The Dark Side of Blue Light

It should not be a surprise that our increasingly artificial environment can sometimes adversely impact our health. One basic element in our biology is the sleep-wake cycle. In nature, when the sun goes down melatonin production increases to induce sleep. However, exposure to artificial light – blue light in particular - can disrupt this process.

"Study after study has linked working the night shift and exposure to light at night to several types of cancer (breast, prostate), diabetes, heart disease, and obesity."

http://www.health.harvard.edu/staying-healthy/blue-light-has-a-dark-side

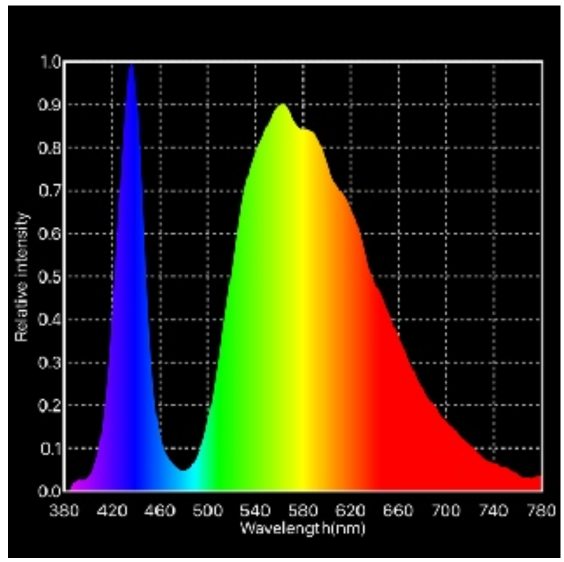

Figure 1 – 4000K LED

Harvard Health goes on to state: "Light at night is part of the reason so many people don't get enough sleep ... researchers have linked short sleep to increased risk for depression, as well as diabetes and cardiovascular problems."

In addition, evidence is emerging that blue light, which is the higher energy end of the visual spectrum, can over time contribute to the development of macular degenerations, glaucoma, and other retinal degenerative diseases.

http://www.bluelightexposed.com/#blue-light-and-macular-degeneration

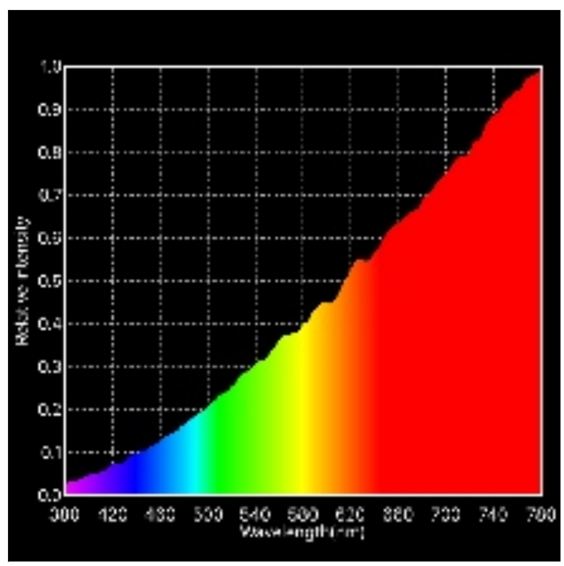
Figure 2 - "Soft White" incandescent

More obvious, direct blue light can cause painful glare that hinders visibility, as anyone who has approached a vehicle with LED headlights on a dark road can attest.

All the foregoing, including the glare issue that presents its own safety risks, particularly for the elderly, has prompted the AMA to issue several public health statements regarding the risk of light at night (LAN). The most recent one specifically focuses on LED street lighting. [1]

LED fixtures have become popular because they are extremely efficient, but they tend to evidence a "blue spike" as shown in Figure 1. Comparing this to a traditional "soft white" incandescent light shows the dramatic difference - Figure 2.

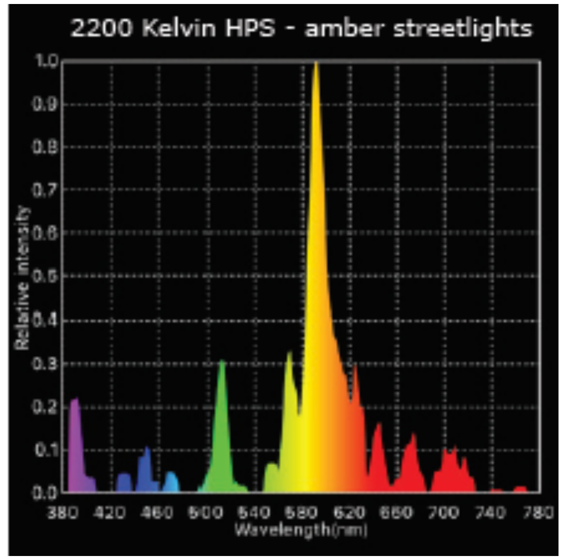

Figure 3 – high-pressure sodium

Prior to LED most streetlights employ high-pressure sodium fixtures, sometimes referred to as monochromatic light because it shines in such a narrow yellow-red band - Figure 3.

Health issues aside, some cities that have installed high blue content LED streetlights have had to replace them, due to citizen complaints about the harsh light and glare, with warmer "soft white" LED fixture now available. Figure 5.

These newer LED fixtures have less offending blue light and because white light provides superior visibility to monochromatic light, and LED fixtures place light more precisely than traditional lighting, it is possible to use less total light, further reducing blue light exposure.

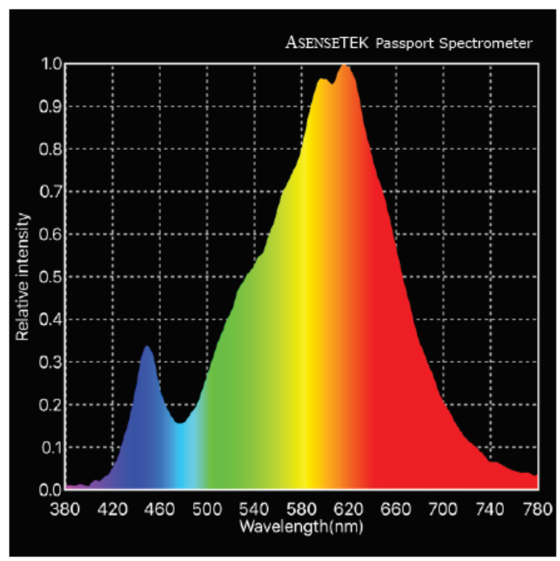

Figure 4 – 2700K "soft white" LED

Properly selected, shielded and installed, warm LED fixtures (CCT 3000K>) can provide efficient effective lighting without harsh blue light glare, reduced health risk, light trespass and light pollution along with the various other adverse environmental impacts associated with it.

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[1] See the two Internet sites above for guidance on protecting yourself generally from harmful LAN.

AMERICAN MEDICAL ASSOCIATION

The Public Health Human and Environmental Effects of Light Emitting Diode (LED) Community Lighting – Report of the council on science and public health

REPORT OF THE COUNCIL ON SCIENCE AND PUBLIC HEALTH

CSAPH Report 2-A-16

Subject: Human and Environmental Effects of Light Emitting Diode (LED) Community Lighting

Presented by: Louis J. Kraus, MD, Chair

Referred to: Reference Committee E
(Theodore Zanker, MD, Chair)

INTRODUCTION

With the advent of highly efficient and bright light emitting diode (LED) lighting, strong economic arguments exist to overhaul the street lighting of U.S. roadways.[1-3] Valid and compelling reasons driving the conversion from conventional lighting include the inherent energy efficiency and longer lamp life of LED lighting, leading to savings in energy use and reduced operating costs, including taxes and maintenance, as well as lower air pollution burden from reduced reliance on fossil-based carbon fuels.

