

Seizure anticipation: Are neurophenomenological approaches able to detect preictal symptoms?

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Abstract

Analysis of electroencephalographic signals and several brain imaging studies suggest that a preictal state precedes the onset of seizures. In this study, we used phenomenological strategies to detect modifications in patients' experience before their seizures. We observed that patients with partial epilepsy feeling an aura ($n = 9$) frequently experienced prodromes ($n = 6$). Prodromes were subtle preictal symptoms, varying among patients and having common negative features. They were generally continuous before seizures and could last hours, whereas auras were sudden and intermittent. All patients were able to recognize facilitating factors. We also found that patients spontaneously develop cognitive countermeasures to avoid facilitating factors ($n = 6$), to prevent a seizure ($n = 1$) or to interrupt a seizure ($n = 5$). Prodromes are not specific enough for clinical use, but could refine the behavioral strategies used in the treatment of epilepsy and the pathophysiology of the preictal state.

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1. Introduction

The unpredictable nature of seizures leads to permanent insecurity for patients with epilepsy and their families, and is the main cause of their altered quality of life. Despite important progress in the understanding of the cellular mechanisms of epilepsy and in the localization of the epileptogenic focus, the pathophysiology of seizure emergence remains unclear.

Analysis of the electroencephalographic signal using mathematical methods suggests that it is possible to detect a preictal state in electroencephalographic dynamics before seizure onset [1–5]. In particular, phase synchrony analysis

has revealed a decrease in synchrony between brain areas surrounding the epileptogenic focus before seizures, underlining the role of dysfunctioning networks in partial epilepsy. A few functional brain imaging studies, using single-photon emission computed tomography (SPECT), functional magnetic resonance imaging (fMRI), or an intracranial thermal probe, have also identified modifications of local cerebral blood flow before seizures. However, these methods are not specific enough for current clinical application. In addition, they do not explain the underlying abnormalities. Finally, these strategies indicate the brain structure, but not the nature of the preictal phenomena.

Complementary approaches are therefore needed to acquire additional insights into the preictal period. Concerning the patient's lived experience, the phenomenological aspect, some patients report subjective symptoms

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before their seizures. These preictal symptoms are also called *prodromes*, *premonitory sensations*, or *warning symptoms*. These should be distinguished from the *aura*, which is an ictal symptom, also called *simple partial seizure*. Auras can be classified, according to the International League Against Epilepsy [6], into sensory, motor, autonomic, and psychic simple partial seizures. As they provide crucial information in localizing epileptogenic zones where the seizure starts, neurologists and epileptologists are involved in identifying the aura, the emergence of which is related to the epileptic discharge on the electroencephalogram (EEG). Auras are usually brief, lasting a few seconds or minutes (<5 minutes). Auras can be isolated or can evolve into a complex partial seizure.

On the other hand, prodromes are less studied or acknowledged subjective symptoms, probably because neurologists and epileptologists have often neglected these symptoms, which seem to have no localization value. The frequency of prodromes is difficult to evaluate, and they are probably underdiagnosed, but prodromes seem to be more frequent in partial epilepsy than in primary generalized epilepsy. Studies have relied on questionnaires with fixed items or on open-ended interviews. The main symptoms reported are headache and dysphoria [7–10]. Prodromes may occur between 5 minutes and 24 hours before the seizure, and do not correspond, by definition, to epileptic discharges on the EEG.

Prodromes therefore represent an additional argument suggesting the existence of a preictal period. A better description of these symptoms may help us understand the neuronal mechanisms that underlie the transition from the interictal to the ictal state. These symptoms may be combined with the neurodynamic modifications detected before the seizure onset by analyzing the EEG signal. In addition, these symptoms may represent an interval during which the seizure may be prevented by some acute therapeutic intervention. That is why awareness of these symptoms is the core of the behavioral treatment of epilepsy.

