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How is the brain working? Research on brain oscillations and connectivities in a new "Take-Off" state

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ABSTRACT

The present report is a trial to survey analysis and applications of brain oscillations in cognitive impairment for opening the way to a new take off in research on brain oscillation. Although the number of papers related to brain oscillations rapidly increases, it is important to indicate the common principles governing the functioning of brain oscillations in the brain and body. Research scientists need a global view on the types of analysis, applications and existing oscillations.

Further, scientists dealing with brain oscillations must have some knowledge from theoretical physics, system theory, and also general philosophy. The neuroscientists working on brain oscillations can mentally integrate several papers in the present report, and try to discover new avenues to augment knowledge on brain functions. A new take off in the search of brain oscillations indicates the strong need to survey this brunch of neuroscience in a broad panoply of science.

1. Introduction

> *Everything in the universe could be explained in terms of a few intelligible systems and simple approaches, upon which the stars and the earth and all visible worlds may have been produced.*
>
> [*Renée Descartes*]

The philosophic views of René Descartes are found relevant in research of physics, chemistry, and astrophysics. These views are also valid in neuroscience. New trends in neuroscience are based on the above concept. In the present special issue, 19 contributions are included, which could provide a new take off in the understanding of EEG–brain oscillations and their spectral connectivity. Possibly a "Big Bang" will occur in neuroscience literature based on brain–body oscillations and connectivity.

The present report aims to introduce 19 steps that may aid in a new take on EEG–oscillation analysis. This may, in turn, open new avenues to prepare efficient responses to the following questions:

a) How does the brain work?
b) Can we better understand the functionality of the brain by extending the Brodmann areas with connectivity concept?[1]
c) What can we learn from the "Broken Brain"?
d) Is the brain a dynamic syncytium and memory a continuum in time space?

1.1. What is the place of psychophysiology in the interdisciplinary sciences and brain oscillations?

Can interdisciplinary approaches again gain terrain?

What is psychophysiology, and what is physiology? Are there bridges between physics, physiology and psychophysiology? Do we again need a common language in the 21st century?

Psychophysiology is an integrated field of physiology and neuroscience. Through electrophysiological and neuroimaging techniques, it establishes methodologically essential and crucial links for the investigation, understanding and mapping of brain functions. Psychophysiology looks at basic cognitive, emotional and motivational processes as well as normal and pathological conditions. Further, psychophysiologists are scientists integrating scopes of several disciplines.

Can the four "P's": *Physics*, *Physiology*, *Psychology* and *Physiology* provide a common language or common links? I favor the following view: A union between biophysics, (which combines realms of physics, physiology and molecular biology) and psychology is indispensable. Both disciplines are inseparable.

In the 19th century, an experimental biophysicist named Hermann von Helmholtz unified the four P's. He not only launched predictions, but also provided a strong empirical foundation by raising questions

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[1] CLAIR means: connected-coherence, linked, associative and integrative responses.

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and trying to find experimental evidences. In the 20th century, C.F. Hayek launched a very important theoretical frame, but did not perform genuine experiments since he was an economist (i.e. a theoretician).

In the first half of the 20th century, the field of psychology went through a magnificent breakthrough with the works of Karl Lashley, Donald Hebb, and B.F. Skinner, just to mention a few. Marcel Proust and Henri Bergson combined philosophy and psychology to open the way to the concept of episodic memory. Hans Berger, Ramon ŷ Cajal and Lord Sherrington launched breakthroughs in neurological sciences. Parallel to this, a magnificent breakthrough took place in physics with Henri Poincarré, Albert Einstein and the Copenhagen School with work of Niels Bohr, Werner Heisenberg, Max Born, and E. Schrödinger.

New steps included the evolution of molecular biology with Jacques Monod, cybernetics by Norbert Wiener, synergetics by Hermann Haken, study of dissipative structures by I. Prigogine, and catastrophe theory by René Thom. New approaches to cognitive processes have been very successful by the use of fast computers, fMRI, MEG and PET.

At the century of René Descartes (1596–1650) and of Blaise Pascal (1623–1662) tools for measuring the "Thinking Processes" were not available. Now, we have some of them.

Are the progresses in science now powerful enough to describe the processes of mind? Mankind achieved important steps, although we will never be able to completely solve the problem of brain body and mind incorporation. However, we must have to continue to research and ask further questions.

In the twentieth century, the structure of the atom was successfully illuminated, but the processes of thought continued to seem illusive. Has the time come to tackle common concepts from all branches of science and philosophy?