Not all LED light is optimal, however, when used as street lighting. Improper design of the lighting fixture can result in glare, creating a road hazard condition.[4,5] LED lighting also is available in various color correlated temperatures. Many early designs of white LED lighting generated a color spectrum with excessive blue wavelength. This feature further contributes to disability glare, i.e., visual impairment due to stray light, as blue wavelengths are associated with more scattering in the human eye, and sufficiently intense blue spectrum damages retinas.[6,7] The excessive blue spectrum also is environmentally disruptive for many nocturnal species. Accordingly, significant human and environmental concerns are associated with short wavelength (blue) LED emission. Currently, approximately 10% of existing U.S. street lighting has been converted to solid state LED technology, with efforts underway to accelerate this conversion. The Council is undertaking this report to assist in advising communities on selecting among LED lighting options in order to minimize potentially harmful human health and environmental effects.

METHODS

English language reports published between 2005 and 2016 were selected from a search of the PubMed and Google Scholar databases using the MeSH terms "light," "lighting methods," "color," "photic stimulation," and "adverse effects," in combination with "circadian rhythm/physiology/radiation effects," "radiation dosage/effects," "sleep/physiology," "ecosystem," "environment," and "environmental monitoring." Additional searches using the text terms "LED" and "community," "street," and "roadway lighting" were conducted. Additional information and perspective were supplied by recognized experts in the field.

ADVANTAGES AND DISADVANTAGES OF LED STREET LIGHTS

The main reason for converting to LED street lighting is energy efficiency; LED lighting can reduce energy consumption by up to 50% compared with conventional high pressure sodium (HPS) lighting. LED lighting has no warm up requirement with a rapid "turn on and off" at full intensity. In the event of a power outage, LED lights can turn on instantly when power is restored, as opposed to sodium-based lighting requiring prolonged warm up periods. LED lighting also has the inherent capability to be dimmed or tuned, so that during off peak usage times (e.g., 1 to 5 AM), further energy savings can be achieved by reducing illumination levels. LED lighting also has a much longer lifetime (15 to 20 years, or 50,000 hours), reducing maintenance costs by decreasing the frequency of fixture or bulb replacement. That lifespan exceeds that of conventional HPS lighting by 2-4 times. Also, LED lighting has no mercury or lead, and does not release any toxic substances if damaged, unlike mercury or HPS lighting. The light output is very consistent across cold or warm temperature gradients. LED lights also do not require any internal reflectors or glass covers, allowing higher efficiency as well, if designed properly.[8,9]

Despite the benefits of LED lighting, some potential disadvantages are apparent. The initial cost is higher than conventional lighting; several years of energy savings may be required to recoup that initial expense.[10] The spectral characteristics of LED lighting also can be problematic. LED lighting is inherently narrow bandwidth, with "white" being obtained by adding phosphor coating layers to a high energy (such as blue) LED. These phosphor layers can wear with time leading to a higher spectral response than was designed or intended. Manufacturers address this problem with more resistant coatings, blocking filters, or use of lower color temperature LEDs. With proper design, higher spectral responses can be minimized. LED lighting does not tend to abruptly "burn out," rather it dims slowly over many years. An LED fixture generally needs to be replaced after it has dimmed by 30% from initial specifications, usually after about 15 to 20 years.[1,11]

Depending on the design, a large amount blue light is emitted from some LEDs that appear white to the naked eye. The excess blue and green emissions from some LEDs lead to increased light pollution, as these wavelengths scatter more within the eye and have detrimental environmental and glare effects. LED's light emissions are characterized by their correlated color temperature (CCT) index.[12,13] The first generation of LED outdoor lighting and units that are still widely being installed are "4000K" LED units. This nomenclature (Kelvin scale) reflects the equivalent color of a heated metal object to that temperature. The LEDs are cool to the touch and the nomenclature has nothing to do with the operating temperature of the LED itself. By comparison, the CCT associated with daylight light levels is equivalent to 6500K, and high pressure sodium lighting (the current standard) has a CCT of 2100K. Twenty-nine percent of the spectrum of 4000K LED lighting is emitted as blue light, which the human eye perceives as a harsh white color. Due to the point-source nature of LED lighting, studies have shown that this intense blue point source leads to discomfort and disability glare.[14]

More recently engineered LED lighting is now available at 3000K or lower. At 3000K, the human eye still perceives the light as "white," but it is slightly warmer in tone, and has about 21% of its emission in the blue-appearing part of the spectrum. This emission is still very blue for the nighttime environment, but is a significant improvement over the 4000K lighting because it reduces discomfort and disability glare. Because of different coatings, the energy efficiency of 3000K lighting is only 3% less than 4000K, but the light is more pleasing to humans and has less of an impact on wildlife.

Glare

Disability glare is defined by the Department of Transportation (DOT) as the following:

> "Disability glare occurs when the introduction of stray light into the eye reduces the ability to resolve spatial detail. It is an objective impairment in visual performance."

Classic models of this type of glare attribute the deleterious effects to intraocular light scatter in the eye. Scattering produces a veiling luminance over the retina, which effectively reduces the contrast of stimulus images formed on the retina. The disabling effect of the veiling luminance has serious implications for nighttime driving visibility.[15]

Although LED lighting is cost efficient and inherently directional, it paradoxically can lead to worse glare than conventional lighting. This glare can be greatly minimized by proper lighting design and engineering. Glare can be magnified by improper color temperature of the LED, such as blue-rich LED lighting. LEDs are very intense point sources that cause vision discomfort when viewed by the human eye, especially by older drivers. This effect is magnified by higher color temperature LEDs, because blue light scatters more within the human eye, leading to increased disability glare.[16]

In addition to disability glare and its impact on drivers, many residents are unhappy with bright LED lights. In many localities where 4000K and higher lighting has been installed, community complaints of glare and a "prison atmosphere" by the high intensity blue-rich lighting are common. Residents in Seattle, WA have demanded shielding, complaining they need heavy drapes to be comfortable in their own homes at night.[17] Residents in Davis, CA demanded and succeeded in getting a complete replacement of the originally installed 4000K LED lights with the 3000K version throughout the town at great expense.[18] In Cambridge, MA, 4000K lighting with dimming controls was installed to mitigate the harsh blue-rich lighting late at night. Even in places with a high level of ambient nighttime lighting, such as Queens in New York City, many complaints were made about the harshness and glare from 4000K lighting.[19] In contrast, 3000K lighting has been much better received by citizens in general.

Unshielded LED Lighting

Unshielded LED lighting causes significant discomfort from glare. A French government report published in 2013 stated that due to the point source nature of LED lighting, the luminance level of unshielded LED lighting is sufficiently high to cause visual discomfort regardless of the position, as long as it is in the field of vision. As the emission surfaces of LEDs are highly concentrated point sources, the luminance of each individual source easily exceeds the level of visual discomfort, in some cases by a factor of 1000.[17]

Discomfort and disability glare can decrease visual acuity, decreasing safety and creating a road hazard. Various testing measures have been devised to determine and quantify the level of glare and vision impairment by poorly designed LED lighting.[20] Lighting installations are typically tested by measuring foot-candles per square meter on the ground. This is useful for determining the efficiency and evenness of lighting installations. This method, however, does not take into account the human biological response to the point source. It is well known that unshielded light sources cause pupillary constriction, leading to worse nighttime vision between lighting fixtures and causing a "veil of illuminance" beyond the lighting fixture. This leads to worse vision than if the light never existed at all, defeating the purpose of the lighting fixture. Ideally LED lighting installations should be tested in real life scenarios with effects on visual acuity evaluated in order to ascertain the best designs for public safety.

