PHASE-LOCKING OF EVENT-RELATED ALPHA OSCILLATIONS

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By applying a new method for measuring phase-locking based on the Wavelet Transform, we studied the responses in the alpha range to pattern visual stimuli. Alpha post-stimulus amplitude enhancements were mainly due to phase-locking between single trials.

1 Introduction

The study of different rhythmicities of the brain and their relation with different pathologies and functions keep the attention of researchers since the beginnings of electroencephalography. EEG activity, and in particular brain oscillations, are present in a spontaneous way or can be generated as a response to stimulation (event-related potentials; ERPs). In contrast with the conventional view of ERPs as signals being added to a noisy background EEG, it was proposed [1] that ERPs arise from the ongoing EEG as an evoked synchronization of spontaneous EEG rhythms.

Due to the low amplitude of ERPs, it is a common practice to average several trials with the drawback of loosing information about the variability upon single trials. In this work we analyze phase-locking between single trials of event-related alpha ($\sim 10Hz$) oscillations.

2 Method

2.1 Subjects and experiments

In 10 healthy subjects, responses to visual stimulation were analyzed with the following two experiments:

1. No-task visual evoked potential (VEP): subjects were watching a checkerboard pattern, the stimulus being a checker reversal (N = 100 stimuli).

2. Non-target(NT) - target (T) stimuli (oddball paradigm): subjects were watching the same pattern as above. Two different stimuli were presented in a pseudorandom order. Non-target stimuli (75%) were pattern reversal, and target stimuli (25%) consisted in a pattern reversal with horizontal and vertical displacement of one-half of the square side length. Subjects were instructed to pay attention to the appearance of the target stimuli (N = 200 stimuli).

The inter-stimulus interval varied pseudo-randomly between 2.5 and 3.5 s. After each pattern reversal, the reverted pattern was shown for one second, then the pattern was re-reverted. Recordings were made following the international 10/20 system in seven different electrodes (F3, F4, Cz, P3, P4, O1, O2) referenced to linked earlobes. Data were amplified with a time constant of 1.5 sec. and a lowpass filter at 70 Hz. For each single sweep, 1 sec. pre- and post-stimulus EEG were digitized with a sampling rate of 500 Hz.

2.2 Data Processing

After visual inspection of the data, 30 sweeps free of artifacts were selected for each type of stimulus (VEP, NT and T) for the analysis. A Wavelet Transform was applied to each single sweep using a quadratic B-Spline function as mother wavelet. The multiresolution decomposition method was used for separating each single sweep into scale levels (see [3] for details). Coefficients of the scale level 4, corresponding to the alpha band (8-16Hz), were analyzed.

2.3 Phase-Locking factor

After decomposing the ERPs in different scale levels, wavelet coefficients corresponding to the alpha band were averaged with and without a previous rectification. In the first case non phase-locked oscillations will add and in the second case they will cancel, thus being the ratio between both averages a measure of phase-locking. Then, following [2], the phase-locking factor was defined as

$$\phi = \frac{|\sum_k C_{i,j}|}{\sum_k |C_{i,j}|} \tag{1}$$

where k are the different single trials, and $C_{i,j}$ are the wavelet coefficients. Then, with this definition, a phase-locked activity will have a value of 1 and a non phase-locked activity values tending to 0. For space reasons, results of phase-locking will be showed only in O1 electrodes upon target stimulation.

3 Results

The grand average (across all subjects) wideband filtered (0.5-70 Hz) event-related potentials are shown in the left side of fig. 1 (only response to target stimulation of the left electrodes shown). The P100 response (a positive deflection at 100 ms post-stimulation) was clearly visible upon all stimuli types (VEP, NT, T), best defined in occipital locations. In the case of target stimulation, a marked positive peak appears between 400 and 500 ms, according to the expected cognitive (P300) response. Middle and right side graphs show the alpha coefficients and the signal reconstructed from these coefficients respectively. Amplitude increases after stimulation were distributed over the entire scalp for the three stimulation types, having a better definition in the occipital electrodes (for details and a functional interpretation, see [3]).

Figure 2A) shows the alpha phase-locking, average of rectified coefficients (for simplicity it will be called energy) and the conventional average for one typical subject. Pre-stimulus energy values about 10-12 increase to values about 15-20 in the first 250 ms post-stimulation. Post-stimulus increases are clearly marked in the phase-locking factor. Values about 0.1-0.4 increases nearly up to 1 after

