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Publisher's version / Version de l'éditeur:
https://doi.org/10.1016/j.jenvp.2014.06.005
Journal of Environmental Psychology, 39, pp. 1-4, 2014-06

Submission; do not circulate until published.
Journal of Environmental Psychology, 2014

From blind spot into the spotlight
Editorial to the special issue 'Light, Lighting, and Human Behaviour'

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"*A painter should begin every canvas with a wash of black, because all things in nature are dark except where exposed by the light*."
— Leonardo da Vinci

Without light, there would be no life on Earth. Electromagnetic radiation (EMR) across a very wide spectrum heats the planet sufficiently for biological activity; EMR across the range from ~380 to ~780 nm is responsible for most plant life and, most importantly to us, stimulates photoreceptive cells in the retina of most creatures with eyes. This is so important to humans that the very definition of light in the Système International d'Unités [the International System of Units] is based on our biological response to this part of the electromagnetic spectrum (Commission Internationale de l'Eclairage [CIE], 2011), the only physical quantity that is linked to a human capability. This photodetection reveals the world to us through vision and attunes us to the cyclical pattern of light and dark so that we – as virtually all life on earth (fauna and flora) – have periods of activity and periods of rest. It is hard to overestimate the role light has in all aspects of human function, and particularly those of interest to psychologists: perception, cognition, affect, communication, comfort, sleep.

Not only does light influence behaviour, but our choice to use lighting *is* a behaviour, one that has environmental consequences. By one estimate, lighting accounts for 19% of global electricity consumption (International Energy Agency, 2006). Furthermore, fuel-based lighting, used in parts of the world without a stable electrical supply not only contributes to carbon dioxide emissions but also creates local problems with air quality. Providing more efficient, higher-intensity, higher-quality light has benefits for health and quality of life. Outside psychology, much lighting research aims to support limits on lighting energy use while creating lighting conditions that do not adversely affect human needs.

Surprisingly, light and lighting have not received much attention from this journal: A quick search through the annals of the *Journal of Environmental Psychology* yielded only 6 papers with 'light' or 'lighting' as a keyword (in contrast, 281 used noise or sound). In the 34 years that our domain has had this journal, it has featured no more than 27 articles reporting on the experience or psychological effect of light or lighting, i.e., less than one article per year on average (see also Figure 1). Interestingly, there are over 4000 articles in the APA PsycInfo database with the keyword "illumination" over the same 34-year period, as well as thousands of papers in multidisciplinary, engineering, architecture, physiology, and physics journals. We are puzzled by the apparent inattention that environmental psychologists have given to this important topic, and have sought to inspire our colleagues to take up this topic by presenting this special issue.

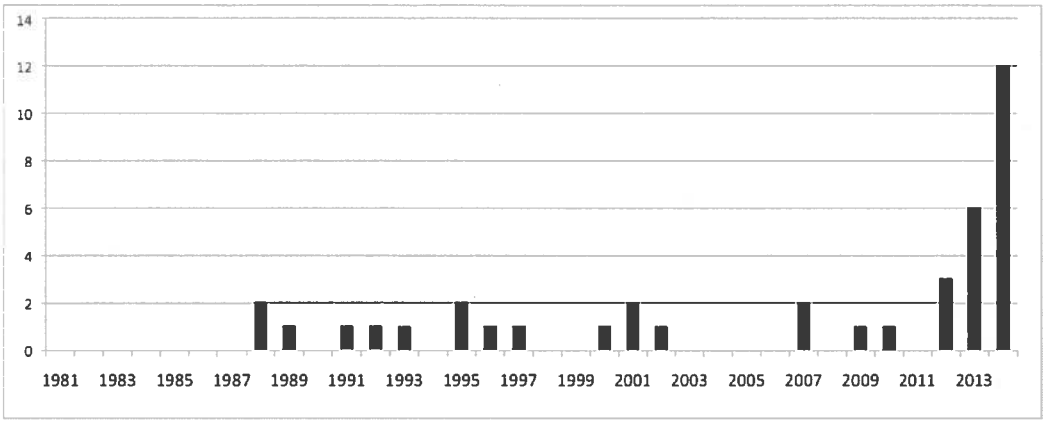

Figure 1. The number of publications on light or lighting in the Journal of Environmental Psychology since its conception