Proper Shielding

With any LED lighting, proper attention should be paid to the design and engineering features. LED lighting is inherently a bright point source and can cause eye fatigue and disability glare if it is allowed to directly shine into human eyes from roadway lighting. This is mitigated by proper design, shielding and installation ensuring that no light shines above 80 degrees from the horizontal. Proper shielding also should be used to prevent light trespass into homes alongside the road, a common cause of citizen complaints. Unlike current HPS street lighting, LEDs have the ability to be controlled electronically and dimmed from a central location. Providing this additional control increases the installation cost, but may be worthwhile because it increases long term energy savings and minimizes detrimental human and environmental lighting effects. In environmentally sensitive or rural areas where wildlife can be especially affected (e.g., near national parks or bio-rich zones where nocturnal animals need such protection), strong consideration should be made for lower emission LEDs (e.g., 3000K or lower lighting with effective shielding). Strong consideration also should be given to the use of filters to block blue wavelengths (as used in Hawaii), or to the use of inherent amber LEDs, such as those deployed in Quebec. Blue light scatters more widely (the reason the daytime sky is "blue"), and unshielded blue-rich lighting that travels along the horizontal plane increases glare and dramatically increases the nighttime sky glow caused by excessive light pollution.

POTENTIAL HEALTH EFFECTS OF "WHITE" LED STREET LIGHTING

Much has been learned over the past decade about the potential adverse health effects of electric light exposure, particularly at night.[21-25] The core concern is disruption of circadian rhythmicity. With waning ambient light, and in the absence of electric lighting, humans begin the transition to nighttime physiology at about dusk; melatonin blood concentrations rise, body temperature drops, sleepiness grows, and hunger abates, along with several other responses.

A number of controlled laboratory studies have shown delays in the normal transition to nighttime physiology from evening exposure to tablet computer screens, backlit e-readers, and room light typical of residential settings.[26-28] These effects are wavelength and intensity dependent, implicating bright, short wavelength (blue) electric light sources as disrupting transition. These effects are not seen with dimmer, longer wavelength light (as from wood fires or low wattage incandescent bulbs). In human studies, a short-term detriment in sleep quality has been observed after exposure to short wavelength light before bedtime. Although data are still emerging, some evidence supports a long-term increase in the risk for cancer, diabetes, cardiovascular disease and obesity from chronic sleep disruption or shiftwork and associated with exposure to brighter light sources in the evening or night.[25,29]

Electric lights differ in terms of their circadian impact.[30] Understanding the neuroscience of circadian light perception can help optimize the design of electric lighting to minimize circadian disruption and improve visual effectiveness. White LED streetlights are currently being marketed to cities and towns throughout the country in the name of energy efficiency and long term cost savings, but such lights have a spectrum containing a strong spike at the wavelength that most effectively suppresses melatonin during the night. It is estimated that a "white" LED lamp is at least 5 times more powerful in influencing circadian physiology than a high pressure sodium light based on melatonin suppression.[31] Recent large surveys found that brighter residential nighttime lighting is associated with reduced sleep time, dissatisfaction with sleep quality, nighttime awakenings, excessive sleepiness, impaired daytime functioning, and obesity.[29,32] Thus, white LED street lighting patterns also could contribute to the risk of chronic disease in the populations of cities in which they have been installed. Measurements at street level from white LED street lamps are needed to more accurately assess the potential circadian impact of evening/nighttime exposure to these lights.

ENVIRONMENTAL EFFECTS OF LED LIGHTING

The detrimental effects of inefficient lighting are not limited to humans; 60% of animals are nocturnal and are potentially adversely affected by exposure to nighttime electrical lighting. Many birds navigate by the moon and star reflections at night; excessive nighttime lighting can lead to reflections on glass high rise towers and other objects, leading to confusion, collisions and death.[33] Many insects need a dark environment to procreate, the most obvious example being lightning bugs that cannot "see" each other when light pollution is pronounced. Other environmentally beneficial insects are attracted to blue-rich lighting, circling under them until they are exhausted and die.[34,35] Unshielded lighting on beach areas has led to a massive drop in turtle populations as hatchlings are disoriented by electrical light and sky glow, preventing them from reaching the water safely.[35-37] Excessive outdoor lighting diverts the hatchlings inland to their demise. Even bridge lighting that is "too blue" has been shown to inhibit upstream migration of certain fish species such as salmon returning to spawn. One such overly lit bridge in Washington State now is shut off during salmon spawning season.

Recognizing the detrimental effects of light pollution on nocturnal species, U.S. national parks have adopted best lighting practices and now require minimal and shielded lighting. Light pollution along the borders of national parks leads to detrimental effects on the local bio-environment. For example, the glow of Miami, FL extends throughout the Everglades National Park. Proper shielding and proper color temperature of the lighting installations can greatly minimize these types of harmful effects on our environment.

CONCLUSION

Current AMA Policy supports efforts to reduce light pollution. Specific to street lighting, Policy H-135.932 supports the implementation of technologies to reduce glare from roadway lighting. Thus, the Council recommends that communities considering conversion to energy efficient LED street lighting use lower CCT lights that will minimize potential health and environmental effects. The Council previously reviewed the adverse health effects of nighttime lighting, and concluded that pervasive use of nighttime lighting disrupts various biological processes, creating potentially harmful health effects related to disability glare and sleep disturbance.[25]

RECOMMENDATIONS

The Council on Science and Public Health recommends that the following statements be adopted, and the remainder of the report filed.

1. That our American Medical Association (AMA) support the proper conversion to community-based Light Emitting Diode (LED) lighting, which reduces energy consumption and decreases the use of fossil fuels. (New HOD Policy)

2. That our AMA encourage minimizing and controlling blue-rich environmental lighting by using the lowest emission of blue light possible to reduce glare. (New HOD Policy)

3. That our AMA encourage the use of 3000K or lower lighting for outdoor installations such as roadways. All LED lighting should be properly shielded to minimize glare and detrimental human and environmental effects, and consideration should be given to utilize the ability of LED lighting to be dimmed for off-peak time periods. (New HOD Policy)

Fiscal Note: Less than $500

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Acknowledgement: The Council thanks George Brainard, PhD (Thomas Jefferson University); Richard Stevens, PhD (University Connecticut Health Center); and Mario Motta, MD (CSAPH, Tufts Medical School) for their contributions in preparing the initial draft of this report, and the commentary by Travis Longcore, PhD, on the ecological impact of nighttime electrical lighting.

REPORT 4 OF THE COUNCIL ON SCIENCE AND PUBLIC HEALTH (A-12)
Light Pollution: Adverse Health Effects of Nighttime Lighting
Authors: David Blask, PhD, MD (Tulane University School of Medicine); George Brainard, PhD (Jefferson Medical College); Ronald Gibbons, PhD (Virginia Tech); Steven Lockley, PhD (Brigham and Women's Hospital, Harvard Medical School); Richard Stevens, PhD (University Connecticut Health Center); and Mario Motta, MD (CSAPH, Tufts Medical School).

EXECUTIVE SUMMARY

Objective. To evaluate the impact of artificial lighting on human health, primarily through disruption of circadian biological rhythms or sleep, as well as the impact of headlamps, nighttime lighting schemes, and glare on driving safety. Concerns related to energy cost, effects on wildlife and vegetation, and esthetics also are briefly noted.

Methods. English-language reports in humans were selected from a PubMed search of the literature from 1995 to March 2012 using the MeSH terms "circadian/biological clocks/rhythm," "chronobiology/disorders," "photoperiod," "light/lighting" "sleep," "work schedule," or "adaptation," combined with the terms "physiology," "melatonin," "adverse effects/toxicity," "pathophysiology," "neoplasm," "epidemiology/etiology," "mental disorders," "energy metabolism," and "gene expression." Additional articles were identified by manual review of the references cited in these publications; others were supplied by experts in the field who contributed to this report (see Acknowledgement).

