Highlights

- Pattern-sensitive patients use uncomfortable images to self-induce seizures
- Images with abnormal scores occur in the "Objects" and "Patterns" categories
- Pleasant visual symptoms changes uncomfortable images into pleasant stimuli
- Photographs may help to identify epileptogenic visual stimuli
- Drawings may contribute to describe visual symptoms
- This modern approach may improve the management of visually induced seizures

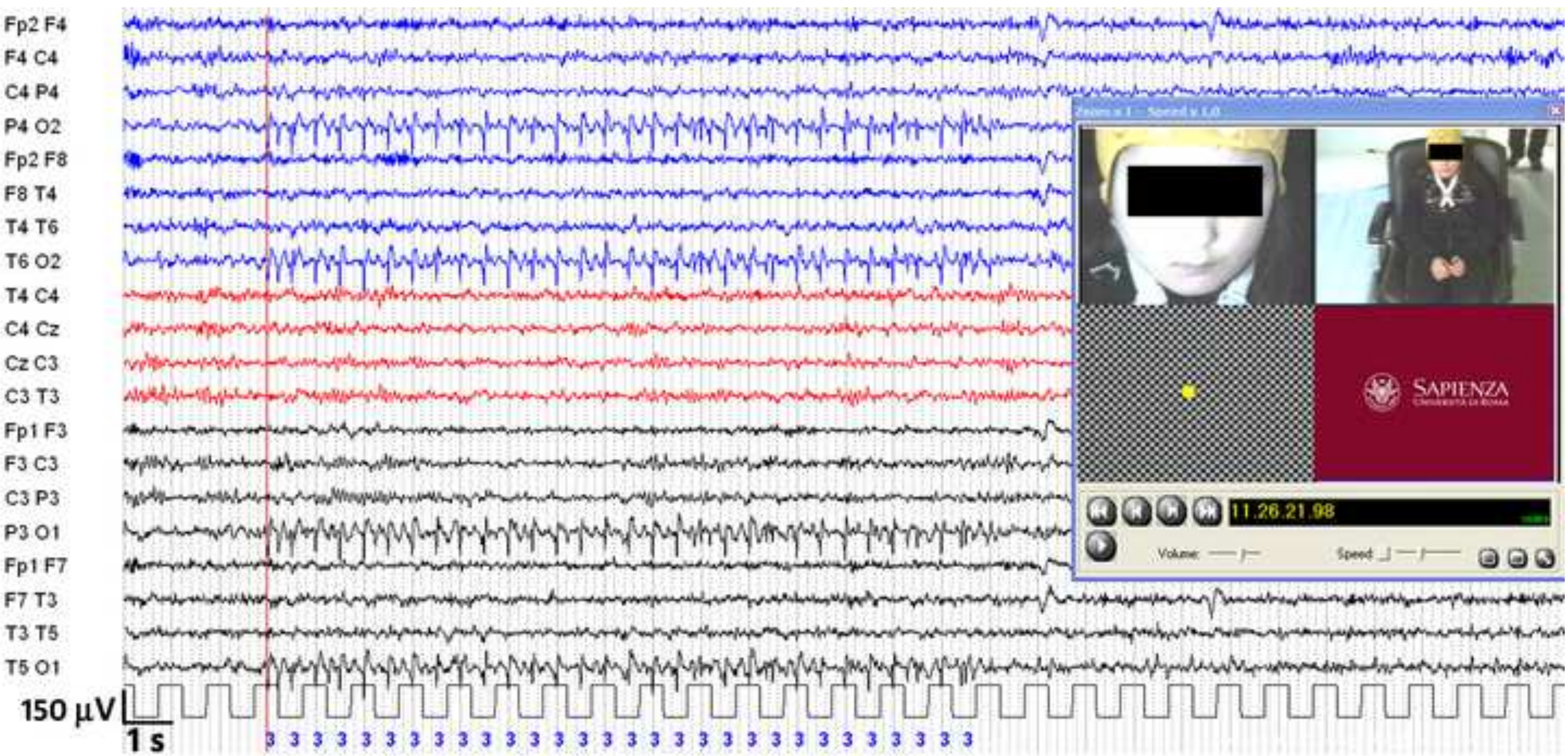
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Figure 2

