Epilepsy Research (2013) **104**, 246—252

journal homepage: www.elsevier.com/locate/epilepsyres

Dynamic characteristics of absence EEG recordings with multiscale permutation entropy analysis

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Received 18 March 2012; received in revised form 1 October 2012; accepted 12 November 2012
Available online 12 December 2012

KEYWORDS
Absence seizure;
EEG;
Multiscale permutation entropy;
Classification

Summary Understanding the transition of brain activities towards an absence seizure, called pre-epileptic seizure, is a challenge. In this study, multiscale permutation entropy (MPE) is proposed to describe dynamical characteristics of electroencephalograph (EEG) recordings on different absence seizure states. The classification ability of the MPE measures using linear discriminant analysis is evaluated by a series of experiments. Compared to a traditional multiscale entropy method with 86.1% as its classification accuracy, the classification rate of MPE is 90.6%. Experimental results demonstrate there is a reduction of permutation entropy of EEG from the seizure-free state to the seizure state. Moreover, it is indicated that the dynamical characteristics of EEG data with MPE can identify the differences among seizure-free, pre-seizure and seizure states. This also supports the view that EEG has a detectable change prior to an absence seizure.

Introduction

Absence seizures are a form of generalized seizure accompanied with spike-and-wave discharges (SWD) in the electroencephalogram (EEG) (Meeren et al., 2002; Gorji et al., 2011). These sudden and abrupt seizures are transient signs and/or symptoms of abnormal, excessive, or synchronous neural activities in the brain (Polack et al., 2007; Amor et al., 2009; Bai et al., 2010), and may have significant impact on the educational development of sufferers (Killory

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0920-1211/$ — see front matter
http://dx.doi.org/10.1016/j.eplepsyres.2012.11.003

et al., 2011). Over the past decade, seizure dynamics, from seizure-free to seizure onset and to seizure ending, have been investigated using different mathematical methods, both linear and non-linear (Kramer et al., 2010; Neymotin et al., 2010; Schindler et al., 2007). To some extent, these results indicated that the characteristic of EEG changes during pre-seizure phases may be detectable in focal epilepsy a few minutes before the actual seizure onset (Mormann et al., 2006, 2007; Stacey et al., 2011). However, the prediction of sudden and abrupt seizures by detectable dynamic changes in the EEG is still debated in absence patients (Li et al., 2007; Stacey and Litt, 2008). It is challenging to understand the transition of brain activities towards an absence seizure and look for some precursor activities (Crunelli et al., 2011; Rosso et al., 2009a, 2009b; Gupta et al., 2011). Our previous analysis of dynamic changes in the EEG (in Genetic Absence Epilepsy Rats from Strasbourg) has demonstrated that EEG epochs prior to seizures exhibit a higher degree of regularity/predictability than seizure-free EEG epochs, but they present a lower degree than that in seizure EEG epochs (Li et al., 2007; Ouyang et al., 2008). Sitnikova and Luijtelaar showed that the SWD activity (in Wistar Albino Glaxo/Rijswijk rats) is preceded by short lasting delta and theta precursor activities in cortex and thalamus, but the combination rarely occurs during control periods (Sitnikova and van Luijtelaar, 2009; Sitnikova, 2010; van Luijtelaar et al., 2011). These EEG precursors in rat models give us a clue in predicting human absence epilepsy. To investigate possible changes in the EEG activities before the onset of seizures, it is necessary to conduct further analysis in absence patients.

