



Clinical and electrophysiological pattern of startle epilepsy: a comprehensive literature review


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<https://doi.org/10.53480/emerg-neurol.de3b>

Received: 3 February 2022

Accepted: 23 May 2022

Published: 28 November 2022

Referees:
Alexandre Leclancher
Rania Zouari

Citation:

Margaux Cheval, Jacques Jonas,
Emerg Neurol 2022;1:3
<https://doi.org/10.53480/emerg-neurol.de3b>

Startle epilepsy is a rare form of epilepsy characterized by recurrent seizures that are triggered by a surprising stimulus. It affects children between 10 months and 14 years of age, with a history of brain damage due to ante- or neonatal hypoxia, and hemiparesis. The most common triggers for these seizures are auditory stimulation, followed by somesthetic stimulation and visual stimulation. Typical startle seizures are rare, and they have a large variety of clinical manifestations. The most frequent type is short hemitonic flexion seizures, followed by myoclonic seizures, and bilateral tonic seizures.

Few studies have focused on the electrophysiological features of this condition and the literature is controversial regarding the EEG pattern. Interictal EEG is often normal. The most frequent interictal abnormalities are a slowing of the background rhythm, associated with focal spikes in the frontal, central, and parietal regions. Several ictal EEG patterns have been reported: diffuse flattening of the background rhythm, focal fast activity, an isolated focal spike followed by a discharge of spikes. Intracerebral EEG recording shows primary and secondary motor cortex involvement as initial discharge areas. The most efficient antiepileptic drugs are Lamotrigine, Oxcarbazepine, and benzodiazepines. But most patients are often drug-resistant. Surgery is a possible albeit rare therapeutic option.

We describe the case of a 13-year-old female patient with hemitonic seizures triggered by surprising auditory stimuli. The video EEG allowed us to record and define an EEG pattern of her seizures. Interictal EEG showed right fronto-central abundant spikes. The ictal EEG showed right fronto-central and medial spikes followed by a fronto-central fast rhythm discharge. The clinical and electrographic data permitted the diagnosis of startle epilepsy. Our patient was treated with Levetiracetam during 6 months followed by Oxcarbazepine and Clobazam with a partial improvement (reduction of the frequency of focal to bilateral tonic-clonic seizures). Considering the usual pharmaco-resistance of this type of epilepsy, we proposed our patient a presurgical evaluation. This case shows that the diagnosis should be considered in paroxysmal dystonic movements with a stereotyped triggering factor, and underlines the importance of repeating the EEG recordings in this type of epilepsy. In this article we will review the literature, discuss the underlying pathophysiology, and identify the common electrophysiological characteristics associated with startle epilepsy.

Keywords: startle epilepsy, clinical pattern, pathophysiology, EEG pattern



Présentation clinique et électrophysiologique de l'épilepsie sursaut : une revue systématique

L'épilepsie sursaut est une forme rare d'épilepsie caractérisée par des crises déclenchées par un stimulus surprenant.

Cette forme d'épilepsie touche les enfants âgés de 10 mois à 14 ans, ayant le plus souvent des antécédents de lésions cérébrales dues à une hypoxie anté- ou néonatale, et une hémiparésie. Les crises sont le plus fréquemment déclenchées par une stimulation auditive, ou plus rarement par une stimulation somesthésique ou visuelle. Les crises de sémiologie typiques sont rares et les manifestations cliniques sont très variées. Le type de crise le plus fréquent est la crise en flexion hémi-tonique brève, suivies par les crises myocloniques et les crises toniques bilatérales.

Quelques études se sont penchées sur les caractéristiques électrophysiologiques de cette pathologie, et la littérature est très hétérogène concernant les aspects EEG de l'épilepsie sursaut. L'EEG interictal est souvent normal. Les anomalies inter-ictales les plus fréquentes sont un ralentissement du rythme de fond, des pointes focales, dans les régions frontale, centrale et pariétale. Plusieurs aspects EEG ictaux ont été rapportés : aplatissement diffus du rythme de fond, rythmes rapides localisés, pointe focale isolée suivie d'une décharge de pointes. Les enregistrements EEG intracérébraux montrent l'implication du cortex moteur primaire et secondaire comme zones de décharge initiales. Les médicaments antiépileptiques les plus efficaces sont la lamotrigine, l'oxcarbazépine et les benzodiazépines. Néanmoins la plupart des patients sont résistants aux médicaments. La chirurgie est une option thérapeutique possible mais qui nécessite un bilan pré-chirurgical rigoureux.

