Review of: "The Case for Conscious Experience Being in Individual Neurons"

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Potential competing interests: No potential competing interests to declare.

The paper is a good attempt to address some of the “quantum consciousness” ideas, as well as some quantum biological mechanisms in the abstract, but the problem with many of those mechanisms is that they cannot integrate neural signals in a manner that is consistent with the rich experience of phenomenal consciousness. As noted in the paper, “At a quantum level, it can indeed support a unified rich distributed interaction in a well-defined domain of space and time. As indicated later, such correlation may be plausible in a neuron but there is no known receiver unit of this sort at a larger scale.” However, there is in fact a known receiver or mechanism that can integrate highly processed neural signals. The catecholaminergic neuron electron transport (CNET) neural action selection and binding mechanism was first proposed as a hypothesis in 2018, as reported in Rourk, Christopher John. "Ferritin and neuromelanin “quantum dot” array structures in dopamine neurons of the substantia nigra pars compacta [SNc] and norepinephrine neurons of the locus coeruleus [LC]." Biosystems 171 (2018): 48-58. It is based on the observation that ferritin and neuromelanin concentrations in catecholaminergic neurons are sufficient to potentially provide an energy transport mechanism that can allow electrons to move between large neuron somas. The release of iron from ferritin resulting from that transfer can trigger calcium-induced calcium release and action potential, as discussed in Hidalgo, Cecilia, and Marco T. Núñez. "Calcium, iron and neuronal function." IUBMB life 59.4-5 (2007): 280-285.

One of the predictions made by the hypothesis was that electron tunneling in the ferritin and neuromelanin structures in that neural tissue should be detectable using conductive atomic force microscopy (CAFM), and subsequent CAFM tests performed by a commercial lab (EAG Labs in Silicon Valley) on fixed human SNc tissue provided strong evidence of that electron tunneling. See Rourk, Christopher J. "Indication of quantum mechanical electron transport in human substantia nigra tissue from conductive atomic force microscopy analysis." Biosystems 179 (2019): 30-38. Those tests were performed by Dr. Sara Ostrowski, a skilled researcher with years of experience in conducting CAFM tests, who is now at Stanford University. Dr. Yeuming Hua, a staff scientist at Bruker, the CAFM equipment supplier, also reviewed those results and confirmed that they were not due to equipment misoperation or any other problems. However, because these were the first CAFM tests ever performed on SNc tissue, people generally do not understand them.

Another prediction made by the hypothesis was that electrons should be able to tunnel over distances of 10 microns or more, which is the separation distance between the large soma in the SNc and the LC. Evidence of that function was first provided by Bera, Sudipta, et al. "Long-range solid-state electron transport through ferritin multilayers." Journal of Materials Chemistry C 7.29 (2019): 9038-9048.

Another prediction made by the hypothesis was that a switching/routing mechanism would exist in such ferritin structures. Evidence of that function was first provided by Rourk, Christopher, et al. "Indication of Strongly Correlated Electron Transport and Mott Insulator in Disordered Multilayer Ferritin Structures (DMFS)." Materials 14.16 (2021): 4527. That research also provided supporting evidence of long-range transport of electrons through ferritin structures. Other researchers in the field have confirmed one of the key observations of those tests, see Labra-Muñoz, Jacqueline A., et al. "Ferritin-Based Single-Electron Devices." *Biomolecules* 12.5 (2022): 705. An explanation of the way that mechanism relates to integration of information is provided in Rourk, Chris. "Application of the Catecholaminergic Neuron Electron Transport (CNET) Physical Substrate for Consciousness and Action Selection to Integrated Information Theory." *Entropy* 24.1 (2022): 91.

Another prediction made by the hypothesis was that cortical signals provided to striatal dendrites should trigger action potentials in large SNc neurons, which are also coupled to the striatal dendrites, and should also result in action selection. That prediction was controversial, because the convention wisdom at the time was that the SNc does not mediate action selection. The first evidence that the convention wisdom was wrong and that dopamine release from large SNc neurons is temporally and spatially precise and mediates action selection was provided by Prof. Pascal Kaeser at Harvard Medical School, Liu, Changliang, Pragya Goel, and Pascal S. Kaeser. "Spatial and temporal scales of dopamine transmission." Nature Reviews Neuroscience 22.6 (2021): 345-358. Prof. Kaeser also demonstrated that cortical signals at striatal dendrites can trigger action potentials in SNc axons that are coupled to the striatal dendrites, Liu, Changliang, et al. "An action potential initiation mechanism in distal axons for the control of dopamine release." Science 375.6587 (2022): 1378-1385. These astounding results from a highly reputable research institution are only beginning to be understood.

The striatum integrates widespread cortical neural signals as well as sensory neural signals, see, e.g. Yeh, Fang-Cheng, et al. "Population-averaged atlas of the macroscale human structural connectome and its network topology." Neuroimage 178 (2018): 57-68. Thus, there is in fact at least one mechanism that can integrate neural signals at a large scale.

Further evidence of quantum biological functions arising from electron tunneling associated with ferritin is provided in Perez, Ismael Diez, et al. "Electron tunneling in ferritin and associated biosystems." IEEE Transactions on Molecular, Biological and Multi-Scale Communications (2023). This reference provides evidence that the mechanism is quite widespread, and may occur in the retina, the cochlea, macrophages, mitochondria and other biological systems. It is unrelated to any quantum consciousness mechanisms that require large scale coherence and is instead an incoherent electron tunneling mechanism that is similar to electron tunneling that has been shown to occur in proteins and other biological systems and processes, although in the SNc and LC it acts on a large scale. This very new discovery should be seriously considered by anyone who is addressing neural processes associated with consciousness, although the reviewer notes that many researchers he has contacted about it dismiss this considerable body of research out of hand, sometimes with statements that reflect that they do not understand how it differs from “quantum consciousness” ideas that require large scale coherence. A discussion of CNET and this evidence should be added to the paper and given serious consideration, as CNET is new, and many are unfamiliar with it. It is unlike and unrelated to any “quantum consciousness” idea.