Characterising the patterned images that precipitate seizures, and optimising guidelines to prevent them

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Abstract

The use of guidelines to prevent the broadcast of epileptogenic television programme content has reduced the incidence of seizures in Britain and Japan. Epileptogenic content includes both flicker and patterns. The guidelines for flicker were developed on the basis of a model that related stimulus parameters to the proportion of patients affected. We here extend the model to pattern stimuli. A set of rules is advocated that keeps the level of risk to a consistent minimum and simplifies compliance. We propose that striped patterns that last longer than 0.5s, occupy more than one quarter the area of the screen and have bright stripes more than 50cd.m^{-2} in luminance are restricted as regards the number of cycles admissible. The guidelines are estimated to protect at least two thirds of susceptible patients.

Introduction

In the general population about 1 in 6,000 is liable to photosensitive epilepsy (PSE). Between 7 and 20 years of age the susceptibility to seizures from visual stimulation is five times greater than in adulthood. Convulsions can be triggered by a variety of visual stimuli, including flashing lights and steadily illuminated patterns (1, 2).

In 1993, a broadcast advertisement (Golden Wonder Pot Noodles) precipitated epileptic seizures in three viewers in the United Kingdom. On 17 December 1997, a broadcast children's programme 'Pokemon' in Japan resulted in 685 admissions to hospital. On later investigation, 560 of these viewers were shown to have suffered epileptic seizures, and 76 per cent of these patients had no previous history of epilepsy (3). The use of alternating red and blue backgrounds on successive frames was implicated in precipitating the seizures (4).

The above incidents have led to national guidelines in the UK and Japan, now extended internationally by the International Telecommunications Union (ITU). The guidelines incorporate the following restrictions:-

1. *Frequency*. Flashes with frequency greater than 3Hz are prohibited.

2. *Opposing changes in luminance*. Flashes greater than or equal to 20cd. m^{-2} are prohibited.

3. *Area of flashes*. Flashes greater in area than one quarter of the screen are prohibited.

4. *Colour*. Flicker from saturated red light is prohibited.

Following the Pokemon incident and the introduction of guidelines, a decrease in the number of patients with seizures from television has been noted in Japan. There has been no corresponding change in the number of patients with seizures from video games, suggesting that the broadcast guidelines have been responsible for the decrease in seizures (5).

Over the three years that the revised ITC guidelines have been in place in Britain only one seizure precipitated by broadcast programmes has been reported. This related to flickering patterns. The ITC Guidance Note addresses the risk from patterns as well as flicker and the following is an abstract of the current guidance.

"5. A potentially harmful regular pattern contains clearly discernible stripes when there are more than five light-dark pairs of stripes in any orientation. The stripes may be parallel or radial, curved or straight, and may be formed by rows of repetitive elements such as polka dots. If the stripes change direction, oscillate, flash or reverse in contrast they are more likely to be harmful than if they are stationary. If the patterns obviously flow smoothly across, into, or out of the screen in one direction they are exempt from restriction.
5.1. Potentially harmful patterns are not permitted when either of the following two conditions apply:
i. the stripes are stationary and the pattern occupies more than 40% of the displayed screen area; or
ii. the stripes change direction, oscillate, flash, or reverse in contrast and the pattern occupies more than twenty five per cent of screen area; and in addition to either of the above two conditions applying, when
iii. the screen luminance of the darker bars in the pattern is below 160 cd.m^{-2} and differs from the lighter bars by 20 cd.m^{-2} or more…

The above guidelines for patterns differ from those for flicker in that they evolved on an *ad hoc* basis and were not developed from a model, as the guidelines for flicker had been. The model has been described elsewhere (6). The guidelines for patterns are difficult to understand and, it will be shown, unnecessarily restrictive. The remainder of this paper is devoted to a revision of the guidelines for pattern, a revision that extends to patterns the model applied thus far only to flicker (6). We propose guidelines that are likely to be less restrictive but (1) maintain or improve the theoretical level of risk (2) simplify administration and (3) improve comprehensibility.

