Characterizing the Flashing Television Images that Precipitate Seizures

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Television is by nature a flickering medium. It is also designed to convey images that flash or flicker. This paper seeks to characterize the stimulus parameters of broadcast materials that have been responsible for triggering epileptic seizures. Three sources of evidence are considered: the characteristics of flicker and pattern predicted to induce seizures on the basis of clinical studies; the statistics of broadcast images; and the characteristics of video sequences that have been associated with anecdotal reports of seizures. The results of these studies have contributed to a revision, in mid-2001, of a Guidance Note issued by the Independent Television Commission (ITC) in the U.K. seeking to protect, so far as is reasonably practicable, the section of the population that is liable to photosensitive epilepsy.

A small proportion of the population, about 1 in 6,000, is liable to photosensitive epilepsy (PSE) under certain circumstances. However, in a young population, between 7 and 20 years, the proportion susceptible is five times greater. That is, convulsions can be triggered by rapidly flashing lights, or images that flicker in certain ways. In 1993, following a report in the U.K. that a broadcast advertisement had precipitated epileptic seizures in three viewers, the Independent Television Commission (ITC), the regulator for commercial television services in the U.K., with the aid of medical advice, produced guidelines on the use of flashing images and regular patterns in television. In subsequent years there were further complaints of seizures occurring in relation to specific programs or advertisements.

On 17 December 1997, a broadcast program, "Pokemon," in Japan, resulted in 685 admissions to hospital of viewers experiencing seizures. On later investigation, 560 of the viewers were shown to have had epileptic seizures; 76% of them had no previous history of epilepsy. It was shown by Harding[1] that the use of alternating red and blue backgrounds on successive frames had precipitated these seizures. Following this incident, the ITC revised its Guidance Note to incorporate the requirement to avoid flashes of highly saturated red and carried out other revisions. The guidelines were again reviewed in 2000; these further studies are reported here.

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Flicker Predicted to Induce Seizures on the Basis of Clinical Studies

The probability of epileptic seizures can be estimated without inducing seizures from the occurrence of certain epileptiform waves in the electroencephalogram (EEG) recorded from scalp electrodes. For this reason, the investigation of patients with known or suspected epilepsy usually includes an EEG examination in which the patient is exposed to visual stimulation such as intermittent light from a xenon gas discharge lamp and geometric patterns. From such studies it is known that seizures can be provoked by visual stimuli such as flicker and certain geometric patterns, particularly stripes.

Flicker is produced when a light varies over time with respect to its luminance or color; the variation may be cyclic or non-cyclic. Flicker can vary in terms of the frequency at which the cycles are repeated, the depth of modulation of luminance in each cycle, and the luminance averaged over time across the cycle. The probability of seizures is affected not only by these variables, but by the area of retina stimulated and the duration of the flicker.

Frequency

Figure 1 shows the percentage of patients exhibiting a photoparoxysmal EEG response to intermittent photic stimulation. The solid line indicates data from Jeavons and Harding[2]; the broken line, data from Kasteleijn-Nolst Trenite.[3] Note that few patients are sensitive to flashes with a rate of occurrence of 3 Hz or less, and that above this frequency the number of patients who are sensitive increases rapidly.

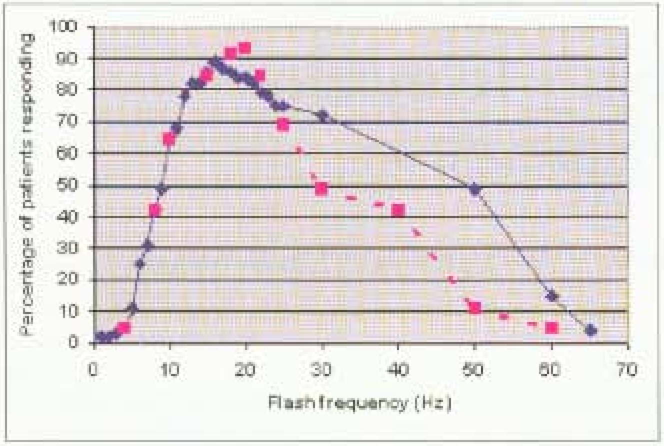

Figure 1. Percentage of patients affected according to flash frequency.

