Illumination from Darwin and Discomfort from Illumination

Arnold J. Wilkins
University of Essex
Contact: arnold@essex.ac.uk

ABSTRACT

The human visual system evolved in the natural world and processes natural scenes efficiently. The natural world has little flicker, few repetitive contours and modest colour contrast. When lighting is un-natural it results in inefficient neural processing and this in turn leads to discomfort.

FLICKER

In the natural world flicker results mainly from light reflected from the surface of water or interrupted by the branches of trees. It is never regular and continuous. In the urban environment it is difficult to avoid regular continuous flicker from electric lighting. The flicker is seldom visible, although when it is, it constitutes a potential hazard. The visibility of flicker varies with frequency. It is maximal at about 20Hz, and minimal above 60Hz, see Figure 1. The figure also shows the effects of frequency on the visibility of illusions of colour evoked by flicker, and the percentage of individuals with photosensitive epilepsy who are liable to seizures [1].

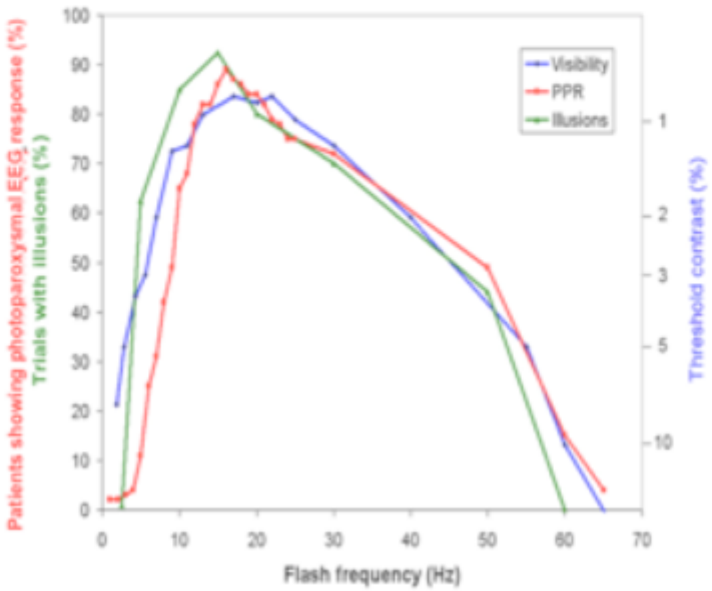

Figure 1. Visibility of diffuse flicker, percentage of trials with illusions of colour, and percentage of patients with photosensitive epilepsy showing a photoparoxysmal EEG response, indicative of seizure susceptibility

Flicker from fluorescent lighting with magnetic ballast is not usually visible. It is nevertheless resolved by the human retina, disturbs the control of human eye movements, causes headaches and impairs visual performance [2]. The flicker is above the critical flicker fusion threshold, CFF. The CFF is measured with diffuse flicker during steady gaze that avoids large rapid eye movements (saccades). These viewing conditions are atypical because we make 2 or 3 saccades every second, and some of these are large. When they are large they are fast, with velocities of up to about 700 degrees per second. The scene we look at is rarely uniform but contains many contours, and these contours are swept across the retina with each saccade. Under lighting that fluctuates in brightness repetitively the contours form a repetitive pattern, known as the *phantom array*. This intra-saccadic pattern is rarely visible, largely because it is masked by the images before and after the saccade. When these have few contours, as at night, the phantom array can become intrusive, for example when the LED tail-lights of cars appear in a striped pattern [3], see Figure 2.

Figure 2. A simulation of the phantom array

We have measured the visibility of the phantom array as a function of the contrast of the flicker. For flicker at 100Hz or 120Hz the array becomes visible when the Michelson contrast exceeds about 15%. Incandescent lighting, which is rarely associated with complaints has a contrast less than this. Fluorescent lighting from magnetic ballast, which was often associated with complaints, has a contrast that is greater than 15%. The phantom array provides for a repetitive spatial pattern during a saccade. When present in text, repetitive spatial patterns are known to impair reading by interfering with the appropriate re-alignment of the eyes following each saccade [4], [5]. There is therefore a potential mechanism whereby the phantom array might impair reading.

Repetitive patterns of stripes at low contrast can most readily be seen when their spatial frequency is about 3 cycles per degree subtended at the eye [6]. For a 10-degree saccade, with velocity of about 300 degrees per second, the phantom array should therefore be most visible with flicker at about 1kHz. We have measured the visibility of the phantom array as a function of the contrast of the flicker and it *increases* progressively from 100Hz to 300Hz, as expected. The upper limit of perception of the array should be at about 10kHz when its spatial frequency is close to the acuity limit for gratings. We have recorded the array with bright narrow stimuli, and it is visible at a limit of 10kHz in some observers, although many observers have a lower threshold frequency.

REPETITIVE PATTERNS

The visual system has adapted to process natural images and these images have a Fourier amplitude spectrum close to 1/f [8], [9]. The human contrast sensitivity function is optimized for encoding images with this structure, as are the receptive fields of neurons in the primary visual cortex [10], which produce a sparse cortical response, thereby reducing metabolic demand [9]. In computational models of the visual system, striped patterns, which are rare in nature and do not conform to a 1/f amplitude spectrum, result in an excess of 'neural activity' and a non-sparse distribution of 'neural' firing [11].

Wilkins [3] reviewed neuroimaging studies and concluded that images that are uncomfortable to observe are generally associated with an elevated cortical haemodynamic response. Further, individuals who are susceptible to discomfort exhibit a larger haemodynamic response than those who are not. Both findings are consistent with the view that discomfort is a homeostatic mechanism that avoids excessive cerebral metabolism.

The above suggests that images are processed inefficiently by the brain if they are unnatural, do not have a 1/f amplitude spectrum and in consequence are uncomfortable to look at. Juricevic [12] and others [13] asked observers to rate the discomfort from images of modern art and of filtered visual noise or shapes. For all categories of image, the discomfort was minimal for those images with a 1/f Fourier amplitude spectrum. Penacchio & Wilkins [14] developed a simple algorithm that measured the extent to which the Fourier amplitude of the images approximated that of images found in nature. A cone with a slope of 1/f was fitted to the two-dimensional Fourier amplitude spectrum, and the residuals (errors) were weighted by a contrast sensitivity function gleaned from the literature. The algorithm had no free parameters but it was well able to predict observers ratings of visual discomfort. (The algorithm accounted for more than 25% of the variance in observers' ratings.) It has also been shown to predict the size of the cortical haemodynamic response to images [15].

In many lighting installations the spatial arrangement of luminaires is repetitive and uncomfortable. There are many examples. Figure 3 shows one.

Figure 3. Uncomfortable lighting

COLOUR

The use of high colour contrast is rare in nature. Repetitive coloured patterns can evoke discomfort and a large cortical haemodynamic response, and they do so in proportion to the difference in the chromaticity of the component colours [16]. Many environments, particularly in primary schools use material with high colour contrast, see Figure 4. This is also true of much advertising and electronic material, particularly videos for children.

In summary, the lighting industry and society at large may take inspiration from the designs in nature.

Figure 4. An example of a classroom with high colour contrast, and with saturation decreased, reducing contrast.

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