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The CLAIR model: Extension of Brodmann's areas based on brain oscillations and connectivity

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A R T I C L E I N F O

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A B S T R A C T

Since the beginning of the last century, the localization of brain function has been represented by Brodmann areas, or maps that are a result of anatomic organization. They are used in order to provide a global idea of cortical structures for given sensory cognitive functions. In recent decades, the analysis of brain oscillations has gained high importance for the correlation of brain functions. Moreover, the use of the spectral connectivity provides information on the dynamic connectivity between various structures. In addition to this, according to Luria (1966), brain responses have dynamic features and structural localization is almost impossible. According to these features, brain functions are very difficult to localize and need joint analysis of oscillation and event related coherences. In the present report, a model called "CLAIR" is described to extend and possibly to replace the concept of the Brodmann areas. To design a perfect functioning CLAIR model will require many years; however, the beginning step is provided in the present report.

1. Introduction

1.1. The problem and the line of attack "Why the Brodmann concept should be extended?"

The idea to aim an extension or changes in Brodmann's concept or "Reshaped Brodmann Areas" considers developments in neuroscience since the beginning of 20th century. Possibly, the most important discovery and concept establishment may be attributed to Ramón y Cajal with the "neuron doctrine". According to measurements by Ramón y Cajal, the brain is composed of functional elements: "Neurons". It is self explanatory that the analyses of Brodmann towards functional brain areas opened the way to the neuron doctrine. This also means that the brain is not as a "syncytium", but it has several substructures or compartments performing to develop a variety of functions.

The CLAIR acronym is an abbreviation of the following words: cortical-coherence, links, associating, integrating, and responsive-areas.

Hans Berger discovered electroencephalography (EEG), which excited the neuroscience world between 1930 and 1960, in his efforts to try to discover a variety of brain functions. However, in the 1960s most neuroscientists claimed that EEG was composed of just noise, and alpha activity manifests the idling of the brain. On the contrary, Cajal's neuron doctrine dominated the 20th century neuroscience literature. Mostly, throughout the entire 20th century, the idea of integrative brain function developed. According to Sherrington, one cardinal neuron could be responsible for the integrative function of the brain. Of note, in Sherrington's book, the cognitive processes and the cerebellum are discarded. It is difficult to understand how in such a model the expression "integrative" could be used (Sherrington, 1948).

In the middle of the 20th century two important conceptual developments took place. "The organization of behavior as neuropsychologic theory" was introduced by Hebb (1949). Hebb's neurons are responsible for connectivity and providing a pathway, such that learning would create new larger ensemble of neurons in a learning functional progress. Hayek (1952) also provided an important step in saying that the brain would not react in the same manner as time is developing. This is one of the most interesting views describing the dynamic organization of the brain.

In the 1960s at MIT, Norbert Wiener, John Barlow and Marie Brazier used computers to analyze brain maps and display evoked potentials in a more convenient way to analyze brain responses. This was a continuation of the preliminary improvement of Dawson (1954). In 1964, in addition to the analyses of sensory evoked potentials Sutton et al. (1965) recorded event related responses. A cognitive load was elicited to bring about sensory stimulations. Between 1970 and 1980, two laboratories contributed essentially to these developments with experimental techniques and analyses of oscillations. Freeman (1975) developed a concept about gamma activity and claimed that gamma oscillatory activity in neural ensembles is most important to explain dynamics of brain function. Başar et al. (1975a, 1975b, 1975c) and Başar (1980) wrote also that EEG oscillations are the most important signals of the central nervous system. Başar (1980) emphasized that all EEG oscillations alpha, beta, gamma, theta, and delta are essentially manifestations of brain functions (see also Başar-Eroğlu et al., 1991; Schürmann et al., 1997; Sakowitz et al., 2001; Başar-Eroğlu et al., 2001; 1993). Further,

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alpha activity is not idling of the brain, but one of most important manifestations of integrating brain functions, including memory.

An important integrative concept was the brilliant idea from Roy John defining the "hyperneuron", as a neural population acting as a giant neuron during functional processing. Another development is the concept of "cognit" that was proposed by Fuster (2013). In both of the cases (cognit and hyperneuron) ensemble of neurons can be essential by performing a brain function. In 1999, Başar proposed that multiple oscillations are a physiologic behavior, and the most important building blocks in performing brain functions. However, activation of several oscillations in distributed areas of the brain is not enough to explain the brain. Event related connectivity (coherences) has to be analyzed in order to describe brain functions physiologically. Recently, by reconsidering the concept of superposition of oscillations, spectral connectivity, the hyperneuron, and cognitive concepts, a new idea was born to try a new model: "CLAIR" (Başar et al., 2014).

