Viewpoint

# What is visual discomfort?

*The pattern in Fig. 1 can provoke anomalous visual effects: illusions of colour, shape and motion. People differ considerably in their susceptibility to these effects and some find the pattern unpleasant to look at. Readers who suffer from migraine or epilepsy are advised not to look at the pattern because it might bring on an attack.*

In this article it will be argued that the pattern (Fig. 1) may cause discomfort, illusions, headaches and seizures by a common physiological mechanism.

The susceptibility to seizures can be studied, without causing seizures, by using the electroencephalogram (EEG). Waveforms composed of spikes and slow waves appear when photosensitive epileptic patients are exposed to flickering light. Sometimes these waveforms also appear when patterns such as Fig. 1 are viewed.

The illusions can be measured by asking observers to check the visual effects they see against the following list: red, green, blue, yellow, blurring, bending of stripes, shimmering, flickering, or shadowy shapes. The various effects do not dissociate from one another. All are influenced by similar pattern characteristics in similar ways, and for this reason I will treat the illusions as a group. Generally speaking, the more illusions, the more unpleasant the pattern.

**Illusions and epileptiform activity are evoked by similar patterns**

Fig. 2 summarizes data from two studies. In the first, volunteers with photosensitive epilepsy were shown various patterns on repeated randomized presentations (usually lasting 10 s), and the probability of epileptiform EEG activity was estimated[1]. In the second study, groups of normal observers recorded the illusions they saw[2]. Comparison of the curves from the two studies shows that the epileptiform activity and the illusions are affected in the same way. Both illusions and epileptiform activity are most likely to occur:

(1) In response to stripes rather than checked patterns (as can be seen from Fig. 2a both visual and epileptic phenomena increase with the height/width ratio of the checks).

(2) When the stripes have equal bar width and spacing (i.e. a square-wave luminance profile), see Fig. 2b.

(3) When the bars have a width of about 10 minutes of arc (spatial frequency near 3 cycles $deg^{-1}$), see Fig. 2c.

(4) When the bars are sufficiently contrasted (both visual and epileptogenic effects increase approximately linearly with the logarithm of Michelson constant, see Fig. 2d).

In addition to the above, both illusions and epileptiform activity are most likely to occur with binocular as opposed to monocular viewing.

The likelihood of both visual and epileptic effects occurring is crucially dependent on the size of the pattern. Pattern size has been manipulated by: (1) varying the radius of a centrally-fixated pattern of stripes, circular in