Starting assumptions

The probability of epileptic seizures can be estimated, without inducing seizures, from the occurrence of certain *epileptiform* waves in the electroencephalograph (EEG) recorded from scalp electrodes. The probability of epileptiform activity has been studied as a function of a variety of stimulus

parameters under conditions in which one parameter at a time has been varied while other parameters remain constant (2). The current ITC guidelines for flicker and those of the ITU were based on a model that related the probability of seizures to the obvious stimulus parameters (6). For the sake of simplicity it was assumed that the effects of each parameter were independent. The proportion of patients affected by flicker with particular parameter values was estimated from the product of the proportions of patients affected when each parameter took its particular value and the other parameters remained unchanged. The assumption that the various parameters have effects that are independent is almost certainly false. Nevertheless, when one parameter was studied, the values of the other parameters were close to those values that are maximally epileptogenic. The product of proportions is therefore likely to give rise to an estimate of risk that is worst case.

We will now consider in turn each of the spatial parameters of patterns that induce epileptiform EEG activity.

Effects of spatial frequency

We will begin by considering bright high-contrast patterns, i.e. those with luminance and contrast sufficiently high to be a risk to all susceptible patients. The proportion of patients affected by patterns of this kind is known to depend upon the spatial frequency of the pattern as shown in Figure 1: Panel 1[1]. Spatial frequency refers to the number of cycles of the pattern (pairs of light-dark stripes) subtending one degree at the eye. The function used to describe the data is shown in the figure legend. Although continuous functions are used for simplicity, here and elsewhere in this paper the predicted proportions are limited to values between 0 and 1.

The shape of the function in Figure 1: Panel 1 has been shown to be similar for stationary and vibrating patterns, and to be broadly independent of the temporal frequency of vibration and its spatial extent (reference (2); p. 23, Figure 2.15). Only the lower frequency limit will be considered. This is because patterns with spatial frequency sufficiently high as to be above the upper limit of sensitivity are likely to interfere with the screen raster, generating low spatial frequency Moiré effects and flicker. In all the emerging display methods, these secondary effects will be suppressed prior to presentation.

Insert Figure 1 about here

[1] Note that the function describes patterns that have a square-wave luminance profile (i.e. sharp edges). Its shape is therefore unlike that of the contrast sensitivity function that describes the ability to detect faint patterns (7).

Effects of area of retina stimulated.

The probability of epileptiform EEG activity in response to striped patterns of different areas has been investigated in two studies summarised in Reference (2): Figures 2.11 and 2.18, with a total of 19 patients. The data from these studies have been combined in Figure 1: Panel 2. The proportion of patients at risk from patterns increases linearly with the proportion of the visual cortex to which the pattern projects.

Effects of pattern size

The size of a pattern was estimated from the spatial parameters of television displays and the distance from which the displays are customarily viewed (8). For example, a television with a 4/3 aspect ratio and 20-inch screen viewed from a distance of 7 times screen height (2.1m) can be calculated to stimulate an area of the visual field that projects to 25% of the visual cortex.

Assuming the relationship shown in Figure 1: Panel 2, it is possible to estimate the proportion of patients affected by patterns that occupy different areas of the screen, bearing in mind the simplifying assumptions outlined earlier. Following previous work (6), we assume that 100% of patients is affected by patterns that occupy all of the screen of a 20-inch television (diametric measurement). The proportion affected by patterns that occupy one half, one quarter, one eighth and one tenth of the screen area can be calculated on the basis of Figure 1: Panel 2.

