*Mapping of Brain Functions and Spatial Luminance Distributions
as Innovative Tools for Assessing Discomfort Glare in the Built Environment*

Peter Raynham, University College, London

Werner Osterhaus, Victoria University of Wellington

Michael Davies, University College, London

Abstract

A series of "proof-of-concept" projects are set out aimed at bringing together built environment researchers attempting to understand what constitutes 'comfortable' space and neuroscientists investigating the functional characteristics of the human brain. The long-term goal is to address the question of whether there are regions of the brain that are specifically engaged when people experience spaces they consider to be comfortable, pleasing or even beautiful.

Glare is an area of research that has been recognised as a problem in both interior and exterior lighting. Recent advances in technology make it an ideal candidate for the proposed "proof-of-concept" study.

The mapping of brain functions through functional magnetic resonance imaging, the mapping of luminance distributions in a visual scene, and the study of distraction and its influence on discomfort glare can be combined to form the basis of an innovative tool box for new research.

Introduction

More comfortable buildings have the potential to provide healthier and more productive environments. Data from post occupancy evaluation studies, for example, have shown perceived differences in productivity of up to 25 percent between comfortable and uncomfortable staff (CABE 2005). Other studies have demonstrated a 20 percent increase in student learning in school classrooms which provide good daylighting (Heschong Mahone Group 1999).

Comfort in buildings has traditionally been approached through building physics. The physically based concepts related to our experience of spaces in response to heat, light and sound are now generally well described. Further progress requires an understanding of perceptual mechanisms in the interaction between built environments and human health and well-being.

In the outdoor built environment the same issues of providing a comfortable visual environment also exist. In the area of road lighting, for instance, the aim is to provide a comfortable safe environment for the night time street user whilst at the same time minimising the energy used for lighting.

Road lighting is a significant undertaking in the UK with 7.1 million lighting points installed consuming around 2.8TWh of electricity per year. The theoretical basis of the current road lighting design methods has recently been challenged (Raynham 2004). Any attempt to improve the current design of street lighting for motorists and pedestrians while reducing the electrical power consumed will be conditional on a better understanding of disability glare.

Glare has long been recognised as a problem in both interior and street lighting. In interiors the main problems are the eye strain caused by working in the presence of discomfort glare and problems associated with reflected images of lighting sources in display screens. Glare from street lamps and vehicle headlamps can cause discomfort and a reduction in the conspicuity of objects for both motorists and pedestrians. Whilst the basis for the disability glare has been understood for a number of years there is some evidence that the current theory may not explain fully the changes in visual performance that relate more to the size and the colour of the glare source. The situation is further complicated by the possibility that visual distraction associated with discomfort glare may reduce the ability of an observer to process information about a complex visual environment.

The gaps in our current state of knowledge of discomfort glare are well exposed in a paper by Perry (1988) and the correspondence (Jay 1989) (Perry 1990) that followed it. In the paper Perry argues that the current models used to describe glare whilst useful for stopping the worst excesses of electric lighting design does not in any way provide a predictive model of discomfort glare sensation. Figure 1 is taken from the paper and shows that there is little correlation between a calculated glare rating and a subjective impression of glare.

Figure 1. Individual glare ratings plotted against glare index (from Perry)

The idea that glare is a term used to describe a number of different physiological processes is also developed. Perry suggests that developments in visual science will eventually provide a route to the better understanding of glare.

Over a decade on from Perry's work we are still not a lot further on in the understanding of glare. There are several reasons for this. Firstly, developments in visual science have generally confirmed that there are multiple mechanisms at play creating the sensation of glare. This has added complexity to the problem rather than providing a solution. Secondly, we have come to realise how the complexities of the visual environment can impact on the visual system but we have yet to develop the methodology for analyzing and describing luminance patterns. The third problem is the use of subjective responses of experimental subjects as the means of assessing glare. This is a process which at best can only produce values of limited significance after working with a large number of subjects.

We set out a series of "proof-of-concept" projects aimed at bringing together building researchers attempting to understand what constitutes 'comfortable' architectural space, visual scientists studying the eye-brain-system and neuroscientists investigating the functional characteristics of the human brain. The long-term goal is to address the following questions:

- Are there regions of the brain that are particularly engaged when people experience glare or visual discomfort/comfort?
- Are there ways of characterizing the visual environment so that we can assess glare due to the whole field of view and not just from a series of glare sources?
- Are there objective tests that can be used to assess discomfort glare?
- What is the impact of glare on visual performance in real life situations?

This paper lists the ideas for projects which address these points and which are currently under development.

The knowledge gained from these projects will enable the application of such concepts to the built environment, whether interior or exterior applications, and the interaction of the various disciplines involved. The methods proposed would be applicable to a number of design scenarios.

Road Lighting Project

Considering glare aspects in road lighting applications has great potential for the testing of the proposed methods due to the extreme contrast situations and variability of the glare source location and intensity. This project has the aim of investigating all aspects of glare that are important for night time road users with the aim of developing better design guidance for the designers of street and vehicle lighting, especially considering the dark adaptation of the eye.