Results. Biological adaptation to the sun has evolved over billions of years. The power to artificially override the natural cycle of light and dark is a recent event and represents a man-made self-experiment on the effects of exposure to increasingly bright light during the night as human societies acquire technology and expand industry. In addition to resetting the circadian pacemaker, light also stimulates additional neuroendocrine and neurobehavioral responses including suppression of melatonin release from the pineal gland improving alertness and performance. Low levels of illuminance in the blue or white fluorescent spectrum disrupt melatonin secretion. The primary human concerns with nighttime lighting include disability glare (which affects driving and pedestrian safety) and various health effects. Among the latter are potential carcinogenic effects related to melatonin suppression, especially breast cancer. Other diseases that may be exacerbated by circadian disruption include obesity, diabetes, depression and mood disorders, and reproductive problems.

Conclusion. The natural 24-hour cycle of light and dark helps maintain precise alignment of circadian biological rhythms, the general activation of the central nervous system and various biological and cellular processes, and entrainment of melatonin release from the pineal gland. Pervasive use of nighttime lighting disrupts these endogenous processes and creates potentially harmful health effects and/or hazardous situations with varying degrees of harm. The latter includes the generation of glare from roadway, property, and other artificial lighting sources that can create unsafe driving conditions, especially for older drivers. More direct health effects of nighttime lighting may be attributable to disruption of the sleep-wake cycle and suppression of melatonin release. Even low intensity nighttime light has the capability of suppressing melatonin release. In various laboratory models of cancer, melatonin serves as a circulating anticancer signal and suppresses tumor growth. Limited epidemiological studies support the hypothesis that nighttime lighting and/or repetitive disruption of circadian rhythms increases cancer risk; most attention in this arena has been devoted to breast cancer. Further information is required to

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Action of the AMA House of Delegates 2012 Annual Meeting: Council on Science and Public Health Report 4 Recommendations Adopted as Amended, and Remainder of Report filed.

evaluate the relative role of sleep versus the period of darkness in certain diseases or on mediators of certain chronic diseases or conditions including obesity. Due to the nearly ubiquitous exposure to light at inappropriate times relative to endogenous circadian rhythms, a need exists for further multidisciplinary research on occupational and environmental exposure to light-at-night, the risk of cancer, and effects on various chronic diseases

AMERICAN MEDICAL ASSOCIATION

Rep. 4-A-12 Council on Science and Public Health – Addressing the public health and environmental consequences of light pollution and glare and recommending fully shield fixtures and other mitigations and study.

REPORT OF THE COUNCIL ON SCIENCE AND PUBLIC HEALTH

CSAPH Report 4-A-12

INTRODUCTION

Current AMA Policy H-135.937 (AMA Policy Database) advocates for light pollution control and reduced glare from (electric) artifical light sources to both protect public safety and conserve energy. Lighting the night has become a necessity in many areas of the world to enhance commerce, promote social activity, and enhance public safety. However, an emerging consensus has come to acknowledge the effects of widespread nighttime artificial lighting, including the: 1) impact of artificial lighting on human health, primarily through disruption of circadian biological rhythms or sleep; 2) intersection of ocular physiology, vehicle headlamps, nighttime lighting schemes, and harmful glare; 3) energy cost of wasted and unnecessary electric light; and 4) impact of novel light at night on wildlife and vegetation. In addition to these health and environmental effects, an esthetic deficit is apparent with the progressive loss of the starry night sky and interference with astronomical observations. With the assistance of experts in the field, this report evaluates the effects of pervasive nighttime lighting on human health and performance. Concerns related to energy cost, effects on wildlife and vegetation, and esthetics are also briefly noted.

METHODS

English-language reports in humans were selected from a PubMed search of the literature from 1995 to March 2012 using the MeSH terms “circadian/biological clocks/rhythm,” “chronobiology/disorders,” “photoperiod,” “light/lighting” “sleep,” “work schedule,” or “adaptation,” combined with the terms “physiology,” “melatonin,” “adverse effects/toxicity,” “pathophysiology,” “neoplasm,” “epidemiology/etiology,” “mental disorders,” “energy metabolism,” and “gene expression.” Additional articles were identified by manual review of the references cited in these publications; others were supplied by experts in the field who contributed to this report (see Acknowledgement).

LIGHT AND HUMAN PHYSIOLOGY

The solar cycle of light and dark provides the essential basis for life on Earth. Adaptation to the solar cycle has resulted in fundamental molecular and genetic endogenous processes in virtually all life forms that are aligned with an approximately 24-hour period (circadian biological rhythm). The circadian genetic clock mechanism is intimately involved in many, if not most, facets of cellular and organismal function.[1] Although the circadian system spontaneously generates near-24-hour rhythms, this master clock must be reset daily by the light-dark cycle to maintain proper temporal alignment with the environment. In humans and other mammals, this daily entrainment is achieved primarily by novel photoreceptors that project directly to the site of the circadian clock (suprachiasmatic nuclei (SCN) of the hypothalamus).[2-5] The tandem development of an endogenous rhythm sensitive to light presumably evolved to allow for precise 24-hour regulation of rest and activity, and for adapting to seasonal changes in night-length, while maintaining the advantages of an underlying physiology that anticipates day and night. Understanding the molecular and

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physiological basis of endogenous rhythms, how light information is communicated, and the health implications of disruptions to this system are topics of intensive study.

ELECTRIC LIGHTING AND HUMAN HEALTH

Biological adaptation to the sun has evolved over billions of years. The power to artificially override the natural cycle of light and dark is a recent event and represents a man-made self-experiment on the effects of exposure to increasingly bright light during the night as human societies acquire technology and expand industry. At the same time, increasing numbers of people work inside buildings under electric lighting both night and day. Artificial lighting is substantially dimmer than sunlight and provides a very different spectral irradiance. Sunlight is strong at all visible wavelengths, peaking in the yellow region, whereas electric lighting has either extreme characteristic wavelength peaks (fluorescent) or exhibits a monotonic increase in irradiance as wavelength lengthens (incandescent). In contrast to outdoor lighting conditions, much of the modern world now lives and works in relatively dim light throughout the day in isolation from the sun, with often poor contrast between night and day, even for those who live and work in sunny environments.[6]

Extensive nighttime lighting is required for contemporary society and commerce. Therefore, it is imperative to evaluate the unintended adverse health consequences of electric lighting practices in the human environment, and determine their physiological bases so that effective interventions can be developed to mitigate harmful effects of suboptimal light exposure. For example, engineers have already developed less disruptive night lighting technologies, and continued progress in this area is anticipated. That such technologies exist, however, does not guarantee that they will be purchased, installed and properly implemented. The medical community and public can take the lead on advocating a healthier environment, as illustrated by recent changes in public smoking policies worldwide. As the research on the biology of circadian rhythms has advanced, the range of potential disease connections due to disrupted circadian rhythms and sleep has expanded.

Biological Impact of Light on Human Physiology

Light is the most powerful stimulus for regulating human circadian rhythms and is the major environmental time cue for synchronizing the circadian clock. In addition to resetting the circadian pacemaker, light also stimulates additional neuroendocrine and neurobehavioral responses, including suppression of melatonin release from the pineal gland, directly alerting the brain, and improving alertness and performance.[7-9] Melatonin is one of the most studied biomarkers of the human physiological response to light.[10] This substance is the biochemical correlate of darkness and is only produced at night, regardless of whether an organism is day-active (diurnal) or night-active (nocturnal). Conceptually, melatonin provides an internal representation of the environmental photoperiod, specifically night-length. The synthesis and timing of melatonin production requires an afferent signal from the SCN. Ablation of this pathway, which occurs in some patients from upper cervical spinal damage, completely abolishes melatonin production. Certain other circadian rhythms (e.g., cortisol, body temperature, sleep-wake cycles) do not depend on this pathway and persist if the SCN pathway is damaged.

Light is not required to generate circadian rhythms or pineal melatonin production. In the absence of a light-dark cycle (e.g., totally blind individuals), the circadian pacemaker generates rhythms close to, but not exactly a 24-hour periodicity, reflecting the timing of processes under SCN control.[2] However, as previously noted, the timing of SCN rhythms and consequently the rhythms controlled by the circadian clock are affected by light, and require daily exposure to the light-dark cycle to be synchronized with the 24-hour day.

