Article

Neural Oscillations & Consciousness: Attention as a Litmus Test for the Quantum Mind Hypothesis

Seán O'Nualláin*

ABSTRACT

The "quantum mind" hypothesis, the notion that quantum phenomena are causal and perhaps even essential in mentation and particularly consciousness, has met with fierce resistance. This has been particularly the case over the past 20 years, and the first task of this paper is to show that while there are indeed strong - mainly empirical - arguments against the thesis, the 'in principle arguments published to date evince premature closure.

The burgeoning field of "Quantum cognition" has established that quantum models are appropriate for decision-making, and that of "Quantum biology" has now made the notion of quantum effects at physiological temperatures plausible. If quantum effects are relevant to consciousness, they are likely to be seen in the contrast between attended to and not attended to streams of information. An exciting confirmation of this theme is the fact that attended to streams involve a decorrelation of the informational fluctuations in streams not so attended to. This gives rise to the idea that perhaps what enters our consciousness is the result of such a decorrelation from a superposed state.

Decorrelation for the purposes of sparsification is prevalent in the brain; what may enter consciousness in the schema proposed here is mental processes with a duration greater than the sampling rate of consciousness (about 80ms) the wave function of which is undergoing state-vector reduction in a manner described by the Quantum Zeno effect. This allows also for truly voluntary action in the manner Von Neumann suggested. This is distinct from the situation with binocular resolution dichoptic stimuli which is a mixture, and is an example of what Fodor calls a "vertical" module with its operation mandatory. There is nothing to be gained by making binocular synthesis subject to voluntary choice. Likewise, it is realistic to propose that attention in lower animals with their less complex brains involves a much simpler mechanism than human consciousness.

A model of the individual neuron as a harmonic oscillator is outlined, with a causal role for ion channels in the generation of the oscillations. It is clear that ion channels are critical for attention. Moreover, at a mesoscopic level, it is demonstrated that the brain enters a quiet "shutter" mode several times a second in which quantum effects may be appropriately amplified. If quantum effects exist in the brain, it is likely that this complex of phenomena will be central to them. The de Barros and Suppes models, in addition to the similar formalism due to Henry Stapp, are also briefly described.

Key Words: quantum mind, harmonic oscillator, attention, phase synchrony.

*Correspondence: Seán O Nuallái, Ph.D. University of Ireland, CA, USA. E-mail: president@universityofireland.com

1. Introduction

The "quantum mind" hypothesis, the notion that quantum phenomena are causal in mentation, is one of the truly exciting ideas of the past century. Until recently, it also seemed very unlikely. If true, it gives us a language to describe our thought in the context of the emanation of the cosmos, and – on what is relatively a prosaic level – to assert human free will, soul, and mental capacity greater than Turing machines. This article begins its analysis below by considering one of this theory's main proponents, Henry Stapp

In previous work (2012) this author has indicated how the non-classical probability regime that epitomized the quantum vacuum prior to the creation of the inflaton and the big bang may be recapitulated in the brain through consciousness. Many leaps of faith are required, and this article proposes the evidence that will be necessary from a variety of disciplines to make this hypothesis plausible. Alternatively put, the subject/object relationship in QM is the most bare in nature; my 2008 paper describes the various other types of epistemological relations that hold a, for example, we move around the world, or map a domain in terms of the formal symbols used in language.

In the first place, we need some regime in which quantum effects can be causal in biological systems. We then need some evidence that the artillery of Hilbert spaces is relevant for cognition as for quantum mechanics. As it happens, neither hypothesis – unthinkable even a generation ago – is in the slightest currently implausible, and we will simply refer to prior art.

For example, Hu et al (2010) give a list of various theories that have emerged, and the empirical evidence on which they are based. That article features work analyzing the evidence for non-locality in neural phenomena which is not the focus here; rather, a targeted analysis of attention and how it might be subject to quantum effects is going to be the core of this paper. Ball (2011) authoritatively announces the field of "quantum biology". While skeptical about the "quantum mind" hypothesis, de Barros and Suppes (2009) point to the existence of quantum cognition, and presage their later work of how neural oscillator structures may give rise to these phenomena, echoing the work described later in this paper.