The key points that will be tested are:

Light scatter within the eye is a good predictor of the change in visual performance when glare is present. This will be tested by assessing the light scattering properties of the eyes of a number of subjects in the laboratory and then taking the subjects to an open air test centre and giving them a series of tasks representative of those carried out by pedestrians and drivers at night under different levels of glare.

Discomfort glare is a function of source size. Whilst there is a lot of literature that suggests that this hypothesis is true, there has been relatively little work to establish that it is also true in road lighting conditions. It is also not known what the impact the light source colour has on discomfort glare. This will be tested with a series of laboratory experiments assessing the comfort/discomfort threshold for various light source colours, sizes and geometries, and by subjective assessment of different lighting schemes in the outdoor test laboratory.

• **Discomfort glare can reduce visual performance.** It has been suggested that there is a relationship between discomfort glare and distraction. If this is indeed the case, then discomfort glare may disrupt the processing of complex visual tasks. To test this we will run a series of experiments in the laboratory, where the subject has to perform a series of visual tasks that are each relatively easy to see but where it is hard to do them all simultaneously. By using a series of different glare sources we will assess the impact of discomfort glare. This will be checked by doing facial recognition tasks in the outdoor laboratory with different levels of discomfort glare carefully set up so that they provide similar levels of disability glare.

• **Discomfort glare is a real phenomenon and can be detected in the brain.** To test this idea we will select from our cohort of subjects a group who experienced the worst

effects of discomfort glare and another group who had only minor problems. We will study the brain activity of both groups via functional magnetic resonance imaging (fMRI) whilst they are given various visual tasks to do with different levels of discomfort glare. From the fMRI scans we hope to find certain patterns of brain activity that are associated with the sensation of glare. This work is discussed in more detail in the following section on fMRI.

Functional Magnetic Resonance Imaging and Discomfort Glare

Currently, designers are limited to using empirically derived glare indices based on subjective responses of volunteers. These methods have been known to be unreliable for many years. Recent developments have the potential to change that.

In the medical field, functional magnetic resonance imaging (fMRI) has become a routine method for mapping neural activity in the human brain. It is a non-invasive method and works by measuring the flow of blood in the brain. The brain controls the flow of oxygenated blood to brain regions where there is more neuronal activity. Blood in its oxygenated state (oxy-hemoglobin) and blood in its oxygen-reduced state (deoxy-hemoglobin) have different magnetic properties, and this can be picked up by the MRI scanner.

Of key importance to this proposal is that previous fMRI studies have shown an increase in the blood oxygenation level-dependent (BOLD) signal activation levels within the visual cortex (V1) with increasing stimulus luminance contrast. Areas V1 and V2/V3 of the visual have also been shown to respond reliably and strongly to changes in the luminance of uniform surfaces.

These cortical areas are regarded as possible candidates for representing the dimension of perceived brightness and thus may provide an *objective* measure of discomfort glare. The visual field is known to be mapped topographically onto the visual cortex. The position of the source will thus be mapped using standard procedures in order to indicate regions of interest (ROIs).

We will investigate whether the BOLD signal response varies in the expected way with the variables known to influence discomfort glare. We hypothesize that the BOLD signal in the ROI will increase as the source becomes larger, brighter and more central to the field of vision. The signal would also be expected to increase as the

background luminance decreases. The relative weighting required in order to optimize the correlation will be compared with those weightings in the existing indices.

Alongside the fMRI experiments, electromyogram (EMG) measurements can be taken in an attempt to provide further evidence of any link between discomfort glare (inferred from the EMG measurements) and the BOLD response in areas V1 and V2/V3 of the human brain.

A specific outcome of this work could be to show that the factors and weightings currently used in discomfort glare indices can be improved. Future studies would then be in a stronger position to search for other neural correlates with discomfort glare. In addition, the use of functional magnetic resonance imaging may also open up the possibility of undertaking similar research in the areas of thermal comfort, acoustics and the overall aesthetic response to architectural space.

Spatial Luminance Mapping

A number of recently conducted experiments utilised luminance mapping cameras to record the luminous characteristics in spaces with varying lighting.

A luminance camera image provides calibrated luminance (absolute measured luminance) values for each pixel in a visual scene. The visual scene might be an interior of a building, an outdoor environment in the city, or a lit road in the country side.

Previously available methods relied on spot luminance measurements with a hand-held luminance meter. Without an array of luminance meters, it was difficult to achieve simultaneous readings for each desirable measurement position, making it almost impossible to assess dynamic lighting situations, e.g. under varying daylight or sunlight conditions and in roadlighting, where light sources vary in intensity and position, for example with the movement of vehicles.