Neurophenomenological methods [11] are rigorous approaches that have been demonstrated to be highly efficient in the cognitive neurosciences in studying perception and emotion. These methods are used to establish correlations between precise “first person” descriptions of the subjective experience of a given cognitive process (phenomenological descriptions) and “third person” measures of the corresponding neuroelectric activity. For example, first person descriptions of three distinct attentional states before the realization of a given cognitive task enabled detection of three characteristic patterns of phase synchrony between EEG signals during the task [12]. In our study, we used a neurophenomenological strategy to describe precisely patients’ preictal and ictal experience, then we analyzed and compared these descriptions to identify prodromes. This phenomenological analysis of nine patients with drug-resistant partial epilepsy led to the detection of prodromes that correspond mainly to

“negative” symptoms. We also found that a number of patients tried to prevent or control their seizures through specific countermeasures. Finally, we hypothesized a correlation between these negative symptoms and the preictal state that can be detected through electroencephalographic dynamics.

2. Methods

2.1. Patient population

Nine patients with drug-resistant partial epilepsy with subjective symptoms preceding their seizures were included. They were selected from patients examined at the Epilepsy Unit of La Pitié-Salpêtrière Hospital in Paris. The selection criteria were (1) the ability to recognize a “high-risk” state for a complex partial seizure spontaneously, even without awareness of precise “warning” symptoms, the description of which will be refined in the course of the interviews; and (2) a capacity for introspection and expression sufficient to participate in a phenomenological interview. All patients underwent brain MRI scans and EEGs, seven of the nine patients also underwent long-term video/EEG monitoring. In addition, three patients underwent brain fluorodeoxyglucose-positron emission tomography (FDG-PET) and two underwent ictal SPECT to better localize their epileptogenic focus. Table 1 summarizes the main clinical, imaging, and EEG characteristics of the patients.

2.2. Phenomenological analysis

2.2.1. Collecting descriptions of the preictal subjective experience

We used a specific interview technique, called the explication session, which helps the patient become aware of his or her experience and describe it [13,14]. This process of explication unfolds in four stages:

First, we choose a particular seizure from the past for which the patient retains a memory. If the patient sometimes feels warning sensations, we choose a seizure in which these sensations were especially vivid; if the patient does not experience warning sensations, we choose a recent seizure or one that she or he remembers. Then we have to identify the right moment to begin the description. In the case of warning sensations, we choose a temporal marker shortly before the start of these sensations, and begin the description there. If the patient did not feel anything in particular, we start from the morning preceding the seizure.

Second, we guide the patient toward a concrete evocation of this particular preictal experience, by helping him or her rediscover, in a precise manner, the images, sensations, and sounds associated with the experience, until the patient feels that she or he is “reliving” it.

Third, when the evocation is sufficiently stabilized, we help the patient to turn his or her attention toward the internal process, which may have been unconscious, “pre-reflected,” until then. By use of a specific form of questioning, the patient is guided through an exploration of various registers of her or his subjective experience: visual, kinesthetic, auditory, and olfactory sensations; emotions; and internal dialog. A set of precise clues, which may be verbal (e.g., use of the present tense), paraverbal (e.g., slowing of the word flow), or nonverbal (e.g., coverbal gestures, or the shifting and unfocusing of the eyes, i.e., the subject disengages with the interviewer and looks off into empty space, beyond the horizon), enable the interviewer to check that the patient is actually returning to a past experience.

Finally, we enable the patient to put his experience into words, the main difficulty being the paucity of vocabulary for describing these subtle sensations.

The average length of an explication interview was 1 hour 30 minutes. All patients were interviewed at least twice. The subsequent interviews, which focused on other preictal experiences, enabled us to specify more precisely and/or complement the initial descriptions (i.e., to obtain a finer description of the same type of sensation or a description of sensations that had not yet been described).

