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Video Material and Epilepsy

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Summary: Nine patients who had epileptic attacks while playing computer games were studied in the laboratory. Patients had an EEG recorded as well as their response to intermittent photic stimulation (IPS) at flash rates of 1–60 fps. In addition, pattern sensitivity was assessed in all patients by a gratings pattern. Only 2 patients had no previous history of convulsions, and only 2 had a normal basic EEG. All but 1 were sensitive to IPS, and all but 1 were pattern sensitive. Most patients were male, but although this appears to conflict with previously published literature results regarding the sex ratio in photosensitivity, it was due to the male predominance of video game usage. We compared our results with those reported in the literature. Diagnosing video game epilepsy requires performing an EEG with IPS and pattern stimulation. We propose a standard method of testing. **Key Words:** Epilepsy—Video games—Pattern sensitivity—Photosensitivity—Television—Electroencephalography—Intermittent photic stimulation.

Since 1985, there have been increasing reports of patients who have had convulsions precipitated by video material. Because both prerecorded video material displayed on domestic TV and video games have become widely available, this is not surprising; indeed, we predicted in 1979 such an increase in incidence (Wilkins et al., 1979).

Rushton (1981) first described an epileptic seizure induced by video games. Jeavons et al. (1981) next described the first case of attacks precipitated by a small handheld video game. Since then, 20 other patients have been reported in the literature. Some of those cases were reviewed by Maeda et al. (1990), who also reported 7 more patients.

Many investigators consider the condition to be an extension of photosensitive epilepsy (Daneshmend and Campbell, 1982; Dahlquist et al., 1983; De Marco and Ghersini, 1985; Hart, 1990; Cook and Hoskins, 1992) or, alternatively, a form of pattern-sensitive epilepsy (Jeavons et al., 1981; Harding, 1986; Maeda et al., 1990). Photosensitive epilepsy is a relatively rare condition with an incidence of 1:4,000 of the general population (Jeavons and Harding, 1975; Harding, 1980), with onset usually between the ages of 5 and 20 years, most commonly around puberty. It is characterized by a history of attacks precipitated by flickering and/or patterned stimuli; the most common precipitant (61%) is a TV set. However, sleep deprivation, stress, or other causes of lowered convulsive threshold may be involved (Dahlquist et al., 1983; Wong et al., 1983; De Marco and Ghersini 1985; Henchey and Gilmore, 1993).

Video games epilepsy has similarities to photosensitive epilepsy. The most common precipitant is the domestic TV set (used as a computer monitor). The mean age of onset is around puberty, and age range of 4–17 years, except for one case of post-traumatic epilepsy and one case of drug withdrawal (both patients aged 32 years). However, the male/female sex ratio is 4.7:1 for video game epilepsy (Maeda et al., 1990) and 1:1.7 for photosensitive epilepsy (Jeavons and Harding, 1975).

We reviewed >600 patients with photosensitive epilepsy whom we had examined in the EEG laboratory (Jeavons et al., 1985) and identified those clinically reported to have had convulsions associated with viewing video games.

MATERIAL AND METHOD

Nine patients were identified as having attacks while playing video games: 6 boys and 3 girls. Age range at the time of the initial attack was 12–15 years, but 1 of the patients, after a 6-year interval, had a further attack with a different form of game. One other boy had a further attack, using a different form of game, 2 years after his initial attack. All

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patients had a comprehensive EEG investigation. Routine EEGs included hyperventilation.

