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Darwin's evolution theory, brain oscillations, and complex brain function in a new "Cartesian view"

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ABSTRACT

Comparatively analyses of electrophysiological correlates across species during evolution, alpha activity during brain maturation, and alpha activity in complex cognitive processes are presented to illustrate a new multidimensional "Cartesian System" brain function. The main features are: (1) The growth of the alpha activity during evolution, increase of alpha during cognitive processes, and decrease of the alpha entropy during evolution provide an indicator for evolution of brain cognitive performance. (2) Human children younger than 3 years are unable to produce higher cognitive processes and do not show alpha activity till the age of 3 years. The mature brain can perform higher cognitive processes and demonstrates regular alpha activity. (3) Alpha activity also is significantly associated with highly complex cognitive processes, such as the recognition of facial expressions. The neural activity reflected by these brain oscillations can be considered as constituent "building blocks" for a great number of functions. An overarching statement on the alpha function is presented by extended analyzes with multiple dimensions that constitute a "Cartesian Hyperspace" as the basis for oscillatory function. Theoretical implications are considered.

1. Introduction: The New Cartesian View

In a recent essay Başar and colleagues theorized that, "In order to understand complex processes of brain–mind we have to analyze also brains of less developed living beings and compare them with the more intelligent and intuitive processes of the human mind" (Başar, 2005; Başar and Güntekin, 2007). Further, a new Cartesian System was introduced to analyze brain–body processes with its all histories and integration with all elements and the environment. The present essay provides an application of this new Cartesian concept to include evolution of species, brain maturation, and recognition of facial expressions. The overall goal is to characterize how neural processes can be approached by using several analytical windows.

The famous French mathematician and philosopher Henri Bergson (1907) studied Darwin (1859) and proposed a model basing on comparative physiology to describe memory and brain-to-mind processes. Authors such as Darwin (1859), James (1890) and Le Doux (1999) consider "emotion" to be a basic survival process that plays a major role in evolution and complex cognitive function. Emotion is related to a sensory modality — an internally directed sensory modality that provides information about the current state of the body (Solms and Turnbull, 2002). Hence, emotion adds a "sixth sense" to our conscious experience. The present thesis attempts to bridge philosophical concepts, electrophysiology during evolution of species, and emotion-processes related to recognition of facial expression. The essay emphasizes the philosophical bases and empirical results from comparative physiology and human electrophysiology.

At first glance, it seems "ambitious and not in the usual trend" to bring together Aplysia ganglia and emotional behavior of the human brain with its unique "intuition[1] ability". But this is a rule of René Descartes (1840) from "Discours's de la Méthod": Omit nothing, analyze everything, discard the wrong seeming judgments, and search basic and common elements of the problem under study. What we do in the present study is what Descartes strongly emphasized. We propose that what is needed is a new multi-coordinate "Cartesian System in Hyperspace".

2. Darwin's Theory

One of the most revolutionary developments in biological sciences has been Charles Darwin's (1859) introduction on "evolution of species". Darwin has worked within a framework of the living world as initiated earlier by Jean-Baptiste de Lamarck (1809). The theory of Darwin rests on two fundamental ideas: The first is the concept of "heritable variation". This is appearing spontaneously and at random as it was individual members of a population and is immediately transmitted through descendants. The second is the idea of "natural selection", which results from a "struggle for life". Only individuals whose hereditary endowments enable them to survive in a particular environment can multiply and perpetuate the species.

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[1] Intuition is the act or faculty of knowing immediately, directly and holistically without rational processes and without being aware of how we know. It also is the channel or process through which realms of truth and knowledge are accessed.

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The genius French philosopher Henri Bergson (1907), who studied the work of Charles Darwin came to the conclusion that the superiority of the human brain in comparison to lower species is his ability of "intuitive and creative thinking". Henri Bergson (1907) emphasized three types of mental abilities during evolution of species: instinct, intelligence, and intuition. Instincts are observed in low living beings as invertebrates. Intelligent behavior belongs also to functional properties of lower vertebrates and mammalians. However, only human beings have the ability of intuition and are, according to René Descartes (1840) and John Locke (1690), what makes the human being different from other species. At the beginning of 20th century the proposal of Bergson could not be analyzed by means of electric recordings. This view gains importance from recent empirical studies and new analyses in which brain development of alpha activity during species evolution is characterized by asking fundamental questions considered below.

3. Unifying Questions to Understand Processes in the Brain and Nature

René Descartes stated that "Everything in the universe can be explained in terms of a few intelligible systems and simple approaches." Alfred Fessard (1961) emphasized that the brain must not be considered simply as a juxtaposition of private lines, leading to a mosaic of independent cortical territories, one for each sense modality, with internal subdivisions corresponding to topical differentiations. What are principles dominating the operations of hetero-sensory communications in the brain? This knowledge needs an extensive use of multiple microelectrode recordings, together with a systematic treatment of data by computers (e.g., Eckhorn et al., 1988; Gray and Singer, 1989).