The second step after quantum biology is the justification of the "quantum mind" hypothesis, the notion that there is some real quantum process causally affecting the mind. The Penrose/Hameroff model has argued that human cognition cannot otherwise be described; rather less well known is the painstaking investigation of Berkeley's Henry Stapp into the consequences of Von Neumann's analysis of the system and the observer. That shall constitute our next port of call. If Stapp is right, then Penrose/Hameroff may similarly be correct in their insistence that, through quantum effects, the mind transcends the chugging of the Turing machine, and both models assert human free will as a consequence.

Should this model be valid, it is reasonable to expect the neural data to reflect it. In particular, it should be possible to see phenomena in attention that resemble state-vector reduction. Remarkably, here our model holds up well in the face of the thorough research into attention by Jude Mitchell, inter alia.

A complicating factor is the lack of metatheory in neuroscience, it is fair to say that we must emphasise how time is increasingly being agreed on as the lingua franca of the brain. It may be asserted with some confidence that information is conveyed by markings on the phase of neural oscillations like gamma – or indeed the individual neurons that we study below. In particular, phase synchrony seems to be essential for cognition in general, and for both consciousness and meditation in particular. In fact, even if the quantum model is wrong, the fact that it has focused attention of waves and their effect in neural function may in itself have justified the area, if not the extravagant claims. The data with which I end this paper are valid whether "quantum mind" is right, or another beautiful, well-motivated and failed theory.

According to Tegmark (2000) the theory is indeed a failed one. With some patience, he explains neural impulses/firing, and demonstrated that decoherence would occur far too quickly for any conceivable "condensate' to last long enough to support a conscious experience. However, he fails completely to reference gap junctions, which allow almost instantaneous transmission of signals and do not need the conventional "action potentials" that Tegmark describes. (Shepherd et al, 2010). In fact, Tegmark is in many ways the George W Bush of this area; faced with what only he considered an existential threat, he attacked the wrong enemy.

In like vein, Reimers et al (2009) point out that the then favoured location of coherent states for the Hameroff/Penrose model – Froehlich condensates – is impossible in principle. While this may indeed be right, it also, like Tegmark misses the target. In fact, it belongs to a near-phrenological obsession with locating the "faculties' of the mind in specific cerebral locations, a bizarre recapitulation of a Victorian thread that we will consider in the last section below.

There is, on the contrary, an emerging and indeed burgeoning consensus that the attested fact that the brain can support stable patterns of oscillatory circuits, particularly through dendro-dendritic connections (Shepherd et al, 2010) is critical for 21st century neuroscience. The remainder of this paper will examine several such models and their background.

2. The work of Henry Stapp

In the famous "quantum zeno" effect (Stapp 2009; forthcoming, 2013), the QM event selects the code to be used in the next Energetic cycle. This result in a situation where the tiny time-scales involved in Qm can have macroscopic effects. Much of my published experimental neuroscience work (2008, 2009; with Tom Doris, 2009, 2011) has shown how individual neurons, correctly described as harmonic oscillators, can have their oscillations entrained by large-scale and synchronized gamma to recruit them to produce states more congenial for quantum effects.

Stapp (2009) is allowed speak for himself about the details of his model. Tegmark (2000) glosses Stapp as proposing that "interaction with the environment is probably small enough to be unimportant for certain neural processes" which is rather like saying that "certain Iraqis may object to our presence".. In fact, Stapp (2009) is extremely aware of the problem of environmental decoherence. He suggests, correctly, that the existence of harmonic oscillators is not in doubt and proposes what are trivial extensions to give them quantum traction. He then argues that the "quantum zeno" effect allows Von Neumann' process 1, the putting of a question to nature and apprehending the result, ensures that conscious choice is neurally as plausible as it clearly is physically plausible, embedded as it is in the structure of Von Neumann's classical approach to QM. Note that one can also allow that state-vector reduction occurs absent any observers, be that mechanism spontaneous localization or whatever.

