

A Simulation for Neurophotonic Quantum Computation in Visual Pathways

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(Dated: December 25, 2014)

One of the answers to the measurement problem in quantum theory is given by the Copenhagen-Interpretation of quantum theory (i.e. orthodox quantum theory) in which the wave function collapse happens in (by) the mind of observer. In fact, at first, great scientists like Von Neumann, London, Bauer and Wigner (initially) believed that the wave function collapse occurs in the brain or is caused by the consciousness of observer. However, this issue has been stayed yet very controversial. In fact, there are many challenging discussions about the survival of quantum effects in microscopic structures of the human brain, which is mainly because of quick decoherence of quantum states due to hot, wet and noisy environment of the brain that forbids long life coherence for brain processing. Nevertheless, there are also several arguments and evidences that emergence of large coherent states is feasible in the brain. In this paper, our approach is based on the latter in which macroscopic quantum states are probable in the human brain. Here, we simulate the delayed luminescence of photons in neurons with a Brassard-like teleportation circuit, i.e. equivalent to the transfer of quantum states of photons through the visual pathways from retina to the visual cortex. Indeed, our simulation considers both classical and quantum mechanical aspects of processing in neurons. As a result and based on our simulation, it is possible for our brain to receive the exact quantum states of photons in the visual cortex to be collapsed by our consciousness, which supports the Copenhagen-Interpretation of measurement problem in quantum theory.

I. INTRODUCTION

The feasibility of wave function collapse in the human brain has been the subject of vigorous scientific debates since the advent of quantum theory³⁵. Scientists like Von Neumann, London, Bauer and Wigner (initially) believed that wave function collapse occurs in the brain or is caused by the mind of the observer⁶¹. Mainstream cognitive neuroscience has far largely ignored the role of quantum physical effects in the neuronal processes underlying cognition and consciousness. Classical physics is viewed by most scientists today as an approximation to the more accurate quantum theory, and therefore due to the nature of this classical approximation the causal effects of our conscious activity on the material substrate may appear to be eliminated. There are a wide range of specific theories and models that have been proposed, appealing to a variety of quantum phenomena to explain a diversity of features of brain processes in general and consciousness in particular. Recent discoveries indicate that living organisms might process information quantum mechanically, either at the bio-molecular level, or the cellular/neuronal level. For example, it has been hypothesised that a quantum information processing inside the human brain is feasible^{30,31} in structures called microtubules (MTs), and consciousness is the result of a collective wave function collapse occurring in these structures. On the other side, Max Tegmark⁶⁹ obtained several results that there is no any long-lived quantum effect in the brain and thus the nature of brain processing is not quantum mechanical for cognitive processes. He has considered two systems for quantum states: superposed ions and solitons in microtubules. His results indicate that decoherence times are in the order of 10^{-20} s to 10^{-13} s, so the behaviour of neurons is classical. On the other side, Hagan et al²⁹ and Rosa and Faber⁵⁹ have determined other estimations for decoherence times for quantum states of microtubules in neurons in which some of their results indicate that there are still possibilities for quantum coherent states to be effective in brain processing. Another argument against collapse of quantum states by consciousness is that the quantum states of photons do collapse in the human eye and there is no the possibility of collapse by visual cortex or the brain⁴³. Here, we simulate a model in which quantum states of photons can be transferred to the brain intact despite collapse in the eye.

II. IS OUR BRAIN CLASSICAL OR QUANTUM MECHANICAL SYSTEM?

Living systems are composed of molecules and atoms, and the most advanced theory for the explanation of the interaction between atoms and molecules is quantum theory. For example, making and breaking of chemical bonds, absorbance of frequency specific radiation (e.g. photosynthesis and vision), conversion of chemical energy into mechanical motion (e.g. ATP cleavage) and single electron transfer through biological polymers (e.g. DNA or proteins) are all quantum effects. The all above systems are small structures but the brain is a very big system to be considered quantum mechanical. However, there are several reasons that the brain may behave quantum mechanically. For example, the EEG waves associated with two distant neurons are strongly correlated and this supports the view that EEG waves may be related to the properties of the brain as a coherent quantum system. It is not possible for a scalp EEG to determine the activity within a single dendrite or neuron. Rather, a surface EEG reading is the summation of the synchronous activity of thousands of neurons that have similar spatial orientation, radial to the scalp⁶¹. Another reason to consider the brain as a quantum system is the "binding" problem. It means that we receive many sensory inputs at once: visual, auditory, olfactory, tactile and thermal. The time intervals and locations of processing are different for each of them, but they interact with each other despite their relative distant locations and we perceive them as simultaneous events. Third, Synaptic transmission and axonal transfer of nerve impulses are too slow to organize coordinated activity in large areas of the central nervous system⁶¹. The duration of a synaptic transmission is at least 0.5 ms and thus the transmission across thousands of synapses takes on the order of hundreds to thousands of milliseconds. The transmission speed of action potentials varies between 0.5 m/s and 120 m/s along an axon. More than 50 percent of the nerves fibers in the corpus callosum are without myelin, thus their speeds are reduced to approximately 0.5 m/s. Another argument regarding the assumption that the brain may be quantum mechanical is that the human body is made up of many organs, which themselves are made up of many billions of cells. How can such a system with billions of semi-autonomous components function effectively and coherently?^{55,61} Perhaps quantum coherence is a major factor responsible for our bodies, and especially our brains, being so efficient and well coordinated. In contrary, in order to have a very high degree of coherence between bio-molecules in the brain, Bose-Einstein condensation may be a viable effect, but we note that the ambient temperature in the human brain is too high for this phenomenon to occur. The question is "can bio-molecules condense at this temperature or maintain coherence like lasers under these warm conditions?". Also, the sizes of bio-molecules and neurons are very large by physical standards to be regarded as typical quantum systems. Moreover, because of the noisy environment, according to decoherence theory, quantum states of these mesoscopic bio-molecules would collapse very rapidly. It was already suggested that microtubules may possibly utilize nonspecific thermal energy for "laser-like" coherent pumping, for example in the GHz range by a mechanism of "pumped phonons" suggested by Froehlich²¹⁻²³. According to Hagan et al.²⁹ microtubules in neurons of the brain process information quantum mechanically and they avoid decoherence via several mechanisms over sufficiently long times for quantum processing to occur. Recently, the possibility of quantum coherent state in microtubules are proved theoretically¹³ and experimentally^{25,60,64,65}. The Bandyopadhyay group in Japan has shown that creation of large scale coherent states in microtubules and neurons of the brain is possible, supporting the Orch OR model of Penrose and Hameroff^{25,30}.

III. SUPERPOSED PHOTONS COLLAPSE IN THE RETINA

Photon is a quantum mechanical concept and has no a classical equivalent, and photoreceptor molecules in the eye can detect single photons, indicating that photoreceptors are quantum detectors.

