Coupling of Oscillatory Activities between Brain Regions – an Analysis of Depth EEG Signal

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Abstract. Functional integration refers to the interactions among multiple specialized neuronal populations, and how these interactions depend upon context. In the present paper we describe the procedure of evaluation repeated EEG signals obtained from deep brain structures. Coupling of oscillatory activities was measured by the correlation function for all the combinations of available channels in two frequency ranges (1 – 45 Hz, 55 – 95 Hz). Statistical test for paired samples was applied to find significant differences in correlation of intervals before and after stimuli.

1 Introduction

The repetitive EEG event-related signals are studied to understand the function of different brain structures. We studied executive functions, which are associated with complex mental operations. We evaluated the repetitive human EEG event-related signals, recorded from depth brain electrodes, which were implanted in order to localise the epileptogenic foci before neurosurgical treatment of some types of farmacoresistent epilepsy. The data is unique because was obtained from deep populations.

2 Methods

2.1 Subjects

Intracerebral stereoelectroencephalographic (SEEG) data was recorded from different brain structures within frontal, temporal, and parietal lobes at the optimal mesoscopic scale in ten epileptic patients during presurgical videoEEG monitoring at Brno Epilepsy Center, Masaryk University. A standard visual oddball task was utilized. It is a simple discrimination task with a randomly alternating presentation of two types of sensory stimuli: one frequent and one rare. The subject performing the oddball task is instructed to ignore frequent stimuli and to perform a certain task (motor response, counting, etc.) when rare (target) stimuli are detected. Target stimuli in this task indubitably trigger in the brain a whole set of cognitive processes that are mostly linked to attentional mechanisms, short term memory, assessment of stimulus relevance, decision making, and response. It is noteworthy that most of these processes are not triggered by frequent stimuli [1].

2.2 Data analysis

The EEG data was off-line processed and analyzed using ScopeWin software. Segmentation according to the stimulation trigger onset was done, and the EEG segments containing any artefact activity or mistaken response were visually inspected and omitted from further analysis. Electrode contacts with no relevant or damaged information were excluded, as well. The number of channels over subjects was 93.6 ± 16.68; the number of segments was, on average, 45. Further processing was performed with artefact-free EEG...
trials with target and frequent stimuli separately. The interstimulus interval was 4 seconds, position of stimulus was in the middle of each segment, and the sampling rate was 1024 Hz.

The time correlation was calculated for each pair of channels according to expression (1) known as Pearson’s correlation coefficient [2], which is obtained by dividing the covariance of the two variables by the product of their standard deviations. This normalization yields the results in the range from -1 to 1.

\[
\rho_{xy}(m,n) = \frac{C_{xy}(m,n)}{\sigma_x^2(m)\sigma_y^2(n)} \quad (1)
\]

Calculation of time evolution of the correlation was carried out gradually in time window of length 375 ms (frequency range 1 - 45 Hz) and length 30 ms (55 - 95 Hz) with 90% overlapping between adjacent windows. In order to decrease an influence of the marginal parts of time window a multiplication by the Hamming window was applied for each time window, in advance (Fig 1). An improvement of time resolution can be achieved by shortened time window, however, it is demanded to correlate as long part of period as possible for the respective frequency bands.

![Fig 1](image)

**Fig 1.** Principle of time evolution of correlation calculation within two channels. The red part of the correlation curve depicts statistically significant difference after stimuli comparing to reference interval before stimuli.

### 2.3 Statistical analysis

From the time evolution of correlation the statistical significance of the differences between mean values observed during the reference period (100 – 700 ms before stimulus) and subsequent periods measured in intervals after stimulus. The statistical significance was expressed as a probability value (p) using a non-parametric Wilcoxon Rank Sum (Signed rank) test for paired samples [3]. The Bonferroni correction addressing the problem of multiple comparisons was applied. The changes were considered as significant when p<0.05. The results were transformed into the set of two values indicating increase (red colour) and increase (blue colour) of correlation in post-stimuli intervals comparing with the reference period before stimuli. The changes in time of post-stimuli intervals for all the combinations of channels with the B’1 channel are displayed in Fig 2.
3 Results

After an inspection of the resulting data in general (Fig 3), the statistical significant differences of correlations between assessed pairs of channels in intervals before and after stimuli were found. In both examined frequency ranges (Tab 1) the correlations changed after targets remarkably more often than after frequents (32.04% and 17.47% in comparison to 5.61% and 2.96%).

