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The Effect of Television Frame Rate on EEG Abnormalities in Photosensitive and Pattern-Sensitive Epilepsy

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Summary: *Purpose:* Seizures provoked by television viewing may be triggered by patterns in the television image or by flicker from the display itself. We examined the incidence of EEG abnormalities elicited by patterns displayed on television sets with two different frame rates to evaluate the likely contribution of photosensitive and pattern-sensitive mechanisms to television- and video-game epilepsy.

Methods: Televisions with frame rates of 50 and 100 Hz were used to present 35 patients who were photosensitive or pattern-sensitive with grating patterns. These patterns comprised vertical square-wave and sine-wave gratings of 90% contrast, and the spatial frequency was varied between 0.25–7 cycles/degree. EEGs were analysed for laboratory sensitivity to patterned and unpatterned intermittent photic stimulation (IPS).

Results: Significantly fewer EEG abnormalities were elicited by patterns displayed on the 100 Hz frame-rate television than on the 50-Hz frame-rate television. No abnormalities were observed in response to the blank screens of either television. Thirty-three patients showed abnormalities in response to patterned IPS but only 15 in response to diffuse flash. Two patients showed no laboratory evidence of photosensitivity. Patients who were sensitive to patterned IPS at 50 Hz were significantly more likely to demonstrate abnormalities to patterns displayed on the 100-Hz frame-rate television than were patients who were not sensitive to 50-Hz patterned IPS.

Conclusions: We suggest that for many patients, the combination of high-contrast patterns and screen flicker may elicit the observed EEG abnormalities. For patients with sensitivity to screen flicker, the use of a high frame-rate television may be beneficial in reducing the risk of seizures. **Key Words:** Photosensitive epilepsy—Pattern-sensitive epilepsy—Television—Frame rate—Computer game seizures.

Photosensitive epilepsy is a condition that affects 1 in 3,000 of the population (1) and comprises 2% of all patients newly presenting cases with epilepsy (2). The most common ages of onset of photosensitive epilepsy range from 7 to 19; when this age group is considered exclusively, the incidence rises to 10% of those with newly diagnosed cases of epilepsy (2). Pattern-sensitive epilepsy is a less documented syndrome and is triggered commonly by patterns such as those formed by escalators, window blinds, and patterns displayed on televisions and video games (1,3).

Patients with photosensitive epilepsy and those with pattern-sensitive epilepsy frequently report that their seizures occur while watching television. Commercial television sets have interlaced[1] screens, with a frame rate of 50 Hz in Europe and 60 Hz in the U.S.A. The resulting flicker components are 50 and 25 Hz in Europe and 60 and 30 Hz in the U.S.A. For an observer to perceive the lower frequency component, the screen lines must be resolved, requiring the television to be viewed at short distances (4). The distance which permits a subject to resolve the screen lines has been estimated at twice the screen diagonal (1,4). Such short viewing distances are common when playing computer and video games. When the display screen is a television rather than a computer monitor (generally non-interlaced with a frame rate of 70 Hz), the risk of inducing seizures in photosensitive patients is high. In their study of 460 photosensitive patients, Jeavons and Harding reported ~50% as having experienced a seizure while close to a television (5). Epileptic seizures elicited by playing video games were first described in 1981 (6) and there have since been several reports of such cases when games were played with arcade screens (7,8) and televisions (9–15). With the increased popularity of video games and interactive television the incidence of seizures induced by these games is likely to increase. Indeed, a recent Department of Trade and Industry survey has indicated that the incidence of a first seizure occurring while playing an elec-

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[1] On interlaced displays, the picture is built up by transmitting every alternate line of the picture in one frame and then transmitting the remainder in the subsequent frame. This results in television displays containing 2 temporal-frequency components, that of the frame rate and also half the frame rate.

tronic screen game is 1.5/100,000 for the 7–19 age group (16), estimated at 22% of all patients in this age group with abnormalities on photic stimulation.

The distribution of sensitivity to IPS as a function of temporal frequency indicates that the majority of patients with abnormalities elicited by television viewing are sensitive to flash rates of 50 (49%) or 25 Hz (75%) (1). In the U.S.A., the television frame rate of 60 Hz results in display flicker components of 60 and 30 Hz. Laboratory studies indicate that only 15% of patients are sensitive to IPS at 60 Hz (1) and the incidence of television epilepsy is correspondingly lower in the U.S.A. than it is in Europe (17). This suggests that the use of a high frame-rate television (100 Hz) would decrease the probability of eliciting seizures in patients with photosensitive epilepsy. A television with a frame rate of 100 Hz will have flicker components of 50 and 100 Hz, the 50 Hz component being perceived only at short viewing distances. Patients sensitive to IPS at 25 and not at 50 Hz, may be at risk of seizures from a traditional (50 Hz frame-rate) television but not from a high frame-rate (100 Hz) television screen.

