Institution: University of Manchester

Unit of Assessment: UoA5

Title of case study: Re-designing artificial lights to suit our biological needs

1. Summary of the impact

Regulation of our sleep-wake cycle is crucial to health and well-being. The quality (intensity and spectral distribution) of artificial light is currently described according to its ability to activate rod and cone photoreceptors in the human eye. This approach ignores the discovery of a third photoreceptor that Lucas and his group have shown to be responsible for a range of sub-conscious neurophysiological and neurobehavioural responses to light, which together strongly contribute to health, productivity and well-being. Their research has established ways of measuring light that predict its effect on these newly discovered photoreceptors. They have partnered with industrial [text removed for publication] and public policy (various) organisations to translate this knowledge into improved artificial light sources and updated international standards for architectural lighting, for use in a wide range of domestic, public and industrial settings.

2. Underpinning research

The impact is based upon research that took place in Manchester from 2003 to the present. Key researchers in that time:

Professor Robert Lucas (2003-2004 Senior Lecturer; 2004-present GSK Chair in Neuroscience)

Post-doctoral research associates:

Dr Emma Tarttelin (2003-2009); Dr James Bellingham (2003-2007); Dr Gurprit Lall (2004-2007); Dr Vikki Revell (2007-2009); Dr Timothy Brown (2008-2012).

PhD students:

Jazi Al Enezi (2007-2010); Annette Allen (2008-2011).

The mammalian retina responds to light not only using the well-known rod and cone photoreceptors, but also through a third type of directly photoresponsive cell. This additional photoreceptor was discovered only ten years ago and comprises a particular class of retinal ganglion cell (termed intrinsically photosensitive retinal ganglion cells or ipRGCs). Lucas's previous work contributed to their discovery, and since 2003 his research group in Manchester has been studying the basic biology and functional significance of these ipRGC photoreceptors, showing that:

1.) ipRGCs rely upon a protein called melanopsin for their sensitivity [1].

2.) ipRGCs are the origin of a wide range of normal neurophysiological and neurobehavioural responses to light [2], such as photoentrainment (synchronising the body's circadian rhythms to the light-dark cycle) and the pupillary light reflex (change in pupil diameter with light intensity), and also contribute to aspects of visual perception [3] in mice.

Given the importance of ipRGCs to normal human physiology and behaviour, one area of particular interest is how the discovery of this new photoreceptor can influence good practice in the lighting industry. At present, the intensity and spectral composition of artificial lighting is determined solely according to its impact upon cone and (to a lesser extent) rod photoreceptors. There is now great commercial and public policy interest in whether/how lighting could be changed to ensure adequate stimulation of the ipRGC photoreceptor.

In addressing this question, Lucas's group firstly determined the extent to which the vital biological systems that are responsive to rod/cone photoreceptors are also influenced by ipRGCs, and thus how important regulation of ipRGC activity is likely to be. In a series of publications [4,5] they demonstrated that ipRGCs provide information about the light environment (absolute light intensity under daylight conditions) that is not available from rods and cones and that is an important determinant of neurophysiological/neurobehavioural state. Secondly they addressed how the development of artificial lights could change to match the requirements of ipRGCs. They have shown that this is partly a matter of increasing light intensity [4,5]. However, ipRGCs are not

equally responsive to all wavelengths of light and so such increases should be targeted at specific parts of the spectrum. They have therefore conducted a number of experiments describing the spectral sensitivity of ipRGCs, which have culminated in the validation of a robust and accessible method for predicting the ipRGC activating efficiency of any polychromatic light [6].

3. References to the research

The research was published in the most prestigious interdisciplinary journals and the best respected journals in the fields of neuroscience and chronobiology.

1. Melyan Z, **Tarttelin EE, Bellingham J, Lucas RJ**, Hankins MW (2005). Addition of human melanopsin renders mammalian cells photoresponsive. Nature 433:741-5. doi:10.1038/nature03344
2. Güler AD, Ecker JL, **Lall GS**, Haq S, Altimus CM, Liao H-W, Barnard AR, Cahill H, Badea TC, Zhao H, Hankins MW, Berson DM, **Lucas RJ**, Yau K-W and Hattar S. (2008) Melanopsin cells are the principal conduits for rod–cone input to non-image-forming vision. Nature 453:102-105. doi: 10.1038/nature06829
3. **Brown TM**, Gias C, Hatori M, Keding SR, Semo M, Coffey PJ, Gigg J, Piggins HD, Panda S, **Lucas RJ** (2010) Melanopsin Contributions to Irradiance Coding in the thalamo-cortical Visual System. PLoS Biology 8(12):e1000558. doi:10.1371/journal.pbio.1000558
4. **Lall GS, Revell VL**, Momiji M, **al Enezi J**, Altimus CM, Güler AD, Aguilar C, Cameron MA, Allender A, Hankins MW, Hattar S and **Lucas RJ** (2010). Distinct contributions of rod, cone and melanopsin photoreceptors to encoding irradiance. Neuron 66:417-28. doi:10.1016/j.neuron.2010.04.037
5. **Brown TM**, Wynne J, Piggins HD, **Lucas RJ** (2011). Multiple hypothalamic cell populations encoding distinct visual information. J Physiol 589(5)1173-94. doi:10.1113/jphysiol.2010.199877
6. **al Enezi J, Revell V, Brown TM**, Wynne J, Schlangen L, **Lucas R** (2011). A 'melanopic' spectral efficiency function predicts the sensitivity of melanopsin photoreceptors to polychromatic lights. J Biol Rhythms 26(4):314-23. doi:10.1177/0748730411409719