Likewise for bistable stimuli, those that change from one perception to another in th manner of the Necker cube and the rabbit/duck fluctuation. In this case, there is work indicating that a single perception can be maintained for 3 seconds, giving a zeno moment of perhaps 30 ms, compatible with gamma waves. (Atmanspacher et al, 2008)

So without violating any real neuroscience, Stapp (forthcoming) puts it we can say that we are "psychophysical agents that can freely instigate probing actions of our own mental choosing ". All that we need is a very limited but relatively free capacity to choose the object of our attention – as I wrote before (2012), we do not have absolute free will to change long-entrenched habits but we do have the capacity to change our focus and thus begin to work on ourselves. Thereafter as it is possible to demonstrate, attention becomes biased in the direction of the free choice previously made, as Sheng He and his colleagues have demonstrated (Jiang et al, 2006). My own work on the subject can be found in my 2010 paper.

Similarly, in visual attention work, as it turns out from He et al,, stereoscopic fusion does NOT happen without attention. Instead, in the absence of attention, a fused/patchwork image gets relayed. So there is a role for attention with perhaps QM implications; however, it looks as though what obtains in binocular vision more resembles a mixture. (Zhang et al, 2011) than a superposition.

As Stapp (forthcoming) puts it "Each observing ego is empowered to pose probing questions about the facts of the world in which it finds itself. ". That is all we need for at least a limited notion of free will ; we can look on will (self-mastery) as something that can vary from person to person, and involves familiarity with the thousands of years of human culture in which we're immersed, the fact that we're highly social primates used to living in groups, and other factors which shape us; nevertheless, there is a "free" core. As Stapp (forthcoming) puts it about development;

"The ego of the infant begins in the womb to inquire about the structure of its world, and by virtue of its intrinsic conceptual capacities begins, by trial and error, to acquire a conception of the world in which it finds. This conception is a construction in terms the validated feeling about it."

This can usefully be expanded by looking at the work of Jean Piaget , whose constructivism has survived the attack of his experiments (see my 2003 book)

It is worthwhile thinking of the analogy of the cinema, with 28 frames per second being necessary to fill. Once a stream is the object of attention, it reaches a threshold (perhaps 10 frames/sec) and gets promoted to conscious awareness. Once in consciousness, it can "broadcast" to the rest of the processes in the brain in the manner of an actor on stage. This broadcast is achieved, at least partially, by modulating the fast gamma oscillations in the brain.

In consciousness, these oscillations become more synchronized. In reality, consciousness involves perhaps 12 frames per second; 80 ms seems the minimum time we need to recognize objects. (Again, please see my 2010 paper)

A fundamental point that presents itself is the status of “elements of reality” in Qm. Indeed here Bohr and Von Neumann are greatly at odds. In particular, Bohr is committed to an epistemological interpretation in Born's view – “the electron IS FOUND at x” – whereas Von Neumann is willing to say “the electron IS at x”. There are profound reasons for this distinction, arising from Mach who also corrupted Einstein– albeit in such a way that Bohr and Einstein felt themselves in disagreement.
As Stapp (ibid.) expresses it “ the empirical validity of certain predictions of quantum mechanics entails that some supposedly mere practical tools for the calculation of predictions, namely the actualized quantum mechanical states, are real essences “

This is the core of the issue and what we're doing is trying to cash it out in terms of present knowledge; “Thus quantum mechanics becomes, in von Neumann’s orthodox formulation, directly and explicitly, a theory of the mind-brain connection.” (ibid). However, it is this author’s view, further developed below, that the notion of what “elements of reality” may never be resolved in terms of cognition, or indeed in terms of classical epistemology; QM, accurate beyond our wildest dreams, may forever remain inscrutable.

