International Journal of Psychophysiology xxx (2015) xxx–xxx

Contents lists available at ScienceDirect

International Journal of Psychophysiology

journal homepage: www.elsevier.com/locate/ijpsycho

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The brain as a working syncytium and memory as a continuum in a hypertime space: Oscillations lead to a new model

Q5 Erol Başar *, Aysel Düzgün

Istanbul Kultur University, Brain Dynamics, Cognition and Complex Systems Research Center, Istanbul, Turkey

ARTICLE INFO

Available online xxxx

Keywords:
Memory
Episodic memory
Working memory
Semantic memory
Brain syncytium
Intuition
Bergson
Oscillations
Delta
Alpha
Gamma

ABSTRACT

The aim of the present study is three fold, as follows: (1) We propose a new framework describing the neurophysiologic functioning and cognitive processing of neural populations, and we extend the neuron doctrine to the physiology of neural assemblies; (2) The extension from neurons to neural populations implies that the brain, with its connectivities, should be considered a working syncytium, which extends Brodmann Mapping to the "CLAIR" model, which includes oscillatory components and their connectivity; and (3) In such a working syncytium, a new description of "memory" is needed in the broad time–space continuum, which embraces all memory states. This will be called "hypermemory".

Q6
1. Introduction

1.1. The brain is a working syncytium

1.1.1. History

Based on his analysis of signaling, Ramón y Cajal believed that the brain is an organ constructed of specific, predictable circuits. This was much different from the prevailing view, which saw the brain as a diffuse nerve net, in which every imaginable type of interaction could occur anywhere in the brain (Kandel, 2006).

Although Cajal believed that the brain was built from neural networks with several individual and autonomous firing neurons, the connectivities between long distance neural networks actually cause the brain to act as a working syncytium.[1] In a working syncytium, every imaginable type of interaction can occur anywhere, which is in contrast to the statement of Cajal. This interpretation has been clearly described in the CLAIR model by Başar and Düzgün (in this volume-b), which includes oscillatory activity and connectivity.

In the last three decades, another working hypothesis has been developed, which is derived from the neuron doctrine. Several investigators have shown that a brain function (except for simple reflexes) cannot be performed with small numbers of neurons or only with a unique brain structure. Several areas of the brain are activated, especially during cognitive processes (Yener et al., in this volume). Examples of this activation include the cognitive functions performed upon the oddball paradigm, event related oscillations, and the connectivity in long distance areas of the brain, which are used for the realization of perception, sensory performances, short term memory, and decision making. Therefore, the well-established Brodmann concept should be extended or replaced by the newly introduced CLAIR model, which should act as a transition from the neuron doctrine to the concept that neural populations are distributed throughout the whole brain. This new explanation could act as the new brain mapping model for perception, memory, sensation, and emotion.

1.1.2. What is the mind?

According to encyclopedic knowledge, the "mind" refers to the collective aspects of *intellect* and consciousness, both of which are manifested in some combination of *thought*, *perception*, *emotion*, *will*, and/or *imagination*. There are many theories regarding the mind and how it works, which date back to the Ancient Greeks, including Plato and

* Corresponding author. Tel.: +90 212 498 43 92; fax: +90 212 498 45 46.
E-mail address: e.basar@iku.edu.tr (E. Başar).

[1] Initially we have tentatively described the brain as a dynamic syncytium. This expression was criticized by Claudio Babiloni as follows:
"The concept of syncytium can be misleading. Physiologists use this term when several elements are aligned by anatomical features: skeletal muscle is composed by several cells sharing their nuclei and the action potential run along the fibers without any barrier formed by the separation of the single cells. I think that the main feature of the brain neural networks is that they are not syncytium. They are anatomically and functionally formed to allow functional synchronic co-activation (on mode) and asynchrony for de-activation. They can integrate and dis-integrate different nodes and modules on the basis of different functional states and inputs. Integration and dis-integration is a different concept of "syncytium" implying "all or none" behavior of several functional units".
The working brain is anatomically not a syncytium in the classical sense. The axonal communication between separate cells causes the brain to work as a syncytium.

http://dx.doi.org/10.1016/j.ijpsycho.2015.02.019
0167-8760/© 2015 Published by Elsevier B.V.

Aristotle. Modern theories, which are based on a scientific understanding of the brain, explain the mind as a phenomenon of psychology, and often psychiatry, and the term “mind” is often used synonymously with “consciousness.”

2. What are the conceptual essences of the reports in the present special issue?

According to the results of the reports in this special issue, the electroencephalography (EEG) is a quasi-deterministic or a chaotic signal, and should not be considered as simple background noise. The information in these reports leads one to the conclusion that the oscillatory activity, i.e., EEG, governs the most general transfer functions in the brain (Başar, 1990).

The theory that the brain works as a syncytium proposes that integrative brain function is based on the coexistence and cooperative actions of many interwoven and interacting sub-mechanisms. This theory also includes mechanisms that consist of super-synergy, superbinding, and reciprocal interactions of attention, perception, learning, and remembering (APLR-alliance).

These mechanisms have been grouped under eight structural and/or functional levels.

In order to describe the cognitive, functional, and behavioral aspects of the brain, it is important to gather all of the facts and theories relating these aspects to brain oscillations. According to prior knowledge as well as the reports of this special issue, a more speculative change of ideas might be considered the eighth category. We call this category the “dark side of the brain,” which is similar to the expression “the dark side of the moon” or “the dark matter” from astrophysics.