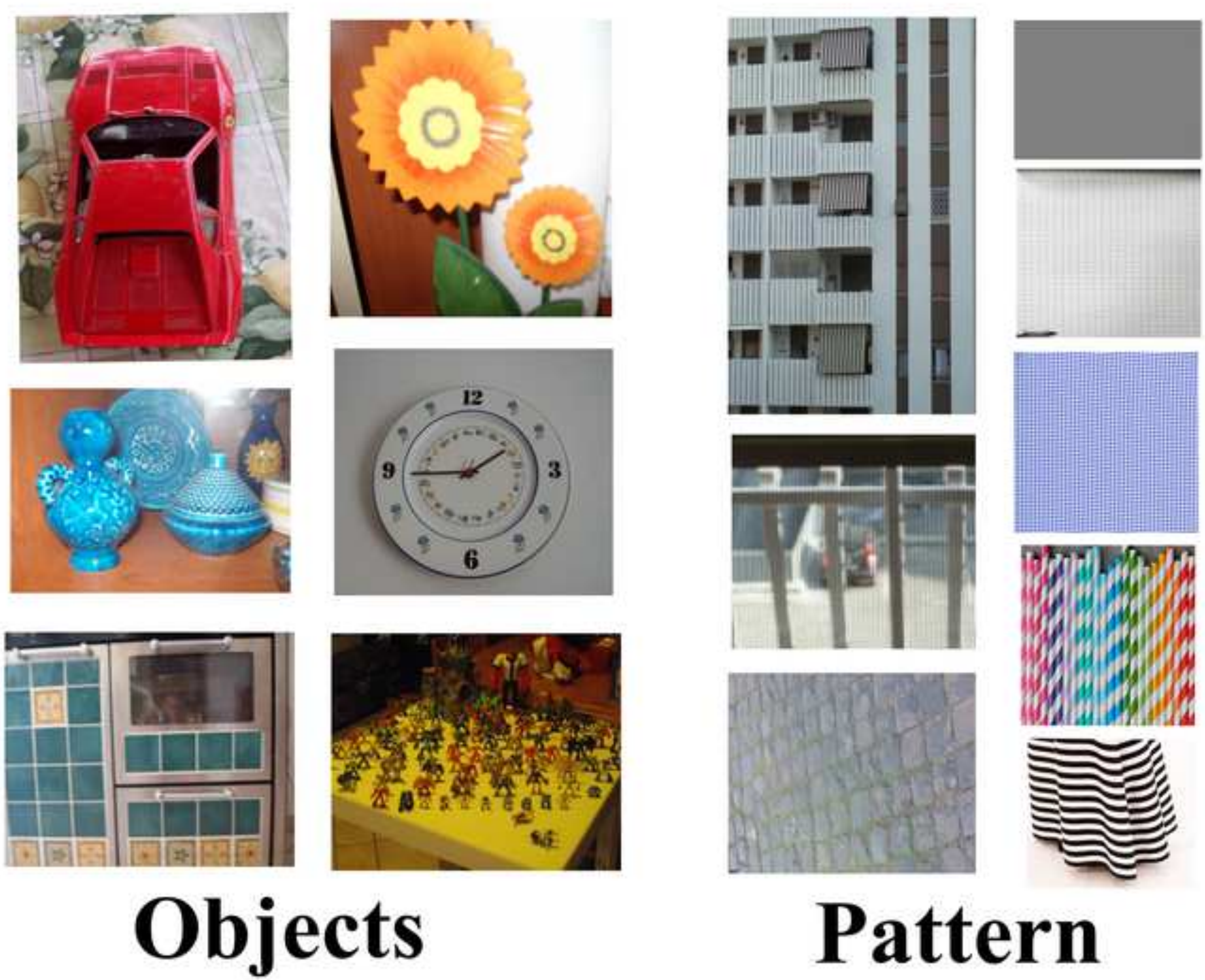

Figure 3 Click here to access/download;Figure;Brinciotti-Figure 3.tif

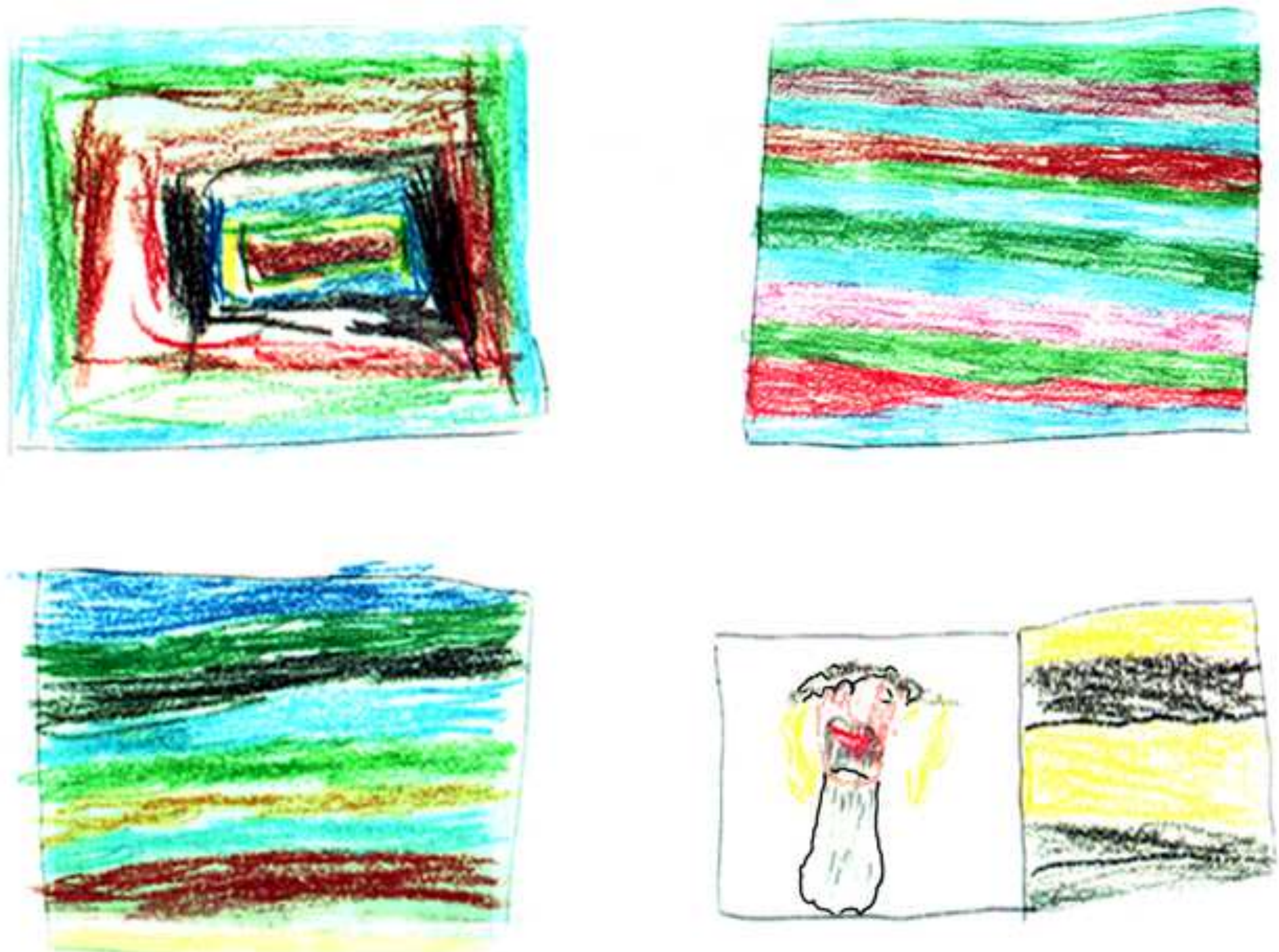

Table 1

Main demographic data of studied patients

Type of seizures	
Spontaneous (11/14)	Absence 1 Absence + tonic-clonic 2 Focal onset with sensory symptoms (visual) 2 with motor signs 2 to bilateral tonic–clonic 4
Reflex (14/14)	Focal onset with sensory symptoms (visual) 8 with motor signs 4 to bilateral tonic–clonic 2
Age at onset epilepsy (mean ± SD)	6.3 ± 3.7 years
Age at onset self-induction (mean ± SD)	7.3 ± 3.2 years
Follow-up (mean ± SD)	6.6 ± 1.8 years
IQ (WISC-III)	Normal 13 Borderline 1
AE drugs (5/14)	Valproate 3 Valproate + Ethosuccimide 2
EEG data	
Spontaneous discharges (11/14)	Focal Occipital 1 Temporo-occipital 6 Parieto-occipital 2 Frontal 1 Generalized 1
Spontaneous seizures (2/14)	Focal with spreading 2

Table 2

Image analysis for category

Group		**Residuals**					
	N	**Mean***	**SD**	**Confidence limits**		**Abnormal****	
				-95%	**+95%**	**N**	**(%)**
a. Objects	29	6,81	6,72	4,25	9,36	17	(59)
b. Pattern	19	9,05	6,86	5,74	12,4	14	(74)
c. External scenes	15	2,11	1,07	1,52	2,70	0	(--)
d. Screens	4	1,38	0.40	0.74	2,03	0	(--)
Total	67	6,07	6,32	4,53	7,61	31	(46)

