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Comment

# The need for a physical basis of cognitive process

## Comment on “Consciousness in the universe. A review of the ‘Orch OR’ theory” by Hameroff and Penrose

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Does consciousness belong in the realm of natural sciences? This question has been on the minds of many scientists whose opinions diverge due to the subjective nature of consciousness. The existence of this phenomenon cannot be denied as we all experience it as sentient humans. Hameroff and Penrose over the past two decades generated a large body of literature [1] and generated a theory known as “Orch OR” (orchestrated objective reduction). It is an attempt to place consciousness within the empirical sciences as a fundamental concept in science. This is in contrast to emergent phenomenon approaches or spiritualistic/dualistic concepts. Orch OR has linked this phenomenon to numerous enigmatic features and observations ranging from the intelligent behavior of single-cell organisms to anesthesia. The central postulate of the Orch OR theory is that the site of action of consciousness is located within the brain’s microtubules (MTs) which operate at the interface between classical neurophysiology and quantum gravitational forces. These are very bold claims that have found both ardent supporters and vocal critics in the scientific community. The enduring power of attraction of Orch OR for a solid base of support across science, philosophy and beyond is a testament to the creative influence of this work on the field. However, crucial validation or falsification of Orch OR must come from experimentation. This is very challenging since the current “gold standard” in neuroscience is fMRI and its spatial resolution is on the 1 mm scale while temporal resolution is on the 1 s scale. This is orders of magnitude higher than the 1 nm and 1 ns scales of tubulin’s size/time operational dimensions as studied by molecular biophysics, let alone the quantum gravity effects hypothesized by Orch OR to be occurring on the Planck scale of space–time geometry ( $10^{-35}$  m;  $10^{-44}$  s). This huge gap between the current experimental capabilities and the claims made by Orch OR poses the greatest challenge to the acceptance of these tenets. Several technical objections should also be stated. First, Orch OR appears to be decoupled from the animate/inanimate divide as it never takes into account the fact that the MTs in question belong to a live neuron as opposed to a bundle of MTs assembled in a microfluidic channel, for example. Divorcing consciousness from life forms puts it back into the spiritual/dualistic type of reasoning that Orch OR rejects. How can one account for metabolism taking place in neurons, which would be a minimal requirement for making Orch OR account for life? Second, the emphasis based on the gravitational interactions is difficult to accept within conventional physics. Gravitational interactions are many orders of magnitude weaker than even

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thermal noise [2]. The time-tested approach to solving equations of motion in (both classical and quantum) physics is a perturbation method where the first approximation is given by the strongest forces and then these solutions are subjected to the next weaker force, etc., giving a reasonable representation of reality by mathematical convergence of approximate solutions. By this token, allowing two tubulin monomers to interact by classical electrostatic, chemical and van der Waals forces is best treated by molecular dynamics methods. Next come quantum effects, which may or may not be destroyed by thermal noise [3,4]. Finally, one could consider gravitational forces, which would be negligible compared to the previous interactions.

I foresee major progress in bridging the gap between nanoscience and consciousness in the area of nanoneuroscience [5] where MT's, actin filaments and motor proteins connect between neurophysiology and molecular biology. Studying the neural phenomena at a nanoscale will lead to monumental breakthroughs in science and medicine and aid in consciousness studies.

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