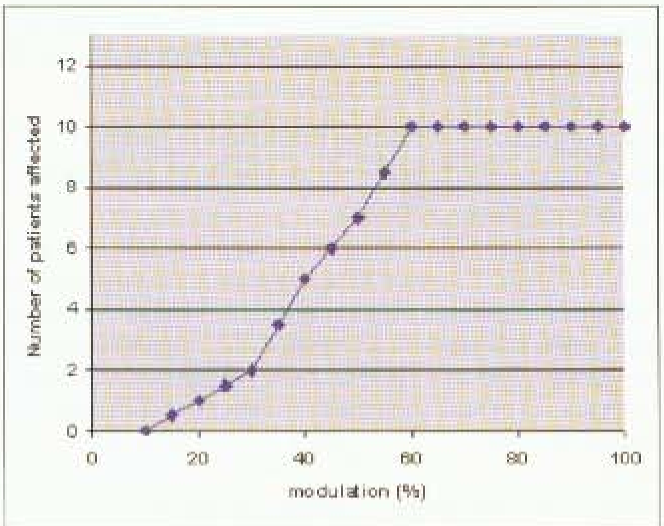

Figure 2. Number of patients affected according to modulation depth.

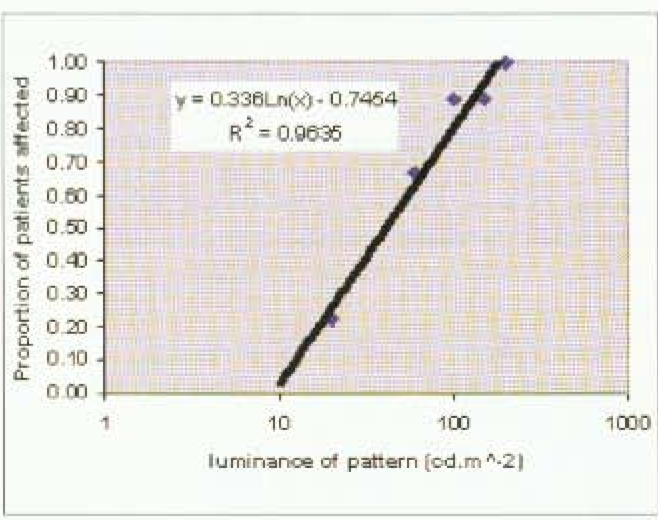

Figure 3. Proportion of patients affected according to luminance of pattern.

Modulation Depth

The number of patients affected increases with the modulation depth of the flicker, according to the function shown in Fig. 2. The data in this figure were obtained in a study by Harding and Fylan[4] in which 13 patients were exposed to vertical gratings with square-wave luminance profile reversing phase at 1 Hz presented on a 50-Hz television screen. The plateau above 50% modulation probably reflects saturation in the contrast response of visual neurons according to Wilkins.[5]

Time-averaged Luminance

The data from Wilkins et al.,[6] have been plotted in Fig. 3 and show a linear increase in the number of patients affected by a striped pattern with log luminance in the range 10 to 200 cd/m^{-2}. There are no corresponding data for flicker. However, in view of the similarity of the effects of temporal modulation of flicker and spatial modulation of pattern, it has been assumed that the effects of luminance are similar for both spatial and temporal modulation.

Flash Intensity

A potentially harmful flash occurs when there is a pair of opposing changes in luminance (i.e., an increase in luminance followed by a decrease, or a decrease followed by an increase). It has already been shown that flashes occurring at a rate of less than 3 Hz are not generally hazardous (Fig. 1), but it is necessary to also consider the permissible intensity of flashes.

Figure 4 shows how the proportion of patients affected by flashes of a given luminance varies with the luminance of the screen. The curves have been obtained from the product of the functions shown in Figs. 2 and 3. As can be seen, flashes with luminance of 5 cd/m^{-2} above and below screen luminance are safe at all screen luminances. Flashes of 20 cd/m^{-2} above and below screen luminance are a risk when the screen luminance is less than 100 cd/m^{-2} and also when the contrast of the flash is in the epileptogenic range.