Introducing light – pathways of light

For decades, lighting research focused on visual performance, to ensure that workers had enough light to see fine details. At the highest levels, vision is well understood, although there are many details yet to be worked out: Light falls onto the retina and is detected by special cells called photoreceptors, setting off a cascade of signals through the optic nerve, optic chiasm and lateral geniculate nucleus to the visual cortex (the geniculostriate pathway). Interpretation begins at the retinal level, but integrated images require cortical activation (Boyce, 2003). The more light reaches the retina, the smaller the detail one perceives, but the relation is not linear and has many moderators. At low light levels, even a small increase in the quantity of illumination makes a large difference to visual performance; at high light levels (typical of most interiors), increases have a negligible effect on visual performance (Rea & Ouellette, 1991). The size, location, contrast and colour of the objects to be seen also influence their visibility, as do characteristics of the viewer (Boyce, 2003).

Psychologists know, however, that perception concerns much more than detecting details. Light has meaning in and of itself. We interpret the time of day from our knowledge of where the sun ought to be, its intensity and its colour. Light gives – and takes from – aesthetic value to scenes; it can create or enhance an atmosphere. Bright versus dim, warm versus cold, red versus green: Light has emotional connotations, implicit and explicit personal or culturally-shared associations and these colour our thoughts, behaviours and moods. Lighting communicates a message (Boyce, 2003). Interpretations of this message influence such outcomes as environmental satisfaction, self-appraisal, and physical comfort (Veitch, Newsham, Boyce, & Jones, 2008), as well as socially relevant behaviours including for instance dishonesty (Zhong, Bohns, & Gino, 2010), collaboration (Baron, Rea, & Daniels, 1992) or prosocial behaviour (Steidle, Hanke, & Werth, 2013).

Yet light itself can also be a stressor. Glare – an area of excessive light intensity in the field of view – can cause discomfort, which can be manifested in ocular pain and muscle strain (Berman, Bullimore, Jacobs, Bailey, & Gandhi, 1994) as well as in avoidance behaviours (Rea, Ouellette, & Kennedy, 1985). The mechanism for this discomfort is unknown (Boyce, 2003), although there are models available to predict the degree of discomfort in certain circumstances, the predominant model for interior lighting being the Unified Glare Rating (CIE, 1995). Although no concrete evidence to date supports this, some hypothesize that a second pathway of light, described below, may contribute to its incidence (e.g., Borisuit, 2013). Moreover, new light

sources with different characteristics from those used in the development of these models reveal the need for new work.

Recent advances in photobiology have set off revolutions among both lighting researchers and the lighting industry. We now know that there is a separate pathway for information about light energy, leading through the retinohypothalamic tract from the optic chiasm to different parts in the brain, including the suprachiasmatic nuclei (SCN) in the hypothalamus (Cajochen, Chellappa, & Schmidt, 2014; Moore, 1972), which form the central internal clock. This route is called non-image forming because these signals do not reach the visual cortex and hence do not contribute to our visual experience, nor do we become consciously aware of them. In fact, nothing of the 'image' is retained in the signal except for the amount of light falling onto the retina.

By this route, information about the amount of light falling on the retina regulates the operation of the SCN, controlling circadian rhythms, including sleep and waking. "[L]ight affects our circadian rhythms more powerfully than any drug" (Czeisler, 2013, S13). The regularly repeating daily exposure to light and dark results in a stable sleep-wake cycle, which is essential for mental and physical health (e.g., Alvarez & Ayas, 2004; Alvaro, Roberts, & Harris, 2013).

Importantly, the non-image forming signal comes predominantly from a different photoreceptor than the visual signal. Over the past decade, we have learned that a fifth type of photoreceptor – an intrinsically photoreceptive retinal ganglion cell (ipRGC), with a peak sensitivity in relatively short-wavelengths (i.e., in the blue part of the spectrum) – produces the strongest input to this signal (Berson, Dunn & Takao, 2002; Hattar, Liao, Takoa, Berson & Yau, 2002; Lucas et al., 2014), although complex interconnections exist between the ipRGCs and the visual photoreceptors (rods and codes).

The retinohypothalamic tract has extensions to several other brain structures, which are only beginning to be examined. Apparently, light information that passes through this non-image forming pathway also acutely influences structures related to wakefulness and alertness (Cajochen, et al., 2014), limbic, and cortical areas (Vandewalle, Maquet, & Dijk, 2009). Long-wavelength light (i.e., red) also seems to have an acute effect on alertness independent of circadian regulation (Figueiro & Rea, 2010; Kayumov et al., 2005). Much remains to be learned about these effects.

