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Electromagnetic Loop Theory - A New Paradigm in Consciousness Research

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--*ABSTRACT*--

This paper presents a conceptual basis for a paradigm shift in looking at how the brain works. This paradigm shift is embodied in the proposal that generating endogenous electromagnetic (EM) fields, observed as EEG "brain waves," is a neuron's primary function rather than being a by-product of its direct, synaptic message function. Thus, the synaptic interconnections between neurons are a facilitating mechanism for the neurons' primary role in creating EM fields. Furthermore, these EM fields function to stimulate the cerebral cortex and maintain a feed-back loop between brain regions. If this is the case, the conventional neuronal model of mental activity needs to be revised. This concept is explored, along with its implications in terms of sensory perceptions, consciousness, memory and related mental functions. Certain aspects of neural anatomy and neuro-physiology are used to show how brain cells and their structures can create and react to endogenous EM fields. These observations lead to a hypothesis that the cerebral cortex is a complex sensory organ that has evolved to sense EM fields produced by groups of sub-cortical neurons. Given these structures and capabilities, consciousness and memory are shown to be resident in active feed-back loops that exist between the cerebral cortex and complex groups of sub-cortical neurons. The existence of this sensory organ and its EM environment are further proposed to mediate consciousness and memory.

KEYWORDS:- Consciousness, electromagnetic fields, neuronal networks

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I. INTRODUCTION

There are a surprising number of theories to explain consciousness in the scientific literature, most of which postulate that consciousness arises from the brain and focuses on neural correlates of consciousness (NCC) (Crick, 1990). These theories propose that consciousness arises from neurocomputations due to nerve firing and other electrical activity of the brain (Tononi, 2004). Some models propose a key role for membrane potentials in dendrites in such neurocomputations (Poirazi, 2001). More specific models postulate that apical dendrites of pyramidal cells in the neocortex are involved because they receive hundreds of thousands of synaptic inputs, which could account for the large number of neuro-computations the brain is capable of (Eccles, 1992). These theories start with the known fact that there is a very large variability in neuronal firing thresholds and timings from one type of neuron to the next and from one brain region to another. It is postulated that some unknown phenomenon, called the X factor, regulates and controls these neuronal firings (Bussolon, 2016). It is further proposed that consciousness is integrally linked to, if not identical to, the X factor.

In contrast, several newer theories propose that neural activity arises out of consciousness, as consciousness is fundamental (Kafatos, 2011). What these apparently opposite theories have in common is the key role for electromagnetic (EM) fields. EM field theories of consciousness basically state that qualia (individual instances of subjective, conscious experience -- e.g. the perceived sensation of headache pain, the taste of wine or the colors of an evening sky) are identical with certain as yet defined spatial-temporal patterns in the endogenous EM fields of the brain. McFadden proposed that the defining features of conscious EM patterns are their intensity and their ability to initiate motor neuron firing (McFadden, 2002). Other theories propose such ideas as Walter Freeman's classic experiments indicating that the EM patterns he measured at the surface of the rabbit brain during smelling were defined by the spatial features of these patterns and not by their overall amplitude, frequency or phase properties (Freeman & Baird, 1987).

Since these early pioneering studies, numerous theories have been presented characterizing consciousness in the brain in terms of endogenous EM fields. However, no model proposes that these fields are generated from neuronal networks. The theory of Dehaene, et.al (which considers how visual stimuli are processed) proposes that such sensory information excites subcortical thalamic neurons, which are organized in granular column networks (Dehaene, 2003). The theory further proposes a type of feedback loop within a given top-down network, where sensory signals are received at the top of a given network and amplification signals are then sent back down to all lower levels. In this model, the incoming sensory stimuli activate thalamic neurons which initiate spontaneous, self-sustaining neural activity.

The model presented herein extends the Dehaene model by proposing that the incoming stimuli are not limited to sensory information and are EM in nature. It further proposes a feedback loop that is not contained within a single neural network but rather occurs between a neuronal network in subcortical regions and dendritic arbors in the cerebral cortex via endogenous EM fields.