Table 1
Clinical, imaging, and electrophysiological data

Patient	Sex	Age at epilepsy onset	Age at time of phenomenological interview	Medical history	Brain imaging	EEG	Antiepileptic drugs
1	M	16	38	Brain trauma at 15	<i>MRI</i> : right polar frontal and temporal atrophy, associated with medial temporal atrophy	<i>Interictal EEG</i> : right frontal and temporal interictal epileptic abnormalities	Carbamazepine, tiagabine
2	F	1	38	Zoster encephalitis	<i>MRI</i> : Left hippocampal sclerosis	<i>Video/EEG</i> : left rhythmic activity in the temporal lobe	Carbamazepine, lamotrigine
3	F	4	25		<i>MRI</i> : small dysplastic gyration in left opercula <i>FDG-PET</i> : left opercular and temporo-occipital hypometabolism <i>Ictal SPECT</i> : increased blood flow in left frontal opercula and insula	<i>Video/EEG</i> (6 nocturnal seizures): artifacts, no interictal abnormalities	Valproate, oxcarbamazepine, lamotrigine
4	M	12	53	Glomerular nephritis at 12	<i>MRI</i> : right hippocampal sclerosis	<i>Video/EEG</i> (7 seizures): right rhythmic activity in the anterior temporal lobe	Carbamazepine, lamotrigine
5	F	15	28	Febrile seizure at 2	<i>MRI</i> : normal <i>FDG-PET</i> : moderate left temporo-occipital and anterior temporal hypometabolism <i>Ictal SPECT</i> (late injection): increased blood flow in left temporal, parietal, and frontal lobes	<i>Video/EEG</i> with 8 intracranial electrodes in the left frontal, temporal, and parietal lobes (5 seizures): no clear identification of the epileptogenic zone (presumed to be in the insula or deep in the central sulcus)	Carbamazepine, phenytoin
6	M	11	35	Head trauma at 3 months, febrile seizure at 2	<i>MRI</i> : right hippocampal sclerosis	<i>Video/EEG</i> (12 seizures): right rhythmic activity in the temporal lobe	Carbamazepine, valproate, lamotrigine
7	F	16	23		<i>MRI</i> : normal	<i>Interictal EEG</i> : no epileptic abnormalities	Valproate, topiramate
8	M	5	31		<i>MRI</i> : normal <i>FDG-PET</i> : moderate right basal and mesial temporal hypometabolism	<i>Video/EEG</i> : 15 simple partial seizures without scalp EEG abnormalities, and 4 complex partial seizures with unclear expression; right temporal interictal epileptic activity.	Valproate, gabapentin, oxcarbamazepine
9	M	10	24	Febrile seizure at 1	<i>MRI</i> : left hippocampal sclerosis	<i>Video/EEG</i> (10 seizures): diffuse activity with left temporal lobe predominance	Carbamazepine, valproate, topiramate, clobazam

2.2.2. Analyzing and comparing the collected descriptions

Once the descriptions are gathered, reorganization and analysis are necessary to delineate and reveal the structure of the experiences described. The main stages follow:

We resequence the description. The chronology of the process of awareness and the chronology of the experience are not identical. When the subject relives the experience for the first time, he or she provides quite a coarse “large-mesh” description. The patient needs to go over it several times to become conscious of all the dimensions of the experience, and to provide a fine-mesh description.

We analyze each description to extract the microstructure of the experience, that is, the precise sequence of sensations and possible actions that constitute the experience (e.g., “I feel this sensation of compression in my lungs/I recognize it/I get off my bicycle in order to protect myself”).

Then we detect possible regularities on different levels: diachronic, synchronic, or functional. A regularity on the *synchronic* level is a sensation of the same nature, for example, a particular visual sensation preceding the seizure, described several times by the same patient or by different patients. A regularity on the dynamic or *diachronic* level is a succession of sensations of the same nature. A *functional* regularity is a succession of mental and/or physical operations of different natures that have the same objective, for example, preventing or stopping a seizure.

2.3. Classification of the subjective symptoms

Symptoms described by the patients during the phenomenological interviews were then classified either as auras (ictal phenomena), if they fit those previously described during their medical evaluation in the Epilepsy Unit or those classically described in simple partial seizures, or as prodromes (preictal phenomena) if they do not.