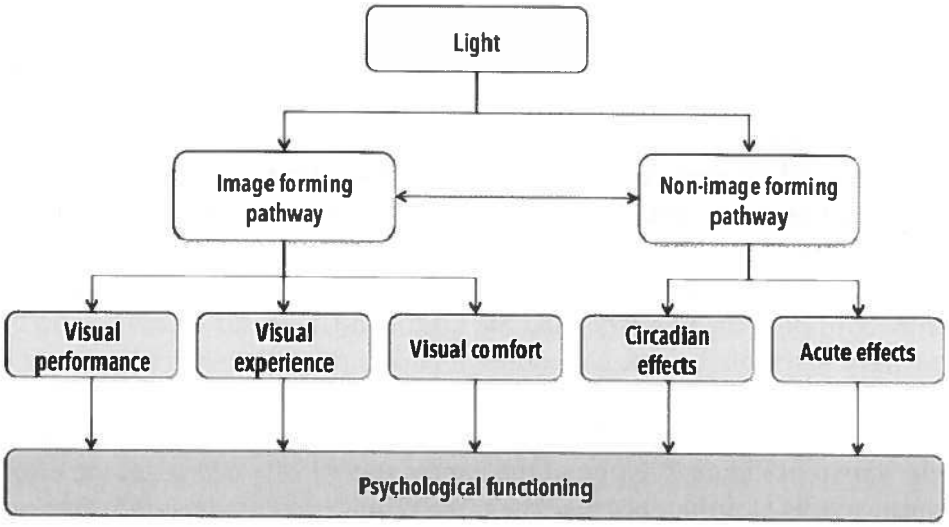

Figure 2. Pathways of light relevant to psychological functioning

Figure 2 presents a schematic overview of the pathways discussed above. Researchers from various domains, many beyond psychology, argue over the details of the categories shown here. Vision scientists and neuroscientists claim the visual processes as their research territory. Psychologists might claim the visual experience path, but (as noted) we rarely investigate it in detail; architects, interior designers, lighting designers and illuminating engineers usually claim that space. Chronobiologists and medical physicists generally claim the circadian rhythm domain, and these groups and some neuroscientists recently have moved towards the acute effects.

We argue that all classes of effects are relevant to environmental psychology, because all of them influence behaviour. For instance, cognitive performance varies according to circadian patterns (e.g., Blatter & Cajochen, 2007), has been shown to benefit acutely from alerting effects of more intense lighting (e.g. Smolders, de Kort & Cluitmans, 2012), depends on seeing fine details (Boyce, 2003), and is moderated by appraisals of lighting in one's space (Veitch, Stokkermans, & Newsham, 2013). That the same visual stimuli can simultaneously, in parallel and with interactions, influence behaviour, makes this topic both interesting and complex.

The current issue – process and content

We published the call for submissions for the present special issue in December 2012, inspired by 'Experiencing Light', an international conference on the effects of light on well-being (http://www.experiencinglight.nl/). Through this initiative we wanted to bring together a selection of original studies in the broad domain of lighting and psychology, encompassing daylight and electric lighting, and covering the relationship between light received at the eye and behavioural outcomes (e.g., affect, perception, cognition, motivation, performance, health) in various settings (e.g., work, home, school, care and leisure environments). We received 27 submissions, of which 10 were accepted, thereby increasing the number of light and lighting articles in this journal by 33% at once. Interestingly, many of the submissions had lead authors who are not affiliated with psychology units. The submissions and the accepted papers reflect the multidisciplinary nature of lighting investigations. Similarly, we were forced to draw upon reviewers from a broad range of disciplines; many of the usual reviewers for this journal declined on the basis that they lacked the expertise for this topic. More disturbing to us were the few who declined on the basis that the topic was not sufficiently psychological for the journal.

The multidisciplinary backgrounds of the researchers contributed to the pace of production (over a year to complete all the reviews for all of the submissions), as even interesting work required many revisions to reach the reporting standard of this journal. To make a sweeping generalization: Psychologists tend to emphasize the operationalization of the dependent measures and internal validity; researchers from design and building sciences tend to emphasize careful photometric measurements (characterizing independent variables) and external validity. Lighting research that reveals internal processes with the intent of changing practical applications requires both. Thanks to the diverse reviewer pool we finally assembled, and to the patience of both the publisher and the Editor-in-Chief (for which we are very grateful), we believe we have assembled a fine collection of papers that illustrates a broad set of interesting findings concerning the effects of light and lighting design on human behaviour.

