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Mutlivariate synchronization analysis of EEG recordings from epilepsy patients

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1. Introduction

We compute multivariate synchronization measures from electroencephalographic (EEG) recordings of epilepsy patients. We extract alarms from the temporal profiles of these synchronization measures and study their potential for the prediction of epileptic seizures. The predictive performance of these alarms is assessed using analytical performance estimates and alarm time surrogates.

2. Methods

We applied a multivariate synchronization analysis to EEG recordings from epilepsy patients. For a single window of EEG signals recorded simultaneously with a number of k electrodes, at first two symmetric interdependence matrices, of dimension k times k, are extracted. One matrix contains all pairwise covariance values [1, 2] and the other all pairwise values of the mean phase coherence [3, 4]. Here the phases are extracted based on the Hilbert transform. Subsequently, the k eigenvalues of both matrices are determined, and an entropy value for each of the eigenvalue spectra is calculated [5]. We denote the entropy extracted from the covariance by *SC* and the one extracted from the mean phase coherence by *SR*. A moving window technique results in temporal profiles of *SC* and *SR*.

As EEG recordings we used a database that largely overlaps with one previously studied by Schad and colleagues [6]. This database consists of continuous long-term EEG recordings from six patients comprising a total duration of 460h and including 28 seizures of various types (simple partial, complex partial and generalized tonic-clonic seizures). All patients were undergoing pre-surgical epilepsy diagnostics at the Epilepsy Center, University Hospital of Freiburg. A distinctive feature of this database is that all recordings consist of simultaneous scalp and intracranial EEG. The scalp electrodes were placed according to the international 10-20 system, and the intracranial EEG was recorded from the surface of the cortex or from deeper structures of the brain. This recording setup allows us to probe different compositions of electrode groups as input to the multivariate synchronization analysis. In particular, we compare results derived from groups of scalp EEG recordings versus those derived from different groups of intracranial EEG recordings.

3. Results

Common features of the *SC* and *SR* profiles are reported, such as a strong temporal modulation reflecting the sleep-wake cycle of the patients. In addition, distinct differences such as a higher robustness of *SR* against artefacts in the recordings are shown. It is studied whether temporal variations of these profiles can serve to derive alarms to predict seizures. In particular, we use a simple threshold crossing to produce these alarms. We show that the sensitivity and specificity of the alarms for impending seizures largely depends on parameters such as the prediction horizon, smoothing of the profiles, or the value used for the threshold. Depending on these parameters, a very high sensitivity can be obtained for moderate false positive rates. We use analytical performance estimates [7] as well as seizure predictor surrogates [8] to compare this performance against the one expected under different well-defined null hypotheses. These tests provide strong evidence that rather than being indicative for a true predictive power of the extracted alarms this performance is consistent with the one expected by chance.

[1] Müller M, Baier G, Galka A, Stephani U, Muhle H. Detection and characterization of changes of the correlation structure in multivariate time series. *Phys Rev E* 2005; 71:046116.

[2] Schindler K, Leung H, Elger C, Lehnertz K. Assessing seizure dynamics by analysing the correlation structure of multichannel intracranial EEG. *Brain* 2007; 130:65-77.

[3] Mormann F, Lehnertz K, David P, Elger CE. Mean phase coherence as a measure for phase synchronization and its application to the EEG of epilepsy patients. *Physica D* 2000; 144:358-69.

[4] Allefeld C, Müller M, Kurths, J. Eigenvalue decomposition as a generalized synchronization cluster analysis. *Int J Bifurcat Chaos* 2007; 17: 3493-97.

[5] Carmeli C, Knyazeva M, Innocenti G, De Feo O. Assessment of EEG synchronization based on state-space analysis. *Neuroimage* 2005; 25:339-54.

[6] Schad A, Schindler K, Schelter B, Maiwald T, Brandt A, Timmer J, Schulze-Bonhage A. Application of a multivariate seizure detection and prediction method to

non-invasive and intracranial long-term EEG recordings. *Clin Neurophysiol* 2008; 119:197-211.

[7] Schelter B, Winterhalder M, Maiwald T, Brandt A, Schad A, Schulze-Bonhage A, Timmer J. Testing statistical significance of multivariate time series analysis techniques for epileptic seizure prediction. *Chaos* 2006; 16:10 [article ID 013108].

[8] Andrzejak RG, Chicharro D, Elger CE, Mormann F. Seizure prediction: Any better than chance? *Clin Neurophysiol* 2009; 120:1465-78.