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Functional and effective connectivity during focal epileptic seizures

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Background:

The aim of this study was to investigate the dynamics of neuronal networks during focal seizures using dynamic imaging of coherent sources (DICS) (Gross et al. 2001) and renormalized partial directed coherence (RPDC) (Schelter et al. 2009). Ictal EEG recordings from a patient with drug resistant, focal epilepsy, due to a focal cortical dysplasia (FCD) in the left parieto-occipital region, shown by a high resolution 3-T MRI, were analyzed

Data and Methods:

The EEG recordings from a non-invasive pre-surgical video-EEG monitoring with a 10/10 system was used for the analyses. 9 habitual, nocturnal complex motor seizures with initial eye deviation to the right and irresponsiveness, followed by tachycardia, left sided tonic posturing and right sided automatisms were analyzed. EEG recording were showing initial ictal activity over the left parieto-occipito-temporal regions. Objective EEG evaluation, by two experienced neurophysiologists and power spectrum analyses were performed to identify the ictal frequency. In order to describe the seizure dynamics three time points: pre-seizure phase, seizure onset and seizure propagation were selected based on the power spectral density. The brain area with the strongest power in the analyzed frequency (9-15 Hz) range was defined as the reference region. A high resolution 3-T MRI was used to create a realistic boundary element head model for the forward solution. DICS was used to compute the coherence between the strongest reference region and the entire brain (functional connectivity). RPDC was used to describe the informational flow between the described sources (effective connectivity). Additionally interictal PET and SPECT investigations were performed for the detection of epileptic zone.

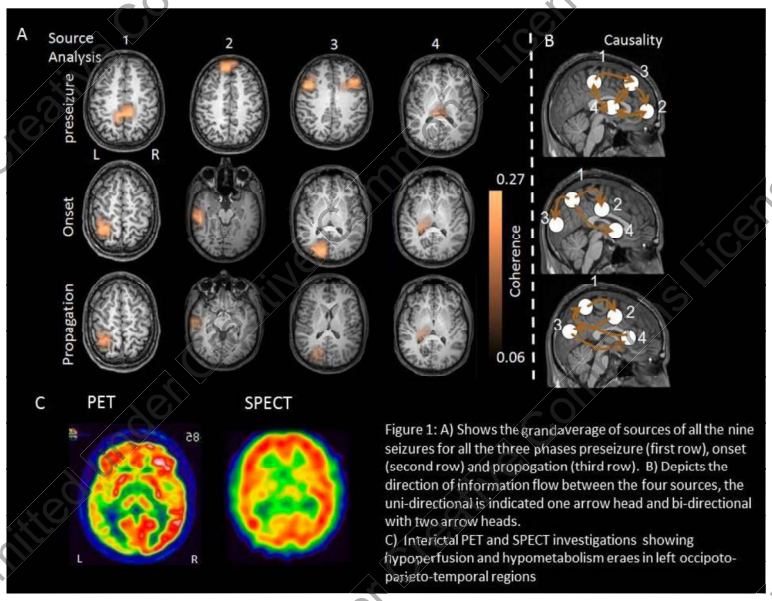

Figure 1: A) Shows the grandaverage of sources of all the nine seizures for all the three phases preseizure (first row), onset (second row) and propogation (third row). B) Depicts the direction of information flow between the four sources, the uni-directional is indicated one arrow head and bi-directional with two arrow heads.
C) Interictal PET and SPECT investigations showing hypoperfusion and hypometabolism eraes in left occipoto-parieto-temporal regions

