LIGHTING:
THE WAY TO HEALTH & PRODUCTIVITY

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Executive Summary

- Scientific research has proven the importance of light for enhancing human health as well as its power to enhance productivity in a variety of settings from homes to schools to workplaces
- Biologically-optimal lighting can enhance focus and productivity, improve health through circadian rhythm and hormone regulation, and lower the incidence of pathophysiological disorders such as cancer, diabetes, heart disease, obesity, and insomnia
- Exposure to blue wavelengths of light during evening hours (or pre-sleep hours for shift workers) suppresses the release of melatonin and disrupts sleep (especially restorative sleep) and circadian rhythms
- Fatigue-related productivity losses cost companies $1,967 per employee annually (Rosekind et al, 2010)
- Daily exposure to 4-6 hours of light enriched with blue spectrum wavelengths (460-485 nm) can help entrain the circadian rhythm to ensure proper regulation of the body's complex biological systems, while exposures of as little as 20 minutes have been shown to have alerting effects. (Cajochen, 2007; Lowden et al., 2003)

Biological Effects of Light

Properly spectrally-tuned indoor lighting, simulating nature's sun-based light-dark cycle, can increase productivity and have positive effects on physical and mental health. Direct benefits of early to mid-day blue spectrum (460-485 nm wavelengths) light exposure (more specifically, melanopic lux) are:

- Setting the circadian rhythm so the release of restorative and calming hormones such as melatonin (an antioxidant) occur later in the day or in pre-sleep scenarios (Lucas et al, 1999)
- Activation of alertness-related subcortical structures (hypothalamus, brainstem, thalamus) and limbic areas (amygdala and hippocampus), followed by modulations of activity in cortical areas (Vandewalle et al, 2009)
- Increase in alertness and speed of information processing, important determinants of intelligence active when the central nervous system is at its physiological peak via dopamine and nor-epinephrine (Lehrl et al, 2006)
- An increase in stimulatory hormones like cortisol (Scheer and Buijs, 1999)
- Regulation of healthy levels of metabolic hormones like leptin and insulin that control hunger and blood glucose levels, which can lead to improved focus, energy, and decreased incidences of diabetes and obesity (Rüger M, Scheer FA, 2009)

Conventional indoor illumination, including color temperature shifting technology, does not emit sufficient blue light during the day and emits too much at night. Through the cognitive and hormonal effects mentioned above, proper exposure to blue wavelengths of light will increase alertness and productivity, enhance mood, control glucose levels, boost metabolism, and encourage restorative sleep. These effects are especially pronounced in shift workers who are negatively impacted by the sun during the time they are trying to sleep and do not benefit from the power of the sun to entrain their circadian rhythm at the beginning of their shift.

It is important to note that the spectrum of light is not the same as color temperature (CCT). The human eye does not perceive the true spectral content of a light source; however, spectrum has profound biological effects. These biological effects are why spectrum is critical and not to be confused with CCT when it comes to health and productivity.

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Most people, regardless of their sleep and work schedules, are not exposed to biologically-optimal light indoors which leads to circadian desynchronization. The retina of the eye is responsible for sensing light and transmitting information to the brain. In addition to the photoreceptors that are responsible for sight, there is a third type of photoreceptor in the retina – the melanopsin receptor. These highly specialized receptors are sensitive to blue wavelengths of light and are the single largest source of input to the suprachiasmatic nucleus (SCN) which controls hormone release and is considered the master biological clock of the human body (Dijk & Cajochen 1997; Wurtman 1975).

