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A statistical basis for visual field anisotropies

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Abstract

There exist numerous psychophysical paradigms for which performance varies with location of stimulus presentation within the visual field. The following considers potential bases for visual anisotropies, considering the possibility of a statistical basis for such effects in cases where basic sensory asymmetries are present. In particular, the relationship between scene statistics and both upper–lower and lateral visual field asymmetries is considered. Finally, an argument is put forth concerning the apparent radial organization of the visual field, with the suggestion that geometric perspective may give rise to the statistical bias responsible for this effect.

Keywords: Vision; Anisotropy; Oblique effect; Laterality; Radial organization

1. Introduction

It has long been apparent that there exist anisotropies in human visual processing. For example, performance in various psychophysical tasks is much better for grating stimuli oriented horizontally or vertically than for the same stimuli presented at oblique orientations (see [3] for a review). This phenomenon has been termed the oblique effect. Previous efforts have considered a statistical basis for this effect and others, and in the case of the oblique effect, there does exist a bias in image content in favour of vertically and horizontally oriented edges [4]. In this work, we examine a different set of anisotropies, namely, domains for which performance varies as a function of position of stimulus in the visual field. Studies concerning laterality make up the bulk of psychophysical results fitting this category, with performance differences for stimulus presentation in left and right visual field considered. Much of the literature considers the interaction between visual field and spatial frequency of stimuli, with a right visual field advantage for high spatial frequency content and a left visual field advantage for low spatial frequency content. There also exist upper–lower visual field asymmetries that have received relatively less attention in the literature. Articles describing upper–lower visual field asymmetries typically read very similar to a standard visual field laterality study with the exception that the visual world is rotated 90° [1]. It has been suggested that upper–lower visual field asymmetries might arise from the difference in statistics between sky and ground [1]. This claim has yet to be validated through consideration of actual scene statistics. Another interesting anisotropy concerns the so-called radial organization of the visual field. A variety of studies have found that judgments related to line orientation are best for lines oriented towards the centre of the visual field and worst for lines orthogonal to the centre [8,2]. There does not exist a consensus on the origin of upper–lower and lateral asymmetries, or the so-called radial organization of the visual field. In the sections that follow, each of these effects is considered in the context of local statistics, with the aim of determining whether there might exist a statistical basis for such effects.

2. A look at the statistics

Explanations for the cause of visual field anisotropies are sparse in the literature, with the majority of work describing *what* is observed rather than *why*. The following effort aims at observing the manner in which spatial frequency and orientation statistics vary across the visual

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field as these are the primary factors considered in most visual field anisotropy studies, and evaluating these observations in the context of existing psychophysical results. In this light, we seek a local representation of statistics that allows observation of spatial frequency and orientation content as such content varies across the visual field (image), and lends itself well to qualitative analysis (i.e. orientation and spatial frequency statistics are directly observable). The problem may then be stated as finding a suitable means of observing the 4D data set comprised of spatial frequency and orientation content, along x and y spatial dimensions. An intuitive means of achieving such a representation, is to provide only *snapshots* along 2 of the 4 dimensions. Since the distribution of spatial frequency and orientation content is most important, discrete sampling along x and y spatial dimensions is most appropriate. We propose that each image might be divided into smaller windows, and the spatial frequency and orientation content observed in a continuous representation within these windows. Arriving at the representation required within each local window is straightforward. A common representation that adheres to the desired properties most often employed in the domain of signal processing, is the (log) power spectrum of an image. The power spectrum of an image I is given by $P(u) = |F(u)|^2$, the square of the magnitude of the Fourier transform of I. Although this offers only coarse discrete sampling over space, the resolution should be sufficient to make inferences concerning the plausibility of statistics as a basis for the various visual anisotropies. Fig. 1 shows a single image (left) cast into the proposed local power spectra representation (right). The first attempt in this work at observing statistics in general, was made through considering an average of the representation of the form depicted in Fig. 1 obtained from 3600 different natural images, and normalized over each window to give a sense of the relative proportion of high and low spatial frequency content within each section of the visual field. The images are drawn from the Corel Stock photo database and consist largely of outdoor photos from both rural and urban areas including scenery, animals, landscapes and people. Processed images were 1408×896 pixels, and were divided into 77 (11 by 7) 128×128 windows. Fig. 2a demonstrates the local log power spectra averages from the 3600 images. The depiction is limited to every second window in the horizontal $(1, 3, 5, 7, 9, 11)$ and vertical $(1, 3, 5, 7)$ directions for greater visibility. The origin is centred within each subwindow, and the x and y axes correspond to dx and dy, respectively. Without further analysis, qualitative biases visible in such a representation are marginal as demonstrated in Fig. 2a with a strong bias for low spatial frequency content over the entire visual field. However, given what is observed in Fig. 2a it is clear that an overall bias for low spatial frequency content may mask any subtle asymmetries existent in the local power spectra. We overcome this difficulty in Fig. 2b, by demonstrating the difference between each of the spectra depicted in Fig. 2a, and the average local log power spectrum derived from every local window over the entire image. This offers an idea of the difference in shape of local power spectra across the visual field and makes visible the subtleties present in the statistics.