Intermittent photic stimulation (IPS) was performed according to our standard method (Jeavons and Harding, 1975) using a Grass PS22 photostimulator at a distance of 30 cm from the patient's eyes. At this distance, the visual angle subtended was 25°. The intensity of the stimulus was 1,363 cd/m^2. All investigations were initially performed with IPS at each specific flash rate for 5 s with eyes open, followed by eye closure, and 5 s more with eyes closed. If a photoparoxysmal response in accordance with our standard definition was evoked [i.e., widespread bilateral and involving anterior and posterior regions and consisting of the following responses: (a) bursts of spike and wave activity, usually with a slow component at 3 Hz; (b) bursts of high-amplitude theta waves (4–7 Hz) with spikes; (c) bursts of polyspike or polyspike and wave; (d) bursts of spikes at the same rate as the flash but distinguished from occipital spikes because they extend into the anterior regions; (e) discharges of 3-Hz spike and wave activity lasting >5 s after the flashing has ceased and associated with a clinical absence; (f) bilateral high-amplitude slow waves without spikes observed in all regions (Jeavons and Harding 1975)], stimulation was immediately discontinued and was reinitiated for 2-s periods only, with eyes either open or closed. In addition, for most patients, pattern sensitivity was tested with a SC Electronics T22 Gratings Generator with a Hitachi video monitor. The patient sat 1 m from the set, which subtended a visual angle of 20° horizontally and 15° vertically. The stimuli consisted of vertical black and white square-wave gratings with a contrast of 96%. The gratings could be presented either stationary and appearing from a gray background; alternatively, they could be made to reverse at a reversal rate of 1 Hz. The spatial frequency of the gratings could be varied in steps between 0.5 and 6 cpd. The luminance of the white grating was 90 candelas/m^2, and each stimulus was provided for a 10 s or was discontinued earlier if a photoparoxysmal response occurred. The effect of monocular occlusion was also assessed. If the patient wore glasses, care was taken to ensure that the glasses were correctly refracted for the distance being used. In some cases, testing was also performed with the patient's own video games in the laboratory.

RESULTS

Case 1

A 15-year-old boy had played computer games for 1 year before experiencing a tonic-clonic convulsion while watching the monitor. He had no previous history of convulsions. Investigation in our department showed that he had experienced minor attacks involving his right hand and confusion when trying three different computers at a computer exhibition. His EEG showed a left-sided slow wave abnormality with occasional spike elements. He was sensitive to IPS at flash rates of 17, 35, 50, and 55 fps but was not sensitive at 25 fps. He was also pattern sensitive to spatial frequencies between 1 and 2.5 cpd. He was successfully treated with valproate (VPA) and his EEG became normal. However, due to noncompliance, he had another tonic-clonic seizure 6 years later when playing a car-driving game in a video game arcade.

Case 2

A girl who had a tonic-clonic seizure at age 12 years while playing a computer game had previously had a nonpyrexial attack age 1 year. An EEG 1 year later showed polyspikes and waves. She continued to have seizures and was treated with phenobarbital (PB) and epanutin. Her EEG remained abnormal, and she continued to have daily episodes of eyelid flickering despite treatment with VPA, ethosuximide (ESM), and carbamazepine (CBZ). In 1984, she had a tonic-clonic seizure while playing a computer game. Her EEG showed brief bilateral discharges of spikes and waves, and IPS showed photosensitivity at flash rates between 1 and 43 fps. Pattern stimulation showed sensitivity between 0.76 and 1.25 cpd.

Case 3

A boy who had his first definite attack while playing a video game at age 14 years had previously experienced a possible attack 4 years earlier, but an EEG performed at that time at a different hospital was normal. Because he had had two tonic-clonic seizures while playing a computer game using his home TV as a monitor at a distance of 3–4 feet, he was treated with VPA 500 mg twice daily. Three weeks later, his EEG in our laboratory was entirely normal, but pattern sensitivity was not tested at that time. Subsequently, he was tested when viewing specific sequences of the video game (Fig. 1). He was shown to be sensitive to the spatial frequency contained in a street grid pattern (1.50 cpd). No other game sequence produced this abnormality.