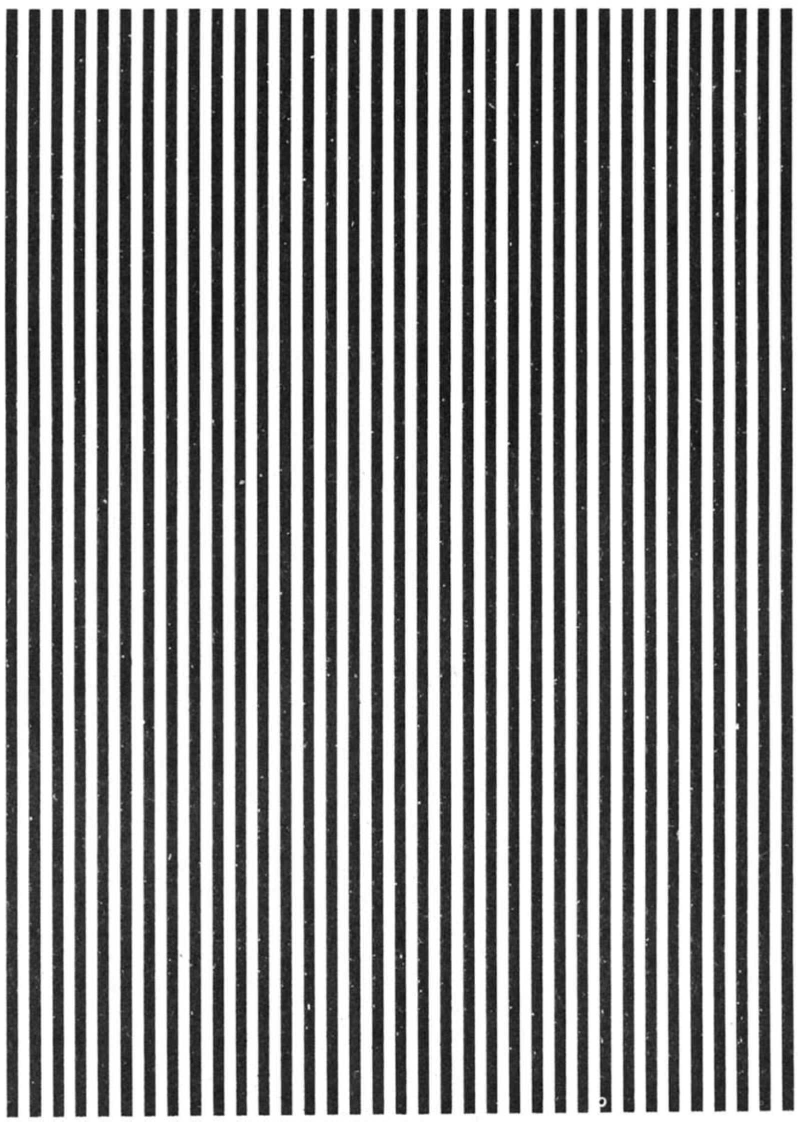

**Fig. 1.** *An example of an epileptogenic pattern. When viewed from a distance of 40 cm the pattern subtends 18° by 24° at the eye, and the individual lines about 10 minutes of arc (i.e. the grating has a spatial frequency near 3 cycles $deg^{-1}$). The Michelson contrast of the grating is about 70% It can be seen from Fig. 2 that the grating has parameters close to those for which illusions and epileptiform activity are maximally likely.*

outline (see Fig. 3a and b); (2) changing the inner and outer radii of an annular pattern of stripes (see Fig. 3b and c); and (3) changing the number and angular size of diametrically-opposed sectors of concentric rings (see Fig. 3c, d and f). All the patterns had a constant spatial frequency (measured radially or longitudinally) and thus no account was taken of the increase in receptive field size with eccentricity. Nevertheless, in every case the functions relating pattern size to the probability of epileptiform activity or illusions depended not on the area of the pattern so much as on the area of visual cortex to which the pattern projected, as calculated from published estimates of the human cortical magnification factor[3]. Both visual and epileptiform effects increased directly with pattern area when the area of the pattern was manipulated by varying the angular size or the number of sectors of patterns such as those in Fig. 3d, e and f. Both effects increased linearly with the logarithm of pattern area (or the logarithm of pattern radius) when the size of a pattern of stripes was manipulated by varying its radius, see Fig. 2e.

Sleep deprivation has long been known to increase susceptibility to seizures[4,5]: if normal observers are deprived of sleep the number of illusions they see in a pattern such as Fig. 1 increases[2].

