A White Paper from the IALD European Regulatory Affairs Working Group

Lighting Design for Health, Wellbeing and Quality of Light, A Holistic Approach on Human Centric Lighting

Ioannis Ladopoulos, Jr. Associate IALD, Senior Electrical Engineer, LEED AP BD+C, WELL AP MSc in Renewable Energy Systems Technology, MA in Lighting Design – Architectural Lighting and Design Management

Kevan Shaw, IALD, C. Eng MILP, Lighting Design Director

INTERNATIONAL ASSOCIATION OF LIGHTING DESIGNERS IALD

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Abstract

Designing a good lighting environment is becoming more complex. Until now, lighting designers, architects, engineers, and lighting manufacturers, pretty much anyone involved in lighting design, have concentrated on creating a lighting environment for the visual functions that are completely integrated with architecture and fulfill the latest trends of sustainability and energy efficiency. However, more recent research suggests that the lighting environment should also support human health and wellbeing. [1]

The purpose of this paper is to try and shed light in a very detailed manner in all different aspects of lighting that influence the health and wellbeing of the user. Although this is not a medical or scientific paper it tries to take a more holistic approach of what we are calling "*Human Centric Lighting*".

Human Centric Lighting is the concept describing the connection between lighting, health and wellbeing. Lighting that focuses on people should balance visual, emotional, and biological benefits of lighting and promote good vision while satisfying the emotional and biological needs of the users. The latest development and work done in the field in the last 15 years found that lighting, especially Human Centric Lighting, also stimulates non-visual effects on human psychology and physiology.

Lighting Design and Health

Circadian Rhythms

In humans, the daily pattern of consolidated sleep and awake state is influenced by the timing of exposure to light and darkness.

> "The daily light-dark cycle governs rhythmic changes in the behavior and/or physiology of most species. Studies have found that these changes are governed by a biological clock, which in humans is located in two brain areas called the suprachiasmatic nuclei. The circadian cycles established by this clock occur throughout nature and have a period of approximately 24 hours. In addition, these circadian cycles can be synchronized to external time signals but also can persist in the absence of such signals. Studies have found that the internal clock consists of an array of genes and the protein products they encode, which regulate various physiological processes throughout the body. Disruptions of the biological rhythms can impair the health and well-being of the organism". [2]

Exposure to the 24-hour solar cycle normally ensures that circadian rhythms of performance and alertness peak during daytime and that a consolidated sleep is achieved at night time. Without regulation, the human circadian cycle runs 25 hours in a constant light environment, therefore daylight entrainment is necessary to keep us correctly synchronized with the natural world.

In insomnia or sleep disorders in general that bring fatigue and lack of alertness or performance, artificial light can be used (with the appropriate time exposure) to realign circadian rhythms back to the desired sleep and wake times of the patient.

To put it in simpler terms: daily color and brightness variations in the environment are directly connected to the body's daily rhythmic changes. [3]

Lighting and Circadian Rhythms

There are certain lighting aspects or qualities that affect the circadian rhythms of humans. These in brief are quantity, spectral power distribution of the light source, timing and time of exposure, spatial distribution, and light short term history. One has to understand that the human circadian system reacts differently than the human visual system. When we are referring to quantity of lighting levels we are solely talking about the visual system needs. In order to activate the circadian system, greater amount of "polychromatic" white light is required. The circadian system is more sensitive to short wavelength blue light while the visual system is most sensitive to the middle portion of the visible spectrum.

The most important aspect is that although our visual system is not significantly dependent on the timing of light exposure, therefore responding well to light stimulus at any time of day and night, the circadian system can respond with a phase advance or delay, interfering with the synchronization of our biological clock and a normal day / night cycle.

Also, the visual system reacts in less than a second while the circadian system responds to light only after an exposure of several minutes.

Circadian rhythm, contrary to the visual system, does not respond to spatial patterns. Finally, the higher the exposure to light during the day the lower the sensitivity of the human circadian system at night.

For more information, refer to the historical background on circadian rhythms in Annex 1.