Case 4

A boy aged 15 years reported by Jeavons et al. (1981) had had an attack while playing a "Space Invaders" game on a handheld monitor. He had no previous history of attacks. His basic EEG showed some spike and slow wave discharges, more

1A

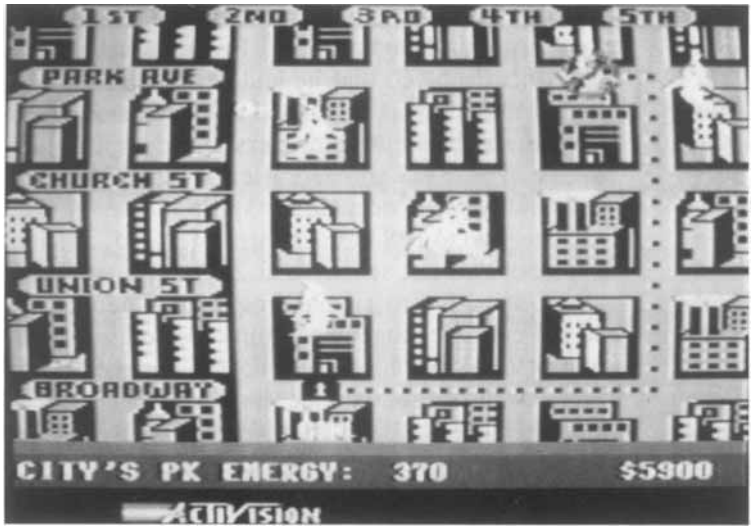
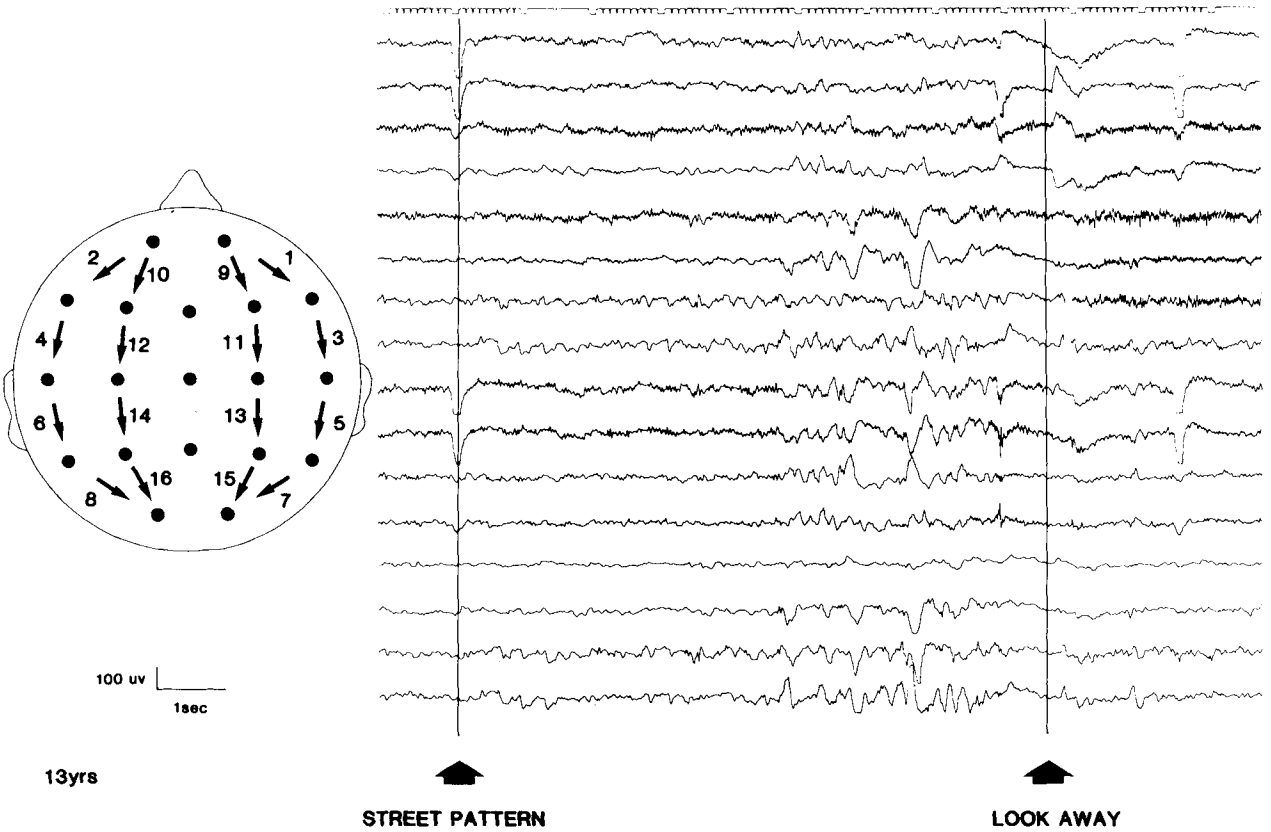