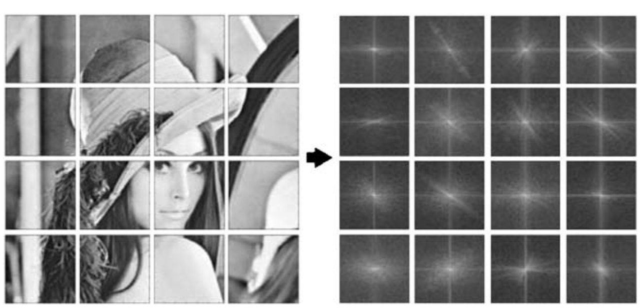

Fig. 1. Representation of local orientation and spatial frequency content of an image based on the proposed local log power spectra representation. Each subwindow on the right corresponds to the subwindow of the original image appearing in the same position on the left. The spectrum is shifted so that the centre of each subwindow corresponds to zero frequency. Presence of a band of spectral energy of a particular orientation corresponds to an edge normal to that orientation.

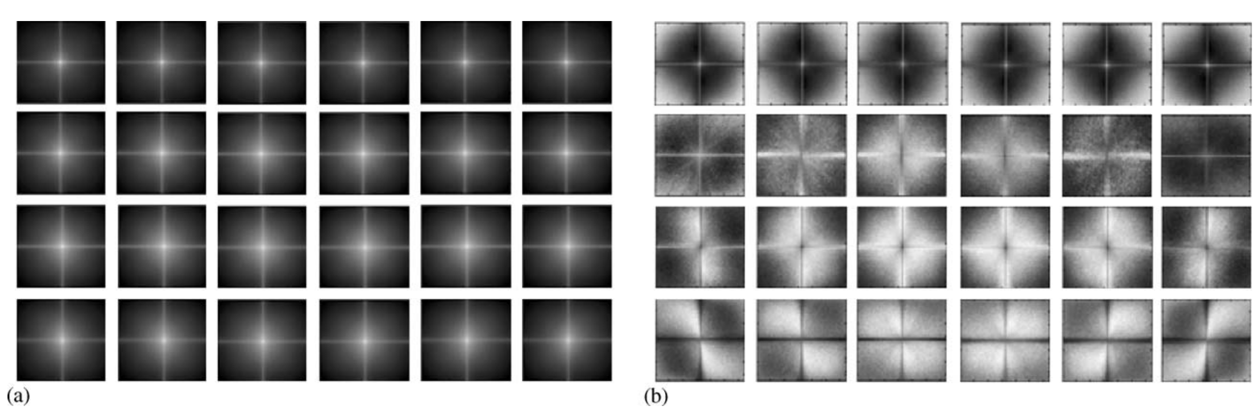

Fig. 2. (a) Average of local log power spectra obtained from 3600 natural images as in Fig. 1. (b) Difference between each local log power spectrum, and average local log power spectrum derived from every local neighbourhood of each image.

2.1. The oblique effect

Recent efforts indicate that the oblique effect persists over the entire visual field [8,9]. As may be seen in Fig. 2a, there is a significant bias in the statistics in favour of horizontally and vertically oriented lines across a wide range of spatial frequencies. This effect has been previously demonstrated through observation of power spectra obtained from entire images, but not locally as depicted in this case. The statistics suggest that there is a bias in favour of horizontally and vertically oriented edges over the entire image in agreement with psychophysical results [8,9].

