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Publisher's version / Version de l'éditeur:

Leukos, 2, October 2, pp. 85-96, 2005-10-01

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NRCC-48330

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A version of this document is published in / Une version de ce document se trouve dans: Leukos, v. 2, no. 2, Oct. 2005, pp. 85-96

Originally published in *Leukos, v. 2(2) (2005), pp. 85-96**

Light, Lighting, and Health: Issues for Consideration

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Abstract
Fundamental research into the effects of light on biology, behaviour, and health is a rapidly-advancing field. As the lighting community learns more about these research results, interest in potential lighting applications is growing. This paper sets out issues for consideration in three areas: research areas in which knowledge is needed; topics that the lighting community should address to lay a strong foundation for application of this knowledge; and, ways in which the lighting community might facilitate the interdisciplinary work needed in order for basic research to lead to application. The integration of light and health knowledge into lighting practice is less a revolution than an evolution, as we continue to develop the general model of lighting quality that emerged in the mid-1990s.

1. Introduction

One may detect a low, but rising, level of excitement in the lighting research community as news of recent findings from biology and physiology laboratories spreads. What was taught as received wisdom, the starting point for learning about vision and perception - “there are two photoreceptors in the human retina” – we now know to be incomplete knowledge, thanks to researchers such as Berson (Berson and others 2002) and Provencio (Provencio and others 2000), among others, who have elucidated the existence of a novel photoreceptor. Great effort continues in various laboratories to determine the action spectrum of this photoreceptor, using effects on melatonin suppression as the indicator of spectral sensitivity (e.g., Brainard and others 2001; Thapan and others 2001). As fundamental science advances knowledge about light’s effects on humans beyond seeing, those whose interests lie in more applied fields naturally wonder how the new information might change lighting practice (Bommel 2005).

The lighting community has already begun the philosophical shift that is required to integrate the new knowledge into lighting practice. We can see this in the model of lighting quality that appears in the 2000 (9th) edition of the IESNA Lighting Handbook (Illuminating Engineering Society of North America 2000). This model encompasses human needs, architectural integration, and economic constraints (including energy) (Veitch 1998; Veitch and others 1998) (Figure 1). Human needs, as defined here, include lighting that is appropriate to maintain good health, as well as lighting for visibility, task performance, interpersonal communication, and aesthetic appreciation. Our goal as we continue to consider what the new light and health knowledge means for lighting practice must be to develop recommendations and ideas that build on this model, so that our lighting installations continue to balance the various, sometimes competing, demands.

*Also published in *Light and Engineering, 13*(4) (2005), 6-13; and, in Russian in *Svetotekhnika*, No. 6 (2005), 28-34.

