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REVIEW ARTICLE

Pokemon seizures

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Abstract

On the evening of December 16, 1997 approximately 700 people around Japan were rushed to hospitals and treated for various acute symptoms. The patients were mostly children with convulsive seizures provoked by watching a popular animated TV cartoon, pocket-monster (Pokemon). It was found that most of the seizure occurred in the critical scene where there were alternating red/blue frames at 12 Hz lasting four seconds. The occurrence of Pokemon seizure appeared to be related to whether the patients have active photosensitive seizure. The sufferers may be previously known patients of photosensitive epilepsy, or healthy young individuals with first seizure. Most of the patients with Pokemon seizure have demonstrable photoparoxysmal response (PPR). Low luminance stimuli with deep-red flicker or flickering geometrical pattern was found to increase the yield of PPR in EEG than stroboscopic intermittent photic stimulation (IPS). Using video hazard blocker was also found to be effective in reducing the risk of the seizure attack. The incident demonstrated that photosensitive seizure from TV is not just an sporadic event, but may involve a large number of people at the same time. Guidelines similar to that of British Independent Television Committee (ITC) for TV production should be introduced in all countries to prevent the occurrence of similar incidents.

Key words: Animated cartoon, television, pocket-monster incident, Pokemon seizure, photosensitive epilepsy

INTRODUCTION

The pocket-monster incident showed that photosensitive seizures due to television (television epilepsy) is not just a sporadic event triggered mostly by flickering images.[1] In this incident, TV images with 12 Hz red/blue flicker provoked photosensitive seizures in a large number of children distributed over a wide area of Japan. It soon became a serious social problem.[2-4]

To elucidate the causal factors of the pocket-monster incident, Study Teams were formed by TV-Tokyo, National Association of Commercial Broadcasters (NACB) in Japan and Nippon Hoso Kyokai (NHK) in collaboration with the Ministry of Health and Welfare (MHW) Study Team as well as Advisory Team from the Ministry of Posts and Telecommunications. Japan Epilepsy Society also contributed to the study. The NACB and NHK subsequently formulated guidelines ("NACB Guidelines") for production of animation programmes. The Pokemon series was thus able to be again broadcast four months after the incident.[2] This paper aims to review the medical literature related the incident.

THE POCKET-MONSTER INCIDENT[2-4]

The Pokemon Episode 38 was broadcast at 6.30 to 7.00 pm on December 16, 1997. Pokemon was a fantasy story of a young hero's quest to capture the wild Pokemon, train them and make them part of his own team. Pokemon had been a very popular television programme in Japan and was aired by six TV stations, including TV-Tokyo. It has a 16.5% share of the audience in the time-slot. It was estimated that 4.15 million families over large areas of Japan watched the said episode. Many individuals subsequently complained of a variety of acute symptoms, including convulsion, loss of consciousness, blurred vision and headache. About 700 viewers from widely distributed area (Fig 1) had

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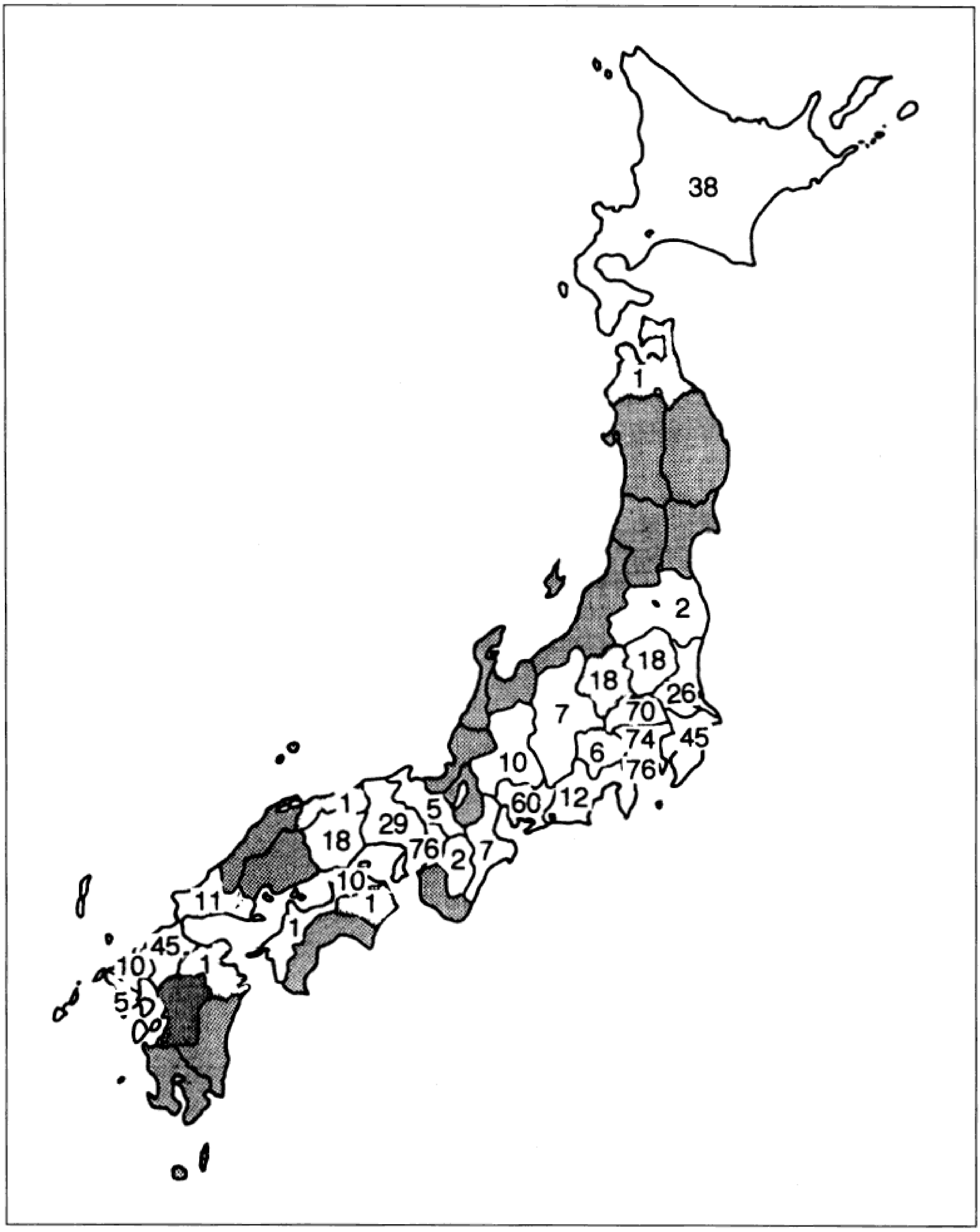

FIG. 1: The distribution of Pokemon seizures in Japan. The number of patients affected in each area were also shown. They occurred most frequently in Tokyo, Osaka and north Kyushu. Pokemon Episode 38 was probably not shown in areas shown in black (permission from Takahashi[4]).

photosensitive seizures (Pokemon seizures).[5] With the onset of seizures, many were brought to hospitals with most having recovered on arrival. About 200 patients were admitted to the hospitals with two patients being admitted for more than two weeks.