4. Details of the impact

Context

It is now widely accepted that disruption of the circadian clock and sleep-wake cycle due to unnatural light exposure can have a profound influence on human health and well-being. This is particularly relevant in shift-workers and care home residents, who experience sleep disturbance due to a lack of natural daylight, and frequent long-haul travellers (jet-lag). Lucas's research has shown that ipRGCs play a distinct role in synchronising endogenous circadian clocks to the external light-dark cycle, and his group has developed a robust novel method for measuring light that activates these photoreceptors. Therefore these findings have important implications for the development of improved artificial light sources and updated standards for architectural lighting.

Pathways to impact

An important component of Lucas's strategy to maximise impact has been to publicise his group's research to the lighting industry. They have achieved this by publishing review articles in industry-focussed publications (e.g. CIE proceedings, Commission Internationale de L'Eclairage = International Commission on Illumination, the international standardisation body for light and lighting, colour and vision, photobiology and image technology), and presenting their work at conferences for industrial researchers organised by the UK National Physical Laboratory, the Deutsches Institut fur Normung (the German institute for standardisation), the Society for Light Treatment and Biological Rhythms, and the International Symposium on the Science and Technology of Lighting. These activities led to three more formal interactions with beneficiaries of the research:

1.) [Text removed for publication].

2.) Since 2011, Lucas has acted as UK representative on a committee (Technical Committee 169; Working Group 13) established by the European Committee for Standardisation (CEN) to define new units of measurement for light that are relevant for ipRGCs [B]. Defining how to measure light is a first step for validating new products and ultimately for bringing in new standards for artificial light environments and light pollution. Currently, there is no accepted way of predicting how effective a given light source will be at activating these new photoreceptors. Lucas's findings (especially [6]) provide the basis for addressing this deficit, and have defined the working draft of this committee's report [C].

3.) In January 2013 Lucas organised and chaired an international conference in Manchester, sponsored by the German Electrical and Electronic Manufacturers' Association, to bring together researchers to agree guidelines on light measurement - based upon current knowledge of ipRGCs - that can be used by industry and regulatory bodies. The outcomes of the meeting will be published as a report on best practice in light measurement, which was commissioned by Div 6 of the CIE on 28 February 2013. It is scheduled to be published as a stand-alone report on the CIE website http://www.cie.co.at/index.php/Publications in the first quarter of 2014 [D].

Reach and significance of the impact:

Commercial applications and product development:

A large number of manufacturers worldwide now market blue-enhanced high luminance light sources for therapeutic applications and/or to replace standard lumieres in domestic/public/industrial settings. Lucas's descriptions of melanopsin's spectral sensitivity (i.e. to blue light) [1] and the significance of ipRGCs for setting neurobehavioural/neurophysiological state (e.g. [2,4,5]) provide much of the scientific justification for this approach. [Text removed for publication].

Public policy:

There is growing interest in how standards and recommendations for artificial lighting should be modified to take account of ipRGCs. Lucas has directly influenced policy in this area by contributing advice based upon his research (especially [1,2]) to the Royal Commission on Environmental Pollution's 2009 report on 'Artificial Light in the Environment', in which he is named as a contributor [E].

The most important barrier to developing national and international guidelines on optimal levels of ipRGC activation in architectural lighting is the absence of an internationally accepted method of measuring light intensity that is relevant for this new photoreceptor. Lucas's research proposes just such a metric [6]. This research is referenced in the draft recommendations of the CEN committee 169, working group 13 [B, C], and will be in the CIE report from the January 2013 meeting Lucas organised and chaired [D]. These guidelines will be used by industry and regulatory authorities worldwide to drive better alignment of artificial and architectural lighting to our biological needs. [Text removed for publication].

5. Sources to corroborate the impact

A. [Text removed for publication]

B. Letter of support from the Chair of CEN (European Committee for Standardisation) Technical Committee 169, Working Group 13, describing Lucas's influence in updating international standards of light measurement.

C. Draft report for the CEN TC 169/WG 13.

D. Letter of support from the Director of CIE Division 6 "Photochemistry and Photobiology" (Commission Internationale de L'Eclairage = International Commission on Illumination), describing Lucas's influence in updating international standards for light exposure assessment.

E. Royal Commission on Environmental Pollution's 2009 report on 'Artificial Light in the Environment':

http://www.official-documents.gov.uk/document/other/9780108508547/9780108508547.pdf