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A Fraser illusion without local cues?

Ariella V. Popple *, Dov Sagi

Neurobiology, The Weizmann Institute of Science, Rehovot 76100, Israel

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Abstract

In the well-known Fraser illusion, a line composed of tilted elements itself appears tilted. The standard explanation of this illusion has been that the global orientation of the line is in some way influenced by the local orientation of the elements. The illusion was recreated using a texture composed of collinear Gabor stimuli, which were vertical. There was no local tilt. The illusory tilt was produced by gradually shifting the phase of the successive Gabors along each line. Although the 2D Fourier transform of this global pattern peaks at off-vertical orientations, the local energy of the patches is predominantly vertical. How does the visual system nevertheless pick up this global information? This can be explained by elongated linear filters, or a phase-tuned second-stage mechanism. We examined the first theory using a stereoscopic demonstration. When lines of opposite tilt are presented in the two eyes, they combine binocularly to produce stereoscopic slant. We tested whether the illusory tilts in the phase-shifted Gabors texture give stereoscopic slant, when opposite tilts are presented to the two eyes. They do not. Instead, stereoscopic depth is dominated by the local phase-disparity of the individual patches. This indicates that the illusion is not present at the stage of linear filters, which are input to stereo, but must involve second-stage interactions or collators.

Keywords: Fraser illusion; Tilt; Local; Global; Lateral interaction; Collator mechanism; Phase tuning; Phase disparity; Stereo; Stereoscopic slant

1. Introduction

Fraser (1908) demonstrated that a line composed of tilted elements itself appears somewhat tilted, in the direction in which the elements are tilted. The Café Wall illusion (Münsterberg, 1897), where phase-shifted rows of tiles appear to converge in alternating directions, can be explained by the formation of contrast-driven Fraser cords in the grout between the rows of tiles (Morgan & Moulden, 1986). To illustrate this point, Morgan and Moulden drew the Fraser illusion using a pattern said to stimulate local oriented filters, which consisted of alternating black, black–white, and white bars (Fig. 1). We created a similar illusory figure, using phase-shifted Gabor patches (Fig. 2). In this case, it is harder to explain the appearance of global orientation through local oriented filters, as the local filters will be maximally responsive at the orientation of the patches, which in this case is vertical. Nevertheless, as with phase-shifted bars, the Fourier components in this image are tilted. In other words, phase shifts can influence global orientation. How is this global tilt detected by the visual system? Elongated linear filters might unite the phase-shifted patches (Fig. 2a). Alternatively, phase-tuned global interactions or secondary filters (collators) might respond maximally at the tilted orientations (Fig. 2b). Some tilt might be perceived in the gaps between the patches, therefore we have included a figure showing the illusion with a larger inter-element separation (Fig. 3). Here the illusion is weaker, because the quarter cycle phase-shifts imply a smaller orientation difference between the columns.

If the mechanism responsible for the illusion is local, and present at a monocular processing stage, opposite tilts in the two eyes should combine to give stereoscopic slant. We tested this (Fig. 4).

* Corresponding author. Current address: College of Optometry, University of Houston, Houston, TX 77204-6052, USA.

E-mail address: apopple@uh.edu (A.V. Popple)

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2. Method and results

The images in Fig. 4 were viewed stereoscopically, on a Silicon Graphics machine, using Crystal Eye E-1 stereo glasses (a shutter goggle system). Additionally, a red–green anaglyph version was prepared for demon-