FIG. 1. A: Street map pattern on the "Ghostbusters" game. The map consists of a grid, which when presented produced abnormal responses in the EEG of case 3 **(B).** When the patient began to look at the street pattern, occipital spikes appeared after ~4 s, followed by a photoparoxysmal response that persisted until he was told to look away. No other video sequence on the game material produced any abnormalities.

1B



marked on the left. He showed photoparoxysmal responses (PPR) at flash rates between 15–18 fps. Pattern sensitivity was tested at the time at spatial frequencies between 0.38 and 2.7 cpd, but sensitivity was only mild at the latter spatial frequency. It is unfortunate that at that time checkerboards rather than gratings were used; the calculation of spatial frequency took this into account. He was subsequently treated with VPA, which normalized the EEG, but 2 years later, after discontinuation of the drug by his general practitioner, he had a tonic-clonic seizure while playing a video game on a domestic TV. At that time, IPS showed minimal abnormality to 30 and 50 fps. Reinstitution of VPA treatment was recommenced.

Case 5

A boy aged 14 years who had several attacks while playing computer games had had a tonic-clonic seizure at age 5 years, and his EEG showed a rolandic spike focus. Five years later, he had several attacks, all occurring in early morning. His ba-

sic EEG at the time showed spike and wave activity, and IPS showed sensitivity between 15 and 50 fps. Two years later, he had a seizure during sleep, and his EEG showed spike and wave activity and a photosensitive range from 9 to 15 fps. After having attacks 2 years later while playing computer games, he was again examined. His basic EEG showed only minimal abnormality, and he was consistently sensitive to IPS at 50 fps, but showed variable responses between this frequency and 20 fps. When investigated for pattern sensitivity, he showed no abnormality to any spatial frequency of pattern, but did show a response to the blank screen. Questioning showed that he enjoyed the blank screen and interference patterns when inserting a new game, and that he approached the screen to induce an attack. He has subsequently been treated with VPA.

Case 6

A girl aged 15 years who had had five attacks while close to the TV had two of these attacks at home while playing a "Terminator" game on her TV. She had a previous history of absence attacks since age 6 years satisfactorily treated with VPA. EEG investigation showed her to be photosensitive. Later, she discontinued VPA; she returned to the emergency department after a TV-induced attack. The size of the TV screen was 14 inches. Her basic EEG showed occasional brief atypical spike and wave discharges, and she had PCR at flash rates between 11 and 56 fps. Pattern sensitivity testing showed her to be sensitive to a wide range between 0.53 and 5.0 cpd. In addition, monocular occlusion provided safety only when her right eye was covered.

Case 7

A boy aged 14 years who had a previous history of seizures from age 7 years was impulsively attracted to the TV and whenever he went near it the television he had a generalized seizure. The condition was diagnosed at the time as photosensitive epilepsy. Later, he appeared to be having early morning myoclonic jerks. Attacks were induced when he played an "Atari Test Drive" game, in which the presentation was a view through a windscreen of a car being driven in and out of dark tunnels. Although this computer was being used with a Phillips monitor, the latter was shown to be a switchable TV system. His EEG showed evidence of brief spike and waves associated with minimal myoclonic jerks; in addition, he was photosensitive at flash rates between 45 and 55 fps. Pattern testing could not be performed at the time.

