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The theory of the whole-brain-work

Erol Başar

Dokuz Eylül University, Brain Dynamics Multidisciplinary Research Center and Faculty of Medicine Department of Biophysics, 35340, Balçova, İzmir, Turkey

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Abstract

The theory of the whole-brain-work basically explains the oscillatory dynamics of the human and nonhuman brain during cognitive processing. The theory is based on principles according to which brain functions are represented by the oscillatory activity. Oscillatory activity in a given frequency band performs multiple functions since they vary on a number of response parameters. There is selective cooperation in the stimulated brain; this produces super-binding between neural populations and super-synergy in the whole brain. The concept of super-synergy thus includes super-binding and, additionally, entropy and the role of EEG-oscillations as control parameters in brain's responsiveness. In super-synergy, spatial integration occurs through the selective cooperation of brain structures. Temporal integration occurs in line with the principle of superposition of oscillations in which the comparative polarity and phase angle are critical for forming the function-specific configurations. Extension of the theory of whole-brain-work to cognitive processing proposes that there is a constant reciprocal activation within the subprocesses of attention, perception learning and remembering and this leads to an APLR-alliance. In such a context, all brain functions are inseparable, for instance, from memory function and, in turn, memory states have no exact boundaries along the time space; memory states thus evolve in the APLR-alliance. The theory claims that the reentry and the dynamic behavior of oscillations during the reciprocal activation in APLR-alliance are among the causal factors for brain dynamics and for cognition.

Keywords: Brain oscillations; Spatial integration; Temporal integration; Super-synergy; APLR-alliance; Causality; Memory; Attention; Perception

> "...The whole burden of philosophy seems to consist in this, from the phenomena of motions to investigate the forces of nature, and from these forces to demonstrate the other phenomena." (Newton, 1687/1726)

1. Introduction

Science seeks for causes. With the exception of the conventional analysis of neural activity which uses single unit recordings, the concept of causality has somewhat been overlooked in neural sciences and the need for rules and theories have thus been overlooked. This has generally been the situation for also EEG-oscillation analysis.

In all natural sciences, the general questions and problems on the concept of causality are based on or are derived from Newtonian dynamics. According to the first law of motion in Newtonian system, "free motion" is uniform motion in a straight line. When a force is applied to a body, it causes the body to deviate from this free motion. All observed motions could be analyzed into two components: a free component (inertia) and a component due to the acting force. The second law states that the force acting on a body is always proportional to the product of its mass and acceleration. Newton (1687/1726) never regarded the word "force" just as a name for this mathematical product. However, as a natural scientist, he eschewed speculation in dealing with the nature of forces and, for scientific purposes, he thought it sufficient to calculate and observe the effects of these forces.

Furthermore, Isaac Newton (1687/1726) was interested not only in *descriptions* pertaining to motions of planets, but he also wanted to find the *mechanism* of gravitation between the planets. Likewise, Galileo Galilei did not only observe the oscillations of clocks, but he also wanted to learn about their *machineries*. Albert Einstein was interested in describing tracks of the molecules as in the case of Brownian motion, but he also analyzed the *causes* of Brownian motion. Furthermore, Einstein was searching for causes of gravitation, but he also wanted to

E-mail address: erol.basar@deu.edu.tr.

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understand the causes of dissipating energy. To establish what has happened in the galactic system, Einstein predicted the existence of "black holes" from not only the facts about astrophysical events, but also from a combination of accumulated data on the motion of stars and *laws of physics.* Einstein thus offered *descriptions and explanations* pertaining to the nature of stars and the galaxy, including those that were not visible to conventional observations, i.e. the black holes.

Due to its breadth and impact, Newtonian dynamics has become the metaphor of all natural sciences. The relevance of the prestimulus EEG as a causal factor in attention, perception, learning and remembering has important parallels with Newton's (1687/1726) first law of motion where the state of a moving body is a causal factor for the further evolution of its movement. The application of this law to electrophysiology is the following: The state of the brain as reflected in the prestimulus EEG is the causal factor for the later brain responses.