II. THE HYPOTHESIS

The role of the neuron, according to the classical thought paradigm, is to generate an action potential and transmit an informational message to an adjacent neuron via the synaptic junction. For sensory neurons, the stimulus begins with some external physical input; sound, light, touch, etc. Motor neurons, on the other hand, are stimulated by other neurons within the brain through their synaptic junctions. In this model, we are concerned with the mechanism and functional consequence of such neuronal excitation.

The dendrite-rich outer layer I of the cerebral cortex is supported and protected by the pial-glial membrane. The glial cells of this outermost layer acts as an insulator against the flow of electrical currents (Griffith, 2006). The dendrites in the outer layer of the cerebral cortex form a complex *apical dendrite arbor.* These dendrites are not post-synaptic; hence, they do not make contact or receive input from other neurons (Mel, 1993). These dendrites are extensions of neurons that lie beneath the surface, (in layers II, III, IV, V and VI), and they do not end at a synapse. The outer layer of the cerebral cortex also contains the *cells of Cajal,* which have dendrites and axons running parallel to the cortical surface and pyramidal cells which extend their axons into the deeper layers of the cortex as well as into the opposite hemisphere (Luhmann, 2003).

In the present model, we also consider subcortical brain regions (e.g. the hippocampus, the thalamus, the cerebellum and the amygdala). Of particular interest is the role of special neurons in these regions which exhibit unusual neural firing patterns including cyclical, oscillatory and phase-locked firing (Joris, 2001). Loop-cyclic firing of neurons can persist for relatively long periods of time after the initial stimulus has been terminated. Loop nerve firings can be generated from reverberating circuits and oscillatory circuits in both cyclical and parallel configurations of neurons (Fuchigami, 2004). Such configurations are referred to as neuronal pools, ensembles and networks in the scientific literature. They are composed of a large number of different types of co-active neurons which interact cooperatively and exhibit collective ensemble behavior (Sporns, 2004). They exhibit complex neuronal firing patterns which are highly variable and dynamic (Aulenbrock, 1969). Individual neurons interact with each other and function on multiple temporal and spatial scales (Buzsaki, 1995). Cyclical nerve firing can be considered a special case of neuronal interactions mediated by non-chemical means.

Our hypothesis proposes that the role of conventional chemical synaptic connections is to enable the formation of specific geometries of small clusters of cyclical firing neurons. We further hypothesized that the stability of these clusters is dependent on its geometry. Stability, in this instance, is related to the spontaneous sequential firing of discrete sets of neurons in response to a single stimuli with no further stimuli required. We tested this hypothesis using a simplistic computational model based on: the total number of neurons (n) in a small group of interconnected neurons, where each neuron is connected to no more than four neighbors; the number of *excitatory* (efferent) axons/synapses (e); the number of *inhibitory* (afferent) axons/ synapses (i); and the natural *time* allowed between consecutive firings (refractory time) (t). An additional simplifying assumption is that (e), (i) and (t) are constant throughout the population of "neurons" in our computational model. The initial condition for each run was that no neurons were "firing."

III. FINDINGS

Findings revealed that, for most conditions of n, e, i, and t, a single stimulus would result in either all neurons firing or the firing sequences would die out with no effect. Under some very restricted conditions of n, e, i, and t, a single stimuli could result in a cyclical, self-sustaining, firing of repeated sequences of neurons. Thus, the hypothesis was confirmed that the stability of small clusters depends critically on the configuration geometry.

Discussion

Most of the knowledge available about neuronal networks has been obtained using simultaneous, large-scale, multi-site EEG scalp recordings (Buzsaki 2002). These studies, in the emerging field of systems neuroscience, have characterized the networks as a system of oscillators with frequency ranges from 0.05 - 500 Hz, where individual frequencies form bands and are capable of interacting or competing with each other (Csicsvari, 2003). Furthermore, neuronal networks exhibit spatial and temporal coherence. (Buzsaki, 1992). The properties of neuronal networks are determined by the size and architecture of the networks as well as conductivity properties of individual neurons (Nunez, 1995). Neuronal network properties have also been correlated with certain behaviors and slow-wave sleep patterns, at least for hippocampal pyramidal cells, which display transient network oscillations up to 200 Hz (Buzsaki, 2004).