To simplify matters, it will be assumed that program content is such that all screen luminances are equally represented. The proportion of patients affected by a flash that differs from screen luminance by a given amount is then as shown in Fig. 5. Note that for low flash luminances, this is a positively accelerating function.

The Effect of Screen Luminance

In order to accommodate different display technologies, it is preferable to relate flash criteria to physical luminance values rather than electrical parameters of specific displays. Fortunately, there are several milestones of display luminance that offer reasonable anchor values.

First among these, historically as well as in luminance value, is the peak white screen luminance experienced in cinemas. This is limited to around 30 cd/m^{-2} simply because any higher level would expose annoying amounts of 48-Hz flicker and image gate wander. The incidence of PSE under these viewing conditions is low,[2] in agreement with the data in Fig. 3.

A threshold value of 20 cd/m^{-2} below which flicker is admissible confers an adequate safety margin, taking account of the effects of both contrast and luminance under domestic viewing conditions as specified in Rec. ITU-R BT.500. This specifies a peak luminance value of 200 cd/m^{-2} for a reference home viewing environment. There is an upper threshold of 160 cd/m^{-2} at or above which the darker image of a cycle of flashing images is acceptable, as this limits the contrast to levels below those at which PSE is a risk (Fig. 2).

Area of Retina Stimulated

The probability of epileptiform EEG activity in response to striped patterns of different areas has been investigated in two studies summarized in Wilkins.[5,7] The data have been combined in Fig. 6, showing the estimated proportion of a sample of 19 patients affected by a pattern of stripes as a function of the area of visual cortex to which the pattern projected, estimated from the formula proposed by Drasdo.[8] Note that no patients are affected when less than 8% of the cortex is stimulated. A similar linear function might be expected to apply to the effects of flickering field but for the possibility that scattered light within the eye might enlarge the effective area of stimulation. The effects of scattered light appear to be small, however, because eccentric fixation of a flickering source greatly reduces the risk of its evoking epileptiform abnormalities.[9]

Screen Area of Flash

Using the preferred viewing distances given in Rec. ITU-R BT.500, it is possible to calculate the percentage of visual cortex to which the screen projects, assuming central fixation of the screen. A television set with a 20-in. screen, viewed at seven times the screen height (7H) stimulates 25% of the visual cortex; a 60-in. screen viewed at 5H would stimulate 34% of the visual cortex.

Assuming the relationship shown in Fig. 6, and if we assume that 100% of patients are affected by a 20-in. screen,