Nous décrivons le cas d'une patiente de 13 ans souffrant de crises hémi-toniques déclenchées par des stimuli auditifs surprenants. L'enregistrement vidéo de l'EEG nous a permis plusieurs crises. L'EEG interictal retrouvait des pointes abondantes fronto-centrales droites. L'EEG ictal montrait des pointes frontocentrales et médianes droites suivies d'une décharge de rythmes rapides frontocentrale. Les données cliniques et électroencéphalographiques ont permis le diagnostic d'épilepsie sursaut. Le patient a été traité par levetiracetam pendant 6 mois puis par oxcarbazépine et clobazam avec une amélioration partielle (réduction de la fréquence des crises avec bilatéralisation tonico-clonique).

Compte tenu de la pharmacorésistance habituelle de ce type d'épilepsie, nous avons proposé à notre patient de commencer une évaluation pré-chirurgicale. Ce cas démontre que le diagnostic doit être envisagé dans le contexte de mouvements dystoniques paroxystiques avec un facteur déclenchant stéréotypé, et souligne l'importance de répéter les enregistrements EEG dans ce type d'épilepsie. Dans cet article, nous réalisons une revue systématique de la littérature, discutons de la physiopathologie et identifions les caractéristiques électrophysiologiques retrouvées dans l'épilepsie sursaut.

Mots-clés : EEG, épilepsie sursaut, physiopathologie, sémiologie

Abbreviations

SMA: supplementary motor area
 EEG: electroencephalogram
 SEEG: stereo-electroencephalography
 MRI: magnetic resonance imaging
 fMRI: functional magnetic resonance imaging
 SPECT: single photon emission computed tomography
 FDG-PET: fluorodeoxyglucose positron emission tomography
 GM1: monosialotetrahexosylganglioside
 GM2: disialotetrahexosylganglioside
 IL 1 RAPL1: interleukin 1 receptor accessory protein-like 1

1. Introduction

Startle epilepsy is a rare disorder. It was first described by Alajouanine and Gastaut in 1955 [1] and subsequently characterized by Chauvel *et al.* in 1992 [2]. Nowadays it is classified as a reflex epilepsy by the International League against Epilepsy [3,4]. This form of epilepsy concerns patients with neonatal hemiplegia or other cerebral lesions of the motor cortex. It often occurs in childhood, however seldom cases of adult-onset epilepsies were reported [5,6]. The term "startle epilepsy" includes different seizure types triggered by a surprising auditory, somesthetic, or visual stimulus. Seizures can be generalized or focal, most often tonic,

and are triggered by a startle motor response. Though the pathophysiological mechanisms and networks involved are still poorly understood, they are thought to originate in the fronto-central regions. Patients are usually drug-resistant, and some studies have suggested the efficacy of surgery [7]. We could diagnose a typical form of startle epilepsy despite the variable clinical and electrophysiological patterns provided in the cohorts of the 83 patients reported in literature [5,8-11].

2. Case report

2.1. Clinical history

We admitted to our department, a 13-year-old right-handed female patient, with a medical history of a neonatal right frontal stroke. She had no other significant personal or family history. She didn't undergo any genetic exploration, to our knowledge. Neurological examination showed a mild left hemiparesis, limited to a difficulty to precise movements in the left hand and a spasticity of the left lower limb. The patient had no cognitive deficits. She was attending school at the normal grade for her age. She was followed by pediatricians and rehabilitation specialists for her neonatal handicap.

Her first epileptic seizure was bilateral tonic-clonic and occurred at six years old. A 15 days post-seizure