Moreover, the following (ibid) needs to be explicated in view of what we now know about attention:

“The mind, or “abstract ego”, has a battery of efforts E each of which corresponds to an act of putting to Nature a particular question about the world inhabited by that ego. According to the quantum precepts, Nature immediately responds by either returning a feeling F that is tied to the effort, F=F(E), or by failing to return immediately a response. “

In fact, it resembles nothing so much as the “self-conscious mind” that John Eccles eventually saw incarnated in a “probability cloud” due to his (mis?) reading of Margenau, described in my 2003 book We do not need this in any case to support the idea that there is a core capacity for voluntary action in humans, and it is hard to uphold in the face of the relevant neuroscience and psychology evidence.

It is better to start from here: “The key to such an understanding is an understanding of the way that a mind is connected to its brain; for that connection is that mind’s bridge to the future.” (Stapp, ibid)

In my 2012 paper I suggest, in this context, that it is possible to achieve a regime of non-classical probability in the brain and indeed Suppes et al (2012) com to precisely the same conclusion in the quantum cognition field, providing a mechanism in terms of neural oscillators similar to the one about to be outlined.

There is no need to assume that all our choices are absolutely “free”; indeed, it would be hard to function. In fact, it may be the case that, even granted a core of free will, and as described in my

2010 paper, nature and culture have gifted us to ability to confabulate, incorrectly to attribute agency to ourselves, the better truly to act freely at times in complex environments.

3. Superposition and the brain

There is a growing consensus that aspects of human decision-making and concept formation can best be described using models from QM (Aerts, 2009, .de Barros, J.A. & Suppes, P. 2009, Suppes et al, 2012). What we are now going to explore is whether the same can be said for attentional mechanisms.

There are arguments on the micro level related to the Quantum Zeno effect –" watched phone never rings". There are facts on the macro level related to attention – but these seem paradoxical in nature, allowing the speculation that attention actually ENDS superposition - eg the work at He's lab showing that non-attended visual data never get binocular synthesis, (Zhang et al, 2011) . However, the stream not attended to is best viewed as a mixture rather than a superposition.

Bressler et al's work (2010, 2013) is also of interest here. It is not in doubt at this stage; attention ups the neural activity of the attendee-to stream, while suppressing response variability. It also suppresses the threads not attended to (ibid). In fact, it arguably turns the attended-to thread into von Neumann's process 1, posing a yes/no question to nature.

That there is a link between neural attention and QM is apparent in these quotes from Dirac and Zhang et al: Dirac; "The intermediate character of the state formed by superposition thus expresses itself through the probability of a particular result for an observation being intermediate between the corresponding probabilities for the original states, not through the result itself being intermediate between the corresponding results for the original states"

Or, as Zhang (2011) et al put it: "Thus attention is necessary for dichoptic images to be engaged in sustained rivalry, and may be generally required for resolving conflicting, potentially ambiguous input, and giving a single interpretation access to consciousness."

4. Attention and Consciousness

I indicate below how a position that accepts at least a limited form of free will can be fleshed out wrt neuroscience and indeed developmental cognitive psychology. Here, then, is my view of the position that can be defended in the face of the QM and neuroscience. Human consciousness consists of the ability to take a stream of processing – for example, an action-perception cycle with feedback present – and to submit it to a regime of superposition and state-vector reduction. This stream must last in the order of tenths of seconds at least as the minimum conscious "moment" is about 80 ms. . Human consciousness is a superset of and distinct from lower animal "attention", the ability to confer salience on a processing stream and up the gain of that stream.

Human consciousness is limited in that our ability to concentrate is limited, with 3 seconds being not a bad estimate (Atmaspaher et al, 2008). It uses mechanisms of decorrelation of an informational stream pervasive in the cortex, but does so in a voluntary way, one subject to will and featuring an immanent sense of self. In that, of course, it is consistent with the Von Neumann formulation of quantum mechanics. Its mechanism of a physiological level can perhaps be found in quantum coherent states related to ion channels, which seem related to the informational gain in attention. Our work will show how these ion channels establish the oscillation period for neurons considered as harmonic oscillators, and how the gamma oscillations synchronized through the cortex associated with consciousness help provide the entropically "quiet" environment in which quantum coherent states might occur.