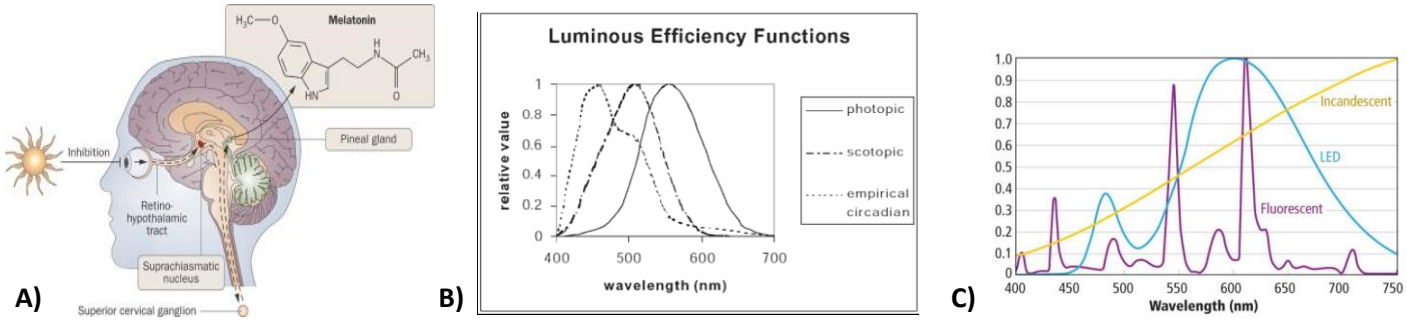

Figure 1: Melanopsin receptors in the retina are specific for 460-485 nm wavelength light and signal the suprachiasmatic nucleus which controls the circadian rhythm (A, Birgit C et al. 2009). Visual receptors in the retina have different sensitivities than melanopsin receptors (B, Mark S. Rea). Most indoor lighting is not designed with circadian or visual sensitivities in mind; they do not emit wavelengths optimized for intended visual or biological function (C, LEDs Magazine Feb 2013).

The Alerting Effects of Light:

By optimizing human circadian rhythms and taking advantage of the profound biological implications of light, the impacts of light can extend beyond improved night sleep and decreased physiological stress. Numerous studies have established that exposure to blue wavelength light increased alertness and improved performance. In one study from Harvard Medical School, a group of adults were exposed to 460 nm light during the daytime hours. These participants exhibited improved auditory reaction time, reduced lapses in attention, and increased alertness as measured by an electroencephalogram (EEG), an instrument that detects brain wave activity (Rahman et al, 2014). This effect on human mindfulness is related to the mechanism by which light interacts with various structures within the brain. In one study, imaging techniques such as PET and MRI were used to visualize brain activity in participants engaging in cognitive tasks. Researchers noted that blue wavelengths of light induced modulations in brain activity at the subcortical structures responsible for alertness, the brainstem and hypothalamus. They also found that limbic areas related to long-term memory, the hippocampus and amygdala, also responded to blue wavelengths of light (Vandewalle et al, 2009).

Previous research indicated that exposure to blue wavelengths of light was responsible for melatonin regulation among transmitters within the human body. The impact of blue wavelength light on human cognition, though, suggests that dopamine and norepinephrine production are also related exposure to blue wavelengths of light (Alkozei et al, 2016). Overall, appropriate

exposure to this type of biologically-optimal light can provide similar effects to caffeine consumption, without the negative side effects such as increased heart rate and other health issues. These breakthroughs in improvements on human cognition and alertness present major implications for human productivity, both in the workplace and in the classroom.

Employee Productivity and Accident Reduction: Employers often pursue ways to improve human performance and productivity in the workplace. Interest in biologically-optimal occupational lighting is increasing due to the significant positive gains without high costs or negative side effects. In a study considering nearly 100 office workers, blue-enriched white light improved the subjective measures of alertness, performance, and concentration as well as positive mood. Furthermore, daytime sleepiness and irritability was reduced, and the quality of subjective nocturnal sleep was improved (Viola et al, 2008). In addition to an economic incentive for the employer, overall betterment of productivity and mood are critical to enhance employee wellness.

Biologically-optimal light exposure can also help to increase workplace safety. A study at a German metal factory noted a decrease in accidents by over 50% with the implementation of biologically-optimal light in the workplace (van den Beld, 2004). In addition to maintaining positive sleep quality at night through circadian rhythm regulation, blue light exposure during the day promotes alertness and decreases fatigue. This synergistic benefit of daytime alertness and nighttime restfulness provides a platform for the widespread using of improved occupational lighting.

Improving Student Focus and Learning: The impact of light on alertness has also been documented on the student population. Decreasing exposure to blue wavelengths of light in the evening hours, through both the use of biologically-optimal lighting as well as reduced exposure to blue-light emitting devices at night, can help students achieve more restful sleep at night and improve mindfulness during the day. The effects, however, extend beyond only circadian regulation. Exposure to blue wavelength light can also enhance learning. Researchers from Germany discovered an increase in alertness as well as improved speed of information processing after exposure to blue wavelengths of light that was not observed after exposure to light with other wavelengths (Lehrl et al., 2007). Information processing is an important determinant of fluid intelligence, which is active when the central nervous system (CNS) is at its physiological peak. This type of study helps to establish the link between exposure to blue wavelengths of light and peak cognitive performance. In conjunction with the ability of light to help sustain focus (Lockley et al., 2006), there exists a strong foundation to promote the use of biologically-optimal light in classroom settings and to make it a seminal component of the learning process.