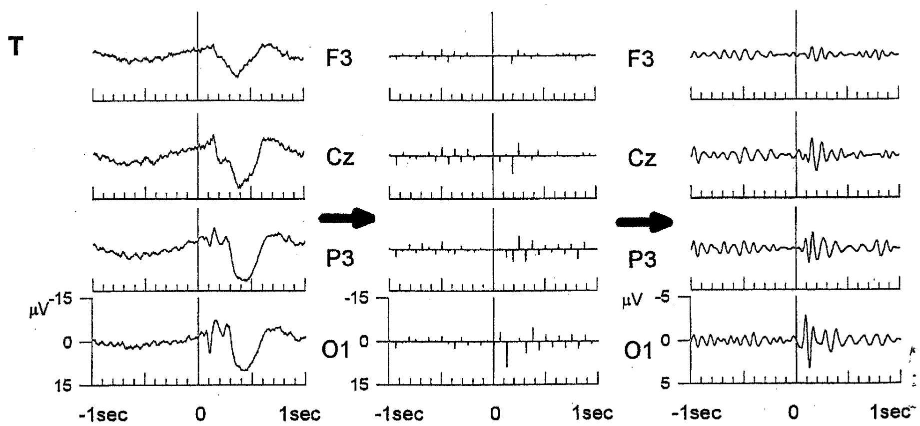

Figure 1. Event-related responses (left side), alpha coefficients after wavelet decomposition (middle) and signals reconstructed from the coefficients (right) upon target stimulation. O1: left occipital, P3: left parietal, Cz: central and F3: left frontal electrode.

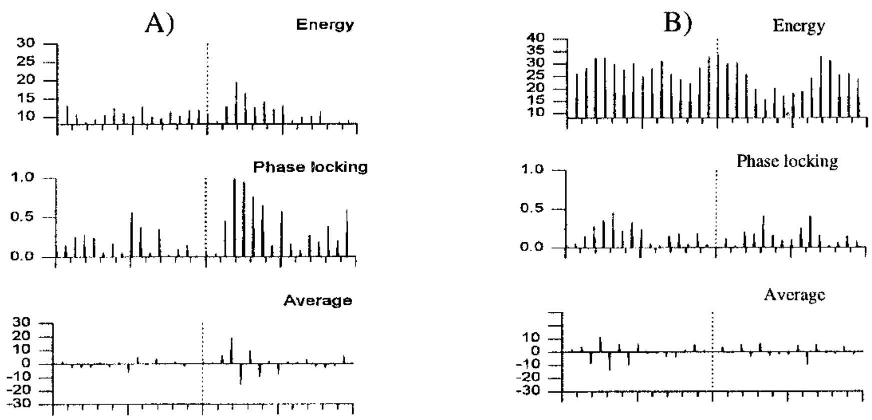

Figure 2. Energy, phase-locking and averaged alpha response for one typical subject (A) and one atypical subject (B). Results correspond to O1 electrode upon target stimulation.

stimulation. The increase in the energy and in the phase-locking is manifested in the averaged response, where pre-stimulus values about 2-3 increases up to 15-20.

Figure 2B) shows one atypical subject, who was the only one without a post-stimulus amplitude increase in the averaged response. As checked in the single trials and in the averaged wide band event-related potentials, this subject had a very important contribution of spontaneous alpha activity which may have blocked the event-related alpha response. In this case there is neither increase in energy nor in the phase-locking factor. It is very interesting to note that other subjects showed no increases in the energy but still having an event-related alpha response, this subject being the only one without increase in the averaged response.

With respect to the grand average of the 10 subjects, the values of energy had a small increase in the first 250 ms after stimulation going from pre-stimulus values of 15 to values around 17-19. On the other hand, increases of phase-locking were clearly significant. The phase locking factor had a value about 0.2 pre-stimulus and reached in the first 250 ms post-stimulation values up to 0.5. The same phenomenon was observed in the averaged responses, where pre-stimulus values of about 0.1-0.2 increases up to 10 after stimulation. Then, although there was a small increase of energy after stimulation, we can conclude that the post-stimulus amplitude increases of the averaged response were mainly due to a phase-locking between the single trials.

To check this, we made two subgroups of 5 subjects each. The first subgroup with subjects with a post-stimulus phase-locking less than 0.5 and the second subgroup with subjects with post-stimulus phase-locking higher than 0.5. Although both groups had nearly the same values of energy (about 15), there was a significant difference in their averaged responses. In the first group post-stimulus amplitude increases of the averaged responses were not well defined, reaching values up to 5. On the other hand, the group with high phase-locking showed post-stimulus increases higher than 10, the pre-stimulus values being of the same magnitude than the ones of the first group. This confirmed our expectation that amplitude increases in the averaged responses, in this case, were mainly due to phase-locking.

4 Conclusion

Although at the single trial level there was some increase of alpha activity, post-stimulus amplitude increases observed in the averaged responses were mainly due to phase-locking between the single trials. This finding is in line with the view that phase reordering plays a major role in ERP genesis [1].

Wavelet Transform as used here permits to analyze how "noisy appearing" EEG oscillations are ordered upon stimulation: Thus, it is a promising approach to deal with the question of deterministic/noisy nature of the EEG already widely studied with methods from Deterministic Chaos.

References

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