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Modelling of intracerebral network interactions that co-occur with interictal epileptic discharges

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Purpose

Interictal epileptic discharges (IEDs) that occur in stereoelectroencephalography (SEEG) recordings are difficult to interpret based on visual review due to their abundance and the complex nature of the underlying network interactions [1]. An analysis framework was developed to unravel the spatiotemporal pattern of the network interactions and to identify the region that initiates the IEDs, which is most likely related to the seizure onset zone (SOZ).

Measure of synchronization

The non-linear correlation $h$ is applied [2] to estimate the coupling strength between all combinations of EEG signals (Fig.1, top row). A regularization procedure is introduced to robustly estimate the delay by maximizing the average correlation of all IEDs while enforcing smoothness.

Evaluation of independence

Spatiotemporal independent component analysis (sICA) [4] is applied for each individual IED (Fig. 2, top row). Hierarchical clustering [5] of the spatial pattern of the independent components is applied to investigate whether independent focal regions can be identified (Fig. 2, bottom row). To estimate the maximal number of independent regions involved the gap statistic [6] is employed. The analysis framework illustrated for the example patient (Pat 1) indicated independent focal regions targeted by the depth electrodes RH (hippocampus) and RO and RP (insula), as visualized in Fig. 3 (left), using the in-house developed depth electrode navigation software [7].

Involvement of brain regions in the epileptic network

The General Linear Model (GLM) is used to model the likeliness of a region to generate epileptiform activity [3]. To this end, the variation in correlation over time and the IED density function are considered (Fig. 1, bottom row). EEG signals with significant GLM outcome are considered to be involved in the epileptic network and are further analyzed.

Results

The SEEG recordings were analyzed retrospectively for patients (N=5). The findings were concordant with the electroclinical hypotheses of each of the five patients studied and with their successful outcome of epilepsy surgery. The spike cluster active at the RH of Pat 1 is concordant with the SOZ as indicated (yellow box) by the clinicians (Fig. 3, right). The analysis procedures for 3 other patients studied (Pat 2 to 4) resulted in a single focal region coinciding with the SOZ targeted by either one or two depth electrodes involved (Fig. 4). The most complex interactions occurred for Pat 5 with alternating involvement of two depth electrodes targeting the right parietal brain region (Fig. 4, right) and additionally with independent involvement of the right and left hippocampus (not shown here).

Conclusions

The results presented indicate that the framework for dynamic connectivity mapping developed in this study describes the complex epileptic network interactions underlying the IEDs, and thereby is able to identify the focal region which is most likely related to the SOZ.

References


Figure 1: Overview of the synchronization analysis (top row) and the general linear model analysis (bottom row) demonstrated for the example patient.

Figure 2: The procedure of independent component analysis applied to individual IEDs (top row) followed by hierarchical clustering and estimation of the number of clusters using the gap statistic (bottom row).

Figure 3: The model of the network organization shows the depth electrodes that are a part of the epileptic network and the spatiotemporal interactions of the epileptic network (left). The active spike clusters at the electrodes targeting the right hippocampus (RH) and the insula (RO/RP) are indicated color coded in a sagittal and axial MR-scan, with the SOZ indicated by the yellow box (right).

Figure 4: The depth electrodes targeting the region that, according to the findings of the clinicians, is concordant with the SOZ of Pat 2 to 5 (yellow boxes).