Disturbance of the Biological Clock

Light is typically installed for the purpose of illuminating space to allow wellbeing, comfort, entertainment, or work. Similarly shutters and windows are often used to prevent exposure to daylight and facilitate prolonged sleep. Bright light enables better vision and affects mood. Additionally, the color temperature is typically adapted to the specific environment, which is an important feature of architectural lighting design. As we now know, spectral content is directly connected to circadian stimulus coefficient and influences circadian rhythms rather than certain lamp technology. As it was described before, the biological clock is more sensitive to the blue part of the spectrum and the more the color temperature increases the greater the proportion of blue in the light spectrum.

When lighting designers or engineers implement a design, the user is exposed to light which affects the circadian rhythm with immediate and medium-term psychological effects. Immediate disturbances of the circadian rhythm can be caused by daylight colored artificial light at inappropriate times of day and medium term disturbances can be caused by sleep deprivation resulting from exposure to certain types of lighting. Only recently have the effects on psychological conditions and wake/sleep cycles been studied systematically. In general, illuminance levels of light intensity remain well below the peak intensity of the sun on a clear day. In this context, these effects are not a feature of a lamp technology, but of lighting and lighting design in general.

Despite the beneficial effects of light, there is mounting evidence that suggests that ill-timed exposure to artificial light, resulting in circadian rhythm disruption, may also cause sleep disorders and worsen even more serious conditions. These effects are directly or indirectly due to light itself, without any specific connection to a certain lighting technology, i.e. LEDs.

Specifically, under certain conditions blue light may be more effective in influencing human biological systems than other visible wavelengths. Thus, monochromatic blue light or light artificially enriched in blue is particularly effective in melatonin phase shift and suppression.

LEDs and Flicker – Temporal Light Artifacts (TLAs)

The hot topic as LEDs are becoming more and more the main lighting technology in use is flickering. In an LED system, it is the electronic driver which dictates the flickering. At the moment, there is no internationally approved standard defining flicker. This results in many bulbs in the market presenting extreme flickering with only a few providing acceptable performance.

As most of the time flickering is not visible to the naked eye, short term effects cannot be measured however it contributes to the surrounding environmental stress.

The International Commission on Illumination (CIE) Technical Note "Visual Aspects of Time-Modulated Lighting Systems – Definitions and Measurement Models" (006:2016) gives different definitions for the perceptual effects that modulated light can produce. The unwanted changes in the perception of the environment due to light modulation are called "temporal artifacts." It can change the visual environment compared to natural light and previous generations of light sources. In CIE's technical note 006:2016, "flicker" is used for direct perception of the modulation. The technical note underlines the need to understand the perception of temporal artifacts by stating that limiting the temporal modulation of a light source has a direct impact on its cost, features, or lifetime.

However, the definition of acceptable limits for specific applications in terms of the amount of modulation is really interesting. This is not part of the scope of work of this paper; however, acceptability thresholds are a topic that the technical committee could work on

In the initial (2010) Institute of Electrical and Electronics Engineers (IEEE) PAR1789[1] standard, risks of seizures due to flicker at frequencies within the 3-70Hz range were presented as well as biological effects on humans due to invisible flicker at frequencies below 165Hz. However, the IEEE 1789-2015 standard "Recommended Practices for Modulating Current in High-Brightness LEDs for Mitigating Health Risks to Viewers"[4] is setting a few ground rules to be followed by suppliers. In its latest report, IEEE puts forwards extremely high frequency limits, which are even higher than the ones which were considered previously.

The US National Electrical Manufacturers Association (NEMA) Working Group on Temporal Light Artifacts (TLAs) suggests however, and rightly so, that the IEEE 1789-2015

[1] PAR stands for Project Authorization Request. It is the means by which standards projects are started within the IEEE Standards Committee. PARs define the scope, purpose, and contact points for the new project.

proposed limits are extremely strict for many applications, adding unnecessary costs to the electronics of LEDs.

On the other hand, NEMA also proposes further assessment of TLAs with new metrics and associated measurement methods for flicker and lighting.

