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Mini Review

Essay on information processes in the human brain

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Abstract

This mini-review discusses the temporal discrepancy between subjective introspection of mental processes and the speed of classical synaptic and action potential transmission to all centers involved. In the latter instruments available measure significantly slower time frames.

Gap junctions as electric synapses are found within the upper cortex layer in a significant number. Much faster would be neuronal computing with quantum information processes – increasingly discussed in publications about biophysics and brain processes. The key feature and the importance of this mini-review is that it compactly summarizes most of the recent models of neuronal processing with the main message that our current instruments only reveal remnants of more rapid biophysical processes lying behind the classical neuronal processes.

Introduction

By subjective, feeling, and introspection, we experience a very fast emergence of a quasi-holistic scenery, transmitted by memories or our sensory organs [1]. While measuring the speed of neuronal processes with today's instruments, there is a big discrepancy between subjective introspection of mental processes and the temporal characteristics of classical chemical synaptic and action potential transmission between all centers involved. The latter would lead to significantly slower time frames.

That is why recent papers discuss the necessity of fast neuronal electric communication, e.g., via gap junctions, also in combination with chemical synapses [2,3] as well as ephaptic coupling [4-7]. Interestingly, recent studies report a very high number of electric synapses within the upper cortex layer, especially in the forebrain [2,3,8]. Here also a dual action of synapses (electrical and chemical) is discussed [2].

Concomitant with the fast development of quantum computers, papers are increasingly published about quantum physics in biology which also drives brain processes. Thus, an important task of this review is to outline the stepwise transposition down from subtle quantum processes via a read-out causing subthreshold oscillations of neuronal membrane potentials. Such oscillations most likely occur in apical dendrites of layer I in the brain cortex, ultimately resulting in an initiation of action potential firing that propagates to other cortical regions and to corticofugal pathways.

Discussion

Regarding consciousness, the hitherto accepted notion is that brain neuronal processes are epiphenomena of mental processes in the form of Action Potential (AP) firing in neuronal networks [9,10]. Another characteristic of these neuronal processes is the binding of coworking brain regions by similar firing frequencies, a hypothesis proposed by W. Singer [11,12]. Here, a global workspace can be seen in effortful cognitive tasks [13]. All these processes are elicited by AP firing and can be detected nowadays by, e.g., functional MRI or EEG.

Different electric and electromagnetic processes within the brain

On the other hand, local electric fields, AP influences local electric fields as well as ionic currents. Furthermore, field potentials and electric fields are able to entrain neuronal networks in a physiological manner [14]. Because of the delicate membrane intertwining of intracellular and extracellular space of neuronal and astrocyte processes in the brain cortex Hales and Pockett suggested that an "ultra-structured 3-D electromagnetic field system, and a large-scale slow electric field system can operate simultaneously in the tissue" [15,16]. Thus, thresholds for neuronal firing can be influenced in a poised manner, by Electromagnetic Field (EMF) fluctuations through constructive interference [17,18].

Regarding the connection to classical molecular biology, T. Görnitz states: "Any biochemical reaction involves an exchange of photons, more specifically, of real and virtual photons" [19]. The motion of ions, electrically charged molecules or atoms, is often described as a response to the action of electromagnetic forces. However, in a precise – i.e. quantum physical – description, this is the action of virtual photons. Real photons are emitted when the motion of charges is not uniform, e.g., being accelerated from rest or slowed down [19].

In any case, EMFs are supposed to mediate information with frequencies till IR [20,21]. Here, Tan, et al. could demonstrate the potential of neural information regulation by THz photons through 2-photon imaging in mice in vivo [20]. Within the intracellular and extracellular spaces, photons are guided along molecules and membranes in the bound water layer [22-28], especially as tunnelling evanescent photons [29]. Here, recent progress in theory and molecular dynamics simulations as well as in ultrafast vibrational spectroscopy has led to new and detailed insight into fluctuations of water structure, elementary water motions, and electric fields at hydrated bio-interfaces [28]. For electric and EMF spreading from cell to cell, Gap Junctions (GJ) are ideally suited [30]. In evolution, they are the forerunners of chemical synapses [31] and they developed in cell networks also of non-neural cells prior to the rise of specialized neuronal cells, like in epithelia and other tissues [32-34].

Interestingly, within the brain, GJs are especially numerous at the apical dendrites of the uppermost cortex layer [35-36]. Thus, this layer is ideally suited for electric modulation of AP firing thresholds in a preformed manner [17].

Quantum physical processes in biology

Regarding GJ, another big player lurks in the background of classical physics [37], that is quantum physics, which still has its appreciation only regarding the nanoscale [38,39]. Here, a common and proven phenomenon is the tunneling of electrons or protons in larger molecules, like in enzymes [40]. Tunneling is a partial transit of such particles through an energy barrier for a reaction that cannot be explained with classical physics – only with quantum physics. A typical example is the Fenna–Matthews–Olson bacteriochlorophyll photosynthetic complex in green sulphur bacteria [41]. Here, a combination of quantum- and vibrational processes takes place: seemingly stochastic movements of the thermic background are perfectly used to drive quantum processes. However, such quantum processes are now being detected more and more in other biological situations [42].