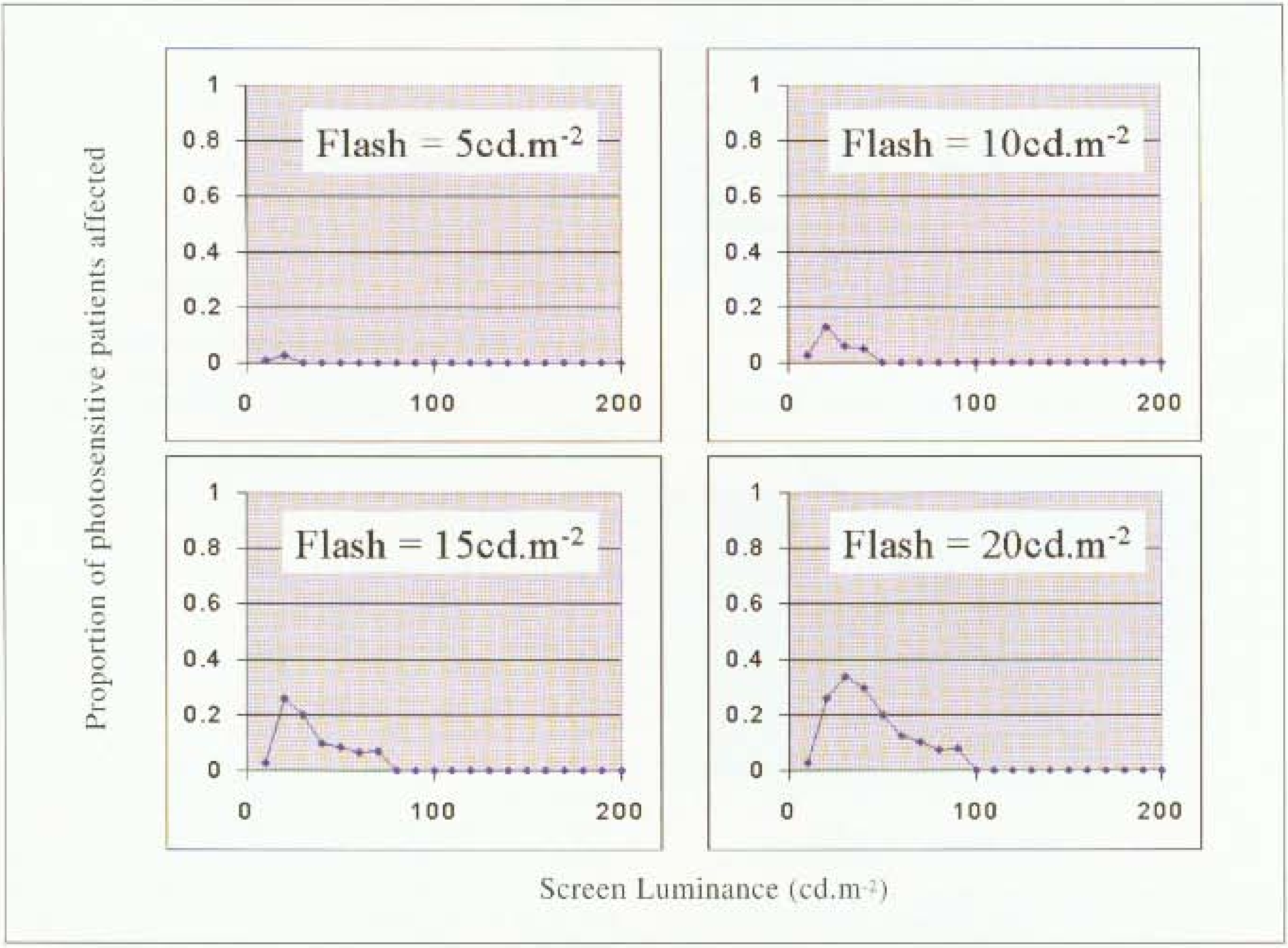

Figure 4. Proportion of patients affected by flashes differing from screen luminance by various intensities.

then the proportion affected by flashes that occupy one-half, one-quarter, one-eighth, and-one tenth of the screen area are as shown in Table 1.

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 in a small proportion of patients the photosensitivity is confined to one hemisphere.[5] The data in Table 1 demonstrate that fixation position has a small effect on the proportion of patients at risk from a flash of a given size. For the sake of simplicity a weighted average has been used. The two categories of eccentric fixation, shown in Table 1, each contributed an equivalent weight equal to one half the weight allocated to central fixation. The result is shown in Fig. 7.

Trade-off between Flash Luminance and Flash Area

Any simple definition of a flash must involve integration of luminous flux over a specified region. Within this area it is not possible to distinguish a small bright area from a large relatively dim area, provided the integrated flux within the specified region remains the same. There is a linear trade-off between area and brightness as far as measurement is concerned.

In general, this is not true of the visual system if the specified integration region is above the resolution limit of a few minutes of arc. More specifically, with respect to the proportion of patients at risk of seizures, the trade-off between the luminance of a flash and the area it occupies is most definitely not linear. This can be appreciated if the model is expanded by assuming that the proportion of patients affected is the product of the effects of modulation depth, luminance, and area. In Fig. 8 the data from Figs. 5 and 7 have

