Oscillatory Event Synchrony During Steady State Visual Evoked Potentials

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Abstract. In this paper we study the dynamics of distributed neuronal assemblies, through the event synchrony of EEG oscillatory bursts. We recorded EEG signals before, during and after steady-state visual evoked potentials (SSVEP) in medium (16 Hz) and high frequency (32 Hz) ranges. The time-frequency oscillatory events are extracted using bump modeling. Thereafter, the recently introduced stochastic event synchrony (SES) method is applied to compare these patterns between brain areas. Significant effects are shown, demonstrating that not only the background activity is affected by flickering stimulation, but also oscillatory patterns.

1 Introduction

Local synchrony of neural assemblies induces bursts of oscillatory activities. In EEG signals, these activities usually appear as successions of oscillatory patterns that can be observed using time-frequency representations. Synchrony among oscillating neural populations is a plausible candidate to mediate functional connectivity, and therefore to allow the formation of spatiotemporal structures [1]. Such neural assemblies can be considered as distributed local networks of neurons, transiently linked by reciprocal dynamic connections [2].

Steady-state visual evoked potentials (SSVEP) are characterized by constituent discrete frequency components remaining closely constant[1] in amplitude and phase over a long stimulation time [3]. There is generally little knowledge, for SSVEP, concerning the trial-by-trial detail of oscillatory patterns dynamics. Studies in neuroscience use classical methods to study the SSVEP responses: superposition, averaging, frequency analysis (narrow band Fourier power), or correlation analysis. Whereas efficient tools for time-frequency analysis were used proficiently for evoked potential or event-related responses investigation [4, 5], time-frequency analysis of SSVEP were unfortunately seldom investigated [6, 7]. We will here make the first attempt to investigate oscillatory pattern synchrony during SSVEP induced by a flickering light stimulus.

[1] This holds only for average of trials. Single trials usually do not show constant activity.

In this paper, a sparse "bump" model of the most prominent time-frequency oscillatory events is used [8]. For each trial, we quantify the pairwise synchrony between bump model approximations of the EEG signals using the Stochastic Event Synchronization (SES) method [9].

2 Methods

Human scalp EEG was recorded in a dark room, while a subject was exposed to flickering light. Stimulus consisted of a single flashing white square with constant time interval EEG data was recorded from 64 sites on the scalp, based on the extended 10-20 standard system. A Biosemi system with average reference was used. Sampling rate was set to 2048 Hz (yielding good frequency resolutions), with offline high pass filter above 3 Hz. Trials were recorded with SSVEP induced at 16 Hz and 32 Hz during a four second stimulation (51 trial per frequency range, thus total = 102 trials). As a first step, wavelet time-frequency maps are computed using complex Morlet wavelets. The complex Morlet wavelet results in the optimal resolution in time and frequency; it has also proven to be well-suited for EEG signals [4, 5, 10]. Here, time-frequency representations were restricted to the frequency ranges of SSVEP, *i.e.* 15-17 Hz or 31-33 Hz, with adequate time and frequency borders for bump modeling [8]. Epochs were analyzed before, during and after stimulation. A frequency dependent z-score normalization [11] was applied comparatively to the pre-stimulus period of each trial:

$$z(f,t) = \frac{c(f,t) - \mu_f}{\sigma_f}, \quad (1)$$

where μ_f and σ_f are the mean and standard deviation of the wavelet map at frequency f, during the pre-stimulus period.

The resulting z-score maps are approximated as a sum z_{bump} of basis (half ellipsoid) functions b, referred to as "bumps" ([8], Fig. 1):

$$z(f,t) \simeq z_{\text{bump}}(\theta) = \sum_{k=1}^{N_b} b(\theta_k). \quad (2)$$

After bump modeling, the 64 electrodes were clustered into nine areas (occipital, parietal left and right, temporal left and right, central, frontal left and right, and prefrontal). Stochastic event synchrony (SES, [9]) quantifies the alignment of two bump models (Fig. 1). A fraction ρ_{spur} of bumps appear in one area but not in the other ("spurious" bumps); other bumps are present in both areas at slightly different positions ("non-spurious bumps").We denote by Δ the average timing offset between pairs of non-spurious bumps, σ stands for the standard deviation of this offset.