2.2. Lateral and upper/lower asymmetries

As one might expect, there appears to be a significant difference in the statistics of upper versus lower visual field, with a bias in favour of high spatial frequency content in upper visual field. In contrast, there is no such bias laterally. This calls into question the argument that basic sensory anisotropies arise from structure in the statistics since the upper–lower and left–right asymmetries seem to manifest in very similar performance benefits/deficits. This conflict may be resolved by considering more recent experiments that reveal qualitative differences between the conditions under which upper–lower versus lateral anisotropies are observed. Upper–lower visual field anisotropies arise in very simple tasks (e.g. detection) whereas lateral anisotropies arise only in tasks with higher cognitive demands (e.g. identification). There is evidence that the parvocellular pathway projects preferentially to visual areas corresponding to upper visual field and magnocellular layers to areas corresponding to lower visual field [1]. The same observation has not been observed for left versus right visual cortices. Maehara et al. observed that a red background, thought to attenuate magnocellular pathways, relative to a green background gave rise to a greater deficit in detecting spot stimuli in the lower visual field than in the upper visual field [5]. Each of these results are suggestive of a primitive neural basis for upper–lower visual field asymmetries attributed to the relative contribution of magnocellular and parvocellular pathways to the processing of the upper and lower visual hemifields. In contrast, lateral anisotropies are not observed for basic detection tasks, and depend heavily on the specific conditions of the task. Mondor and Bryden investigated the effect of varying SOA for a task requiring letter identification and lexical decisions for stimuli presented to left or right visual field and found a right visual field advantage only in the case that the SOA was sufficiently short [6]. Rhodes and Robertson considered the effect of rotating the display during a typical laterality experiment and found that left–right anisotropies persisted in the reference frame of the display rather than a retinal frame of reference [7]. The evidence suggests that lateral anisotropies arise only when a task requires higher cognitive demands and only under specific conditions. In this regard, lateral anisotropies are qualitatively different from all other categories of visual field anisotropies we have considered and evidently require more than simple statistical bias to be explained.

2.3. Radial organization of the visual field

In Section 1, we described the apparent radial organization of the human visual system, wherein judgments on lines oriented towards the centre of the visual field tend to be best (of obliques) and lines orthogonal to the centre tend to give rise to the worst performance [8,2]. Whether there exists a statistical basis for this effect may be determined in observing the orientation statistics as they vary across the image. As is seen in Fig. 2b, a somewhat surprising anisotropy is observed in the orientation statistics, with an apparent bias over the visual field for lines oriented toward the centre. A distinct possibility, is that this effect arises as a result of geometric perspective, with edges in the visual field appearing to fade to the point of fixation. This consideration gains further support if one considers the fact that the orientation bias diminishes from the bottom of the visual field to the top. Items at the top of the image will tend to be further away, and thus appear closer to an orthographic projection than those at the bottom. Based on this observation, the diminished orientation bias from bottom to top supports the suggestion of perspective projection as a basis for the orientation bias. Fig. 3

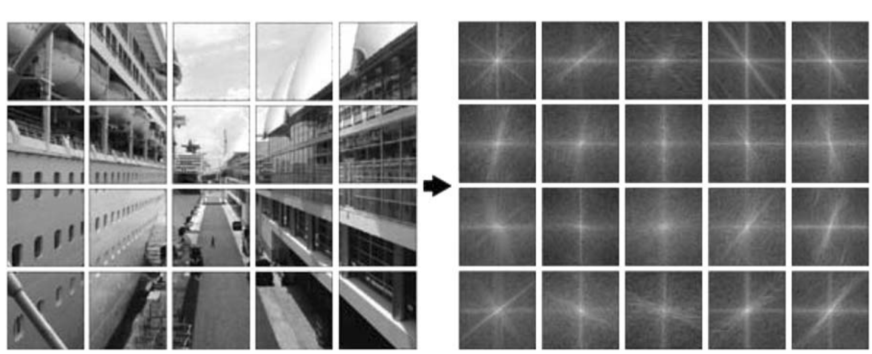

Fig. 3. An image (left) for which the described perspective effect is particularly strong, along with its local log power spectra representation (right).

demonstrates an image for which this effect is especially apparent along with its local log power spectra. Whether this is indeed the basis for the orientation anisotropy remains an open question and will require closer attention to the geometry underlying image formation and in particular looking further at a representation with its roots in orthographic perspective. That said the proposed relationship marks the first explanation for this effect having an environmental and hence statistical backing.

3. Discussion

We have demonstrated for a variety of visual field anisotropies, that there does appear to be support in the statistics for such effects, especially when such effects apply to very basic paradigms (e.g. detection). Further, we have presented an argument dissociating upper–lower visual field asymmetries from lateral asymmetries, in agreement with more recent psychophysical results. Finally, we have put forth a novel explanation for the apparent radial organization of the visual system, suggesting that perspective may produce sufficient statistical bias to account for this effect.

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