The Electromagnetic Network

When neurons fire, an associated electrical discharge and charge redistribution occurs which migrates along the axon and produces an electromagnetic (EM) field which propagates to the skull, where it can be measured by EEG equipment. Although all neurons generate EM fields, here we only consider EM fields generated in the cerebral cortex and in subcortical brain regions. Artificial EM fields generated from a signal generator are well known to influence many functional properties of neurons (like the movement of ions across their cell membrane) (Adey

1981) can induce action potentials causing them to fire (Moghadam, 2008) and induce neurotransmitter release (Dixey & Rein, 1982). Furthermore, electrical stimulation of the brain via electrode probes applied to the surface of the cerebral cortex at specific sites generates exogenous EM fields which can produce sensations like smells, sounds, visual images and motor responses (Gall, 2013). Such external stimuli are one method for exciting apical dendrites to become excited.

In this model, we propose another mechanism whereby apical dendrites in the cerebral cortex can be activated, i.e. from endogenous EM fields generated from subcortical neurons in general and neuronal networks in particular. Thus, we postulate a set of primitive, fundamental neurons (perhaps the thalamic reticular activating system) that perform an automatic, subconscious task of generating basic EM fields. These neurons need not be stimulated by adjacent neurons; they simply need to fire spontaneously on a relatively regular basis and create a fundamental background EM field. It is the densely packed apical arbor dendrites, embedded in glial tissue, that are capable of receiving EM information from these subcortical neurons. This part of the hypothesis is supported by previous studies demonstrating the ability of EM fields (from a cell phone) (Bolla, 2015) and endogenous electric fields (Aspart, 2018) to stimulate apical dendrites in various brain regions. Our model further proposes that sub-cortical neurons, firing in cycles, loops or parallel constructs of neuronal networks, function primarily to create and maintain this EM field. Although the EM fields generated from such cycling neuronal firing have not been characterized, they would likely be very complex and distinct. These endogenous EM field patterns could act in much the same way as external electric probes observed to cause specific sensory experiences. The difference is that, instead of a single site receiving stimulus from a single probe, the dendrites would be stimulated over a very wide area, covering many dendrites in very specific patterns which vary spatially and temporally. This endogenous EM network would be modulated over a wide range of voltages.

In addition to endogenous EM fields generated from subcortical neurons and neuronal networks, we propose that EM fields generated from various neurons in the cerebral cortex can influence subcortical neurons and networks. Although no previous studies have measured the effect of exogenous EM fields on neural networks, several mathematically-based models have addressed this question. Since the Hodgkin-Huxley model only describes the electrical activity of individual neurons, additional models are required to explain the complex, non-linear dynamic behavior of neural networks. These include bifurcation analysis, coherence resonance and random resonance. These models attempt to explain their collective behavior, synchronization, spatial patterns and dynamic responses to external stimuli, like EM fields (Ma, 2017). The complex-valued neural network model (Hirose, 2013) predicts the recurrent properties of neural networks can be controlled by external EM fields by virtue of their information processing capabilities inherent in their phase-information topology.

Our model proposes that the cerebral cortex can function as a sensory organ, receiving incoming EM information from the subcortical neuronal networks and generating its own EM fields in response. These EM fields feed back information to the subcortical neuronal networks, thus forming a feedback loop and a complex endogenous EM network. Although neurons in the subcortical brain regions initially create this EM network, EM fields from the cerebral cortex maintain this network by modifying existing subcortical cyclic firing patterns. This is a primary feedback loop which functions, as in all control systems, to provide stability, enabling fine adjustments and smooth responses to EM and synaptic inputs. Continuity itself is sensed as a separate stimulus, generated entirely within the feedback loop, maintaining the EM field. The infinitely variable EM field is capable of delivering a coordinated set of stimuli simultaneously to numerous dendrites. This process amounts to trillions of bits of data, in both binary terms and analog terms, where the number of dendrites multiplied by the number of combinations of excited dendrites can be considered.