3. Results

3.1. Illustrative example of prodromic sensations

To illustrate the subjective symptoms a patient may experience before a seizure that cannot be related to a simple partial seizure (or aura), we present an extract from an interview with a 30-year-old woman (Patient 5) (**Table 1**) using the phenomenological method. The patient identified a particular state preceding most of her seizures, occurring up to 24 hours in advance. She described this “feeling that a seizure is preparing” as follows:

This can be 24 hours in advance. It’s in the whole body, I feel ill at ease, inside, it’s constant, and it won’t leave me until the fit has manifested. What I feel is ... a little as if my body was abandoning me, therefore it isn’t responding as quickly as usual, taking longer to carry out the orders I give it. I will get a pain in the head, it starts at the forehead, passes to the temples and goes as far as the back of the neck, like a circle around the head, and then down the neck...

Then it’s speech. I have a tendency to slur words, stammer, lots of little things like that. But not all the time: I might be talking correctly and then suddenly, oops! The words won’t come, I’ll start coughing, steady myself and it will pass. Other things also, like slightly feverish but all over the body. It’s like I said a while ago, that my body won’t respond as quickly as usual. And also a lack of energy. If someone suggested doing something, going out, anything, I’ll say no, because I

don’t want to do anything. Because I don’t feel well, because things aren’t going well ... I have no energy, no vitality, no punch.

When she experienced these “premonitory” or prodromic sensations, the patient protected herself by not driving. She also described brief phenomena corresponding to the aura that generally occurred 30 seconds before the loss of consciousness:

There’s this headache: a circle in front of me down to the cervix, which presses in all around the head. Then a feeling of heat inside my body which rises from my stomach to my head. At the same time my heart accelerates. Then just after a little dizziness, like when one moves one’s head quickly, but in this case without moving one’s head. Right after there’s a sensation of panic, of nervousness all over the body.

When she feels the aura sensations, she leans against a wall to avoid falling. If she is alone in a room, she tries to alert her family, for example, by dropping an object. She also tries countermeasures to interrupt the seizure:

I start breathing when I feel my heart accelerating. I breathe from the abdomen to try and calm my heart. I breathe in deeply and stop. If I feel that helps I breathe normally again. If not, I breathe out quickly a little air and inhale deeply again. I have the impression that that decompresses, it seems to make this area here (the chest) more free. The feeling of heat goes, there is more room. It’s the sensation I get when I start to exhale which tells me if I will continue and start breathing normally or again inhale quickly.

3.2. General results

The phenomenological approach allowed patients to recognize subjective symptoms before a complex partial seizure (**Table 2**). All patients experienced auras (ictal phenomena); six experienced prodromes (preictal phenomena).

The auras varied, depending on the suspected epileptogenic focus: vegetative ($n = 7$), dysmnesic ($n = 4$), psychic ($n = 3$), sensory ($n = 1$), or motor ($n = 1$).

The main prodrome (which was often described by the patients with very similar words) was a feeling of “tiredness,” “weakness,” “lack of energy,” or “fragility” ($n = 4$). Other patients described a feeling of distress ($n = 3$), ill-being ($n = 1$), or “loss” ($n = 1$). These feelings were associated with difficulties in concentrating and speaking ($n = 1$); clumsiness ($n = 2$); hypersensitivity to light ($n = 2$), noise ($n = 1$), or other stimuli ($n = 1$); and headache ($n = 2$). Ictal symptoms may usually be described as “positive,” because they often correspond to motor, sensory, or verbal hyperactivity. In contrast, prodromic symptoms frequently correspond to a decrease (in energy or vitality) or a lack (of concentration, words, or physical balance) and may be described as “negative.” They last, often intensifying, until the onset of the seizure.