Case 8

A boy who had a previous history of photosensitivity and was a third-generation member of a photosensitive family previously studied by us (Jeavons and Harding, 1975) had had problems when approaching a television set and had had several generalized seizures. When playing a computer game on a Spectrum computer using a TV monitor at a friend's house, he had a generalized seizure. He played several games, including "Atari Test Drive" and "Sonic I," without having attacks, although he experienced a subjective sensation to the checkerboard pattern in the latter game. A year later, when playing an arcade game, he had another generalized seizure; since then he has avoided playing arcade games. His EEG was normal, and he was not sensitive to photic stimulation, but was very pattern sensitive to patterns at 2.5 cpd.

Case 9

A 13-year-old girl who had a previous history of photosensitive attacks while watching TV at age 7 years had an impulsive attraction to TV. She played games on a Gameboy handheld unit with no problems and has also played games using a friend's TV without difficulty. However, on a visit to a store, she played "Sonic II" on a demonstration unit and had a generalized seizure after 2 min. Her EEG showed some left occipital spikes, and she was photosensitive at flash rates between 8 and 56 fps. She was also markedly pattern sensitive between 1 and 2.5 cpd. (Fig. 2).

EEG results

The results of the EEG investigation of basic record, IPS, and pattern testing on the 9 patients are summarized in Table I.

DISCUSSION

The patients whom we examined all had convulsions precipitated by playing video or computer games. Six had a previous history of epilepsy. Only 2 had a normal basic EEG, and only 3 were female. This profile distinguishes them from the 460 patients with photosensitive epilepsy described in our study. In that study, there was a clear female predominance (1.7:1) in almost every subgroup except those who showed impulsive attraction to TV (1:1.14). It has been suggested that boys are more inclined to play video games than girls (Maeda et al., 1990). We investigated this suggestion with the aid of Sega (Europe), who placed their marketing information at our disposal; according to their survey, 82% of game players were male. Correcting therefore for the photosensitive population sex ra-