When light information fails to reach the SCN to synchronize the clock and its outputs, the pacemaker reverts to its endogenous non-24-hour period (range 23.7-25.0 h). Consequently, the timing of physiology and behavior that is controlled by the circadian system, for example the sleep-wake cycle, alertness and performance patterns, the core body temperature rhythm, and melatonin and cortisol production, becomes desynchronized from the 24-hour day.[2] The resultant clinical disorder is termed "non-24-hour sleep-wake disorder" and is characterized by alternating episodes of restful sleep, followed by poor night-time sleep and excessive day-time napping, as the non-24-hour circadian pacemaker cycles in and out of phase with the 24-hour social day.[11] Another effect of light exposure at night is the immediate suppression of melatonin production. Under natural conditions, organisms would never be exposed to light during the night in substantial amounts and would not experience melatonin suppression. Electric light, however, efficiently suppresses melatonin at intensities commonly experienced in the home at night.[12]

Measures of Illumination

Luminous flux is the measure of the perceived power of light. The lumen is the standard international unit of luminous flux, a measure of the total "amount" of visible light emitted by a source, while illumination is a measure of how much luminous flux is spread over a given area (intensity of illumination). One lux is equal to one lumen/m^2. Luminous flux measurements take into account the fact that the human eye and visual system is more sensitive to some wavelengths than others. The peak luminosity function is in the green spectral region; white light sources produce far fewer lumens. To provide some perspective, the illuminance associated with a full moon is less than 1 lux, versus 50 lux for a typically incandescent lit family room, 80 lux in a narrower hallway, 325-500 lux for office lighting, 1,000 lux for an overcast day, and 32,000-130,000 lux for direct sunlight.

Initially it was thought that bright light of at least 2,500-20,000 lux was needed to suppress nighttime melatonin secretion or phase shift the melatonin rhythm (as in jet lag) in humans.[13-15] It is now established that when exposure of the human eye is carefully controlled, illuminance as low as 5−17 lux of monochromatic green light or 100 lux of broadband white light can significantly suppress melatonin in normal human volunteers.[12,16-18] Similarly, circadian phase shifts of the melatonin rhythm can be evoked with an illuminance of 5 lux of monochromatic blue light or <100 lux of white fluorescent light, however, exposure to red light is not disruptive.[18,19] Typical lighting in bedrooms in the evening after dusk (but before bedtime) can also suppress melatonin and delay its nocturnal surge.[12] Acute enhancement of both subjective and objective measures of alertness can be evoked with as little as 5 lux of monochromatic blue light.[20] Dose-response curves for melatonin suppression by night-time light exposure to fluorescent light show that ~100 lux of light induces 50% of the maximal response observed with 1,000-10,000 lux of light.[18,21]

Ocular Physiology Mediating Photic Effects

Factors that alter the amount and spectral quality of light reaching the retina include gaze behavior relative to a light source, age (of the ocular lens), and pupillary dilation. Once a light stimulus reaches the retina, physiology within the retina and within the nervous system determines the capacity of the stimulus to evoke circadian, neuroendocrine or neurobehavioral responses. This physiology includes: 1) the sensitivity of the operative photopigments and photoreceptors; 2) location of these photoreceptors within the retina; 3) the ability of the nervous system to integrate photic stimuli spatially and temporally; and, 4) the state of photoreceptor adaptation.
In particular, both short and long-term photoreceptor adaptation can significantly modify the biological and behavioral responses to light and acutely suppress melatonin in humans.[22] For

example, a full week of daytime exposure to bright light (by daylight and/or indoor light boxes at ~ 5,000 lux) or a three-day period of exposure to moderate indoor lighting (200 lux) reduces an individual's sensitivity to light suppression of nighttime melatonin compared with exposure to dim indoor lighting (0.5 lux); similar dim light conditions also enhance circadian phase shifting.[23-25] Two hours of exposure to 18 lux of white incandescent light versus full dark exposure in a single evening modifies the sensitivity of an individual for light-induced melatonin suppression later that same night.[26] Hence, photoreceptor adaptation, like the other ocular and neural elements noted above, can significantly modify the biological and behavioral responses to light.[16]

In general, photobiological responses to light are not all-or-none phenomena. In the case of acutely suppressing high nighttime levels of melatonin or phase-shifting the entire melatonin rhythm, light works in a dose-response fashion. Once threshold is exceeded, increasing irradiances of light elicit increasing acute plasma melatonin suppression or longer-term phase-shifts of the melatonin rhythm in healthy individuals.[16,18,27] All humans, however, are not equally sensitive to light; significant individual differences exist in sensitivity to light for both neuroendocrine and circadian regulation.[16,18] For a detailed description of the molecular and cellular basis for how photoreceptive input regulates circadian and neuroendocrine system function, see the Addendum.

HUMAN CONCERNS-DISABILITY AND DISCOMFORT GLARE

Glare from nighttime lighting can create hazards ranging from discomfort to frank visual disability. Disability glare has been fairly well-defined based on the physiology of the human eye and behavior of light as it enters the ocular media. Discomfort glare is less well-defined and more subjective as it is not based on a physical response per se but rather a psychological response. Accordingly, the respective bases of (and research into) these two responses are fundamentally different.

Disability Glare

Disability glare is unwanted and poorly directed light that temporarily blinds, causes poor vision by decreasing contrast, and creates an unsafe viewing condition, especially at night, by limiting the ability of the person to see. There are natural causes of disability glare, such as solar glare at sunset on a dirty windshield which can be lessened by cleaning the windshield. Unfortunately, nighttime glare while driving is not easily remedied. It is caused by the misapplication of luminaires that comprise the lighting design which are generally overly bright and unshielded, and/or sources of poorly directed light that enters the eye and scatters among ocular structures resulting in diminished contrast and impeded vision. Such effects dramatically worsen as the human eye ages, contributing to poor night vision and difficulty in driving at night for older drivers.

Disability glare is caused by light scatter from ocular media.[28] As light enters the eye, it collides with cornea, lens, and vitreous humor, scattering photons and casting a veil of light across the retina[29-31] (see Figure 1). The veil of light reduces the contrast of the object that the driver is trying to see, having the same effect as increasing the background luminance of the object. This veiling light is represented by the term veiling luminance. Veiling luminance is directly related to the illuminance of the light source and inversely related to the square of the angle of eccentricity of the light source with an age dependent multiplier across the entire equation.[28] This means that the disability from a light source is lessened the farther the source is from the line of sight.[α]

[α] As an example, high mast lighting systems where the roadway lighting is over 100 feet in the air have significantly less glare than traditional systems, which are typically located 30−50 feet in the air. Because of

Accordingly, proper design techniques and consideration for the glare caused by lighting systems need to be considered. One of the primary difficulties, especially for roadways, is that the lighting is not governed by a single jurisdiction. Roadway lighting may be designed properly and provide a low level of glare; however lighting can emanate from adjacent properties, spilling out into the roadway thus affecting the driver and overall performance and suitability of a lighting system. Control over all environmental sources of nighttime lighting is therefore critical for the overall control of disability glare.

Discomfort Glare

Discomfort glare is less well defined but emanates from a glare source that causes the observer to feel uncomfortable. The definition of discomfort is not precise, and some research has shown that a person's response to a glare source is based more on his/her emotional state than on the light source itself. Discomfort glare may be based primarily on the observer's light adaptation level, the size, number, luminance and location of the light sources in the scene.[32]

Both overhead roadway lighting and opposing headlamps are involved with discomfort glare in the driver. A numerical rating scale based on the dynamic nature of glare in simulations is available to measure the discomfort level experienced by drivers (Appendix).[33] The overall impact of discomfort glare on fatigue and driver safety remains an issue.