Most of the patients developed the symptoms at around 6.50 pm, while they were watching a flickering scene lasting for four seconds. The said scene depicted exploding vaccine missiles launched to destroy computer virus.

PHYSICAL CHARACTERISTICS OF THE CRITICAL SCENE[2,3]

The changing scenes in the first two-thirds of the 30 minutes Pokemon episode appeared to be not very different from the animation which were broadcasted previously. With further analysis, it was found that there was a previously unused computer graphic technique. There was a flicker series ranging from 0.5-4 seconds with alternating red/white-blue light and red/blue light creating mostly a 12 Hz display. The resultant flickering over a large portion of the television screen caused great discomfort despite the brief duration. There was in particular a critical scene where red and blue frames alternated at 12 Hz lasting for four seconds where most seizures occurred. Fig 2 is the schematic representation of the scene. The upper tracing signifies a part of the scene in "film", whereas lower tracing shows the scene in "TV". The film consists of a frame unit of 24 frames/sec, whereas the TV scene consists of a field unit of 60 fields/sec. Changing the film's two frames in 1/12 seconds into the TV scene in the same time frame results in three red fields and two blue fields. Harding[6] reported that the red frames have two sharp peaks at 625 and 704 nm with luminance of 45.6 cd/m^2 whereas the blue frames that follow have a single peak centred at 452 nm with luminance of 70.2 cd/m^2.

ACUTE SYMPTOMS INDUCED BY POKEMON EPISODE 38

After the episode, the MHW promptly organised a special Study Team consisting of 14 experts.[7] The Team evaluated the questionnaires of 9,209 pupils (aged 6-18 years) from primary, junior high and senior high schools in Tokyo, Kanagawa, Osaka and Fukuoka areas where Pokemon Episode 38 was aired (Fig 1). Iinuma[8] summarised the MHW's report as in the followings. Of the questionnaires received, 4,026 children (43.7%) watched the programme. Of these, 3,005 (74.6%) were under 12 years of age. There were acute symptoms in 417 (10.4%). Multiple complaints were given by the students. The visual symptoms were: opthalmia (40.5%), fixation to the screen (11.0%), persistence of vision (10.3%) and blurring of vision (9.4%). General discomfort was complained by 33%; 29.5% cited headache or confusion and 14% had nausea. The followings were seizure-like symptoms: palpebral myoclonus in 37 (8.9%), convulsion of the extremities in 30 (7.2%) and

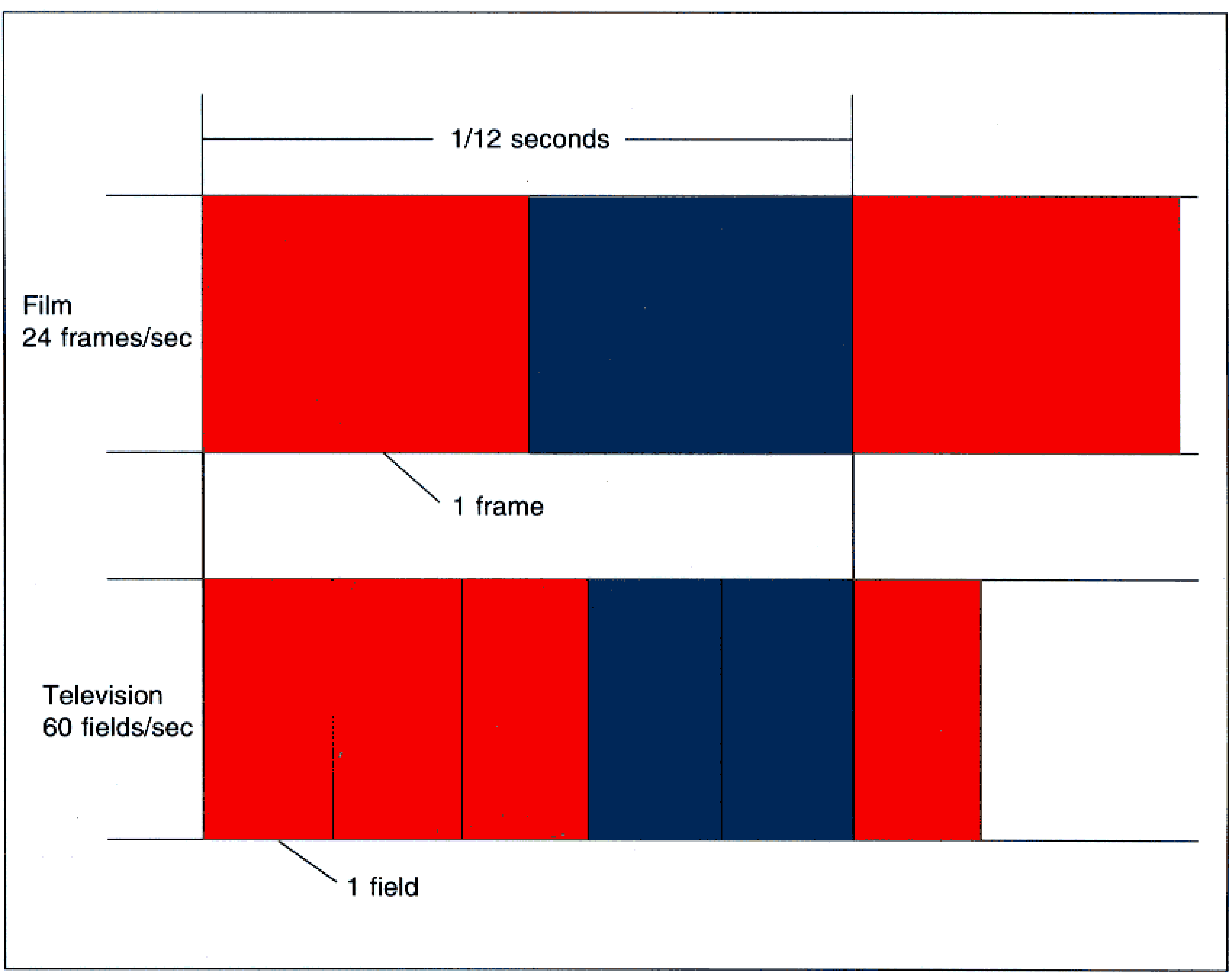

FIG. 2: Schematic representation of the critical Pokemon scene with alternating red/blue light (permission from Takahashi & Tsukahara[2]).

unconsciousness in 24 (5.8%). Analysing the MHW report, Fukuyama et al[9] commented that a total of 56 (13.4%) had symptoms supportive of epileptic seizures with convulsions (30), unconsciousness (24), enuresis (1) and eyes deviation (1). The 56 cases comprised 1.4% of the 4,026 Pokemon-viewers. Fukuyama et al[9] further pointed out that the Pokemen seizure rate is higher than the active epilepsy prevalence rate of 0.5% among the general population.