Photo Biological Safety – The So Called "Blue Light Hazard"

The interaction of blue light with molecules constituting the retina or accumulating in the retina with age or in pathological conditions can induce damage to RPE [2] cells, photoreceptor cells, and to ganglion cells. The so called "blue light hazard" was identified approximately 50 years ago. [5][6]

Later studies have shown that the shortest wavelengths in the visible spectrum are the most dangerous for the retina. Also, the spectral composition of the damaging light is not responsible for the discrepancy on the magnitude of the temperature effect [7]. The mechanisms of light-induced damage have been reviewed previously by others. [8]

A recent review has furthermore analyzed the relevant studies on action spectra of photochemical damage to the retina. The outcome of the analysis that most studies agree on is that retinal damage is higher at shorter wavelengths and decreases with longer wavelengths. [9]

The potential phototoxic retinal damage is expected to occur with wavelengths in the blue light spectrum between 400 and 460 nm (excitation peak at 440 nm) [10].

The wavelength is considered to be one of the factors that enhance the susceptibility to light damage. The action spectrum peaks in the short wavelength region, providing the basis for the concept of blue light hazard.

When light hits a photoreceptor, the cell bleaches and becomes useless until it has recovered through a metabolic process called the "visual cycle." Absorption of blue light, however, has been shown to cause a reversal of the process. In other words, if the cell is not recovered when becoming exposed again, it increases the chances of damage occurring.

Besides a wavelength link, photochemical damage depends on the total dose received. The light intensity and the duration required to cause a certain level of damage are correlated, and that longer light exposure can have the same effect as higher intensity. [11]

In 1966, Noell [12] demonstrated how the cumulative effect of light causes retinal damage. However the cumulative effect does not take place if the retina recovers

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2 The retinal pigment epithelium (RPE) is the pigmented cell layer just outside the neurosensory retina that nourishes retinal visual cells and is firmly attached to the underlying choroid and overlying retinal visual cells. The RPE shields the retinal from excess incoming light [13].

sufficiently from earlier subliminal damage before the next exposure is applied. The cumulative nature of light damage has been observed in several later investigations. It has been confirmed that recurrent light exposure can result in greater photoreceptor damage than continuous exposure.

Susceptibility to light damage increases with age in a process that is distinct from degenerative changes due to ageing.

Blue light seems to be more dangerous than other components of white light. Current studies indicating a blue light hazard within the intensity range of natural light to the retina are based on animal experiments. The relevance of these experimental data for human pathological conditions is not totally clear, although studies made on animals could be extrapolated and hypothesized for retinal damage due to blue light also in humans.

Epidemiologic studies have provided conflicting results regarding the relationship between sun exposure and retinal pathologies, mostly due to the fact that dosimetry is difficult to evaluate during long-term exposure and is highly dependent on other factors. High quality epidemiologic studies are needed to evaluate the real impact of light on retinal diseases. [14]

However not all blue light is bad for human health. In 2012, the Global Lighting Association (GLA) issued a paper on "Optical and Photobiological Safety of LEDs, CFLs and Other High Efficiency General Lighting Sources." It emphasizes the biological importance of blue light. With a peak at round 480nm, it regulates the biological clock, alertness, and metabolic processes. Furthermore, blue and cool white light sources used appropriately and under specific protocols could create such conditions, assisting in maintaining the natural day-night rhythm. For LEDs at the same color temperature, the portion of blue light is not higher than that of other technologies. [15]

Lighting Design and Wellbeing

Designing with Biophilia in Mind [16]

When architects and designers are creating the interior, and biophilia is at the center of the design, certain considerations have to be made:

Nature in the Space

This could mean the incorporation of plants or water into the buildings settings. From potted plants to water features or inner courtyard gardens to natural views from inside the building areas. The latter is what interests lighting designers.

Nature Analogues

As lighting designers, it is not in our immediate scope of work to bring in these elements into the building, it is rather the architect's job. However, creating a natural analogue through lighting design is one way to incorporate biophilia into a designated space. The use of natural materials, biomorphic forms, lighting fixtures that mimic natural shapes, and creating simulated scenes with evident analogies is recommended.

Nature of the Space

The less obvious way to integrate biophilia into the architectural design is the actual nature of the space. This has to do with the actual spatial configuration of a room with users' "natural" preference being open spaces.

