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Light-Emitting Diodes: Materials, Devices, and Applications for Solid State Lighting XV

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Daytime Light, Performance and Sleep

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ABSTRACT

The discovery of intrinsically photosensitive, retinal ganglion cells, the photopigment melanopsin and the description of its action spectrum some ten years ago, initiated a rapid development in the field of light and health. Research in animals and humans has shown a surprising similarity in molecular mechanisms and signalling pathways between unicells, amphibians as well as mammals including humans. These nonvisual light effects contribute to the regulation of e.g. the circadian timing system, sleep-wake, performance, learning, temperature, heart rate and metabolism. The introduction of new light sources is unlikely to worsen the current situation with respect to the nonvisual, eye-mediated, biological effects of light. Rather these new devices will enable light industry, clinical chronobiologists and architects to improve health, save energy and improve learning and performance in large parts of the population. The magnitude of this potential benefit can hardly be overestimated. In order to provide these groups with concrete instructions for application human experimental and applicational studies are desperately needed.

Keywords: light, health, melatonin, alertness, performance, sleep, circadian timing system, melanopsin

Background:

The rotation of the earth is the source of the most reliably recurring event in nature: the daily light-dark cycle. The evolutionary result is a network of internal clocks, governed by a master clock, which drives the predictable part of daily physiological variations in a precise manner. One hand of this clockwork is melatonin. Melatonin is secreted by the pineal gland during darkness, mediated by a signal of the internal clock.

Although industrial progress and life in a 24-hour-society are based on the use of artificial light at night, the endogenous circadian timing system (CTS) is synchronized to the solar day by means of the environmental light-dark cycle. Maintaining synchronized circadian rhythms is important to health and well-being. A growing body of evidence suggests

that a desynchronisation of circadian rhythms may play a role in various tumoral diseases, diabetes, obesity and depression. Shift-workers, who are a model for internal desynchronisation, are known to experience increased morbidity and mortality for a number of diseases, including cardiovascular disorders and cancer.

Research starting in the 1980s / 1990s led at the beginning of this century to the discovery that the mammalian eye contains a subset of directly photosensitive retinal ganglion cells (pRGCs). These pRGCs respond maximally in the blue part of the visible spectrum and utilize melanopsin as the photopigment. The pRGCs project to the circadian clock (located in the suprachiasmatic nuclei of the hypothalamus) and entrain the circadian timing system to the environmental light-dark cycle. Thus, in order to stay synchronized, the circadian timing system needs a daily variation of light and darkness.

Using various designs, it was repeatedly shown that light of high intensity and/or monochromatic blue light not only suppresses melatonin at night, but also induced pupil constriction, increases heart-rate, influences thermo-regulation, enhances alertness, and changes the frequency of the electro-encephalogram. Nevertheless, most of these studies were performed using artificial environments and long-term, high-intensity, polychromatic or monochromatic blue light in a way that seldom occurs even in our world of artificial lighting.

The aim of our recent research was to evaluate the effects of polychromatic light on humans in their natural environment.

In a first experiment we quantified the illumination levels people in an urban environment are exposed to. We found that daytime illumination levels that students in Berlin were exposed to are extremely low when compared to those levels humans are evolutionary made for. One may consider these illumination levels as “living in biological darkness”. In case these illumination levels are representative for the general population one may speculate that the circadian timing system of humans in an urban environment do not receive sufficient light to stay synchronised.

In the next step we conducted various studies on the effects of daytime illumination and nighttime sleep. Ten minutes illumination by everyday lamps significantly suppressed melatonin excretion, increased alertness and changed subsequent sleep. The impact of these studies is that not only monochromatic light in the artificial environment of the lab, but polychromatic light emitted by everyday lamps influences behavior and physiology. The WHO has classified nightshiftwork as probable carcinogenic. The supposed mechanism is the suppression of melatonin by light during nightshift. Furthermore one may speculate that the light induced suppression of melatonin in the evening contributes to the failure to initiate sleep of which a major part of the population suffers from.

In the second part of these studies we investigated the effects of morning illumination on nighttime sleep. Here we found that morning illumination significantly influences subsequent nighttime sleep.

Conclusion:

The rapidly increasing knowledge concerning the circadian timing system and the coordination of physiologic and psychologic processes on the one hand as well as the increasing understanding of the mechanisms of circadian entrainment will induce a substantial change in our daily living. The major aim will have to be to strengthen the circadian timing system which can be achieved by increasing the blue portion in artificial light during day time and by reducing the same blue portion of artificial light during the night and evening hours. Increasing the blue portion of artificial light may improve performance and learning ability in school kids and employees working indoor, health will be improved in patients staying at nursing homes or hospitals. On the other hand a reduction of the blue portion in artificial light during night time hours may prevent shift workers from disorders like cancer and cardiovascular disorders as well as reduce sleep disturbances and their consequences among the general population. Fascinating times are ahead of clinical chronobiologists, light industry and architects to mention just a few.