Albeit these quantum processes are significantly proven for microscopic situations - also in biology – it is very probable that they can be transferred to more macroscopic situations, like brain processes [43]. Technically, an analogous situation can be seen in the enormous progress of quantum computing, today!

Quantum computing within the brain

What could be components for quantum computing within the brain? For this purpose, it is necessary to have electrons, ions, or other very easily shiftable particles or subtle charges. These must be sheltered or isolated to a certain degree from the agitating environment to come into entanglement or at least quantum coherence - despite the thermic jittering of the surrounding molecules [38,44]. In such sheltered zones, a fugitive shifting between two possible states can happen for quantum calculations. However, "the preparation of a quantum system means isolating it from its environment to such an extent that a relationship between system and environment is practically no longer perceptible", as stated by the quantum physicist Görnitz [19]. This sheltering from the environment is equivalent to the so-called Markov blanket [45]. In the next step, a concerted read-out (de-coherence) should proceed in a frequency that can be transposed down to lower frequencies and at least to the electric phenomena we measure in EEG.

The preparation of a quantum system means isolating it from its environment to such an extent that a relationship between system and environment is practically no longer perceptible" and, alternation of possibilities and factual results; from facts new possibilities emerge, while other, previously available possibilities no longer can be realized" [19].

An interesting easy shiftable entity is the nuclear spin of phosphorus atom present within nanoclusters of spherical calcium phosphate (Posner molecule) which can protect this nuclear spin reaction and enable a storage of quantum information [46]. Indeed, Hu and Wu proposed a "spin-correlated consciousness" [47] which should form networks of nuclear spins in neuronal membranes by strongly fluctuating magnetic fields. Possibly, these are modulated by indirect dipole-dipole coupling in the action potentials. Interactions between two nuclear spins result indirectly from the interactions of electrons around the nuclei. According to Hu and Wu, these couplings had frequencies between 5-25 Hz, which are within the EEG activity range. Magnetic fields should be associated with spin-related coupling across the cell membrane with an energy value equal to photon emission. Thus, the spin networks could be linked to photon emissions observed during certain brain activities [48]. The next step would be a coupling to membrane proteins or microtubules [49,50].

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Indeed, Microtubules (MT) are favored by Hameroff and Penrose [49] as candidates for quantum computing. They came across this fact because unicellular organisms [amoebae for instance] can have a very differentiated behavior like coordinated swimming to food sources, avoiding obstacles, etc. [49,50]. By definition, these organisms have no nerve cell networks, they must, however, have a suitable information system – a fact already mentioned by Sherrington [51]. Besides the core material of tubulins, the MT possesses hexagonal benzene-phenyl rings of the MTs that share three delocalized pi orbital electrons among six carbon atoms, forming "pi resonance clouds" that can mediate quantum effects. Thus, quantum coupling is possible between these clouds [52,53]. Such systems can easily resonate and are shielded from the jittering surrounding the cell. Here, coherence times of some minutes or longer are possible.

Another candidate for quantum calculations is Ca2+ and potassium channels in the axons of nerve cells [54]. In the sheltered membrane channels, Bernroider and Roy assume, that tunneling of these ions is possible, so an initiation and transmission of action potentials by these channels seems possible [55].

For a further quantum connection over neuronal networks, Josephson junctions are ideally suited. Here also a kind of quantum-like tunneling is possible [56,57]. Josephson junctions are already realized in semiconductor electronics [56]. In biology this function may be taken over by the GJ (Figure 1) because the geometry and size of GJ strongly suggest a resemblance to Josephson junctions, a hypothesis, proposed by Samoletov [57]. In technical applications, such quanta relay sites are characterized by oscillations in the range of Terahertz (Rabi cycles) [58,59]. However, as stated above, Tan, et al. could demonstrate neural information regulation by THz photons [20]. Possibly, this may also be the "readout speed" of quantum states [60,61]. In these frequencies, the coherence needs to be maintained for picoseconds, making quantum coherence modes more likely. Indeed, as Hameroff [61] cites, a "quantum underground" [62], pervades living systems and, as suggested by Schrödinger [63] and Fröhlich [64,65] quantum dipole oscillations arrayed in geometric lattices can convert ambient heat to synchronized vibrations, resonate and oscillate in terahertz, gigahertz, megahertz, and slower frequencies. This scale-invariant hierarchy is the basis for linking Hameroff´s orchestrated objective reduction (Orch-OR) theory of consciousness to classical neuronal processing [49].

Of clinical interest is the finding that blocking consciousness by general anesthesia is mediated by blocking receptors in apical dendrites of the cortex. Interestingly, anesthetics used for general anesthesia, such as fluoranes, interact exclusively with quantum-entangled photons rather than individual photons [66]. This suggests that after a passage through the quantum world, there can be a mediation via photonic information in the direction of the nerve cells. Then the "largely" isolated, coherent systems come into "contact" with the environment and can no longer resonate freely. In the process of de-coherence, Nambu-Goldstone bosons should appear representing exchange particles such as photons [67,68]. Via these bosons, long-space coherent waves can form within and between brain cells, a model, also used in the "dissipative quantum model of the brain, proposed by Del Guidice, et al. [69].