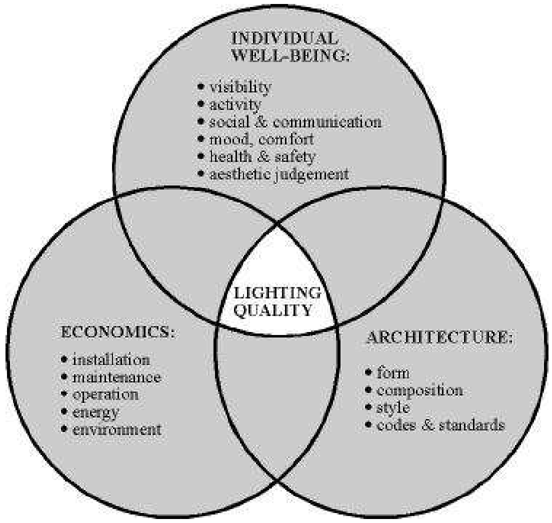

Figure 1: *Lighting quality model (Veitch 1998).*

The editors of the three principal lighting journals (alphabetically, *Leukos*, *Lighting Research and Technology*, and *Svetotechnika)* have taken an unprecedented initiative to raise awareness of the new scientific knowledge, and to foster discussion and debate about its implications for lighting practice, by publishing a series of invited papers on the topic. This is one such paper. It is not a conventional review paper; rather, it is a structured attempt to identify some of the challenges that lie ahead for those who wish to advance our thinking about what DiLaura has identified as "The Next Big Thing. Maybe." (DiLaura 2005). Readers interested in a comprehensive review of knowledge about light's effects on human physiology and health should seek a copy of the Commission Internationale de l'Eclairage (CIE) report 158:2004, titled *Ocular lighting effects on human physiology and behaviour* (CIE 2004), or search the online databases such as Pubmed (http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?db=PubMed) for more recent publications in this fast-moving field (e.g., Brainard and Hanifin 2005). I served as Chairman of the technical committee that produced the CIE report; therefore, its conclusions and recommendations will serve as my starting point for this commentary. That committee has been closed, its report completed; the opinions expressed here are mine alone.

2. Light and Health

This brief commentary is not the place for an extensive listing of research topics that a lighting person would wish to see addressed by fundamental science. I will limit myself to four topics that, in my view, are key information requirements for responsible lighting practice.

2.1 Light Exposure Measurement

Although there is not yet a definitive action spectrum for melatonin suppression by retinal light exposure, it is clear that the action spectrum will not be the same as either V_λ or V'_λ (cf., Brainard and others 2001; Thapan and others 2001). The peak spectral sensitivity for this physiological process lies somewhere between 459 and 484 nm (Brainard and Hanifin 2005). Thus, to measure light exposures using traditional photopic or scotopic luminance or illuminance will give an incorrect indication of the intensity of the illumination experienced by the neural pathway responsible for melatonin suppression. In order to better understand how light exposures affect melatonin suppression (and, by extension, the regulation of circadian rhythms), we need an internationally-sanctioned weighting function and associated units, backed up by widely-available instrumentation that is used by all laboratories and reported in their scientific papers. Until such time as this fundamental measurement issue is addressed, researchers in this field should cease to report only photometric illuminance as the indicator of light exposure, and instead should provide complete characterization of their experimental stimuli, with both the spectral properties of the stimulus and the total irradiance, as received by the research subject (CIE 2004). Anything less makes cross-comparisons between studies using different light sources nearly impossible.

2.2 Beyond Circadian Rhythms

The World Health Organization (WHO) definition of health is "a state of complete physical, mental, and social well-being and not merely the absence of disease or infirmity" (WHO 1948). As yet, a full understanding of how light affects health in all of its dimensions eludes us.

At present our knowledge is dominated by studies of the role of light and dark in the regulation of circadian rhythms, principally through the pineal gland and the action of the hormone melatonin. Thus, we know that the projections from the retina to the suprachiasmatic nucleus (SCN) in the hypothalamus branch into an important pathway leading to the pineal gland. Through the pineal gland, light and dark exert effects on the entrainment of circadian rhythms by regulating the release of the hormone melatonin (Moore and Lenn 1972; Pickard and Silverman 1981; Klein and others 1983; Klein and others 1991; Card 1994). Photobiologists and their clinical research counterparts have studied this pathway extensively and have used this knowledge to develop treatments for various ailments that involve disrupted circadian rhythms, such as sleep phase disorders, restlessness among Alzheimer and dementia patients, and maladaptation to night shift work (CIE 2004). As a result, much of the writing of people in the lighting community about the effects of light on biology has focused on circadian rhythms to the exclusion of other physiological functions (e.g.,Bommel and Beld 2004; Boyce 2004), because these are the best-understood.

However, there are many other connections from the SCN to other brain structures (Klein and others 1991), shown schematically in Figure 2. These systems regulate the production of almost all hormones, which means that light exposure might influence a wide variety of physiological functions beyond circadian rhythms. Although there are a few laboratories studying these other functions, these relationships as yet poorly understood (CIE 2004). Just as we have found that there is more to the retinal processing of light than vision, we should expect that there is more to the effects of light on health than is comprehended by the pineal pathway alone.

