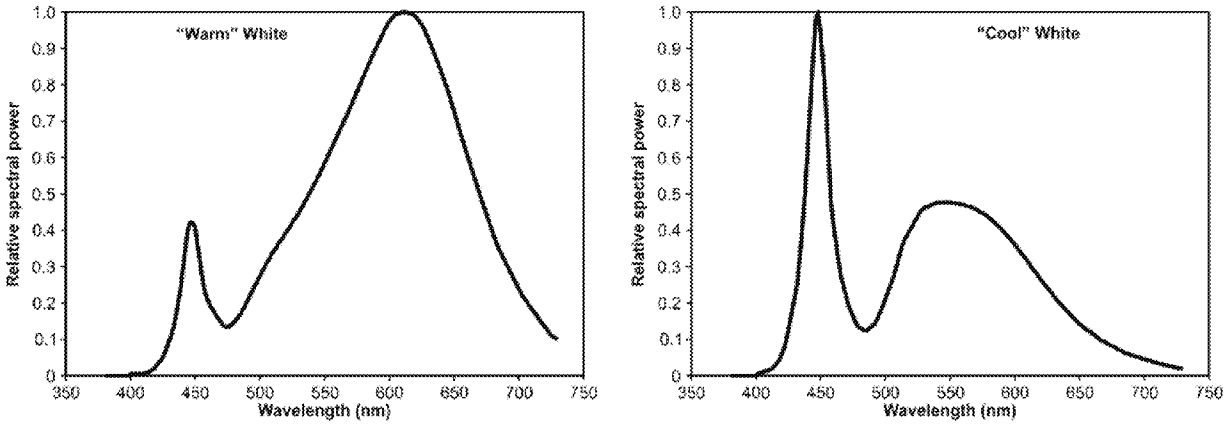
In response to the American Medical Association (AMA) report "Human and Environmental Effects of Light Emitting Diode (LED) Community Lighting," Mark S. Rea, PhD and Mariana G. Figueiro, PhD of the Lighting Research Center at Rensselaer Polytechnic Institute have prepared the below, which is limited to the effects of indium gallium nitride (In-Ga-N) LED lighting on humans.

Recently the AMA has produced a document cautioning the public about In-Ga-N based LEDs used as sources of illumination both indoors and outdoors. These In-Ga-N LED sources generate short wavelength radiation from a solid state die. Some of that radiation is absorbed by a phosphor that, in turn, reemits long wavelength radiation. Together, the light emitted by the die and the light reemitted by the phosphor appear white to the human eye. Depending upon the relative emissions from the LED package, both the die and the phosphor, the white illumination can appear to have a "warm" tint (yellowish-white) or "cool" tint (bluish-white) or can appear neutral.



This solid state lighting technology has, or soon will, displace most other commercially available light sources used for general illumination because they are more energy efficient, have longer life and are more cost effective to own and operate than most other sources of illumination. The concern expressed by the AMA in their report is focused specifically on the short-wavelength emission from these In-Ga-N LED sources as that spectral region might negatively affect, through several modes, human health. Specifically, the following modes are of interest:

- Blue light hazard
- Glare, both disability and discomfort
- Melatonin suppression
- Circadian disruption

To understand the potential risk to human health through each of these modes it is first necessary to characterize the stimulus in terms of its physical properties and then second to relate those stimulus properties to specific, measureable biological outcomes.

Physical stimulus characteristics

Any light stimulus can be analyzed into the following physical characteristics.

- Spectrum
- Amount
- Duration
- Spatial distribution
- Timing
- Polarization

Biological response characteristics

Biological responses to light will mirror the physical stimulus conditions. Collectively, the spectral, temporal and absolute sensitivities of the biological system determine exposure. Hysteresis should also be considered due to non-linear changes in the biological system following exposure.

Exposure:

Spectral sensitivity

Temporal integration

Absolute threshold

Hysteresis

What must be known to make predictions

To meaningfully discuss the consequences of light exposure on human biology, and therefore, health, all of the physical characteristics of light as well as the specific biological response to light must be known. For example, the human retina will not respond to very short- (UV) and very long- (IR) wavelength optical radiation, so optical radiation emitted by sources in those regions will have no impact on visual and non-visual neural systems emanating from the retina. Light incident on the retina between the UV and IR bands can obviously evoke both visual and non-visual system responses by the retina, but each of these systems is tuned to different, relatively narrow wavelength bands. Meaningful discussion of the impact of light on human health as affected by optical radiation incident on the retina must therefore be framed in terms of the spectral emission of the light source and whether the spectral sensitivity of the visual or non-visual system is tuned to that emission. The amount and duration of light exposure must also be defined. The spectral emission from a light source might be perfectly tuned to the spectral sensitivity of the biological system, but if the amount and/or duration of light exposure are too low and/or too short, there will be no biological system responses. The timing of exposure is also important. For example, most biological responses to optical radiation, from humans to fungi, are dependent upon time of day. The same light stimulus may produce one effect at one time of day and a different response at another time. Finally, since biological systems are non-linear in their responses, the impact of a given light exposure can be different depending upon previous light exposure conditions. As a common example, melanin in the skin becomes darker with exposure to UV, thereby affecting the

sensitivity of the system to subsequent radiation. Both sensitization and habituation are exhibited by the biological system. Finally, the spatial distribution of light is fundamentally important because all biological materials have optical properties that affect exposure. The cornea and the lens, for example, refract light to bring images to focus on the retina. Although polarization is another important physical characterization of light, it has, unlike insects, a very small effect on human biology.[1, 2]