This study investigated the incidence of EEG abnormalities elicited by identical patterns displayed on television sets with 50 and 100 Hz frame rates. Sensitivity to the television displays was analyzed in terms of the sensitivity range to IPS. The contributions of pattern-sensitive and photosensitive mechanisms to television epilepsy were examined and the benefits of viewing a high frame-rate television were assessed.

METHODS

Subjects

Thirty-five patients with EEG abnormalities (photoparoxysmal responses and/or occipital spikes) to patterns displayed on a 50 Hz television were included in the study; 22 were female and 13 were male, giving a 1.7:1 female:male ratio, typical of photosensitive epilepsy (1). Many patients had been diagnosed previously as photosensitive, so although the majority had experienced their first photosensitive seizure in the established modal 7–19 years age range, the mean age was higher (mean 26, range 13–54). Photosensitivity persists throughout life in ~75% of patients (18) so it is unlikely that these patients form a sample significantly different from those presenting with their first photosensitive seizure. Twenty-six patients were receiving anticonvulsant medication, usually valproate (VPA), at the time of testing and 9 were seizure-free.

Procedure

All patients underwent EEG recordings to determine the presence of any spontaneous EEG abnormality. Patterns were generated by an SC Electronics T22 grating generator and displayed on two Philips televisions with frame rates of 50 and 100 Hz. The luminance of both screens was 190 cdm^{-2} and the displays subtended 18° horizontally by 14° vertically at a distance of 1.5m. The patterns comprised vertical square-wave and sine-wave gratings of 90% contrast and spatial frequencies 0.5, 1, 2, 2.5, 2.7, 3, 4, 6, and 7 cycles/degree. The gratings were onset from a blank screen with a square-wave temporal envelope and were presented first oscillating at 1 Hz, then stationary for periods of 15 s. All patterns were presented first on the 50 Hz display and then on the 100 Hz display. The patients fixated on a central marker for a period of 5 s, closed their eyes for 5 s and then opened their eyes and fixated the pattern for a further 5 s before the gratings were offset. This protocol was employed to differentiate between an abnormal EEG response to the pattern and abnormalities elicited by eye closure. Since the patterns used are inherently epileptogenic (3), the presence of EEG abnormalities while viewing the pattern was used as an indication of the patient being at risk of experiencing a seizure while viewing a television display whose content may also be epileptogenic. The period of viewing a blank screen of the same mean luminance but without the grating pattern provided an indication of the contribution of screen flicker to the observed abnormalities. IPS was performed according to our standard protocol (1) using a Grass PS22 photostimulator at a distance of 30 cm from the patient's eyes. The strobe subtended 25 degrees and the luminance was 1,363 cdm^{-2} (68 $cd.s.m^{-2}$). Flash frequencies of 1–60 Hz were tested both with (patterned IPS), and without (unpatterned IPS); the presence of a line grid as the addition of a grid has been shown to increase the incidence of EEG abnormalities in patients with a history of photosensitive epilepsy (1,4).

RESULTS

All patients showed EEG abnormalities to patterns displayed with a 50 Hz frame rate. The same gratings displayed with a 100 Hz frame rate did not elicit EEG abnormalities in 16 patients (46%). The EEG recorded to stationary sinusoidal gratings is shown in Fig. 1 for the 50-Hz and the 100-Hz displays. The abnormalities were attenuated in a further 16 (46%) patients (Fig. 2) and were unchanged in 3 (8%) patients (Fig. 3). Analysis of the results indicates that significantly fewer abnormalities were evoked by patterns presented on the 100 Hz-television than were evoked by the same patterns displayed on the 50 Hz-television (χ^2, 1, 70 = 20.74, $p < 0.0005$). No abnormalities were observed while patients viewed the blank screens.

