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Discomfort from urban scenes: Metabolic consequences

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HIGHLIGHTS

- Certain statistical properties of images are responsible for visual discomfort.
- These properties are prevalent in images of the modern urban environment.
- The discomfort is associated with inefficient neural processing and a large metabolic demand.

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ABSTRACT

Scenes from nature share in common certain statistical properties. Images with these properties can be processed efficiently by the human brain. Patterns with unnatural statistical properties are uncomfortable to look at, and are processed inefficiently, according to computational models of the visual cortex. Consistent with such putative computational inefficiency, uncomfortable images have been demonstrated to elicit a large haemodynamic response in the visual cortex, particularly so in individuals who are predisposed to discomfort. In a succession of five small-scale studies, we show that these considerations may be important in the design of the modern urban environment. In two studies we show that images from the urban environment are uncomfortable to the extent that their statistical properties depart from those of scenes from nature. In a third study we measure the haemodynamic response to images of buildings computed as having unnatural or natural statistical properties, and show that in posterior brain regions the images with unnatural statistical properties (often judged uncomfortable) elicit a haemodynamic response that is larger than for images with more natural properties. In two further studies we show that judgments of discomfort from real scenes (both shrubbery and buildings) are similar to those from images of the scenes. We conclude that the unnatural scenes in the modern urban environment are sometimes uncomfortable and place excessive demands on the neural computation involved in vision, with consequences for brain metabolism, and possibly also for health.

1. Introduction

Scenes from nature have in common the characteristic that their gross aspects have a higher contrast than the fine detail. In mathematical terms, the Fourier amplitude spectrum decreases approximately as the reciprocal of the spatial frequency, i.e. approximately as 1/f (Field, 1987). The neural computation involved in sight is well-designed to take advantage of the 1/f characteristic (Field, 1987, 1994; Geisler, 2008).

Images with unnatural amplitude spectra are judged uncomfortable to look at (Fernandez & Wilkins, 2008; Juricevic, Land, Wilkins, & Webster, 2010; Penacchio & Wilkins, 2015). Such uncomfortable stimuli include the patterns of repetitive stripes that are commonplace in the modern urban environment. Computational models of the visual cortex by Hibbard and O'Hare (2014) and Penacchio, Otazu, Wilkins, and Harris (2015) suggest that such uncomfortable repetitive patterns render the firing of cortical neurons less "sparse", increasing the overall firing rate, with the potential of raising metabolism in consequence. Indeed, there is growing evidence for a raised metabolism in so far as uncomfortable stimuli trigger a strong haemodynamic response in the visual cortex. Huang, Cooper, Satana, Kaufman, and Cao (2003) used functional magnetic resonance imaging (fMRI) and measured the blood

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oxygen level dependent (BOLD) response to achromatic gratings with a range of spatial frequencies. Contrast sensitivity is maximal at mid spatial frequencies and Huang et al. showed that high contrast gratings with mid spatial frequency (which are uncomfortable) gave the largest BOLD response. Haigh et al. (2013) used near infrared spectroscopy (NIRS) over the visual cortex and measured the haemodynamic response to coloured gratings. They found that coloured patterns of stripes gave a larger oxyhaemoglobin response if they had large differences in their component colours and were therefore uncomfortable to view.

Individuals differ in susceptibility to visual discomfort, and those individuals who are relatively susceptible show a larger haemodynamic response than those who are less so. This has been demonstrated in several studies involving patients with migraine but also those without. Thus Huang et al. (2003) demonstrated that patients with migraine report both discomfort and perceptual distortion when viewing gratings, and show an abnormally large BOLD response to such stimuli. Martín et al. (2011) compared 19 patients with migraine and 19 controls. Patients with migraine had a larger number of activated occipital voxels in response to lights than did controls. Cucchiara, Datta, Aguirre, Idoko, and Detre (2014) found that in migraine patients who experienced aura the number of symptoms of discomfort they reported by questionnaire correlated with the amplitude of the BOLD response to visual stimulation.

Although the studies reviewed in the above paragraph concerned patients with migraine, the relationship between discomfort and the size of the haemodynamic response occurs independently of this diagnosis. Thus, Alvarez-Linera et al. (2006) compared 20 photophobic patients with 20 controls who viewed a light source at various intensities. There was a direct relationship between stimulus intensity and the size of the BOLD response, and the response was larger in the photophobic individuals. Finally Bargary, Furlan, Raynham, Barbur, and Smith (2015) compared normal participants with high and low thresholds for discomfort glare while they identified the orientation of a Landolt C surrounded by peripheral sources of glare. The group that was sensitive to discomfort glare had a larger BOLD response localized at three discrete bilateral cortical locations: in the cunei, the lingual gyri and in the superior parietal lobules. In conclusion, both in terms of the visual stimuli and in terms of the people they affect, uncomfortable visual stimuli are associated with a large haemodynamic response.