<u>Lighting and Glare</u>. Both discomfort and disability glare have specific impacts on the user in the nighttime environment. Research has shown that both of these glare effects occur simultaneously. Research also shows that the effects of the glare are cumulative, meaning that the glare from two light sources is the sum of the glare from the individual light sources. As a result, every light source within the field of view has an impact on the comfort and visual capability of the driver.

Overhead lighting

For overhead roadway lighting, design standards include a methodology for controlling the disability glare through a ratio of the eye adaptation luminance to the veiling luminance caused by the light source. As the veiling luminance is related to the illuminance the light source produces at the eye, a roadway luminaire that directs light horizontally has a much greater effect on the driver than a light source that cuts off the horizontal light. A trend towards flat glass luminaires, which provide a cut off of light at horizontal angles, provides a lower level of both disability and discomfort glare.

Decorative luminaires (e.g., acorn or drop lens) have a high level of horizontal light and typically are used in areas where pedestrians are the primary roadway users. The horizontal light in this situation is useful for facial recognition of a pedestrian, but it limits the driver's ability to perceive other objects in the roadway. As a result, many cities are designing and installing two lighting systems, one for the pedestrian and one for the roadway.

Luminaires employing solid state technologies and light-emitting diodes (LED) provide light from an array of small sources rather than a single large source. These designs either rely on each small source to provide a component of the light distribution, or the components of the lighting array provide individual luminating fields of the light distribution. In the first instance, the arrays are

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the inverse squared relationship, a high mast system reduces glare by 75% compared with a traditional system.

typically flat and have an optic to provide the light distribution; if a single LED fails, the others still provide the light distribution. In the second method, the components of the array are aimed to different areas of the beam distribution. This approach typically results in light aimed at the driver and pedestrians causing a higher glare impact. The other issue with the multiple sources used in LED luminaires is that each of the sources typically has a very high luminance itself as the source is very small and very bright; in the absence of sufficient diffusion, they cause significant glare. Accordingly, solid state lighting systems typically have a higher glare impact than traditional sources.

The final issue with glare from overhead lighting is the cyclic nature of the impact. As drivers course along a roadway, they pass from one luminaire to another. The glare experience increases as they approach the luminaire and then diminishes as they pass beyond. While typically not an issue for disability glare, this repetitive process can cause discomfort and fatigue.[34]

<u>Opposing vehicle headlamps</u>

Vehicle headlamps are aimed at the opposing driver eye level resulting in very high ocular illuminance and significant disability glare. The impact of opposing headlamps on the ability of the oncoming driver to observe beyond the headlamps is significant. For example, the visibility of a pedestrian standing behind a vehicle can be reduced by as much as 50%.[35]

In order to minimize the glare impact, headlamps are designed with lower left side light intensity than the right side. This reduces the glare to an opposing vehicle but does not eliminate it. New technologies such as turning headlamps and headlamps that hide part of the headlamp beam when a vehicle passes are possible solutions for this issue. With the advent of high intensity discharge Xenon headlamps and LED-based technologies, the glare issue has become more serious. While the intensity towards a driver is limited, the small but brighter source generates a much higher impression of glare than traditional technologies. These "blue" headlamp sources have a higher complaint rate for glare than for any other light source.

Effects of Lighting Design on Traffic Accidents

Adult, and especially elderly drivers, experience increased glare sensitivity, and elderly drivers may not be able to sufficiently fulfill the criteria for night driving ability because of contrast and glare sensitivity.[36] Prospective studies indicate that reduction in the useful field of view, visual field loss, and glare sensitivity increase crash risk in older drivers.[37,38] Crash risk begins to increase around age 50 years of age and continues to increase with aging.[39] No studies have explicitly compared traffic accident rates under different highway lighting conditions.

HEALTH EFFECTS OF DISRUPTED CIRCADIAN RHYTHMS

Epidemiological studies are a critical component of the evidence base required to assess whether or not light exposure at night affects disease risk, including cancer. These studies, however, are necessarily observational and can rarely provide mechanistic understanding of the associations observed. Carefully designed and controlled basic laboratory studies in experimental animal models have the potential to provide the empiric support for a causal nexus between light exposure at night and biological/health effects and to help establish plausible mechanisms. One area of considerable study on the possible effects of nighttime light exposure involves cancer.

CANCER

Light at Night, Melatonin and Circadian Influences on Carcinogenesis

Experimental Evidence. The majority of earlier studies in experimental models of either spontaneous or chemically-induced mammary carcinogenesis in mice and rats demonstrated an accelerated onset of mammary tumor development accompanied by increased tumor incidence and number in animals exposed to constant bright fluorescent light during the night as compared with control animals maintained on a strict 12 hours light/12 hours dark cycle.[40-51]

More recent work has focused on the ability of light at night to promote the growth progression and metabolism in human breast cancer xenografts. Nocturnal melatonin suppresses the growth of both estrogen receptor negative (ER-) and estrogen receptor positive (ER+) human breast cancer xenografts; the essential polyunsaturated fatty acid, linoleic acid is necessary for the growth of such (ER-) tumors, and its metabolism can be used as a biomarker of cellular growth.[52-55] Exposure of rats with such cancer xenografts to increasing intensities of white, fluorescent polychromatic light during the 12 hour dark phase of each daily cycle results in a dose-dependent suppression of peak nocturnal serum melatonin levels and a corresponding marked increase in tumor metabolism of linoleic acid and the rate of tumor growth. Exposure to even the very dimmest intensity of light during the night (0.2 lux) suppressed the nocturnal peak of circulating melatonin by 65% and was associated with marked stimulation in the rates of tumor growth and linoleic acid metabolic activity. In this model, measurable effects on xenograft growth and linoleic acid metabolism were apparent with 15% suppression in nocturnal melatonin levels.

The ability of light exposure at night to stimulate tumor growth (including dim exposures) has been replicated in rat hepatoma models.[54,56-58] The reverse also is true; gradually restoring circulating melatonin by reducing initial exposure to light at night (24.5 lux) is accompanied by a marked reduction in tumor growth and linoleic acid metabolic activity to baseline rates in the breast cancer and hepatoma models.[59]

The important role of melatonin as a nocturnal anticancer signal is further supported by the growth responses of human breast cancer xenografts perfused with human whole blood collected from young, healthy premenopausal female subjects exposed to complete darkness at night (e.g., high melatonin), compared with xenografts that were perfused with blood collected from the same subjects during the daytime (e.g., low melatonin).[54] The growth of xenografts perfused with blood collected during the dark was markedly reduced. Addition of a physiological nocturnal concentration of melatonin to blood collected from light-treated subjects restored the tumor inhibitory activity to a level comparable to that observed in the melatonin-rich blood collected at night during total darkness. Moreover, the addition of a melatonin receptor antagonist to the blood collected during darkness (i.e., high melatonin) eliminated the ability of the blood to inhibit the growth and metabolic activity of perfused tumors. Some evidence also exists that circadian disruption by chronic phase advancement (e.g., simulating jet lag) may increase cancer growth in laboratory animals.[60,61]

Potential Anticancer Mechanisms of Melatonin

The preponderance of experimental evidence supports the hypothesis that under the conditions of complete darkness, high circulating levels of melatonin during the night not only provide a potent circadian anticancer signal to established cancer cells but help protect normal cells from the initiation of the carcinogenic process in the first place.[62,63] It has been postulated that disruption in the phasing/timing of the central circadian pacemaker in the SCN, in general, and the suppression of circadian nocturnal production of melatonin, in particular, by light at night, may be an important biological explanation for the observed epidemiological associations of cancer risk and surrogates for nocturnal light exposure (such as night shift work, blindness, reported hours of sleep, etc.) (see below).[64]

Melatonin exerts several cellular effects that may be relevant in this regard. It exhibits antiproliferative and antioxidant properties, modulates both cellular and humoral responses, and regulates epigenetic responses.[65-67] Melatonin also may play a role in cancer cell apoptosis and in inhibiting tumor angiogenesis.[68,69]

Human Studies

While the experimental evidence from rodent cancer models links disruption of circadian rhythms and circulating melatonin concentrations (inversely) with progression of disease, the human evidence is indirect and based on epidemiological studies. Breast cancer has received the most study.