The sensitivity range of each of the patients was determined for both patterned and unpatterned IPS. The results showed that 2 (6%) patients did not demonstrate EEG abnormalities at any of the frequencies tested (1–60

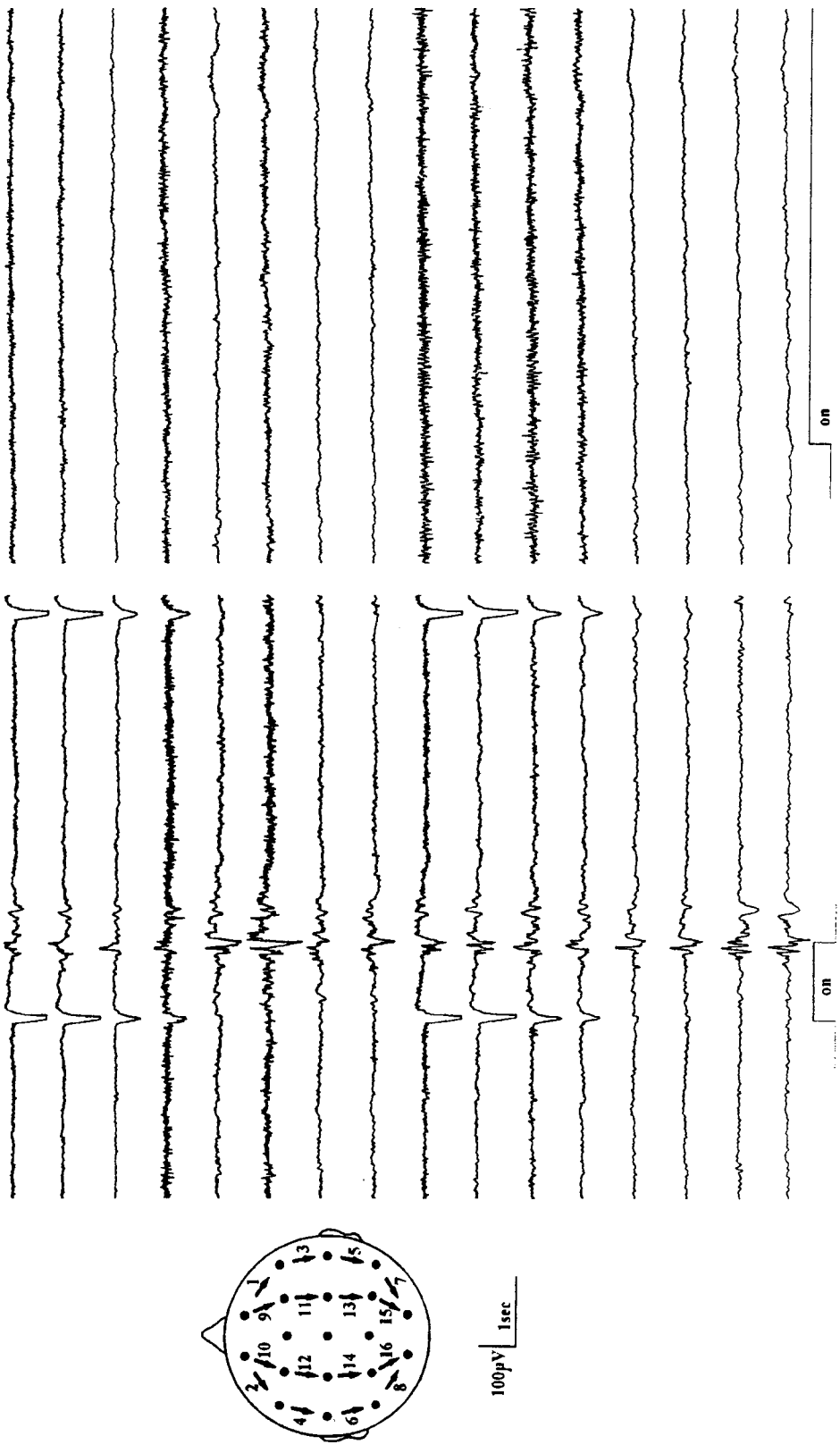

FIG. 1. The EEG recorded in response to stationary sinusoidal gratings of 2.5 cycles/degree displayed on television screens of frame rate 50 Hz **(left)** and 100 Hz **(right)**. The gain was 100μV/cm, the time constant was 0.3 s and the high-frequency filter was 60 Hz. The montage is shown on the left of the figure and the duration of the pattern presentation is indicated by the marker trace at the base of the figure. The pattern displayed on the 50 Hz television elicits a high-amplitude paroxysmal discharge, but the same pattern displayed on the 100 Hz television fails to elicit any abnormal EEG activity.

