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Video games are exciting: a European study of video game-induced seizures and epilepsy

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We were deeply saddened by the death of our dear colleague Stefano Ricci in January 2000.

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ABSTRACT – Background: Video game seizures have been reported in photosensitive and non-photosensitive patients with epilepsy. The game Super Mario World, has led to many cases of first seizures. We examined whether this game was indeed more provocative than other programs and whether playing the game added to this effect.
Methods: We prospectively investigated 352 patients in four European cities, using a standard protocol including testing of a variety of visual stimuli. We correlated historical data on provocative factors in daily life with electroencephalographic laboratory findings.
Results: The video game, Super Mario World proved more epileptogenic than standard TV programs and as provocative as programs with flashing lights and patterns. Most striking was the fact that video game-viewing and-playing on the 50 and 100 Hz TV was significantly more provocative than viewing the standard program ($P < 0.001$, $P < 0.05$ respectively).
Playing the video game Mario World on a 50 Hz TV, appeared to be significantly more provocative than playing this game on the 100 Hz TV ($P < 0.001$).
Of 163 patients with a history of TV-, VG- or CG-seizures, 85% of them showed epileptiform discharges in response to photic stimulation, 44% to patterns, 59% to 50 Hz TV and 29% to 100 Hz TV.
Conclusions: Children and adolescents with a history of video game seizures are, in the vast majority, photosensitive and should be investigated with standardised photic stimulation. Games and programs with bright background or flashing images are specifically provocative. Playing a video game on a 100 Hz TV is less provocative [published with videosequences].

With the widespread introduction of video games (VGs) for home entertainment, an increasing number of case histories of video game epilepsy have been reported [1-6]. Following massive sales of video games as Christmas presents in 1992, numerous cases of video game epilepsy began attracting media attention in January 1993. These incidents were particularly attributed to the Nintendo video game *Super Mario World*.

Until now it has not been made clear whether specific video games (such as *Super Mario World, being still one of the most popular VGs for home-entertainment*) provoked epileptic seizures in susceptible children or whether this was purely coincidental or dependent on the properties of the television screen that the game is played on.

VG seizures are reported to occur most often in boys of about ten years of age, while visual-sensitive patients are predominantly female adolescents. Epilepsy in general has the highest incidence among children, and the occurrence of a seizure whilst playing a video game could thus be a coincidence. Non-specific epileptogenic factors, such as fatigue or stress may also be involved. However, there are several reasons suggesting that most of these children belong to a group of susceptible, visual-sensitive epilepsy subjects. First, the majority of children playing video games sit very close to the TV set and sensitivity to the epileptogenic effects of television increases with proximity [7]. This is partly a function of the area of retina that is stimulated but, at close viewing, subjects who are not sensitive to flicker at the screen refresh frequency (60 Hz in North America and parts of Japan, and 50 Hz in Europe), may react to the 30/25 Hz alternating pattern of the raster [8, 9]. Secondly, most of the patients with video game-induced seizures appeared not only to be sensitive to intermittent photic stimulation (IPS) in the laboratory, but also had a clear history of other visually-induced seizures, such as sunlight shining through the trees and television screens in general.

In addition, certain images presented on the television screen, such as slowly moving patterns and bright static images, appear to be especially epileptogenic [10, 11]. This effect is more pronounced on a 50 Hz television screen than on a 100 Hz screen.

Studies that considered this issue performed so far, either included small numbers of patients (monocentric studies) or else used different photic stimulation and video game testing procedures with various interpretative criteria (multicentric studies [3, 10, 12]). Therefore, no firm conclusions could be drawn concerning the impact of the video games themselves [13]. In this multicenter and multinational clinical study, we examined whether the video game *Super Mario World* was more provocative than other programs and whether playing the game adds to this effect. We also wanted to correlate historical data on provocative factors in daily life, such as television seizures and pattern-evoked seizures in general, with laboratory findings in order to establish the usefulness of encephalographic investigations in patients with a history of video game seizures.