CLINICAL-EEG STUDIES IN POKEMON SEIZURES

Funatsuka et al[10] from Tokyo reported four patients (one boy and three girls) whose convulsive seizures were first provoked by Pokemon Episode 38 showing photoparoxysmal response (PPR). The four patients were very sensitive to pattern-reversal and two patients were also sensitive to deep-red flicker stimuli. Hayashi et al[11] from Yamaguchi-ken reported 12 patients (three boys and nine girls) whose seizures (convulsion, 10 patients; unconsciousness, two patients) were first induced by Pokemon. Six of the patients showed PPR. Enoki et al[12] from Okayama-ken reported 20 patients (8 males and 12 females; age range: 6-30) who had acute symptoms induced by Pokemon (convulsion, 13 patients; other symptoms, 7 patients). PPR was elicited in 12 of 13 patients (92.3%) who had convulsions, whereas only one of seven patients (14.3%) with other symptoms had PPR. Ishida et al[13] from Fukuoka-ken reported four patients who had seizures induced by Pokemon. They were classified as: Juvenile myoclonic epilepsy (1), photosensitive epilepsy (1), first seizure (2). PPR was seen in three of the patients. Kobayashi et al[14] reported a case of Pokemon seizure in a 11-year-old girl who had hallucination in the right visual field followed by muscular cramp on the right face and aphasic speech arrest. The EEG showed a TV-induced left occipital seizure spreading towards the left inferior frontal lobe, suggesting a functional link from the occipital lobe to the frontal operculum.

Takada et al[15] from Nagoya conducted a questionnaire survey in Aichi-ken. The questionnaire was sent to 75 hospitals in and around Aichi-ken. The diagnosis and classification of epileptic seizures were by three paediatric neurologists. Sixty-one hospitals responded to the questionnaire survey. Of the 95 patients with suspected seizure for evaluation, 93 patients were diagnosed to have Pokemon seizure. Most seizures occurred during the scene with red and blue frames alternating at 12 Hz. Sixty-nine patients (74%) had no previous history of epilepsy. Thirty-nine patients had generalised seizures and 49 patients had partial seizures. Partial seizures were more frequent in the younger age group. The EEG demonstrated PPR in 43% of patients. It was seen in 54% of patients with previous history of epilepsy and 38% of patients where Pokemon seizure was the first seizure. Takada et al concluded that almost all seizures were induced by the Pokemon TV programme were epileptic, and partial seizures were more frequent than generalised seizures. Prevalence of Pokemon seizures was estimated to be about 1 in 4,923 viewers aged 6-18 years.

Thus, most of the patients with Pokemon seizures have demonstrable PPR. In a Western European study, prevalence of photosensitive epilepsy was found to be 1 in 4,000 and the most common precipitating factor was TV.[16] This prevalence rate is close to that of Pokemon seizure estimated by Takada et al.[15]

The Pokemon seizure sufferers may be patients previously known to have active photosensitive epilepsy, or healthy young individuals with photosensitivity previously not known to have seizure.[7,15] According to the MHW study[7], of 61 Pokemon sufferers who underwent EEG examination, 39 (63.9%) showed PPR in response to direct stroboscopic intermittent photic stimulation (IPS). Of these 39 cases, 21 (65.9%) had Pokemon seizure was their first seizure. Study by the Japanese Epilepsy Society Long Term Plan Committee[17] also showed that 70% of the 279 patients had Pokemon seizure as their first seizure.

MECHANISM OF SEIZURE GENERATION IN POKEMON SEIZURE

Harding[6] investigated six British photosensitive epilepsy patients using the critical Pokemon scenes. Five patients had EEG abnormalities. However, the EEG was normal when the patients were presented with monochromatic versions of the images. Harding claimed that colour was essential to provoke EEG abnormalities and was probably the critical factor in the pocket-monster incident. Spectral output of the red gun during the critical Pokemon scene contained two sharp peaks at 625 and 704 nm; it has a longer wavelength than the most sensitive range of the red cones in the human eye. Unlike blue and green light, such as that emitted from the blue frame, long wavelength red light such as that from the red frame (deep-red[1-4]) only stimulated red cones while no matching inhibitory signals were elicited from other cone populations. These resulted in maximal stimulation of the visual cortex and resulted in seizures in the photosensitive individuals.

Tobimatsu et al[18] reported four Japanese children with Pokemon seizure. They demonstrated that the PPR was more frequently observed in response to rapid colour (blue/red) frame changes as compared to monochromatic frame changes. These children were all diagnosed to have photosensitive epilepsy. Tobimatsu et al[18] also concluded that chromatic sensitivity played an important role in generation of such seizures.

It has been known that photosensitive individuals are particularly sensitive to deep red flicker and/or flickering geometric pattern stimuli when low-luminosity (10-30 cd/m^2) is employed as a light source.[1-4,19] The parameters that are most likely to elicit PPR are: flicker frequency 10-30 Hz, geometric pattern 1-4 c/deg, wavelength 620-710 nm (Fig 3). Using circular-type strobo-filter method (Nihon Kohden, Fig 4) that was able to produce low luminance (30 cd/m^2) deep-red flicker and flickering geometric pattern (2 c/deg)[19,20] stimuli, we made a comparative study in eliciting PPR by visual stimuli via the circular-type strobo-filter method and the critical Pokemon scene in 52 epilepsy patients.[4] On the basis of PPR provocation, subjects were divided into three groups: (1) 23 photosensitive epilepsy patients in whom PPR was elicited by either 18 Hz deep-red flicker and/or 18 Hz flickering geometric pattern stimuli; (2) 10 photosensitive epilepsy patients who were previously sensitive to either deep-red flicker and/or flickering geometric pattern stimuli, but were not currently sensitive to the same stimuli; (3) 19 non-photosensitive epilepsy patients. The critical Pokemon scene displayed on a 14-inch TV screen was able to elicit PPR in 14 patients (61%) in group one, but none in group two and three. Thus, Pokemon seizure was closely related to whether the viewer has active photosensitive epilepsy. Of the 14 patients with PPR, 10 were sensitive to deep-red flicker and all 14 were sensitive to flickering geometric pattern (Fig 5).