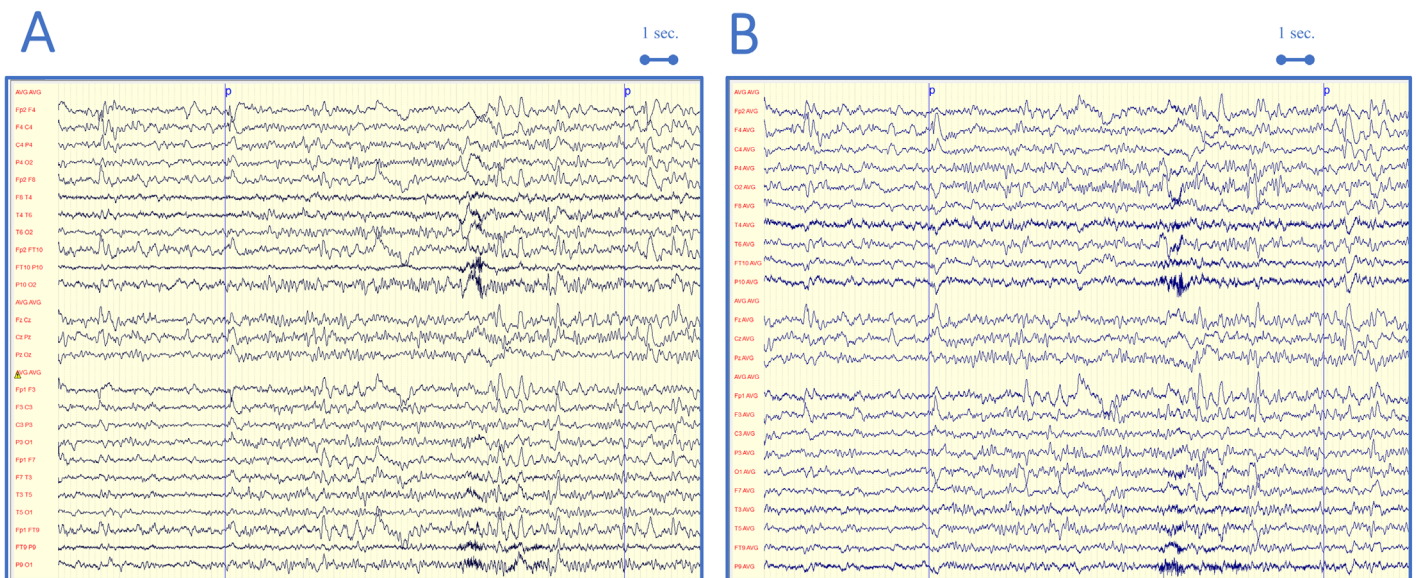


Figure 1. Interictal 23-electrodes EEG recording showing spikes and spikes-waves on the right fronto-central region and right parieto-occipital region. (A) Longitudinal bipolar setup. (B) Monopolar setup (p for spike-waves).

electroencephalogram (EEG) was normal and no treatment was started. Follow-up EEGs showed right frontal spikes. Subsequently, the patient had two similar seizures (at 1 year interval). Since these seizures were rare, the neuro-pediatricians did not retain the diagnosis of epilepsy and therefore did not start an anti-seizure medication. Three years later, a new type of seizures appeared. These began with paresthesia in the left arm, which sometimes expanded to the left lower limb. As a consequence, the left upper limb would reach a tonic position (flexion of the elbow and the wrist) with an inconstant involvement of the lower limb. At this stage, seizures either stopped, or resulted in a loss of consciousness and a secondary tonic-clonic generalization. Surprise, fear, and surprising "metallic" noises were the main triggering factors. The patient also reported nocturnal seizures, associated with nightmares. The frequency of these seizures increased rapidly, up to twelve episodes per day, with secondary generalization every 3 to 4 days. She was treated with Levetiracetam (500 mg twice a day, according to weight) during 6 months. Because of the absence of improvement, she was switched to Oxcarbazepine in March 2020 and had a decrease in the frequency of seizures. EEG inconstantly showed right frontal spikes. In brain MRI she had a porencephalic cavity in the right frontal lobe. The patient was referred to a neurologist for advice on this "paroxysmal dystonia". During the consultation, a seizure was provoked when the patient was surprised by the fall of a bunch of keys on the ground suggesting an underlying epileptic origin. The patient was referred to our epileptology tertiary "center for rare epilepsy" for an etiological assessment.

We performed sleep and wake video EEG recordings during five days with hyperventilation, intermittent light stimulation, and surprise stimulation to trigger seizures. We also reduced by half the dosages of Oxcarbazepine and maintained the patient awake during the first night of hospitalization. The patient did not receive benzodiazepine during these recordings.