Methodology

General

Because a controlled clinical trial with randomisation and blinding was not feasible, we chose a more empirical and descriptive design, which allowed for investigation of a large group of patients and generalisation of the results. All participating centres had specific interests, experience and knowledge with regard to visual sensitivity and epilepsy. Historical data were compared with investigational EEG data. Furthermore, extensive testing of patients with simultaneous EEG recording allowed patient comparisons of the different programmes in order to establish the impact of the various programmes with respect to their provocative effect.

Subjects

The study was performed in three countries (the Netherlands, Portugal and Italy) and at four sites. The study population comprised patients referred for EEG investigation, because of either of a history of VG or of other visually-induced seizures or of complaints such as eyelid-myoclonias, loss of consciousness, visual aura, epigastric sensations, dizziness, nausea. Such complaints represent in fact, seizures that were not recorded on EEG, whether or not they had a known sensitivity to IPS. All eligible patients capable of co-operating were invited to take part on the basis of informed consent. No other selection criteria were used.

Methods

A standardised history was taken and patients and carers were asked specifically about any relationship of seizures to:

(i) watching television, the effects of distance, the type of screen, and the program content;

(ii) playing electronic screen games, the effects of the viewing distance, the display device;

(iii) the games software used, the type of game, the time spent playing the game;

(iv) environmental flicker: sunlight, discotheque lighting, etc.;

(v) environmental pattern: venetian blinds, escalators, striped fabrics, etc.;

(vi) general precipitating factors: sleep deprivation, stressful events, etc.

The same standardised methods of EEG investigation (with a total duration of approximately one hour) were used, with a routine examination followed by:

(i) photic stimulation (Grass PS 33 photo-stimulator at 30 cm from the patient's eyes, separate trains of flashes of between 2 Hz and 60 Hz during eye closure and with eyes closed and open [9]);

(ii) linear static pattern stimulation (circular cards of 6, 13, 26 and 48 degrees visual angle with black and white hori-

zontal and vertical stripes of a spatial frequency of two cycles per degree, contrast 0.7 [8];
(iii) television programs and video game testing (a 50 Hz and 100 Hz Philips colour television at distances of 2 m, 1 m and 0.5 m, two minutes per test item and with resting periods in between) [14].
Four conditions per patient were then compared:
1. viewing a pre-recorded standard program without any flashing sequences exceeding three flashes per second;
2. viewing a potentially provocative program (a video clip, cartoon, or commercial);
3. observing the Nintendo video game *Super Mario World*;
4. actively playing the same game.
The least provocative programs were generally static, without bright geometrical patterns or potentially epileptogenic flicker frequencies, and were checked (by CD Binnie) for compliance with the draft guidelines of the British Independent Television Authority. The most provocative program (video clips, cartoons, and commercials) consisted of fast-moving images, changes in colours and/or high contrast geometrical patterns. None of the programs contained deep red flicker [15]. To gain and keep attention of the patients the standard and most provocative programmes were in the native languages of each patient. Analysis of the EEG was performed separately in each centre, using the same proforma. Both the historical and investigative data were gathered (questionnaire) and combined in a specifically designed database, the overall analysis of which was performed in one centre. Workshops were held to check uniformity of methodology and data input.

Statistical analyses

The software package SPSS version 10.0 was used.The independence of row and column variables in cross-tabs was tested using the Pearson Chi-square test. In order to test the null hypothesis that the measured threshold distances for the various TV programs came from the same population, Friedman's rank test was performed. The difference between pairs of programs was tested by the Wilcoxon signed rank test. Conservative Bonferroni correction for multiple testing was used to establish significance (alpha = 0.05, two-tailed).

Results

Clinical history

A total of 352 patients were investigated: 183 in the Netherlands, 90 in Portugal, 52 in Rome and 27 in Bologna, Italy. Of these patients, 59% (209) were female. The largest number of patients (34%, 119) were between 13 and 18 years old at the time of investigation. *Table I* gives the details of age and sex, and anti-epileptic medication, usually valproic acid (VPA).