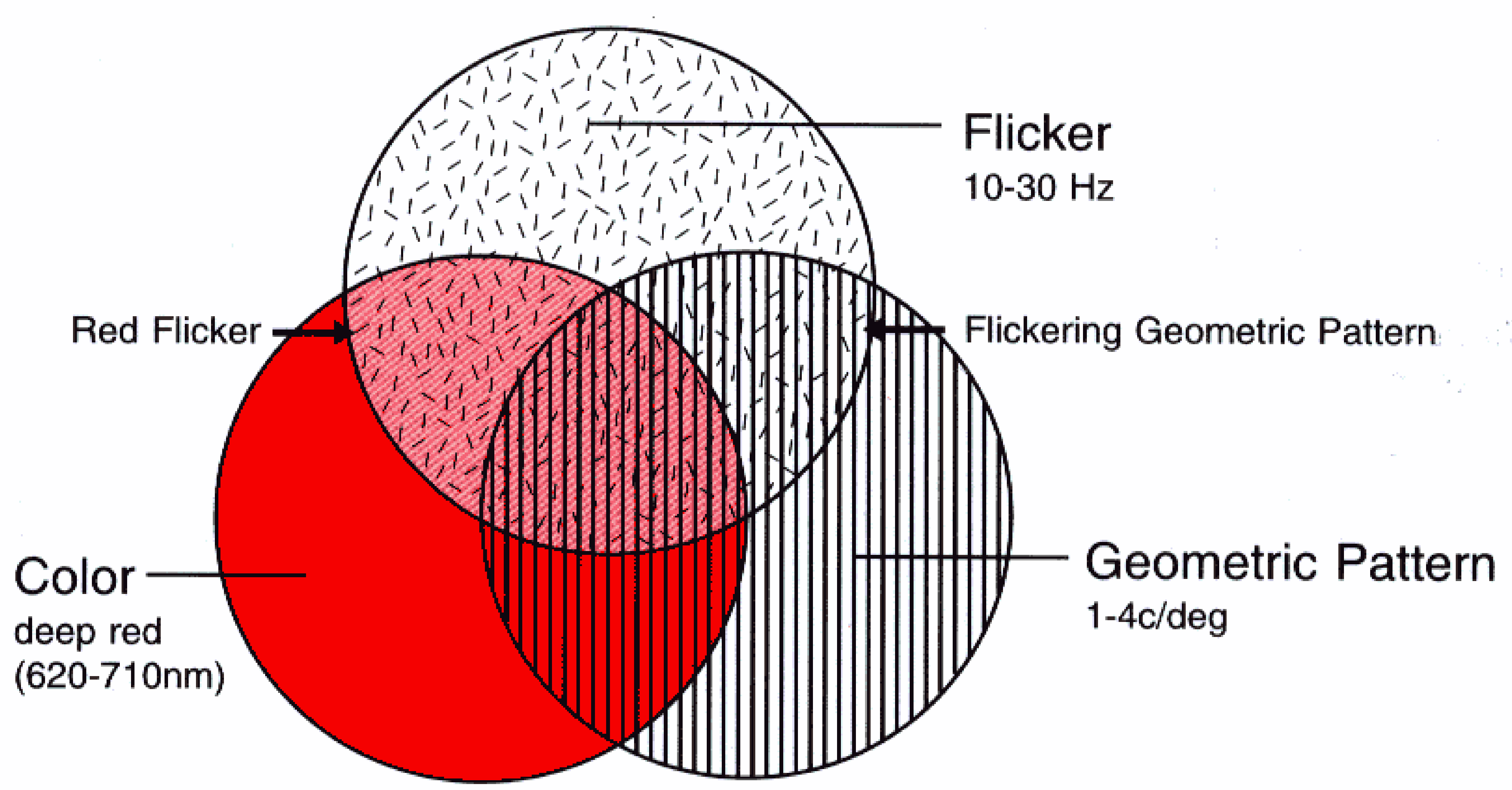

FIG. 3: Various stimuli that are able to elicit PPR in photosensitive subjects (permission from Takahashi[4]).