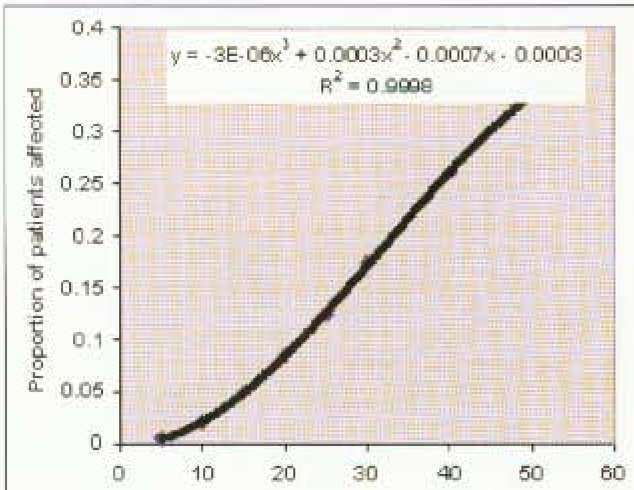

Figure 5. Proportion of patients affected by flashes as a function of the difference between screen luminance and luminance of the flash.

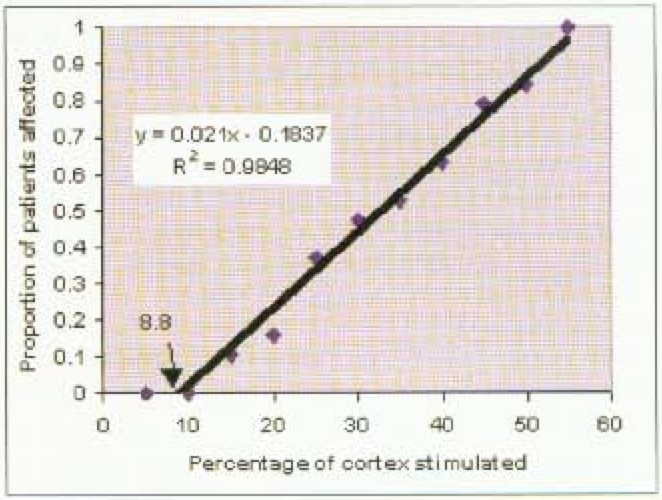

Figure 6. Proportion of patients affected by flashes as a function of the area of visual cortex to which the pattern is projected.

been combined. Note that doubling the screen area is safer than doubling the flash luminance when the flash luminance is 20 cd/m^{-2} or below.

Color

Previous studies in Europe and Japan to examine the effects of flicker that arise from variations in color rather than from changes of luminance produced conflicting results. Binnie et al.[10] used a technique known as silent substitution in which variation occurred only in one class of photoreceptor. They showed that co-modulation of color and luminance of this kind was more epileptogenic than the equivalent luminous modulation of white light. They attributed this effect to inhibitory interactions between photoreceptor classes and argued that absence of such interactions explained the greater epileptogenic properties of deep red light.

Further studies are required if it is wished to develop more precise guidelines regarding the effects of colored flashes in television.

Statistics of Broadcast Images

The statistics of broadcast images may be used to check parameters of proposed rules designed to protect photosensitive patients from flashing or patterned images. If over-strict rules are violated frequently during the course of normal broadcast programs they would clearly lose creditability.

Various sequences of broadcast program material, each lasting just under 3 h (10 ks), were recorded off-air over a range of different channels for subsequent analysis. The screen of a calibrated monitor was covered by a 4 x 4 array of cells that integrated the light captured from an area 1/16th that of the screen. The light captured in each cell was monitored by a V-lambda-corrected photodiode, amplified and

Table 1—The Proportion of Patients Affected by Flashes of Different Size

Area of Screen Flashing	Central Fixation	Eccentric Upper/Lower Margin	Eccentric Lateral Margin	Weighted Average
Full	1.00	-	-	1.00
Half	0.63	0.50	0.80	0.64
Quarter	0.32	0.31	0.50	0.36
Eighth	0.09	0.16	0.25	0.15
Tenth	0.03	0.12	0.19	0.09

low-pass filtered. The system was calibrated by interrupting the light at several fixed background brightness levels. Similar video generated patterns were then used to check the video-brightness relationship. The low-pass-filtered brightness level was recorded. The findings were corroborated using two different recordings with different systems and machines. Note that with the analysis technique employed, false alarms can arise from the effects of motion. The findings are shown in Table 2.