The Ionian philosophers Anaxagoras, Leucippus, and Democritus of the fifth century B.C. postulated that all matter is made of a set of particles, which were atoms to denote their presumed invisibility. Their concept of a world made up of invisible, incompressible eternal atoms in motion is best known through the writings of the Latin poet Lucretius (98 to 55 B.C.)

2. The contributions of this special issue point to a big change in the study of brain oscillations

The papers in the present special issue are chosen in order to orient the readers to the analysis of multiple oscillations via multiple strategies. In particular, the transition from healthy brain to diseased brain opens the possibility to discover the important relation between oscillations and neurotransmitters. Additionally, we have new possibilities to study the anatomy of the intact brain and the brain with injuries. Brain imaging methods such as MRI and DTI are very efficient complimentary tools understanding avenues in brain functioning.

In the last two decades, the analysis of brain oscillations is one of the most important developing research areas in neuroscience literature. This type of progress has opened the way to generation of publications that analyze less important details and do not contain new breaking progresses. Lord Kelvin stated, "every science is measurement, but every measurement is not science." We should somewhat change these last words: Every measurement does not belong to important new breaks in science.

As we will explain in the next section, during the last 45 years one of coauthors (E.B.) has been involved in several types of experimental research and theoretical achievements in the field of brain oscillations. According to this longstanding experience, we can evaluate which new steps in neuroscience research could elicit new avenues leading to a gigantic new take-off in the field.

3. Surveys in the special issue

3.1. Multiple methods

More than eighty years has been past since the discovery of Hans Berger. According to Herrman et al. (in this volume), most cognitive processes have been linked to at least one of the traditional frequency bands in the delta, theta, alpha, beta, and gamma ranges. Although the existing wealth of high-quality correlative EEG data led many researchers to believe that brain oscillations promote various sensory and cognitive processes, a causal role can only be demonstrated by directly modulating such oscillatory signals. Hermann et al. (in this volume) highlight several methods to selectively modulate neuronal oscillations, including EEG-neurofeedback, rhythmic sensory stimulation, repetitive transcranial magnetic stimulation (rTMS), and transcranial alternating current stimulation (tACS). The modulation of neuronal oscillations demonstrates causal links between brain oscillations and cognitive processes, leading to obtain important insights on human brain function.

3.2. A methodological survey of oscillation analysis and strategies

The paper by Başar et al. (in this volume-a) is an account of methods such as evoked/event-related spectra, evoked/event-related oscillations, coherence analysis, and phase-locking. The report does not aim to cover all strategies related to the systems theory applied in brain research literature. However, the essential methods and concepts mentioned in this paper are applied to multiple important disease states such as Alzheimer's disease (AD), schizophrenia (SCZ), and bipolar disorder (BD). Such disease examples demonstrate fundamental findings in the search for neurophysiological biomarkers in cognitive impairment. An overview of the results clearly demonstrates that it is obligatory to apply the method of oscillations in multiple EEG frequency windows to search functional biomarkers and to detect the effects of drugs. Again, according to the summary of results in AD and BD patients, multiple oscillations and selectively distributed recordings must be analyzed and should include multiple locations. Selective connectivity between selectively distributed neural networks has to be computed by means of spatial coherence. Therefore, in designing a strategy for diagnostics and application of (preventive) drugs, neurophysiological information should be analyzed within a framework including multiple methods and multiple frequency bands. The application of drugs/neurotransmitters gains a new impact with the analysis of oscillations and coherences. A more clear and differentiated analysis of drug effects can be attained in comparison to the application of the conventional wide-band evoked potential (EP) and event-related potential (ERP) applications.

4. Alpha band is not "idling of the brain"

As early as 1980, Basar demonstrated the functional relevance of alpha activity (Başar, 1980). The same author showed that the EEG is not a noise signal and that alpha does not manifest the "idling of the brain." All contributions of the present issue indicate the same trend.

5. Importance of delta window in cognitive processes

In the last decade, neuroscience literature focused on the brain's oscillatory responses. The studies on human delta (0.5–3.5 Hz) oscillatory responses in cognitive paradigms date back to 1984. Pilot studies of Başar and Stampfer (1985) and Stampfer and Başar (1985) showed that delta oscillatory responses were involved in "perception, attention, learning, decision and working memory."

The manuscript by Güntekin and Başar (in this volume) comprehensively reviews the studies looking at delta oscillatory responses. This paper focuses on delta responses that impact on cognitive stimulation

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