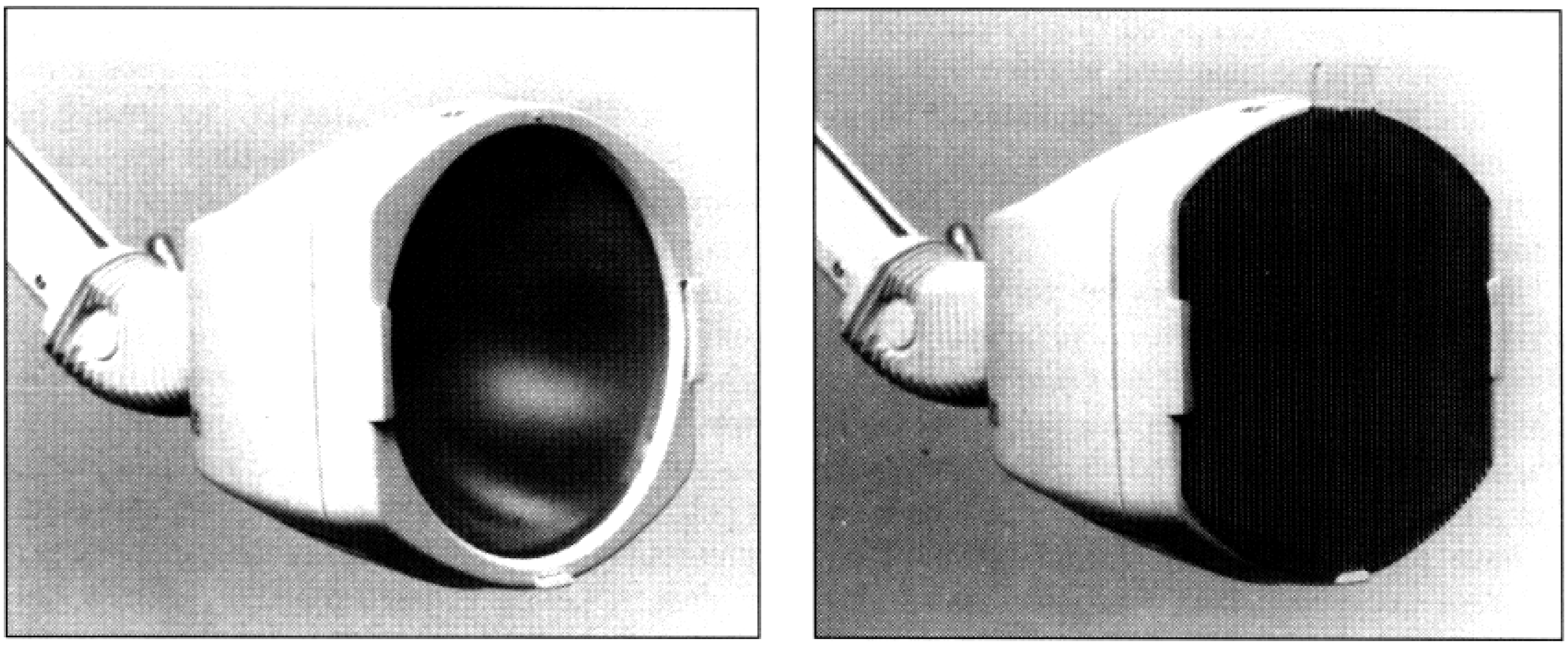

FIG. 4: Direct stroboscopic IPS and low-luminance stimuli by the use of circular-type strobo-filter. Luminance of direct stroboscopic IPS by use of LS-706A (Nihon Kohden) as shown in the left is 3939 cd/m^2. Inserting a vertical grating pattern along the filter holder on the front of the flash lamp as shown in the right reduces the luminosity down to 30 cd/m^2. Five strobo-filters are available from Nihon Kohden. They are: deep red[3], dot-pattern[20], vertical grating, horizontal grating and white. The luminance with the strobo-filter is 30 $cd.m^2$. Spatial frequency of each pattern is 2 c/deg when the distance between the flash lamp and the eyes is kept at 30 cm.
Preparation for EEG activation by use of low luminance stimuli is as follows: put the flash lamp 30 cm from the patient's eyes, dim the examination room. While stimulation is applied, the patient should be kept awake with the eyes open. Patients with glasses should have the glasses on. Ask the patient to stare at the centre of the lamp without blinking. *Procedure for PPR testing* is as follows: (a) With the vertical grating-pattern strobo-filter, apply 18 Hz flickering vertical grating-pattern stimuli for 5 seconds. (b) With deep-red strobo-filter, apply 18 Hz deep-red flicker stimuli for 5 seconds. (a) is the most effective method to induce PPR. When PPR is elicited, immediately stop the stimulation. For a patient who is clinically suspected to have photosensitive epilepsy where (a) & (b) procedures do not elicit PPR, apply 18 Hz flickering horizontal grating-pattern stimulation for 5 seconds with the horizontal grating-pattern strobo-filter. If further examination is necessary, apply 18 Hz flickering dot-pattern stimulation for 5 seconds with the dot-pattern strobo-filter.

PREVENTION OF PHOTOSENSITIVE SEIZURE IN TV

Guidelines on Production of Animation Programmes

NACB and NHK subsequently formulated the so-called NACB Guidelines for production of animation programmes. In the process of the formulation of the Guidelines, the author (TT) strongly recommended the followings: (1) deep-red flicker scenes should not be aired; (2) "flickering geometric pattern" was also a strong stimulus for eliciting PPR. Great care should be exercised in airing scenes containing such graphical components; (3) guidelines by the British Independent Television Committee (ITC) formulated in 1994 were an excellent model for Japan to follow. The NACB Guidelines[8] formulated are as follows: (1) In principle, images or flickering especially vivid red flickering of more than 3 Hz should be avoided. In the case of non-red images, flickering of more than 5 Hz is prohibited. The brightness variation should be less than 20%. Duration of flickering should be less than 2 seconds. (2). Reversal of contrasting images and rapid conversion of images should be fewer than three per second. (3) Strips, whorls and concentric circles should not occupy large part of the screen.

Contributions by Professor Harding who helped to formulate the British Guidelines[21] should also be mentioned. He has contributed significantly to the formulation of similar Guidelines in Japan. With the formulation of the Guidelines, on April 16^{th}, 1998, four months after the Pokemon incident, the popular Pokemon series was able to be re-broadcast. With regard to the red flicker stimulus, article 3.3 of the ITC Guidline[22] stated that "flashes involving highly saturated red are particularly dangerous and should be avoided."

