A few thoughts on “What is a seizure?”

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Abstract

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When discussing seizure detection or seizure prediction, the assumption is often that the object of study, the seizure, is clearly defined. If it is not possible to clearly define a seizure, how can we discuss its detection or its prediction? We will see that there are several definitions of “seizure,” that the definition depends on the context of the study, and that we probably have to live with a fuzzy definition. Despite this fuzziness, however, it is possible to work effectively on seizure prediction and detection. We do not discuss below the issue of epileptic versus nonepileptic seizures and assume that the seizures under consideration are epileptic.

The original definition of an epileptic seizure is that of a behavioral event, perceived by a patient or noted by an observer. The different types of epilepsy were defined from the careful observation of these behavioral events and the patients’ descriptions of their feelings. Some of the behavioral manifestations are minimal (blushing, small muscle twitch), and some of the feelings described by the patient are minimal or uncertain (short inattention, slight tingling, strange feeling). One can already see that the definition of a seizure from behavior can lead to uncertainty: Is the small twitch part of normal behavior or is it part of the seizure? The situation is made more complex by the fact that some behavioral manifestations of seizures can be detected only by interacting with the patient: a seizure may include an amnesic component, revealed only if the patient is given something to remember during the seizure and interrogated afterward, or the inability to speak, missed if the patient is simply watching television or sleeping. Finally, one can hypothesize that some behavioral manifestations occur but we are not able to detect them because our testing is too crude or incomplete. We know for instance, that some parts of the frontal lobe are involved in planning the execution of complex tasks. If a seizure discharge is limited to such a region, it is most likely that the patient’s planning ability during the seizure is impaired. It is also most unlikely that it will be possible to objectively demonstrate this impairment, at least in the context of standard observer–patient interaction. One can conclude that some seizures are totally unambiguous, some are very uncertain, and there is continuity between the two extremes.

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The behavioral seizures felt by the patient or observable by others are the medical problem of patients with epilepsy. It is for these seizures that the patient seeks treatment. It did not take long for early electroencephalographers (EEGers) to discover the tight coupling between such behavioral seizures and EEG discharges. This early discovery and work with experimental models of epilepsy led to the commonly used definition of a seizure as a temporary dysfunction of the brain consisting of an excessive synchronous neuronal discharge. For the purpose of this article, we assume that indeed an epileptic seizure is defined by such a discharge, implying also that such a discharge is an epileptic seizure. We will come back later to the fact that this definition is incomplete (what is “excessive,” “synchronous”? How long should the discharge be?). In practice, however, this definition is not very useful because we are usually not in a position to observe a large number of neurons and determine if they are firing excessively and with a particular level of synchrony. We use the EEG as a substitute.

We saw above that the determination of the presence of a behavioral seizure depends on how closely one observes the patient and interacts with her or him. In a very similar way, the presence of a seizure discharge on the EEG during an epileptic seizure depends on how closely the EEG is able to detect the part of the brain where the excessive and synchronous neuronal discharge takes place. In some cases, the seizure discharge is visible on scalp EEG, in other cases it is invisible on scalp EEG but visible with intracerebral electrodes; in still other cases, it is altogether invisible, presumably because the intracerebral electrodes are located too far from the excessive discharge. Just as we discussed above the existence of *behavioral seizures*, we can define *EEG seizures*. Unlike the definition that is sometimes used (seizures present on the EEG but without clinical manifestations), I define an EEG seizure as an event on the EEG (by whatever means it is recorded), *independent of its possible behavioral accompaniment*. Because of the weaknesses in behavioral observation and in EEG recording, the correspondence between behavioral seizure and EEG seizure is far from perfect: some behavioral seizures are not accompanied by EEG seizures and vice versa. In many cases, particularly with large seizures, EEG and behavioral seizures are concomitant and clear. With smaller seizures, whether EEG or behavioral, the pairing of the two events is more uncertain.