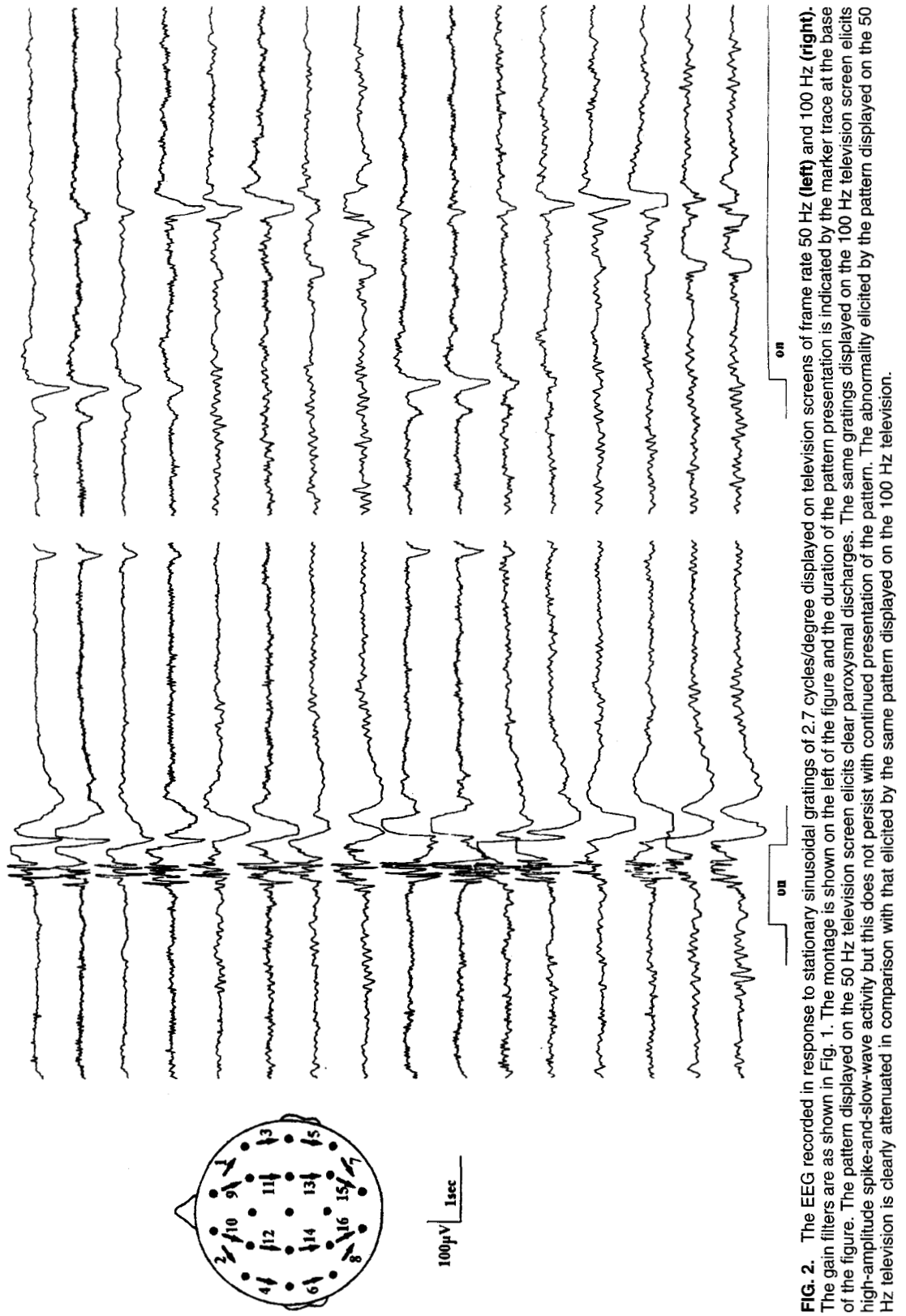

FIG. 2. The EEG recorded in response to stationary sinusoidal gratings of 2.7 cycles/degree displayed on television screens of frame rate 50 Hz **(left)** and 100 Hz **(right)**. The gain filters are as shown in Fig. 1. The montage is shown on the left of the figure and the duration of the pattern presentation is indicated by the marker trace at the base of the figure. The pattern displayed on the 50 Hz television screen elicits clear paroxysmal discharges. The same gratings displayed on the 100 Hz television screen elicits high-amplitude spike-and-slow-wave activity but this does not persist with continued presentation of the pattern. The abnormality elicited by the pattern displayed on the 50 Hz television is clearly attenuated in comparison with that elicited by the same pattern displayed on the 100 Hz television.