Table I — Patient characteristics by site (%)

	SITE				
	Bologna	Rome	Heemstede	Porto	Total
Number of patients	27 (8)	52 (14)	183 (52)	90 (26)	**352 (100)**
Sex (m/f)	12/15	21/31	70/113	40/50	**143/209 (41)/(59)**
Age					
0-12 yrs	–	19	38	11	**68 (19)**
13-18	11	25	57	26	**119 (34)**
19-30	14	8	51	42	**115 (33)**
> 30	2	–	37	11	**50 (14)**
Anti-epileptic medication	18 (8)	30 (13)	115 (48)	74 (31)	**237 (67)**

In *table II*, the seizure history of all patients is given. It was found that 83% (294) had a history of epileptic seizures, and visually-induced seizures were found in 76.5% (225) of those with a seizure history (294). Television was the provocative stimulus most frequently reported (48%, 140); VGs were implicated in 15% (45) and CGs in 10% (28). Although multiple, provocative visual stimuli (such as sunlight, disco, artificial light, or patterns)) were often reported (52% of the 163 patients), many (48% of these 163) had suffered (first) seizures related to only one type of visual stimulus. A total of 17 patients had a history of VG seizures (10) or CG seizures only (7), and one a combination of the two. In the other 40 VG and /or CG cases, multiple visual stimuli were reported as being provocative.
The others patients without a clear seizure history (58 or 17%) either had complaints about visual stimuli or were found to be IPS-sensitive by coincidence on an EEG performed because of a family member with epilepsy, learning problems, headache or epilepsy in general. A small majority (59% of the 308 patients with information about their habits) had never played VGs, 1% only once, 32 occasionally, and 8 frequently. Computer games (CG) were used less frequently: 67% (206 of the 308) stated that they had never used CGs, 2% "once", 23% "sometimes" and 8% "often". Thus, more patients had experience with VGs (41%) than with computer games (33%).

Laboratory investigations

Sensitivity to IPS was demonstrated in 85% of all patients: they demonstrated generalised, or in a small minority focal, epileptiform activity *(table III)*. Pattern sensitivity was demonstrated in 38% of patients (92/244). Forty-six percent of patients (162/352) proved to be sensitive to a 50 Hz television for either the standard television program, the *Super Mario* video game or the provocative program. For the same programs, sensitivity to the 100 Hz television was found in 27% (71/264). About a third of the patients sensitive to a 50 Hz television, were also sensitive to a 100 Hz television. Only two patients were apparently sensitive to the 100 Hz television, and not to the 50 Hz television. Spontaneous epi-

Table II — Seizure history and seizure precipitants (% of those with a seizure history)

Seizure history			
History			%
	Yes	**294**	**83**
	No	58	17
	Total	**352**	**100**
Seizure types (*n* = 294/352)			
More than one type per patient possible			
Tonic-clonic		211	72
Myoclonic		99	34
Absence		84	29
Partial, sec. generalised		50	17
Other		13	4
Visually-induced seizures (*n* = 225/294)			
TV, VG or CG game only or in combination with other stimuli:		163	55
sunlight, disco, artificial light, pattern only or in combination		62	21
All – TV		140	48
– sunlight		83	28
– video games		45	15
– disco/artificial light		42	14
– computer game		28	10
Video game (VG) specific (*n* = 45/225)			
VG only		10	3
VG and TV		17	6
VG and TV and sunlight		4	1
VG and disco/artificiam		2	1
VG in other combinations		12	4
Sleep deprivation or stress-induced (*n* = 37/294)			
Sleep deprivation		20	7
Stress		13	4
Both		4	2

leptiform discharges were found in only 10% (36) of all patients; 27 of these also exhibited discharges whilst viewing a 50 Hz television, suggesting that up to 17% could possibly be false positive television responders. However, as all of them showed a clear increase in epileptiform discharges during television stimulation, it is unlikely that this was fortuitous in any substantial proportion of apparent television responders. Both the IPS-evoked and 50 Hz television-evoked EEG reactions were more frequently generalised than those due to other stimuli (68 and 66% respectively of the evoked EA, *table III*).