Fessard (1961) further indicated the necessity of discovering principles that govern the most general or transfer functions of multi-unit homogeneous messages through neuronal networks. The transfer function describes the ability of a network to increase or impede transmission of signals in given frequency channels. The transfer function can be represented mathematically by frequency characteristics or wavelets constituting the main framework for signal processing and communication (Başar, 1980; Başar-Eroglu et al., 1992). The existence of general transfer functions could be interpreted as the existence of networks distributed in the brain having similar frequency characteristics facilitating or optimizing the signal transmission in resonant frequency channels (Başar, 1998). In an electric system[2] an optimal transmission of signals is reached when subsystems are tuned to the same frequency range. Does the brain have such subsystems tuned in similar frequency ranges, or do common frequency codes exist in the brain?

The empirical results reviewed here imply a positive answer and provide a satisfactory framework to Fessard's question. Brain tissues that contain selectively distributed oscillatory networks (delta, theta, alpha, beta, and gamma) constitute and govern mathematically the general transfer functions of the brain. According to Fessard's prediction all brain tissues, both mammalian and invertebrates would have to react to sensitive and cognitive inputs with oscillatory activity or with similar transfer functions. The degree of synchrony, amplitudes, locations and durations or phase lags is continuously varying, but similar oscillations are most often present in the activated brain tissues (Başar, 1999). The general brain transfer functions manifested in oscillations strongly indicate that frequency coding is one of the major candidates to govern brain functioning.

4. Generalization of Descartes and Fessard to Brain–Body Interaction and to "Evolution of Species"

As noted above, Fessard (1961) posed a question similar to Descartes, who mentioned the possibility of the existence of some common principles and rules governing the nature: Are there some general principles that govern the transmission of the signals in the brain? The relevant question of Alfred Fessard related to electrical signals in the brain can be extended and generalized for the Brain–Body integration. "Are there also some general transfer functions in functional interactions of the brain with the vegetative system and biochemical pathways? Do cranial nerves and the brain stem link the vegetative system to cortex and provides also cognitive/memory integration?" (Başar and Güntekin, 2007). Are there also some general transfer functions in electrical activity of nervous system during evolution of species?

Fig. 1 illustrates representative evoked potentials from several species in order to characterize electrophysiological changes (or mutation of activity) during evolution (Başar et al., 1999; Bullock and Başar, 1988). Electrophysiological signals across species consisting in recordings of spontaneous electrical activity and evoked potentials have been analyzed (Başar et al., 1999; Bullock and Başar, 1988). In addition to the conventional electrophysiological recordings, oscillatory brain dynamics were applied to data from isolated ganglia of Aplysia, Helix Pomatia, and brains from low vertebrates as goldfish and ray. Cortical and sub-cortical structures of the cat brain and the scalp recordings from the human brain were also assessed, with delta, theta, alpha, beta, and gamma oscillations quantified.

During the evolution of species the central nervous systems of various living beings starting from invertebrates to low vertebrates, vertebrates, mammalians and human brain went through great changes in anatomical structures and their biochemical pathways took place accompanied by changes in the electrical activity (Bullock and Başar, 1988; Bullock et al., 1995). Invertebrates have less ample low frequency responses. In the fish brain slow evoked potentials are increased in comparison to the invertebrate ganglia. In the mammalian brain slow responses are much higher in comparison to the fish brain. Thus, the evolution also demonstrates a type of dynamic behavior.

A second type of dynamic change in the morphology takes place during maturation of the human brain. The brain of the fetus, the brain of the newborn baby, brains of 3-year-old children, and the adult brain have morphological differences especially in frontal lobes (see also Solms and Turnbull, 2002). In addition, during evolution of species and during maturation of the brain, a similar type of development is related to cognitive processes and more precisely to processes of thought. Important changes to evolution of species and maturation of the human brain are the increase of intelligent behavior, and at the final stages of both developments, the ability of creative processes in relation with the intuition and synthesis power. Neither babies nor low level living beings have creativity, decision making and intuition.

5. Electrical Neural Activity During Evolution of Species and Maturation of the Brain

Fig. 2 illustrates a more detailed frequency analysis such that invertebrate ganglia have very low amplitudes in the 10 Hz frequency range (Schütt et al., 1999). The 10 Hz range activity in Helix Pomatia has maximal 10 µV peak-to-peak amplitudes. In the human brain scalp recordings 10 Hz activity can reach amplitudes up to 50 µV.

Table 1 summarizes a data set accumulated over the last 20 years from laboratories in Ankara, Lübeck, and San Diego (Başar et al., 1999). The frequency positions of maxima in several species ranging from invertebrates to the human brain have been evaluated. In Helix Pomatia five types of ganglia are presented, in Aplysia's cerebral ganglion two groups of measurements, in the ray mesencephalon and medulla, in goldfish telencephalon, mesencephalon and medulla, in the cat brain auditory cortex, reticular formation and hippocampus are presented. The human studies cover central, occipital, parietal and frontal areas. In the invertebrate ganglia, 10 Hz activity is scarcely obtained, whereas measurements of higher brain levels demonstrated more 10 Hz activity.

[2] The brain is a system with the ability to have electrophysiological transmission property. This means that the electrical tuning of the brain can be studied similar to the analysis of an electric circuit, for example a simple electronic device.