Insert Table 1 about here

Table 1 shows the proportion affected for stimuli (flashes or patterns) that are eccentrically fixated as well as those that are centrally fixated. When the stimulus occupies the upper or lower fields symmetrically (third column) the proportion of patients affected is simply related to the area of the pattern. When the stimulation is confined to one lateral visual field (fourth column) only one cerebral hemisphere is stimulated, and it is necessary to allow for the fact that the seizure thresholds in the two hemispheres can be quite different, and that when one hemisphere is responsible for the seizures, only stimulation in the contralateral visual hemifield is a risk. It was assumed that this was the case in one third of patients (Reference (2); p.27). The data in Table 1 demonstrate that gaze position has little effect on the proportion of patients at risk from a stimulus of a given size.

For the sake of simplicity, the effects of gaze position were ignored and central fixation was assumed. The proportion of patients affected was calculated for the case of a 20-inch screen with 4/3 aspect ratio and 24-inch screen with 16/9 aspect ratio, both of which have a screen height of 0.3m and a preferred viewing distance of 7 times this height. It was assumed that 100% of patients was affected by the full screen. Calculations were also undertaken for a 60-

inch screen with 4/3 aspect ratio, and a 73-inch screen with 16/9 aspect ratio, at a (preferred) viewing distance of 5 times picture height. Figure 1: Panel 3 shows some of the results. The solid curve is for the 20inch television with a 4/3 aspect ratio at the preferred viewing distance: the broken curve is for a screen with a 16/9 aspect ratio from the unusually close viewing distance of 4 times picture height (children often sit closer to the television than the recommended "preferred" viewing distances). All the remaining functions lie between these two curves. Note that the aspect ratio has little effect. The way in which the proportion of patients affected decreases with the size of the stimulus is similar for all screens and viewing distances.

Combining the effects of spatial frequency and pattern size

If we consider the number of pairs of light and dark stripes on the screen and the percentage of the screen that the stripes occupy, we can calculate the spatial frequency of the pattern and estimate the proportion of patients affected from the product of the proportions shown in Figure 1: Panels 1 and 3. This approach was used in the development of the guidelines for flicker, and, as has been argued above, estimates the worst case risk, given that the stimulus parameters have been investigated individually, maintaining other parameters at or near their most epileptogenic values. The estimate obtained from the product of the proportions is shown in Figure 1: Panel 4 for 4/3 screens with 20-inch diagonal measurement. Three important points emerge[2].

First, the proportion of patients affected by any pattern that occupies less than 25% of the screen is small regardless of the number of lines it possesses, at least for screens viewed from distances shown in Reference (8). If the screen is viewed from closer, the spatial frequency is reduced but the area of the pattern on the retina is increased. The two effects counteract one another.

Second, the proportion of patients affected by 5 stripe pairs is similar for patterns that occupy the entire screen and those that occupy only a quarter of the screen. The 5 stripe pairs filling the screen have a lower spatial frequency, which compensates for the larger area of pattern. The same conclusions apply when the functions shown in Figure 1: Panel 4 are calculated for 12-inch and 60-inch screens. The present limit of 5 stripe pairs would therefore seem to provide adequate protection without specifying the pattern size, as is currently the case. Note that 25% of the screen area corresponds to a solid angle of approximately 0.006 steradians. This gives rise to the rule proposed at the end of this paper.

[2]For those familiar with the area, there is also a fourth, abstruse consideration. In the range 1-5 stripe pairs, an increase in the proportion affected is to be expected simply on the basis of the energy in the pattern. Were this factor to be considered, it would increase the slope of all three functions in Figure 4 equivalently and leave unchanged the conclusions drawn from the figure.

The third important point to emerge from Figure 1: Panel 4 is that the proportion of patients affected approximately doubles as the number of stripe pairs increases from 5 to 8, at least as regards patterns of reasonable size. Again similar considerations broadly apply for smaller and larger screens. If it were desired to relax the restrictions of the current guidelines, it is possible to do so by specifying an equivalent risk for patterns that are static and those that reverse in phase, vibrate or flicker. Patterns that change in this way are approximately twice as likely to evoke seizures as stationary patterns. The rule described in the guidelines proposed at the end of this paper therefore restricts the number of light-dark pairs of stripes to 8 in the case of static pattern and 5 in the case of patterns that reverse in phase, vibrate or flicker. This proposal limits the proportion of patients affected to about 0.5 for all pattern types, but is generally less restrictive.

