Robustness of permutation entropy-based methods in the analysis of EEG signals for distinguishing eyes-open and eyes-closed brain states

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Developing reliable methodologies to decode brain state information from electroencephalogram (EEG) signals is an open challenge, crucial to implementing EEG-based brain-computer interfaces (BCIs). For example, signal processing methods that identify brain states could allow motor-impaired patients to communicate via non-invasive, EEG-based BCIs. In this work, we focus on the problem of distinguishing between the states of eyes closed (EC) and eyes open (EO), employing quantities based on permutation entropy (PE)[1]. An advantage of PE analysis is that it uses symbols (ordinal patterns) defined by the ordering of the data points (disregarding the actual values), hence providing robustness to noise and outliers due to motion artifacts. Using ordinal patterns that encode information of temporal or spatial order between data points, it has been reported that the EO state is characterized by higher entropy and than the EC state [2,3,4]; but the large variability between subjects prevents the differentiation of the EC and EO states of individual subjects. In this work, we study the robustness of PE-based features for EC/EO state classification in a dataset of $N = 107$ subjects with one-minute 64-channel EEG recordings in each state. We show that these features are robust, specifically to the blinking artifacts that are present in the EEG recordings of subjects with their eyes open. These artifacts are usually removed in the pre-processing stage by an Independent Component Analysis (ICA), which needs to identify the blinking component, delete it, and reconstruct the data without the artifacts, or by applying a filter, which could also filter out valuable information. In contrast, we show that many usual statistical features, that were reported to work in the distinction of the EO and EC states[5], are mainly driven by these artifacts, and once removed, these metrics are not able to distinguish between these states. Additionally, we show that the spatial approach to PE is not only robust, but also able to work with really short time series ($< 1s$), which makes it a very promising technique when a fast classification is required, as in many real world applications. Our work highlights the importance of pre-processing, as well the advantages of PE methods in distinguishing the eyes' state, and at the same time, the possibility of their use for very fast analysis and classification.

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