The visual stimuli that are uncomfortable can be quantified mathematically. As shown by Fernandez and Wilkins (2008) and Penacchio and Wilkins (2015) they differ from natural images in having an excess contrast energy at mid-range spatial frequencies. The excess is relative to the energy expected on the basis of the reciprocal relationship between Fourier amplitude and spatial frequency typical of natural scenes (1/f). This characteristic is common in images from the urban environment, and it is this visual aspect of the environment that we explore with a series of five small-scale studies.

In the first two studies we show that photographs of certain buildings are consistently rated as uncomfortable and have an excess of energy at mid spatial frequencies relative to that expected from 1/f. (Spatial frequency refers here to the spatial repetition of contours on the retina and is therefore determined both by the size of the pattern and the distance from which it is viewed.) In a third study we show that observation of photographs with the statistical properties of unnatural images elicits a larger haemodynamic response than for other images, consistent with inefficient neural processing of unnatural and uncomfortable scenes. In two further studies we show that photographs of scenes are a good surrogate for the scenes themselves: the ratings observers make when looking at buildings or trees and shrubs correlate strongly with those made when observing photographs of the same scenes. The implication of these studies is that the design of the urban environment is such as to render the neural computation involved in vision more complex than it needs to be, with consequences for brain metabolism.

2. Studies 1 and 2: images of buildings

2.1. Procedure

Un-posed images of urban scenes were obtained by the simple expedient of standing at the side of a curb and aiming a camera across the street, angled so as to capture as much as possible of the facade of the building opposite from a distance of 5–12 m. A Sony α-390 DSLR camera (without a zoom) was used and the viewing angle of the camera was estimated from technical literature to be about 50°. The images were 960 pixels wide by 720 pixels high. Fig. 1 shows maps of the locations where the photographs were obtained, and Fig. 2 a sample of 25 such images.

The images were divided into two sets, one set for each study, each set consisting of 74 different photographs presented in random order on the 344 mm × 194 mm screen of an Acer Aspire 5734Z laptop computer from a viewing distance of 0.6 m, at which distance they were 18° high. Each image was presented until the observer had given a rating and they were encouraged to do so within 10 s. Observers were asked to rate the images on a 7-point Likert scale with 1 labelled "Very Comfortable" and 7 labelled "Very Uncomfortable".

2.2. Participants

Students at the University of Essex (12 males and 8 females aged 19–28) observed each of the images and gave a rating. Ten different students took part in Study 1 and 10 in Study 2, which was a replication.

2.3. Results

The images differed significantly with respect to the ratings they received (Study 1: $F(73, 657) = 3.00$, $p < 0.001$, $\eta2 = 0.25$; Study 2: $F(73, 657) = 6.39$, $p < 0.001$, $\eta2 = 0.41$). Cronbach's alpha between raters was 0.67 in Study 1 and 0.84 ("good") in Study 2.

2.4. Image analyses

The images were analysed using the algorithm described by Penacchio and Wilkins (2015). In their paper the studies are numbered 4 and 5. The algorithm measured how closely each image approximated a natural image in respect of the shape of the two-dimensional Fourier transform. In images from the natural world the amplitude of the spectrum decreases with increasing spatial frequency approximately as 1/f, so that on log–log coordinates the spectrum approximates a cone in shape, with a slope of −1. By varying the height of the cone, the algorithm obtained the best fit to the Fourier transform of each image and weighted the residuals by a contrast sensitivity function sourced from the literature, see Fig. 3. The monitors were not gamma-corrected, but such correction typically affected the slope of the spectral power distribution by less than 2%. The contrast sensitivity function had a peak at 7 cycles/degree and was reduced to 78% of its peak value at spatial frequencies of 3.5 and 14°, so variation in spatial frequency over a factor of about two, such as occurred with the variation in viewing angle was of little consequence. The sum of the weighted residuals correlated 0.60 with the ratings of discomfort from images used in Study 1 and 0.53 with those in Study 2. In other words, in both studies the algorithm explained more than 25% of the variance in the judgments of discomfort: images that best approximated the cone were rated as most comfortable. Altering the shape of the cone so