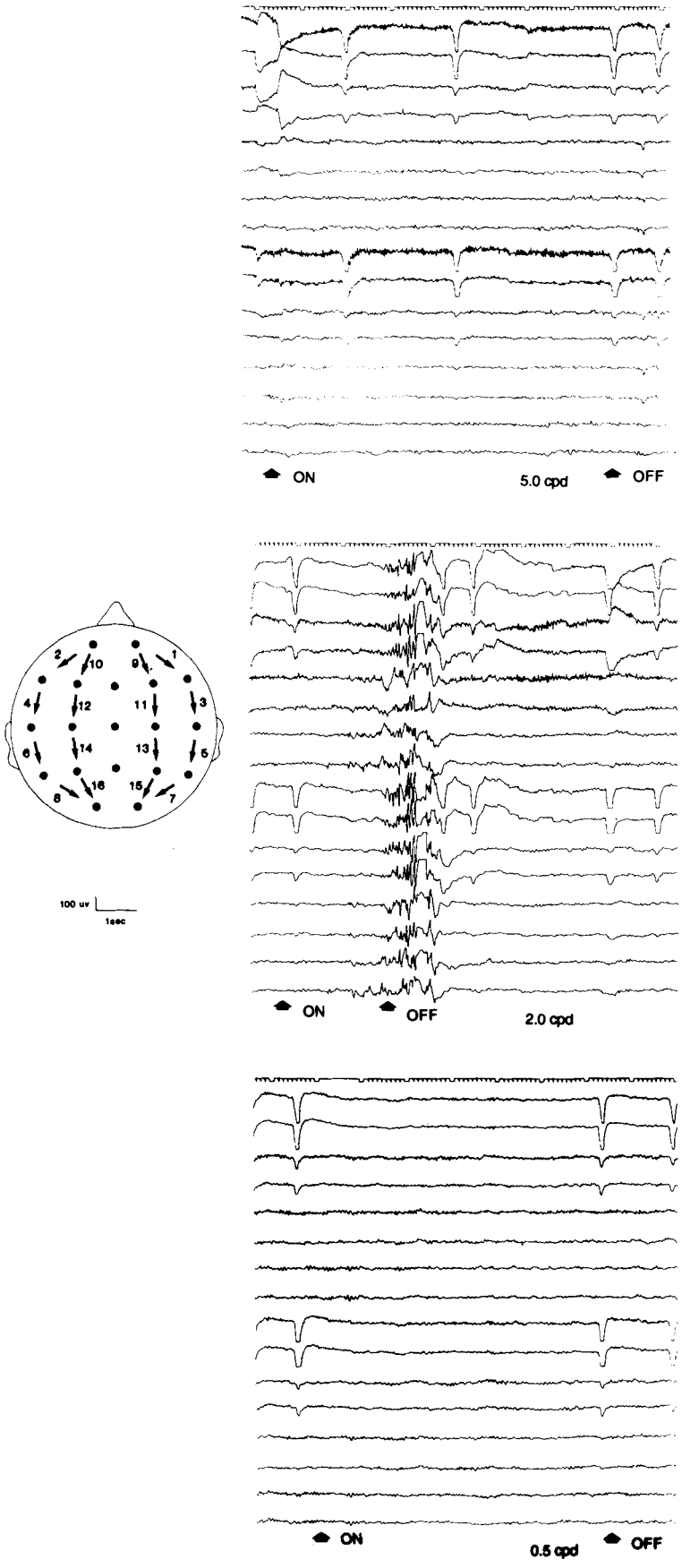


FIG. 2. EEGs recorded from case 9 during presentation of vertical square-wave black and white gratings of high contrast at three spatial frequencies. **Top:** Stimulation at 5 cpd produced no abnormality in either the stationary or reversing condition. At 2 cpd, even with the gratings stationary, a clear photoparoxysmal response occurred and stimulation had to be discontinued prematurely. **Bottom:** Stimulation at 0.5 cpd in either stationary or reversing mode failed to evoke abnormality. EEG derivations shown **(center, left)** were the same for all three conditions for which the response to stationary stimulation is shown.

TABLE 1. *Patients in the literature and the present study*

Reference Age (yr)/sex	Clinical history	Basic EEG	Photo-sensitivity (fps)	Pattern sensitivity (cpd)	Game sensitivity	Video game	Monitor
Ruston, 1981							
17/M	Febrile convulsion	Normal	None	Not tested	Not tested	"Astro Fighter"	Arcade
Jeavons et al., 1981							
15/M	None	Spike and wave L	15–18	Chequerboard 0.38–2.7	Yes	"Space Invaders"	Handheld game[a]
Daneshmend and Campbell, 1982							
17/F	None	Normal	15–21	Not tested	Not tested	"Dark Warrior"	TV
Dahlquist et al., 1983							
15/M	None; later photosensitive epilepsy to environmental stimuli	Basic normal spike and wave during sleep and on awakening	15 and 20	Not sensitive to geometric patterns	No abnormality	1. "Combat" 2. "Pac-man"	TV (60 Hz)
Helfgott and Meister, 1983							
8/M	None	Spike and wave L	Not known	Not tested	Not tested	Not known	Arcade
Glista et al., 1983							
14/M	None	Spike and wave	None	Not tested	Not tested	"Intellivision" game	TV (60 Hz)
15/M	None	Normal	None	Not tested	Not tested	"Turbo"	Arcade
Wong et al., 1983							
32/M	Severe head injury	Normal	Not known	Not tested	Not tested	Not known	TV (60 Hz)
De Marco and Ghersini, 1985							
8/M	None	Not reported	10–25 fps	Not tested	Not tested	"Space Invaders" and other	TV
13/M	None	Left occipital spikes	None	Not tested	Not tested	Not known	TV
Ferry et al., 1986							
12/M	Not given	Not reported	Not reported	Not reported	Not reported	"Chopper"	Not reported
Ambrosetti and Tassinari, 1987							
32/M	Previous history of epilepsy; VPA discontinuation	Normal	20; no further details	Not tested	Not tested	Not known	Not known
16/F	Previous history of epilepsy; VPA withdrawal discontinuation	L sharp waves	Convulsive responses; no further details	Not tested	Not tested	Not known	TV
Hart, 1990							
13/F	None	Normal?	8–16; not total test	Not tested	Not tested	"Super Mario Bros"	TV (60 Hz)
Maeda et al., 1990							
7/M	None; later tonic-clonic	Occipital slow waves	3–30[b]	Checkerboard	Yes	"Super Mario Bros"	TV[c]
10/F	Migraine?	Occipital slow waves	12–30[b]	Checkerboard	Yes	"Link's Adventure Quest"	TV[c]
12/F	Migraine?	Normal	None	None	Yes	"Dream Factory"	TV[c]
4/M	Febrile convulsions	Normal	None	Not tested	Yes	"Wrecking Crew"	TV[c]
12/M	Migraine	Normal	15–30[b]	Checkerboard occipital spikes	Not tested	"Links Adventure Quest"	TV[c]
13/M	None	Normal	12–30[b]	Not tested	Not tested	"Hydlide"	TV[c]
9/M	None	Normal	3–30[b]	Not tested	Not tested	"Dragon Quest 2"	TV[c]