As we now know, in a rather detailed matter, daylight boosts our emotions and enhances the feeling of wellbeing. Stephen P. Kellert in his book *Biophilic Design* [17] gives seven attributes to light described in brief below:

1. *Natural Light*: This attribute includes the effects of daylighting including the full color spectrum of natural light. In effect, although as lighting designers we tend to think of artificial lighting first, but natural light is the most important attribute when biophilia is considered.
2. *Filtered and Diffused Light*: The benefits of daylight are enhanced by adjustable light and in particular by reducing the effects of glare. Filtered or diffused daylight can also enhance observation and feelings of connection between indoor and outdoor spaces.
3. *Light and Shadow*: The complementary contrast of light and dark spaces can cause a feeling of content for building users. It can create emotions of mystery, curiosity, and even excitement.
4. *Reflected Light*: Lighting reflecting off surfaces (walls, ceilings etc.) is a standard technique used by lighting designers. Mitigation of glare and more penetration of light in interior spaces are just some of the advantages.
5. *Light Pools*: Pools of connected light can help users to find their way in shadowed areas such as dark corridors. It can also produce a feeling of security and protection same as a lit fireplace would do.
6. *Warm Light*: Warm lit areas, such as spots of sunlit areas surrounded by darker spaces, can create a feeling of welcome and security in an interior space.
7. *Light as a Shape or Form:* When we try to control natural light, the results can be dynamic, stimulating shapes and forms. Emotions like curiosity, imagination and a feeling of exploration submerge to supplement the aesthetic result.

When we are considering lighting for buildings we should try and bear in mind these attributes and integrate them as much as possible in our lighting design. Also remember biophilic could mean daylight, natural views, "natural" colors, and making reference to scenery and nature with clear analogues, e.g. a light cove imitating a daylight crevice creeping into a room during the day.

The Work of Lighting Europe

Lighting Europe (LE) is the industry association that represents the lighting industry in Europe. Lighting Europe promotes efficient lighting practices for the benefit of the global environment, human comfort, and the health and safety of consumers.

As part of its work, Lighting Europe has released several papers concerning lighting and health which was the work of several workgroups and stakeholders.

Lighting Europe is defining Human Centric Lighting through basic notions that seem self-evident but most of the time are being ignored. They have stressed the difference between artificial lighting being static whereas natural light is dynamic. In the last four to five years, companies have introduced tunable white luminaires to try and simulate the dynamic nature of daylight and the technology is becoming increasingly more affordable. However, both in the control methodology and the actual determination of the appropriate protocol or schedule, we still have a lot to learn and lighting designers should be very responsible in their use.

Tunable white luminaires can be used for control, maintenance, or even entrainment (determining or modifying the phase or period) of the circadian rhythm but are not to be used lightly. However Human Centric Lighting as defined with the use of the appropriate color temperature and right lighting levels, at the right time at the right place improves vision, wellbeing and performance of the user.

The "Lighting for Health and Wellbeing in Education, Work Places, Nursing Homes, Domestic Applications and Smart Cities" [18] is a very thorough work introducing different aspects and methodologies with adequate literature overview and background of extremely distinguished researchers in the field. This Lighting Europe guide on photobiological safety in general lighting products for use in working places is intended to be used by luminaires designers [19].

The WELL Building Standard [20]

There are several green building standards (LEED, BREEAM, Minegie, Estidama etc.) that address issues related to artificial lighting and daylighting. However, most of the lighting related credits focus on energy saving and sustainability issues. These credits include daylight integration, energy savings and lighting control. However latest rating systems go beyond those standards that focus broadly on environmental wellbeing. The WELL Building Standard focuses on the people in the building. It is noted that the UK Building Research Establishment, authors of BREEAM, are currently undertaking a revision that will include elements of the WELL Building Standard.

The illumination guidelines included in the standard aim to minimize disruption to the body's circadian system, enhance productivity, support good sleep quality and provide appropriate visual acuity.

There are 4 preconditions and 7 optimization credits.