Note: departures with respect to natural scenes (mean, SD and Confidence limits of residuals) have been divided by 10^{11} for clarity

*) $p = .0036$ (ANOVA)

**) Abnormal = residual value < 4,88; Chi^2 $p < .0279$ (group a *vs* group b = NS; group c *vs* group d = NS)

Pattern-sensitive epileptic patients use uncomfortable visual stimuli to self-induce seizures

Mario Brinciotti [a], Arnold J Wilkins [b], Olivier Penacchio [c], Maria Matricardi [a]

[a] Department of Human Neuroscience, Sapienza University of Rome

[b] Department of Psychology, University of Essex, United Kingdom.

[c] School of Psychology and Neuroscience, University of St Andrews, United Kingdom.

Abstract

Sensory stimuli can induce seizures in epileptic patients and predisposed subjects. Visual stimuli are the most common triggers, provoking seizures through an abnormal response to light or pattern. Sensitive patients may intentionally provoke their seizures through visual stimuli. Self-induction methods are widely described in photo-sensitive patients, while there are only a few reports of those who are pattern-sensitive.

We analysed 73 images of environmental visual triggers collected from 14 pattern-sensitive patients with self-induced seizures. The images were categorized according to their topics: 29 Objects (43%); 19 Patterns (28%); 15 External scenes (22%); 4 TV or computer screens (6%). Six photos were of poor quality and were excluded from analysis. Images were analysed by an algorithm that calculated the degree to which the Fourier amplitude spectrum differed from that in images from nature. The algorithm has been shown to predict discomfort in normal observers. The algorithm identified thirty-one images (46%) as "uncomfortable". There were significant differences between groups of images (ANOVA p

= .0036; Chi2 p < .0279), with higher values of difference from nature in the images classified as "Objects" (mean 6,81E+11; SD 6,72E+11; n.17, 59%) and "Pattern" (mean 9,05E+11; SD 6,86E+11; n.14, 74%). During the semi-structured face-to-face interviews, all patients described the visual triggers as ‘uncomfortable’; the appearance of enjoyable visual epileptic symptoms (especially multi-colored hallucinations) transformed uncomfortable images into pleasant stimuli. Patients considered self-induction as the simplest and most effective way to overcome stressful situations, suggesting that self-inducing pattern-sensitive patients often use uncomfortable visual stimuli to trigger their seizures. Among the reasons for the self-inducing behavior, the accidental discovery of pleasurable epileptic symptoms related to these "uncomfortable" visual stimuli should be considered.

Keywords: pattern-sensitive epilepsy, self-induction, visual stimuli, uncomfortable images

1. Introduction

Simple or complex sensory stimuli can trigger seizures in epileptic patients or predisposed individuals. The ILAE classification defines these attacks as 'Reflex Seizures' (RS) [1], [2], [3]. Visual stimuli represent the most common cause of RS [4], [5] through an abnormal response of the visual system to light (photo-sensitivity) or to spatially structured patterns (pattern-sensitivity). About 70-80% of photo-sensitive patients show pattern-sensitivity, but both types of sensitivity can also be found to exist alone [6], [7], [8]. A photoparoxysmal response (PPR) is the typical EEG trait of photo-sensitivity, characterized by epileptic abnormalities elicited by intermittent photic stimulation (IPS). The PPR is considered an age-dependent heritable electroencephalographic trait [9], [10], often associated with clinical signs and symptoms. Sensitive patients may intentionally cause themselves seizures through visual stimuli. Self-induction methods are widely described in photo-sensitive patients [11], [12], [13], while there are only a few reports of those who are pattern-sensitive [14], [15]. The aims of this study were: 1) to collect images of environmental stimuli used by pattern-sensitive patients to self-induce seizures; 2) to analyse the characteristics of these images mathematically so as to classify them as ‘comfortable' (pleasant) or ‘uncomfortable’ (unpleasant); 3) to analyse the triggering effectiveness of each visual stimulus, as perceived and assessed by patients through a self-assessment scale, and to correlate it with the characteristics of the images obtained using the algorithm; 4) to analyse motivations and subjective experiences related to self-induction behaviors.

2. Methods

2.1. Selection of patients

All patients attended our epilepsy centre (Neurophysiopathology of childhood and adolescence, Department of Human Neuroscience, Sapienza University of Rome) for advanced diagnostic evaluation. Older patients were included if their seizures began in childhood and they had ongoing follow-up at our Epilepsy centre. Selection was based on the following criteria: 1) clinical history of RS induced by visual stimuli; 2) diagnosis of RS and pattern sensitivity confirmed by video-EEG monitoring; 3) occurrence of self-induced seizures triggered by environmental pattern stimuli, ascertained through clinical data.