Two different parameter combinations, which produced three alarms, identified the same three video sequences. All other events could be considered as spurious, e.g., running feet, trains passing, shaking of a coin box, fast pans, etc. The data in Table 2 show that guidelines prohibiting a train of four or more flashes that exceeded a contrast of 20% and occupied more than 1/4 screen area would yield a sufficiently low rate of alarms.

Selection of Parameters for Guidance Note

A "catalog" of some 30 video sequences, each of which was the subject of either a complaint or a reported seizure, was assessed by medical experts for risk. Parameters for the proposed rules were selected on the basis of the theoretical model that was developed. Parameters were chosen to ensure that items of known risk are detected, while not resulting in excessive numbers of false alarms when using the simple automatic analysis tool that has been described.

It is important to strike a balance between affording protection to those susceptible to photosensitive epilepsy and ensuring that the rules can be readily implemented by program-makers. A public consultation with licensees and other interested parties was carried out by the ITC in early 2001. An extract from the current guidance[11] is given below. The parameters will be reviewed again in early 2002.

Rules on Flashing Images

A potentially harmful flash occurs when there is a pair of opposing changes in luminance (i.e., an increase in luminance followed by a decrease, or a decrease followed by an increase) of 20 candelas per square meter ($cd.m^{-2}$) or more (see Notes 1 and 2). This applies only when the screen luminance of the darker image is below 160 $cd.m^{-2}$.

Irrespective of luminance, a transition to or from a saturated red is also potentially harmful.

Isolated single or double flashes are acceptable, but a sequence of flashes is not permitted when both the following occur:

i. the combined area of flashes occurring concurrently occupies more than one quarter of the displayed (see Note 3) screen area; and

ii. there are more than three flashes within any one-second period. For clarification, in a 50-Hz environment, flashes for which the leading edges are separated by 9 frames or more are acceptable, irrespective of their brightness or screen area.

Notes:

1. Video waveform luminance is not a direct measure of screen brightness. Not all domestic display devices have the same gamma characteristic, but a display with a gamma of 2.2 may be assumed for the purpose of determining electrical measurements made to check compliance with these guidelines (see Appendix I).
2. For the purpose of measurements made to check compliance with these guidelines, pictures are assumed to be displayed in accordance with the "home viewing environment" described in Recommendation ITU-R BT.500 in which peak white corresponds to a screen illumination of 200 $cd.m^{-2}$.
3. It may be assumed that overscan for each picture edge on modern domestic television receiver displays will normally be in the range 3.5% to 1% of the overall picture width or height (as indicated in EBU Technical Recommendation R95-1999).

It is recognized that such potentially harmful images

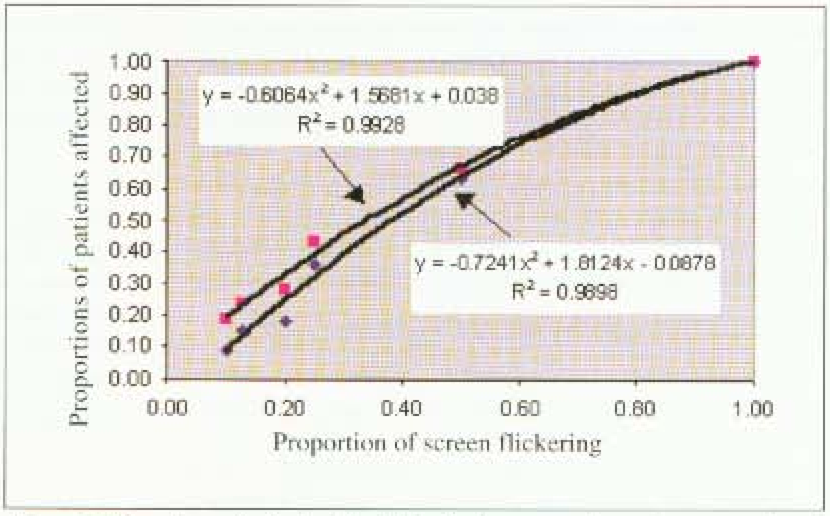

Figure 7. Proportion of patients affected by flashes occupying a given proportion of the screen (lower function is for a 20-in. screen, upper, for a 60-in. screen).