The above considerations apply to patterns that are of high contrast and luminance, and the proportion at risk can be reduced to more acceptable levels by specifying the contrast and luminance admissible, as will now be shown.

Effects of luminance and contrast

Space-averaged luminance. The data from Reference (9): Figure 2.12 have been replotted in Figure 1: Panel 5 and show a linear increase in the number of patients affected by a striped pattern with log luminance in the range 10-200 $cd.m^{-2}$.

The proportion of patients at risk from a large bright pattern with the most epileptogenic spatial frequency is shown as a function of the Michelson contrast of that pattern in Figure 1: Panel 6. These data were obtained using a stationary pattern (Reference (2) p. 20) and differ from those used previously to estimate the effects of flicker (6).

At present, the guidelines limit the difference in luminance between the bright and dark bars (stripes) to $20cd.m^{-2}$ when the luminance of the dark bar is less than $160cd.m^{-2}$. This does not provide an even restriction on pattern contrast. Patterns in which the luminance of the dark bar is $161cd.m^{-2}$ and the bright bar $200cd.m^{-2}$ provide a Michelson contrast of 0.108 and a space-averaged luminance of 181 $cd.m^{-2}$. The proportion of patients likely to be affected by a pattern of this contrast and luminance has been estimated from the functions shown in Figure 1: Panels 5 and 6 to be 0.66. If, however, the luminance of the dark bar is less than $160cd.m^{-2}$, for example, $159cd.m^{-2}$, then the maximum luminance of the bright bar is restricted by the guidelines to $179cd.m^{-2}$, the contrast to 0.34, the space averaged luminance to $169cd.m^{-2}$ and the proportion of patients at risk can be estimated to be 0.33. Given the present guidelines, changing the luminance of the darker bar by a negligible amount ($2cd.m^{-2}$) has changed the proportion of patients at risk by a factor of two. This change is not simply a reflection of the abrupt limit, but is due to an unfortunate choice of threshold luminance for the darker bar.

The functions shown in Figure 1: Panels 5 and 6 have been used to estimate the proportion of patients at risk from patterns composed of bright and dark stripes of a wide range of possible luminances. The results are shown in Figure 1: Panel 7. In this figure the size of the points is proportional to the proportion of patients affected. The small points adjacent to the diagonal represent patterns associated with a risk that is similar and low. The points are those in which the difference in luminance between the light and dark stripes is constant. By limiting the maximum difference in luminance between bright and dark stripes to 20cd.m^{-2} we obtain a risk that varies by a factor of less than two over a wide range of pattern luminances, as shown when the data are replotted as in Figure 1: Panel 8. Note that it is quite unnecessary to specify a threshold luminance level, as at present.

Unfortunately, the limit of 20cd.m$^{-2,}$ stringent as it is, reduces the maximum risk only modestly. The worst case risk can be estimated from Figure 1: Panels 8 as 56%. In other words 56% of patients sensitive to vibrating patterns are at risk. Since a substantial proportion of photosensitive patients are sensitive to vibrating patterns, this risk may be considered unacceptably high. A more stringent limit is required, and it is difficult to provide this by limiting still further the difference between the luminances of the bright and dark bars. The variation in the settings of brightness and contrast of domestic receivers is such that it is difficult to maintain a small luminance difference, even if the difference is transmitted appropriately.

The various functions in Figure 1: Panel 8 give similar risk when the luminance of the brighter stripe is 50cd.m^{-2}, regardless of the luminance of the darker stripe. This suggests that by restricting the luminance level of the brighter stripe to 50cd.m^{-2} the level of risk is held similar for all luminance differences, and is lower than that when a luminance *difference* of 20cd.m^{-2} is specified, as is currently the case. With a limit of 50cd.m^{-2} a maximum of 45% of patients is at risk.