Table 2

Facilitating factors, prodromes, and auras

Patient	Facilitating factors	Prodrome	Aura (simple partial seizure)
1	Fatigue, sleep deprivation	No (the seizure cancels what happens before)	Feeling of absurdity, tachypsychia, sudden reminiscences, epigastric oppression
2	Intermittent photic stimulation	Distress, feeling of loss, irritation provoked by various stimuli	Déjà vu, warm feeling, breathing difficulty
3	Anxiousness, annoyance, fatigue	Fatigue, feeling of head compression since the awakening, buzzing in the ears, lower limb weakness, vertigo, and distress	<i>Daytime seizures</i> (infrequent): right hand anesthesia (or right nasal paresthesia), anxious, right upper limb elevation, then tonic posture of the four limbs and falls without loss of consciousness <i>Nocturnal seizures</i> (frequent: each night): tonic posture of the four limbs starting from the right upper limb
4	Cold (and cold drinking), rapid movement of the head	Feeling of fragility, fatigue, troubled by noise, bad mood (according to his wife); these symptoms sometimes occurred 24 hours before the seizure	Dizziness, cold feeling in the lower limb, fear of dying as a “earthquake”; rarely, thoracic oppression, then complex partial seizure
5	Fatigue, stress, onset of menses	Feeling of ill-being, weakness, lack of energy and vitality, clumsiness; aching, troubled by noise and light, concentration difficulty, elocution difficulty, headache; these symptoms sometimes occurred 24 hours before the seizure	Feeling of going out, of losing control of her body, tachycardia, warm feeling, aphasia then loss of consciousness, and frequent secondary generalization
6	Stress, relaxing period, alcohol	No	Ascending epigastric warm feeling, dizziness, then complex partial seizure
7	Fatigue, alcohol, sleep deprivation	Distress since the awakening	Right hand paresthesia, then modification of hearing perception, then complex partial seizure
8	Stress, fatigue, noise, video game, emotion	Weakness, fatigue, and fragility since the awakening	Feeling of flash or explosion in the head, tachycardia, distress, then complex partial seizure
9	Fatigue, alcohol, sleep deprivation, period of stress or of decreasing stress	No	Ascending epigastric feeling, then sometimes déjà vécu, or dreamy state, nausea, then complex partial seizure

Prodromes preceded seizures usually by several hours (≤ 24 hours), whereas auras occurred a few seconds or minutes before the other ictal symptoms. Except for this difference in time courses, patients were not able to distinguish between prodromes and auras.

Prodromes were continuous and progressive, whereas auras were sudden and intermittent.

All patients were also able to recognize facilitating or provoking factors (Table 2). These consisted of fatigue

($n = 6$), stress ($n = 4$), sleep deprivation ($n = 3$), alcohol consumption ($n = 3$), intermittent photic stimulation including video games ($n = 3$) and other rhythmic sensory stimulations ($n = 2$), emotion ($n = 1$), and relaxation ($n = 1$).

Finally, we found that patients spontaneously adopted different cognitive or behavioral countermeasures: (1) to prevent the seizure by recognizing either precipitating factors or prodromes, and (2) to interrupt seizures during

Table 3

Summary of countermeasures developed by the patients to avoid or to stop their seizures

Patient no.	Countermeasures to avoid the seizure	Countermeasures to stop the seizure
1	Sleeping, relaxing	To get up, to walk, to have a look at his plants or his cat, in order to recover his sense
2	No	Inward monologue: “I must stop”
3	Relaxing. During prodrome: to take her mind off things (for instance, by working), to speak of that annoys her	No
4	Relaxing	No
5	Relaxing, sleeping, half-time working	Abdominal breathing
6	No	No
7	No	Her friend tells funny stories. She twists her fingers
8	Relaxing, fishing	No
9	When stressed, regular breathing. When too quiet, hands rubbing	High amplitude breathing to decrease the heart rhythm. Hands rubbing