TABLE 1—(*Continued*)

Reference Age (yr)/sex	Clinical history	Basic EEG	Photo-sensitivity (fps)	Pattern sensitivity (cpd)	Game sensitivity	Video game	Monitor
Cook and Hoskins, 1992							
11/M	None; later photosensitive	Normal	9–16	Not sensitive to geometric pattern	"Super Mario 2" flash sequence	"Super Mario 2"	TV
17/M	None	Normal	11–20	Not sensitive to geometric pattern	"Super Mario 2"	Super Mario 2"	TV
Henchey and Gilmore, 1993							
17/M	L anterotemporal lobectomy	Occasional L temporal sharp waves	Normal	Not tested	Not tested	"Nintendo"	TV
Thompson, 1993							
15/M	Febrile convulsion	Normal	None	Not tested	Not tested	Not known	Arcade
Harding et al., present study							
15/M	None	L spike and wave	17, 35, 50, 55	1–2.5 cpd	Not tested	Not known; "Car Race"	TV, arcade
12/F	Epilepsy	Spike and wave	14–43	0.76–1.25	Not tested	Not known	TV
14/M	Single convulsion	Normal	None	1.5 cpd	Yes; street grid only	"Ghost Busters"	TV
15/M	No previous history	Spike and wave	15–18	0.38–2.7 cpd (checker-board)	Not tested	i) "Space Invaders"	Handheld
						ii) Not known	TV
14/M	Epilepsy	Spike and wave	15–50	None	None	Blank screen between games	TV
15/F	Epilepsy	Spike and wave	11–56	0.53–5.0	Not tested	"Terminator"	TV
14/M	Epilepsy	Spike and wave	45–55	Not tested	Not tested	"Atari Test Drive"	TV
13/M	Previous history of photosensitivity	Normal	None	2.5 cpd	Not tested	1. "Spectrum" game	TV game
						2. Not known	Arcade
13/F	One previous TV attack	L occipital spikes	8–55	1–2.5 cpd	Not tested	"Sonic the Hedgehog II"	TV (store demo)

VPA, valproate.
[a] Later had a convulsion while playing computer game using TV monitor.
[b] Maximum frequency tested: 30 fps.
[c] Mains frequency in Japan is either 50 or 60 Hz depending on location.

tio, the expected ratio of male to female video game patients should be 2.38:1. Table I shows all known cases in the literature and in this study: The male:female ratio is 2.75:1. Therefore, this group is not distinguished from the general photosensitive population by gender.

In our original study, spikes and waves were observed in the basic EEG of just more than half the patients (259), a proportion matched by those in the literature, whereas spikes and waves were observed in the basic EEG in all but 2 of the patients in the present study. The exceptions were patients who also differ from the larger group in that they do not show PCR in response to IPS. These patients may highlight a further stimulus factor in this group, and 8 other patients described in the literature were reported not to be laboratory photosensitive (Table 1). All but 1 of the patients tested were sensitive to pattern stimuli, and in each case sensitivity was present at ~1–2.5 cpd. Only 3 patients were tested for video-game sequence sensitivity, and sensitivity to specific sequences could be demonstrated in 2. For the third patient, a blank screen was used as the photoparoxysmal precipitant. Most patients reported in the literature were not tested for pattern sensitivity.