Moving patterns

Patterns that drift continuously in one direction are generally less epileptogenic than those that are stationary (2). For this reason, the current guidelines do not restrict the use of patterns that "flow smoothly across, into, or out of the screen in one direction". The absence of restriction has permitted two instances in which drifting patterns may have provoked seizures. In both cases there is uncertainty as to whether the seizures arose from a brief freeze frame at the end that may or may not have been broadcast, and in one instance there is the possibility that the pattern moved and changed in size in such a way as to provide flicker. Nevertheless in both cases the patterns had a spatial frequency close to that at which seizures are most readily evoked, and the patterns filled the screen. The similarity between the two examples would seem to suggest that, despite the doubt concerning the exact cause of the

seizures, it would be sensible to prohibit large patterns with the worst spatial frequencies, even when they drift. There is difficulty in separating continuous drift from vibratory movement, particularly on refreshed screens, and one option might be to consider moving patterns in the same way as those that are stationary or that move in other ways. If this option is considered to be too restrictive it is possible to maintain a similar level of risk for drifting patterns by restricting those that have more than 12 pairs of stripes of whatever kind. Twelve pairs of stripes rarely occur from natural or everyday scenes, with the exception of the occasional views of railings and Venetian blinds.

Colour and colour contrast

Patterns that vary in luminance across the boundaries of the stripes can be epileptogenic whatever the chromaticity, although for individual patients, there may be certain chromaticities that are more epileptogenic than others (10). Gratings with red/green stripes that do not differ in luminance are not epileptogenic, at least for patients with normal colour vision (2). It is not known whether isoluminant patterns of red/cyan stripes are epileptogenic, although red/cyan isoluminant flicker is known to be so (4). Given the available evidence, it will be assumed for simplicity that the epileptogenic properties of a pattern depend on the luminance contrast across its stripes without respect to chromaticity.

Pattern duration

The response to patterns is probabilistic, and so the longer a pattern is presented, the greater the risk. There are no studies that have formally investigated the effects of pattern duration, but in those studies that have been undertaken by the authors it has been rare indeed for a paroxysmal response to pattern to have occurred in less than 0.5s. The latency is typically in the order of 1-2s. It is proposed that the guidelines apply to those patterns that last longer than 0.5s. Patterns of shorter duration should not repeatedly be shown because of flicker and the possibility of cumulative risk.

A suggested rewording of the Guidance Note as it concerns patterns

It is now possible to use the above data to propose a revision to the guidelines for pattern.

> *A potentially harmful regular pattern contains clearly discernible stripes when there are more than five light-dark pairs of stripes in any orientation.*
>
> *The stripes may be parallel or radial, curved or straight, and may be formed by rows of repetitive elements such as polka dots. If the stripes change direction, oscillate flash or reverse in contrast they are more likely to be harmful than if they are stationary. If the patterns obviously*

flow smoothly across into or out of the screen they are less likely to be harmful than stationary patterns. The larger the patterned area, the greater the risk.

When the light and dark stripes of any pattern collectively occupy a total area greater than one quarter that of the screen

and

the luminance of the lightest stripe is greater than 50 cd.m^{-2}

and

the patterns are presented repeatedly or for longer than 0.5s

then the following restrictions shall apply:

i. If any of the stripes change direction, oscillate, flash or reverse in contrast, the screen should show no more than five light-dark pairs of stripes;

ii. If all the stripes are stationary the screen should show no more than eight light-dark pairs of stripes;

iii. If all the stripes obviously move smoothly across, into, or out of the screen, the screen should show no more than 12 light-dark pairs of stripes.

If the pattern is such as to produce a 'flash' by virtue of its movement or an interaction with the screen refresh then the restrictions on flashes shall apply.