Having described a non-chemical communication network between the cerebral cortex and its underlying subcortical regions, it is reasonable to propose that the primary function of most neurons is to generate and support endogenous EM fields. That is, what has previously been thought to be a by-product of neuronal activity is, in fact, the neurons' primary function. Thus, *the primary function of the subcortical neurons is to create and maintain a highly complex and varying EM field in order to stimulate the dendrites in* *the apical arbor.* That function is to create and maintain an EM field that stimulates the apical dendrites in the cerebral cortex. We further propose that the neurons of the brain perform multiple functions, which is contrary to a widely-held belief that specific sets of interconnected ("hard-wired") neurons perform only specific functions. Functional brain regions have been mapped, and specific mappings have been identified with related areas in explaining certain sensory, perceptual and motor aspects of brain function (Kriegeskorte, 2006). We further postulate a multiple function for all neurons, and that mappings of functionality actually overlap both in space and time. For example, the specific areas mapped as receptor sites for visual stimulation may also function in enhancing the EM network.

Modulating the EM Network

Having described a basic EM network, we now need to postulate a means to amplify and modulate that endogenous EM environment via an intentional control mechanism.It is postulated that there is a specific set of neurons that provide the continuous, or steady-state, EM field; and, second, that individual neurons and sets of neurons perform multiple functions. Thus, it is possible to construct a hypothesis, or conceptual model, for a directly modifiable auto-stimulus of the apical dendritic arbor. We must also postulate an effector mechanism; one that can intentionally make and modify the EM network.

By having an EM field to stimulate a vast number of dendrites, it is possible to use a principle of feed-back to then modify the field to create a new stimulus, or one that is slightly different from the one that immediately preceded it. Thus, we have a means of modifying the originating base EM field in a purposeful way giving the cyclical firing neurons a primary function to make specific modifications in the EM environment. The apical dendrites respond to the variations in the EM field and send new combinations of stimuli to other sensory and motor neurons to affect all other actions.

A Mechanism for Cognitive Function

Consciousness is an elusive term. It is an every-day experience; however, that in itself leads to the questions:

- What entity is it that experiences consciousness?
- What is that essence of self that has the ability to have an experience?
- What is the screen upon which the images of every-day life are projected?
- What is the vessel that contains the memories of a lifetime?

IV. CONCLUSION

We hypothesize in this model that consciousness and the entity that experiences life is *the intelligence underlying the brain's endogenous EM field and the ability of the cerebral cortex to sense and maintain such an EM network.* Thus, consciousness is not in the neurons, nor in their interconnections; rather, it is associated with endogenous EM fields, which form a feedback loop between different brain regions and which is sustained, modulated and used to initiate mental and motor functions. Specifically, *the apical arbor of dendrites in layer I of the cerebral cortex functions as a sensory organ, self-regulating the EM network.* Moreover, this very special sensory organ is capable of responding to sensory stimuli and sensing extremely complex EM fields, most (if not all) of which are generated by changing cyclical firing of subcortical neurons and neuronal networks. Consciousness is associated with the complex, ever-changing EM field, continuously stimulating the dendrites in the apical arbor. The vast number of dendrites in the cerebral cortex and the extreme complexity of the endogenous EM fields involved could account for the vast amount of information contained within the conscious mind. Rephrased, we view consciousness as a continual balance between the EM stimuli from the cerebral cortex and the resultant neural firing in the subcortical neuronal networks. The specific response of these neurons generates a modified EM field, which then stimulates the cerebral cortex in a slightly different way, thereby producing a slightly modified output EM field in a purposeful way. This process can be visualized as the modified feedback loop being nested within the original loop. Furthermore, the cyclical firing neurons respond to the variations in the EM field and send new combinations of stimuli to other sensory and motor neurons to affect virtually all functions of the brain.

It is proposed that mental functioning depends on an EM loop mechanism to produce the variety and complexity of controlled reactions that we describe as "consciousness" and "thinking." Such a mechanism is one way to arrive at a non-computational model for consciousness as proposed by Roger Penrose (Penrose, 1994). We also postulate that a thinking brain requires stable patterns of firing neurons, which are generated from cyclical nerve firings and some form of auto-stimulation. In addition to mental activity, our model also offers a reasonable mechanism to explain memory, learning, intentionality, abstraction, inference, language, intelligence, creativity, conceptual/symbolic formulation and manipulation, conceptualization and even instinct.

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