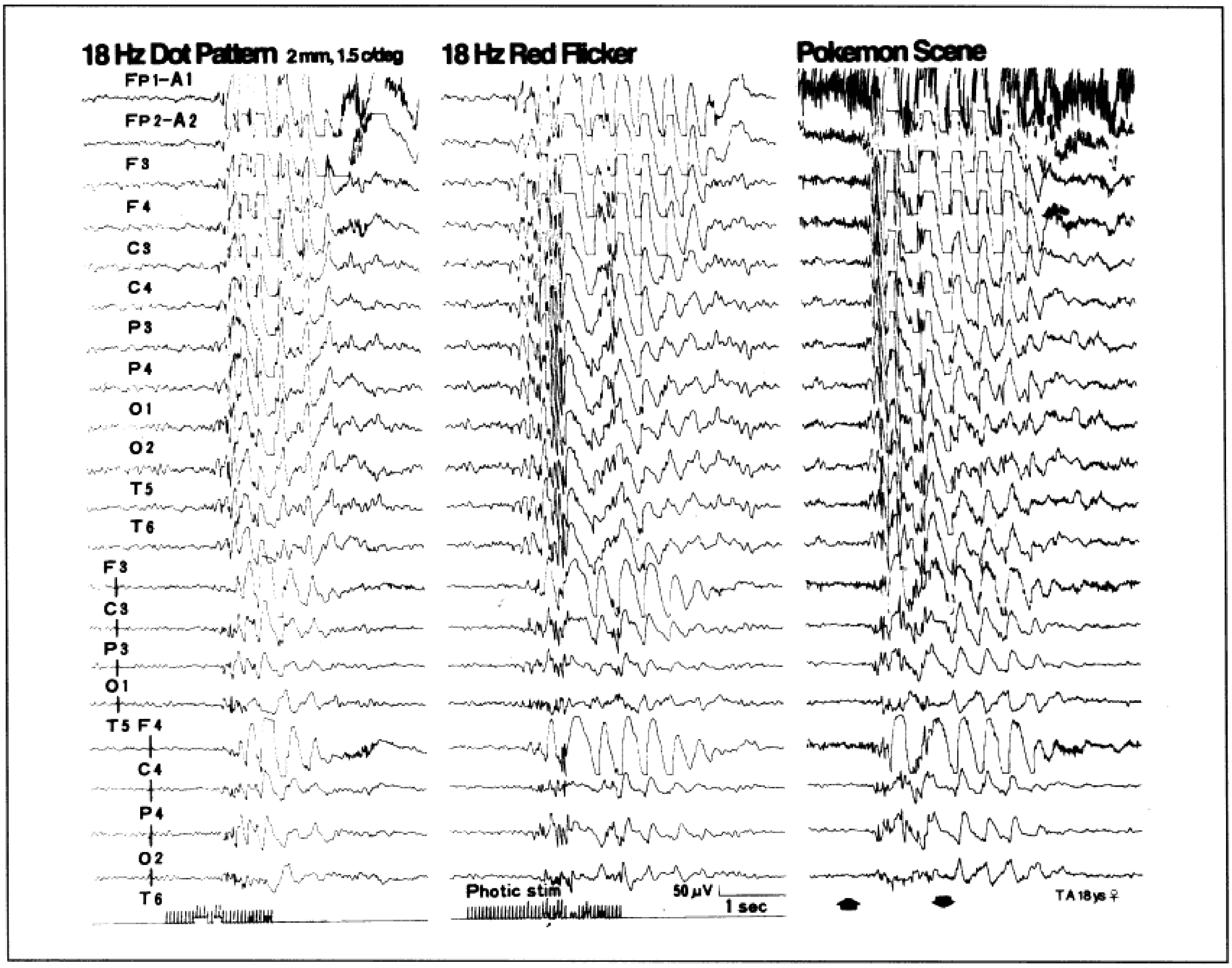

FIG. 5: EEG changes in response to 18 Hz flickering dot-pattern, deep-red flicker and the critical Pokemon scene stimuli in an 18 year-old female with photosensitive epilepsy. For the former two stimuli, square type strobo-filter method was used. EEG was recorded with the patient taking zonisamide 300 mg/day.

Recommendations for TV Viewing

After the Pokemon incident, the following recommendations for viewing TV have also been stressed to children to prevent photosensitive seizures.[23] (1) Watch TV at a distance of more than two meters. (2) Watch TV in a well lit room. (3) Don't watch images that occupy the whole TV screen. (4) Manipulate TV images with a remote-control while sitting at some distance. (5) Cover one eye with your hand when you notice flickering TV images. (6) Avert your eyes from TV images when you feel something is wrong. (7) Don't watch TV in poor physical conditions, such as insufficient sleep, fatigue and constipation. (8) Don't watch TV for prolonged periods of many hours. In addition, the usefulness of blue sunglasses in photosensitive individuals were also emphasized.[24]

Video Hazard Blocker

After publication of the Guidelines, TV images in Japan have become "milder". However, particularly in commercial advertisements, there are still occasional scenes that may be stimulative to photosensitive subjects. Nomura[25] reported that visual cortical cell responses resonate to 10-30 Hz flickering images, possibly triggering photosensitive seizures. He developed a device to filter the flickers to prevent the seizure. Video Hazard Blocker (VHB) is manufactured by NEC. It was based on the theoretical consideration discussed above as well as clinical evidences.[4,26,27] We compared the effects of the critical Pokemon scene on 13 photosensitive epilepsy patients with and without the use of VHB (unpublished observation). Without VHB, the scenes promptly elicited PPR. With VHB, only one patient had an attenuated PPR (Fig 6). The device is thus effective in preventing flicker induced seizure.

