Continuous Attention Test, EEG propagation,
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TRANSMISSION OF INFORMATION DURING CONTINUOUS ATTENTION TEST

The aim of the paper is a study of information processing in brain connected with cognition. The Continuous Attention Test (CAT) is a specific differentiation tool in cognitive studies in particular on deficits of attention, based on visual information processing. The EEG signal recorded during CAT performance was analyzed by means of multivariate autoregressive model. The patterns of transmission were determined by means of Short-time Directed Transfer Function. The most characteristic feature was propagation in the gamma band from right side frontal area to the electrodes located over left side motor cortex.

1. INTRODUCTION

It is of primary interest to gain the information how the different cognitive resources held in specific cortical areas are integrated to form a coherent stream of perception, cognition and action. The study of transmission between brain areas can elucidate the problem of the interaction between brain structures and help in understanding the cooperative action of neural assemblies. However the proper method have to be applied for this kind of study. Such an estimator should provide the information about the direction, time course of the propagation and its spectral content. The measure, which fulfills this requirement, is a Short-time Directed Transfer Function (SDTF) [10], [7], which is a time-variant version of the Directed Transfer Function [9]. SDTF was successfully applied in the investigations concerning the motor task performance and its imagination [7], [8]. Contrary to the bi-variate measures of directionality or coherence, which often give very fragmentary or even misleading information [14], [2] DTF is estimated in the framework of multichannel autoregressive model (MVAR), which takes into account all channels of the process simultaneously and provides the information on the fully multivariate structure of the process.

The Continuous Attention Test (CAT) [18] is a specific differentiation tool in studies on deficits of attention, based on visual information processing. Topographic ERP studies, concerning the same CAT paradigm by means of the low-resolution electromagnetic tomography (LORETA) [1], revealed that the strictly cognitive activity, reflected by inter-condition differences (switching from non-target to target condition) was found mainly in prefrontal-cortex structures. The role of the rhythmic beta activity propagation connected with attention was considered in [13]. In this work

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we shall concentrate on transmission especially in the gamma band, since it is connected with the active processing of information.

2. MATERIAL AND METHOD

2.1. MATERIAL AND EXPERIMENTAL PARADIGM

The investigated group were 10 male normal subjects. Here we present preliminary results for 3 cases. The CAT experiment consisted of 720 consecutively displayed geometrical patterns. In order to eliminate systematical influence of bioelectrical activity related to forecasting by subject the time of pattern appearance, the stimuli were presented in random time intervals in the range: 1.5 to 2.5 s. The target was defined as any directly repeated pattern. After the appearance of the target the subject had to press the button with his right thumb. EEG was recorded from 21 electrodes (10-20 system) referenced to the linked mastoids and sampled at 250 Hz and filtered in 10-45 Hz band, since beta and gamma rhythms were of interest. The 1 s epochs after each stimulus were evaluated. The muscle artifacts were eliminated.

The trials concerning both CAT conditions were synchronized with respect to the onset of the visual CAT items and processed separately for detected target and non-target stimuli. 160 ms window were used for calculation of MVAR coefficients, it was shifted by 1 point (4 ms).

2.2. METHOD

The DTF method is based on fitting to the signal a multivariate autoregressive model (MVAR). In terms of the model a *k*-channel process can be represented as a vector **X** of *k* EEG signals recorded in time: $\mathbf{X}(t)=(X_1(t), X_2(t), ..., X_k(t))$. Then the MVAR model can be expressed as:

$$\mathbf{X}(t)=\sum_{i=1}^{p}\mathbf{A}(i)\mathbf{X}(t-i)+\mathbf{E}(t) \qquad (1)$$

where $\mathbf{X}(t)$ is the data vector in the time t, $\mathbf{E}(t)$ is the vector of white noise values, $\mathbf{A}(i)$ are the model coefficients and p is the model order.

Transfer matrix H(f) is not symmetric and its non-diagonal elements give the information about the causality relations between corresponding channels. Directed Transfer function (DTF) was first introduced in [9] in the form:

$$\gamma_{ij}^2(f)=\frac{|H_{ij}(f)|^2}{\sum_{m=1}^{k}|H_{im}(f)|^2} \qquad (2)$$

Normalization of DTF was performed in such a way that γ_{ij} described the ratio between the inflow from channel *j* to channel *i* to all the inflows of the activity to the destination channel *i*. Such ratio takes values from [0, 1] range. Its value close to 1 indicates that most of the signal in channel *i* consists of signal from channel *j*, values of DTF close to 0 indicate that there was no flow from channel *j* to channel *i* at this frequency.