In simple words: What J. Fuster and Roy John did is extremely important. These authors started with the neuron doctrine and came to the conclusion that "not single neurons", but a population of neurons are responsible for performing or initiating brain functions. This is an important step away from Sherrington's integrative brain function in our opinion, this step is also a trend to modify Brodmann's concept, which is not a dynamic functioning system. However, in both theories the possibility of multiple EEG oscillations being "building-blocks of functioning" has not been considered. In a broader extension of these views, Başar (2011) emphasized the importance of Fessard's (1961) view that in the brain, some general transfer functions do exist and these transfer functions govern all machineries of the brain.[1] After considering that the EEG oscillations discovered by Hans Berger are not noise (Başar, 1980), the concept of the hyperneuron and cognits (Roy John, Joaquin M. Fuster), and all papers published in the present volume, it seems that the time has come to extend or reshape the concept of "Brodmann areas".

2. Critical reviews for the concept of Brodmann

Since beginning of the 20th century, one functional mapping of the brain is illustrated in the "Brodmann areas". There are several methods for understanding brain function, especially to discover the location of diverse functions, such as memory and cognitive functions. Also, primitive perceptions as a simple light or simple tone require functioning of "iconic memory" and "echoic memory". They have been several methods and strategies to discover and define cortical areas responsible for all types of function.

2.1. History of Brodmann areas

Brodmann areas were originally defined and numbered by the German anatomist Korbinian Brodmann based on the cytoarchitectural organization of neurons. Brodmann published his maps of cortical areas in humans, monkeys, and other species in 1909, along with many other findings and observations regarding the general cell types and laminar organization of the mammalian cortex. A similar, but more detailed cortical map was published by von Economo and Koskinas (1925).

Many Brodmann areas are defined based solely on their neuronal organization. They are correlated closely to diverse cortical functions. For example, Brodmann areas 1, 2 and 3 are the primary somatosensory cortex; area 4 is the primary motor cortex; area 17 is the primary visual cortex. Areas 41 and 42 correspond closely to primary auditory cortex. Higher order functions of the association cortical areas are also consistently localized to the same Brodmann areas by neurophysiological, functional imaging, and other methods (e.g., the consistent localization of Broca's speech and language area to the left Brodmann areas 44 and 45). However, functional imaging can only identify the approximate localization of brain activations in terms of Brodmann areas since their actual boundaries in any individual brain require its histological examination.

Brodmann areas have been discussed, debated, refined, and renamed exhaustively for nearly a century and remain the most widely known and frequently cited cytoarchitectural organization of the human cortex.

According to the reports of the present special issue and other publications related to functional correlates of oscillations, the description of brain function now requires new parameters and concepts. The brain is a dynamic system, this means that the different functional units of the brain are "time varying". In other words, it is imperative to observe and record electrical changes in all areas of the brain. Further, there are many types of connections between all the structures described in Brodmann areas. These connections are defined as "axons", "synapses" etc. Moreover, the connectivity between different areas of the brain is subject to change upon the release of neurotransmitters. All these properties of the brain have recently been described together as "the whole brain work" by Başar (2006, 2011). Long distance connectivity in the brain was also described by (Varela et al., 2001). Long distance spectral connectivity in alpha, beta, delta, and theta in the cat brain was described by Başar et al. (1979a,1979b, 1998) and Başar (1980).

The most important fundamental idea of the present study is the following:

According to Luria (1966), there are no anatomical centers for the psychological functions of the mind. Mental functions, too, are the products of complex systems, the component parts of which may be distributed throughout the structures of the brain. The task of neuroscience is therefore not to localize the "centers", but, rather, to identify the components of the various complex systems that interact to generate the mental functions. Luria called this task "dynamic localization". Mental functions, in short, are not localized in any of the component structures, but rather between them. Like the mental apparatus as a whole, they are virtual entities (Solms and Turnbull, 2002) (Fig. 1). Q7

According to the present results, the understanding of the whole brain function also requires the analysis of spectral coherences, i.e. the increased connectivity between structures upon cognitive load, together with enhanced temporal oscillatory responses. Furthermore, in addition to Luria's view, it seems that Brodmann areas should be extended to a more dynamic presentation, in which, sensory and cognitive areas should be described as superposition of multiple primary and secondary functions.

As a consequence of the above concluding remarks, and especially the views of Luria and the concept of dynamically linked Brodmann's areas, we propose that all sensory-cognitive paradigms (as is here the

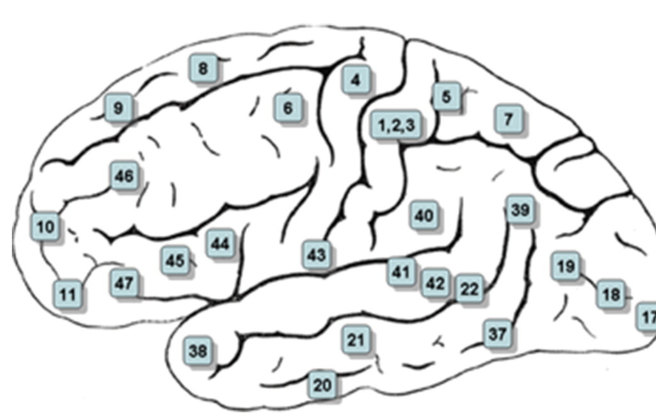

Fig. 1. The numbers labeled in several cortical locations are assigned to functional correlates of these locations.

[1] Are they most general transfer functions that govern connection of signals in the brain (Fessard, 1961).

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