EEG DIAGNOSIS OF PHOTOSENSITIVE EPILEPSY

The pocket-monster incident provided strong

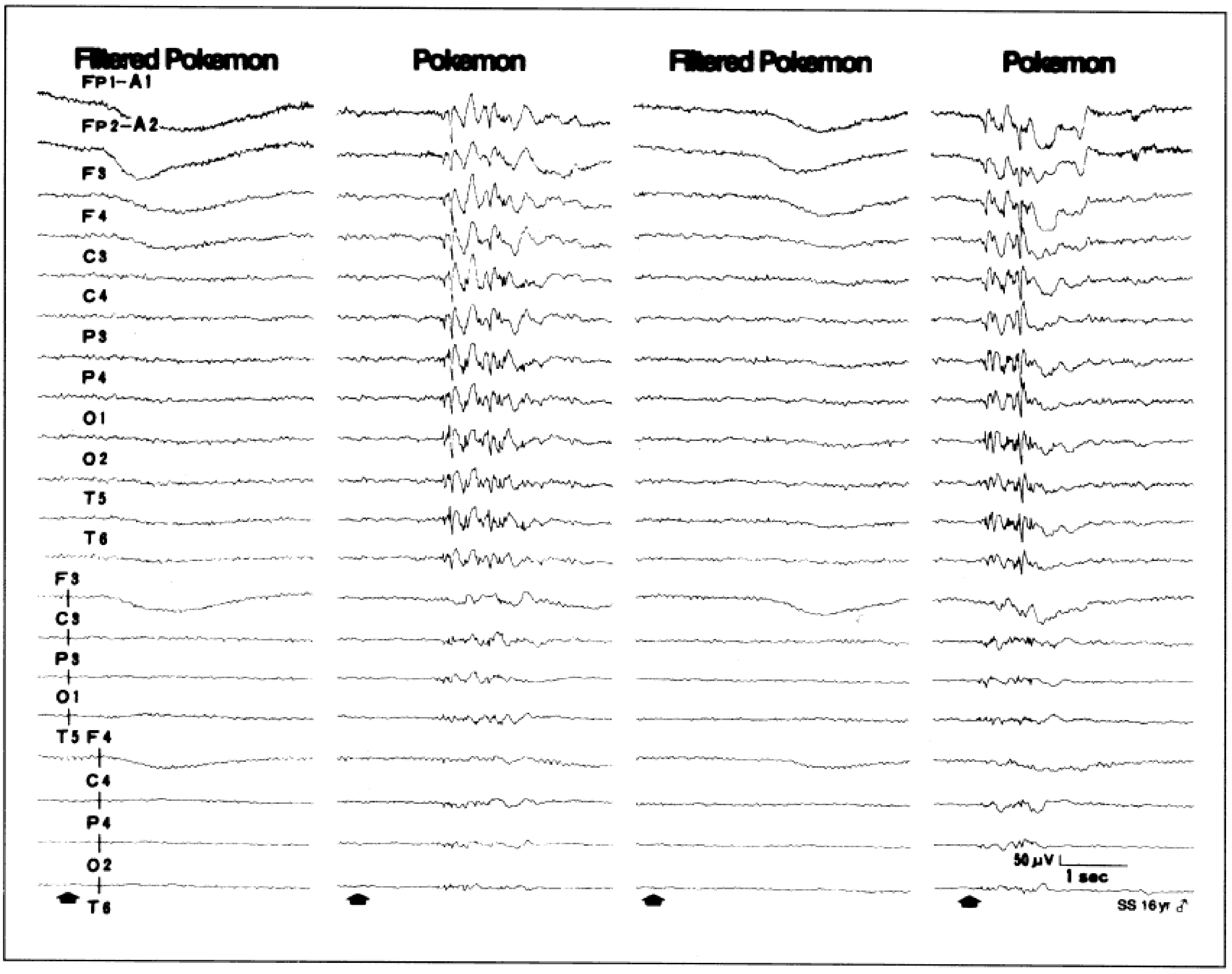

FIG. 6: EEG changes in response to filtered and non-filtered Pokemon scenes in a 16 year-old male with photosensitive epilepsy. As for filtered Pokemon scenes, computer-simulation images made from Nomura's theory[25] were utilized in this case. The EEG was done with the patient taking sodium valproate 600 mg/day.

evidence in support of the use of deep-red flicker stimulus in the EEG diagnosis of photosensitive epilepsy.[1] In addition, we also routinely used flickering geometric pattern as activation procedure. Luminance of both stimuli were kept low at 10-30 cd/m^2. The rate of PPR provocation by low-luminance visual stimuli on epilepsy patients was 18%. It was more than 3.5 times that of the commonly accepted 5% prevalence using intermittent photic stimulation (IPS) as reported by Binnie and Jeavons.[16,28] Our own data showed that low luminance visual stimuli (20 cd/m^2, 18 Hz deep-red flicker and 18 Hz flickering 2 c/deg geometric pattern, Fig 7) was able to provoke more than twice the rate of PPR from stroboscopic IPS (Grass PS33-plus photic stimulator, 3,939 cd/m^2, 18 Hz).[1] Thus, low-luminance visual stimuli as described above are very useful for EEG diagnosis of photosensitive epilepsy. We have further found that low-luminance visual stimuli with circular type strobo-filters (Nihon Kohden, Fig 4) gave similar results as compared with square type strobo-filters (Nihon Kohden, unpublished observations). The former is easy to use and suitable for routine clinical laboratory examination. A recent questionnaire conducted by the Japan Society of EEG & EMG's Photosensitive Seizure Committee found that deep-red flicker and flickering geometric pattern stimuli were being used in 31 and 22 hospitals respectively in Japan, demonstrating their increasing popularity.[29]

Stroboscopic IPS vs Low-luminance Visual Stimuli[1-4,19,20,28]

For the purpose of making EEG diagnosis of photosensitivity, stroboscopic IPS has traditionally played an important role in eliciting PPR. Over the past three decades however, other modes of visual stimuli such as pattern, pattern-reversal[30], flickering pattern and red flicker have also been advocated. When the stroboscopic IPS was first introduced in 1946[31],

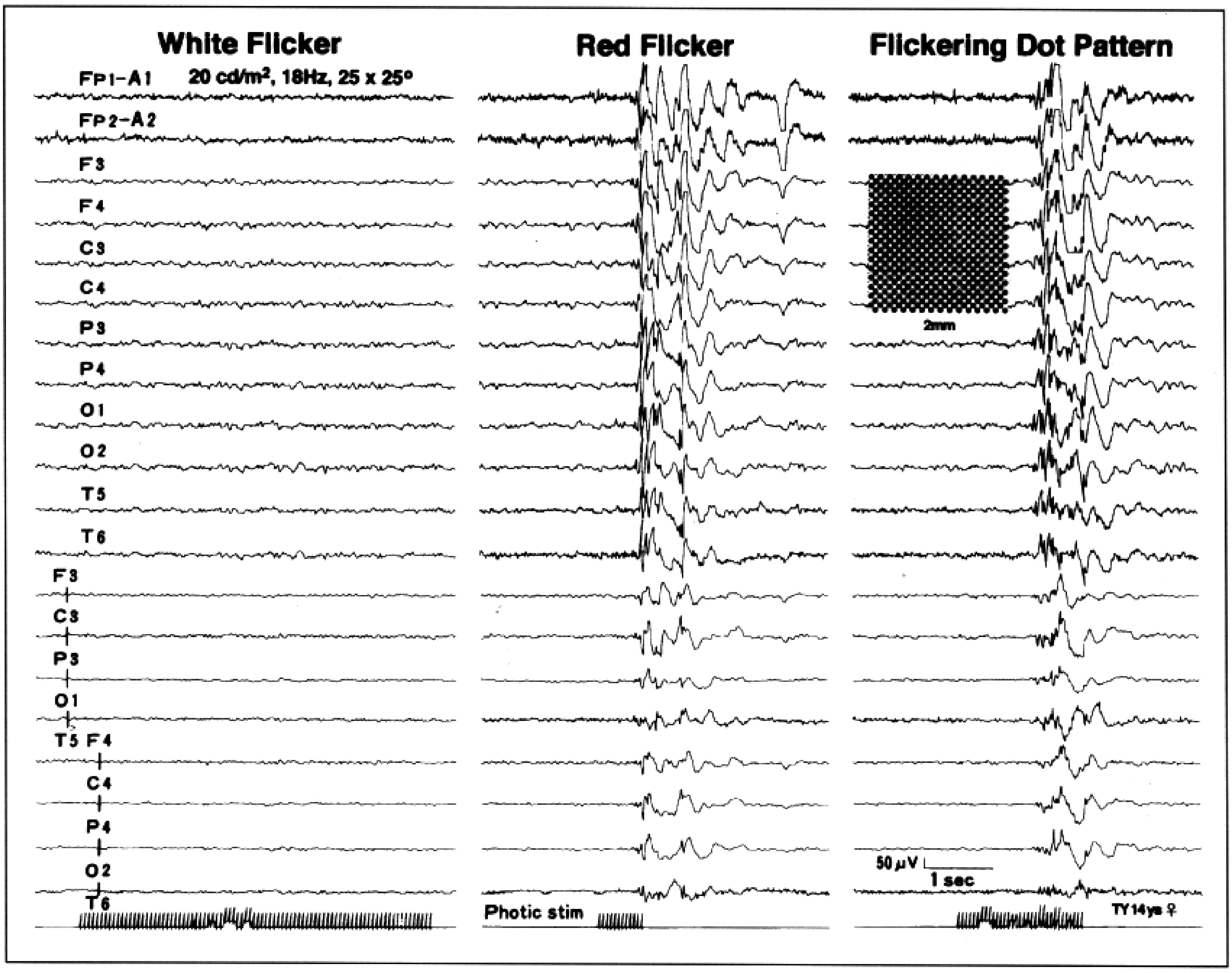

FIG. 7: EEG changes in response to white flicker, deep-red flicker and flickering dot-pattern stimuli in a 14 year-old female with photosensitive epilepsy. Visual stimuli were given by use of square-type strobo-filter. The EEG was recorded with the patient taking sodium valproate 400 mg/day.