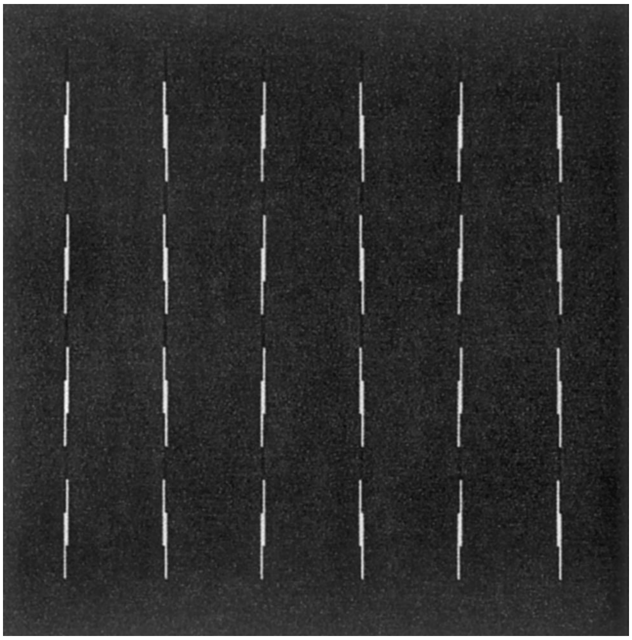

Fig. 1. The Fraser illusion, after Morgan and Moulden (1986). Alternating black and white bars give rise to local orientation, which drives the illusory tilt.

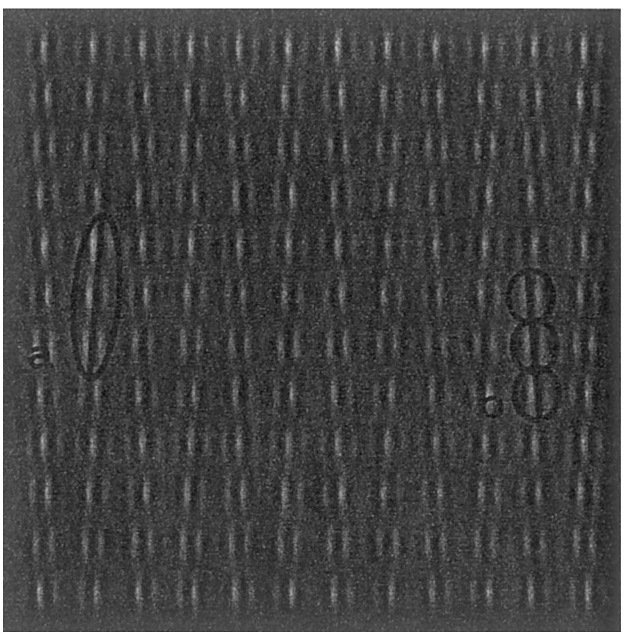

Fig. 2. The Fraser illusion with no local cues (phase-shifted Gabors) — two models. In (a) neighbouring patches are summed by an elongated local filter. (b) Shows a global collator tuned to phase, which collates activity from local filters spatially coincident with the patches, but at a tilted orientation.

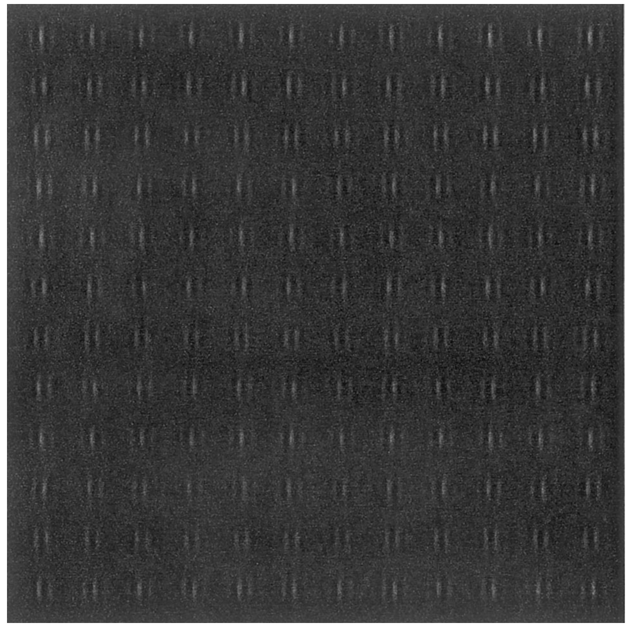

Fig. 3. The Fraser illusion with no local cues. Here the separation between neighbouring elements is over four times their carrier period, precluding a within field effect. The illusion is weaker than in Fig. 2, but this might be because the degree of tilt implied by the phase shifts is smaller.

