Discomfort and hypermetabolism

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Abstract. In general, the visual stimulation that is uncomfortable on the eye gives rise to a large haemodynamic response in the visual cortex, suggesting that the sensation of discomfort is homeostatic and acts to prevent a large metabolic load. The large haemodynamic response is consistent with evidence from computational models that the visual stimuli responsible for discomfort cannot be processed efficiently. These visual stimuli differ from those encountered in nature in respect of their image structure and colour contrast. Strong sensory stimulation may be metabolically demanding to process, although there are individual differences in response to these stimuli.

1 INTRODUCTION

In the following paper we show that the discomfort people experience from looking at certain images has a basis in neurology and in the computational resources required to encode these images. Images that are difficult for the brain to encode are uncomfortable to look at. In particular, we consider the effects of the colour content of images on discomfort, individual differences in the extent to which this is experienced, and the role of precision tints in minimising visual discomfort.

2 NATURAL IMAGES AND DISCOMFORT

Most images in nature have a particular spatial structure – they are "scale invariant" which means that the complexity of the image remains the same across spatial scale. This results in a Fourier spectrum that decreases in amplitude with increasing spatial frequency. In many natural images, this decrease in amplitude is approximately proportional to the reciprocal of spatial frequency (1/f), so that a plot of amplitude against spatial frequency on log coordinates has a slope of -1. Given that the visual system has adapted to process natural images one might anticipate that images with this scale invariant spatial structure would be computationally easy for the visual system to process.

Juricevic, Land, Wilkins and Webster [1] created images from filtered random noise and randomly disposed rectangles. When the images had an amplitude spectrum that approximated 1/f they were rated as more comfortable to look at than images with spectra having steeper or shallower slopes. Fernandez and Wilkins [2] used a wider variety of images including works of art and photographs as well as artificial images formed from filtered noise. They showed that images with a 1/f amplitude spectrum were rated comfortable to look at. Images with an excess of contrast energy at mid-range spatial frequencies relative to that expected on the basis of a 1/f spectrum were rated as uncomfortable. Reducing the energy at mid-range frequencies was sufficient to make the images comfortable again. O'Hare and Hibbard [3] confirmed these findings. They filtered random noise and showed that visual noise with a 1/f amplitude spectrum was judged more comfortable than any image with a relative increase in contrast energy within a narrow spatial frequency band ranging from 0.375-1.5cycles/degree.

In all the above studies, the effect of orientation on the amplitude spectrum was not considered. Pennachio and Wilkins [4] pointed out that some of the most uncomfortable (and unnatural) images (viz patterns of stripes) have amplitude spectra that are concentrated in one orientation. Averaging over orientation loses this discriminative feature. They therefore fitted a cone with slope 1/f to the two-dimensional Fourier amplitude spectra. They obtained the best fit by permitting the mean of the cone to vary, but not its slope. They found that the residual error after fitting the cone was strongly correlated with ratings of discomfort. The correlations between the residual error and the ratings of discomfort explained a greater proportion of the variance than that explained by the one-dimensional fit. Across images, ranging from photographs to works of art to artificial images, they were able to explain more than 25% of the variance in judgments of discomfort with a parameter-free model.

3 DISCOMFORT AND HYPERMETABOLISM

There are several reasons for supposing that visual processing is more efficient when images have the spatial characteristics of typical natural images [5]. For example, the human contrast sensitivity function is optimised for encoding images with a 1/f structure [6]. Also, the receptive fields of neurons in the primary visual cortex are such that natural images produce a sparse cortical response [6,7,8] The defining characteristic of this sparse response is that the distribution of neuronal firing is kurtotic, with few neurons highly active and many inactive, thereby reducing metabolic demand. O'Hare, Clarke and Hibbard [9] have used a computational model of visual area V1 to show that uncomfortable stimuli such as striped patterns, which are rare in nature and do not conform to a 1/f structure, result in an excess of "neural activity" and a non-kurtotic distribution of "neural" firing.

