Epileptic Seizure Prediction Using the Electric Fields of the Brain

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Introduction

Epilepsy is the second most common neurological disorder (after stroke).

Successful epileptic seizure prediction will open the possibility for novel preventative therapies (as illustrated in Fig. 1).

Our approach of measuring responses to electrical stimulation of the brain could yield new results that will aid millions of epilepsy suffers worldwide.

Aim

To detect a state of the brain where there is a high probability of an epileptic seizure.

This will have to be done in a suitable timeframe so that a focal therapy may be delivered to prevent impending attacks.

This hyper-excitable (pre-seizure) state can be tracked via monitoring the electrical fields of the brain recorded from intracranial electrodes.

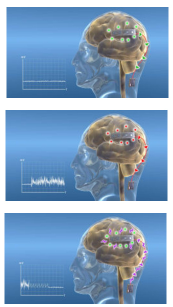
Detection of a hyper-excitable state will allow for new therapeutic techniques such as electrical stimulation and focal drug delivery.

Figure 1: Illustration of the operation of a seizure abatement device using direct electrical stimulation.

A) Shows electrodes implanted on the cortical surface recording normal electrical activity.

B) Shows electrodes recording pathological seizure activity.

C) Demonstrates corrective electrical stimulation, abruptly ending the seizure.



Method

Experiments

Patients who were candidates for epilepsy surgery had electrodes implanted under their skull for cortical mapping. Electrode positions can be seen in Fig. 2 below.

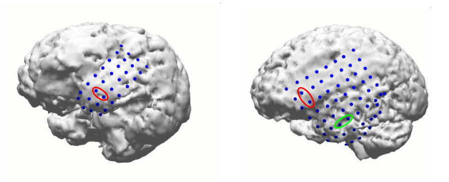


Figure 2: Co-registered CT and MRI images from patient 1 (left) and patient 2 (right) showing their respective electrode positions. Ovals highlight electrodes used in electrical stimulation experiments.

Electrical fields were amplified and recorded using our custom research system.

Stimulation patterns consisted of single square biphasic pulses delivered at a rate of 1Hz. The pulse width was 100µs. Current intensity varied between 1-2mA.

Analysis

Phase clustering analysis was computed on segments of the neural recordings around the stimulation times as described below.

The complex wavelet coefficients, $c_{a,k}$ of the neural time series $x(t)$

$$\psi_{a,k}(t) = \frac{1}{\sqrt{a}}\psi\left(\frac{t-k}{a}\right)$$

$$c_{a,k} = \int_{-\infty}^{\infty} x(t)\psi_{a,k}(t)\,dt$$

The instantaneous phase, ϕ_x

$$\phi_{a,x}(t) = \arctan\left(\frac{imag(c_{a,k})}{real(c_{a,k})}\right)$$

The phase-locking index (PLI) over N stimulations

$$PLI_{a,x}(t) = \left|\frac{1}{N}\sum_{k=1}^{N} e^{i\phi_k(t)}\right|$$

The maximum of an area of interest (time-frequency range) was used to compare between channels and epochs.

Results

The figures in this section summarise phase clustering in response to electrical stimulation around two focal epileptic events (one for each patient).

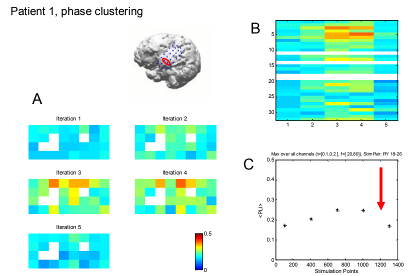
Increases in phase clustering can be seen at the times leading to the epileptic events.

Figure 3 (graphics below and to the right): Summarised results from electrical stimulation experiment from two patients.

A) Each element of the images represent phase clustering in one electrode. The elements are arranged in the same orientation of the electrode geometry. White spaces indicate electrodes not used in analysis.

B) Gives an indication of the time evolution of the phase clustering for each channel. Warm colours indicate higher phase clustering.

C) Shows the average phase clustering over all channels plotted against the time of the first stimulation in the pulse train. The red arrow indicates time of epileptic event.



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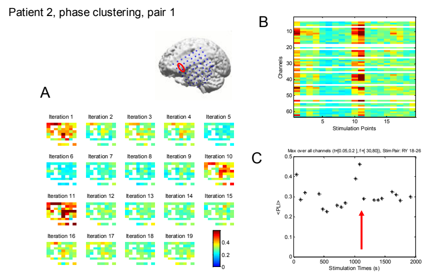
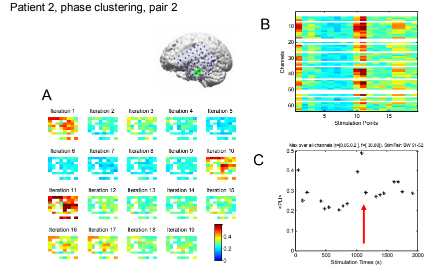
Results (cont.)





Conclusions

An active approach for seizure prediction has been taken by probing the brain using direct electrical stimulation to the cortex.

Responses to the stimulation can be tracked via extraction of phase clustering in the electrical signals recorded from the intracranial electrodes.

Results from pilot studies demonstrate that a change in phase clustering of the electric field potential is a good marker of cortical excitability.

This approach could yield new results that will aid millions of epilepsy suffers worldwide.