stration at an open day. At the Weizmann Institute of Science Open Day, all of the 20 (approx.) viewers (aged about 8–55), saw the Fraser illusion, and observed the stereoscopic effects. The same effects can be observed by free-fusing the left and right half-images in Fig. 4. Each half image is composed of a 12×12 array of vertical Gabor patches, separated by three periods of the carrier, with envelope standard deviation equal to $\sqrt{2}/2$ carrier periods. Successive Gabor patches in each vertical column are phase-shifted by a quarter of a cycle. In alternate columns, these phase shifts are positive or negative to create opposite illusory tilts. For comparison, an image containing real tilts of the texture columns is shown below (Fig. 4b). It is clear that, unlike with real tilt, no stereoscopic slant is produced by the illusory tilt. Instead, alternate rows are seen in different depth planes.

3. Discussion

Successive phase shifts between the elements of a column of Gabor patches can give rise to the illusion of global tilt. Opposite monocular illusory tilts are not combined stereoscopically to give illusory three-dimensional slant, although real tilts of the same magnitude do give rise to the perception of slant.

In the traditional Fraser illusion (Fig. 1), tilted elements give rise to the perception of illusory global tilt. What are the tilted elements in the phase illusion?

(1) Filters between the patches. (2) Elongated filters. (3) The mean orientation of filter activity along the column. (4) Collators or (5) Lateral interactions.

Filters between the patches (1) would be active at a tilt of about 10°, as can be seen by close inspection of Fig. 2 and Fig. 4a. However, inserting tilted elements between the patches of a uniform-phase texture gives rise to little, if any, illusory tilt (Fig. 5).

The elongated filters (2) illustrated in Fig. 2a might form the tilted elements of the illusion. If so, why is the orientation disparity between the two eyes not input to stereo? Stereo is based on binocular disparities, which could be more accurately computed from elongated filters, were these available. However, simple neurones appear to have an aspect ratio of close to unity ($\sigma_y \approx \sigma_x$), and a bandwidth equivalent to $\sigma_x \approx 0.5\lambda$ (Ohzawa, DeAngelis & Freeman, 1996, in cat). The mean orientation of filter activity along the column (3) can approximate perceived tilt, but only if the filters are sufficiently elongated (2λ) to pick up an oriented signal in the first place, and if this mean is calculated along the length of the column. Some mechanism is required to group the elements of a column together for the mean to be calculated along a single column.

Collators (4) or collector units (Morgan & Hotopf, 1987) are second-stage filters which integrate the activity of first-stage filters along their axis. Such units have been used to model the Fraser illusion (Fig. 1), by assuming they are tuned to input filters oriented along their axis (Morgan & Baldassi, 1997). In effect, collators centred on a single location perform orientation averaging at that location, within the range of orientations specified by their orientation tuning profile. Collators could form the tilted elements of the phase illusion (Figs. 2–4a) if they acted like elongated filters. Lateral interactions (5) can be envisaged as virtual collators, which integrate the activity of neighbouring first-stage filters.

Collators and/or lateral interactions are the theoretical background for a range of psychophysical phenom-