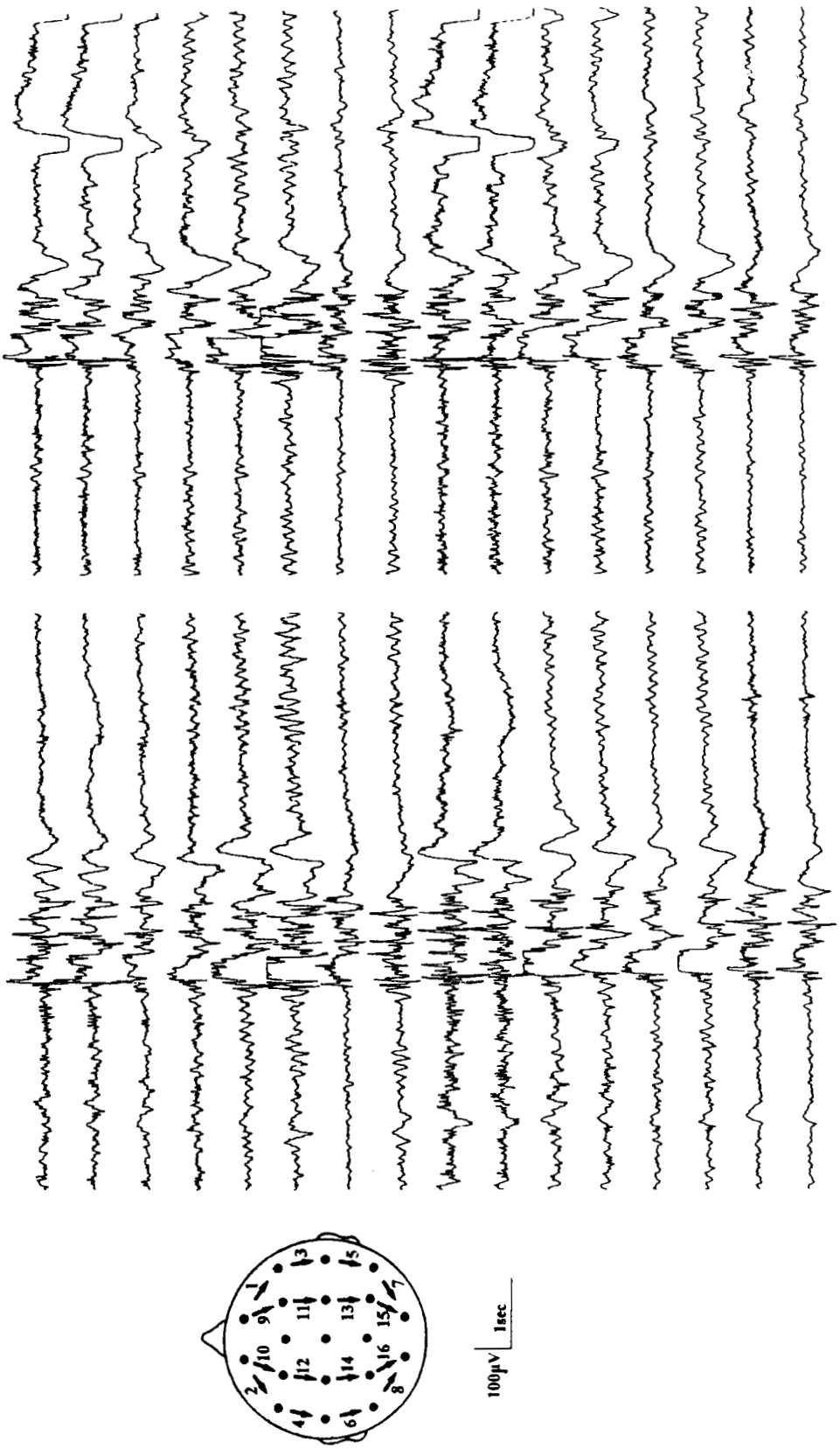

FIG. 3. The EEG recorded in response to stationary sinusoidal gratings of 4 cycles/degree displayed on television screens of frame rate 50 Hz **(left)** and 100 Hz **(right)**. The gain and filters are as shown in Fig. 1. The montage is shown on the left of the figure and the duration of the pattern presentation is indicated by the marker trace at the base of the figure. The pattern elicits high-amplitude paroxysmal discharges when presented on both television displays.