Sleep and the Circadian Rhythm:

Melatonin is one of the major hormones produced in the brain that induces sleepiness and controls the circadian rhythm. Melanopsin receptors set the circadian phase with blue light upon waking by shutting down melatonin production. Exposure to the same blue wavelengths of light in the evening will interfere with sleep and disrupt the circadian rhythm (Gooley et al., 2012; Czeisler et al., 1995). This resulting phenomenon is called circadian desynchronization and is manifested as daytime sleepiness and disturbed sleep at nighttime. Lack of alertness during the day is a major cause for decreased productivity and cognitive function, as well as the source of increased stress, all of which are directly related to a lack of restful sleep. Insomnia, though, is not the only disturbance to restful sleep; circadian desynchronization prevents the body from fully entering the various phases of sleep, which is a critical restorative time for the human body (McConnell, 1980). Furthermore, the impact of circadian disruption extends beyond mindfulness during the day and sleep at night. In 2012, The American Medical Association issued a policy statement on the negative impacts of inappropriate circadian light exposure due to its link to obesity, cardiovascular disease, and several forms of cancer.

Impact of Light and Sleep on Disease:

Obesity and Diabetes: Sleep is significant regulator of hormone release, glucose management, and heart function. During our most restorative sleep stage, release of the anabolic growth hormone and cortisol are highly regulated which are intricately connected with the metabolic systems in our body. Research indicates that disruption during sleep can lead to an imbalance in these hormones at night, severely affecting appetite and energy usage, making poor sleep a risk factor for obesity and Type II diabetes (Cauter, 2008). Currently, though, the link is weak, and researchers are investigating other metabolic markers to further establish the relationship these diseases and sleep.

Hormonal Cancers: In a healthy individual with a correctly aligned circadian rhythm, during nighttime darkness, the SCN triggers release of melatonin by the pineal gland. Melatonin is the quintessential "sleep hormone," facilitating the onset of and regulation of the duration of sleep. However, it also has a role in maintaining immune function directly related to the prevalence of cancer. Melatonin has been shown to mitigate tissue damage and inflammation, inhibiting cancer development and growth. This is likely due to its antioxidant properties, though the exact mechanistic pathways of function are currently being researched (Reiter, 2006). For example, there is also a relationship between sleep and the immune system, independent of direct melatonin action. Melatonin release mediates the production of cytokines, signaling proteins that control cell growth. There are various forms of cytokines, both oncogenic and oncostatic, and it is possible that sleep interruptions, such as improper exposure to blue wavelengths of light at night, can lead to direct alterations in cytokine balance that exert cancer-stimulatory influences on the body (Blask, 2009).

Cardiovascular Disease: Improper regulation of blood pressure is a major risk factor for several forms of heart disease. Melatonin aids in reducing blood pressure, and blue light exposure during the evening hours prevents this anti-hypertensive action. Furthermore, melatonin's impact on sleep and blood pressure can lead to sleep apnea, a disorder that leaves the brain without oxygen for short periods of time through the night. The link between sleep apnea and heart disease is well established, and the additive effects of light exposure at night can exacerbate this effect. The American Heart Association has extended the impact of sleep apnea as a risk factor for other cardiovascular disorders, including coronary artery disease, stroke, and atrial fibrillation (Somers, et al. 2008).

Depression, Seasonal Affective Disorder, and Anxiety: Melatonin regulation and sleep have also been connected to neurological disorders in adults, such as depression and anxiety. Patients with insomnia and sleep disturbance due to circadian desynchronization are about ten times more likely to develop depression and fifteen times more likely to develop anxiety disorders than those achieving adequate night sleep. This correlation includes not only lack of sleep, but also quality of sleep (Taylor et al., 2005). Regulating light exposure throughout the day and night can aid in night sleep, and possibly relieve depressive and anxiety symptoms in patients.