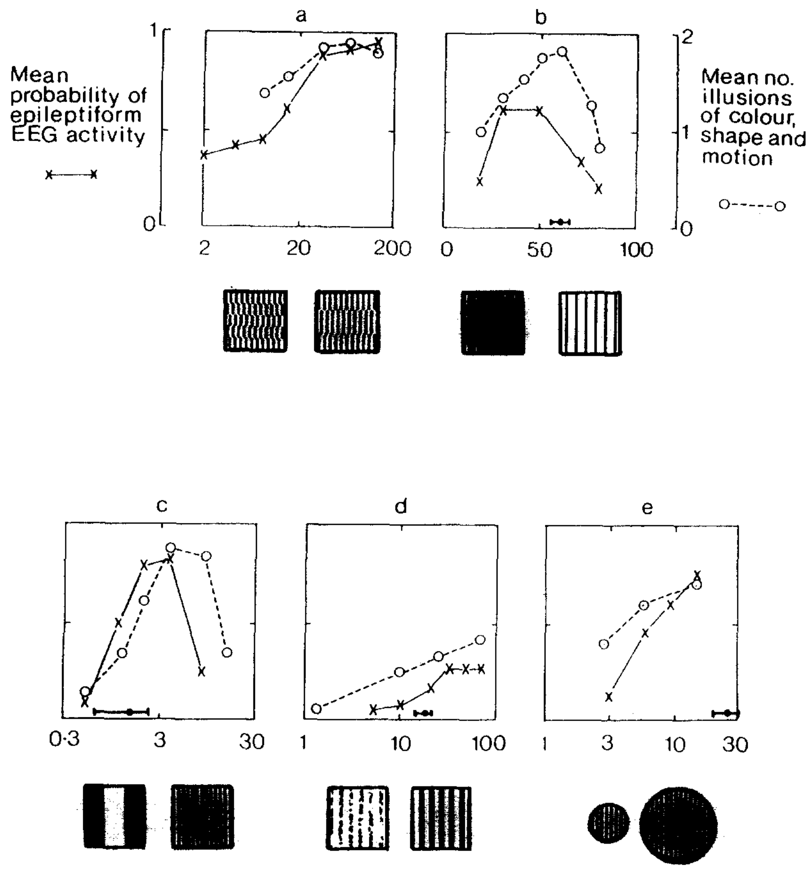


**Fig. 2.** *The influence of various pattern characteristics on the illusions seen by normal observers and the occurrence of epileptiform activity in the EEG of patients with photosensitive epilepsy[1,2]. Each pattern parameter was manipulated independently, the values of the other parameters remaining close to those optimal for the induction of illusions and epileptiform activity. Schematic diagrams of the stimuli are shown beneath the abscissae. The mean number of illusions for a group of observers and the mean probability of epileptiform activity for a group of photosensitive patients are shown as a function of:* (**a**) *pattern type (checks of varying height/width ratio);* (**b**) *duty cycle (proportion of spatial cycle occupied by bright bars);* (**c**) *spatial frequency (number of cycles in one degree subtended at the eye);* (**d**) *Michelson contrast [the ratio (L2 − L1)/(L2 + L1), where L2 and L1 are the luminance of the bright and dark bars, respectively];* (**e**) *pattern radius. The horizontal points and bars near the abscissae show the mean and SD of values typical of printed text when the latter is considered as a pattern of horizontal stripes. Note that the relative scaling of the two ordinates is arbitrary, but constant for all graphs.*

## The origin of the illusions

Despite a century of study, little is known about the origin of the illusions. Some are undoubtedly due to ocular mechanisms[6], others questionably so. The illusions of colour, for example, are usually attributed to different temporal characteristics of the cones. Other illusions, especially those of shape (e.g. the rhomboid lattice) have no simple explanation in terms of peripheral factors. It has been proposed on more than one occasion that cortical mechanisms are involved[7–10]. Illusions of colour are often integrated with those of shape in a unitary percept, and considerations of parsimony would suggest that illusions other than those of shape also have cortical mechanisms. The absence of any dissociation between the various types of illusions may indicate that many of the illusions share common cortical mechanisms. As will now be shown, such a suggestion receives support from the similarity between the patterns that induce illusions and those that induce seizures, given the evidence that the seizures are triggered in the visual cortex.

## The origin of visually-evoked epileptiform activity

In patients with photosensitive epilepsy, the evoked epileptiform activity appears to be triggered at the level of the visual cortex, and may remain sustained within it. There are four main lines of evidence for such a view:

(1) Stripes are more epileptogenic than checks, and the length of line contour within the pattern is critical. Cells within the visual cortex have linear receptive fields.

(2) When one eye sees a horizontal grating and the other a vertical grating, epileptiform activity is less likely to occur than when both retinal images are similar. Cells in the striate and prestriate areas have binocular inputs.

(3) Patterns in one lateral visual field induce a response over contralateral posterior head regions, and in some patients patterns in the upper visual quadrants induce responses with lower scalp topography than that for the responses to patterns in the lower visual quadrants: the topography of the electrical activity is therefore appropriate for generators in the visual cortex[11].

(4) When the generalized photoconvulsive EEG response is suppressed by the anti-epileptic drug sodium valproate, abnormal discharges are confined to the posterior region of the head before disappearing, and there then remains a characteristic abnormality of the visual evoked response[12,13].

Photosensitive patients can have normal vision, at least between seizures. They can have normal Snellen

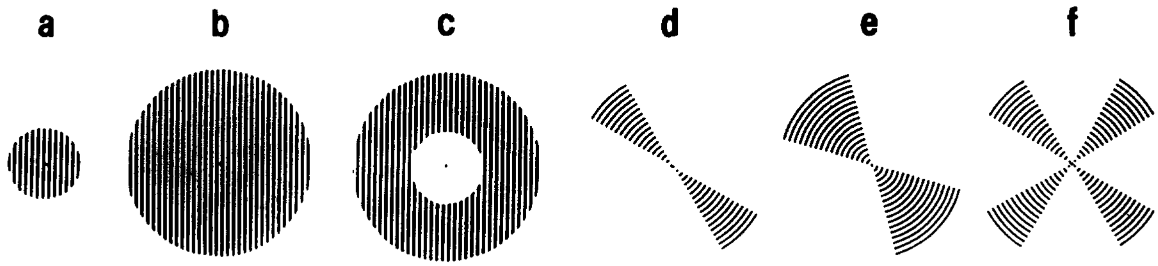


**Fig. 3.** *Schematic diagrams of gratings that vary in size by virtue of a change in outer radius* (**a,b**); *inner radius* (**b,c**); *angular size of sector* (**d,e**); *and number of sectors* (**d,f**). *Patterns (e) and (f) have the same total area and similar cortical projections; patterns (a) and (c) have different area but similar cortical projection.*

letter acuity, normal stereopsis, and their ability to see low-contrast gratings can also be normal, even when the characteristics of the gratings are such that at higher contrasts epileptiform activity would be induced[14]. Given the effects of pattern size described above, it is therefore possible to infer that the epileptiform response occurs when normal physiological excitation in the visual cortex exceeds some critical 'mass'.