3 Results and Discussion

A first observation on wavelet maps (Fig. 1) is that EEG trials remain organized in oscillatory bursts during SSVEP stimulation: we can observe on Z-score maps,

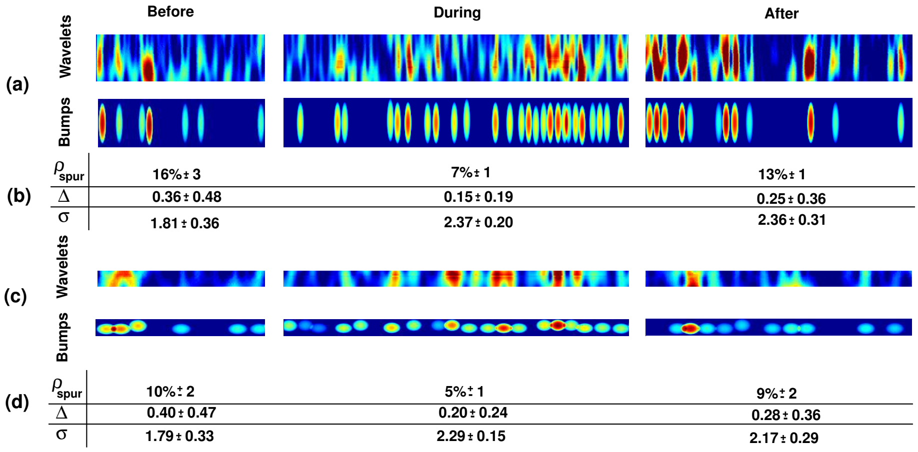

Fig. 1. Application of SES to SSVEP signals. Bumps are modeled with central frequencies close to the SSVEP rate ± 1 Hz. (a) z-scored wavelet transform (26 to 38 Hz) and bump modeling of a typical signal with SSVEP at 32 Hz. (b) SES parameters for all signals at 32 Hz. (c) z-scored wavelet transform (13-19 Hz) and bump modeling of a typical signal with SSVEP at 16 Hz . (d) SES parameters for all signals at 16 Hz.

during and after as well as before SSVEP, intermittent patterns of activity. The average of a sufficient number of trials would show instead a more constant activity in the frequency range of interest. Earlier investigations [6] also revealed such rhythmic patterns.

We present the first application of oscillatory event synchrony to SSVEP responses in EEG. We first compared EEG periods using magnitude square coherence. "Before vs. During" condition and "During vs. After" condition yields significant p-values ($p<0.01$, Mann-Whitney test). SES also shows (Fig. 2) a general increase of synchrony (ρ_{spur} and $|\Delta|$ decreased significantly) between oscillatory patterns, but with an induced perturbation of organization (σ increases significantly). Note that σ captures fluctuations "within" a trial, whereas the distribution of $|\Delta|$ reveals fluctuations "from trial to trial". Note that with a high ρ_{spur} in the "Before" period, the estimate of σ may be less reliable. Likewise, σ may be small in the "Before" period since there are only few bumps (= fluctuation within a trial); however, the fluctuations in $|\Delta|$ are large (from trial to trial) during this period. We need to investigate this more carefully with surrogate data.

Therefore, during SSVEP, not only background activity increase its coherence, but also oscillatory events. Considering the assumption that oscillations and long distance synchrony both play key roles for cognition [2, 1], we can moreover expect from these results that SSVEP stimuli could induce some cognitive side-effects. This conjecture will be verified in our future investigations.

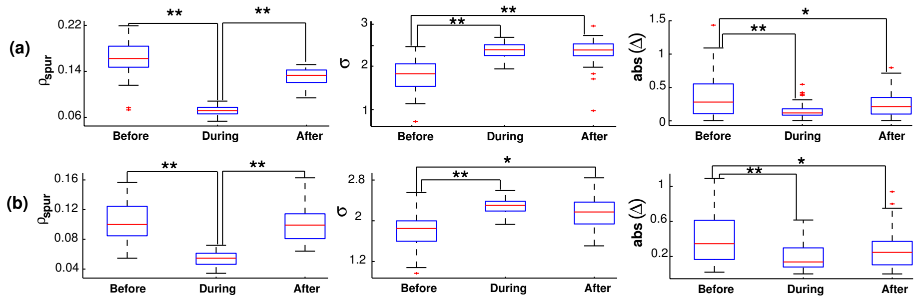

Fig. 2. Boxplots of the three SES parameters. * and ** represents respectively significant ($p < 0.05$) and strongly signicant ($p < 0.01$) differences (Mann-Whitney test). Red crosses represents outliers.(a) stimulation at 32 Hz. (b) stimulation at 16 Hz.

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