From the information provided by a luminance camera image about the luminance of each pixel in a visual scene, critical luminance ratios, adaptation luminance values and maximum luminances can be computed. In addition, luminance maps indicating regions of similar luminance can be produced. They typically identify iso-luminance contours and luminance peaks, analogous to elevation lines and

peaks on a topographic map (Wienold and Christoffersen 2005).

All of the information can be utilised for the computation of glare indices or other possible identifiers for visual comfort. Luminance camera images thus allow a lighting designer or building scientist to assess the complete visual scene from a specific view point for various aspects of visual comfort, including glare.

Such equipment would also be helpful at a later stage of the functional magnetic resonance imaging research to investigate direct correlations between the luminance map of the visual scene and the perceptual map represented in the human visual system.

The luminance mapping technique gives researchers the ability to completely characterise the visual field encountered by subjects in a glare experiment. We can thus develop the understanding of the visual environment beyond analyzing it as a set of glare sources viewed against a fixed background luminance. This development can lead to a much greater knowledge of the important features of the lit environment and the findings could then be integrated into existing or new computer simulation programs and be applied to future design situations.

Figure 2. Luminance map of an interior office space taken by a calibrated luminance camera. (Image source: Jens Christoffersen, SBI, Denmark).

Distraction and Discomfort Glare

It has long been recognised that there is a relationship between discomfort glare and distraction. However, it has been common to treat the two phenomena separately as their consequences are different. The relationship between glare and distraction was explored by Lynes (1997). In his paper he argued that distraction was likely to follow the detectability of the potential source of distraction. This detectability against a dark background is governed by Piper's law. Lynes modified Piper's law using the formulae developed by Marsden (1970) to allow for different background luminances. The resulting formula for distraction was equivalent to the formula used to evaluate discomfort glare in the UK at the time (IES 1967).

Whether glare and distraction share a common cause within the visual system or whether they are just caused by similar visual stimuli, the study of distraction is likely to reveal useful information about glare. Also, it is possible that information about distraction is likely to be important in its own right for the design of productive workplaces.

The property of distraction to slow down visual processing may be a useful aid to the further investigation of discomfort glare. The use of distraction gives the possibility of an objective test. The observers can be presented with a task that is relatively easy in terms of size and contrast but may take some study before the task can be completed. The task can be carried out in a 'neutral environment' and then with the presence of discomfort glare. By measuring the change in the time taken to perform the task it might be possible to assess the significance of the glare stimulus.

One test task that is currently being evaluated is that of letters appearing from a random sequence of squares. More and more squares appear in apparently random positions of the screen eventually forming a recognizable letter. Figure 3 below shows such a letter being formed.

Figure 3. More and more squares appear in apparently random positions of the screen eventually forming a recognizable letter.

The key feature of this test is that the individual squares that make up the letter are very easy to see in terms of their contrast and size. The impact of any disability glare caused by a glare source is therefore very small, and any change in performance is thus caused by distraction.

Conclusion

Progress in the understanding of discomfort glare has not advanced significantly for a number of years. This lack of progress is largely due to the existing methods of researching glare and lack of interest in the subject as there were methods for controlling glare to acceptable levels within standard lighting installations.

With constraints on the use of energy forcing us to rethink the way lighting is provided, it is now very important to know the impact of new lighting techniques on glare. This provides the motivation for more in-depth studies of both disability and discomfort glare. As discussed in this paper, there are now several new techniques that can be employed to better understand the complex processes that lie behind the sensation of glare.

References:

The Commission for Architecture and the Built Environment (CABE) and the British Council for Offices (BCO). May 2005. The impact of office design on business performance, London, 20 pp.

Heschong Mahone Group. 1999. Daylighting in schools: An investigation into the relationship between daylighting and human performance, The Pacific Gas and Electric Company, San Francisco, 31 pp.

Raynham, P. 2004. An examination of the fundamentals of road lighting for pedestrians and drivers, *Lighting Research and Technology*, Vol 36, No 4, pp 307-316.

Perry, M. J. 1988. Fundamental vision: A glaring case, *Lighting Research and Technology*, Vol 20, No 4, pp 161-165.

Jay, P. 1989. Mechanisms of Discomfort Glare, *Lighting Research and Technology*, Vol 21, No 2, p 81.

Perry, M. J. 1990. Mechanisms of Discomfort Glare, *Lighting Research and Technology*, Vol 22, No 3, p 159.

Wienold, J. and Christoffersen, J. 2005. Evaluation methods and development of a new glare prediction model for daylight environments with the use of CCD cameras and Radiance. Submitted to *Energy and Buildings*, Special Issue on Daylighting.

Lynes, J. A. 1997. Discomfort Glare and Visual Distraction, *Lighting Research and Technology*, Vol 9, No 1, pp 51-52.

Marsden, A. M. 1970. Brightness – Luminance Relationships in an Interior, *Lighting Research and Technology* Vol 2, No 1, pp 10 – 16.

IES Technical Report No. 10. 1967. Evaluation of Discomfort Glare: The IES Glare Index System for artificial lighting installations, The Illuminating Engineering Society, London.