Short-time Directed Transfer Function [10], [7] is estimated by means of calculation of correlation matrix (from which model coefficients are found) by ensemble averaging over realizations for short data epochs. The SDTF as a function of time and frequency is found by application of sliding window.

The errors of SDTFs were estimated by means of bootstrap method [6]. The variance of function value is obtained by repeated calculation of the results for a randomly selected pool of original data trials, which corresponds to simulating another experimental session. By repeating the procedure several times , one can get an estimate of the variance. On the basis of bootstrap error estimates the values of DTF in the post stimulus epoch DTF_{post} significantly different from the ones in the pre- stimulus epoch DTF_{pre} were found by means of t-test (the normal character of the distribution was checked). The ratios of significant DTF_{post} to DTF_{pre} were presented as functions of time and frequency. More detailed description of statistical procedures may be found in [12]

2. RESULTS

We have analysed the data for 3 patients, so the preliminary results will be presented. In Fig. 1 an example of the pattern of significant transmissions in target condition is illustrated, together with spectra, which are plotted on the diagonal. Considering the time-frequency evolution of spectral power, desynchronisation (decrease in spectral power) in the beta band and increase of activity in the gamma band is visible as could be expected [16]. In the non-target condition (Fig.1 - bottom), when the movement was not performed, these effects did not occur.

Off-diagonal panels illustrate the propagation as a function of time and frequency, namely the significant changes in respect to the epoch before the presentation of the stimulus are shown as a functions of time and frequency. One can observe the effect of target-related transmission in the gamma frequency band, originated from the right-sided electrodes: Fp2 and (less intensively) F8, towards electrode C3 (overlying the primary motor area of the right hand) and neighboring electrodes. We can also notify bilateral communication between prefrontal and frontal locations.

The propagation in the gamma band from right side frontal electrodes to the electrodes located over left side motor cortex was characteristic for all studied cases. In the non-target condition these effects were not observed.