We assume here that the quantum state of a system (i.e. outside our brain) is reported by superposed photons. As is documented in the literature on the biophysics of vision, 4% of incident photons into the eye are reflected from the cornea. 50% of the remaining photons are dissipated through ocular media absorption. The rest of the photons enter the 200-250 μm thick retina. There, they interact with the photoreceptors in the layer composed of rods and cones following an 80% loss due to retinal transmission⁶¹. In this case, we consider just a few remaining photons which are in a superposed quantum state. The expression "superposed quantum states" of the remaining photons is based on our first assumption that photons enter into the eye in superposed states, and also because the retina is largely transparent to photons so they can be received in the last layer of retina⁷¹. Thus, we assume that the few remaining photons (which are not reflected, dissipated or absorbed) are still in a superposed state. The key question here is whether the quantum state of a photon can be reported to the visual cortex in the brain or not. When this state interacts with the last layer of retina, it seems that this superposed photon undergoes a wavefunction collapse, because the photon's information signature will be converted into electrical signals after it leaves the retina. On the other hand, photons can be absorbed and then transformed into classical signals.

IV. DELAYED LUMINESCENCE AND BIOPHOTONS IN NEURONS OF THE BRAIN

Energy or charge transfer is one of the most important phenomena in physical and biological systems. Life-enabling transport phenomena in the molecular mechanism of biological systems occur at scales ranging from atoms to large macro-molecular structures. Energy transfer processes in photosynthetic structures^{10,18,36,46} is a very good example in the context of quantum effects in biology. Recently, it has been put forward the idea that quantum mechanics might have positive effect on the efficiency of energy or charge transfer in living systems. One of the most important effects of quantum mechanics in biological systems has been evidenced in the Fenna-Matthews-Olson (FMO) complexes²⁰ in a photosynthetic system in which quantum coherence is observed during energy transfer of photons from light harvesting complexes to the reaction centre, by experimental methods via ultrafast spectroscopy¹⁸.

Delayed luminescence is a luminescence which can be observed shortly after irradiation of the sample with light. The typical intensity of delayed luminescence is of order 10^{10} times weaker than the incident light intensity⁵⁰. In photosynthetic systems, delayed luminescence is the light that is emitted from chlorophyll in the sample in the visible region of the spectrum which lasts few seconds to few minutes after they have been exposed to light^{16,26,45}. Delayed luminescence reportedly originate in a relatively small fraction of available chlorophyll molecules located in the vicinity of the corresponding electron transport. Delayed luminescence 10^{-5} s originates in a reverse electron flow of the photosynthetic electron transport. Delayed luminescence in the minutes time scale is also photosynthesis related due to chlorophyll molecules (i.e. chlorophyll-a molecules associated with the core complex of photosystem II (PSII)).

As we discussed before, the excitation energy transfer in photosynthesis is quantum mechanical and delayed luminescence occurs after this process. It is comparable with a similar mechanism in neurons of the human brain in which it is possible to have quantum coherent states in neurons and delayed luminescence in the form of biophotons. Neurons incessantly emit biophotons such as all living cells of plants, animals and humans that continuously emit ultraweak biophotons in the optical range of the spectrum, which is associated with their physiological states and can be measured using special equipments. The intensity of biophotons is in direct correlation with neural activity, cerebral energy metabolism, EEG activity, cerebral blood flow and oxidative processes^{38,42}. Biophoton emission from neural tissue depends on the neuronal membrane depolarization and Ca^{2+} entry into the cells⁴⁴. This biophoton emission can be facilitated by the membrane depolarization of neurons by a high concentration of K^+ and can be attenuated by application of tetrodotoxin or removal of extracellular Ca^{2+} . Bokkon suggested that biophysical pictures may emerge due to redox regulated biophotons in retinotopically organized cytochrome oxidase-rich neural networks during visual perception and imagery within early visual areas⁶. Moreover, they proposed that retinal phosphenes may originate from natural bioluminescent biophotons within the eyes⁵. One of the experimental evidences for the above hypothesis has been obtained recently by Sun et al.⁶⁸, who demonstrated that neurons can conduct photon signals. Moreover, Wang et al.⁷² presented the first experimental proof of the existence of spontaneous and visible light induced biophoton emission (i.e. delayed luminescence) from freshly isolated rat's whole eye, lens, vitreous humor and retina. It has been shown that the process of radiative relaxation of the electro-solitons allows for the transfer of energy via interactions with deoxyribonucleic acid (DNA) molecules to induce conformational changes in DNA molecules producing an ultra weak non-thermal spontaneous emission of coherent biophotons through a quantum effect¹¹. In general, several aspects of brain dynamics and cognitive properties can be explained via biophoton emission in neurons³⁻⁹.

V. PHOTORECEPTORS IN BRAIN CELLS

It is well known that photoreceptors (e.g. rhodopsin) are located in the retina and the transformation of light to electrical signals occurs via retina photoreceptors. Now the question is: are biophotons important in neurons of the brain while they cannot be absorbed by the retina photoreceptors? Are there other photoreceptors in brain cells to process biophoton signals? As we discussed above, the signals in neurons of the brain may be formed in the shape of biophotons as well. In fact, neurons contain many light sensitive molecules, such as porphyrin rings, flavinic, pyridinic rings, lipid chromophores and aromatic amino acids^{39,40,47,70}. In particular, mitochondria, the machines inside cells which produce energy, contain several prominent chromophores^{39,40}. So, the presence of light sensitive molecules makes it hard to imagine how they might not be influenced by biophotons.

VI. NEUROPHOTONIC QUANTUM COMPUTATION

Recently research in quantum state transfer, especially in quantum teleportation, has emerged as one of the major research areas of theoretical and experimental quantum mechanics⁴⁹. Quantum teleportation is a process that transmits the exact quantum state of an atom or photon from one location to another location by using both classical communication and a quantum channel between the sending and receiving locations. For example, assume that Alice wants to send Bob an unknown quantum state, but, when she receives this state, she does not know anything about that, unless she affects it and collapses it to a classical state, or in other words she destroys that quantum state. She can just send classical signals to Bob through a classical channel, but if there is a shared entangled channel between Alice and Bob, Bob can reconstruct the initial quantum state with the help of a classical signal which is sent by Alice and a quantum channel between them. This operation is implemented by the use of special unitary operators^{49,61}. In the next section, we would like to answer this question by our simulation: how can our brain receive quantum information of photons while photons are collapsed in the eye before reaching to the brain? If yes, is this process equivalent to a quantum teleportation mechanism between the retina and the brain? In fact, retina is part of the central nervous system. It seems that bioelectronic and biophotonic processes are not independent biological events in the nervous system and the external light can induce light inside the neurons of the brain which is called "delayed luminescence", appearing in the form of biophotons⁵⁶.