The hypothesis that the increasing use of electricity to light the night might be related to the high breast cancer risk in the industrialized world, and the increasing incidence and mortality in the developing world was first articulated in 1987.[70] Potential pathways include suppression of the normal nocturnal rise in circulating melatonin and circadian gene function.[54,71,72] Conceptually, this theory would predict that non-day shift work would raise risk, blind women would be at lower risk, reported sleep duration (as a surrogate for hours of dark) would be inversely associated with risk, and population nighttime light level would co-distribute with breast cancer incidence worldwide.[72,73] Only the first hypothesis has been systematically evaluated. Based on studies of non-day shift occupation and cancer (mostly breast cancer) published through 2007, the International Agency for Research on Cancer (IARC) concluded "shift-work that involves circadian disruption is *probably carcinogenic* to humans" (Recommendation Level 2A).[74] A detailed review of the individual studies supporting this conclusion is available.[75]

Since the IARC evaluation was conducted, several new studies of breast cancer and nighttime light have been published with mixed results.[76-79] Two found no significant association between shift work and risk of breast cancer.[76,77] A large case-control study of nurses in Norway[78] found a significantly elevated risk in subjects with a history of regularly working five or more consecutive nights between days off, and another found that as the type of shift (e.g., evening, night, rotating) became more disruptive, the risk increased.[79,80] In the Nurses Health Study cohort, increased urinary excretion of melatonin metabolites also was associated with a lower risk of breast cancer.[81] Each of these studies has strengths and limitations common to epidemiology, particularly in exposure assessment and appropriate comparison groups (e.g., no woman in the modern world is unexposed to light-at-night, but quantifying that exposure is difficult).

Although shiftwork represents the most extreme example of exposure to light at night and circadian disruption, perturbation of circadian rhythms and the melatonin signal is also experienced by non-shift workers with a normal sleep/wake-cycle.[12] Anyone exposing themselves to light after dusk or before dawn is overriding the natural light-dark exposure pattern as noted in the earlier discussion on measures of illumination.

After lights out for bedtime, it is not yet clear whether the ambient background light from weak sources in the bedroom or outside light coming through the window could influence the circadian system; a brief exposure at these levels may not have a detectable impact in a laboratory setting, although long-term chronic exposure might. Four case-control studies have now reported an association of some aspect of nighttime light level in the bedroom with breast cancer risk.[82-85] The elevated risk estimate was statistically significant in two of them.[83,85] As case-control designs, in addition to the limitation of recall error, there is also the potentially significant limitation of recall bias.

Despite the difficulty of gathering reliable information on bedroom light level at night, the possibility that even a very low luminance over a long period of time might have an impact is important. The lower limit of light intensity that could, over a long time period, affect the circadian system is not established. In the modern world few people sleep in total darkness. When eyelids are shut during sleep, only very bright light can penetrate to lower melatonin and only in some individuals.[86] Frequent awakenings with low level light exposure in the bedroom and certain nighttime activities (e.g., bathroom visits) may disrupt the circadian system, but any related health effects are unknown.[87]

Other Cancers

Light-at-night and circadian disruptions have been suggested to play a role in other cancers including endometrial, ovarian, prostate, colorectal, and non-Hodgkins lymphoma but evidence comparable to that obtained for breast cancer has not yet been developed.[88] On the other hand, engaging in night shift work may protect against skin cancer and cutaneous melanoma.[89]

Other Diseases

<u>Obesity, Diabetes, and Metabolic Syndrome.</u> The modern world has an epidemic of obesity and diabetes that may be influenced by lack of sleep, lack of dark, and/or circadian disruption.[90] Non-day shift workers have a higher incidence of diabetes and obesity.[91] Epidemiological studies also show associations of reported sleep duration and risk of obesity and diabetes.[92] Circadian disruption may be a common mechanism for these outcomes and potential links between the circadian rhythm and metabolism.[93-95]

<u>Other Disorders</u>. Although in the early stage of development, emerging evidence suggests that other chronic conditions also may be exacerbated by light at night exposure and ongoing disruption of circadian rhythms, including depression and mood disorders, gastrointestinal and digestive problems, and reproductive functions.[88]

DARK VERSUS SLEEP

The circadian rhythm and sleep are intimately related but not the same thing. Adequate daily sleep is required for maintenance of cognitive function and for a vast array of other capabilities that are only partially understood. Sleep is not required to synchronize the endogenous circadian rhythm, whereas a stable 24-hour light-dark cycle is required. The epidemiological and laboratory research on sleep and health cannot entirely separate effects of sleep duration from duration of exposure to dark, because the sleep-wake cycle partitions light-dark exposure to the SCN and pineal gland.[96] The distinction is important because a requirement for a daily and lengthy period of dark to maintain optimal circadian health has different implications than a requirement that one must be asleep during this entire period of dark; many individuals normally experience a wakeful episode in the middle of a dark night.[87]

Light during the night will disrupt circadian function as well as sleep, and the health consequences of short sleep and of chronic circadian disruption are being intensively investigated.[97] A growing number of observational and clinical studies on sleep and metabolism suggest short sleep periods have substantial harmful effects on health; however, it is not yet clear that sleep and dark have been entirely disentangled in these studies.[97,98] For example, in one study, sleep duration (verified by polysomnography) was associated with morning blood levels of leptin, a hormone that plays a key role in energy expenditure and appetite.[99] However, the duration of typical sleep reported by each subject was more strongly associated with leptin concentrations. Mean verified sleep was 6.2 hours, whereas mean reported sleep was 7.2 hours. Reported "sleep duration" probably reflects the time from when a person turns out their light for bed and falls asleep and when they get up in the morning (i.e., actual hours of dark exposure). An important question is to determine what portion of the health effects of dark disruption is due to sleep disruption and what portion is due directly to circadian impact of electric light intrusion on the dark of night.

Media use at night (i.e., televisions, computer monitors, cell phone screens) negatively affects the sleep patterns of children and adolescents and suppresses melatonin concentrations.[100-102] The American Academy of Pediatrics recommends removing televisions and computers from bedrooms to assist in limiting total "screen time" on a daily basis.[101] This action also may help in improving sleep patterns.

ENERGY COST

Electric lighting accounts for about 19% of electricity consumption worldwide and costs about $360 billion.[103] Much of the light that is produced is wasted, for example, by radiating light into space away from the task or environment intended to be illuminated. Estimates of how much is wasted vary; one estimate from the International Dark-Sky Association is 30% in the United States.[104] Such a percentage worldwide would account for an annual cost of about $100 billion.

ENVIRONMENTAL ISSUES

Although not directly under the purview of human health and disease, the following considerations are indirectly related to human well-being.

Esthetics

The Milky Way is no longer visible to the majority of people in the modern world. As societies have increasingly used electricity to light the night, it has become difficult to see more than a few of the innumerable stars from Earth's surface.[105] This has been carefully documented in a cover story by National Geographic Magazine in November 2008, which includes extensive visual documentation on its website.[106] Though the major impact of electric light at night is in major metropolitan areas, even the once pristine nights of the U.S. National Parks are beginning to be degraded, more rapidly in the East but also in parks in the West as well.[107]

Impact on Wildlife

Life on the planet has evolved to accommodate the 24-hour solar cycle of light and dark. Human imposition of light at night and disruption of the natural dark-light cycle represents a dramatic change to the environment.[108] Study of the effects of light at night on animal and plant life is in the early stages, but the entire spectrum of life, including animal, plant, insect, and aquatic species, may be affected.