Seasonal affective disorder is a specific type of mood disorder characterized by depression during the winter months. This disorder is directly related to low luminosity, specifically blue light deficiency, during the daytime hours, which provides inadequate stimulation for serotonin and dopamine release – hormones that contribute to an improved mood (Salgado-Delgado, et al. 2011). Furthermore, the absence of serotonin results in a lack of melatonin during the evening hours, causing insomnia and sleep disturbances. Poor sleep exacerbates the depressive symptoms and hormone imbalance. Like depression, light therapy is a widely accepted method of treatment and often improves hormone regulation to encourage positive mood and adequate sleep.

Attention deficit hyperactivity disorder (ADHD): Individuals suffering from ADHD often also present with major sleep disturbances resulting from delayed sleep phase syndrome (DSPS). The shift in the circadian rhythm can amplify ADHD symptoms, and patients are often over-medicated due to a misdiagnosis of their behavioral disorders. DSPS results from a delay in the onset of melatonin production, sometimes caused by exposure to blue enriched light at night. This poor sleep at night results in agitation in ADHD individuals during the day. In one study, an ADHD patient with DSPS was exposed to bright light therapy, which alleviated not only sleep disturbances but also ADHD symptoms (Gruber, et al. 2007). This research indicates a relationship between these neurological disorders, sleep, and light and provides a basis for future work to further treat these patients.

Though some still require further validation, these conclusions bring attention to complex interconnectedness of biological pathways, like the immune system, metabolic system, neurological

system and circadian clock and highlight the profound impact of sleep and circadian alignment on overall human health. Due to the significant impact of light, several leading circadian researchers published an editorial on the importance of lighting technology (such as biologically-optimal lighting) to alleviate this public health concern (Stevens et al., 2013).

Shift Work:

Shift workers have the most difficulty getting circadian-appropriate light since their work schedules can rotate between day and night shifts. The significance of light to health is most readily apparent in this population as their circadian misalignment can be highly amplified and illustrative of the effects that biologically-suboptimal lighting can have on all employees. Night shift work has been consistently associated with significant health risks. A large study of 75,000 registered nurses (The Nurses' Health Study) analyzed 22 years of data and found that working the night shift for prolonged periods of time correlated with an increased incidence of cardiovascular disease, breast cancer, and lung cancer (Gu et al., 2014, Schernhammer et al., 2001). A separate study of over 3,000 male shift workers in Canada found that men who worked the night shift had triple the rate of prostate cancer, and double the risk of colorectal cancer (Parent et al., 2012). That study also found a correlation between night shift work, bladder cancer and lung cancer in the men studied (Parent et al., 2012).

There is a large body of research that highlights the link between night shift work and cancer, and as a result, numerous leading health organizations, including the World Health Organization in 2007, have labeled night shift work a "probable carcinogen." Research suggests that properly timed light exposure could help shift workers gradually shift to a new schedule as needed to avoid conflict within the body (Duffy and Czeisler 2009), such as utilizing blue-enriched lighting before the night shift and blue-reduced lighting when upon returning home in the morning.

Light as a Preventative & Therapeutic Treatment

Several studies have shown the profound effects biologically-optimal lighting can have, separate from preventing heart disease and cancer. Among them are better performance on cognitive tasks, improved mood and feelings of well-being, and better sleep (Veitch and McColl 2001; Viola et al 2008). Research suggests properly timed exposure to biologically-optimal lighting (maximizing blue wavelengths of light before work and minimizing blue wavelengths of light before bed) could alleviate many symptoms of circadian misalignment by managing important hormones and regulatory systems within the body (Schernhammer et al., 2001; Duffy and Czeisler 2009). The most dramatic impacts are exhibited in individuals performing work with non-traditional schedules. For example, one study of night work at NASA in connection with a space shuttle launch indicated that use of light boxes before and after sleep increased subjective sleep quality, performance, and well-being (Stewart et al., 1995). A separate study of truck drivers concluded that short (20 min) exposures to bright light increase alertness and suppressed melatonin levels in the groups that received treatment (Lowden et al., 2003).

Most of us, though, experience subtle, less severe circadian misalignment than shift workers on a daily basis, but prolonged misalignment can have significant health impacts as described above. For this reason, the general population would also greatly benefit from proper light exposure. One study of white-collar workers over four weeks assessed various measures between workers exposed to regular white light versus blue-enriched white light. Those in the blue-enriched light setting showed significant improvements in alertness, performance, positive mood, concentration, and nighttime sleepiness as well as significant reductions in daytime sleepiness, irritability, and eye discomfort (Viola et al., 2008).