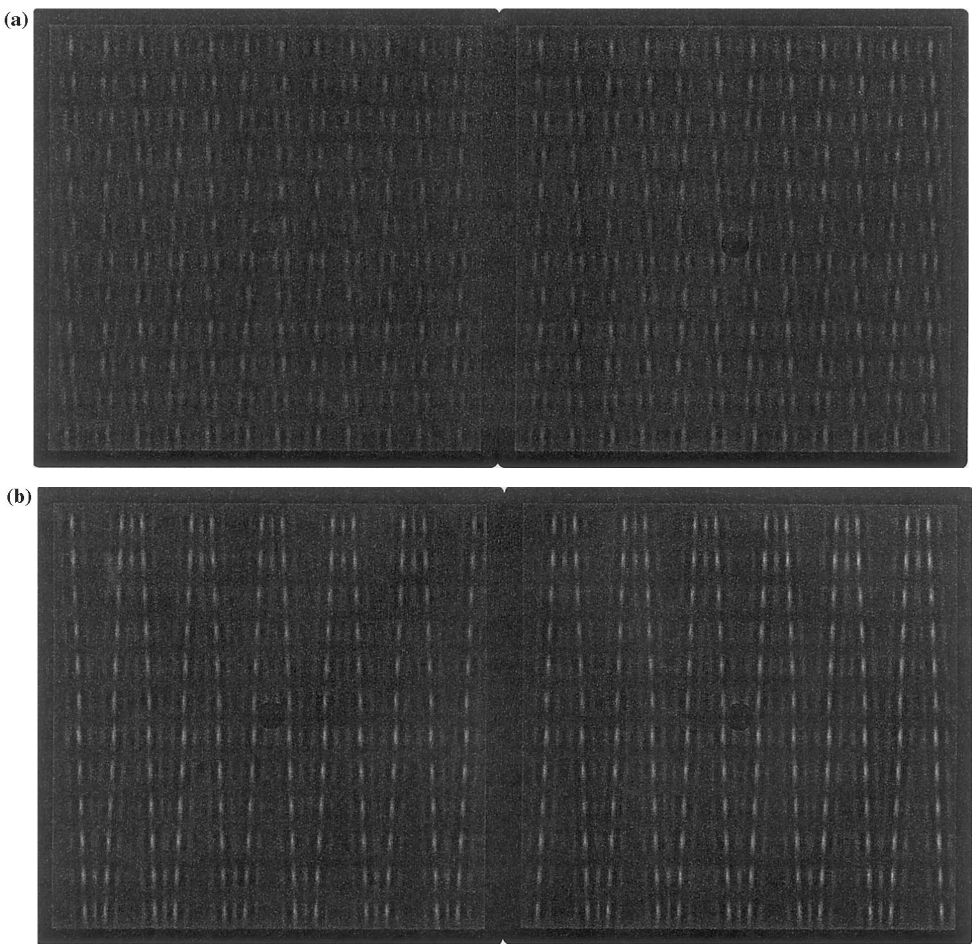

Fig. 4. (a) Binocular Fraser display with Gabors. (b) Really slanted Gabors. The half-images in (a) and (b) look similar, but the alternating tilts in (a) are illusory, the result of gradually varying the phase of the elements. On free-fusing the half images, only (b) yields the percept of columns of alternating slant (The tilt of the columns in (b) is 1°, Fig. 7 shows this is more than enough to compensate for the illusory tilt of the columns in (a)).

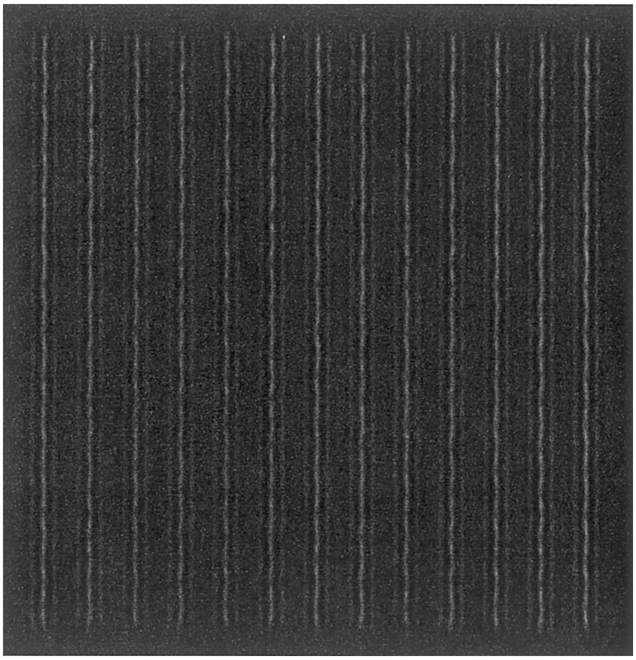

Fig. 5. Inserting oriented patches between the elements of a uniform-phase texture gives little apparent tilt.