2.2. Diagnostic criteria and clinical assessment

Seizures and epilepsies were diagnosed and classified according to the criteria of the Commission on Classification and Terminology Commission of the International League Against Epilepsy [1], [2], [3]. The study was conducted in accordance with The Code of Ethics of the World Medical Association (Declaration of Helsinki), and with appropriate ethical standards as required by the Ethics Committee of our Institution. All enrolled subjects or their parents provided written informed consent prior to participation, based on their age. Demographic features, medical and family history, disease course, and treatment were collected from parents during a face-to-face interview. All patients were clinically evaluated by standard general and neurological examinations. CT scan and/or MRI were performed according to the clinical needs.

From January 2009 to January 2019, a total of 273 patients were consecutively examined for visually induced seizures; 209 showed photosensitivity (associated with pattern sensitivity in 198 cases) whereas 48 had pattern sensitivity only (no epileptic EEG abnormalities were detected in the remaining 16 patients). From this overall sample, we selected 14 patients who met our inclusion criteria and were enrolled in this study as pattern sensitive patients with self-induced seizures.

2.3. Video-EEG recording and procedure of visual stimulation

All patients underwent a digital video-EEG recording (21 electrodes) at rest and during a standard procedure of visual stimulation with IPS, pattern stimulation, and at least 30 minutes of TV watching. IPS was tested, according to internationally recommended guidelines [16], in a darkened room by white flashing light 30 cm from the patient’s eyes (frequency range 1-60 Hz). Each frequency was tested by separate trains of flashes with an inter-stimulus free period of five seconds, with eyes opened, eyes closed, and during eye closure. Pattern sensitivity was tested using a standard procedure of stimulation, according to recommended guidelines [17] , as reported elsewhere [18]. Briefly, we used three types of black-and-white full-field pattern (checks, horizontal stripes, vertical stripes), two black-and-white hemi-field patterns (left and right, horizontal stripes), and one red/blue full-field pattern (horizontal stripes). Pattern reversal is the preferred stimulus for most clinical purposes, especially for visual evoked potential [19]. During this stimulation, the black and white elements (checks, stripes, etc.) change phase (reverse) abruptly (i.e., black to white and white to black) with no overall change in the total luminance of the screen, since each reversal shows equal numbers of light and dark elements in the display. Moreover, displays used for standard visual evoked potentials are specially designed to avoid transient luminance artifacts [20]. For the pattern-reversal protocol, we used this display system. Stimuli were presented with high contrast (Michelson > 0.8) and different sizes of the constituent elements giving different spatial frequencies. Stimuli were presented in reversal mode (1.6 Hz) to ensure a constant total luminance, and any reversal was synchronized with a digital marker (Figure 1). Each pattern was shown for 15 seconds to obtain an adequate number of stimuli, considering the reversal rate, with a free interval of at least 10 seconds. If any paroxysmal activity appeared, the stimulus was promptly stopped to avoid seizure induction.

2.4. Image collection and evaluation of their efficacy in triggering seizures

Each patient was asked to take a photo of the environmental stimuli they believed were effective to self-induced seizures. Indeed, previous studies [21] showed that photographs of scenes were a good substitute for the scenes themselves: for example, the assessments that observers made when looking at urban landscapes (buildings, streets, etc.) or natural scenes (lawns, trees , etc.) were strongly correlated with those made by observing photographs of the same places. Therefore, the photos thus obtained from each patient were then shown to all patients in the sample, asking them to carry out a self-assessment of the effectiveness of each stimulus to trigger seizures, according to a range of values from 1 (poor efficacy) to 10 (very effective). The images for self-assessment were presented during a clinical interview but not under EEG recording.

2.5. Analysis of the images

Several properties of visual stimuli can be quantified mathematically. The images provided by our patients were analysed using the algorithm developed by Penacchio and Wilkins [22], and classified thereby as 'comfortable' (pleasant) or 'uncomfortable' (unpleasant) as previously reported [23]. Briefly, uncomfortable stimuli differ from natural images in having an excess contrast energy at mid-range spatial frequencies (around 3 cycles per degree). The algorithm measures how closely each image approximates a natural image based on the shape of the two-dimensional Fourier amplitude spectrum. In images from the natural world the amplitude of the spectrum decreases with increasing spatial frequency approximately as 1/f, so that on log-log coordinates the shape of the spectrum approximates a regular cone with a slope of -1. By varying the height of the cone, the algorithm obtains the best fit to the Fourier amplitude spectrum of each image and weights the residuals by a contrast sensitivity function to give a single number that measures the departure between the amplitude spectrum of the image and the average amplitude spectrum for natural scenes according to the sensitivity of the visual system. Images with a high departure are generally rated as "uncomfortable" to view. To get the best unbiased images, photos taken by one of us (A.J.W.) were grouped into categories, and used to establish the normative values. The images provided by the patients were analysed with the same method and compared with those previously obtained in a group of normal subjects.

