Correspondence: Daylighting: Why infra-red should be explored.

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In their recent paper, Knoop *et al*[1] present a convincing case for daylighting. In agreement with a contemporary understanding of the role of lighting,[2] their analysis goes beyond the strictly perceptual effects of light on humans, as well as the spectral boundaries of visible radiation. They mention the importance of vitamin D production, which is linked to UVB exposure.[3] They also discuss thermal properties of infra-red (IR) radiation and define the long end of daylight's wavelength spectrum as ~2600 nm. More importantly, they elaborate on circadian entrainment and the invigorating effects of short-wavelength light, pointing out that while relevant studies usually employ electric sources, natural light should likewise provide these benefits through potentially high intensity and colour temperature.

Some noted ramifications of daylighting, however, remain without physiological explanation in their paper. Although the existence of purely psychological effects or a non-physical property[1,4] of sunshine are intriguing propositions, low-level explanations ought to provide a better ground for empirical inquiry. While the visible spectrum can also differ in many details between electric and natural light, the IR portion is insignificant in the most commonly used fluorescent and LED lamps and always present in daylight, thereby being a reasonable suspect for the source of differences in observed effects. Indeed, a large body of literature demonstrates connections between long-wavelength radiation and basic physiological functions, possibly in line with the acclaimed advantages of daylighting[1] regarding retinal functions[5-11] or increased glare tolerance[12,13] and overall comfort.[14-16] Grasping the potential connection between these benefits of daylight and the existing knowledge on low-level effects of IR radiation would require targeted experimental testing, and until then, contemplating such a link remains theoretical. Adding to the uncertainty, most of our insight into the physiological significance of various long wavelengths comes from studies on animal models. Furthermore, thermal effects of IR in natural light can have a negative impact on comfort and adding IR to existing electric light sources would greatly decrease their energy efficiency. Therefore, the aim of this letter is not to directly promote the use of IR in general lighting. Instead, the following points are made to draw attention to some, often neglected, non-visual effects of red and IR radiation. These effects might play a role in daylighting, deserve further study, and could possibly be utilized in specific lighting applications.

Red and near infra-red (NIR) exposure influences eye health,[17-25] mood and neuropsychological well-being,[26,27] and has various further clinical effects.[28-36] While some medical applications aim for short and intense treatments, the most efficient use of red and NIR for health purposes appears to be at low irradiation levels over long durations.[37] These levels are still generally higher than that of daylight NIR irradiance, but the ranges are overlapping.[37,38] Daylight might also be relevant in longer time frames (e.g., across years), can cover larger surface area, and includes far infra-red radiation that has possibly similar effects[39,40] to those of NIR. Comparing various application scenarios is further complicated by that irradiance and dosage on a given anatomical structure depend on its distance from the surface. The extent of this is not easily quantifiable, as beyond the power-independent attenuation in various kinds of tissue,[41] systemic effects are instrumental as well.[42] Implications for the skin and the eye are nevertheless consequential even at low irradiance levels.[43] Similarly to beneficial properties, these are the locations where harmful effects of light are most detectable. NIR radiation can contribute to photoaging and cause thermal damage at higher intensities, although this does not immediately translate to a general need for skin protection.[44,45]

Effects of various parts of the spectrum are also in interaction with each other. For example, exposure to NIR radiation can aid in the recovery from damage induced by shorter wavelengths.[46-49] Due to mechanisms based on chromatic aberration, narrow-band light of both short and long wavelengths, or a lack of either part of the visible spectrum, can disrupt emmetropization.[50-52] These observations speak for daylighting, where the ratio of various wavelengths is balanced. They also allude to new possibilities for health-oriented applications by means of electric lighting, given that the underlying processes are sufficiently understood.

A fascinating and so far largely unexplored question is whether different narrow-band portions within the NIR spectrum have disparate physiological effects. Pioneering research from the lab of Maik Hüttemann indicates that this might indeed be the case: even antagonistic effects can be achieved by choosing different, yet not too distant, wavelengths.[53] On the one hand, these oppositions are likely balanced out when the whole spectrum is present – making the effects of daylight even more difficult to compare to those of most laboratory-based experiments. On the other hand, understanding the mechanisms behind them could open up novel ways to utilize narrow-band LED sources.

Contemporary lighting places much emphasis on human well-being and the non-visual effects of light. Despite this, the ever-growing amount of empirical and theoretical knowledge about the physiological effects of various wavelengths around and beyond red has not yet found its place in the conversation about lighting practices. These effects show some resemblance to those of daylight, while dosage and other considerations are difficult to quantitatively compare between the various light sources and applications. Adding to the complexity, different narrow-band regions of NIR can even have contrasting physiological effects, and complementary interactions between short and long wavelengths are known to affect developmental and recovery processes in the retina. These observations lend further support to daylighting, where such interactions are presumably well-balanced. They also show that interdisciplinary study and discussion of the physiological effects of red and NIR radiation is necessary for the evaluation of lighting practices.

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