Six of the patients were sensitive to 50 or 25 fps. The first flash rate is the rate of flicker on most domestic TV sets in Europe and represents the mains or line frequency; the second is the frequency observed in the alternate lines of the two-line interlace. In our previous studies, we showed that 49% of patients are sensitive at 50 fps and 75% are sensitive at 25 fps (Jeavons and Harding, 1975; Harding, 1980). Wilkins et al. (1979) showed that a clear relation exists between sensitivity to IPS at either

50 or 25 fps and the viewing distance from the TV at which paroxysmal discharges are produced; they also showed that patients who were sensitive to 50 fps were sensitive to TV at a ≥1-m viewing distance, but that those who were sensitive at flash rates <50 were sensitive only at close viewing distances. In addition, they conclusively demonstrated that it was the visual angle of the interlaced lines that was the critical factor in these patients, not the increased retinal angle subtended by the TV screen. Oscillating patterns are also more likely to produce PCR than either stationary or drifting patterns (Binnie et al., 1985), and the interlacing of the lines on the TV, with their alternating brightness, provide exactly that stimulus. Equally, the frequency of the interlace oscillation is close to the optimum frequency (15–20 Hz) of pattern oscillation (Binnie et al., 1979).

Therefore, domestic TV apparently provides almost optimum conditions for provoking photosensitivity, particularly if viewed closely. Many individuals appear to view the set more closely when playing video games than when viewing broadcast or videotape material. However, our findings leave little doubt that patients are also provoked by specific patterns present in the video material, and similar findings have been reported in studies in which this feature has been tested (Table 1); only 2 of the patients tested in the laboratory for sensitivity to game material failed to show abnormal responses in EEG. One of these patients was shown to be impulsively attracted to the blank screen and was sensitive to 50 fps (case 5).

Two other factors are of interest (Table 1). In many patients, attacks are caused by non-TV stimulators, i.e., handheld monitors and arcade monitors. Because such monitors do not involve interlace generation of the image, such patients probably are sensitive to specific video patterns or, in the case of arcade games, to the mains or line frequency of flicker. It is unfortunate that most of them were not tested for pattern sensitivity. Furthermore, many patients are reported to have attacks precipitated by playing video games on U.S. 60-Hz TV. We cannot differentiate in this way the cases of Maeda et al. (1990), since the frequency of the mains frequency in Japan is either 50 or 60 Hz depending on location; 15% of the photosensitive population are sensitive to 60 fps (Jeavons and Harding, 1975).

The literature results and our own clearly show that our previous recommendation (Jeavons and Harding, 1975) of testing for photosensitivity requires modification. Although pattern sensitivity occurs in ≤70% of photosensitive patients (Wilkins et al., 1979, 1980), it is rare in isolation (Panayiotopoulos, 1979; Matricardi et al., 1990). Two of our patients (cases 3 and 8) clearly demonstrated laboratory sensitivity to specific patterns, however, and were not sensitive to IPS. We therefore recommend that laboratory testing should include testing to high-contrast black and white square-wave grating patterns at spatial frequencies between 0.5 and 6 cpd, displayed on monitors at mains frequency in both the stationary and reversing conditions. In addition, in any situation in which specific video material is believed to precipitate an epileptic attack, the effect of this stimulus should also be tested in the laboratory.

One should not assume that provocative video material is restricted to that used in computer games. Recently, specific advertising material with high rates of image change of high-contrast stimuli has induced similar attacks (ITC, 1993). The provocation was successfully removed by changing the material to an image change rate <3/s and by ensuring that the stimulus material was close to isoluminance. Similar modifications could be applied to video material in computer games to remove or reduce the photoparoxysmal risk. We consider either avoidance of the stimulus, monocular viewing (Jeavons and Harding, 1975) or, alternatively, VPA treatment (Harding et al., 1978) the only effective therapies.

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