A. Our Simulation

As we discussed above, the transduction of light into electrical signals takes place in the photoreceptors in the retina. The stacked disks in the outer segment of rods and cones contain a membrane protein, *rhodopsin*. In the dark, the side chain is bent at the 11th carbon atom. In this form it is called 11-cis-retinal. If this molecule absorbs a photon, it undergoes photoisomerization, forming straight chain version, all-trans-retinal (see Fig 1).

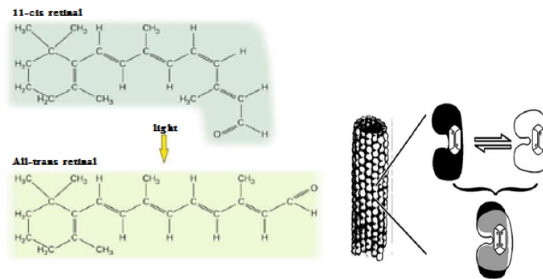


FIG. 1. Left) Rhodopsin molecule in two states: cis and trans. Right) Microtubules and its components, tubulins, in superpositioned state.

Our simulation is based on the Brassard teleportation circuit². In every step, the ket $|0\rangle$ is equal to $\binom{1}{0}$ and ket $|1\rangle$ is equal to $\binom{0}{1}$. In each line there is a two states entity. In this simulation, top line is the state of photon. The middle line is the state of rhodopsin molecule and the bottom line is the state of tubulin. Microtubules are composed of tubulin dimers. Tubulin dimer is an intrinsically fluorescent molecule mainly due to 8 tryptophan residues it contains. Rhodopsin is a membrane structure, and microtubules interact with membrane structures mechanically by linking proteins, chemically by ions and second messenger signals, and electrically by voltage fields⁶¹. This interaction may entangle rhodopsin with the cytoskeletal structures. It is worth stressing here that centrioles and cilia, which are complex microtubular structures, are involved in photoreceptor functions in single cell organisms and primitive visual systems.

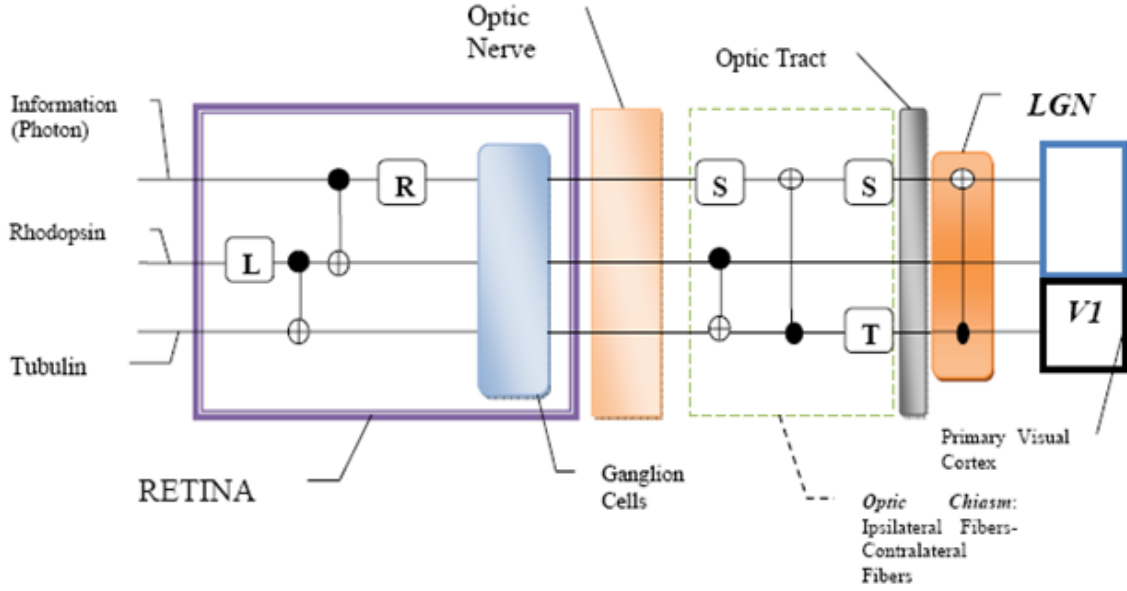


FIG. 2. Simulation of visual pathways in the human brain with the Brassard teleportation circuit².

Cilia are also found in all retinal rod and cone cells. The interaction of light and rhodopsin creates a superpositioned state of rhodopsin which is correlated to special states of neurons in the visual cortex⁶⁶.

We know that in accordance to Einstein-Podolsky-Rosen (EPR) pair¹⁹, when two entities are originated from a common source, or interact with each other, they can become entangled¹. In fact, the definition of EPR pair for organs in living systems (e.g. in the brain) is difficult and may be discussed via some nonlocal interactions between the brain and receiver cells⁶¹. Retina has a similar layered structure as the gray-matter top layers of the cerebral cortex of the brain. In fact, the retina is an extension of the central nervous system (the brain and spinal cord) that forms during embryonic development. This is one reason why scientists are interested in retinal processing; the retina is an accessible part of the brain that can be easily stimulated with light¹⁷, so it is not weird if the superposition state of rhodopsin is correlated to special states in the visual cortex. In the Fig 2, the first quantum gate L, converts the state of rhodopsin to a superpoed state: $\frac{1}{\sqrt{2}}(|cis\rangle + |trans\rangle)$. After that, we can write three lines as follows:

$$\begin{aligned}
 &|\psi\rangle \\
 &\frac{1}{\sqrt{2}}(|cis\rangle + |trans\rangle) \\
 &|tubulin\rangle
 \end{aligned}$$

This step entangles the two bottom lines using the Controlled-NOT gate. This gate is the representative of the interaction of rhodopsin with a tubulin. Here, the control line is the state of rhodopsin and denoted c , and the data line is tubulin and denoted d . The d and c indices throughout the steps show the data and control lines respectively.