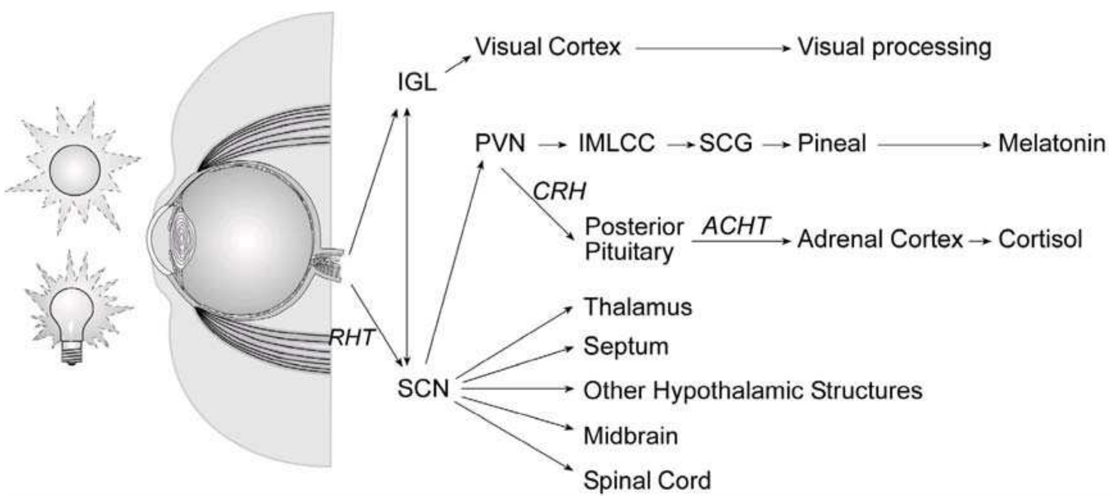

Figure 2: *Schematic diagram of eye-brain pathways. Light received by the eye is converted to neural signals that pass via the optic nerve to two pathways, one visual and one non-visual. RHT = Retino-hypothalamic tract. IGL = Intergeniculate leaflet. SCN = Suprachiasmatic nucleus of the hypothalamus. PVN = Paraventricular nucleus of the hypothalamus. IMLCC = Intermediolateral cell column. SCG = Superior cervical ganglion. CRH = Corticotropic releasing hormone. ACTH = adrenocorticotropic hormone. Figure from CIE Report 158:2004, © CIE, 2004. Used by permission.*

2.3 Daily Light Dose

Based on their literature review, the authors of the CIE report concluded that the total daily light exposure of day-active people in Western, industrialized countries might be lower than it should be for the maintenance of optimal well-being (CIE 2004). There is evidence that people with no overt symptoms of disease can benefit from increased light exposure over days or weeks, showing increased self-reported vitality, alertness, and improved mood following a treatment period with an increased white light exposure of approximately 4 times the usual illuminance (Partonen and others 1998; Partonen and Lönnqvist 2000;

Noguchi and others 2004). However, this evidence is, at best, preliminary. We need to know the action spectrum for the effect; the necessary total light exposure (both intensity and duration being important); and, the best time of day for the exposure. Furthermore, exposure and timing might differ for different populations, such as those who are predisposed to be more active in the morning ("larks") or evening ("owls"), for whom patterns of hormone secretion are known to differ (Bailey and Heitkemper 2001). It would help to have a clearer understanding of the physiological mechanism for this effect, if it is real. It appears unlikely to be the melatonin-controlled circadian rhythm regulation system, because melatonin is not known as a mood-enhancing hormone, and its circulating level during midday is very low, such that increased light exposure could not suppress it further (Wetterberg 1993).

2.4 Roles for Rods and Cones?

Photobiologists have established the existence of a novel photoreceptor involved in circadian regulation, with a new action spectrum peaking in the range 459-484 nm (Brainard and Hanifin 2005). For this reason, the CIE report concluded that healthy lighting should be rich in energy from that spectral region (CIE 2004). Some might interpret this as evidence that light sources for healthy light should be tuned to emphasize short-wavelength light. This may be so, but before applications people rush to design new light sources, there is need for more information. It also appears that there is a role for the rods and cones in circadian regulation (Brainard and Hanifin 2005). Figueiro et al. (2004) suggested that there exists an opponent process, in which the melatonin-suppressing effects of short-wavelength light are reduced if there is simultaneous exposure to longer wavelengths. This and other studies raise important questions not only for understanding retinal physiology, but for potential architectural lighting applications. A better understanding of these fundamental mechanisms should precede the development of novel light sources, the effect of which may be difficult to predict based on current knowledge.