ena, including lateral facilitation (Polat & Sagi, 1993, 1994; Adini, Sagi & Tsodyks, 1997; Bonneh & Sagi, 1998; Chen & Tyler, 1999; Polat & Tyler, 1999), contour integration (Field, Hayes & Hess, 1993, 2000) and alignment (Mussap & Levi, 1996, 1997). These phenomena have been found insensitive to phase (Field et al., 1993), only slightly sensitive to phase (Field et al., 2000), sensitive to phase only at short separations (Waugh & Levi, 1993; Zenger & Sagi, 1996), or only in the periphery (Chen & Tyler, 1999). A phase insensitive mechanism would integrate the patches in Figs. 2–4a along their principle orientation, and cannot form the basis of the tilt illusion in those figures. This points to the possibility that both phase sensitive and phase insensitive processes exist with their response differentially expressed, depending on stimulus and task. While studies concerning contour integration (Field et al., 1993) and lateral interactions (Polat & Sagi, 1993) required the observers to detect the presence of a target among distractors or in empty field (saliency), the present task involves shape perception. Models of early vision make a distinction between saliency detection and form perception (Julesz, 1981), where the former can be modeled using phase independent second-stage mechanisms (Rubenstein & Sagi, 1990) while the latter requires phase information (Piotrowski & Campbell, 1982). Thus, while both phase dependent and phase independent processes respond to our stimuli, providing ambiguous orientation signals, the unique orientation perceived is determined by the phase selective process in the absence of other disambiguating signals (see below).

The most probable tilted elements of the illusion are thus collators (4) or lateral interactions (5). Our stereoscopic percept, on fusing columns of opposite illusory tilts in the two eyes (Fig. 4a), is not the stereoscopic slant obtained by fusing opposite real tilts in the two eyes (Fig. 4b). Instead, the stereoscopic percept is dominated by the local phase disparity of the elements. This phase disparity is ambiguous (180°), and the texture is seen grouped by rows which stand out in depth. In effect, stereo disambiguates the illusion to reveal the true organisation of the monocular half-images. The simplest explanation of the absence of illusory slant is that the tilted elements of the illusion are themselves computed by a binocular mechanism. However, it is not clear whether the traditional Fraser illusion gives illusory slant when viewed binocularly (Fig. 6a, compare real slant in Fig. 6b). Additionally, it is possible that, although monocular by nature, such collators or interactions are not input to stereo, or that the stereoscopic percept is dominated by local energy.

We see the texture in Fig. 4a organised by rows of equal disparity. Some rows have unambiguous, zero disparity. Elements in the other rows have ambiguous (crossed or uncrossed) phase disparity, however we see all the elements in each row at the same disparity. This grouping by disparity might be the result of a 2nd order process (e.g. lateral interactions) tuned to disparity (Popple & Findlay, 1998). It may be the strong grouping by rows of equal disparity which overrides any illusory slant along the columns.

Fig. 7 is included at the suggestion of a reviewer. It shows illusory tilt compensated by 1° of real tilt in the opposite direction. Binocular fusion of the two half images yields a percept at first dominated by the interocular phase shifts. Upon further inspection the slants of the columns can be seen (like in Fig. 4b), showing that stereo disambiguates the illusory tilt due to phase shifts between successive elements of the monocular half-images, revealing the true tilt of the columns. In other words, here although monocular tilt is ambiguous, we do see some stereoscopic slant.