Protection afforded by the guidelines

The guidelines for flicker are simple to administer and appear to be working well. The ITC guidelines for pattern also appear to be effective, although they are less easy to interpret, are more restrictive than they need to be, and provide a variable level of risk. The new proposals provide a risk to patients that is theoretically consistent over a wide range of pattern types, luminances and contrasts. The estimated risk is lower than for the current guidelines, even though the new proposals are likely to be less restrictive. Nevertheless, the protection is poorer than it might otherwise be because of the threshold size and luminance below which the guidelines are not held to apply. If a pattern had maximally epileptogenic characteristics but an area slightly less than one quarter that of the screen then about one third of patients would be at risk, according to Figure 1: Panel 3. If a larger pattern passed the guidelines because its bright bars had a luminance slightly less than the limit of 50cd.m^{-2}, a similar proportion of patients would be at risk, according to Figure 1: Panel

8. The protection afforded by the guidelines appears to be limited to about two thirds of patients. It is quite possible to reduce this risk, but only by introducing further restriction on patterns. When the stimuli are such that the guidelines are applied, the protection is better: the risk is estimated to be 0.3*0.5=0.15; that is, 85% of patients who are sensitive to a pattern with the most epileptogenic spatial properties filling an entire screen would be protected.

The guidelines proposed above have been formulated for conventional video screens viewed from conventional distances. If a more general formulation is required, the specification of 25% of screen area could replaced by stipulating a solid angle of 0.006 steradians at the minimum expected viewing distance.

Application of the above guidelines by automata

Devices have been built that automatically recognise video material likely to cause seizures (5, 11, 12). The revised guidelines are insufficient for such purposes as formulated above because they fail to define a stripe. If stripes are defined in terms of the luminance difference across their boundaries, the question arises as to the threshold luminance difference sufficient to characterise a stripe. From the class of functions shown in Figure 1: Panel 8, it can be shown that a luminance difference of less than $3cd.m^{-2}$ is likely to affect fewer than 15% of patients. The small difference in luminance is attributable to the low contrast at which patterns can provoke seizures: stripes that differ by more than $3cd.m^{-2}$ are potentially a problem.

The automatic recognition of epileptogenic material is not a straightforward matter and is beyond the scope of this paper. If Fourier analysis of the image is used to recognise a striped pattern, it is worth bearing in mind that the addition of energy in orthogonal orientations acts to decrease rather than increase the epileptogenic potential of a pattern, (see ref (2), p. 14).

Correction of images that fail the above guidelines

The above guidelines are simple to understand. They also provide for a simple remedy in the case of video material that fails the guidelines. It is necessary only to reduce the luminance of patterns so that the luminance of the brightest stripe is less than $50cd.m^{-2}$. Note that this is far simpler than reducing the contrast of a pattern, as the present ITC guidelines might require. There are various ways in which the luminance or its equivalence in voltage or pixel values can be measured.

The steps necessary to evaluate material reduce to the following:-

Look at the screen

Are there more than five stripes?
If so, do they last longer than 0.5s?
If so, does the brightness exceed the stated limit?
If so, categorise the motion of the pattern
Are the guidelines contravened?
If so, reduce brightness.

Emerging display technologies

In the home, flat-panel displays using either plasma or liquid crystal thin film transistor (TFT) technologies are likely to become dominant over the conventional cathode ray tube (CRT) displays within a decade, whilst in public installations, the large light emitting diode (LED) matrix displays are gaining a presence more rapidly still, both indoors and outdoors.

The growing "home cinema" market employing pre-recorded media exemplified by the DVD family is likely to provide the first mass high definition (HD) sources, although digital television transmission standards also enable higher definition services to be offered to the public. All these services will be viewed on displays that are intended to subtend roughly twice the retinal area of standard definition displays. Although the plasma and TFT displays are unlikely to exceed the CRT in terms of brightness, LED based "digital billboards" normally have a surface luminance of 1200 $cd.m^{-2}$, and with diligent cooling they can reach 3000 $cd.m^{-2}$ quite easily. These luminosity levels are designed to enable daylight readability, although such levels are often employed in dim indoor situations for added (advertising) impact. Display resolution, is normally lower than that of broadcast television, often by a factor of two, increasing the potential for harmful patterns.