### The role of synchronization

Stripes that repeatedly change their direction of motion, or their phase (black to white, white to black), are much more epileptogenic than stationary stripes[1,15]. (The temporal tuning of the response to the two types of pattern alternation is similar and independent of the spatial tuning, and within limits the amplitude of the movement has relatively little effect[1].) Stationary stripes are more epileptogenic than those that drift continually towards fixation. These differences between the various types of pattern motion suggest a role for synchronization. Cortical units respond selectively, within a restricted velocity range, to one direction of motion. Patterns that repeatedly change phase or direction of motion might therefore be expected to cause an organized sequence of bursts of excitation. No such temporal organization should accompany a drifting pattern since the receptive fields of neurons overlap. The temporal organization of the excitation from stationary patterns might be expected to lie between these two extremes by virtue of the eye movements that occur during fixation. The differences between the responses to drifting patterns and to those with other types of motion, summarized in Fig. 4, suggests that epileptogenesis is facilitated when patterns induce a physiological excitation that is temporally organized.

### Differences between patterns that induce illusions and those that induce epileptiform activity

As may be seen from Fig. 4, drifting patterns are as effective as vibrating or phase-reversing patterns at inducing illusions. Fig. 4 shows the illusions of colour because these are the easiest to measure when the patterns are in motion, but the remaining illusions appear to be affected in a broadly similar way. As already mentioned, it is conventional to think of the illusions of colour as having a different origin from those of shape and as being due to the different temporal properties of the cones. If this were the case, one might expect the illusions to dissociate from one another more readily than they do. The illusions of colour (and perhaps also those of shape and motion) would appear to be a response of the visual system to massive excitation, regardless of its synchronization.

The illusions and epileptiform activity differ not only with respect to the effects of pattern motion, but also as regards the separate stimulation of different regions of the visual field. Patterns presented in the left or right visual hemifields are more likely to induce epileptiform activity than are similar patterns positioned in the upper

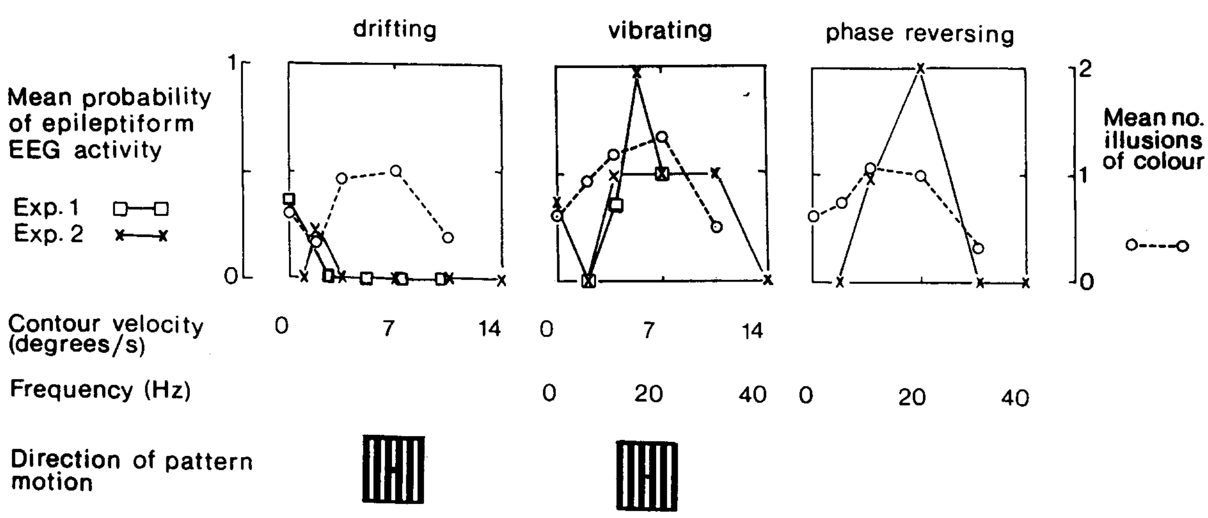


**Fig. 4.** *The influence of drifting, vibrating and phase-reversing gratings on the mean number of illusions seen by normal observers, and on the mean probability of epileptiform EEG activity in patients with photosensitive epilepsy. The vibrating gratings oscillated with triangular space–time profile in a direction orthogonal to the main axis of the stripes. The left and right halves of the drifting grating moved towards a central fixation point, eliminating optokinetic nystagmus. The data for normal observers are unpublished. The data for photosensitive patients are taken from two studies*[15]*, the first with ten patients and the second with two.*