TABLE 1. *The incidence of laboratory-measured sensitivity to patterned and unpatterned IPS as a function of EEG abnormalities elicited by the 100 Hz and the 50 Hz frame-rate televisions*

	Abnormalities to the 100 Hz TV	No abnormalities to the 100 Hz TV
Sensitivity to 50 Hz patterned IPS	16	7
No sensitivity to 50 Hz patterned IPS	3	9
Sensitivity to 50 Hz unpatterned IPS	4	2
No sensitivity to 50 Hz unpatterned IPS	15	14

Hz), under either condition. Of the remainder, all 33 (94%) were sensitive to patterned IPS but only 15 (43%) were also sensitive to unpatterned IPS. These results indicate a significant increase in abnormalities elicited when IPS was performed with the presence of a line grid (χ^2, 1, 70 = 17.70, $p < 0.0005$). The effect of the grid was not dependent on age: the mean age of patients sensitive to the grid was 25 and that of those not sensitive to the grid was 26.

The abnormalities elicited by the 50 and 100 Hz televisions were analysed in terms of the patients' laboratory-measured sensitivity to patterned and unpatterned IPS at 50 Hz. The results, shown in Table 1, indicate that patients with sensitivity to patterned IPS at 50 Hz were significantly more likely to show EEG abnormalities while viewing the 100 Hz television than patients were who did not show sensitivity to patterned IPS at 50 Hz (χ^2, 1, 35 = 6.29, $p < 0.05$). The association was not significant for unpatterned IPS (χ^2, 1, 35, = 0.45, $p > 0.05$).

DISCUSSION

Thirty-five patients with EEG abnormalities elicited by grating patterns displayed on a 50 Hz frame-rate television were tested for abnormalities elicited by the same patterns displayed on a 100 Hz frame-rate television. Three patients showed similar abnormalities when the gratings were displayed on a 100-Hz television. A further 16 showed abnormalities that were attenuated in comparison to those elicited by the 50-Hz television. The remaining 16 subjects showed no abnormalities to patterns displayed on the 100-Hz television. Analysis of the results confirmed that there was a significant reduction in abnormalities elicited by the 100-Hz frame-rate television. Because the televisions were matched for field size and luminance and the gratings were of identical contrast and spatial frequencies, the results suggest that screen flicker present in the 50-Hz television contributes to the observed abnormalities. The flicker components of the 50-Hz television (50 and 25 Hz) result in television being a provocative stimulus for many photosensitive patients, particularly if the screen is viewed at short distances (4).

Photosensitivity was tested with IPS over a range of temporal frequencies spanning 1–60 Hz. Patterned IPS was significantly more provocative than unpatterned IPS, confirming previous reports of the increased incidence of EEG abnormalities when IPS utilizes such a patterned grid (1,4). This increase in abnormalities to patterned IPS may be due to the increased sensitivity of centre-surround receptive fields associated with cortical neurons to contours rather than to diffuse light (19,20).

These results show that patterned IPS is an extremely provocative technique and emphasise the importance of the use of a line grid during routine clinical testing for photosensitivity. At the time of testing, 24 patients were not well controlled and had experienced recent seizures or absences; these included patients sensitive to patterned but not to unpatterned IPS. Several additional patients experienced subjective sensations when viewing lights and patterns in the environment and were able to look away, thus avoiding a seizure. For patients with sensitivity restricted to patterned IPS experience seizures, the use of the line grid is unlikely to make IPS testing too sensitive; thus EEG abnormalities in response to photosensitive and pattern-sensitive testing do indicate a susceptibility to visually provoked seizures. Although the lack of sensitivity to unpatterned IPS could be due partly to the effective use of anticonvulsants, 5 patients with sensitivity to patterned but not to unpatterned IPS were not receiving medication. If anticonvulsant medication was indeed the cause of the lack of laboratory sensitivity to unpatterned IPS, this might indicate that different mechanisms underlie photosensitive and pattern-sensitive epilepsy. A thorough investigation of this hypothesis would require monitoring IPS sensitivity under both patterned and unpatterned conditions, and with and without medication; this will form the basis of further investigation.