None of the changes in display in technology reduce the need for broadcast guidelines; rather the increases in screen subtense and brightness make guidelines more necessary. If the current recommendations are to apply not only to the current generation of display screens but also to future generations it may be necessary to be more restrictive as screen size and brightness increase. For now, the recommendations can be taken to apply to screens that subtend about 10 degrees at the eye.

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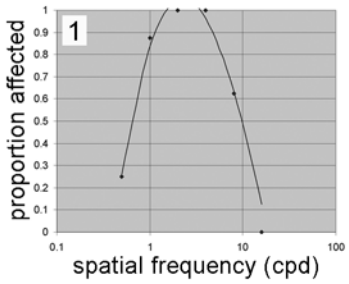
Tables and Figures

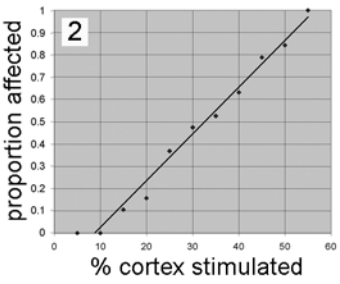
Table 1. The proportion of patients affected by stimuli (flashes or patterns) of different size, assuming all are affected by stimuli that occupy the entire screen of a 20-inch television. Data are shown for central and eccentric gaze.

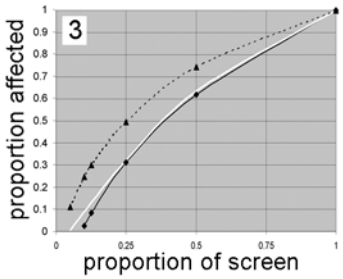
Area of screen with stimulus	Central gaze	Eccentric Upper/ lower margin	Eccentric Lateral margin	Weighted average
Full	1.00			1.00
Half	.63	.50	.80	.64
Quarter	.32	.31	.50	.36
Eighth	.09	.16	.25	.15
Tenth	.03	.12	.19	.09

