Editorial: EEG Phenomenology and Multiple Faces of Short-term EEG Spectral Pattern

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Abstract: An electroencephalogram (EEG) signal is extremely nonstationary, highly composite and very complex, all of which reflects the underlying integral neurodynamics. Understanding the EEG "grammar", its internal structural organization would place a "Rozetta stone" in researchers' hands, allowing them to more adequately describe the information processes of the brain in terms of EEG phenomenology. This Special Issue presents a framework where short-term EEG spectral pattern (SP) of a particular type is viewed as an information-rich event in EEG phenomenology. It is suggested that transition from one type of SP to another is accompanied by a "switch" between brain microstates in specific neuronal networks, or in cortex areas; and these microstates are reflected in EEG as piecewise stationary segments. In this context multiple faces of a short-term EEG SP reflect the poly-operational structure of brain activity.

Keywords: Electroencephalogram (EEG) phenomenology, short-term spectral patterns, neuronal assemblies, EEG oscillatory states, brain oscillations, EEG frequencies.

EPIGRAPH

"*The measurement, interpretation and analysis of EEG signals depend on a specific technology that has evolved since Berger's time*". *Shaw J.C. [1].*

NEED FOR A NEW FRAMEWORK

Thirteen years ago Bullock [2] wrote "We are in a primitive stage of looking at the time series of wide-band voltages in the compound, local field, potentials and of choosing descriptors that discriminate appropriately among brain loci, states (functions), stages (ontogeny, senescence), and taxa (evolution)." Today, in the year 2010, the situation is not very different although some progress has been done. The reason for such an unfortunate state of affairs is as follows: the vast majority of neuroscientists are not studying (not looking at) the electroencephalogram – EEG (time series) as a "subject" of investigation, instead they just use it as an objective tool for clinical purposes or to elucidate neurophysiological processes of cognitive activity. However, sparse studies demonstrated that the EEG signal as a neurophysiological phenomenon has its own structure[1] and rules of organization [4-8] (for the reviews see [9-12]). Only when one knows these characteristics, it is possible to make proper use of EEG as a tool and to give adequate interpretations of the obtained data. Another reason for the lack of studies of the EEG signal itself is related to fashion in science and was expressed by Shaw [1]: "A majority of present-day scientists … prefer to use the most recent technological facilities, on the assumption that, by doing so, they may gain a lead over competitors. It is almost general practice today that a scientist, when drafting his project, is guided by the contingency of the tools he has at his hands, rather than to develop at first a genuine and definite plan …. This holds even more true for brain research, which seems to be influenced more by the latest available tools and by technological developments, rather than by personal ideas."

In this context Basar's call for a new framework for Neuroscience and related new approaches for integrative brain activity [13] is still relevant. What can this framework look like? The main tenet of such a framework should be the notion that any system (EEG in our case) has a particular structure or organization i.e. the type of connections between the elements of a system. Therefore, the main task of EEG research should be the revealing of the content of the system as having a structure (for a discussion see [14]).

EEG PHENOMENOLOGY FRAMEWORK

Introductory Aspects

Recent advancements in Neuroscience have established several observations important for EEG phenomenology, - these are:

- EEG is characterized by several types of natural rhythmic oscillatory activity in various frequency ranges: delta (0.1-3.5 Hz), theta (4-7.5 Hz), alpha (8-13 Hz), beta (14-30 Hz) and gamma (>30 Hz) [15, 16] which reflect neurophysiological processes at different temporal scales.
- EEG rhythms are information-rich signs (telltale measures) of the underlying neurodynamics on the one hand and the signals (that is, they exert causal influence) for neuronal assemblies on the other [2, 17].
- The frequency bands of the various EEG oscillations are kept relatively constant throughout mammalian evolution, even though the numbers of neurons and their connections have increased enormously [18].
- All EEG oscillations exhibit high heritability thus being determined genetically (for a review and meta-analysis, see [19]).

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[1] Structure – totality of elemental units and interrelations between them, according to which this totality forms a single entity with its own spatial-temporal definiteness [3].

- All brain areas react to sensitive and cognitive inputs with EEG oscillatory activity within almost invariant and general governing frequency bands [13]. Experimental results show that the degree of synchrony, amplitude, duration, and phase lag continuously vary, but similar EEG oscillations are always present in the activated brain tissues [13]. Thus, EEG frequency generators are selectively distributed across the entire brain.
- Types of neurons do not play a major role for frequency tuning of oscillatory networks. The neural architectonics of the cerebellar cortex, cerebellum, and hippocampus are completely different. In spite of this, all these structures behave with almost similar frequency responses [13].
- Neurophysiologically different EEG frequencies appear to be related to the timing of different neuronal assemblies, which are associated with different types of sensory and cognitive processes [20] thus being of fundamental importance for mediating and distributing "higher-level" processes in the human brain [21-24].
- Functions in the brain are manifested by varied degrees of superpositions of oscillations in EEG frequency ranges [13, 25].