The total number of patients, sensitive to a particular program was determined, and a comparison was made between the various programs *(table IVa)*. Most patients were sensitive to the most provocative program, both on the 50 and 100 Hz television. The smallest number of patients reacted to the standard program with epileptiform activity. Subsequently, we determined a within-patient ranking order of sensitivity for the different programs on the 50 Hz television and the 100 Hz television, based on the threshold distance *(table IVb)*. Most striking was the fact that VG viewing and VG playing on the 50 and 100 Hz television was significantly more provocative than viewing the standard program ($P < 0.001$ and $P < 0.05$ respectively, *table VIc*). Playing the video game *Super Mario World* on the 50 Hz television appeared to be significantly more provocative than playing this same game on the 100 Hz television ($P < 0.001$).

Overall, no significant differences were found between the various sites of study, and ranking of the programs appeared to be the same for all sites. Furthermore, the use of medication did not influence the differences found.

Correlation between clinical history and investigation

Patients with at least a clear history of TV-induced, VG-induced or CG-induced seizures (163 patients) appeared to be, in the majority of cases, IPS-sensitive (85%), and sensitive to a 50 Hz television (59%), while only 29% of cases were sensitive to a 100 Hz television. Pattern sensitivity was found in 44%.

Table III — Results of laboratory investigations

EEG	IPS	Pattern	50 Hz TV	100 Hz TV
Generalised EA	195 (55)	43 (18)	108 (31)	34 (13)
Multifocal EA	88 (25)	48 (19.6)	47 (13)	33 (12.5)
Focal EA	16 (5)	1 (0.4)	7 (2)	4 (1.5)
Total number of positive patients (EA)	**299 (85)**	**92 (38)**	**162 (46)**	**71 (27)**
Total number of negative patients (No EA)	**53 (15)**	**152 (62)**	**190 (54)**	**193 (73)**
Total tested	**352**	**244**	**352**	**264**

EA = epileptiform activity; ( ) = percentages.
All 352 patients were investigated with intermittent photic stimulation (IPS) and a 50 Hz television (standard program and provocative program, and the video game *Super Mario World*). Fewer patients were tested with black and white striped patterns and a 100 Hz television (all programs). The type of EA is given for each stimulus; if a patient showed more than one type, only one type per patient was noted, with generalised EA considered as most important, followed by multifocal and finally focal EA.

Thus, for the total group, with a history of television, VG or CG seizures, 15% proved not to be IPS-sensitive. A possible explanation could have been the use of AEDs at the time of investigation, but this was not the case as 76% of the non-sensitive *versus* 68% of the sensitive subjects were on AEDs. There was also no difference in age found between IPS-sensitive and the rest of the population. However, there were twice as many males among the non-IPS-sensitive patients. This indicates the likelihood of coincidental seizures.

Of the 45 patients with a clear history of VG epilepsy, 80% proved to be sensitive to IPS, 38% to pattern and 65% to television. Five of the eight non-IPS-sensitive patients were on valproic acid medication, which may have led to abolition of the reaction to IPS. The other three, all boys, were not taking AEDs. One 14-year-old had experienced a tonic-clonic seizure while playing a video game one month before the investigation, but had had no further seizures and his EEG was normal. Another patient, an 18-year-old boy, had suffered three tonic-clonic seizures while playing video games, and had shown generalised EA during hyperventilation. The third boy was 15 years of age, had a history of two tonic-clonic seizures when playing computer games, and had, between the ages of four and six, experienced generalised seizures during periods of fever. Occipital and rolandic spikes were also found in his EEG.

A history of exclusively VG-evoked seizures was found in 22% (10/45) of all video game subjects. This "pure" video game group had about the same sex and age distribution as the combined group, *i.e.* those patients with provocation of seizures by other visual stimuli also. However, differences could be found in sensitivity to IPS: in the combined group, significantly more patients were photosensitive ($P < 0.05$). For pattern and television, no significant differences between these groups were found.