In addition to maintaining overall health, in recent years, light has also been used as a therapeutic treatment to treat individuals with dementia such as Alzheimer's disease. In one study, individuals suffering from dementia were exposed to bright blue-enriched light during the day and blue-deficient light at night. The researchers noted an increase in sleep duration and a reduction in nighttime agitation (Kim et al., 2003). A second, long-term study also included observations on daytime behavior. Patients exposed to bright blue-enriched light during the day from 10a-6p were noted to have a decrease in depressive symptoms and an increase in functional cognition (Lyketsos et al., 1999). Because biological light therapy does not cause adverse effects like pharmacological intervention, it is a desirable alternative for treatment; current research is underway to determine the optimal blue-light dosage for patients living with dementia.

The positive health benefits of biological light exposure are diverse and well established. Specifically, blue-enriched light during daylight hours and blue-deficient light during the evening hours are critical to maintain circadian alignment. While most conventional indoor lights have some blue light, they do not have enough to entrain the circadian rhythm during the day, but it can still interfere with sleep at night (Wahnschaffe et al., 2013). Current estimates indicate that 4-6 hours of daily exposure to light enriched with wavelengths of 460-485 nm would help prevent disease, increase cognition, and decrease sleep disturbances. This spectrum of light mimics natural sunlight and significantly aids in realigning circadian rhythms.

Spectrum vs. Color Temperature

White light from an ordinary LED bulb actually is a blend of three primary colors – red, blue, and green. Often, however, the light skews very subtly toward one of these shades. Correlated Color Temperature (CCT) indicates the particular color, measuring it in Kelvin (K) degrees. Warm, red-skewing light, for example, corresponds to a CCT of ~2700K, whereas a cooler blue will be ~5000K. An increase in Kelvin indicates a cooler hue of light. The importance to our eyes is these temperatures can be the difference between a color appearing vibrant or dull.

Spectrum, on the other hand, refers to the distribution of wavelengths emitted by a light source. Each wavelength corresponds to a particular color of light. Green light, for instance, has a wavelength of 495-570 nanometers (nm). In effect, these wavelengths determine the amount of each color permeating a

given space. According to Lighting Research Center, color is a human perception constructed from the combination of the spectral power distribution (SPD) of the light source and so, full spectrum light sources, which are the most like natural light, allow better color rendering.

The human eye does not perceive the spectrum colors radiating from a light source, but they do have a profound effect on bodily processes. These biological effects are why spectrum is much more important than CCT when it comes to health and productivity.

Visual Effects of Light

With respect to the visual system, both too little and too much light can have undesirable effects. Insufficient lighting can cause eye-strain, fatigue, headaches, musculoskeletal pain, stress, errors, and accidents. Too much light produces glare which can have similar effects (Joines et al., 2015).

To enhance productivity and reduce eye strain, the visual environment has to provide proper lighting and task visibility. Glare – improperly focused light and its reflection off of surrounding surfaces – is a common problem in most work environments, including offices. It can cause visual problems, mental strain, and musculoskeletal problems as the body attempts to compensate. Some considerations according to the International Labor Organization are exposure to natural light, positioning lights so that workers don't have to adjust their posture, shining lights required for detailed work directly on the task area rather than in worker's eyes, and minimizing glare that can occur as light reflects off computers, furniture, walls, windows, floors, and equipment through proper fixture design (International Labor Organization, Indoor Workplace Lighting OSH Brief No. 3c). Innovative fixture design allows for tailored light focus for office employees in addition to employees who work in warehouses, manufacturing facilities, and other industries.

Solutions for a Healthy and Productive Lighted Environment

As our understanding of human biology becomes more sophisticated, so should our demands for biologically-optimal lighting. Through much scientific investigation, researchers have found that light enriched in the blue wavelengths (460-485 nm) drives a circadian response that promotes the release of stimulating hormones like cortisol and inhibits the release of drowsiness hormones like melatonin. Exposure to blue wavelength-enriched light creates biological responses that enhance cognitive function, minimize stress, and promote a positive mood. To ensure healthy sleep habits, exposure to blue wavelength deficient light in the evening helps the body prepare for sleep. This type of biologically-optimal light promotes the healthy regulation of the body's complex biological systems–just as the sun does naturally.

For Further Reading

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