14th World Congress of Psychophysiology, St Petersburg, 2008

Symposium «Differentiation of Mentally-specific and Non-specific Brain Activations: Temporal and Spatial Scales».

EEG Oscillatory States: Temporal and Spatial Microstructure

Alexander A. Fingelkurts and Andrew A. Fingelkurts
BM-Science – Brain & Mind Technologies Research Centre, Espoo, Finland

At present, almost all methods of quantitative EEG analysis are based on certain implicit assumptions regarding the statistical characteristics of EEG, particularly with respect to the extent of stationarity and Gaussianity of the signal. Different EEG parameters are usually derived from averaged EEG signal, based on extended periods of time and/or broad fixed frequency bands for a specific lead. However, the averaging of the EEG signal might not only mask the dynamics of EEG characteristics, but also may lead to ambiguous data interpretation.

In this context experiments and analytical work have established several important facts:

(1) The ongoing EEG is characterized by natural dynamics and piecewise stationary structure. Piecewise stationary structure of EEG is considered as a result of “gluing” of stationary casual processes with different probability characteristics. Within the duration of one segment, the system that generates the EEG oscillations supposed to be in the steady stationary state.

(2) The power variability of the main EEG spectral components for successive short (5–10 sec) EEG segments is in the range of 50–100%. As such, the average spectral characteristics of a broad frequency band predominantly reflect an influence of high-amplitude synchronized segments of the long EEG epochs and the low-amplitude desynchronized ones may be totally obscured.

(3) In terms of the EEG variability, not only the stochastic fluctuations of the EEG parameters, but also a temporal structure of the signal can be observed.

Therefore, averaging of EEG estimates most likely shows the balance of diverse state/task/drug-related EEG changes rather than actual – “principal” – processes over total signal or over all trials. Hence, when examining the average brain EEG activity, it is not clear whether the observed effect is real (not the “virtual” result of averaging procedure), stable and typical for the whole analyzed signal. Thus, regardless of how powerful or statistically significant the different estimations of averaged EEG phenomena may be, there might be difficulties in the meaningful interpretation of these if they are not matched to the EEG unstationary structure.

Such observations have, however, been neglected in basic cognitive EEG research.

A new promising area of the study of EEG transformations during cognitive processing is based on the reduction of the signal to the elementary EEG-patterns sequences.

It has been suggested that the operational elements of behavioral and mental activity are originated in the periods of short-term meta-stable states of the whole brain and its individual subsystems. From this viewpoint, it is possible to obtain an entire set of individual short-term stationary EEG segments. It was demonstrated that the parameters of the relative presence of the individual EEG segments of each type and the peculiarities of their alternation and synchronization in the analyzed multichannel EEG are adequate characteristics of brain operational activity.

Research of our colleges and us indicated the indubitable functional significance of the segmental EEG architectonics (Fingelkurts & Fingelkurts, 2001, 2004, 2005; Fingelkurts et al., 2002, 2003):

(1) It has been demonstrated that EEG signal consists of a restricted number of typical quasi-stationary segments (not more than 10-35 types for different EEGs), which do not exceed 1-2 sec, but usually has duration of 10-300 ms. In such a way, the dynamics of brain activity can be considered as a sequence of relatively stable and fixed EEG segments.
(2) The relative incidence of types of EEG segment change during the transition between neighboring EEG epochs was more than 0.50 (around 65% from the maximum possible rate), but significantly less than stochastic level (0.83). Moreover, types of EEG segments changed more frequently during an increase in the functional loading.
(3) It was shown that different types of EEG segments have different importance to the brain – their occurrence is less or more probable for particular functional state of the brain.
(4) EEG segments of the same type have the tendency to be stabilized in time. The maximum length of periods of temporal stabilization varied between 4.5 and 6.5 sec for different brain functional states. It was demonstrated the reduction in the maximum length of periods of temporal stabilization during the increase in the functional loading.
(5) Under constant experimental conditions the composition of types of EEG segments and their percent ratio for each subject demonstrated considerable test-retest reliability (0.7-0.9, measured by coefficient of

correlation) for both resting conditions and cognitive task. Within-subject test-retest reliability was: rest conditions < cognitive tasks and anterior part > posterior part.

(6) It was shown that there is functional synchronization between segments found in different EEG channels.
(7) Global stabilization of the functional state within several seconds is an exception rather than a rule for the normal operation of the brain.
(8) The inter-channel segmental EEG synchrony reflects the meta-stable principle of brain functioning.
(9) The operational acts of behavioral and mental activity are reflected in the periods of short-term *metastable states* of the whole brain and its individual subsystems

Advanced methods for analysis of such EEG micro-structure were developed. They are sensitive to dynamic and temporal characteristics of neural activity:

- o Adaptive probability-classification analysis of the individual short-term spectral patterns;
- o Measure of large-scale local and remote functional connectivity and metastability in the cortex.

Both of these methods are robust, model-independent techniques which

- consider the nonstationarity of EEG,
- are sensitive to temporal structure of the EEG,
- do not require prior knowledge of the underlying dynamics,
- do not contain averaging procedures,
- have special tests for non-random and non-occasional nature of the results and
- produce results which are ease to interpret in terms of their neurophysiological correlates

Both of these approaches were used in the following experimental paradigms:

- memory (Kaplan et al, 1997; Fingelkurts et al., 2003a,b)
- attention (Fingelkurts, 1998a,b)
- audio-visual speech integration (Fingelkurts et al., 2003c, 2007)
- sleep (Kaplan et al., 2001; Verevkin et al., 2008)
- functional states (Shishkin et al., 1998)
- ontological shifts in brain activity (Kaplan et al., 2005)
- schizophrenia (Borisov et al., 2005)
- depression (Fingelkurts et al., 2006, 2007)
- epilepsy (Fingelkurts et al., 2006a,b)

- psychopharmacology (Fingelkurts et al., 2004a,b,c)
- opioid dependence (Fingelkurts et al., 2006 a,b)
- opioid withdrawal (Fingelkurts et al., 2007, 2008)
- methadone treatment (Fingelkurts et al., 2007, 2008)
- meditation (Lobusov et al., 2001)
- hypnosis (Fingelkurts et al., 2007a,b)

Publications can be found at: http://www.bm-science.com/team/fgk-publ.html