Table IVa — Video game/program comparison

50 Hz TV					
Program	**Threshold distance from the screen**			**Total number of sensitive patients**	**Total number of patients tested**
	2 m	**1 m**	**0.5 m**		
Mario World playing	24	17	18	59 (22%)	274
Mario World viewing	24	35	51	110 (31%)	352
Provocative	25	43	60	128 (37%)	350
Standard	15	22	35	72 (20%)	352
100 Hz TV					
Program	**Threshold distance from the screen**			**Total number of sensitive patients**	**Total number of patients tested**
	2 m	**1 m**	**0.5 m**		
Mario World playing	10	5	5	20 (9%)	236
Mario World viewing	8	12	9	29 (11%)	263
Provocative	13	21	22	56 (21%)	262
Standard	6	2	8	16 (6%)	263

Total number of patients sensitive per program for both the 50 Hz and 100 Hz television at threshold distances. If a patient is, for example, sensitive at a distance of 2 m, it implies that he is also sensitive at a closer distance and more sensitive than a patient sensitive only at a distance of 1 m or 0.5 m.

Table IVb — Provocative factor ranking		
	Type of TV (HZ)	Friedman score
1 *Mario World* playing	50	4.99
2 *Mario World* viewing	50	4.85
3 Provocative	50	4.77
4 Provocative	100	4.38
5 Standard	50	4.36
6 *Mario World* viewing	100	4.29
7 *Mario World* playing	100	4.25
8 Standard	100	4.10

Mean ranks of the programs according to provocativeness. Within-patient ranks were calculated using the threshold distance for a particular program or VG.

Table IVc — Statistical comparison				
	50 Hz TV		100 Hz TV	
MWV *versus* S	$P<0.001$	$N=352$*	$P=0.02$	$N=263$
MWP *versus* S	$P<0.001$	$N=274$*	$P=0.05$	$N=236$
MWP *versus* MWV	$P>0.1$	$N=274$	$P>0.5$	$N=236$
MWV *versus* P	$P>0.1$	$N=350$	$P<0.01$	$N=262$*
MWP *versus* P	$P=0.05$	$N=274$	$P>0.1$	$N=236$
S *versus* P	$P<0.001$	$N=350$*	$P<0.001$	$N=262$*

MW = *Super Mario World*, the video game.
Wilcoxon signed-ranks testing of data from IVa. Above.
MWV = *Mario World* viewing; MWP = *Mario World* playing; S = standard program; P = provocative program; * statistically significant.

General provocative factors, such as sleep deprivation and stress were not found more often in patients with a history of visually-induced seizures in general, or in those with video game seizures.

Discussion

The video game *Super Mario World*, which led to many reports in the media of provoked seizures, indeed proved to be more epileptogenic than the standard television programs tested, and as provocative as the tested television programs with flashing lights and patterns. Actively playing the video game *Super Mario World*, displayed on the same screen, increased the sensitivity within the same patient, but not significantly. Possibly, not only were the background colours (bright blue and green) and movements of the figures responsible, but also the increase of horizontal eye movements added to the effect by increasing stimulation of the extra foveal areas of the retina [10, 16]. It has also been demonstrated that VGs with bright steady backgrounds (more than 100 lux), including *Super Mario World*, were especially provocative [14].

We have found that patients with a specific history of TV, VG or CG seizures (163 patients) are sensitive to IPS (85%), to black and white striped patterns (44%), to a 50 Hz television (59%) and a 100 Hz television (29%). In half of those patients with a history of VG seizures, a clinical history of other visual provocative factors was mentioned, such as television, sunlight, disco lights etc. These findings are in line with those of previous studies and indicate that the VG-seizure patients mainly belong to the photosensitive group and often react to the flickering screen itself [1, 4, 5, 10, 12]. The fact that some authors have reported a higher proportion of patients who were not photosensitive and yet had a history of VG-seizures could be explained by differences in methodology [12, 17]. The intensity of the photic stimulator, the frequencies used and the eye conditions tested, will determine whether or not the patient is found sensitive. In this study, all four sites used exactly the same equipment and methodology.