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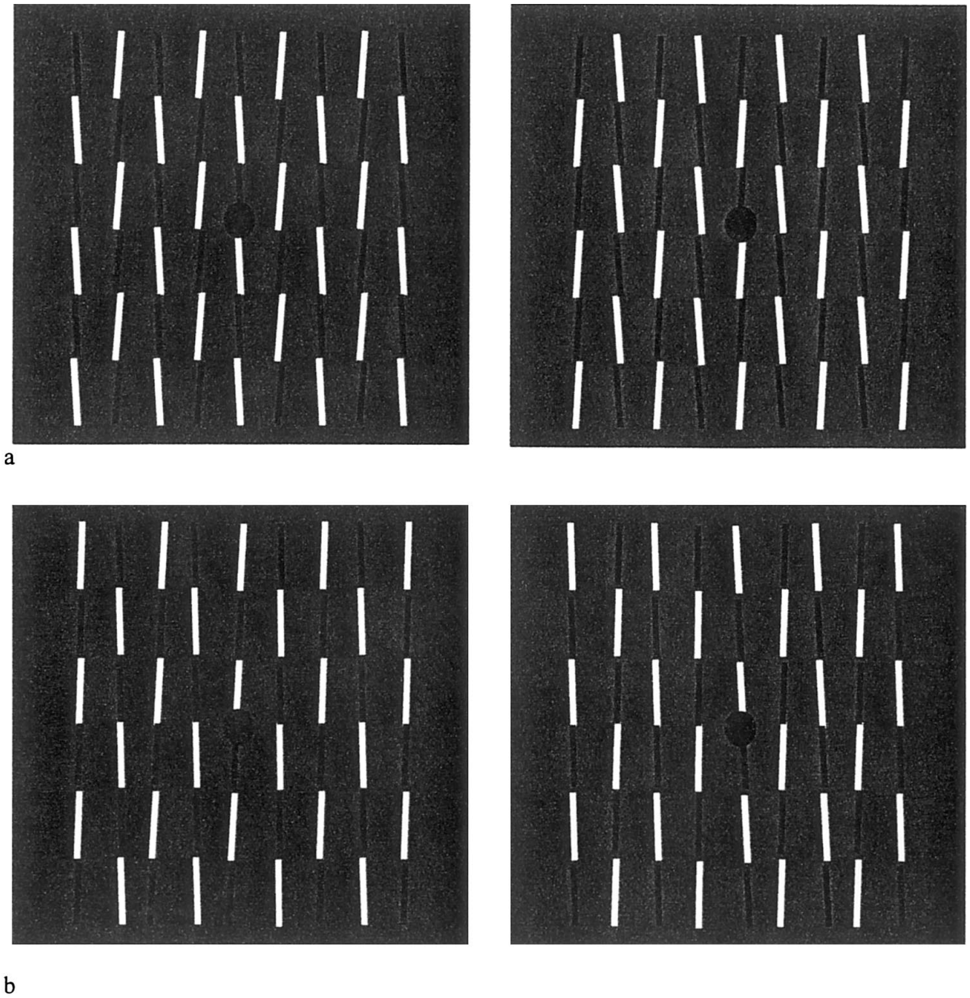

Fig. 6. (a) Traditional binocular Fraser illusion figures combined interocularly with opposite apparent tilts also give little illusory global slant. (b) Shows the same elements combined with real tilts in opposite directions.

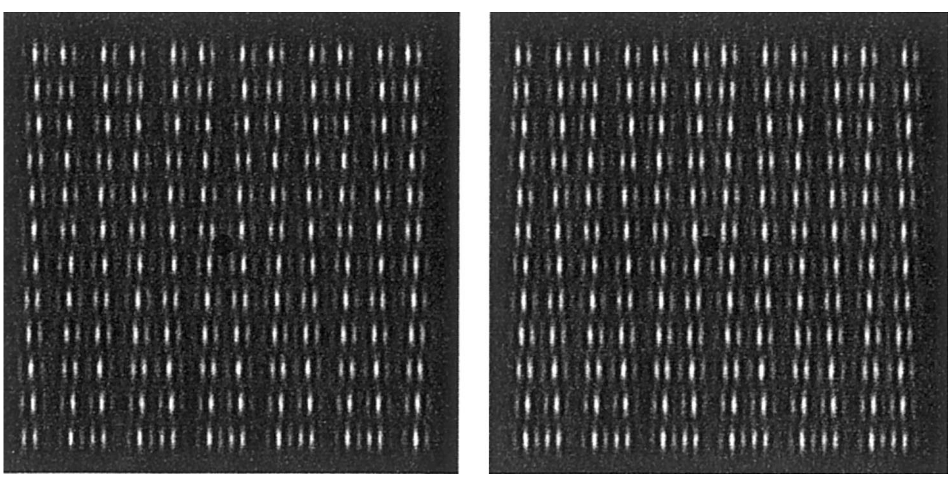

Fig. 7. Monocular half-images with illusory tilt balanced by 1° real tilt in the opposite direction yield an ambiguous stereoscopic percept with some slant, as well as local phase disparity.

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