3. Lighting and Health

The many open research questions related to light and health will take some time to answer with sufficient clarity and certainty to support lighting practice recommendations. During this time, the lighting community – those interested in applying knowledge to lighting installations – should not lie passively waiting, but should prepare the way for integrating the new knowledge into its domain. I will discuss four issues here.

3.1 Laying the Foundation

Fortunately, preparing to incorporate knowledge about light and health into lighting practice does not mean throwing away existing knowledge; rather, it is a matter of continuing to develop the concept of lighting quality. It will always be true that light carries the information for seeing, and that we provide lighting in part to ensure visibility. The change will lie in explicitly recognizing that other biological processes occur simultaneously, and in finding suitable ways to provide appropriate illumination for those processes at the same time as achieving other lighting goals. For North Americans, this change began with the 2000 edition of the *IESNA Lighting Handbook* and is continuing with the recent revision of IESNA educational materials and the development of a design guide for lighting quality, under development by IESNA's Quality of the Visual Environment committee. While we await clarity on research issues that fundamental scientists can address, we can continue this work so that a strong foundation is laid for a more comprehensive way of thinking about lighting goals. (I regret that I am less familiar with the situation worldwide, and therefore unable to comment on initiatives in Europe, Asia, Africa, Australia, or South America.)

3.2 Design Criteria

Although it is premature to recommend specific new light sources in the absence of scientific consensus about the most desirable spectral properties of light for biological effects, it is not too soon to begin to think differently about *where* we deliver light for biological effect. For physiological processes that arise from retinally-detected light leading to signals in higher brain structures, what matters is the intensity, duration, spectral content, and timing of light delivered *to the eye*. High light levels on room surfaces or objects that are rarely viewed will not have a significant biological effect, and could represent wasted energy. Part of the development of lighting quality recommendations has been to broaden the set of design criteria beyond horizontal illuminance (or sometimes vertical), to a wider range of ways to describe the lit environment. For example, the IESNA Lighting Design Guide provides direction for designers regarding the relative importance to the lighting design of a given task area in a given setting, of criteria such as room surface luminance, source-eye-task geometry, sparkle, colour rendering, colour appearance, and glare control (to name a few) (IESNA, 2000). We do not yet have an easy way to describe the amount of light delivered to the occupant's eye, nor is this quantity commonly predicted by lighting software. We would do well to begin to add this to our list of design criteria, in preparation for lighting recommendations intended to promote good health. (Some issues related to this topic were addressed at the CIE Expert Symposium on Light and Health in 2004 (Veitch and others 2004).)

3.3 Daylighting

One can expect that daylighting will play a large role in new lighting recommendations for health. It is rich in the spectral region of the peak in the action spectrum for the new photoreceptor, and is intense enough to deliver a high light dose in a short time, with no energy requirement for lighting (CIE 2004). If increasing daytime light exposures proves to be a component of lighting for health, increasing the use of daylight might be the optimal design solution for many applications. However, as is well known, successful daylighting requires control. At the same time as increasing light exposure, we will need to limit glare and solar heat gain to avoid compromising comfort and creating new energy-use problems for heating and cooling. Achieving these several goals will require continued technical developments for windows, shading, and their related controls, and increased use of predictive tools in daylighting design. We also will need tools to assess the light exposure and light dose from daylight in buildings, preferably using dynamic daylight performance metrics in place of static metrics such as the commonly used daylight factor. Work along these lines has already begun among daylighting researchers (C. F. Reinhart, personal communication, August 24, 2005). Ideally, any such metric would be easily adapted for use with the new photometric system discussed above in section 2.1.