Transfer of quantum process into the real world of the brain

The next, "deeper" level of information transfer within the brain is the preparation and read out of the quantum information by shifting EMFs in a lower "clock frequency" (THz and MHz, see above) [61]. Then the "electrical" part

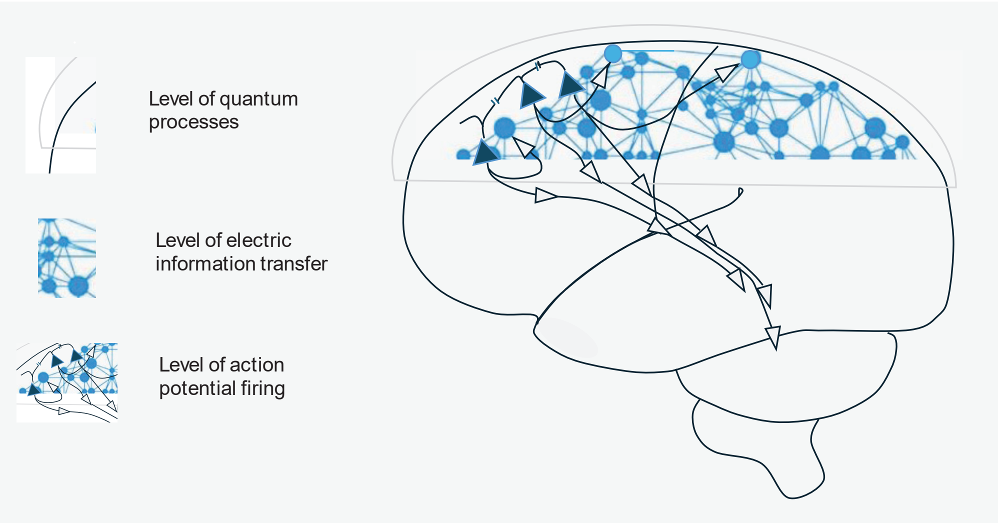

Figure 1: Hypothesis about the gradual fixation of information processes from ultrafast quantum calculations in the uppermost layers of the cortex to a read out of collapsing quantum processes via accompanying EMF photons (level of quantum processes; left row). Then, a very fast electrical or photonic inter-neural transmission takes over via gap junctions predominantly within layer I of the cortex (see "-II-"connections of apical dendrites), eliciting a sub-threshold shifting of membrane potentials (level of electric information transfer, left row). Finally, thresholds are reached with the firing of action potentials (symbolized by pyramidal cells) leading to classical neurotransmission into other brain regions (open arrowheads) and to corticofugal pathways (arrowheads to brain stem).

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begins with a shifting of the firing threshold of cells and neuronal networks via GJ (Figure 1). Of note, these electric synapses are present in neuronal connections of cortex layer I - especially in association areas, e.g., in the forebrain [70-72]. EMFs can then influence the firing of pyramidal cells as a final readout via the frequencies of action potentials, as they are measured by EEG [73]. Pyramidal neurons involved are also in layer III leading to other neurons of the cortex or to giant pyramidal cells of layer V projecting down to the brain stem or spinal cord [74] (Figure 1).

In the end, arrays of neurons or even the whole cortex of the brain can get informationally "unified" in a momentary coherent state at the quantum level. These calculations drop down as decisions to the next level the slower-working electrical level. Here, very fast weighing and calculating is possible even within a single neuron. The electrical information can spread via GJs (or as quantum information via Josephson junctions) at the apical dendrites of pyramidal cells and finally elicit action potentials.

These mechanisms of classical neuronal information exchange can lead to local circuits possibly representing local consciousnesses [72] or they are integrated as a global workspace representing the pilot of our mind [75,76]. To bind such circuits and to create a global workspace, large-scale resonances are important for an orchestrated interplay of all network hierarchies [77] with multiple oscillations varying in frequency [78]. In the end, we see the remnants or "skid marks" of our thinking as action potential firing, measured by our instruments like EEG or functional MRI.

Conclusion

Regarding time frames of brain neuronal processing, the following characteristics could be gathered from the literature available:

- Ultrafast quantum calculations are supposed to occur predominately in the uppermost layers of the cortex.
- A readout of quantum processes by decoherence should take place and is accompanied by EMF photon generation.
- Then, a very fast electrical or photonic inter-neural transmission takes over via gap junctions, eliciting a sub-threshold shifting of membrane potentials.
- Finally, thresholds are reached for firing of action potentials leading to classical neurotransmission into other brain regions and to corticofugal pathways.

This all is orchestrated in a concerted system of oscillation speeds, possibly explaining discrepancies between the rapidity of subjective impressions and the slow speed of measured action potentials within the brain.

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