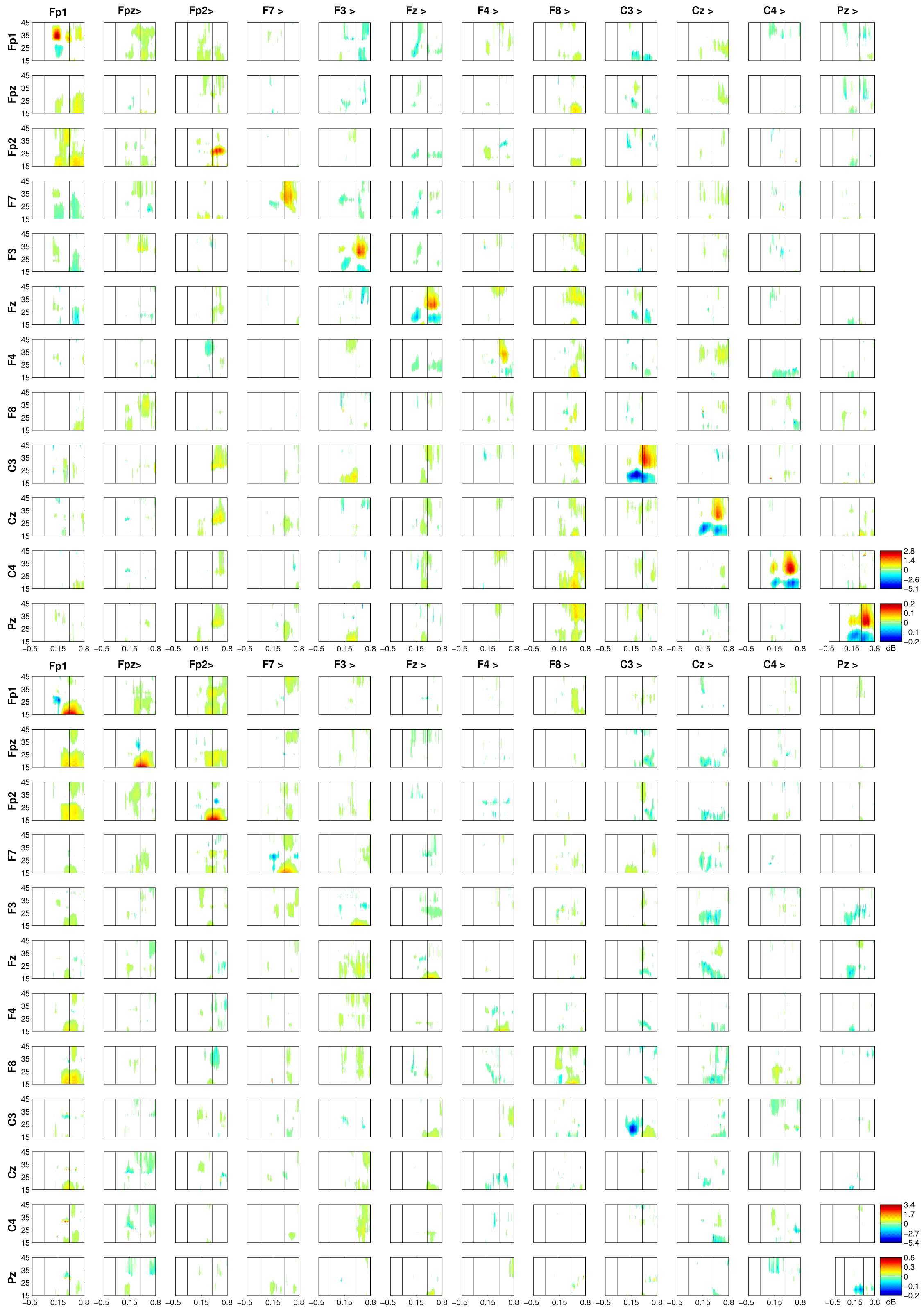

Fig.1. The significant changes in the propagation pattern during CAT test, (DTF_{post}/DTF_{pre}) presented in log scale of intensity. Upper panel – target, lower panel non-target condition. The propagation from the electrode marked above

each box toward the electrode marked at the left of the figure. In each box: horizontal scale - time , vertical scale - frequency. The vertical lines mark: appearance of stimulus and start of motor reaction. Intensity scale in colors: red – strongest increase in propagation, blue - strongest decrease of propagation, white – no significant change.

3. DISCUSSION

There exists rich evidence that synchronized oscillatory activity of neural assemblies subserves information processing by linking neuronal groups with similar functional state. Oscillatory activity of local field potentials plays a role in spatially selective multiregional cortical binding [15]. Hence, study of the role of EEG rhythms in the coupling of brain structures and investigation of spectral characteristics of signal propagation can bring valuable evidence concerning the mechanisms of the information processing in the brain.

It has been shown that beta and gamma rhythms have different synchronization properties [11] and that in motor control tasks a decrease of beta may be accompanied by an increase in the gamma band [8]. Beta rhythm is connected with the processes of attention and expectation [4]. Gamma activity has been interpreted as the information carrier [3] essential for binding processes. In experiments involving subdural electrodes the role of gamma activity in motor control was found to be essential [5].

We can conjecture that the cognitive processes related to the proper recognition of visual target and subsequent decision of motor reaction are connected with the enhanced propagation in the gamma band from prefrontal areas toward the left side motor sites. In particular it concerns the propagation from electrodes overlying prefrontal cortex of right hemisphere involved in visual information processing. The above pattern of transmission was specific only for target condition. The enhanced reciprocal communication between prefrontal structures can be associated with non-specific stimulus related cognitive activity.

In this work we have demonstrated the role of gamma rhythms in the test connected with cognition. It is especially interesting in the view of the role of the gamma activity in the feature linking [17]. Brain activity in the gamma band is very hard to observe in the EEG recorded from the scalp electrodes, since it is strongly damped by the head structures, besides it is often obscured by muscle artifacts. Usually, the gamma rhythm can be identified in a small fraction of the population. In this study it was observed in all subjects. This was possible because of the unique properties of the SDTF function, which is very robust in respect of noise and constant phase disturbances. SDTF is sensitive to phase differences between signals, so it allows us to extract phenomena connected with the shift of phase from a constant phase background. Due to this property of SDTF it was possible to observe a fast changing pattern of communication between brain structures in the gamma band.