Like it or not, materialists have to accept that that the Von Neumann formulation is consistent and can be interpreted as supportive of a form of dualism, more nuanced than the crude mind/body version. Like it or not, dualists have to accept that there are plausible neuroscientific accounts of a good deal of our perceptual experience, at least limited computer simulations of how symbols can be produced – though indications are that symbolic behavior at a higher level needs consciousness - and psychological evidence (a la Libet) that many of our choices are less free than we believe them to be. In fact, we confabulate a lot, not least to ourselves

The following any objections coming from the Libet et al (1983) work which argued that "conscious" intent was, follwing Hume, a "wont' rather than a will, distinct from Von Neumann's Proocss 1. Of course preafference will occur, whereby the brain lines up hypotheses for likely perceptual experience, and prepares responses. It is precisely the assimilation of such processes to an informational stream, and the use of a superposition and state-vector reduction on that stream, that constitutes human consciousness. That in turn introduces quantum indeterminacy into human decision making, and Aerts (2009) and many others have demonstrated the pervasiveness of quantum cognition in the human case, even be that cognition less than useful for particular decision-making tasks.

It also leads to the hypothesis that animals may forever be better at some attentional tasks than humans, as the mechanism used is simpler and does not involve free will; there is some evidence supporting the viewpoint that the types of process involved are different (Zangenehpour et al, 2008). This is of course aside from the obvious perceptual adaptations that attune animals to different parts of the electromagnetic spectrum to us, or better reflexes in cats, to take one example.

My guess is that the Quantum mind hypothesis is testable under this regime: 1. Does human consciousness involve superpositions? If not, it is game over and there are no quantum effects; and 2. If yes, and this superposition is indeed to be seen in the suppression of response variability in attention, even in macaques, is it the case that humans can modulate their attention to create new superpositions in their execution of complex plans?

The fact that Tversky and Kahneman's results are interpretable as "quantum cognition" rather than straightforward application of Bayes or some other regime now comes into play. What this writer finds really interesting about Mitchell's work (2009) is that attention DECORRELATES information so it is irreversible - pretty much what we want for state-vector reduction. In fact, it's beginning to look as plausible that our stream of consciousness is serial not parallel as a result of exploitation of quantum effects.

The critical issue then is that attention decorrelates information fluctuations. If this looks more like state-vector reduction than anything classical, the QM approach to mind is vindicated. Therefore, the Libet et al (1983) work actually supports the Quantum mind hypothesis as only one course of action was being "prepared". There exists also the possibility that Libet's instruments were not sensitive enough to detect alternative actions. Where such measurements have taken place (Bressler et al, 2010, 2013) it is clear that streams not being attended to, while retaining thir physiological integrity, have their activity suppressed in the service of keeping one stream, the focus of attention, enriched.

So what we defend is a notion that, as W James put it, the mind seizes on one of many streams of activity in the brain which then becomes the focus of attention. This stream is then characterized by differential informational statistics, as Mitchell et al (2009) have demonstrated, and this confirms a refutable hypothesis. In particular, we now have a “deus ex machina” - attention- preparing an observation in a way that shows purely “mental” effects on the “physical” world of the brain. It is indeed possible that this process may become assimilated to neural activity afterward; nevertheless the capacity is there for voluntary action.

The immediately above goes for bistable perception in general. There is also compelling evidence that the statistics of attended -to streams are different from those not so attended (Mitchell et al, 2009), and that response variability is less in attended-to streams (Cohen et al, 2009). Finally, He's lab has also demonstrated that attention is initially assigned unconsciously but in a way consistent with the disposition and formation of the observer (Jiang et al, 2006).