3.4 Professional Development and Ethics

Many educational and training paths lead to lighting practice careers, and there exist few educational institutions with specialized programs in lighting. This paper is not the place for a detailed discussion of issues related to professional credentials; however, those involved in lighting education should not cease debating and discussing issues of curriculum, practical training, professional practice standards, and continuing education requirements for all types of lighting practice, not only the application of light and health. DiLaura (2005) rightly observed that applying information about light and health in lighting practice will place a new responsibility on lighting practitioners. We need to be certain that those who would apply this knowledge on behalf of all of us – for instance, in writing recommended practice documents – have the appropriate expertise to make the translation from research to practice; and equally, we need a means to ensure that those who intend to achieve a biological effect with a lighting installation understand what they are attempting and are willing to take responsibility for the success or failure of the effort. The responsibility is not entirely new to the lighting community – consider, for example, the responsibility for safety associated with roadway, marine, airport, or industrial lighting installations – but it will apply more broadly as the goals for good-quality lighting extend to the achievement of good health.

4. Facilitating Interdisciplinary Efforts

The U.S. National Academy of Science has defined interdisciplinary research as

> "…a mode of research by teams or individuals that integrates information, data, techniques, tools, perspectives, concepts, and/or theories from two or more disciplines or bodies of specialized knowledge to advance fundamental understanding or to solve problems whose solutions are beyond the scope of a single discipline or area of research practice." (Committee on Facilitating Interdisciplinary Research, Committee on Science, Engineering, and Public Policy, National Academy of Sciences 2005)

Interdisciplinary research differs from multidisciplinary research in that it involves an integration of knowledge from more than one field. In a multidisciplinary project, researchers from more than one field work on a common problem, but work separately, from their different perspectives. It is clear to most that in order to incorporate fundamental knowledge about light and biology into lighting practice, we will need interdisciplinary efforts combining fundamental science and applied lighting research (e.g., Bommel 2005;

Loe and Veitch 2004).

The lighting community needs to take the initiative to make this interdisciplinary work happen. Except for a few rare individuals who see the potential for application and are interested by it, the scientists who study neurophysiology, medicine, cognitive science and related disciplines share with the general public a disinterest in practical lighting questions and a lack of awareness of the value and potential of lighting for improving the human condition (cf., DiLaura 2005). We need to reach out to the varied scientists who study light and biology to interest them in the questions that we find interesting and important.

In order to do so, we should seek to understand what facilitates, and what prevents, interdisciplinary research. Latham and Latham (2003), writing in the context of organizational psychology and human resource management, described a three-part framework for understanding what prevents diverse groups from working together. The three parts are the different cultures of the groups, the people involved, and the institutions within which the individuals and groups work. This framework could equally apply to the challenge facing the lighting community today. Latham and Latham provided specific prescriptions for overcoming barriers that with some modification can be applied to the goals for developing lighting and health recommendations based on light and health research.

4.1 Culture

Professionals are trained to speak the language of their disciplines, and to value those things that support and sustain the disciplines. Those in academic or pure science careers are said to speak an abstruse dialect, and to be incapable of expressing their work in terms that practitioners can apply in a straightforward way. Practitioners, viewed from the scientists' perspective, may appear to seek naïve answers to support short-term goals. These values influence behaviour. So long as the two solitudes cannot communicate and perceive one another with distrust, collaboration and interdisciplinary work are impossible (Committee on Facilitating Interdisciplinary Research, 2005; Latham and Latham 2003). The lighting community must take the initiative here to create opportunities to meet academic researchers, develop networks both of individuals and their professional societies, and above all, to develop mutually interdependent goals that would benefit both groups if achieved (Latham and Latham 2003). Working together to achieve such goals builds trust.

There have been two conferences thus far combining fundamental scientists and applied lighting researchers among the speakers (the Fifth International LRO Lighting Research Symposium: Light and Human Health in November 2002, and the CIE Expert Symposium on Light and Health in September 2004), which is encouraging in this regard, but those who were present at both know that we are not yet at the point of true exchange of ideas from which shared goals might emerge. Scientists are inspiring lighting practitioners and researchers (witness the existence of this journal article), but we have not yet inspired them to anything like the same degree. We can hope that further progress along this line will occur at the CIE Symposium on Lighting and Health, planned for September 2006 in Ottawa, Ontario, Canada (co-hosted by the National Research Council of Canada, Institute for Research in Construction).