BIBLIOGRAPHY

[1] Basińska-Starzycka A., Pasqual-Marqui R.D., Prefrontal structures involved in the continuous attention test performance as localised by the low-resolution electromagnetic tomography, In: Recent Advances in Human Brain Mapping, Elsevier, Intern. Congress Series, Vol. 123, pp. 433-437, 2001.

[2] Blinowska K.J., Kus R., Kaminski M., Granger causality and information flow in multivariate processes, Physical Review E, Vol. 70, 050902, 2004.

[3] Bressler S.L., The gamma wave: a cortical information carrier?, Trends in Neuroscience, Vol. 13, pp.161-162.

[4] Buser P., Rougeul-Buser A., Do cortical and thalamic bioelectric oscillations have a functional role? A brief survey and discussion, Journal of Physiology Paris, Vol. 89, pp.249-254, 1995.
[5] Crone N.E., Miglioretti D.L., Gordon B., Lesser R.P., Functional mapping of human sensorimotor cortex with electrocorticographic spectral analysis II: Event-related synchronization in the gamma band, Brain, Vol. 121, pp. 2301-2315, 1998.
[6] Efron B. and Tibshirani R.J., An Introduction to the Bootstrap, Chapman & Hall, 1993.
[7] Ginter J.Jr., Blinowska K.J., Kamiński M., Durka P.J., Phase and amplitude analysis in time-frequency space - application to voluntary finger movement, Journal of Neuroscience Methods, Vol. 110, pp. 113-124, 2001.
[8] Ginter J.Jr., Blinowska K.J., Kamiński M., Durka P.J., Pfurtscheller G., Neuper C., Propagation of EEG activity in beta and gamma band during movement imagery in human, Methods of Information in Medicine, Vol. 44, pp.106-113, 2005.
[9] Kamiński M., Blinowska K.J., A new method of the description of the information flow in the brain structures, Biological Cybernetics, Vol. 65, pp. 203-210, 1991.
[10] Kamiński M., Ding M., Truccolo W., Bressler S., Evaluating causal relations in neural systems: Granger causality, directed transfer function and statistical assessment of significance, Biological Cybernetics, Vol. 85, pp. 145-157, 2001.
[11] Kopell N., Ermentrout G.B., Whittington M.A., Traub D., Gamma rhythms and beta rhythms have different synchronization properties, Proceedings of the National Academy of Sciences, Vol. 97, pp.1867-1872, 2000.
[12] Korzeniewska A., Kus R., Franaszczuk P., Crainiceanu C., Crone N.E., Dynamic high-gamma interactions during language-related task performance, Epilepsia, Vpl. 46, Suppl. 8, p: 317, 2005.
[13] Kuś R., Blinowska K.J., Kaminski M., Basinska-Starzycka A, Propagation of EEG activity during continuous attention task, Bull Polish Academy Sciences, Technical Sciences, Vol. 53, pp. 217-222, 2005.
[14] Kuś R., Kamiński M., Blinowska K.J., Determination of EEG activity propagation: pair-wise versus multichannel estimate, IEEE Transactions on Biomedical Engineering, Vol. 51, pp. 1501- 1510, 2004.
[15] Lopes da Silva F.H., The rhythmic slow activity (theta) of the limbic cortex: an oscillation in search of a function, In: Başar E., Bullock T.H., Induced Rhythms in the Brain, pp. 83-102, Boston, 1992.
[16] Pfurtscheller G., Graimann B., Huggins J.E., Levine S.P., Schuh L.A., Spatiotemporal patterns of beta desynchronization and gamma synchronization in corticographic data during self-paced movement, Clinical Neurophysiology, Vol. 114, pp.1226-1236, 2003.
[17] Singer W., Gray C.M., Visual feature integration and the temporal correlation hypothesis, Annual Review of Neuroscience, Vol.18, pp. 555-586, 1995.
[18] Tiplady B., A continuous attention test for the assessment of the acute behavioural effect of drugs, Psychopharmacology Bulletin, Vol. 24, pp. 213-216, 1988.