About 30% of all vertebrate species and 60% of invertebrate species on Earth are nocturnal and depend on dark for foraging and mating.[108] Documented wildlife destruction by light at night has been evident in bird species, which fly into lit buildings at night in enormous numbers when migrating, and in the disruption of migration and breeding cycles in amphibians.[108-111] The most studied case in reptiles involves sea turtle hatchlings on the coast of Florida, which historically have scurried from their nest directly to the ocean. With increased development along the coast, and attendant increased electric lighting at night, these hatchlings become confused and often migrate away from shore to the lights. Hundreds of thousands of hatchlings are believed to have been lost as a result of this stray electric lighting at night in Florida.[109] Furthermore, many billions of insects are lost to electric light annually, which reduces food availability for other species in addition to unnecessarily reducing living biomass. It is concerning that light at night also may be vector attractant for diseases such as malaria.[112]

The circadian biology of plants is as robust as animals, and the impact of light at night on plant life may also be considerable due to the role of light in photosynthesis and the fact that many plants are pollinated at night.[113,114]

POLICY AND PUBLIC HEALTH IMPLICATIONS OF LIGHT AT NIGHT

Some responses to public health concerns associated with light-at-night exposures are readily apparent, such as developing and implementing technologies to reduce glare from vehicle headlamps and roadway lighting schemes, and developing lighting technologies at home and at work that minimize circadian disruption, while maintaining visual efficiency and aesthetics. Additionally, clinical studies support efforts to reduce child and adolescent night-time exposure from exogenous light derived from various media sources, especially in the bedroom environment. Recommendations to use dim lighting in residences at night raise issues for elderly patients. The American Geriatrics Society recommends ensuring well lit pathways within households to reduce the incidence of falls in elderly patients.[115]

Individuals who are subject to shift work experience disrupted circadian rhythms, fatigue, and cognitive dysfunction. Many industries, including hospitals, require a 24-hour workforce. The American College of Occupational and Environmental Medicine has established guidelines to address fatigue risk management in the workplace.[116] In healthcare workers, such as nurses who experience rapidly rotating shifts, brief morning light exposure improves subjective symptoms and performance.[117] The judicious use of bright light and/or melatonin supplements can improve adaptation to permanent, long-term night work.[118]

SUMMARY AND CONCLUSIONS

The natural 24-hour cycle of light and dark helps maintain precise alignment of circadian biological rhythms, the general activation of the central nervous system and various biological and cellular processes, and entrainment of melatonin release from the pineal gland. Pervasive use of nighttime lighting disrupts these endogenous processes and creates potentially harmful health effects and/or hazardous situations with varying degrees of harm. The latter includes the generation of glare from roadway, property, and other artificial lighting sources that can create unsafe driving conditions, especially for older drivers. Current AMA policy advocates that all future outdoor lighting be of energy efficient designs to reduce energy use and waste. Future streetlights should incorporate fully shielded or similar non-glare design to improve the safety of our roadways for all, but especially vision impaired and older drivers.

More direct health effects of nighttime lighting may be attributable to disruption of the sleep-wake cycle and suppression of melatonin release. Even low intensity nighttime light has the capability of suppressing melatonin release. In various laboratory models of cancer, melatonin serves as a circulating anticancer signal and suppresses tumor growth. Limited epidemiological studies support the hypothesis that nighttime lighting and/or repetitive disruption of circadian rhythms increases cancer risk; most attention in this arena has been devoted to breast cancer. The quality and duration of sleep and/or period of darkness affect many biological processes that are currently under investigation. Further information is required to evaluate the relative role of sleep versus the period of darkness in certain diseases or on mediators of certain chronic diseases or conditions including obesity. Due to the nearly ubiquitous exposure to light at inappropriate times relative to endogenous circadian rhythms, a need exists for further multidisciplinary research on occupational and environmental exposure to light-at-night, the risk of cancer, and exacerbation of chronic diseases.

RECOMMENDATIONS

The Council on Science and Public Health recommends that the following statements be adopted and the remainder of the report be filed:

That our American Medical Association:

1. Supports the need for developing and implementing technologies to reduce glare from vehicle headlamps and roadway lighting schemes, and developing lighting technologies at home and at work that minimize circadian disruption, while maintaining visual efficiency. (New HOD Policy)

2. Recognizes that exposure to excessive light at night, including extended use of various electronic media, can disrupt sleep or exacerbate sleep disorders, especially in children and adolescents. This effect can be minimized by using dim red lighting in the nighttime bedroom environment. (New HOD Policy)

3. Supports the need for further multidisciplinary research on the risks and benefits of occupational and environmental exposure to light-at-night. (New HOD Policy)

4. That work environments operating in a 24/7 hour fashion have an employee fatigue risk management plan in place. (New HOD Policy)

5. That Policy H-135.937 be reaffirmed. (Reaffirm HOD Policy)

Fiscal Note: Less than $500

Acknowledgements

The Council gratefully acknowledges the following national experts who contributed to the content and development of this report: David Blask, PhD, MD (Tulane University School of Medicine); George Brainard, PhD (Jefferson Medical College); Ronald Gibbons, PhD (Virginia Tech); Steven Lockley, PhD (Brigham and Women’s Hospital, Harvard Medical School); Richard

Stevens, PhD (University Connecticut Health Center); and Mario Motta, MD (CSAPH, Tufts Medical School).

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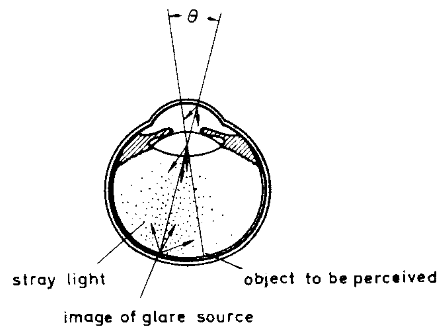
Figure 1. Stray light in the ocular media



Appendix

DeBoer Scale

DeBoer Numerical Rating	Glare Intensity
1	Unbearable
3	Disturbing
5	Just Admissible
7	Satisfactory
9	Unnoticeable

Addendum

Molecular and Cellular Basis for Photoreceptive Regulation of Circadian and Neuroendocrine System Function

In the past decade, there has been an upheaval in the understanding of photoreceptive input to the human circadian and neuroendocrine systems. A study on healthy human subjects confirmed that the three-cone system that mediates human vision during the daytime is not the primary photoreceptor system that transduces light stimuli for acute melatonin suppression.[119] That discovery was rapidly followed by the elucidation of two action spectra in healthy human subjects that identified 446-477 nm as the most potent wavelength region for melatonin suppression.[3,4] To date, ten published action spectra have examined neuroendocrine, circadian, and neurobehavioral responses in humans, monkeys, and rodents. The action spectra demonstrate peak sensitivities in the blue region of the visible spectrum, with calculated peak photosensitivities ranging from 459 nm to 484 nm.[120-122] Further, a set of studies has confirmed that shorter wavelength, monochromatic light is more potent than equal photon densities of longer wavelength light for evoking circadian phase shifts, suppressing melatonin, enhancing subjective and objective correlates of alertness, increasing heart rate, increasing body temperature, and inducing expression of the circadian clock gene Per2 in humans.[19,20,123-126]

Studies using both animal and human models are clarifying the neuroanatomy and neurophysiology of the photosensory system that provides input for circadian, neuroendocrine, and neurobehavioral regulation. A recently discovered photopigment, named melanopsin, has been localized both in the retinas of rodents and humans.[127] More specifically, melanopsin is found in a subtype of intrinsically photoreceptive retinal ganglion cells (ipRGCs).[128,129] These light sensitive ganglion cells project to nuclei and regions of the central nervous system that mediate the biological and behavioral effects of light.[130,131] Although ipRGCs provide the strongest input for regulation of biology and behavior, studies on genetically manipulated rodents, normal monkeys, and humans demonstrate that the visual rod and cone photoreceptors integrate into this physiology.[5,132-134] Continued advances in understanding the physiology of this phototransduction will undoubtedly yield further insights into potential health impacts of electric lighting.