

SUPERBINDING IN INTEGRATIVE BRAIN FUNCTION AND MEMORY

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Abstract

In this report a proposal related to the superbinding of the activity of neural populations is outlined. Basing on the observation of EEG-Oscillations, this proposal aims to replace the Sherrington's single neuron doctrine for interpretation of the mechanisms of complex percepts and integrative brain function.

Keywords- superbinding, oscillations, binding, coherence

1 Aim of the report

The present report aims to introduce the superbinding theory to describe the machineries of integrative brain function instead of single neuron doctrine. This concept is based on *superposition of selectively distributed multiple oscillations and their parallel functioning*. This proposal is shaped by numerous measured observations and can possibly give rise to new approaches aiming to establish brain theories and develop strategies for new experiments.

At the turn of the century, the approach of Sherrington opened the way to the single-neuron doctrine by introducing the notion of "*one ultimate pontifical nerve-cell*" which integrates CNS function. In this concept, the integration the functional mapping was a type of only movement mapping; memory and cognitive functions have not been included in brains integrative function.

Following the discovery of the EEG, Hans Berger (1929) has argued that a physical correlate of mental performances of the brain could now be tapped, as "psychic energy" in Berger's words [1]. This view has again gained tremendous importance [2,3].

2 Binding

The problem of linking or "*binding*" was posed for experimental study with the discovery that the neural activities evoked by the complex features of perceptual targets are processed in separate neocortical areas. The question is how the activities within and between those separate processing areas are unified in momentary association to form a coherent representational state- the neural basis of a perception. The results of many microelectrode recording experiments suggest the hypothesis that the synchronization of neural activity in the several nodes of a distributed system is a flexible mechanism for binding together the results of processing for different stimulus features in the nodes. Binding is assumed to delineate by recombination a neural image of the stimulus as a whole. Synchronized activity is linked to the stimuli

that evoke it; only those activities evoked by stimuli with common stimulus features are bound together in a dynamically formed ensemble [3].

The current literature in favour of the so called "**binding theory**" considers the binding as the unique functional correlate of only gamma activity and is based on experiments with multiple microelectrodes in small portions of cortical areas [4,5].

3 The Superposition principle

This principle describes that complex and integrative brain functions are manifested with the superposition of several oscillations as Karakas, Erzenin, Basar recently described [2,6,7]. Relevant examples of superposition principle related to cognitive function and memory were in the meantime described by several authors [8,9,10].

4 Selectively distributed oscillatory networks.

In a recent report, we reviewed experiments concerning oscillatory responses to events in the *alpha, theta, and delta* ranges as possible correlates of sensory and cognitive functions. It was argued that *selectively distributed delta, theta, alpha, and gamma oscillatory systems* act as resonant communication networks through large populations of neurons, with functional relations to *memory and integrative functions*. The results reviewed, hint at function-related frequency selectivities in *selectively distributed oscillatory networks*. According to models, *cognitive and memory processes* involve the formation of specific templates as *selectively distributed processing* in anatomically differentiated localizations [2,11].

5 Selectively coherent neural populations

According to new concept emerged by study of brain oscillations, the role of temporary and spatial coherence gained also considerable importance [5]. The description of integration needs morphological, functional interrelated in defined durations in the time space, the degree of interactions between two signals can be measured by coherence. Coherency is a statistical measure: the value of coherence depends on the amount of repeated correlations between events in the frequency domain. The phase relationship between the two signals is less relevant, however it must be stable. Since the signal at each electrode site mostly reflects the network activity under the electrode,

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coherence between two electrodes should measure interactions between two neural populations. The statistical nature of coherence helps to unravel them from noise if they repeat consistently.

Recently von Stein and Sarthein also emphasized the important role of functional integration and frequency response that long-range interactions in the alpha and theta ranges are specifically involved in processing of the mental context. Although this statement confirms findings of Basar [3], such a step needs measurement with depth electrodes. In order to confirm and extend the findings on distributed and parallel evoked coherency increases our group more specifically analyzed evoked coherencies in freely moving cats [14].

Oscillatory neural populations are selectively distributed. These *oscillatory neural populations* are activated upon sensory stimulation or event related tasks by manifestation of

1. *enhancements, (or resonances)*
2. *delay of oscillations*
3. *blocking or desynchronization of oscillations;*
4. *prolongation of oscillations*
5. *increase or decrease of coherences in distant brain areas*

6 Superbinding

The binding of percepts in the brain cannot be explained only with the binding of 40 Hz oscillations recorded by means of a local array. The functional role of alpha, theta, and delta oscillations in long distance locations as superposition has been clearly demonstrated [6,7,8,9,10].

Even the most simple percept is manifested with multiple oscillations in a large amount of selectively distributed oscillatory networks.

A long distance coherency increase in alpha, beta frequencies between cortex, brain stem, thalamus and hippocampus was already shown [15]. Now, it has been shown that *event related coherence* increase in distributed networks is also selective. This is an important step in understanding of functioning of oscillatory networks: Not only the amplitudes of oscillations and the frequency components, but also their coherences are selectively distributed. The result is that extremely large number of combinations of oscillatory parameters is manifested by sensory- cognitive information processing.

The crucial implication of all these results is that the explanation of perception with 40 Hz binding is not only an extreme reductionism, but it is “just impossible”. But the binding of numerous selectively distributed oscillatory networks with varied degrees of event related enhancements and varied degrees of coherency is, empirically seen, a much more tenable proposition. At every cognitive and sensory event not only primary sensory areas but at least frontal

areas are also activated as fMRI and electrophysiological data demonstrated [12,16].

Furthermore, according to new developments, we assume that, Sherrington’s and Barlow’s single neuron doctrine and the recently emerged simple binding hypothesis can not explain the mechanisms of integrative brain functions [17]. Accordingly, we tentatively introduce the machineries of “**superbinding**” consisting of an ensemble of (at least) 5 submechanisms acting in synergy following a sensory or cognitive input. It is proposed that the coexistence and cooperative action of these interwoven and interacting submechanisms can partly explain the mechanisms of integrative brain functions

1. Excitability (responsiveness) of selectively distributed oscillatory neural populations, in gamma, alpha and theta bands [4].
2. Temporal coherency between cortical cells [3,11,15].
3. Superposition principle in alpha, beta, gamma, theta and delta bands.
4. Temporal and spatial changes of entropy (from disorder to order or vice versa)[18].
5. Spatial coherence over long distances: selectively distributed and selectively coherent oscillatory systems [13,14,15].

7 The grandmother percept formed by superbinding

The grandmother neuron is a neuron that responds to nothing else but to the face of one's grandmother.

Does *The Grandmother Percept* involves multiple and distributed oscillations? According to previous reviews *selectively distributed oscillatory networks* (delta, theta, alpha, beta and gamma) play a major role in brain functioning. *Sensations* and *cognitive events* evoke superimposed oscillations that are transferred to topological distributed tissues with various degrees of intensity, synchronization, duration and delay, varied degrees of coherency almost in parallel.

Significant theta and gamma response amplitude increases in distributed areas of the brain by bimodal stimulation compared with unisensory responses has been reported [19]. A new report stated that retrieval of visual experience from short- term memory (mental imagery) is associated with 40 Hz activity [20].

Gamma band coherence increases between regions of the brain that received different classes of stimuli (haptic and visual) in an associative learning task [21].

Since the existence of these submechanisms have been experimentally demonstrated [2,10,11,14,18,21], we suggest that complex percepts (such as a picture of the *grandmother*) are formed and/or manifested by means of the ensemble of “oscillatory superbinding dynamics” explained above.

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