By using CONT gate, tubulin and rhodopsin would be entangled with each other. To show this mechanism, we encode the cis state of rhodopsin with the ket $|0\rangle$ and the $trans$ state with the ket $|1\rangle$. The state of tubulin dimer is always considered as a two states entity like a qubit. Here, we encode the state of tubulin as one of it's states. We assume it is in $|0\rangle$ state. Now, the superposition state of rhodopsin becomes $\frac{1}{\sqrt{2}}(|0\rangle + |1\rangle)$. After the operation of CONT gate we have:

$$\begin{aligned}
 &\oplus \frac{1}{\sqrt{2}}(|0\rangle_c + |1\rangle_c)|0\rangle_d \\
 &= \frac{1}{\sqrt{2}}(\oplus|0\rangle_c|0\rangle_d + \oplus|1\rangle_c|0\rangle_d) \\
 &= \frac{1}{\sqrt{2}}(|0\rangle_c|0\rangle_d + |1\rangle_c|1\rangle_d)
 \end{aligned}$$

The state of the circuit at this stage is:

$$\begin{aligned}
 &|\psi\rangle \\
 &\frac{1}{\sqrt{2}}(|0\rangle|0\rangle + |1\rangle|1\rangle)
 \end{aligned}$$

The photon interaction with rhodopsin (which was entangled with the tubulin before) may causes to entangle three states. It means that the next operation entangles $|\psi\rangle$ with the middle state, which is already entangled with the bottom state. This means that three lines can be entangled with each other.

$$\begin{aligned}
& \oplus |\psi\rangle_c \frac{1}{\sqrt{2}} (|0\rangle_d |0\rangle + |1\rangle_d |1\rangle) \\
&= \frac{1}{\sqrt{2}} \oplus (a|0\rangle_c + b|1\rangle_c) (|0\rangle_d |0\rangle + |1\rangle_d |1\rangle) \\
&= \frac{1}{\sqrt{2}} (a(\oplus(|0\rangle_c |0\rangle_d) |0\rangle + \oplus(|0\rangle_c |1\rangle_d) |1\rangle) \\
&\quad + b(\oplus(|1\rangle_c |0\rangle_d) |0\rangle + \oplus(|1\rangle_c |1\rangle_d) |1\rangle)) \\
&= \frac{1}{\sqrt{2}} (a(|0\rangle_c |0\rangle_d |0\rangle + |0\rangle_c |1\rangle_d |1\rangle) + b(|1\rangle_c |1\rangle_d |0\rangle \\
&\quad + |1\rangle_c |0\rangle_d |1\rangle))
\end{aligned}$$

At this time, photon and rhodopsin and tubulin are entangled with each other. The state of retina is no longer in a state that would let us isolate any of the states.

After the collision of the photon with rhodopsin, rhodopsin naturally decoheres. For this case, operator R operates on this state which means that the branch connected carbon-11 of rhodopsin rotates 90 degrees to right. The operator R is:

$$R = \frac{1}{\sqrt{2}} \begin{pmatrix} 1 & 1 \\ -1 & 1 \end{pmatrix}$$

After the operation of R we have:

$$\begin{aligned}
& R \frac{1}{\sqrt{2}} (a(|0\rangle_R |0\rangle |0\rangle + |0\rangle_R |1\rangle |1\rangle) + b(|1\rangle_R |1\rangle |0\rangle \\
&\quad + |1\rangle_R |0\rangle |1\rangle)) \\
&= \frac{1}{\sqrt{2}} (a(R|0\rangle_R |0\rangle |0\rangle + R|0\rangle_R |1\rangle |1\rangle) \\
&\quad + b(R|1\rangle_R |1\rangle |0\rangle + R|1\rangle_R |0\rangle |1\rangle)) \\
&= \frac{1}{\sqrt{2}} (a(\frac{1}{\sqrt{2}}|0\rangle_R - |1\rangle_R) |0\rangle |0\rangle + \frac{1}{\sqrt{2}}(|0\rangle_R \\
&\quad - |1\rangle_R) |1\rangle |1\rangle) + b(\frac{1}{\sqrt{2}}(|0\rangle_R + |1\rangle_R) |1\rangle |0\rangle \\
&\quad + \frac{1}{\sqrt{2}}(|0\rangle_R + |1\rangle_R) |0\rangle |1\rangle)) \\
&= \frac{1}{2} (a|0\rangle_R |0\rangle |0\rangle - |1\rangle_R |0\rangle |0\rangle + |0\rangle_R |1\rangle |1\rangle \\
&\quad - |1\rangle_R |1\rangle |1\rangle + b(|0\rangle_R |1\rangle |0\rangle \\
&\quad + |1\rangle_R |1\rangle |0\rangle + |0\rangle_R |0\rangle |1\rangle + |1\rangle_R |0\rangle |1\rangle))
\end{aligned}$$

At this stage we reach the measurement point. At this point, photon and rhodopsin decohere naturally. This is equivalent to collapse of the quantum information $|\psi\rangle$ in the retina. This operation causes to collapse the state to one of four states $|00\rangle$, $|01\rangle$, $|10\rangle$, $|11\rangle$. This process forces the bottom line (tubulin) into a state that is commensurate with whatever the upper lines become and with the original quantum state of all three lines.

Information from receptors is transferred both radially across and trans-retinally through the retina. Except for the ganglion cells, none of the retinal cells display action potentials (digital forms i.e. classical states)⁶¹.

Now, we would like to investigate the four possible states ($|00\rangle$, $|01\rangle$, $|10\rangle$, $|11\rangle$) for collapse:

A) Suppose the upper two lines decohere to $|0\rangle|1\rangle$ (or $|01\rangle$).

It means the total state becomes:

$$a|0\rangle|1\rangle|1\rangle + b|0\rangle|1\rangle|0\rangle$$

No possible measurement outcome results in information loss about either a or b.

The first operation on the right hand side applies \oplus to the second and third line. We continue with our convention of making control and data states with c and d.

$$\begin{aligned}
& a|0\rangle \oplus (|1\rangle_c |1\rangle_d) + b|0\rangle \oplus (|1\rangle_c |0\rangle_d) \\
&= a|0\rangle |1\rangle_c |0\rangle_d + b|0\rangle |1\rangle_c |1\rangle_d
\end{aligned}$$

Axons leaving the temporal half of the retina traverse the optic nerve to the optic chiasm, where they join the optic tract and project to *ipsilateral* structures. Axons leaving the nasal half of the retina cross the midline at the chiasm and terminate in *contralateral* structures. This arrangement means that all the axons in the optic tract carry information about the contralateral visual field. Axons of the optic tract terminate in 3 areas of the central nervous system, the lateral geniculate nucleus (LGN), the superior colliculus and the pretectal area⁶¹.