Taking these observations together suggests that EEG oscillations are important rhythmic electrical events in the brain and may be considered as the "building blocks" of EEG phenomenology.

Methodological Aspects

The history of EEG oscillations studies has demonstrated that they can be quantified successfully by EEG power spectrum. EEG power spectrum is a compact integrative real measure of the spectral energy (i.e., the energy per unit frequency interval). In neurophysiological terms EEG power spectrum reflects the strength of neuronal assemblies' activity [26].

It is well known that EEG power spectrum exhibits high variability. Indeed, it was found that the power variability of the main EEG spectral components for sequential short (5-10 sec) EEG segments is 50-100% [27]. For a long time this variability was considered as measurement error, noise or stochastic fluctuations. However, later studies [5, 28] (for the review see [9]) showed that in the phenomenon of EEG spectral variability, not only the stochastic fluctuations of the EEG parameters, but also the temporal structure of the signal is reflected. It is suggested that temporal structure of EEG signal is determined by a sequence of relatively stable brain microstates in specific neuronal networks, or cortex areas, which are reflected in EEG as piecewise stationary segments [5, 29, 30] (for the review see [31]). Functionally, each piecewise stationary EEG segment corresponds to a particular brain operation in a given cortex area [32, 33]. Therefore, segmental structure of the EEG signal reflects the poly-operational structure of brain activity.

In this context the identity of each type of EEG segment can be characterized by a particular type of short-term spectral pattern (SP) [7, 8, 34, 35]. Therefore, EEG spectral variability is functional: fluctuations in individual short-term SPs reflect fluctuations in underlying neuronal states (*see contribution of Fingelkurts and Fingelkurts to this Special Issue*).

Taken together these observations suggest that calculation of short-term EEG SPs is a more adequate measure of dynamic EEG oscillations than averaged power spectrum, which presents a "static" picture and tells nothing of the EEG temporal structure (*see contribution of Fingelkurts and Fingelkurts to this Special Issue*). Therefore, reduction of the signal to the elementary spectra (SPs) of various types in accordance with the number of types of EEG stationary segments instead of using averaged power spectrum for the same EEG is justified.

In this sense short-term EEG SPs of a given type by itself become the phenomenon that characterises the EEG. Following this approach, a phenomenology of EEG can be developed, by means of which different types of short-term SPs are considered to be characteristic for certain states of local EEGs (*see contribution of Fingelkurts and Fingelkurts to this Special Issue*).

Empirical Aspects

Conceptual meaning of short-term EEG SP of a given type, the functional significance of its morphology and functional relevance of the parameters of the composition of short-term EEG SP types has been demonstrated. This also includes their percent ratio and the peculiarities of SP type alternation in the analyzed EEG in accordance with the changes of functional brain state, cognitive tasks and with different neuropsychopathologies (*see contribution of Fingelkurts and Fingelkurts to this Special Issue*).

An important, although relatively less studied, aspect of short-term SPs is the temporal variability and individual differences in the cortical distribution of short-term spectral power at different frequency bands and association of this distribution with different personality traits. These phenomena are presented in the experimental study by *Knyazev* (see *this Special Issue*). This work is of prominence since it was suggested that a particular topographic distribution of the EEG spectral power along the antero-posterior cortical axis can be viewed as a "fingerprint" of sort which enables researchers to distinguish individuals.

Another important aspect of short-term EEG SPs that has not yet been addressed is their functional role during extreme condition within a continuum of possible conditions, – in this case – anesthesia. An experimental study presented by *Ozgoren* (see *this Special Issue*) demonstrated changes in the types of short-term SPs during the administration of anesthesia. This study is very important in providing a useful model for the study of short-term spectral phenomena of the brain in relation to loss and gain of consciousness.

AIM OF THE SPECIAL ISSUE

The objective of this Special Issue is aimed at providing a current update on the relation between a power spectrum computed from short epochs of ongoing EEG and the actual state of the neuronal assemblies in the underlying network.

Contributions from different experts in the field provide experimental studies and a detailed review of this challenging frontier of neuroscience. We hope this Special Issue will help interested researchers become familiar with research achievements and new directions.

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