Preconditions

- Visual Lighting Design credit establishes the appropriate light levels for basic visual performance. It promotes the pairing of dimmable direct task lighting with indirect ambient lighting. Lighting levels for visual acuity focus are defined along with brightness management strategies.
- Circadian Lighting Design credit promotes the establishment of lighting conditions assisting circadian health. It introduces the EML (Equivalent Melanopic Lux) which is an alternate metric defining the melanopic light intensity for work areas.
- Electric Light Glare Control credit sets limitations on glare by shielding lamps by specific angles for a certain range of luminance.
- Solar Glare Control credit prescribes different methods for controlling disruptive glare from windows including shielding, baffles, controls and dimmable glass.

Optimizations

- Low Glare Workstation Design credit tries to minimize glare and high luminance contrast between computer screens and surrounding background by considering spatial orientation properties of the referenced occupant spaces.
- Color Quality credit relies on the definition of CRI limits to measure color quality in order to depict colors accurately and enhance user comfort.
- Surface Design credit sets parameters for the reflective quality of surfaces in order to control the overall light intensity within a space. Defining LRVs (Light Reflectance Values) for ceilings, walls and furniture ensures sufficient amount of light reaches the eye without increasing glare or energy consumption.
- Automated Shading and Dimming Contro*ls* credit promotes the use of an automated control system in order for window shades to block sunlight glare and the limitation of artificial lighting when adequate light levels are available within the designated space. Automated sunlight control and responsive light control are introduced.
- Right to Light credit is trying by setting minimum distances from windows for regularly occupied spaces that daylighting is maximized within buildings.
- Daylight Modeling credit introduces lighting simulations to demonstrate adequate spatial daylight autonomy and annual sunlight exposure.
- Daylight Fenestration credit defines design parameters for windows sizes and properties to optimize quantity and quality of daylighting by minimizing glare and heat gain.

The latest WELL Building Standard version 2.0 is expected to be more specific and include references to meet the Illuminating Engineering Society of North America (IES) Recommended Practices and/or the European Committee for Standardisation CEN/TC169

Application Norms. BREEAM and WELL have also announced their standards alignment agreement to make it easier for projects pursuing both standards.

Light and Color Therapy

After wellbeing and performance, we examine the therapeutic values of light and color. The ultimate scope of this mention is really to get a glimpse of the overall potential light has as a healing tool and how essential "good lighting" is in the architectural design of facilities as going too deep into light and color should be part of a more thorough research.

Color therapy and the healing power of color light have been explored by Dinshah Ghadiali. His work has been received with skepticism and reserve

Ghadiali was born in Mumbai, India in 1873 and developed the Spectro-Chrome as a color healing system. However, he made it clear that in surgical cases it is not to be used as an alternative, although complementary use, even in cases where conventional drug treatment is used, is possible.

The US Food and Drug Administration (FDA) prevented and still does prevent the selling of his Spectro-Chrome color projectors, considering them medical devices. [21]

According to Ghadiali, each element gives off a distinctive color wave. Sunlight as received by the body is split into the prismatic colors as white light is split when passing through a prism. There are many shades of each color and each shade is produced by a different wavelength. Remarkably enough, Ghadiali after excessive experiments and work, came up with exact protocols and color combinations for particular diseases and ailments.

One cannot help but wonder could a specific color, having certain attributes and recommended for specific ailments, be integrated in a rooms' lighting design, depending on the type of use"? And how careful should one be using color light integrated into the lighting design of a building?

How easy going and consequence free is the use of color lighting for general lighting purposes (i.e. in bars, restaurants and other circumstances) having all this knowledge?

International Light Association (ILA)

ILA[3] has many members doing great work in the field of light and health and in particular color light and health. The International Light Association is a diverse group of individuals, comprising those with a professional interest in light and color, as well as those with a personal or creative connection to light. Some members are light therapy practitioners or health professionals, while others are scientists and educators. Creative ILA members include artists, architects and designers. It is this diversity that depicts with vivid colors the magnitude of the field of Human Centric Lighting.

[3] Special thanks to Anadi Martel President of ILA for the assistance in accessing this information.