<table>
<thead>
<tr>
<th>Subject</th>
<th>1 - 45 Hz</th>
<th>55 - 95 Hz</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Target</td>
<td>Frequent</td>
</tr>
<tr>
<td>1</td>
<td>27.33%</td>
<td>1.58%</td>
</tr>
<tr>
<td>2</td>
<td>23.76%</td>
<td>11.98%</td>
</tr>
<tr>
<td>3</td>
<td>24.12%</td>
<td>2.26%</td>
</tr>
<tr>
<td>4</td>
<td>8.70%</td>
<td>1.13%</td>
</tr>
<tr>
<td>5</td>
<td>35.13%</td>
<td>6.97%</td>
</tr>
<tr>
<td>6</td>
<td>21.80%</td>
<td>5.05%</td>
</tr>
<tr>
<td>7</td>
<td>44.53%</td>
<td>8.35%</td>
</tr>
<tr>
<td>8</td>
<td>50.90%</td>
<td>11.63%</td>
</tr>
<tr>
<td>9</td>
<td>55.10%</td>
<td>2.34%</td>
</tr>
<tr>
<td>10</td>
<td>28.99%</td>
<td>4.78%</td>
</tr>
<tr>
<td>Mean</td>
<td>32.04%</td>
<td>5.61%</td>
</tr>
<tr>
<td>Std.Dev.</td>
<td>13.66%</td>
<td>3.81%</td>
</tr>
</tbody>
</table>

Tab 1. Portion of the combination with a change of correlation in post – stimuli interval.

In the Fig 3 it is remarkable that in the lower frequency range, an increase of correlations after targets prevailed in all the subjects; in the gamma range a predominant decrease of correlations was observed. This finding is noticeable in Tab 2. In the frequency range 1 – 45 Hz were on average 76.40% of the changes an increase of the correlation and 73.69% were a decrease in the frequency range 55 – 95 Hz.
Fig 3. Subject 8, time evolution of the correlation for the combinations of 86 channels.

<table>
<thead>
<tr>
<th>Subject</th>
<th>1 – 45 Hz</th>
<th>55 – 95 Hz</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>75.50%</td>
<td>27.89%</td>
</tr>
<tr>
<td>2</td>
<td>57.33%</td>
<td>1.53%</td>
</tr>
<tr>
<td>3</td>
<td>64.53%</td>
<td>14.06%</td>
</tr>
<tr>
<td>4</td>
<td>69.07%</td>
<td>30.63%</td>
</tr>
<tr>
<td>5</td>
<td>82.01%</td>
<td>37.41%</td>
</tr>
<tr>
<td>6</td>
<td>85.42%</td>
<td>32.55%</td>
</tr>
<tr>
<td>7</td>
<td>61.95%</td>
<td>22.04%</td>
</tr>
<tr>
<td>8</td>
<td>94.42%</td>
<td>6.97%</td>
</tr>
<tr>
<td>9</td>
<td>95.03%</td>
<td>84.68%</td>
</tr>
<tr>
<td>10</td>
<td>78.70%</td>
<td>5.37%</td>
</tr>
<tr>
<td><strong>Mean</strong></td>
<td><strong>76.40%</strong></td>
<td><strong>26.31%</strong></td>
</tr>
<tr>
<td><strong>Std.Dev.</strong></td>
<td><strong>12.48%</strong></td>
<td><strong>22.77%</strong></td>
</tr>
</tbody>
</table>

Tab 2. Portion of the total number of the changed combination with an increase of correlation.

4 Discussion

It is obvious that rare target stimuli evoke a brain activity detectable by the correlation function. After frequent stimuli it is not supposed any activity, which was confirmed. Interestingly, dynamics of post-stimulus changes differed obviously – inter-areal couplings of oscillatory activities in lower frequencies were generally less stimulus-locked than changes in the gamma range.
5 Conclusions

The correlation function might be favourably used for the study of inter-area synchronous neural oscillations too. Time evaluation of correlations of SEEG data gives us a new perspective on processes in brain contrary to correlation of a single moment [4]. Our data further supports the hypothesis that slower oscillations are more involved in long-range synchrony, and possibly involved in the coordination of faster oscillations in functionally related but spatially segregated areas.

References