This special issue presents studies that add to knowledge in three of the five classes of effects of light shown in Figure 2. None of the papers specifically addresses the effect of light on visual performance; this is fitting, because the topic is quite well understood. One paper specifically addresses visual discomfort: Geerdinck, Van Gheluwe, and Vissenberg (2014)

address a topic of immediate importance because of the introduction of light-emitting diodes (LEDs) in office lighting: discomfort arising from non-uniform light sources, which are different from those used to develop the predictive models currently used by designers.

The majority of the manuscripts submitted for this special issue relate most explicitly to the visual experience of light, or – more frequently – of environments as a function of lighting. The majority of earlier light-related publications in JEP have also typically been in this domain (e.g., Gifford, 1988; Knez, 1995; Veitch, 1997). The papers in this issue greatly expand the range of settings and research methods. Johansson, Pedersen, Maleetipwan-Mattsson, Kuhn and Laike (2014) focus on outdoor lighting quality, making a valuable addition in the form of a validated scale to assess this construct. The study by Boomsma and Steg (2014) investigates whether information on lighting's environmental impact influences public acceptance of reduced street lighting policies and perhaps even translates into changes in safety perceptions of more scarcely lit streetscapes. Their investigation is the only one in this special issue that focuses on the balance between lighting energy use and lighting applications.

Three papers examine how interpretations of visual stimuli moderate behaviour, using methods and explanatory processes that most psychologists might recognize in laboratory experiments. Quartier, Vanrie, and Van Cleempoel (2014) investigate whether and how three different but realistic light settings influence atmosphere perception, emotions and behaviour respectively, in a realistic mock-up of a supermarket. Steidle and Werth (2014) describe an impressive set of five studies exploring whether bright environments, through self-awareness processes, might promote reflective versus impulsive behaviour. In a series of experiments, Haans (2014) investigates whether appraisals of light produced by different light sources can be partly understood as being grounded in preferences for naturalness.

One team conducted a field investigation to test an applied hypothesis. Wei and colleagues (2014) compare visual comfort and satisfaction with fluorescent lighting varying in CCT and lumen output to test the spectrally enhanced lighting (SEL) method, a lighting strategy developed by U.S. lighting scientists, in which higher colour temperature is combined with lower lumen output. The SEL method was developed with the aim of reducing energy usage while maintaining equal spatial brightness perception and performance.

Although we received submissions dealing with circadian regulation, the review process excluded them from this special issue. Three papers, however, appear to address acute effects through the non-visual pathway. Smolders and de Kort (2014) examine whether brighter light conditions help individuals feel more vital and alert, and perform better on cognitive tasks and particular whether this alerting effect is stronger or faster for those who are fatigued. Changes in light source spectrum, rather than intensity, are the focus in the manuscript by Ferlazzo et al. (2014). They investigate whether lighting with more power in the peak of the ipRGC's sensitivity curve enhances executive functioning and performance of visual rotation tasks. The report by Wessolowski, Koenig, Schulte-Markwort, and Barkmann (2014) of a field experiment of a variable lighting system designed to reduce fidgetiness among schoolchildren demonstrates the potential overlap between the pathways, as current knowledge cannot differentiate between these explanations.

Summary

Light stimulates vision, and a growing body of knowledge shows that the environment thus revealed affects mood, health, and cognition. Recent neurological and biological discoveries of non-visual processes stimulated by light have spurred a wealth of research in those areas, but

these processes are as behavioural, and therefore psychological, as they are physiological. Lighting research is an interdisciplinary activity, one that we think should attract greater attention from environmental psychologists. Those concerned with environmentally responsible actions as well as those concerned with the effects of environmental conditions on human well-being and behaviour may find interesting research questions in this domain. This special issue on "Light and Lighting Design" greatly expands the coverage of this topic in the *Journal of Environmental Psychology*. Its 10 papers discuss the role of light and lighting in outdoor environments, shops, and offices; report on new scientific insights in perception and appraisal, environmental preferences, comfort, cognitive performance, self-regulation and health behaviours. The issue showcases studies with both fundamental and applied perspectives, that were conducted in labs, simulated, and real environments. In short, we trust that the issue will bring something new and valuable to every reader of this journal. Above all, we hope that, collectively, the papers in this special issue convey the message that light and lighting deserve more attention from psychologists; rather than being a fringe topic, it should be near the heart of the domain of environmental psychology.

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