The ILA mission is to share and disseminate information, educate, initiate and promote research and create integrative community in the field of Light.
ILA aims to: develop a network of people who are focused on the therapeutic uses of light; determine professional standards and develop a code of ethics in the field of light and its applications; disseminate information about the field of light; provide integrative education about light and its applications; and promote internationally the field of light, its applications, and link to members and their work [22].

Lighting Design and Quality of Light [23]

The Quality of Light is very largely a subjective, experiential matter. It is also completely influenced by context. There have been many attempts to create a metric for lighting quality however none have managed to encompass all the many variables, not only of measurable parameters, but of different people's varied visual experience. It is clear that light levels alone do not indicate quality; however, this measure can be important for specific task lighting where visual acuity is required. Similarly, color fidelity metrics can be important both for some specific tasks and for general lit experience. Glare metrics are also important in certain task situations however the quality of lighting sparkle (Richard Kelly's "Play of Brilliants") adds a specific quality to many lit environments.

Clearly lighting quality must include aspects of health and wellbeing that we are identifying in this paper, appropriate lighting levels, and color fidelity to achieve the visual tasks in the space being designed for, however it must be understood that aiming for higher levels of the measurable factors certainly does not result in high lighting quality. One consideration to bear in mind is that humans have evolved with natural light over many millennia. This includes daylight at high levels during daytime and firelight at night. We have only had significant levels of man-made light for around 200 years, therefore we react to the stimuli of natural light and where we aim to provide man made light need to be aware of our reactions to this compared to natural light. A full consideration of all these factors, the particular design of the space and how users feel are all factors that need to be considered in designing for high lighting quality.
The definition of Quality of Light is as vague and as objective as the number of lighting designers in the world. Many believe you cannot really define light quality. Even more some would argue that the emotional benefits of a good lighting design for health and wellbeing cannot be quantified. And although this to some extent is true, when it comes to light and health there are ground rules. It would be useful to have standards and guidelines integrated in legislation to be used as a tool for even better design.

Color Rendering Index (CRI)

As lighting designers, one of the important metric tools we use in our quest to define lighting quality is the color rendering index (CRI). CRI in its definition is “a measure of a light source's ability to show object colors ‘realistically’ or ‘naturally’ compared to a familiar reference source, either incandescent light or daylight.” However, a light source with a higher CRI does not necessarily guarantee a better Quality of Light.

The IES Method for Evaluating Light Source Color Rendition (IES TM-30-15) tried to identify the limitations of the CRI metric. It proposes a new metric concept with two metrics a Fidelity and a Gamut index. In addition, a Color Vector Graphic is provided for better understanding.

Although TM-30-15[24] seems very appealing, with the Color Vector Graphic in its simplicity being useful in understanding the properties of a light source, it has still not replaced CRI by any means. However, it has identified the need for an alternative, or better an upgrade, of the existing CRI metric.

Conclusions

When research started trying to understand the human visual system, there were confronting theories of color vision. It was until much later that researchers were able to establish that these theories were complementary.

So, should lighting designers start changing their design practices according to the latest theories? Unfortunately, there is no definite answer to this question as the maturity of research and our full understanding of photoreception is quite vague.

The lighting industry is already seeing LED products marketed for their health benefits.

In the latest lighting exhibitions LEDs are starting to occupy 90 %, maybe 95%, of the stands and health lighting products are presenting a strange, yet welcomed, marketing frenzy promising to promote healthcare and wellbeing.

While today’s LEDs are generally no more beneficial or dangerous to human health than other, “conventional” light sources, they have the potential to be carefully tuned to meet all the more demanding tasks set by architects, owners and other stakeholders. Their flexibility and the prospect of even higher efficacies in the near future is an attractive perspective for Lighting Designers.

However, it is important to keep in mind that no lighting product is a panacea. In fact, any benefit derived is dependent on the proper use of the product.
Even worse one has to consider that wrongful use might have harmful results instead.
Like many health questions, there is no easy answer. One thing is certain, however: the lighting industry cannot ignore nonvisual needs indefinitely and Lighting Europe is a step to the right direction. [25]

So, after all these developments in lighting and health sector and the ongoing revelations, does that mean that the lighting designer has to have a medical degree in order to design? The key word is responsibility. As lighting design professionals, we always should research and work with the user in the center of our design. We need to see this new framework and possible standards to be introduced as an opportunity and not a threat to our artistic vision and professional progress. On that note, we have and should have a key role and a saying on where things should be going in terms of research, the lighting industry, and lighting design of the future.