5. Neural models: mesoscopic and microscopic and the relation with gamma waves

There are models attested by ECOG data that invite speculation that the brain enters “limit cycles” a few times per second (Freeman et al 2008). These limit cycles correspond to synchronized gamma, meditation and consciousness as my various papers on the subject (2009, 2012) and those with Doris (2011) attest. The 2009 paper is consistent with the researchers who have proposed that the signature of the meditative state is the phase synchrony of the relatively fast gamma waves (40 Hz approx). The general approach of the Freeman work in summarized in my own 2008 paper.

The existence of phase coherence in gamma waves in the brain, and the relation of this phenomenon to consciousness, is a point of much consensus. It has been further argued that the entropically minimal state resulting from this phase coherence might yield an environment conducive to quantum coherence.

While we believe that the work of Walter Freeman indeed is indicative of entropically minimal states in the brain occurring several times a second, we also believe that the EEG/ECOG signal is too coarse to indicate synchrony. Indeed, we can adduce findings from PCA , among other methods, indicating that a 64-electrode grid produces at most two signals with any dgree of magnitude. In fact, there are data to indicate that much of the statistical inferences in classical EEE/ECOG evince premature closure, and that this approach is certainly not ready – pace, the ORCH OR proponents – for the non-classical world. So the gamma hypothesis, though beautiful, is "not proven'. The PCA work can be found in my 2011 paper with Doris which also finally gives the lie to the notion that epileptic seizure is a minimally entropic state.

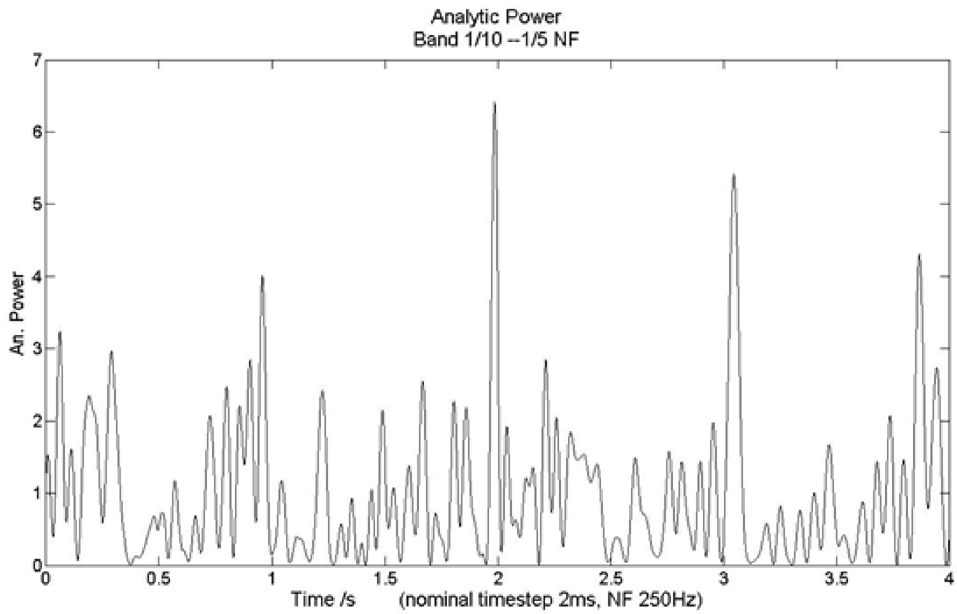
As for phase coherence, the stated electronic specifications of the equipment used in ECOG and EEG expressly prohibit any such inference, as the error range of the equipment is too large. This argument may become ever more salient over the years to come, as it does appear to be the case that one of the critical mechanisms used by the brain to convey information is frequency modulation of a carrier wave (like FM radio). In particular, phase information may indeed turn out to be critical once we learn how to measure it accurately.