There is some suggestion that these uncomfortable images actually do indeed induce abnormally large activity in the brain, as estimated from the fMRI BOLD response. BOLD relies on the detection of local fluctuations in magnetic susceptibility attributed to changes in the concentration of paramagnetic deoxyhaemoglobin. The haemodynamic response is an interplay between the effects of blood flow, blood volume, oxygen consumption, and the activity of nerve cells and glia. It broadly reflects local field potentials [10] and these in turn reflect, in part, the neural activation by a stimulus. Huang et al [11] asked normal observers and patients with migraine to observe patterns

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of stripes (square-wave luminance profile) with different spatial frequencies. They showed that there was a large amplitude BOLD response to the gratings, particularly those with mid-range spatial frequencies. The response was larger in individuals with migraine, who found the patterns particularly uncomfortable. In other words, both in terms of differences between stimuli and between observers, a large haemodynamic response was associated with discomfort. This relationship between the haemodynamic response and discomfort can be seen as homeostatic. After all, the purpose of pain is to reduce exposure to environmental stimulation that harms the body. Perhaps visual discomfort is homeostatic in the same way and acts to reduce an unsustainable metabolic load [12] on the brain.

4 DISCOMFORT, COLOUR AND HYPERMETABOLISM

Webster and Mollon [13] showed that images in nature have a modest colour contrast. Juricevic et al. [1] varied the colour contrast in artificial images and showed that when the colour contrast was similar in magnitude to that obtained in natural images the images were rated as comfortable. Images with high colour contrast were rated as uncomfortable. The colour contrast was manipulated along an axis that represented differences in the energy captured by the long and middle wavelength cone photoreceptors and along an axis that represented the difference in the energy captured by the short wavelength photoreceptors and the other two photoreceptors. These "red-green" and "yellow-blue" cardinal colour axes are important in capturing the colour signal that emerges at the retina, but in the visual cortex, colour appears to be represented differently. Xiao Wang and Felleman [14] for example, showed that in visual area V2 in the monkey colour differences are represented in terms of a topological map. Neurons are disposed across the cortical surface in terms of the differences in the colour they represent, larger colour differences being more widely separated. Haigh et al [15] measured the haemodynamic response of the visual cortex using near infrared spectroscopy and showed that the amplitude of the response to a coloured grating was dependent on the difference in colour (separation in CIE UCS chromaticity) between the two bars of the grating. This relationship between colour difference and the haemodynamic response was independent of the cardinal colour axes. Larger colour differences created more discomfort regardless of the particular colour contrast. Once again a simple relationship emerged between the discomfort a visual stimulus evoked and the size of the haemodynamic response to that stimulus.

It seems likely that the amplitude of the haemodynamic response is inversely related to the efficiency with which the brain processes the visual stimulus. If so, it follows that images with a large colour contrast are more costly to process. Why might images with a large colour contrast produce large neural responses? The implications are that the system of cortical coding for colour depends on the separation of colour in a perceptual space and not simply on the differences in the excitation of the photoreceptors. Within the cortex, the inhibitory connections, which might otherwise minimise excessive responses, are local [16]. On the basis of the topological maps discovered by Xiao et al., [14] the inhibition available for a large colour contrast may be less than for small. Large colour differences may be less inhibited than small colour differences. There are implications for the neural computation of colour (and perhaps also for colour computation more generally). The implications are that as the strength of a sensory stimulus increases beyond levels that are typical, so the metabolic demands of neural computation also increase.

5 INDIVIDUAL DIFFERENCES

Huang et al [17] measured the BOLD response to achromatic square-wave gratings of low, mid and high spatial frequency. The response was of abnormally high amplitude in patients with migraine. The patients were asked to select a colour of light that improved the comfort and clarity of their vision when observing text. Each patient chose a different colour. When gratings were observed through lenses tinted so as to provide the chosen colour, the oxygenation was normalised. Other similar colours were without this beneficial effect, indicating that the therapeutic tint was individual. The study shows that although large colour differences are in general associated with a large haemodynamic response, and tints may perhaps reduce the haemodynamic response because they reduce colour differences, there are individual differences that may modulate this effect. It is possible that these individual differences relate to the abnormal contrast gain functions observed in individuals with migraine [18].

6 CONCLUSION

The discomfort people experience when observing visual stimuli may be homeostatic and act to reduce the hypermetabolism that occurs when the stimuli cannot be efficiently analysed. There are individual differences in this respect.

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