Summary: Predictions of health consequences from light exposure depend upon an accurate characterization of the physical stimulus as well as the biological response to that stimulus. Without fully defining both the stimulus and the response, nothing meaningful can be stated about the health effects of any light source.

Biological Response Characteristics

Blue light hazard

High radiance, short-wavelength light focused on the retina by the optics of the eye for an extended duration has the *potential* to cause permanent damage to the retina.[3, 4] Diffuse short-wavelength light, as with the blue sky, does not cause damage nor do brief exposures to high radiance sources, as with incandescent filaments in a clear bulb. The American Conference of Governmental and Industrial Hygienists (ACGIH) provide specifications for exposure limits for blue light hazard.[5] To determine risk, the radiance of the light source (not the irradiance from the light source), the spectral distribution, and the duration of focused exposure on the retina must be known. Unless all of those terms are specified, it is not possible to assess blue light hazard.

Practically, however, the LED package (die + phosphor) can have high radiance in a spectral region that can cause damage. So, by calculation, focused, steady viewing of a 500 mW LED package (≈ 5 W/cm^2/sr) for approximately 10 seconds can cause damage. Humans' natural photophobic response to bright light would likely limit focused exposure to much less than a few seconds; however, some individuals may not have the capacity to avert gaze, such as premature infants.

Summary: Notwithstanding certain sub-populations that deserve special attention, blue light hazard from In-Ga-N LEDs is probably not a concern to the majority of the population in most lighting applications due to human's natural photophobic response.[3-11]

Disability and discomfort glare

There are two types of glare, one that can impair visual performance, disability glare, and one that causes an unpleasant sensation, discomfort glare. To determine the magnitudes of disability and discomfort glare, different formulations are necessary. Disability glare depends upon the amount of scattered light from small particles in the eye, but these particles are large enough that scatter is independent of wavelength. Therefore, short-wavelength and long-wavelength light produce the same amount of entopic scatter. Where visual performance (e.g., reading or judging speed and direction of a moving automobile) is important, the deleterious effects of scattered light can be weighted by the conventional photopic luminous efficiency function [$V(\lambda)$]. The well-established Fry (1954) disability glare formulation can be used to assess the impact of the light source in terms of conventional, photopic illuminance at the cornea and the angular distance between the line of sight and the light source.[12] Therefore, assessing the impact of In-Ga-N LED sources on disability

glare would be the same as it would be for any other commercially available light source that might be used indoors or outdoors.

Discomfort glare is, however, much more complicated to assess. Like disability glare, discomfort glare increases with irradiance at the cornea and with reductions in the angular distance between the light source and the line of sight. Unlike disability glare, however, the spectral composition of the light source also influences discomfort glare; sources with relative greater short-wavelength content are seen as producing more discomfort for equal photopic illuminance at the cornea. All other factors being constant, sources dominated by short-wavelengths will produce relatively more discomfort glare than sources dominated by long-wavelengths. For white light sources, this effect is relatively small, relative to changes in corneal irradiance. The apparent size of the luminous element itself also impacts discomfort glare. Again, all other factors being constant, luminous elements larger than about 0.3 degrees of visual angle will produce more discomfort glare than smaller luminous elements. For light sources viewed from a short distance where the luminous element is 0.3 degrees of visual angle or larger, the discomfort-glare-specific spectrally weighted radiance of the light source must also be known to predict discomfort glare.[13]

Summary: In-Ga-N LED sources dominated by short wavelengths can cause relatively greater discomfort than sources dominated by long wavelengths, including "warm" In-Ga-N LED sources, at the same photopic illuminance at the cornea. As with disability glare, however, discomfort glare is mostly determined by the amount and distribution of light entering the eye, not its spectral content.[12-14]