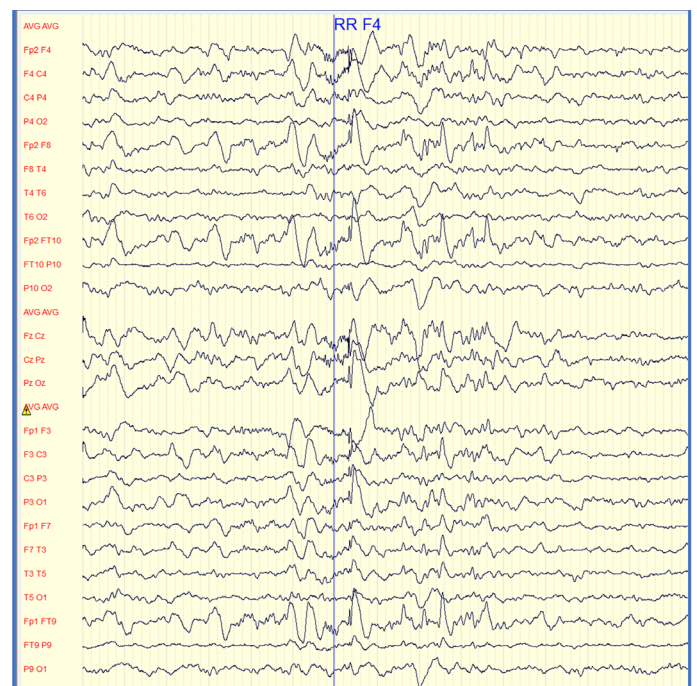


Figure 2. Interictal 23-electrodes non-REM sleep EEG recording (bipolar longitudinal setup) showing bilateral fast activities with a predominance over right fronto central electrodes.

2.2. Interictal EEG recordings

Interictal EEG recordings showed abundant spike activity over the right frontal and central electrodes (Figure 1). We also recorded less frequently, more posterior spikes (over right centro-parietal electrodes). In slow-wave sleep, we found short bilateral fast activity discharges, with an initial right frontal component, not associated with a clinical event (Figure 2).