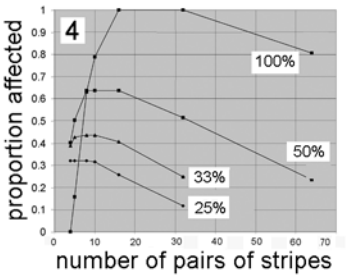
Figure legend

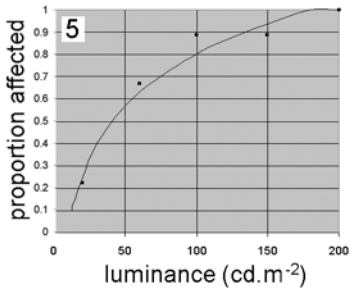
Figure 1: *Panel 1*. The proportion of patients with pattern-sensitive epilepsy at risk from a large pattern of bright high-contrast stripes, shown as a function of the spatial frequency of the pattern expressed in cycles per degree subtended at the eye. The stripes had square-wave luminance profile. The data are from reference (13) p. 4). The function has the following equation for $0<y<1$, $y=0.382(\log(x))^3-2.020(\log(x))^2 + 1.285\log(x) + 0.839$. *Panel 2*. The proportion of a sample of 19 patients affected by a pattern of stripes, shown as a function of the area of visual cortex to which the pattern projected, estimated from the formula proposed by Drasdo (14). Data are from references (13) and (9), summarised in reference (2); Figures 2.11 and 2.18). Note that no patient is affected when less than 8% of the cortex is stimulated. The equation of the line for $0<y<1$ is $y=0.021x-0.184$. *Panel 3*. The proportion of patients with pattern-sensitive epilepsy at risk from a pattern of bright high-contrast stripes, shown as a function of the overall size of the pattern, expressed in terms of the proportion of the screen that it occupies. Solid lines is for a 20-inch television with a 4/3 aspect ratio at the preferred viewing distance of 7 times picture height. The dotted line is for a screen with an aspect ratio of 16/9 viewed from 4 times picture height. Curves for other screens at preferred viewing distance lie between the two black curves. The curves are represented by the expression, $y= -0.708x^2 + 1.792x – 0.083$, for $0<y<1$, shown by the white curve. *Panel 4*. The proportion of patients with pattern-sensitive epilepsy at risk from a pattern of bright high-contrast stripes, shown as a function of the number of bright-dark pairs of stripes constituting the pattern. The curves show the effects of three different sizes of pattern expressed as a percentage of the screen that the pattern occupies, see labels. The data are for a screen with 20-inch diagonal measurement. *Panel 5*. The proportion of a sample of 9 patients affected by a pattern of high-contrast stripes shown as a function of the luminance of the pattern. The data are from reference (9): Figure 2.12. The proportion of patients at risk from a large high-contrast pattern with the most epileptogenic spatial frequency is shown as a function of the space-averaged luminance of the pattern. The equation of the function for $0<y<1$ is $y=0.336\ln(x) –0.745$. *Panel 6*. The proportion of patients with pattern-sensitive epilepsy at risk from a large pattern of bright stripes, shown as a function of the Michelson contrast of the pattern. The data are from reference (13); p.106, Figure 2.1. *Panel 7*. The proportion of patients with pattern-sensitive epilepsy at risk from a large pattern of stripes with luminance as shown on abscissa and ordinate. The size of the points is directly proportional to the proportion of patients at risk, and the isolated white point in the lower right hand side of the graph shows a proportion of 1.0 for comparison. *Panel 8*. The proportion of patients with pattern-sensitive epilepsy at risk from a large pattern of bright high-contrast stripes, shown as a function of the luminance of the brighter bar. The curves show the effects of various differences in luminance between the light and dark stripes (shown beside each curve and expressed in $cd.m^{-2}$).

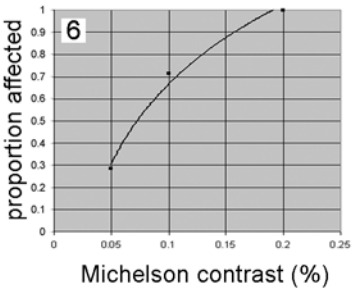

1
proportion affected
spatial frequency (cpd)

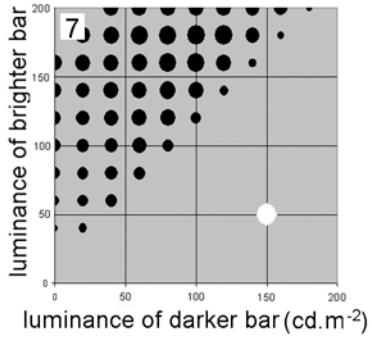

2
proportion affected
% cortex stimulated

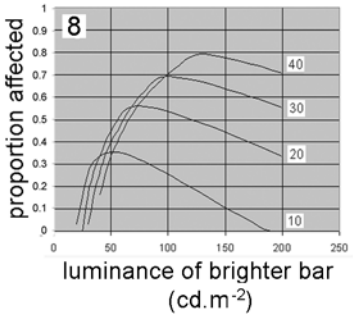

3
proportion affected
proportion of screen


4
100%
50%
33%
25%
proportion affected
number of pairs of stripes


5
proportion affected
luminance (cd.m-2)


6
proportion affected
Michelson contrast (%)


7
luminance of brighter bar
luminance of darker bar (cd.m-2)


8
40
30
20
10
proportion affected
luminance of brighter bar
(cd.m-2)