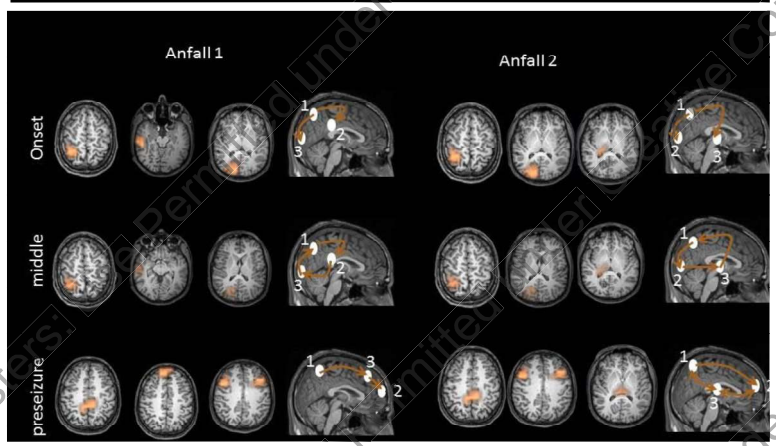

Figure 2: The sources and the RPDC plots for the first two seizures for all the three different time points which are the onset, middle and the pre-seizure. The network of sources are different between the pre-seizure and the onset and also there are significant differences in the connectivity between these three states.

Results:

DICS analyses during onset and propagation phases in all nine analyzed seizures showed similar sources in left parieto-occipito-temporal regions, concomitant with the localization of the FCD and regions of hypometabolism and hypoperfusion shown by PET and SPECT investigation respectively. Additionally, sources in the left thalamus were found in most of the seizures. The sources found by DICS during the pre-seizure phase were found bilaterally in the default mode network (DMN) areas, namely in medial prefrontal cortex and cuneus, as well as in the medial frontal gyrus and thalami.

RPDC analyses during the seizure onset phase showed the informational flow starting from the first strongest source, located adjacent to the parieto-occipital junction, and distributing towards all other sources, whereas, during the propagation phases there was a circular informational flow between all identified sources. RPDC applied during the pre-seizure phase showed mainly bidirectional cortico-thalamic connections. The grand average sources for all three phases of all the seizures, the causality analysis and the PET and SPECT images are shown in Figure 1.

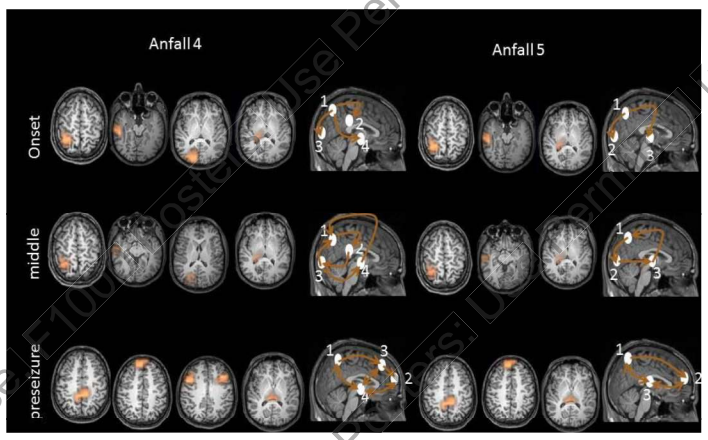

Figure 3: The sources and the RPDC plots for the first two more seizures for all the three different time points which are the onset, middle and the pre-seizure. The network of sources are different between the pre-seizure and the onset and also there are significant differences in the connectivity between these three states.

Conclusion:

DICS revealed the neuronal networks concomitant with the location of the FCD showed by a high resolution 3-T MRI and areas of decreased metabolism shown by functional neuroimaging methods. The sources identified during the seizure onset and propagation phases were similar, only the causality was different showing that the strongest source, located in the occipito-temporal region is most probably a pacemaker/seizure onset zone of the ictal neuronal networks in this case. The DICS analyses of pre-seizure phase showed the sources in the DMN areas of the brain. We can conclude that analyses of multiple habitual seizures of the same patients by the methods of DICS and RPDC gives us valuable information regarding the seizure onset zone and ictal networks and can be a useful additive tool during the pre-epilepsy surgical investigations of the patients with drug resistant focal epilepsies.

References:

Gross J, Kujala J, Hamalainen M, Timmermann L, Schnitzler A, Salmelin R (2001) Dynamic imaging of coherent sources: Studying neural interactions in the human brain. Proc Natl Acad Sci U S A 98 (2):694-699.

Schelter B, Timmer J, Eichler M (2009) Assessing the strength of directed influences among neural signals using renormalized partial directed coherence. J Neurosci Methods 179 (1):121-130.