2.6. Investigation on self-induction behaviors

All patients underwent a face-to-face semi-structured interview to confirm the diagnosis of self-induction and to analyse motivations and subjective experiences related to these behaviors. Furthermore, to ascertain subjective ictal symptoms (hallucinations, micro/macropsies, etc.), immediately after the video-EEG recording, all patients were asked to report their subjective sensations and any symptoms related to the stimuli. We also asked cooperative patients to describe their visual symptoms by drawing.

3. Results

Demographic and clinical data of the sample studied were as follows: 14 patients (10 females and 4 males), age range 4.6 to 40.1 years (mean age 11.4 years). The type of epilepsy was idiopathic focal in 10 (9 occipital, 1 frontal), idiopathic generalized in 3 (absences), and symptomatic focal (occipital) in one. The diagnosis of occipital epilepsy was based on the presence of visual symptoms (hallucinations, micro / macropsies) in both spontaneous and RS, and on the occurrence of focal epileptic EEG anomalies in the occipital regions. Other main clinical and EEG data are shown in table 1.

3.1. Collected images

A total of 73 photos were collected from patients. The images were categorized according to their topics: 29 Objects (43%); 19 Pattern (28%); 15 External scenes (22%); 4 TV or computer screens (6%). Six photos were of poor quality and were excluded from analysis.

3.2. Image analysis

In the reference group of images, the mean departure was 2.34E+11 (SD ± 1.27E+11); therefore, any residual greater than 4.88E+11 was considered as abnormally high and the corresponding image would typically be rated as 'uncomfortable'. In the set of images provided by the patients we found 31 images (46%) exceeding this value. The mean departure and the occurrence of 'uncomfortable' images showed significant differences among subsets (Table 2), with higher values in the "Objects" and "Pattern" categories (Figure 2). Patients reported that the objects in the photographs were those they used to self-induce seizures, although we did not test any of these objects under EEG recording.

The self-evaluation on the triggering efficacy of the images showed considerable inter-individual variability (range of the mean score for patient = 0.1 - 8,9; overall mean score 3.4 ± 3.3).

Departure from the amplitude spectrum of natural scenes showed a low correlation coefficient (r = .09) with the self-assessment scores provided by the patients with respect to the triggering efficacy of the images.

3.3. Main results of the face-to-face semi-structured interviews

In all patients, the diagnosis of self-induction was made during follow-up, after repeated and careful clinical interviews, as patients were very reluctant to both admit self-induction behaviors and describe sensations related to seizures. All patients reported that the visual stimuli used to induce seizures were initially uncomfortable but later became pleasant due to the occurrence of hallucinatory symptoms. Patients reported a positive and pleasant elementary visual hallucination, generally consisting of multicolored stripes (Figure 3) or/and image distortions (micro/macropsies). These visual symptoms occurred when patients self-induced seizures in their natural living environment (also reported during the EEG recording in 8 cases), and were constantly followed by negative sensations (clouding of vision, hemianopia, amaurosis), always unpleasant and often associated with intra-orbital pain. If they endured these uncomfortable symptoms, they were rewarded by a pleasant change in contact with reality; they felt like they were in another pleasant place, light as if they were flying, or as in a dream state. These latter symptoms, if too intense, again became unpleasant with a progressive alteration of consciousness and, sometimes, were followed by bilateral tonic-clonic seizures. Reasons and motivations for self-induction ranged from boredom, anger, happiness, sadness, and were mainly related to emotional distress. Patients considered the self-induction as the simplest and most effective way to overcome stressful situations, and in many cases the self-inducing behavior had characteristics of obsessiveness and compulsiveness.

