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QUANTIFICATION OF TRANSIENT QUADRATIC PHASE COUPLINGS BETWEEN EEG COMPONENTS

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INTRODUCTION

In this study the bispectral analysis is used for the identification of non-linear interactions between EEG components. The identification of interacting EEG rhythms and the manner of the QPC may make a more causal interpretation possible because cerebral rhythmic activities can be thought of as being generated in distinct cortical and subcortical neuronal ensembles. Accordingly, the interactions between rhythmic activities may exhibit interconnections between the generating neuronal structures and a change of the interactions of signal components can be interpreted as a change in the electrophysiological interactions of the involved brain structures caused by the drug or the drug-induced functional suppression (depth of sedation).

In this study all results of EEG burst analysis are summarised and the method of time-variant bispectral analysis is used to study the time profile of the QPC.

MATERIALS AND METHODS

QUADRATIC PHASE COUPLING (QPC) AND ITS BISPECTRAL REPRESENTATION

If EEG signal components at frequencies $f_1, f_2, f_2 - f_1$ and/or $f_2 + f_1$ ($f_2 > f_1$) can be identified and the phase relations are of the same type as the frequency relations ($\theta_1, \theta_2, \theta_2 - \theta_1, \theta_2 + \theta_1$) then a QPC exists and a peak in a bispectral representation (e.g. biamplitude, bicoherence) at the co-ordinates f_1, f_2 will appear. Additionally, a second peak in the bispectrum occurs at the co-ordinates $f_1, (f_2 - f_1)$ because both components and a component of the combination frequency $f_1 + (f_2 - f_1) = f_2$ are present. According to this definition peaks in the bispectral representations reflect both a fixed phase relation between θ_1 and θ_2 (i.e. phase co-ordination) and a non-linear coupling designated by the phase relations $\theta_2 - \theta_1, \theta_2 + \theta_1$ of the resulting components $f_2 - f_1$ and/or $f_2 + f_1$.

DETECTION OF BURST INTERVALS

Special pattern recognition methods have been introduced [2] and adapted to give an accurate detection of burst onsets during the BSP in sedated patients (electrode locations Fp1 and Fp2). By means of the onset detection a pattern-related analysis can be triggered automatically. The onset of burst-like patterns in the EEG, before entering the BSP, has been triggered manually on the basis of a visual inspection of the EEG using a special interactive computer program. The trigger points have been used for triggering the average procedure of the bicoherence estimate.

TIME-VARIANT BICOHERENCE

Our method of time-variant bispectral analysis is based on the Gabor expansion and has been described in detail by Witte et al. [1].

SUBJECTS

The investigations were carried out on a group of 12 patients with various neurosurgical diseases [4]. All of them were given an individual basic sedation to ensure controlled mechanical ventilation and safe nursing.

RESULTS

As shown in our previous study [4], separable peaks in the biamplitude representation mark interrelations between the frequency ranges 0 to 2.5 and 3 to 7.5 Hz as well as the range 0 to 2.5 and 8 to 12 Hz (Fig. 1). It can be excluded that the oscillations in the frequency band 8-12 Hz are harmonics of the oscillations in the frequency range 3-7.5 Hz. The QPC is dominant at frontal electrode montages (Fp1-Cz; Fp2-Cz).

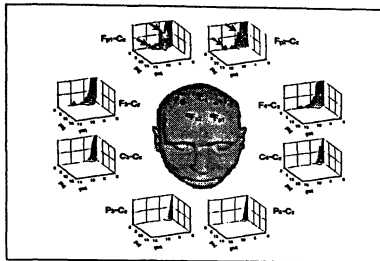


Fig. 1 - Grand mean data of the bi-amplitude estimation of burst patterns from all patients during BSP (z-axis in arbitrary units using identical scales; arrows = separable peaks indicating the QPC between the frequency bands given in the text).

The analysis was repeated for burst-like patterns derived from the EEG during basic-sedation and before entering the BSP. All effects reported above cannot be demonstrated in these patterns.

For estimating the time profile of the QPC directly, the time-variant bicoherence was applied. The results from bicoherence application confirm the general findings given above and provide new knowledge in addition. It can be shown that the dominant QPC within burst activity during the BSP is between the frequency ranges 0 to 2.5 Hz and 3 to 7.5 Hz and that the degree of the coupling is higher at the bifrontal montages Fp1-Cz and Fp2-Cz than at the other montages. Therefore, the representation of results is focussed on Fp1-Cz montage and on this frequency range (Fig. 2).

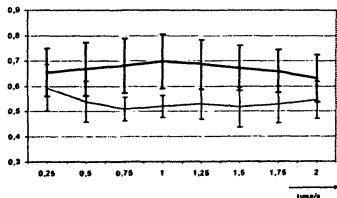


Fig. 2 - Results of the time-variant QPC analysis at Fp1 in twelve patients. From subsequent 250-ms intervals the maximum value of phase bicoherence between the frequency ranges 0.5 to 2.5 and 3 to 7 Hz has been extracted in each patient. The mean value ($n=12$) and the standard deviation was calculated for each time interval. The figure shows the mean values and standard deviations for burst patterns during BSP (thick line) and burst-like patterns during basic sedation (thin line).

The time profile of the QPC during bursting between 0 to 2.5 Hz and 3 to 7.5 Hz (Fig. 2a) shows high bicoher-

ence values within the first 250 ms, i.e. the QPC already exists immediately after the burst onset and before the highest amplitude of the slow wave as well as of the envelope curve appear (> 250 ms). The highest bicoherence values can be obtained in the time range 750-1250 ms. The QPC is maintained over the whole analysis interval (2 s) with a tendency of a moderate decreasing coupling strength. It can also be demonstrated that a QPC in burst-like EEG pattern (baseline EEG) exists, but not so pronounced compared to that within the burst pattern during the BSP.

The magnitude-independent time course (time dynamics) of bicoherence during bursting is unique for all patients and at the montages Fp1, Fp2, F1, F3 versus Cz. The time dynamics of the bicoherence within the burst-like patterns changes randomly from patient to patient as well as from electrode to electrode.

These results are true for grand mean data as well as for averaged data in each single patient.

DISCUSSION

The difference between the bicoherence values of the burst (BSP) and burst-like activity (basic sedation) can be interpreted as a change in the electrophysiological interactions of the involved brain structures caused by the drug or the drug-induced functional suppression (depth of sedation).

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