auras (**Table 3**). The countermeasures were variable in nature. Physical countermeasures consisted of motor (getting up, walking), sensory (rubbing the area where paresthesia occurred), or vegetative (regular breathing) activities. Mental countermeasures were internal (focusing on an object, internal monologue) or external (conversation). These countermeasures were initiated by the patient or by relatives when they detected a seizure. As the goal of an explicitation interview, unlike that of a questionnaire, is not to collect quantitative estimations, but to elicit precise descriptions of a few preictal experiences, we cannot give a precise evaluation of the success of these countermeasures. Nevertheless, we gathered some testimonials that reflect the beliefs of the patients about the effectiveness of their countermeasures: "When a seizure is arriving, my friend tells me funny stories. For little seizures, it always works." "Sometimes, I can stop the seizure with this abdominal breathing that I learnt when I was practicing yoga. But most of the time, it only delays the onset of the seizure."

4. Discussion

In this study, we observed that patients with partial epilepsy who have auras frequently experience prodromes. Prodromes comprise subtle preictal symptoms, which vary among patients, but share the common feature of a distressing modification of the relationship with themselves or with the surrounding world. They are generally continuous until the seizure, and may last hours. Their identification cannot be used clinically as they are not specific enough. Nevertheless, the existence of prodromes is additional evidence suggesting that ictogenesis is a progressive phenomenon. We also found that patients spontaneously develop cognitive countermeasures prevent a seizure or to interrupt a seizure once it has started.

The frequency of prodromes is difficult to evaluate. First, it depends on the technique used to research the prodrome: a questionnaire approach with fixed items is less sensitive than a phenomenological approach with long, repeated, open interviews. Second, distinguishing between prodromes and auras is difficult, for both the patient and the physician. For instance, repeated isolated auras are frequently not recognized by the patient as ictal phenomena. Unless they have a well-documented account of the patient's epilepsy, physicians find it difficult to classify the subjective symptoms into preictal and ictal categories. Therefore, most previous studies analyzed the frequency and characteristics of these subjective symptoms together.

4.1. Description difficulties

Several factors may limit description of the preictal subjective experience:

1. The first difficulty is not specific to epilepsy, but concerns the subjective experience in general. A large part of our experience is prethought, non conscious. This explains the paucity of initial verbal self-reports on any subjective experience. Becoming aware of this prethought dimension necessitates special training and/or the mediation of an interview.
2. Seizures are unpredictable. The descriptions cannot be gathered in "real time," but are elicited *a posteriori*, sometimes long after the seizures.
3. Seizures that occur during sleep are not informative, because the patients are not aware of prodromes.
4. In an awake patient, peri-ictal amnesia may erase memory of the preictal period.
5. Some patients may have a permanent memory deficit or reduced ability to perceive subtle feelings preceding seizures, because the epileptogenic zone is located in the medial temporal lobe or because of the secondary effects of antiepileptic drugs.
6. Some patients are afraid that the evocation of a past seizure may trigger a new seizure.
7. The perception of warning signals often triggers an emotional reaction of distress and panic, which, in turn, hampers the perception of warning signals.
8. The existence of prodromes is not well recognized by physicians. Patients may have been counseled about the unpredictability of their seizures, and preictal symptoms that did not fit classic auras may have been neglected.

The ability to identify preictal prodromes is highly variable. Phenomenological analysis helps patients become better aware of this subjective experience and discover other symptoms. Several strategies could be used in the future to increase patients' awareness of these symptoms: (1) Patients can be allowed to view the video recordings of their preictal period obtained when they are hospitalized for long-term video/EEG monitoring. (2) Patients can be instructed to use a logbook, in which they daily describe their inner mental states, and report all preictal and ictal symptoms after each seizure. (3) Relatives of patients can be involved in the description of the preictal period. (4) Patients can be trained in relaxation techniques to avoid the distress that is sometimes associated with preictal or ictal symptoms and submerges the preictal sensations.