Table 2—The Number of Alarms Generated by Departures from Guidelines Shown

Number of flashes	Contrast of flashes (%)	Screen area	Number of alarms
≥3	>20	>1/16	24
≥=4	>20	>1/16	12
≥=6	>20	>1/16	3
≥4	>20	>1/16	12
≥4	>20	>1/8	9
≥4	>20	>1/4	6
≥4	>20	>1/4	6
≥4	>40	>1/4	3

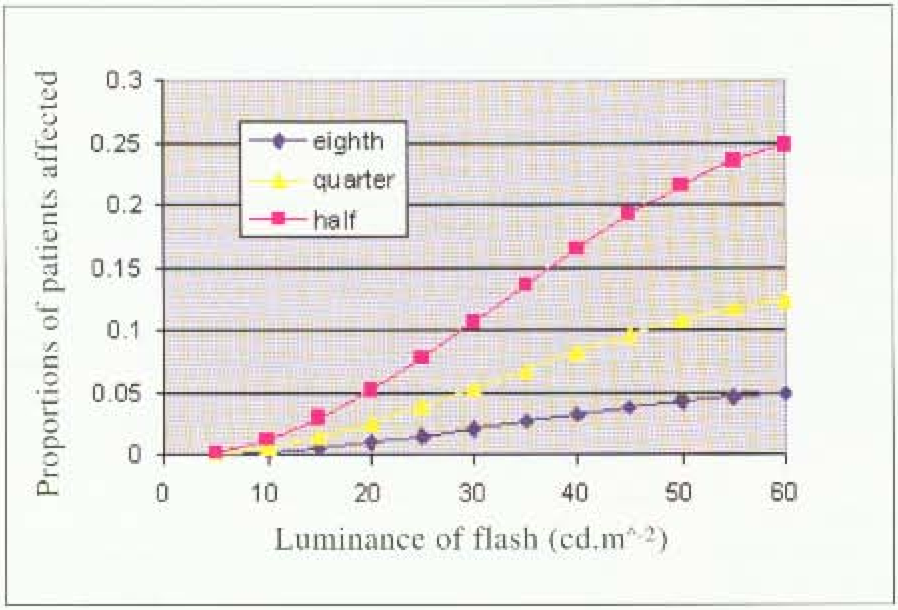

Figure 8. Proportion of patients affected by flashes shown as a function of luminance difference (abscissa) and flash area (key).

occur only rarely during the course of program material with scenes that appear natural or represent real life; examples include photographers' flashlights or strobe lights in a disco. Part of the purpose of the Guidance Note is to assist program producers to avoid inadvertently creating video effects that contain flashing images or patterns likely to be harmful.

Protection Provided by the ITC Guidance Note

If the guidelines proposed in the ITC Guidance Note are adhered to, it is now possible to express the proportion of susceptible patients who remain at risk.

Frequency. Flashes with frequency greater than 3 Hz are prohibited. The percentage of patients sensitive to frequencies of less than 3 Hz is 3% of all the patients sensitive to large flashes of maximum modulation and brightness.

Opposing changes in luminance. Flashes greater than or equal to 20 cd/m^{-2} are prohibited. The percentage sensitive to changes in luminance of less than 20 cd/m^{-2} is 7% of those sensitive at maximum flash luminance, averaged over screen luminance.

Area of flashes. Flashes greater in area than one quarter of the screen are prohibited. The percentage of patients sensitive to flashes having an area less than one quarter of the area of the screen is 32% of those sensitive to full screen flicker. This is based on a 20-in. screen. In the case of a 60-in. screen the percentage is 39%.

Color. Flicker from saturated red light is prohibited. Assuming the effects of the various parameters are independent, the proportion of patients who remain at risk if the guidelines are adhered to may be estimated to be 3% x 7% x 39%=0.1% of those who are notionally liable to a seizure when a television screen of maximum size and maximum luminance is displaying nothing but 12.5-Hz (PAL) or 15-Hz (NTSC) flicker over its entire screen.

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