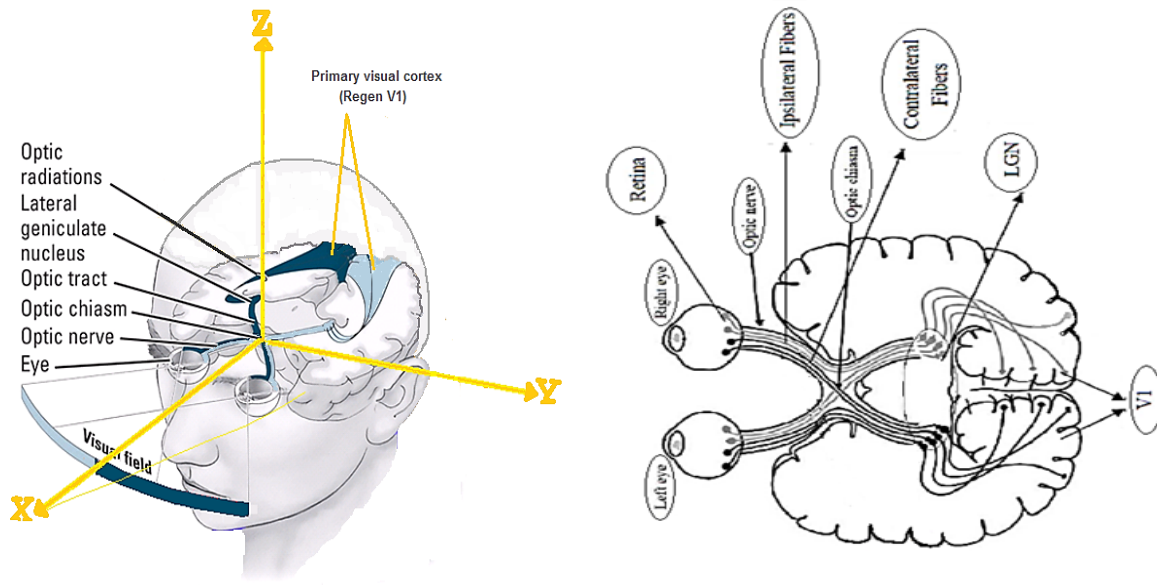


FIG. 3. The contralateral fibers of the left eye cross at the optic chiasm and are connected to the right side of the brain and the contralateral fibers of the right eye cross to the left side of the brain. This crossing causes a phase shift between direct neurons and crossed neurons.

1. Different path-lengths in neurons may act as phase shifters

When the information is collapsed in the retina, action potentials are produced. The shape of action potentials is the same for each neuron, but the main problem is which neurons are fired, or in other words which neurons carry action potentials and information. We will see that crossing of neurons in the visual pathways plays an important role in restoring information in the brain. In Fig. 3 it is seen that the contralateral fibers of the left eye cross at the optic chiasm and are connected to the right side of the brain and the contralateral fibers of the right eye cross to the left side of the brain. This crossing causes a phase shift between direct neurons and crossed neurons. Here we may understand why the shape of action potentials stays the same. Classical models state that 'sensations' are action potentials that reach the brain via sensory neurons, and 'perception' is the awareness and interpretation of the sensation. It is reasonable to assume that the constant shape of action potentials cannot result in different profiles of information. Thus the shape of information should be due to neurons⁶¹. In our approach action potentials just determine which neurons fire and which do not. The contralateral fibers cross in the middle of the path and looks curved and longer relative to ipsilateral fibers, but toward this point ipsilateral fibers approximately are straight. Now the upper line is equivalent to contralateral fibers and is passed through the S gate. Gates S and T represent an example of phase shifts between the ipsilateral and contralateral fibers (Fig 3) with a multiplication by a fixed global phase-shift:

$$S = \begin{pmatrix} i & 0 \\ 0 & 1 \end{pmatrix} = e^{i\pi/4} \begin{pmatrix} e^{i\pi/4} & 0 \\ 0 & e^{-i\pi/4} \end{pmatrix}$$

$$T = \begin{pmatrix} -1 & 0 \\ 0 & -i \end{pmatrix} = e^{i\pi/4} \begin{pmatrix} e^{i3\pi/4} & 0 \\ 0 & e^{-i3\pi/4} \end{pmatrix}$$

Now, the contralateral fiber is passed through the S gate, which in this case simply multiplies by i , so that the state of the fiber becomes

$$ia |0\rangle |1\rangle |0\rangle + ib |0\rangle |1\rangle |1\rangle$$

The trajectory through the LGN is the largest direct pathway in which visual information reaches the cerebral cortex. The most of the optic tract axons synapse in the LGN. Contralateral fibers and ipsilateral fibers couple in the LGN. The ipsilateral fibers of the optic nerve terminate in laminae 2, 3 and 5 of LGN, while the contralateral fibers terminate in laminae 1, 4 and 6 of LGN⁶¹. The neurons in each LGN project to the ipsilateral occipital cortex as the optic radiations. The portion of the cerebral cortex that receives LGN axons is called primary visual cortex or V1. All information in the visual system is processed by V1 first, and then passed out to higher order systems⁷³.

For the circuit, the next operation couples the contralateral fiber and microtubules. At this time, tubulins control the gate.

$$\begin{aligned} & \oplus (ia |0\rangle_d |1\rangle |0\rangle_c + ib |0\rangle_d |1\rangle |1\rangle_c) \\ & = ia |0\rangle_d |1\rangle |0\rangle_c + ib |1\rangle_d |1\rangle |1\rangle_c \end{aligned}$$

Now, we apply S gate to contralateral fiber and T gate to ipsilateral fiber:

$$\begin{aligned} & ia \hat{S} |0\rangle_s |1\rangle \hat{T} |0\rangle_T + ib \hat{S} |1\rangle_s |1\rangle \hat{T} |1\rangle_T \\ & = a |0\rangle |1\rangle |0\rangle + b |1\rangle |1\rangle |1\rangle \end{aligned}$$

And finally after applying inverse Controlled-NOT gate (decoupling):

$$\begin{aligned} & \oplus (a |0\rangle_d |1\rangle |0\rangle_c + b |1\rangle_d |1\rangle |1\rangle_c) \\ & = a |0\rangle_d |1\rangle |0\rangle_c + b |0\rangle_d |1\rangle |1\rangle_c \\ & = |0\rangle |1\rangle \begin{pmatrix} a \\ b \end{pmatrix} = |0\rangle |1\rangle \psi \end{aligned}$$

It is seen that the first state of photon is appeared again, which could be potentially a biophoton or a quantum state (or quantum information) of the photon, which can be received by photoreceptors in brain cells.

B) Suppose the upper two lines in circuit decohere to $|0\rangle|0\rangle$.

It means the total state becomes:

$$a|0\rangle|0\rangle|0\rangle + b|0\rangle|0\rangle|1\rangle$$

The first operation on the right hand side applies \oplus to the second and third line.

$$\begin{aligned} & a|0\rangle \oplus (|0\rangle_c |0\rangle_d) + b|0\rangle \oplus (|0\rangle_c |1\rangle_d) \\ & = a|0\rangle|0\rangle_c |0\rangle_d + b|0\rangle|0\rangle_c |1\rangle_d \end{aligned}$$

Now, the contralateral fiber is passed through the S gate:

$$ia |0\rangle |0\rangle |0\rangle + ib |0\rangle |0\rangle |1\rangle$$

For the circuit, the next operation couples the contralateral fiber and microtubules. At this time, tubulins control the gate.

$$\begin{aligned} & \oplus (ia |0\rangle_d |0\rangle |0\rangle_c + ib |0\rangle_d |0\rangle |1\rangle_c) \\ & = ia |0\rangle_d |0\rangle |0\rangle_c + ib |1\rangle_d |0\rangle |1\rangle_c \end{aligned}$$

Now we apply S gate to contralateral fiber and T gate to ipsilateral fiber:

$$\begin{aligned} & ia \hat{S} |0\rangle_s |0\rangle \hat{T} |0\rangle_T + ib \hat{S} |1\rangle_s |0\rangle \hat{T} |1\rangle_T \\ & = a |0\rangle |0\rangle |0\rangle + b |1\rangle |0\rangle |1\rangle \end{aligned}$$

And finally after applying inverse Controlled-NOT gate (decoupling):

$$\begin{aligned} & \oplus (a |0\rangle_d |0\rangle |0\rangle_c + b |1\rangle_d |0\rangle |1\rangle_c) \\ & = a |0\rangle_d |0\rangle |0\rangle_c + b |0\rangle_d |0\rangle |1\rangle_c \\ & = |0\rangle |0\rangle \begin{pmatrix} a \\ b \end{pmatrix} = |0\rangle |0\rangle \psi \end{aligned}$$

C) Suppose the upper two lines in circuit decohere to $|1\rangle|0\rangle$.