Pattern sensitivity is a well known and important factor in patients with television sensitivity [4, 9, 11, 18]. Patients with a history of television seizures were, in the majority, sensitive to a 50 Hz television (59%) and were often sensitive to black-and white striped patterns (44%). In patients, who were sensitive to a 100 Hz television, a short distance from the set was a less critical factor than in those sensitive to a 50 Hz television. This fits in with the knowledge that patients sensitive to a 50 Hz television, and sitting close to the set, also react to the 25 Hz vibrating horizontal pattern of the television. The 100 Hz television, and in particular playing the video game on a 100 Hz television, was overall less provocative ($P < 0.001$), as has been demonstrated in other studies [12, 14, 18]. The patients sensitive to a 100 Hz television also showed greater differences in threshold (distance), *i.e.* IPS started at a distance of 2 m and if no EA was found at 1 m and nearer testing, was done until EA was demonstrated. This gave us a "per patient threshold-measure" of epileptogenicity in relation to the distance from the TV set in meters. This threshold determination was also done for security reasons.

For children and adolescents, it seems thus advisable to use a 100 Hz television for their video games in order to prevent (first) seizures, rather than the older 50 or 60 Hz television sets that are often used. Although playing the video game might be more provocative than viewing it, the issue of whether intensity of playing increases the likelihood of seizures could not be established. Unlike Ferrie *et al.* [4] who found factors such as fatigue and sleep deprivation important in non-photosensitive patients, neither sleep deprivation nor stress appeared to be a discriminative factor between these groups, or between other subgroups (the type of visual stimulus being provocative) [4]. Perhaps in selected cases, this general provocative factor in epilepsy has been overestimated [19].

Eighty-three percent of all patients had a clinical history of seizures, and the majority had idiopathic generalised seizures, such as myoclonic jerks, absence seizures and tonic-clonic seizures. In a small minority, partial seizures, with or

without secondary generalisation, were reported. This is consistent with earlier studies [5, 9, 20]. Patients with a history of seizures induced by either video games, computer games or television were also more likely to have partial seizures. These seizures can be considered as idiopathic photosensitive occipital seizures, typically with a time lag of minutes between initial stimulation and the time when the induced seizure occurs (although many patients experience visual hallucinations right from the start [21, 22]).

In conclusion, the vast majority of patients with a history of video game seizures are children and adolescents who are sensitive to flashing lights and the television screen, both in daily life and the laboratory. Certain programs, in particular the video game Super Mario World, are additionally provocative. Some video games and programs are more exciting than others; these include bright flashing and flickering images, large bright areas of the screen and high contrast patterns [23]. The outbreak of seizures in 685 children in Japan following broadcast of the animated television film Pokémon, appeared to have been due to a sequence of 12 Hz alternating deep red and blue light [24]. Following the results of this study, one should consider a child or adolescent with a history of a video game seizure as being photosensitive, and preventive measures (avoidance of the video game, the establishment of a sufficient distance from the television or computer, and optical filters [25]) should be taken. A detailed clinical history with special emphasis on other potentially provocative visual factors is helpful.

Media attention regarding medical issues should be taken seriously and investigated thoroughly. □

Videosequence captions

Background information

Italian girl 13 years of age

Clinical history: age at seizure onset was 8 years, with simple partial seizures 1-2/week: little purple balls in central area of her vision, covering other images, both spontaneous, but especially provoked by TV, VG, patterns and strong lights. Normal development.

EEG Investigation (VPA 600 mg, 22 mg.L^{-1})

IPS: generalised EA with L occipital as well as independently L frontal beginning/max; photosensitivity range 6-60 Hz (eye closure, eyes closed and open)

Pattern: generalised EA

TV 50 Hz: generalised EA at distance 1 m or less

TV 100 Hz: negative

18.07.10- 07.30: playing *Super Mario World* at a distance of 1 m from a 50 Hz TV. Short lasting bursts of generalised EA are evoked without apparent clinical signs.

18.42.00-43.30: playing Kart Racing at a distance of 1 m from a 50 Hz TV. The EA is increased in frequency of occurrence and duration. Clinical signs are seen such as eye-lid myoclonia, stopping playing and making mistakes. Complaints of pain in the eyes after series of EA.

As comparison:

19.31.50- 32.30: playing *Super Mario World* at a distance of 0.5 m from a 100 Hz TV. No EA is evoked.

19.35.45- 36.10: playing Kart Racing at a distance of 0.5 m from a 100 Hz TV. No EA is evoked.

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