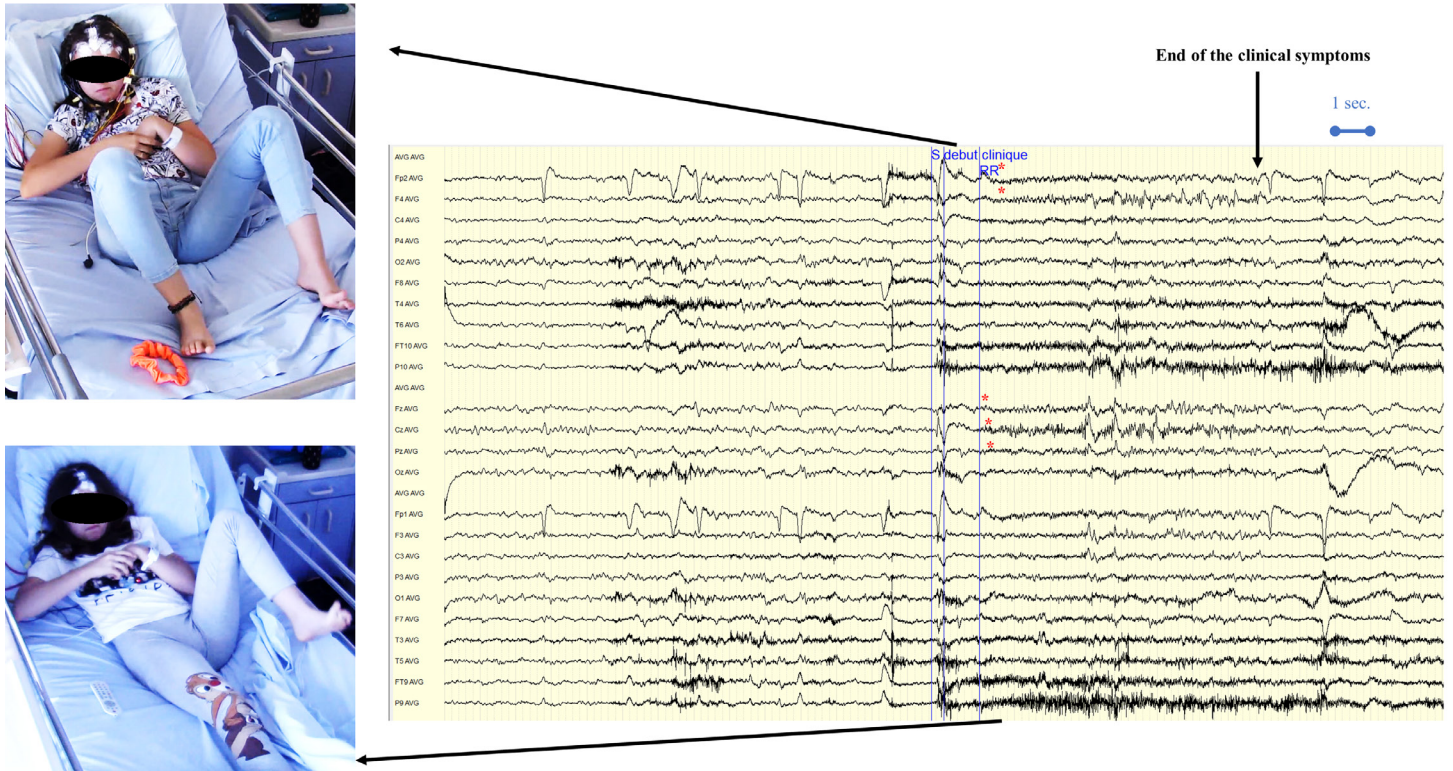


Figure 3. Ictal EEG video recording. Left panel, clinical characteristics. We observed a tonic posture of the left upper limb (flexion of the forearm and hand), tonic grimace, and flexion of the thigh and the hallux). Right panel: Ictal 23-electrodes EEG recording (monopolar montage). We observed a sharp wave followed by a discharge of fast activity (red stars) over right and median fronto-central electrodes. S shows the startling auditory stimulus.

2.3. Ictal EEG recording and clinical semiology

We could record ten seizures during the hospitalization. These seizures occurred mainly during the day, immediately after a surprising stimulus caused a startle reaction; meanwhile one seizure occurred spontaneously during the night. These ten seizures had similar clinical and EEG characteristics (Figure 3).

Clinically, after hearing a surprising noise, the patient had a startle reaction, followed by a tonic grimace of the face. Immediately thereafter, the left upper limb was in a tonic flexion (flexion of the forearm and the hand). During some seizures, a tonic contraction of the lower limb also occurred (flexion of the thigh and the hallux). The tonic posture lasted about 10 seconds and then resolved. There was no loss of consciousness. The patient reported that paresthesia in the left upper limb preceded the motor symptoms. We did not record seizures with secondary tonic-clonic generalization. During the immediate post-critical examination, the patient had a major motor deficit of the left upper limb.

Interpreting ictal EEG was difficult because of the initial startle artifact (Figure 3). The seizure probably started as a sharp wave over electrode Cz was recorded. Then, there was a discharge of fast activity on right and median fronto-central electrodes (Fp2, F4, Fz, Cz). We performed several provocative tests to determine which sensory modalities were involved in the triggering of seizures. Tactile stimulation, whether or not startling, of the left upper limb did not cause a seizure. Surprising visual stimulation (throwing objects)

did not trigger seizures. Seizures were only triggered by surprising noises (e.g., loud call). Noises did not trigger seizures if the patient was informed previously.

2.4. Therapeutic management and follow-up

We hypothesize that the generator of the seizures was in the right sensory-motor cortex. We pursued treatment with Oxcarbazepine (600 mg, twice a day) and combined it with Clobazam (5 mg, twice a day) for long-term treatment. At follow-up, the patient and her family reported a decrease in the frequency of focal seizures to once to twice a day and the absence of generalized seizures. The treatment was well tolerated, except for a slight drowsiness. The neuropsychological assessment revealed a delay in execution and a slight deficit in working memory.

Considering the usual pharmaco-resistance of this type of epilepsy, we offered our patient to start a presurgical evaluation. Because of the pandemic, the patient could not benefit from an intracranial recording by SEEG. We are also awaiting a functional motor MRI.

2.5. Discussion of the case

This case highlights that the clinical and electrophysiological diagnosis of startle epilepsy is not always easy. The diagnosis should be considered in paroxysmal dystonic movements with a stereotyped triggering factor, even if other non-suggestive seizures of reflex epilepsy have occurred previously.

This case also illustrates the importance of repeating the EEG recordings for a precise analysis considering artifacts and pseudo normal patterns during the seizure. In this patient's case, we suggest surgery. A pre-surgical assessment must be very rigorous in the case of patients with mild motor and cognitive deficits, so as to avoid major postoperative complications. The limitations of our case are the lack of follow-up data, as the patient could not benefit from intracranial recordings, and the difficulties of interpreting the ictal EEG.

3. Comprehensive literature review on startle epilepsy

Startle epilepsy was first described in 1955 by Alajouanine and Gastaut [1]. Since then, the literature has been enriched by several small cohorts, thus allowing a better characterization of the syndrome. It should be distinguished from other startle-associated syndromes, such as hyperekplexia, where the exaggerated startle response can lead to falls, but without other clinical manifestations nor changes in EEG [12,13]. The clinical and EEG characteristics of startled-epilepsy patients were studied in five cohorts, corresponding to 83 patients, which showed an important variability [5,8-11] (Table 1).