It means the total state becomes:

$$-a|1\rangle|0\rangle|0\rangle + b|1\rangle|0\rangle|1\rangle$$

The first operation on the right hand side applies \oplus to the second and third line.

$$\begin{aligned} & -a|1\rangle \oplus (|0\rangle_c |0\rangle_d) + b|1\rangle \oplus (|0\rangle_c |1\rangle_d) \\ & = -a|1\rangle|0\rangle_c |0\rangle_d + b|1\rangle|0\rangle_c |1\rangle_d \end{aligned}$$

Now, the contralateral fiber is passed through the S gate:

$$-a |1\rangle |0\rangle |0\rangle + b |1\rangle |0\rangle |1\rangle$$

For the circuit, the next operation couples the contralateral fiber and microtubules. At this time, tubulins control the gate.

$$\begin{aligned} & \oplus (-a |1\rangle_d |0\rangle |0\rangle_c + b |1\rangle_d |0\rangle |1\rangle_c) \\ & = -a |1\rangle_d |0\rangle |0\rangle_c + b |0\rangle_d |0\rangle |1\rangle_c \end{aligned}$$

Now we apply S gate to contralateral fiber and T gate to ipsilateral fiber:

$$\begin{aligned} & -a \hat{S} |1\rangle_s |0\rangle \hat{T} |0\rangle_T + b \hat{S} |0\rangle_s |0\rangle \hat{T} |1\rangle_T \\ & = a |1\rangle |0\rangle |0\rangle + b |0\rangle |0\rangle |1\rangle \end{aligned}$$

And finally after applying inverse Controlled-NOT gate (decoupling):

$$\begin{aligned} & \oplus (a |1\rangle_d |0\rangle |0\rangle_c + b |0\rangle_d |0\rangle |1\rangle_c) \\ & = a |1\rangle_d |0\rangle |0\rangle_c + b |1\rangle_d |0\rangle |1\rangle_c \\ & = |1\rangle |0\rangle \begin{pmatrix} a \\ b \end{pmatrix} = |1\rangle |0\rangle \psi \end{aligned}$$

D) Suppose the upper two lines in circuit decohere to $|1\rangle|1\rangle$.

It means the total state becomes:

$$-a |1\rangle |1\rangle |1\rangle + b |1\rangle |1\rangle |0\rangle$$

The first operation on the right hand side applies \oplus to the second and third line.

$$\begin{aligned} & -a |1\rangle \oplus (|1\rangle_c |1\rangle_d) + b |1\rangle \oplus (|1\rangle_c |0\rangle_d) \\ & = -a |1\rangle |1\rangle_c |0\rangle_d + b |1\rangle |1\rangle_c |1\rangle_d \end{aligned}$$

Now, the contralateral fiber is passed through the S gate:

$$-a |1\rangle |1\rangle |0\rangle + b |1\rangle |1\rangle |1\rangle$$

For the circuit, the next operation couples the contralateral fiber and the microtubules. At this time, tubulins control the gate.

$$\begin{aligned} & \oplus (-a |1\rangle_d |1\rangle |0\rangle_c + b |1\rangle_d |1\rangle |1\rangle_c) \\ & = -a |1\rangle_d |1\rangle |0\rangle_c + b |0\rangle_d |1\rangle |1\rangle_c \end{aligned}$$

Now we apply S gate to contralateral fiber and T gate to ipsilateral fiber:

$$\begin{aligned} & -a \hat{S} |1\rangle_s |1\rangle \hat{T} |0\rangle_T + b \hat{S} |0\rangle_s |1\rangle \hat{T} |1\rangle_T \\ & = a |1\rangle |1\rangle |0\rangle + b |0\rangle |1\rangle |1\rangle \end{aligned}$$

And finally after applying inverse Controlled-NOT gate (decoupling):

$$\begin{aligned} & \oplus (a |1\rangle_d |1\rangle |0\rangle_c + b |0\rangle_d |1\rangle |1\rangle_c) \\ & = a |1\rangle_d |1\rangle |0\rangle_c + b |1\rangle_d |1\rangle |1\rangle_c \\ & = |1\rangle |1\rangle \begin{pmatrix} a \\ b \end{pmatrix} = |1\rangle |1\rangle \psi \end{aligned}$$

It is seen that for each of the four above states of collapse in the retina the quantum state of the incident photon can be exactly restored in the brain.

VII. CONCLUSION

In this paper, we simulated the main visual pathways in the human brain (from retina to the visual cortex) with a quantum teleportation circuit (i.e. Brassard teleportation circuit) in which quantum states of photons can be transferred to the brain intact despite collapse in the eye. According to our simulation, the initial quantum state of the incident light into the eye can be restored

in the primary visual cortex in the form of delayed luminescence (or biophotons) and can be processed via photoreceptors in the brain cells. This can be a potential support for Copenhagen Interpretation for the measurement problem in quantum theory³⁵ in which quantum states are collapsed in (by) the mind of observer.

On the other side, recent advances in the context of quantum information and quantum computation⁴⁹, and quantum biocomputing^{24,28,37,41,54} have opened up new perspectives to develop new quantum artificial intelligence (AI) techniques, quantum-classical hybrid algorithms, quantum-based machine learning⁵¹, and future research prospects for creation advanced AI technologies based on quantum simulations²⁷. Our simulation here is a new approach that is neurophotonic quantum computation, which can be developed, generalised and applied for quantum intelligence and quantum bio-communication technologies. However, we are now at the first steps of development and need more progress, which would be a potential subject of future prospects.