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Annex 1

Historical Background on Lighting and Circadian Rhythms

In 2000, a study demonstrated that even the slightest changes in illuminance and indoor light conditions in general can have a major impact on the entrainment of the human circadian rhythm. [26]

In 2001, George Brainard [27] identified that between 446nm to 477nm is the most potent region for regulating melatonin secretion and thus circadian rhythms. However, the most interesting outcome was the conclusion that the known rod and cones photo pigments for vision at that time did not explain the observed melatonin suppression. Therefore, clear evidence for a new photoreceptor was implied as primarily responsible for melatonin suppression.

The photic entrainment of circadian rhythms starts in the eye and involves a small fraction of ganglion cells. It is the correspondence between the photic properties of these cells and those properties of the entrainment mechanism that suggest these cells represent the primary photoreceptors for synchronizing the circadian clock to environmental time[28].

In 2004, a study [29] demonstrated that a single sequence of intermittent bright light (IBL) can effectively cause phase delays of the human circadian rhythm. The results were compared to very dim light (VDL) and bright light (BL). What is of great interest is that through this study we understand that even brief episodes of light and intermittent exposure to bright light can have a great impact on circadian entrainment. Also, brief episodes of light could be a cost and energy effective way of resetting the circadian system of humans.

In 2008, Brainard [30] demonstrated a relationship between 420nm exposure and melatonin suppression in humans. At the same time the case study clearly demonstrated that 460-nm light is significantly stronger than 420nm light for melatonin suppression.

Figueiro and Rea in 2010 [31] showed that melatonin, cortisol and alpha amylase[4] follow circadian patterns, therefore the hypothalamus suprachiasmatic nuclei (SCN) are involved in their daily production. However, their study also showed that these rhythms have different waveforms and different relationships with time of day.

The study showed that although the circadian system is sensitive to 40 lux of blue light in the cornea it is not sensitive to 40 lux of red light to the cornea as measured by nocturnal melatonin suppression.

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4 α-Amylase is a protein enzyme EC 3.2.1.1 that hydrolyses alpha bonds of large, alpha-linked polysaccharides, such as starch and glycogen, yielding glucose and maltose.[2] It is the major form of amylase found in humans and other mammals.[3] It is also present in seeds containing starch as a food reserve, and is secreted by many fungi.

On the contrary, even if results were mild, cortisol and alpha amylase levels were affected by both the short and long wavelength lights at night. However, during the day cortisol levels did not seem to change dramatically with the same lights exposure.

In a nutshell, the SCN has a key role in the regulation of our endocrine and nervous system. Under dark conditions within a 24-day melatonin, cortisol and alpha amylase have a solid circadian rhythm.

However, the response of each rhythm to environmental light at different times of the day is not the same. Melatonin produced by the pineal gland is influenced only by short wavelength while cortisol produced by the adrenal gland is modulated both by blue and red light.

In 2011, Gooley [32] tested the hypothesis that exposure to room light in the hours before bedtime suppresses melatonin production and shortens the duration. The results indicated clearly that room lighting had a huge suppression on melatonin levels but also reduced the internal representation of night duration. This could mean impacts on sleep patterns, thermoregulation, and blood pressure.

In a 2013 paper, Figueiro of the Lighting Research Center presented a very thorough overview of circadian rhythms and the implications of new lighting sources and systems.

The quantity of white light to activate the circadian system needs to be twice as much as the one that activates the visual system. The circadian rhythm is more sensitive to the blue part of the spectrum with a peak at 480nm, as discovered later by Russel Foster' team at Oxford University, in comparison to 555nm for the visual system.

In the 2013 *Trends in Neuro Science* article "Measuring and using light in the melanopsin age," some of the most important researchers in the field proposed new light-measurement strategy for use by researchers and simple suggestions for artificial lighting are provided for regulatory authorities, lighting manufacturers, designers, and engineers.