or lower fields[11]. The spatial summation that results in the pattern in Fig. 3f being as epileptogenic as that in Fig. 3e applies only within one hemifield, and by implication within one hemisphere. It has been argued that the cerebral hemispheres act independently in the induction of epileptiform activity, and excitation within one hemisphere is integrated in the process of generating the discharge[16]. Patterns presented in a lateral visual field may perhaps be more epileptogenic for this reason. In contrast to the above, there are no differences between the upper, lower and lateral visual fields with respect to the induction of illusions[2].

**Brief theoretical speculations**

The effects of stimulus characteristics on visual illusions and photosensitive epilepsy might show the above similarities and differences for a number of reasons. The values of parameters such as spatial frequency and duty cycle (Fig. 2) at which visual and epileptic effects are most likely are also those values optimal for detection of patterns at low contrast. It may simply be the case that visual stimuli with these characteristics are most effective at exciting the system in some non-specific way. Nevertheless, the effects of pattern size suggest that a critical 'mass' of excitation is necessary for both illusions and epileptiform effects. The visual illusions show no effects of synchronization and the epileptogenic effects summate within hemispheres. One obvious and intriguing possibility is that the illusions reflect a spread of excitation within the visual system, similar to that responsible for epileptic discharges, though far more localized and stable.

**Clinical correlates**

The origin of the illusions is of more than academic interest because of their relationship to a variety of disorders including 'eye-strain' and headaches[2]. People who suffer frequent headaches tend to report more illusions, and on days when they get a headache, susceptibility to the illusions is increased. The correlation between illusions and headaches is maximal for spatial frequencies near 3 cycles $deg^{-1}$ accounting for 20% of the variance. The illusions tend to be associated with symptoms suggestive of migraine. If the headaches are unilateral the illusions predominate in one lateral visual field. The association between the presence of lateralized pain and lateralized illusions lends support to the idea that the illusions may be mainly central in origin. People who suffer 'eye-strain' are particularly susceptible to the illusions. Conversely, patients with photosensitive epilepsy frequently complain of 'eye-strain'[2].

**Ergonomic considerations**

The successive lines of printed text form a pattern of stripes that can have characteristics quite similar to those of patterns that induce discomfort, illusions and seizures. The horizontal bars on the abscissae of Fig. 2b, c and d show the means and SDs of values of duty cycle, spatial frequency and contrast typical for lines of text in a sample of books chosen as having 'clear' and 'less clear' text. The books were individually positioned at a comfortable reading distance. The duty cycle was estimated by comparing the x-height with the interline spacing, and the contrast of the lines was derived from measurements of the mean density of linear sections of the page.

Of course, text comprises many spatial frequency components at many orientations, but these appear to be insufficient to offset the effects of the stripes. When asked to fixate a letter in the centre of a page of text, people report illusions that are similar to those seen in Fig. 1, including the prototypical rhomboid shapes. It may be because of the effects of duty cycle shown in Fig. 2 that line spacing accounts for so much of the variance in judgements of the clarity of textual material. It accounts for more variance than the density of letters on the page, suggesting that books could be printed more clearly at no extra cost.

People who report many illusions in a striped pattern find it beneficial to use a reading mask that attenuates the brightness and contrast of the lines of text above and below those being read, leaving three lines clearly visible. The mask helps to prevent eye-strain and headaches from reading[17], and it is also effective at reducing the occurrence of epileptiform discharges when photosensitive patients read[18].

It has long been known that television can cause seizures in patients with photosensitive epilepsy, and it does so partly because of the 50 per second diffuse flicker visible at normal viewing distances, and partly because of the pattern of stripes formed by the raster, which are visible from close to the screen. The stripes interlace 25 times per second and are highly epileptogenic[18]. Conventional computer display terminals do not usually use an interlacing raster although the stripes from the textual display may perhaps exacerbate any discomfort from the flicker. The intermittent illumination from visual display terminals has recently been shown to disturb ocular motor control, and this disturbance might provide another possible reason for the discomfort with which visual display terminals have been associated[19].

Take another look at the pattern in Fig. 1: there's more to it than meets the eye!

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