4. Discussion

Visual stimuli have been reported as the most common cause of RS [4], [5], through an abnormal response of the visual system to light or structured patterns. Furthermore, self-inducing behaviors have been noted in sensitive patients or predisposed individuals, who tend to voluntarily provoke their attacks using visual stimuli. Self-induction techniques have been extensively described in photo-sensitive patients [24], [25], [26], [27], [28], [29], and have included both natural and artificial lights, often used in different ways; waving fingers in front of the eyes or tremulous squinting eyelids staring at the sun or bright light (so-called "*sunflower syndrome*"), or staring at intermittent artificial lights (disco lights, Christmas tree lights, etc.). Self-induction behaviors in pattern-sensitive patients have been less frequently described, mainly represented by “contact” TV viewing and more rarely by intentional fixation of environmental patterns (mosquito nets, architectural structures, wallpaper, striped clothing, tablecloths, ceiling panels, etc.), skin pores, and round objects [8], [15], [30], [31], [32]. These patients often admitted that they were attracted to certain images, especially striped patterns, even if they initially felt "uncomfortable" looking at them. Penacchio and Wilkins [22] developed an algorithm to predict the discomfort associated with images, through simple mathematical properties of the images themselves. Patterns of stripes with a spatial frequency within two octaves of 3 cycles per degree have been reported to cause discomfort in normal individuals [33], and may induce seizures or migraine in predisposed subjects [17], [34], [35]. The spatial characteristics of images to which migraineurs are sensitive closely resemble those to which photosensitive epileptic patients are sensitive. There are differences but these concern the effects of pattern movement (which the algorithm did not consider). The effects of a vibrating pattern differ from a static pattern in epileptic patients with photosensitivity but not in migraineurs [34], [35]. The algorithm considered only the spatial aspects of images. Many of the images provided by our patients had these spatial characteristics, with high average value of residuals, so they would typically be classified as uncomfortable. Moreover, we found images with abnormally high residuals in the "Objects" and "Pattern" categories. These data confirm that they are normally regarded as unpleasant visual stimuli, frequently reported as triggers of RS [17], and suggest that self-inducing pattern-sensitive patients use these uncomfortable images to provoke their seizures.

Patients' assessment of the triggering efficacy of visual stimuli showed poor correlation with the mathematical characteristics of the images (residuals). The poor correlation could arise because of: i) inter-individual differences among patients in the ability to evaluate the trigger effectiveness of stimuli; ii) electro-clinical features with different degrees of sensitivity to visual stimuli; iii) influence of other factors (psychological, relational, or linked to specific situations) in addition to the visual characteristics of the images. The latter aspect could also explain the prevalence of females in our sample, due to gender-related differences in the types of psychiatric disorders during adolescence, with an increased risk of affective disorders in girls compared to boys [36], [37]. Finally, the evaluation expressed by the patients showed a high subjectivity and inter-individual variability; this aspect could further explain the lack of a significant correlation with the algorithm data.

Furthermore, as emerged in the interviews with patients, the appearance of pleasant visual epileptic symptoms changed uncomfortable images into pleasant stimuli, therefore, to be sought in the surrounding environment. Pleasant sensations have been found as ictal symptoms, especially in temporal lobe epilepsy [38], but were rarely reported in RS. Faught et al. [39] described a 32-year-old woman with self-induced photosensitive seizures that included strong subjective feelings of pleasure and masturbatory behavior. Her EEGs showed generalized polyphasic spike wave discharges in response to photic stimulation. Her behavior leading to seizures could be explained in terms of operant conditioning theory. Other data suggest a correlation between pleasure and voluntary induction of seizures, while ictal pleasure is rare in spontaneous seizures that are not under the control of the patient. Clément et al. [30] described two patients with self-induced seizures triggered by TV, and one of them reported the feeling of being in another pleasurable world after the seizures. Previously, Hutchison [24] reported two similar cases, in one of which self-induction was clearly linked to pleasure. In our patients, as often reported in pattern sensitive epilepsy [6], [7], [8], epileptic discharges clearly started in the occipital lobe, and were often associated with visual symptoms and preserved consciousness, at least at onset. It is conceivable that in these patients the perception of uncomfortable images precedes the onset of seizures; the subsequent appearance of ictal visual symptoms are perceived as a pleasant experience, since consciousness is still preserved. On the contrary, light-induced seizures are often associated with generalized anomalies or with focal discharges with immediate generalization, with loss of consciousness, and prevalence of some clinical signs (especially motor, such as eyelid myoclonia, myoclonic jerks, tonic-clonic, etc.) [4], [5], [6], [7]. Furthermore, the reversal mode we used allowed us to selectively evaluate the effect of spatially structured stimuli, but further studies on larger samples are needed to verify whether pattern reversal stimulation can be considered a predictor for pattern sensitivity in daily life.