Herein, we will outline a summary of structural evidence collected from earlier special issues (Schürmann et al., 1997; Başar-Eroğlu et al., 1991; Başar et al., 2013; Başar, 2008; Başar et al., 2001d). The functional properties of the brain are grouped in the following eight categories.

2.1. From neurons to neural networks

1. The oscillatory activities of the neural assemblies of the brain consist of the alpha, beta, gamma, theta, and delta frequencies. These are natural frequencies, and therefore, they are the real responses of the brain (Başar et al., 2001a,b,c).
2. The type of neuronal assembly does not play a major role in the frequency tuning of oscillatory networks. This is because morphologically different neurons or neural networks are excitable in similar frequency ranges. Research has shown that neural populations in the *cerebral cortex*, *hippocampus*, and *cerebellum* are all tuned to the very same frequency ranges, although these structures have completely different neural organizations (Başar, 1998, 1999; Eckhorn et al., 1988; Steriade et al., 1992; Singer, 1989). Therefore, it has been suggested that all brain networks communicate by means of the same set of frequency codes from EEG-oscillations.
3. In an attempt to describe the integrative functions of the brain upon complex stimulation, prior studies have replaced the functional role of the single neurons with neural assemblies (Başar et al., 2001a). The major point that differentiates the described results in this special issue from Sherrington's “neuron doctrine” and Barlow's “new perception doctrine” is the emphasis on neural assemblies (Barlow, 1995).
4. The brain has *response susceptibilities*. A neural population responds to external or internal stimuli with EEG responses or frequency components that are among its intrinsic (natural) rhythms. Similarly, if a given rhythm does not exist in a neural population's spontaneous activity, it will also be absent in the evoked activity. Conversely, if activity over a given frequency range does not exist in the evoked activity, it will also be absent in the spontaneous activity (Başar, 1972, 1980, 1983a,b, 1992; Başar-Eroğlu et al., 2001; Narici et al., 1990).
5. There is an inverse relationship between EEG and event-related oscillations. Therefore, the amplitude of the EEG serves as a control parameter for brain responsiveness, which can be obtained in the form of evoked potentials or event-related potentials (Barry et al., 2003; Başar, 1998; Başar et al., 2003; Rahn and Başar, 1993).
6. The number of oscillations and the ensemble of parameters that are obtained under a given condition increase as the complexity of the stimulus increases, or as it become more difficult to recognize the stimulus. Oscillatory neural tissues that are selectively distributed throughout the whole brain are activated upon sensory-cognitive input. The oscillatory activity of neural tissues can be described through a number of response parameters. Different tasks, and the functions that they elicit, are represented by different configurations of parameters. Because of this, the brain uses the same frequency range to perform not just one, but multiple functions. The response parameters of the oscillatory activity are as follows: enhancement (amplitude), delay (latency), blocking (or desynchronization), prolongation (duration), and degree of coherence between different oscillations (Başar, 1980, 1998, 1999, 2001a, 2004; Başar-Eroğlu et al., 1991; Kocsis et al., 2001; Miltner et al., 1999; Schürmann et al., 2000).

2.2. Superposition and connectivity are shaping the brain's functional response

The theory of the brain as a syncytium by Başar (2011) is supported by following:

- Several authors have demonstrated that temporal coherence exists between cells in cortical columns (Eckhorn et al., 1988; Gray and Singer, 1989; Herrmann et al., 2002).
- Each function in the brain is represented by the superposition of the oscillations in various frequency ranges. The frequency of the oscillations varies across a number of response parameters. Neuron assemblies do not obey the all-or-none rule that is valid by single neurons (Chen and Herrmann, 2001; Karakaş et al., 2000a,b; Klimesch et al., 2000a,b).
- The superposition principle indicates that there is a co-existence between the alpha, beta, gamma, theta, and delta oscillations during sensory–cognitive tasks. According to the superposition principle, integrative brain functions operate through the combined action of multiple oscillations (Başar, 1980; Karakaş et al., 2000a, 2000b).

Coherence is a measure of phase consistency, and therefore, two signals that remain in phase over time (synchronous) are coherent (coherence equal to one). However, the opposite may not be true. That is, out-of-phase signals (asynchronous) may or may not maintain a fixed phase relationship since coherence can be anything between zero and one. Since EEG is generally composed of multiple frequency components, any pair of signals can be synchronous or coherent in some frequency bands, and asynchronous or incoherent at other frequencies.

7. Parallel processing in the brain is selective. This selectivity is produced by variations in the degrees of spatial coherences that occur over long distances between brain structures/neural assemblies (Başar and Ungan, 1973; Başar, 1980, 1983a,b; Başar et al., 1999a; Kocsis et al., 2001; Miltner et al., 1999; Schürmann et al., 2000).

2.3. Integrating attention, perception, learning, and remembering

The extension of the theory of the brain as a syncytium to cognitive processing is governed by the following principles:

8. *All brain functions are inseparable from memory functions* (Fuster, 1995a, 1995b, 1997; Hayek, 1952). As in all integrative brain functions, memory is manifested as multiple and superimposed oscillations.

Please cite this article as: Başar, E., Düzgün, A., The brain as a working syncytium and memory as a continuum in a hypertime space: Oscillations lead to a new model, Int. J. Psychophysiol. (2015), http://dx.doi.org/10.1016/j.ijpsycho.2015.02.019