Various methods have been proposed to analyze the temporal evolution of EEG recordings (Stam, 2005; Mormann et al., 2007). In particular, a series of entropy-based approaches have been widely used since they can quantify the 'complexity' of an EEG in health and disease (Li et al., 2007; Neymotin et al., 2010; Richman and Moorman, 2000; Yuan et al., 2011). Recently, Bandt and Pompe proposed the Permutation Entropy (PE) method to measure the irregularity of non-stationary time series (Bandt and Pompe, 2002), where the basic idea is to consider order relations between the values of a time series rather than the values themselves. The Sample Entropy (SampEn) algorithm, also a universally adopted approach, relies on the idea that the counts of m-long template matching within a tolerance *r* will also match at the next point (Richman and Moorman, 2000). Compared with SampEn, the advantages of the PE method are its simplicity, low complexity in computation without further model assumptions, and robustness in the presence of observational and dynamical noise (Bandt and Pompe, 2002; Bandt et al., 2002; Rosso et al., 2007). These advantages facilitate the use of PE for investigating the intrinsic structures in EEG data since it could extract informative features from epilepsy EEG data (Li et al., 2007; Nicolaou and Georgiou, 2012), sleep data (Nicolaou and Georgiou, 2011) and anaesthesia EEG data (Li et al., 2008, 2010; Olofsen et al., 2008).

On the other hand, traditional entropy algorithms are single-scale based and therefore fail to account for multiple scales inherent in brain electrical activities (Costa et al., 2002, 2005). To address the problem, Costa et al. proposed the multiscale entropy (MSE) (Costa et al., 2002) to measure the complexity of a time series by considering the correlations over multiple spatio-temporal scales of a time series instead of a single scale (Catarino et al., 2011; Mizuno et al., 2010). Motivated by the merits of PE and MSE, we propose a method called multiscale permutation entropy (MPE) to explore whether PE can replace SampEn in estimating multiscale entropy of EEG recordings. Moreover, we examine whether MPE can be effectively used to represent the dynamic characteristics of absence EEG recordings during different seizure states and evaluate the effectiveness of MPE measures in classifying different seizure states by linear discriminant analysis (LDA) (Webb, 2006).

Materials and methods

EEG recordings

EEG recordings were obtained from 7 patients (4 males and 3 females) with absence epilepsy, aged from 8 to 21 years old. The study protocol had previously been approved by the ethics committee of Peking University People's Hospital and the patients had signed informed consent that their clinical data might be used and published for research purposes. The EEG data were recorded by the Neurofile NT digital video EEG system from scalp surface electrodes (International 10-20 System) with 256 Hz sampling rate using a 16-bit analogue-to-digital converter and filtered within a frequency band of 0.5—35 Hz. In this study, EEG recordings from electrode C3 were selected for further analysis.

To investigate the dynamical characteristics of EEG data during different seizure phases, the EEG signals of absence epilepsy were selected and dissected from seizure-free (dataset I), pre-seizure (dataset II) and seizure (dataset III) intervals, where 60 2 s EEG epochs from 7 patients were selected for each dataset. The timing of onset and offset in spike-wave discharges (SWDs) was identified by an epilepsy neurologist (XZL), and these SWDs were defined as large-amplitude rhythmic 3—4 Hz discharges with typical spike-wave morphology lasting >1.0 s. Short (2 s) EEG recordings were used because 1) it is clinically difficult to obtain long EEG recordings during absence seizures (Sadleir et al., 2011); and 2) the duration of the pre-seizure state is only about a few seconds as determined from the rat model (Li et al., 2007; Ouyang et al., 2008). As shown in Fig. 1, the criteria for the selection of the seizure-free, pre-seizure and seizure data are that the interval between the seizure-free data and the beginning point of seizures is greater than 15 s, the interval is between 0 and 2 s prior to seizure onset, and

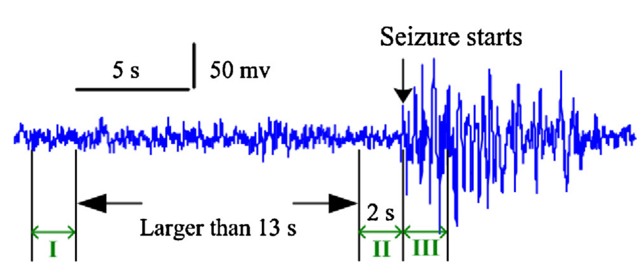

Fig. 1 The continuous EEG recordings with an absence seizure, and EEG epochs during seizure-free, preseizure and seizure intervals denoted by I, II and III, respectively.