Melatonin suppression

Melatonin is a hormone that signals "darkness" to the body; it is produced at night and in darkness. Retinal exposure to light during the nighttime can suppress melatonin synthesis by the pineal gland in the brain, potentially disrupting physiological processes timed to occur at night. "Darkness" is a relative term, however. Humans have a high threshold to retinal light exposure for suppressing melatonin at night.[15, 16] Well below this threshold (approximately 30 lux at the cornea from white light for 30 minutes), both rods and cones in the retina provide adequate visual information to humans for navigation, social interactions and even reading printed materials.[17] Nevertheless, the spectral sensitivity of melatonin suppression is dominated by short wavelengths,[18-24] so conventional means of measuring light exposure based upon the photopic luminous efficiency function (i.e., for visual performance) can underestimate the potential impact of In-Ga-N LED sources for suppressing melatonin at night. Light sources used for domestic and roadway lighting have traditionally been sources dominated by long-wavelengths, so the impact of In-Ga-N LED sources on melatonin suppression could, in principle, be of concern. New photometric instruments along with insights into the mechanisms underlying phototransduction by the retina as it affects melatonin suppression have been developed.[20, 25] Thus, it is now possible to measure and to quantify the impact of light exposure from any spectral irradiance distribution on nocturnal melatonin suppression in humans. These developments have, for example, provided insight into the impact of self-luminous displays on nocturnal melatonin suppression.[26-28]

It should be noted that melatonin appears to have an oncostatic effect on cancer proliferation. Blask and colleagues have shown that melatonin limits tumor progression in nocturnal rodents.[29, 30] The amount and the spectrum of light as they affect nocturnal rodents are quite different than they are for humans, however. Mice are between 3000 to 10000 times more sensitive to light as it

affects melatonin synthesis at night.[31] Therefore, care must be given to any extrapolations from studies of melatonin suppression in nocturnal rodents to those in humans, particularly with regard to both visual and circadian phototransduction.

Summary: In-Ga-N LED sources dominated by short wavelengths have greater potential for suppressing the hormone melatonin at night than sodium-based sources commonly used outdoors. However, the amount and the duration of exposure need to be specified before it can be stated that In-Ga-N LED sources affect melatonin suppression at night.

Circadian disruption

Physiology and behavior of all vertebrates on Earth, including humans, are regulated by the 24-hour light-dark cycle incident on the retina. Disruption of that natural rhythm, either by rapid travel across time zones, or by aperiodic or highly variable exposures to light and dark at the wrong time, can cause disruption of physiology and behavior.[32-38] Epidemiological evidence suggests that humans performing rotating shift work are subject to a wide range of serious maladies from breast cancer to cardiovascular disease.[39-45] Melatonin suppression at night is undoubtedly an important part of circadian disruption, but it is not synonymous with circadian disruption. Staying awake in dim light at night or limited exposure to light during the day can also be disruptive to physiology and behavior, even though there is no effect of the light on melatonin concentrations. These disruptive social-behavioral effects may or may not be associated with nocturnal melatonin suppression.[46-49]

Much less is known about the spectral and absolute sensitivities to light as they affect circadian disruption. However, limited studies with red light exposures, which cannot suppress nocturnal melatonin synthesis, have shown that circadian-regulated physiology and behavior are affected.[50, 51] Again, therefore, it is quite possible that the negative impacts on human health by performing rotating shift work may only have a limited relationship to nocturnal melatonin suppression.

Summary: Until more is known about the effects of long-wavelength light exposure (amount, spectrum, duration) on circadian disruption, it is inappropriate to single out short-wavelength radiation from In-Ga-N LED sources as a causative factor in modern maladies.

The use and misuse of metrics

Lighting metrics have been developed and commonly used to predict biological responses to physical characteristics. Metrics are intended to be short-hand simplifications for characterizing *a particular* stimulus-response relationship. Correlated color temperature (CCT) for example is a simplification of the light source spectral power distribution (SPD) to represent how people will see the tint of illumination from that source (i.e., "warm" or "cool"). The CCT metric ignores nearly all of the important factors associated with light exposure (amount, duration, timing) and is only relevant to a single biological response (perceived tint of illumination). Therefore, CCT should never be used to characterize light as a stimulus for, say, blue light hazard. As a further example, the non-linear response of the human circadian system to white light indicates that for the same corneal photopic illuminance and depending on the SPD of the source, a 3500 K source can produce greater melatonin suppression than a 5000 K source.[52, 53] In general then, it is erroneous and misleading to use a metric developed for one purpose and then apply it to another purpose, particularly with regard to the impact of light on human health.

Overall summary

The public is becoming more aware of the role that light can play in our lives and has become sensitized to the impact that light may have on health. The development of In-Ga-N based LED light source technology has increased the social benefits of lighting by lowering its environmental and financial costs. It is nevertheless natural and appropriate for the AMA to question these advances in LED technology as they might negatively affect human health. Raising awareness is not enough, however. Professional responsibility must include rational and balanced discourse, whereby scientific and technical understanding lends insight into the social benefits as well as the social costs of In-Ga-N technology. The foundations for this discourse must rely upon a complete characterization of the physical stimulus as it affects a specific biological response. Misapplication of metrics, such as CCT, combining just one aspect of the physical stimulus with just one type of biological response, must be strenuously avoided. The present document attempts to draw attention to this problem of misapplying short-hand metrics to the topic of light and health and to provide the reader with published information that should inform rational discourse.

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