3.1. Review methodology

We reviewed literature on startle epilepsy along with the most frequent electrophysiological characteristics reported in PubMed and Google Scholar database. And searched the following keywords: startle AND epilepsy AND electrophysiology OR EEG recording. This review included papers from 1955 to 2021 (this study was conducted in 2021). We selected studies and case reports that matched our keywords and investigated further studies with large cohorts and electrophysiological data. After selecting 35 studies, most of which were isolated case reports, we focused on five cohorts reporting electro-clinical data of over ten patients [5,8-11].

3.2. Epidemiologic characteristics and medical history

Startle epilepsy usually begins between 10 months and 14 years of age [1,5,8-11,14], however a few cases of late adult-onset have been reported [5,6]. The sex ratio is balanced. It often occurs in the context of hemiparesis and brain damage secondary to ante- or neonatal hypoxia [1,5,8-11,14], and less frequently in patients with Down syndrome [15], Lennox-Gastaut or Sturge-Weber syndrome. More rarely, startle seizures can be observed in genetic lysosomal storage disorders (partylglucosaminuria, GM1 and GM2 gangliosidosis and Krabbe disease) [16] or in patients with IL1RAPL1 gene deletion [17].

Patients with neonatal brain lesions often suffer from cognitive impairment [1,5,8-11,14]. However, in the cohort of Chauvel *et al.* [2] and Job *et al.* [18] underlined that cognitive deficit is not systematic and that a proportion of patients could pursue higher education. Brain imaging reveals

abnormalities like multifocal lesions or cortical atrophy (most often fronto-central or parietal) [1,5,8-11,14]. However Job *et al.* [18] reported a series of 3 cases without lesions on cerebral MRI nor pathology screening.

3.3. Triggers of seizure

The auditory modality is the most common trigger of seizures, followed by somesthetic stimulation (most often stimulation of the paretic hemisphere) and visual stimulation. A case of seizures triggered by a strong and startling odor has been described [19]. The intensity of the stimulus which is required to trigger seizures is highly variable, depending on the patient's level of attention and anticipation. The occurrence of seizures during sleep, as in our patient, has been described (25% of patients in the cohort of Aguglia *et al.* [8]). The occurrence of unprovoked seizures is also quite frequent, up to 100% of patients depending on studies, and is described in the 5 cohorts [5,8-11].

3.4. Clinical manifestations of seizures

There is a great heterogeneity in the ictal manifestations described in startle epilepsy. Our patient's seizures starting with paresthesia followed by a hemi-tonic contraction, were reported in 26% of the cases in the cohort of Manford *et al.* [5]. Initial somesthetic manifestations could have been underestimated in the other cohorts, particularly those in which patients suffered a major cognitive impairment [10]. Literature also reports symptoms such as epigastric sensation, automatism, or urination [10]. Hemi-tonic seizures (in the paretic limbs) are the most frequent type of seizure, followed by myoclonic seizures and bilateral tonic seizures. Generalized tonic-clonic seizures are also common and may be found as frequently as tonic seizures in some studies [9]. Rarely, patients may show absence-type seizures [5,11] or atonic seizures [8]. As shown in Table 1, the distribution of clinical data according to seizures' type is variable across studies. The phenomenology of unprovoked and provoked seizures can be similar or quite distinct. In most cases, like ours, unprovoked seizures of different phenomenology can precede by years the onset of startle epilepsy. Literature is homogeneous in terms of high seizure frequency, over one seizure per day.

3.5. Interictal and ictal EEG recordings

There are variable electro-clinical patterns of startle epilepsy described in the literature. Recent series [5,10,11] report normal interictal EEG in 45% of patients. Commonly observed interictal abnormalities include a slowing of the background rhythm, focal spikes (over frontal, centro-parietal, medial electrodes sometimes over temporal electrodes), multifocal spikes [1,5,8-11], or spike-and-slow-wave pattern [20]. Subclinical rhythmic spike discharges were also described [8,11]. In the cohort of Aguglia *et al.* 8 sleep recordings allowed the detection of frontal abnormal activities in all patients.

Recent cohorts focusing on ictal EEG patterns agree on the short duration of seizures, of less than 10 seconds. Like in our patient's case, focal fast rhythms are described at the

Table 1. Systematic review of the five major startle epilepsy cohorts (NB: the Chauvel *et al.* cohort was not included in this table because of its descriptive nature).