This is a fortiori the case as simulations give a lot of support to the "zero power" gamma hypothesis for consciousness. If we simulate groups of 10,000 neurons - the "mesoscopic" level – and consider their firing as a random process with a mean frequency of 200 times/second, then we can graph how the power consumption of the brain is affected by gamma. The graph below indicates that it enters a brief period of "zero power" – of minimal consumption of energy – between 2 and 12 times per second. If this is done in synchrony throughout the brain, we indeed can speculate about health effects of meditation as the brain frees up energy to be used by the rest of the organism. In the diagram below, we have time of the x axis and energy consumption on the y axis.

These same models can be extended with models of individual neurons that explain how the attended- to stream of processing maximizes its gain in the broadcast system of the cortex (O Nualláin, Seán and T. Doris 2010). We consider each neuron as a harmonic oscillator, and consider how the oscillation of the membrane potential is altered in synaptic and dendro-dendritic connections. It is the latter that would seem to be more susceptible to quantum effects. Following are the details of the model, as presented in our 2010 paper.(IFN = the "standard" integrate and fire model; our model claims that this is a subset of the more general resonate and fire (RFN) behaviour in this discussion)

Ours (2004) was the first work to show how single neurons could realistically perform processing of sensory data expressed simply as spectral such data. This work has since been corroborated by, for example, Branco et al. (2010). Essentially, we argued that subthreshold oscillations of the neuron allowed groups of neurons to "own" part of the spectrum. That can be conceived of using only classical physics. As mentioned, we have data to indicate that much of the statistical inferences in classical EEE/ECOG evince premature closure, and that this approach is certainly not ready – pace, the ORCH OR proponents – for the non-classical world.

Since our original work, quantum coherence at physiological temperatures has been demonstrated for biological systems in photosynthesis at the 3nm level characteristic of gap junctions in neurons (Hoyer et al, 2012). This finding converges with a controversy about quantum effects in neurons related to consciousness. While, in related work, we question the assumption in the later that "phase coherence" has in fact been demonstrated in the brain, there is a long-attested corpus of observations suggestive of entropically minimal states several times a second there.



We therefore speculate that gap junctions might allow a quantum superposition of states of the membrane potential of each neuron to be communicated to thousands of others. This will lead to entanglement of a scale that would allow the Fourier decomposition we envisage for the classical case to be extended to a quantum description. This is the only currently physiologically plausible story about Quantum effects in the brain that we can currently envisage as having quantum effects.

Our model (O Nualláin, and Doris 2010) shows how ion channels' activity interacts with the frequency of subthreshold oscillations in a neuron. This is on the one hand causative of different patterns of firing and on the other hand of phase changes in the quantum state and we propose this in conjunction with the current Reynolds work as a possible interrelation of attention and neural processing (Reynolds et al, 2009). It also is consistent with the Suppes et al work (2012) which, while in favour of the harmonic oscillator paradigm, arges that the allegedly quantum effects are in fact artefacts of the structure of neural oscillators.

We will take some time to look at the structure of our model:

The basic behaviour of Harmonic Oscillators is captured by the differential equation:

$$\ddot{\psi} \equiv \frac{d^2\psi}{dt^2}.$$

The parameters which give an oscillator its unique properties are A, w_0 and ϕ. The value of A determines the amplitude of oscillation, that is how far the maximum displacement from equilibrium will be. The w_0 term determines the strength of the returning force. This in turn determines how quickly the mass returns to the equilibrium point (and indeed the velocity at which the equilibrium is passed). This equates to the more familiar concept of the frequency of oscillation. The frequency of oscillation is the number of complete cycles performed per second, and is the inverse of the period, the length of time required to complete a single cycle.