sun-light was the most important provocative factor for photosensitive seizures. Bright light for EEG activation was thus reasonable. With the advent of TV in the '50s, TV epilepsy began to be reported in growing numbers. Colour TVs appeared later, followed by explosive popularity of TV games. The '80s saw the emergence of "video game seizures." Together with the sharper and clearer pictures with the advances in TV technology, the animated cartoons began to rely heavily on high-tech computer graphics. Thus, there have been progressive changes in the triggering factors for photosensitive seizures in the last fifty years. Harding and his colleagues[30] have demonstrated that 50 & 25 Hz flicker produced by PAL-TV and 60 & 30 Hz flicker produced by NTSC-TV, particularly the former, can provoke photosensitive seizures. The TV seizure is thus due to "hardware dependent stimulus". On the other hand, the Pokemon seizures were due to a "software dependent stimulus" or "programme-content dependent stimulus".[4] All these argue for the need of new visual stimulation techniques other than direct stroboscopic IPS for EEG activation.

In the discussion above on the advantage of low-illuminance visual stimuli as activation procedure, the higher PPR-provocation rate was emphasised. In addition, the low-luminance visual stimuli simulate the actual condition of the photosensitive seizure-induction. It causes less discomfort than stroboscopic IPS. The low-luminance visual stimuli are performed with the eyes open. This also allows the use of regional visual stimulation techniques for EEG activation[19] as shown in Fig 8. On the other hand, the direct stroboscopic IPS is usually performed with the eyes closed.

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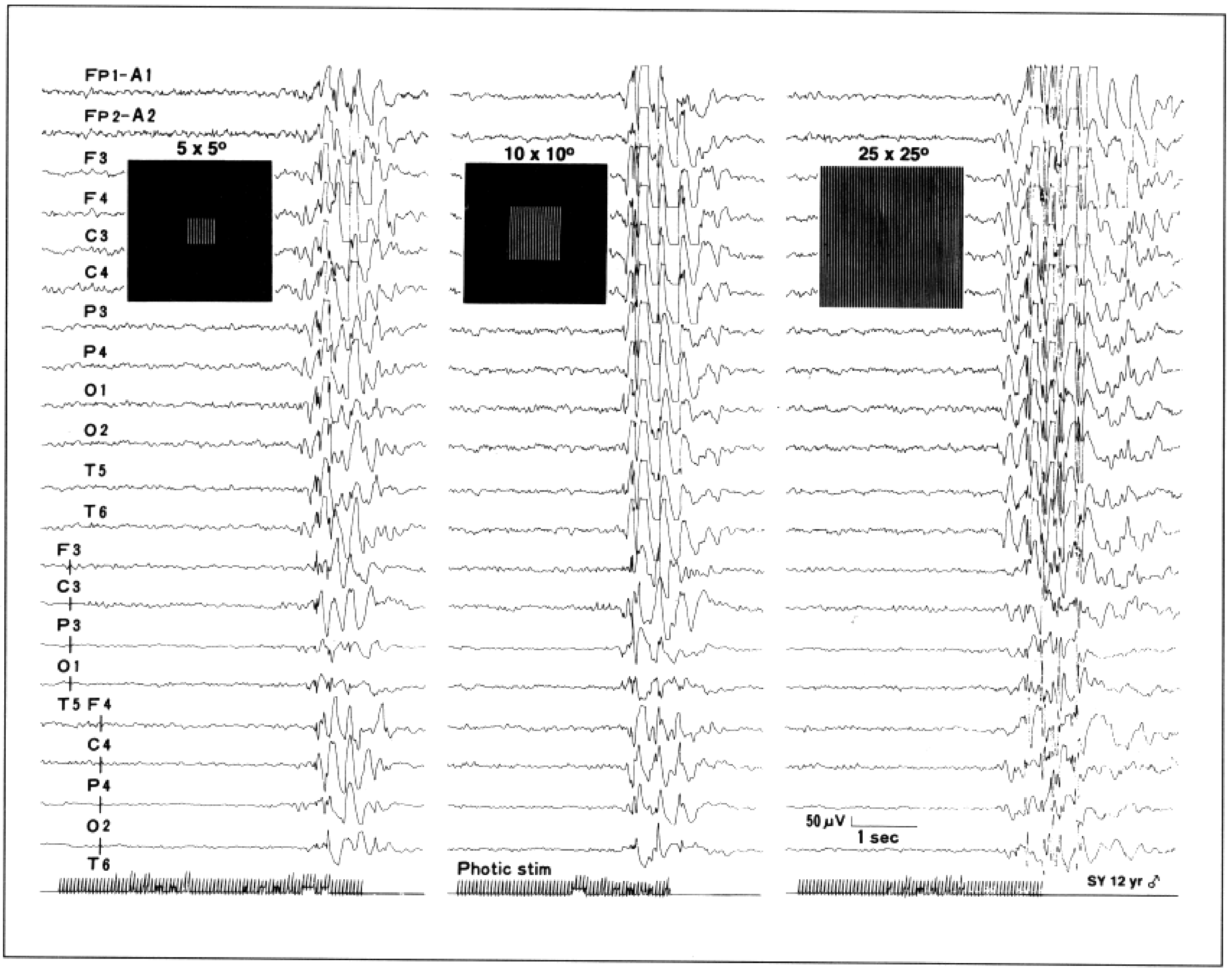

FIG. 8: EEG changes in response to 18 Hz flickering vertical grating-pattern (2 c/deg) stimuli in a 12 year-old male with juvenile myoclonic epilepsy. Visual stimuli were given by square-type strobo-filter. The EEG was recorded with the patient taking sodium valproate 100 mg/day.

based in part on an invited lecture by T Takahashi in the 2nd Congress of the Asian & Oceanian Epilepsy Organisation in Taipei, Taiwan, 1998.

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