The data from our study suggest that patients who self-induce seizures through visual stimuli develop a "*super competency*" on the epileptogenic characteristics of these stimuli. Even in an unfamiliar new environment, they are able to select visual triggers very quickly, adjust them to make them more effective, and calibrate exposure to these stimuli to get pleasant symptoms from seizures. Ng [40] reported several reasons for self-induction behavior: compulsion, intentional avoidance of stress, escape from unpleasant situations, boredom, hedonistic motivations, need to obtain a sense of control over the seizures, or attention-seeking. The accidental discovery of pleasurable visual epileptic symptoms, linked to some "uncomfortable" images, should therefore be added to the causes for self-inducing behavior. Furthermore, this pleasurable experience, fortuitously lived by the patients, could facilitate the development of compulsive behaviors, frequently noted in these cases [8], [28], [29],

[41], [42], with consequent resistance to treatment and difficulties in achieving seizure control. Finally, our observations underline the importance of careful evaluation of the circumstances in which seizures occur, for example, by including photographs of the stimuli and drawings of the visual symptoms. As recently described [43], this modern approach improves diagnosis and management of seizures induced by visual stimuli and may be particularly useful in patients with self-induction.

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Table 1

Main demographic data of studied patients

Type of seizures	
Spontaneous (11/14)	Absence 1 Absence + tonic-clonic 2 Focal onset with sensory symptoms (visual) 2 with motor signs 2 to bilateral tonic–clonic 4
Reflex (14/14)	Focal onset with sensory symptoms (visual) 8 with motor signs 4 to bilateral tonic–clonic 2
Age at onset epilepsy (mean ± SD)	6.3 ± 3.7 years
Age at onset self-induction (mean ± SD)	7.3 ± 3.2 years
Follow-up (mean ± SD)	6.6 ± 1.8 years
IQ (WISC-III)	Normal 13 Borderline 1
AEDs (5/14)	Valproate 3 Valproate + Ethosuccimide 2
EEG data	
Spontaneous discharges (11/14)	Focal Occipital 1 Temporo-occipital 6 Parieto-occipital 2 Frontal 1 Generalized 1
Spontaneous seizures (2/14)	Focal with spreading 2

Table 2

Image analysis for category

Group		**Residuals**					
	N	**Mean***	**SD**	**Confidence limits** -95%	+95%	**Abnormal**** N	(%)
a. Objects	29	6,81	6,72	4,25	9,36	17	(59)
b. Pattern	19	9,05	6,86	5,74	12,4	14	(74)
c. External scenes	15	2,11	1,07	1,52	2,70	0	(--)
d. Screens	4	1,38	0.40	0.74	2,03	0	(--)
Total	67	6,07	6,32	4,53	7,61	31	(46)

Note: departures with respect to natural scenes (mean, SD and Confidence limits of residuals) have been divided by 10^{11} for clarity

*) p = .0036 (ANOVA)

**) Abnormal = residual value < 4,88; Chi^2 p < .0279 (group a *vs* group b = NS; group c *vs* group d = NS)

Figure 1

Example of focal epileptic EEG abnormalities recorded by video-EEG in the occipital regions during pattern stimulation. The numbers indicate the type of pattern (3 = black-white squares) and are synchronized with the stimulus (each number coincides with a reversal)

Figure 2

Example of images collected by patients and categorized as ‘Objects’ and ‘Pattern’

Figure 3

Some of the drawings of visual hallucinations reported by patients. In bottom right example, the child first drew the TV picture (illustrated in the left part of the drawing) before the visual symptom overlay (right part of the drawing)

Pattern-sensitive epileptic patients use uncomfortable visual stimuli to self-induce seizures

Mario Brinciotti [a], Arnold J Wilkins [b], Olivier Penacchio [c], Maria Matricardi [a]

[a] Department of Human Neuroscience, Sapienza University of Rome

e-mail: mario.brinciotti@uniroma1.it; e-mail: maria.matricardi@uniroma1.it

[b] Department of Psychology, University of Essex, United Kingdom.

e-mail: Arnold@essex.ac.uk

[c] School of Psychology and Neuroscience, University of St Andrews, United Kingdom.

e-mail: op5@st-andrews.ac.uk.

Corresponding author: Prof Mario Brinciotti

Department of Human Neuroscience, Sapienza University of Rome - Via dei Sabelli, 108 - 00185 – Rome (Italy)

e-mail: mario.brinciotti@uniroma1.it **tel:** +39-0649972966

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Abbreviations: intermittent photic stimulation = IPS; photoparoxysmal response = PPR; reflex seizures = RS

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