	Aguglia <i>et al.</i> 1984 [8]	Sàenz-Lope <i>et al.</i> 1984 [9]	Manford <i>et al.</i> 1996 [5]	Tibussek <i>et al.</i> 2006 [10]	Yang <i>et al.</i> 2010 [11]
Number of patients	16	15	19	22	11
Age at onset	4 to 33 years	2 to 14 years	Child 73%, Adult 27%	10 month to 14 years	5 month to 7 years
Aetiology					
Perinatal anoxia	62,50%	87,50%	-	13%	18%
Encephalitis	12,50%	6%	5%	8%	18%
Seizure semiology					
Hemi-tonic	50%	40%	52%	-	36%
<i>Focal sensory onset (paresthesia) then hemi-tonic</i>	-	-	26%	-	-
Generalized tonic- clonic	-	53%	5%	4%	9%
Bilateral tonic	38%	-	15%	27%	45%
Myoclonic	-	-	-	36%	54%
Absence-like	-	-	5%	-	9%
Trigger					
Auditory	100%	100%	100%	86%	72%
Somesthetic	50%	6%	31%	31%	36%
Visual	-	-	15%	4%	-
Occurrence of non provoked seizure	37%	26%	47%	54%	100%
Of different semiology than provoked seizure	-	26%	26%	-	-
Cerebral imaging					
Imaging modality	CT	CT	MRI	MRI	MRI
Normal	6%	-	52%	-	18%
Focal cortical atrophy	18%	-	10%	22%	36%
<i>Localization of atrophy</i>	<i>Fronto-temporal or fronto-mesial</i>	-	<i>Peri-sylvian</i>	-	<i>Temporal or frontal or peri-sylvian</i>
Multiple lesions	-	-	-	45%	36%
Bilateral lesions	-	50%	-	-	-
Unilateral lesions	18%	40%	-	-	-
Inter-ictal EEG recording					
Interictal abnormalities localization	Fronto-central	Frontal or temporal	Fronto-central or temporal	-	Generalized or fronto-mesial
Ictal EEG recording					
Normal EEG during seizure	0	0	66%	22%	0
Diffuse electrodecremental pattern	0	Presence	0	59%	63%
Fast rhythms	0	0	11%	40%	9%
Ictal abnormalities localization	Vertex	Vertex	Frontal	Frontal or central or parietal or fronto- mesial	-
Pharmaco-resistance	100%	50%	100%	77%	100%

Notes: Not all data are presented in this table, explaining that the sum of the percentages given in this table do not add up to 100%.

Abbreviations: CT = computed tomography, MRI = magnetic resonance imaging.

onset of seizures [5,10,11,14] in 9 to 40% of cases. The most common initial pattern in these cohorts is diffuse flattening of the background rhythm (called diffuse electrodecremental pattern or DEP), present in approximately 60% of patients. Ictal EEG pattern appears as an isolated focal spike (over median, right, or left fronto-central electrodes) followed by a rhythmic localized or bilateral discharge of spikes. The representation of each ictal EEG pattern is different across the five cohorts [5,8-11]. It is important to note that EEG recording may be normal during a seizure or difficult to interpret due to muscle artifacts in 22 to 66% of cases [5,10]. In fact, identifying startle muscle artifacts can hamper the analysis of the seizure's onset.

3.6. Intracerebral EEG recordings

Chauvel *et al.* [2] provide SEEG recordings from twenty patients with startle epilepsy. The seizure starts with an abnormally high voltage in the primary motor cortex or supplementary motor area, in the same time frame as a spike recorded in scalp EEG over the central median electrode, *i.e.*, Cz (called "evoked spike"). This is followed by a low-voltage rapid discharge, also localized either in the primary motor cortex or in the supplementary motor area, with a propagation to the mesial cortex of the homolateral and contralateral frontal lobes. For Chauvel and colleagues, startle epilepsy seizures thus originate in the motor and premotor cortices. Other recent studies reported a seizure onset zone located in the premotor cortex [21-22], the prefrontal cortex, and anterior and middle cingulate cortex [23]. The SMA was involved in the epileptic network of the majority of cases [21-24]. Using the Epileptogenicity Maps method, Job *et al.* [18] identified an increase of high frequency oscillations in the premotor and prefrontal areas during startle epilepsy seizures and a constant involvement of the SMA.

3.7. Treatment

Startle epilepsy is often drug-resistant. Commonly used treatments with relative efficiency include Lamotrigine [25,26], Oxcarbazepine, and benzodiazepines [8]. Vagus nerve stimulation was effective in isolated case reports [27]. Non-invasive sound generator treatment [28] could reduce 50% of seizure-frequency in two patients out of four. This device produces a background sound that does not disturb hearing but induces a relaxing mood and a feeling of control over the sound environment.