The trajectories (EEG signals) reflecting the activity of neuronal populations can also be analyzed as somewhat similar to the analysis of motion. As the expression "brain dynamics" implies, we intend to also elucidate the causes or mechanisms that give rise to the trajectories of the electrical signals in the brain. Similar to trajectories of missiles, or trajectories in Brownian motion, EEG trajectories is already providing most useful information on neural mechanisms that give rise to different transitions. The EEG seems to serve as a fundamental trajectory that is causally related to memory building and integrative brain function. The application of the Newtonian perspective or Einstein's approach when searching for the mechanisms behind EEG trajectories has already started.

However, recent developments on the dynamics of quantum physics and the new approach on chaos certainly brought a different understanding to the Newtonian causality. In his highly popular book on chaos, Gleick (1987), an advocate of the new science, went so far as to say: "Twentieth-century science will be remembered for just three things: relativity, quantum mechanics and chaos." Chaos is the century's third great revolution in the physical sciences. Like the first two revolutions, chaos cuts away at the tenets of Newtonian physics.

Can these development be useful and have the great impact that the systems of Newton, Galilei and Einstein's has had. The new development, "chaos in brain function", is certainly fascinating. However, in the period of 1985–2000 during which findings on chaotic EEG were obtained, noteworthy progress was also occurring in the study of oscillatory phenomena and neural network resonance at the cellular level. Fruitful findings were also obtained upon application of the concept of entropy to brain processes (Rosso et al., 2001, 2002). The slogan, "EEG is not simple noise", was formulated and this represented the conceptual renaissance in brain electrophysiology. Interpreting their findings, the neurophysiologists stated: "EEG is not noise, but is a quasi-deterministic signal." All these empirically derived approaches were in fact favorable to chaotic dynamics of brain function.

Meanwhile, with a few exceptions, prediction and mathematical description of brain behavior has not been in the mainstream of brain research. Influential ideas such as those of John von Neumann and Burks (1966) may have had their share in this neglect: "…logics and mathematics in the central nervous system, when viewed as languages, must be structurally essentially different from those languages to which our common experience refers." Therefore, the "big bang" of applying chaotic dynamics to brain activity has struck brain scientists all too early, when they were not yet prepared to use these concepts. Accordingly, studies that attempt to explain the brain through chaotic dynamics could not gain the status of a coherent research endeavor.

The present section presents a theory on brain function that basically follows Newton's, Galilei's and Einstein's pathway. In this theory, the language brain uses is the brain waves. The oscillations in the different frequency bands are like the phonemes in languages. Superimposed oscillatory responses are the words. The selectively distributed parallel processing pathways are the syntax of the brain language. And the whole-brain-work that follows the super-synergy is the sentences and the discourse in the language of the brain.

2. The theory of the whole-brain-work: an approach to brain function by means of EEG-oscillations

Chronological evolution of our conceptual framework evolved in the last 20–25 years. The development in the last 5 years has especially been fast. At its present state, the theory of the whole-brain-work represents the extension of the previously formulated neurons-brain theory.

2.1. Basic principles

The theory assumes that functions of the brain, especially those in cognitive processing, are based on EEG and field potentials, shortly, the oscillatory activity. The theory rests on four basic principles.

Principle 1. Brain functions are represented by its oscillatory activity. It is to be noted that this activity is the paradigm change that Mountcastle (1998) had announced for brain sciences toward the end of the last century.

Principle 2. There is cooperation between distant structures of the brain and these can be measured by means of coherence and phase differences. The whole brain is activated during cognitive processing. Thus there is a super-synergy in the brain during all percept-and memory-related processes.

Principle 3. The cooperation between brain structures is selective. The selectivity may be demonstrated in the selective distribution of the coherence functions over various brain structures with values that vary between 0 and 1. The demonstration of the principle of selective cooperation requires the analysis of oscillations in several neural populations and in several frequency windows. Such analyses and the related findings have been instrumental in the further refinement of the concepts pertaining to "whole brain" and "cooperation".