4.2 Person

The cultural practices, while inculcated in groups during their professional socialization, are enacted by individuals. Developing rapport with people in the other group is best accomplished through a few influential individuals in the other group, who can act as champions (Latham and Latham 2003). We have a few such individuals already, scientists who regularly address audiences in the lighting community and who serve on committees in IESNA and CIE (for instance), but we have not yet succeeded in communicating through them to the wider community of scientists who study light and health.

Lighting practitioners who want to apply light and health research also need to learn the language of science in order to communicate better with their counterparts (Latham and Latham 2003). With the language in place, one can identify the underlying assumptions of the other and can begin to understand the other's knowledge base. Not every lighting practitioner or lighting researcher needs to undertake this effort; but those who wish to be active in translating light and health knowledge for the use of lighting practice must do so. In turn, these translators can then educate the basic science community about lighting concepts with which they may be unfamiliar, such as photometry or the operation of common lighting systems, which would strengthen the validity of light and health research as well as linking it to the needs of the practitioner community.

4.3 Institution

People do that for which they are rewarded. If the lighting community wishes to engage fundamental light and health scientists, it needs to understand what motivates scientists and to provide appropriate rewards (Committee on Facilitating Interdisciplinary Research 2005; Latham and Latham 2003). Two inter-related rewards motivate scientists in academic and research institutions: the availability of research funds, and publications in top-tier, peer-reviewed scientific journals. These two criteria drive professional success in their communities and determine who will be hired, granted tenure, promoted, or granted institutional perquisites such as sabbatical leave. Interdisciplinary research is at a disadvantage because it is inherently more time-consuming and risky, with fewer research funds available and fewer widely-recognized journal outlets for the resulting papers.

To obtain the information on light and health that we see as necessary to our goals for lighting practice, we need to remove institutional or systematic barriers. Our research funds are limited, but we need to be proactive in developing new funding sources for interdisciplinary research, both by convincing industry to contribute and by working to explore every avenue with government and charitable sources (Loe and Veitch 2004). Many research granting bodies are interested in interdisciplinary efforts and have funding programs specifically dedicated to projects that combine fundamental and applied goals. Therefore, we will have more success in this arena if we are able to develop project proposals together with our scientist colleagues that address interdependent goals. Both groups would win, as the collaboration would make available funds that would be otherwise unattainable.

We also need to further develop the scientific credibility of our journals, to make them attractive places to publish light and health research. Many academic institutions recognize only those articles published in journals that are tracked and ranked by Thomson ISI's citation indices (Science Citation Index, Social Science Citation Index, Arts & Humanities Citation Index) (http://scientific.thomson.com/). Of the principal lighting journals, only the former *Journal of the Illuminating Engineering Society* (JIES) appeared in the Science Citation Index (*Leukos* is not yet on their list). The citation indices track the success of articles and journals by calculating a quantity called *impact factor*, which is based on the frequency with which others cite the article (averaged over articles to produce the journal value). The 2004 impact factor for JIES (based on citations of articles published through 2003) is 0.22, which is very low in comparison to the *Journal of Biological Rhythms*, at 3.0, or *Chronobiology International*, at 1.52, both outlets for circadian rhythm and melatonin research. Citations depend on the quality of the work, to be sure, but they also depend on widespread awareness of the journal, which means library subscriptions, promotion, and (most importantly) being indexed in key databases (work that is invisible remains uncited). Unless we can demonstrate to light and health researchers than there will be visibility for their work in our journals, we will not find them willing to publish here.

5. Conclusions

Excitement is mounting over the potential lighting applications of light and health research, and for good reason. Opening a new avenue for research and application is intellectually exciting, and the unexpected finding that there is a new photoreceptor is revolutionary. This new direction, moreover, promises to move us beyond a field, vision, in which most of the basic mechanisms relevant to lighting are fairly well established, to one where there is much still to be learned (Boyce 2004). This paper has attempted to identify key issues for consideration as we find our way forward. At this stage, nothing is conclusively known, except that there is much still to learn and much to do to be ready to apply what we learn.

Acknowledgements

I would like to thank the three journal editors, Julian Aizenberg, David DiLaura, and David Loe, for creating this international discussion forum as a way to advance our thinking on this emerging issue. It is an honour to have been invited to participate.

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