Surgery was effective in many studies [7,18,21-24,29,30]. However, the proximity to the primary motor cortex requires rigorous preoperative evaluation and the use of intracranial recordings. Different types of procedures are proposed with similar results: corpus callostomy [7,29], hemispherotomy [30] or focal resection [7,18,21-24]. In these studies, postoperative outcomes at one year (or more) were satisfactory with a majority of Engel class 1 [7,18,21-24,29,30], and showed no associated motor or cognitive deficit. Post-operative motor deficit could also rapidly improve in a few months [24]. One patient [7] had persistent myoclonic jerks several times a day but he no longer had seizures with falls and loss of consciousness. The surgery performed in this patient was a callostomy, which could explain the

reduction of generalized seizures but the persistence of focal seizures.

Job *et al.* findings [18] underline the fact that surgery should be considered even in the absence of MRI lesions. However it is important to note that there probably is a publication bias in favor of the cases with a good response to surgery.

3.8. Pathophysiology of startle epilepsy

There are anatomical, and pathological mechanisms underlying startle epilepsy [1,2,20,31-36]. Surface EEG recordings and functional neuroimaging (fMRI, ictal SPECT, FDG PET) showed mesial fronto-parietal cortex, primary and premotor cortex, supplementary motor area, primary somesthetic cortex and precuneus involvement in the generation of seizures. Chauvel *et al.* recorded startle epilepsy with SEEG and proposed a potential involvement of the proprioceptive transcortical loop in the startle response. The startle stimulus triggers the startle (subcortical mechanism), which generates a proprioceptive signal (through the osteoarticular and muscle receptors). This proprioceptive afferent volley projects on the somesthetic cortex and then on the motor cortex by a reflex transcortical loop, and triggers a critical motor discharge, making it more excitable. For these patients, the motor cortex is the site of neonatal lesions. This hypothesis can be defended sometimes if we identify latency between the occurrence of the "evoked spike" and the first bursts of critical muscle activity. Lamarche and Vignal [36] suggested the existence of such a transcortical loop, connecting the somesthetic afferences coming from neuromuscular spindles to the primary somesthetic cortex and the primary motor cortex. This hypothesis is supported by Bancaud's experiments [32] on an animal model of startle epilepsy. When the animal is curarized, the seizures disappear. This also helps explain how various sensory modalities can induce startle seizures. For our patient, it is important to note that the startle response is amplified, possibly because of brain lesions associating spasticity and loss of cortical feedback control [1,2,32]. Based on functional imaging data, Fernandez *et al.* [33], proposed an evolutionist explanation of the existence of this transcortical loop. The startle reflex aims to prepare for a voluntary movement in response to the threat; this motor response itself requires spatial orientation information, through a somatosensory channel, to be correctly directed. Therefore, the authors hypothesize that the startle reflex would prepare the "defensive" voluntary movement in response to the stimulus, via activation of the supplementary motor area and the premotor cortex, according to the provided spatial information of the primary somatosensory areas.

4. Conclusions

Startle epilepsy is a rare form of reflex epilepsy triggered by a surprising stimulus causing a startle response. Our case illustrates that the diagnosis should be considered in patients with paroxysmal dystonia. The clinical and electrophysiological characteristics are very heterogeneous. However, clinicians should recall the predominance of tonic seizures, most often triggered by an auditory stimulus, the possibility

of unprovoked seizures, the fronto-central localization of interictal abnormalities, and the ictal EEG pattern showing fast rhythmic discharges in the fronto-medial regions during seizures. As shown in our case, electrophysiological diagnosis is not always easy. Long-term video EEG recording helps make accurate diagnosis if associated with sensory modalities stimulations. A pathophysiological study of startle epilepsy, with its provoked seizures, is an interesting way to understand the mechanisms of ictogenesis. Invasive recordings helped demonstrate the involvement of a large fronto-parietal network including the premotor cortex, the primary motor cortex, the supplementary motor area, the primary somesthetic cortex and the cingulate gyrus. The transcortical reflex-loop model, activated by the proprioceptive afferent volley secondary to startle, is the most reliable hypothesis and the most consistent with data from patients and animal models.

Statements

Author contributions. Margaux Cheval : writing – original draft. Jacques Jonas : supervision, review.

Declaration of interest. The authors declare that they have no conflict of interest.

Ethics statement. All patients treated in our unit have signed an authorization to use their data, images, and videos for research or teaching purposes.

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