Seizure detection and prediction rely primarily on analysis of the EEG. Other modalities have also been investigated but they are usually recorded with the EEG and the EEG is used to define a seizure. In this context, I think that behavioral seizures should be ignored: those working with the EEG, and who cannot analyze the behavior of the patient, should be concerned with detecting and predicting *EEG seizures*. Except for large seizures, there is no straightforward procedure to determine from the EEG pattern of a seizure if it is also a behavioral seizure; and there is no way to know with certainty if a behavioral seizure is an EEG seizure. Therefore, analysis of the EEG cannot predict with confidence the occurrence of behavioral manifestations. Therefore, in development of a system of seizure detection and prediction, it makes little sense to separate seizures according to the occurrence of behavioral manifestations. All EEG seizures should be used for training and testing the system. In a final step, it may then be interesting to report how many of the detected or predicted EEG seizures were also behavioral seizures. One should then also report on the behavioral seizures that were not EEG seizures.

The natural question that comes next is of course: “What is an EEG seizure?” Just as we described above from behavioral observation a continuum between large seizure, small seizure, minimal seizure, and no seizure, we have to expect a continuum between a large EEG seizure (e.g., involving all channels with large-amplitude activity compared with background and lasting 1 minute), a small seizure (e.g., involving a few channels with a moderate-amplitude change and lasting 20 seconds), a minimal seizure (e.g., involving two channels with a disputable amplitude or frequency change, lasting 8 seconds), and no seizure at all. As we will never have access to a perfect observation method, that is, electrodes everywhere, we will never know what happens where we are not recording. The only data available to us are what we record. It is always possible that we are not at the focus; we can be at any distance from the focus. The seizure may therefore take any of the above forms. If we accept this concept of *continuum*, then we also accept that there is no *formal* boundary separating seizure from nonseizure. We can only define an *operational* boundary, such as: the discharge must involve at least a 30% increase in amplitude compared with the background, in at least two channels and for at least 10 seconds (I realize that the 30% increase in amplitude is still vague, but it is sufficient for our conceptual illustration.) Using such a boundary allows us to define an EEG seizure for the purpose of detection or prediction and to measure sensitivity and false detection rates. One then has to remember the relative arbitrariness of the definition. When discussing results, it might be interesting to evaluate, for instance, whether false detections have some of the characteristics of EEG seizures: some may have all necessary characteristics but last less than the required 10 seconds; others may be artifacts.

The concept of continuum is consistent with the experience of EEG interpretation. This is true in scalp EEG but probably even more marked in intracerebral EEG, where potential EEG seizures can go from a 3-second burst of spikes to a 5- or 7-second burst, a 4-second run of beta or gamma frequency, or an 8-second run of sharp 10-Hz activity, to a 10-second burst including a few spike-and-wave patterns followed by a fast alpha discharge, to a 12-second pattern starting with a large spike and followed by a rhythmic but evolving beta activity. Is there a natural boundary? Is there a formal boundary between a very short seizure and a long interictal discharge (we know that interictal discharges can be accompanied by minimal behavioral manifestations).

The final step in defining a seizure is defining the seizure onset and the seizure end. The end is usually relatively clear and is generally of less interest than the onset. With respect to the onset, we go back to our concept of continuum. In many seizures, the onset is very clear and does not lend itself to argument. In some seizures, however, the onset is gradual, and finding a boundary involves a degree of arbitrariness. A classic example is the type of onset often seen in the hippocampus and consisting of large spikes becoming gradually more frequent, with a brief burst of fast activity following each of the later spikes, the bursts becoming longer and the interspike interval becoming shorter until a clear seizure discharge is present. One can argue that the first spikes are interictal (they often have the same distribution as interictal spikes seen remotely from the seizure), with a return to baseline between each spike. But then when do these interictal spikes become ictal? I think that the instant of seizure onset does not actually exist and one has to use a convention to define it, here again remaining aware of its operational nature.

It is a little disappointing to realize the fuzziness of the events in which we are so interested, and this fuzziness complicates our life. It is important, however, to realize that it is an intrinsic part of the phenomenon we are studying, a part that cannot be separated from the method of observation we are using. It is not useful to think “if we had another method of observation....” Another method would most likely have similar limitations.