4.2. Hypothesis of the preictal state

Interestingly, prodromes are frequently referred to as *negative* symptoms, whereas auras are frequently referred to as *positive* symptoms, similar to their meanings in schizophrenic disorders. Ictal symptoms in partial epilepsy generally result from hyperactivation of an eloquent focal brain area. On the other hand, preictal symptoms, as observed in five patients in our study, may reflect a

decrease in activity in disparate parts of the brain or a decrease in their interconnection.

Negative symptoms during the preictal period reflect the loss of phase synchrony that has been previously reported in analyses of EEGs [15,16]. Phase synchrony analysis measures the degree of coupling of two EEG signals recorded from intracranial electrodes. In contrast to the hypersynchronization seen during the seizure, the preictal period is associated with a progressive decrease in synchrony between the EEG signal from the epileptogenic focus and the signal from surrounding areas. The epileptic neurons located in the epileptogenic zone, as they lose their large-scale connections to brain dynamics during the preictal period, and as they may lose the inhibitory control from surrounding areas, become idle and can be recruited to build the seizure. The *negative* symptoms observed in five patients in this study may be related to this loss of connectivity and, therefore, may be the clinical expression of the phenomenon (Fig. 1).

4.3. Countermeasures

Some patients not only can identify preictal symptoms, but have also spontaneously developed behavioral strategies to prevent or stop a seizure.

4.3.1. Ability to prevent a seizure

The ability to prevent seizures, developed by six of the nine patients, implies that the patient can identify the precipitating factors, which was the case for all patients in this study, or the prodromes, which was the case for six patients.

The facilitating factors are similar to those previously reported [17–20]. The higher frequency of perception of these factors, and the larger number of factors identified by each patient in our study can be explained by the use of the elicitation interview. Nevertheless, as cleverly underlined by Spatt et al. [19], identification of a facilitating factor by a patient does not necessarily prove its causal relationship with a seizure. Patients may attempt to