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- ¹ Bell JS, *Speakable and Unspeakable in Quantum Mechanics*, Introduction by Alain Aspect, Cambridge University Press, 2004.
 - ² Brassard G, Teleportation as a quantum computation, *Physica D*, 120 (1998) 43-47
 - ³ Bokkon I, V Salari, JA Tuszynski, Emergence of Intrinsic Representations of Images by Feedforward and Feedback Processes and Bioluminescent Photons in Early Retinotopic Areas, *Journal of integrative neuroscience*, 10 (01), 47-64, (2011).
 - ⁴ Bokkon I, Vimal RLP, Wang C, Dai J, Salari V, Grass F, Antal I, Visible light induced ocular delayed bioluminescence as a possible origin of negative afterimage, *Journal of Photochemistry and Photobiology B: Biology*, 103 (2), 192-199, 2011.
 - ⁵ Bokkon I, Phosphene phenomenon: A new concept, *BioSystems*, 92:168-174, 2008.
 - ⁶ Bokkon I, Visual perception and imagery: a new hypothesis, *BioSystems*, 96:178-184, 2009.
 - ⁷ Bokkon I, Salari V, Information storing by biomagnetites, *Journal of Biological Physics*, 36(1), 109-120, 2010.
 - ⁸ Bokkon I, Salari V, Scholkmann F, Dai J, Grass F, Interdisciplinary implications on autism, savantism, Asperger syndrome and the biophysical picture representation: Thinking in pictures, *Cognitive Systems Research* 22, 67-77, 2013.
 - ⁹ Bokkon I, Salari V, Hypothesis about brilliant lights by bioluminescent photons in near death experiences, *Medical hypotheses*, 79 (1), 47-49, 2012.
 - ¹⁰ Brixner T, Stenger J, Vaswani HM, Cho M, Blankenship RE, and Fleming GR, *Nature* 434, 625 (2005).
 - ¹¹ Cacha LA, Poznanski RR, Genomic instantiation of consciousness in neurons through a biophoton field theory, *Journal of integrative neuroscience*, 13 (02), 253-292, 2014.
 - ¹² Cacha LA, Poznanski RR, Associable representations as field of influence for dynamic cognitive processes, *Journal of integrative neuroscience*, 10 (04), 423-437, 2011.
 - ¹³ Craddock TJA, Douglas Friesen, Jonathan Mane, Stuart Hameroff, Jack A. Tuszynski, The Feasibility of Coherent Energy Transfer in Microtubules, *Journal of The Royal Society Interface*, 11: 20140677, 2014.
 - ¹⁴ Craddock TJA, JA Tuszynski, A Priel, H Freedman, Microtubule ionic conduction and its implications for higher cognitive functions, *Journal of integrative neuroscience*, 9 (02), 103-122, 2010.
 - ¹⁵ Craddock TJA, A Priel, JA Tuszynski, Keeping time: Could quantum beating in microtubules be the basis for the neural synchrony related to consciousness? *Journal of integrative neuroscience*, 13 (02), 293-311, 2014.
 - ¹⁶ Creath K and Schwartz GE. Biophoton images of plants: Revealing the light within. *The Journal of Alternative and Complementary Medicine*, 10(1):23-26, 2004.
 - ¹⁷ Dowling JE, *The Retina: An Approachable Part of the Brain*. Belknap Press of Harvard University Press, Cambridge. (1987).
 - ¹⁸ Engel GS, Calhoun TR, Read EL, Ahn TK, Mancal T, Cheng YC, Blankenship RE, and Fleming GR, *Nature* 446, 782 (2007).
 - ¹⁹ Einstein. A, Podolsky. B, Rosen. N., Can quantum mechanical description of physical reality be complete? *Phys. Rev.*, 47,777-780. 1935.
 - ²⁰ Fenna RE and Matthews BW, *Nature* 258, 573 (1975); J.Adolphs and T. Renger, *Biophys. J.* 91, 2778 (2006).
 - ²¹ Froehlich H, Long range coherence and energy storage in biological systems, *Int J Quantum Chem*, 2:641-649, 1968.
 - ²² Froehlich H, Long range coherence and the action of enzymes, *Nature*, 228:1093, 1970.
 - ²³ Froehlich H, The extraordinary dielectric properties of biological materials and the action of enzymes, *PNAS*, 72, 4211-4215, 1975.
 - ²⁴ Gariaev PP, Marcer PJ, Leonova-Gariaeva KA, Kaempf U, and Artjukh VD, DNA as basis for quantum biocomputer, *DNA Decipher J.*, 1(1), 25-46 (2011).
 - ²⁵ Ghosh S, Satyajit Sahu, Anirban Bandyopadhyay, Evidence of massive global synchronization and the consciousness: Comment on Consciousness in the universe: A review of the Orch OR theory by Hameroff and Penrose. *Physics of Life Reviews*, 10, 2013.
 - ²⁶ Golstev V, Zaharieva I, Chernev P, and Strasser RJ. Delayed fluorescence in photosynthesis. *Photosynthesis Research*, 101:217-232, 2009.
 - ²⁷ Neven Hartmut. Launching the Quantum Artificial Intelligence Lab. Google Research. Retrieved February 11, 2014.
 - ²⁸ Hollenberg LCL, Fast quantum search algorithms in protein sequence comparison-quantum biocomputing, *Phys. Rev. E.*, 62(5), 7532-7535 (2000).
 - ²⁹ Hagan S, Hameroff S, Tuszynski J, Quantum computation in brain microtubules: Decoherence and biological feasibility, *Phys. Rev. E*, 65, 061901 (2002).
 - ³⁰ Hameroff SR, Penrose R. Orchestrated reduction of quantum coherence in brain microtubules: A model for consciousness. in S.R. Hameroff, A.Kaszniak, and A.C. Scott(eds.), In: *Toward Science of consciousness The First Tueson Discussions and Debates*, MIT Press, Cambridge, MA. Also published in: *Mathematics and computers in simulation*, 40, 453-480, 1996.
 - ³¹ Hameroff SR, Quantum computation in brain microtubules. The Penrose-Hameroff 'Orch OR model of consciousness. *Philosophical trans-*