Previous studies have indicated that patients with a history suggestive of video-game epilepsy may not demonstrate abnormal EEG responses to IPS in the laboratory (15). Although it has been demonstrated that the presence of a line grid increases the probability of EEG abnormalities being elicited by IPS in these patients, a small percentage are sensitive only to static or oscillating patterns displayed on a television and not to IPS (15). Thorough laboratory investigation of all sensitivity parameters is therefore critical for the identification of patients at risk for video-game epilepsy. Indeed, it should be noted that the EEG provides only investigative support for the clinical diagnosis of epilepsy: a negative result to IPS testing in the laboratory, particularly if only unpatterned IPS is performed, should not preclude the diagnosis of photosensitivity, or television- or video-game epilepsy.

The incidence of abnormalities evoked by patterns displayed on the 100-Hz television was analysed with reference to sensitivity to IPS at 50 Hz. The results showed a significant interaction between photosensitivity to 50 Hz patterned IPS and sensitivity to the 100-Hz frame-rate television. Patients sensitive to patterned IPS at 50 Hz were significantly more likely to show abnormalities to patterns displayed on the 100-Hz frame-rate television than were patients not sensitive to patterned IPS at 50 Hz. These results suggest a major role for photosensitivity in television epilepsy. However, patients viewed the television display at a distance of 1.5 m and were unlikely to have been able to resolve the interlaced screen lines. Furthermore, sensitivity to unpatterned IPS was not associated significantly with sensitivity to the 100 Hz frame-rate television. This contrasts with the results of Wilkins et al. (1979), who found an association between the maximum viewing distance in eliciting paroxysmal EEG activity and unpatterned, but not patterned, IPS. This difference may be attributed to the criteria for inclusion of patients in this study, including the presence of EEG abnormalities elicited by patterns displayed on a television, whereas not all patients described by Wilkins et al. (4) demonstrated such abnormalities. This selection procedure may have resulted in our sample being more sensitive to patterned stimuli than were those patients described by Wilkins et al. (4).

The inability of patients to be able to resolve the screen lines and the absence of a significant association between EEG abnormalities to unpatterned IPS and those to patterns displayed on the televisions suggest that photosensitivity cannot be solely accountable for the abnormalities elicited by the patterns. Indeed, 2 patients with EEG abnormalities to patterns did not show laboratory evidence of photosensitivity, and a further 5 patients, while showing laboratory evidence of photosensitivity, were not sensitive to IPS at either 25 or 50 Hz. For these patients, the nature of the pattern displayed may be more important than the flicker and the underlying mechanism of the observed abnormalities is more likely to be pattern sensitivity. Furthermore, the limited range of spatial frequencies eliciting an abnormality in many of the patients supports a provocative role for the pattern. It is possible that the presence of a flickering high-contrast edge (a combination of a high-contrast pattern and the raster) elicits the observed abnormalities. This suggestion is supported by the observation that none of the patients showed EEG abnormalities in response to a blank television screen of high luminance (190 cdm^{-2}). This contrasts with the high proportion of patients (18 of 21) described by Wilkins et al. (4) who showed abnormalities to a blank television screen; as described previously, this difference may be due to our selection criteria favoring patients with sensitivity to patterned visual stimuli. For the patients described here, the raster alone is unlikely to cause EEG abnormalities, but the combination of the raster and the pattern produces a provocative stimulus. For accurate identification of those patients at risk for pattern-sensitive epilepsy, EEG activity should be recorded in response to a pattern displayed on a flicker-free medium; this forms the basis of an additional investigation.

The results demonstrate that a 100-Hz frame-rate television evokes significantly fewer EEG abnormalities than a 50-Hz frame-rate television. Furthermore, the majority of those patients with EEG abnormalities that persisted when viewing the 100-Hz frame-rate television showed a reduction in sensitivity, either in the form of a reduced range of provocative spatial frequencies, or a reduction in the severity of the abnormality. For patients with photosensitivity to IPS at 50 and 25 Hz flicker rates, the value of a 100-Hz television in reducing EEG abnormalities is apparent. Although abnormalities in the EEG do not necessarily result in seizures, laboratory testing of photosensitive patients with epileptogenic patterns displayed on televisions may enable us to predict which patients are likely to remain at risk of television- or video-game epilepsy when viewing a high frame rate television.

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