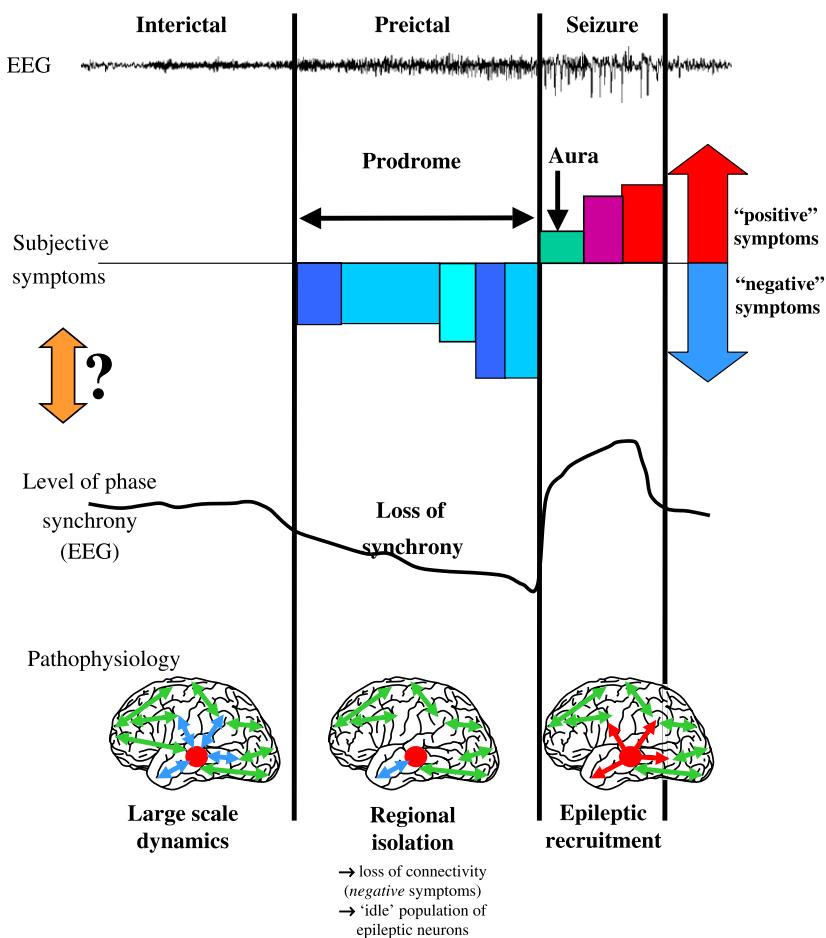


Fig. 1. Hypothesis of the preictal state. We suggest that during the preictal period, patients with partial epilepsy experience prodromes that comprise mainly *negative* symptoms. These prodromes may be concomitant with the loss of synchrony that has been measured between EEG channels connected to the focus. Therefore, the loss of connectivity during the preictal period may explain the *negative* symptoms, and isolation of the focus from the ongoing large-scale dynamics may facilitate epileptic recruitment of the adjacent neurons. The red spot represents the epileptogenic focus, the blue arrows the regional connections, the green arrows the large-scale connections, and the red arrows epileptic propagation.

identify these events to give their seizure a feeling of predictability.

Countermeasures consisted of neutralizing the facilitating factor (relaxing, sleeping) or avoiding it (early sleep, drinking no alcohol, etc.). In addition, one patient experiencing prodromes developed preictal countermeasures (taking her mind off things, or speaking about things that annoy her).

4.3.2. Ability to stop a seizure

The ability to stop seizures, developed by five of the nine patients, implies that the patient can identify auras. The countermeasures were highly varied, and consisted mainly of physical and mental activities.

Several groups interested in cognitive control of seizures have reported promising results [9,21–23]. Dahl proposed adapting countermeasures to the preserved brain functions at the beginning of a seizure, by activating healthy neuronal networks surrounding the presumed epileptogenic zone. Others have suggested that young patients, using biofeedback strategies, may generate a cognitive state similar to that of the postictal inhibitory period, where the probability of seizure recurrence is weak [24]. Patients require long-term training in these behavioral strategies before becoming efficient in their use. Social and familial support is needed [25,26]. Nevertheless, Spatt et al. [19] warned that self-reporting of seizure abortion does not necessarily demonstrate the efficiency of these countermeasures, as auras frequently stop spontaneously.

Difficulties in evaluating the efficiency of countermeasures in stopping a seizure have previously been discussed with respect to patients who undergo vagus nerve stimulation using magnet activation [27]. The placebo effect, indirect effect (mental activities related to activation of the magnet), or direct effect may account for the reported benefit among one-fifth of the patients.

Fenwick [17] suggested that inhibition of the neurons (“group 2” according to the Lockard’s animal model) surrounding the epileptogenic zone may be the correlate of behavioral countermeasures in stopping seizures. In view of previous results from phase synchrony analysis in humans, we can now speculate that preventing the isolation of neurons in the epileptogenic focus using physiological recruitment of surrounding neurons may prevent or stop seizures.

4.4. Perspectives

Further studies are needed to refine the correlation between the phenomenological approach and EEG signal analysis. In the future, we plan to perform simultaneous analyses of EEG synchronization and subjective correlates, during presurgical evaluation of patients with intractable partial epilepsy justifying intracranial EEG electrodes. We will test the hypothesis of the loss of synchrony during negative preictal symptoms. In addition, single seizures

would be subjected to phenomenological analysis. For patients able to interrupt their seizures, we will analyze the neuroelectrical correlates of their countermeasures.

The technical aspects of this correlation are solved, because real-time analysis of EEGs is now possible. On the other hand, comparison of phenomenological and neurodynamic dimensions remains difficult.

5. Conclusion

Our study suggests that patients with partial epilepsy may experience preictal symptoms. Although such prodromes are not fully recognized among the epileptology community, prodromes may be additional proof of the existence of the preictal state. In addition, the neurophenomenological approach to seizure anticipation may reinforce some hypotheses about the neurobiological basis of preictal states and may refine behavioral strategies as treatment for epilepsy.

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