- actions Royal society London(a),.356:1869-1896.(1998).
- 32 Hameroff S, Penrose R, Consciousness in the universe: A review of the Orch OR theory, *Physics of Life Reviews*, 11 (1), 39?78, (2014).
 - 33 Hameroff SR, TJA Craddock, JA Tuszynski, Quantum effects in the understanding of consciousness, *Journal of integrative neuroscience*, 13 (02), 229-252, 2014.
 - 34 Hameroff SR, TJA Craddock, JA Tuszynski, Memory bytes? molecular match for CaMKII phosphorylation encoding of microtubule lattices, *Journal of Integrative Neuroscience*, 9 (03), 253-267, 2010.
 - 35 Howard, D. Who invented the Copenhagen Interpretation? A study in mythology. *Philosophy of Science*, 669?682, (2004).
 - 36 Ishizaki A and Fleming G, *Proc. Nat. Acad. Sci.* 106,17255(2009).
 - 37 Ismaeel AG and S. A. Abdul-Rahman, New method of measuring TCP performance of IP networks using biocomputing, *Int. J. Distributed Parallel Syst.*, 3(3), 167-183 (2012).
 - 38 Isojima Y, Isoshima T, Nagai K, Kikuchi K, Nakagawa H, Ultraweak biochemiluminescence detected from rat hippocampal slices, *NeuroReport*, 6:658-660, 1995.
 - 39 Karu T, Primary and secondary mechanisms of action of visible to near-IR radiation on cells, *J Photochem Photobiol*, B 49:1?17, 1999.
 - 40 Kato M, Shinzawa K, Yoshikawa S, Cytochrome oxidase is a possible photoreceptor in mitochondria, *Photobiochem Photobiophys*, 2:263?269, 1981.
 - 41 Katz E and Privman V, Enzyme-based logic systems for information processing, *Chem. Soc. Rev.*, 39(5), 1835-1857 (2010).
 - 42 Kobayashi M, Takeda M, Sato T, Yamazaki Y, Kaneko K, Ito K, Kato H, Inaba H, In vivo imaging of spontaneous ultraweak photon emission from a rat's brain correlated with cerebral energy metabolism and oxidative stress, *Neurosci Res*, 34:103-113, 1999.
 - 43 Koch C, Hepp K, Concept Quantum Mechanics in the Brain, *Nature*, 440, 611 (2006).
 - 44 Kataoka Y, Cui Y, Yamagata A, Niigaki M, Hirohata T, Oishi N, Watanabe Y, Activity-Dependent Neural Tissue Oxidation Emits Intrinsic Ultraweak Photons, *Biochem Biophys Res Commun*, 285:1007-1011, 2001.
 - 45 Lee C, Yang JM, Park SH, Yi SH, Yang JS, and Soh KS. Delayed luminescence imaging system and its application. *J Int Soc Life Inf Sci*, 22(2):445-449, 2004.
 - 46 Lee H, Cheng YC, and Fleming GR, *Science* 316, 1462 (2007).
 - 47 Mazhul VM, Scherbin DG, Phosphorescent analysis of lipid peroxidation products in liposomes, *Biofizika*, 44:676?681, 1999.
 - 48 Moradi N, F Scholkmann, V Salari, A study of quantum mechanical probabilities in the classical Hodgkin-Huxley model. *Journal of integrative neuroscience*, 1-17, 2014.
 - 49 Nielsen, M.A., and Chuang, I.L., *Quantum Computation and Quantum Information*, Cambridge University Press.(2000).
 - 50 Parkhomtchouk DV and Yamamoto M. Super-delayed luminescence from biological tissues. *J. Intl. Soc. Life Info. Sci*, 18:413417, 2000.
 - 51 Powell D, Quantum boost for artificial intelligence, *Nature*, doi:10.1038/nature.2013.13453, (2013).
 - 52 Penrose, R. (1994). *Shadows of the mind*. Oxford University Press.
 - 53 Poznanski R, L Cacha, Intracellular capacitive effects of polarized proteins in dendrites. *Journal of Integrative Neuroscience* 11 (4), 417-438, 2012.
 - 54 Privman V, Strack G, Solenov D, Pita M, and Katz E, Optimization of enzymatic biochemical logic for noise reduction and scalability: How many biocomputing gates can be interconnected in a circuit?, *J. Phys. Chem. B*, 112(37), 11777-11784 (2008).
 - 55 Rahnama M, Salari V, Tuszynski JA, How Can the Visual Quantum Information be Transferred to The Brain Intact, Collapsing There and Causing Consciousness? *NeuroQuantology*, 7 (4), 2009.
 - 56 Rahnama M, Tuszynski J, Bokkon I, Cifra M, Sardar P, Salari V, *Journal of Integrative Neuroscience*, 10 (1) (2011) 65-88.
 - 57 Reinis S, Robert F. Holub, Pavel Smrz. A quantum hypothesis of brain function and consciousness, translated version of: *Ceskoslovenska fyziologie*, 54 .26-31, 2005.
 - 58 Revonsuo, A. and Newman, J. (1999). Binding and Consciousness. *Consciousness and Cognition*, 8, 123-127.
 - 59 Rosa and Faber, *Phys. Rev. E* 70, 031902 (2004).
 - 60 Sahu S, Subrata Ghosh, Daisuke Fujita, Anirban Bandyopadhyay, Live visualizations of single isolated tubulin protein self-assembly via tunneling current: effect of electromagnetic pumping during spontaneous growth of microtubule. *Scientific reports*. 01/2014; 4:7303.
 - 61 Salari V, Rahnama M, Tuszynski JA, Dissipationless transfer of visual information from retina to the primary visual cortex in the human brain, *ANS: The Journal for Neurocognitive Research*, 54 (1-2), 2012.
 - 62 Salari V, Tuszynski J, Bokkon I, Rahnama M, Cifra M, On the photonic cellular interaction and the electric activity of neurons in the human brain, *Journal of Physics: Conference Series*, 329 (1), 012006, 2011.
 - 63 Salari V, Tuszynski J, Rahnama M, Bernroider G, Plausibility of quantum coherent states in biological systems, *Journal of Physics: Conference Series*, 306 (1), 012075, 2011.
 - 64 Sahu S, Ghosh S, Hirata K, Fujita D, Bandyopadhyay A. Multi-level memory-switching properties of a single brain microtubule. *Appl Phys Lett*, 102, 123701, 2013.
 - 65 Sahu S, Ghosh S, Ghosh B, Aswani K, Hirata K, Fujita D, et al. Atomic water channel controlling remarkable properties of a single brain microtubule: correlating single protein to its supramolecular assembly. *Biosens Bioelectron*, 47:141-8, 2013.
 - 66 Schlosshauer M, Experimental motivation and empirical consistency in minimal no-collapse quantum mechanics, *Ann. Phys.*, 321, 112-149 (2006).
 - 67 Summhammer J, V Salari, G Bernroider, A quantum-mechanical description of ion motion within the confining potentials of voltage-gated ion channels, *Journal of integrative neuroscience*, 11 (02), 123-135, 2012.
 - 68 Sun Y, Wang C, Dai J, Biophotons as neural communication signals demonstrated by in situ biophoton autography, *Photochem Photobiol Sci*, 9:315-322, 2010.
 - 69 Tegmark M, Importance of quantum decoherence in brain processes, *Phys. Rev. E*, 61, 4194?4206, 2000.
 - 70 Thar R, Khl M, Propagation of electromagnetic radiation in mitochondria? *J Theor Biol*, 230:261?270, 2004.
 - 71 Yanoff, M. and Duker, J.S. (2009). *Ophthalmology*, Third Edition, MOSBY Elsevier.
 - 72 Wang Ch, Bokkon I, Dai J, Antal I. Spontaneous and visible light-induced ultraweak photon emission from rat eyes, *Brain Res*, 1369:1-9,

- 2011.
- ⁷³ Zeki, S. The visual image in mind and brain, *Scientific American*, 267:42-50.