The period of oscillation of such a system is denoted τ and related to the other terms as follows:

$$\tau = \frac{2\pi}{w_0}.$$

In a fashion similar to the delta functions used to describe the intergate and fire neuron (IFN) – for Tegamrk (2000) the only type of neural mechanism - , we now demonstrate the operation of the resonate and fire model in mathematical terms. First, we must define some variables unique to the model:

$$\omega_i = \frac{f_i 2\pi}{f_c},$$

where f_i is the resonant frequency of node i, and f_c is the frequency of the global clock. The global clock frequency determines the granularity of simulation and may be set to any value, the default used to produce the graphs discussed previously is 1000. The term ω_i is referred to as the counter multiplier for node i. This term is introduced since it may be calculated once the resonant frequency is specified, and thus does not need to be calculated in subsequently.

$$\Delta\dot{\psi}_i = (\Sigma w_{ij} o_j) - \frac{w_0^2 \psi_i}{f_c} - \beta\dot{\psi}_i$$

The rate of change of the membrane potential ψ of neuron i, or its velocity, is denoted by $\dot{\psi}_i$. The change in the velocity for the current time step is calculated first. The contribution from input pulses from all pre-synaptic neurons is calculated by the sum of products term $\Sigma w_{ij} o_j$, where w_{ij} is the weight of the connection from neuron j to neuron i, and o_j is the current (axonal) output of neuron j. The current axonal output is always either a 1 or a 0, since action potentials are all or none events. The return force's contribution to the velocity calculation is expressed as $\frac{w_0^2 \psi}{f_c}$, which is the expression we arrived at for $\ddot{\psi}$ previously, divided by f_c. We divide by f_c because we are performing a time slice calculation; in each step of the calculation we are simulating a period of time that is the inverse of the global clock frequency. The final term is the damping factor. The damping constant, β ranges from 0 to 1, and is typically assigned a value of around 0.01. The effect of this parameter is to cause the oscillation to gradually die off, slowly reducing the amplitude, as seen previously in the graphs.

$$\Delta\psi = \frac{\dot{\psi}_i}{f_c}$$

The calculation of the new membrane potential, ψ, is straightforward once we have calculated the new velocity. In a single period of the global clock, ψ will change by the product of the current velocity and the time that we are simulating. Since period is the inverse of the frequency, this sum can be expressed as shown above. At this point we have calculated the new membrane potential. All that remains is to handle the production of action potentials and endro-dendritic interactions.

The mathematical structures described thus far handle axonal inputs from pre-synaptic neurons. Another major feature of the model is direct dendro-dendritic connections. This aspect is accommodated through a simple extension to the delta rule.

$$\Delta \dot{\psi}_i = (\Sigma d_{ij}(\psi_j - \psi_i) + (\Sigma w_{ij} o_j) - \frac{w_0^2 \psi}{f_c} - \beta \dot{\psi}_i$$

Finally, the early caveat that quantum effects cannot exist at physiological temperatures in biological organisms no longer applies in the face of what we know about photosynthesis, and perhaps avian navigation; this work just cited provides the possibility that quantum coherent states could be maintained in an otherwise noisy brain.

7. Quantum mind and the sciences

There is a fundamental question prior to how "God' or "spiritual' entities in general, if such exist, can be cognitively apprehended. This question relates to the structure of knowledge itself, in a context in which - perhaps unfortunately - distinctions between the physical, biological, and psychological have been elided to the point that methodologically all are considered fair game for such approaches as the rather grotesquely-named "big data". Indeed, there does not seem to any attested and principled way of distinguishing the physical and social sciences, and - absent a view of self as object - it is difficult indeed to see how we can create a narrative in which the ebb and flow of spiritual experience, an immediate sense of the noumenal that is physical, emotional and intellectual at the same time, can be encompassed. The "thinglessness", the ineffability suggested by quantum mechanics affords an entrée.

This project is an initial foray into this vast question. As argued below, it seeks to reinstate a notion of the ontological to distinguish between the various "physical" sciences, starting with physics and biology. Indeed, we will produce better science – even in the short term – if, eschewing statistical extravagances, we begin to honour ontological distinctions. It argues that the "cognitive" is best thought of in terms of the principles of cognitive science, rather than as "psychologism", the attempt to describe objective (or at least consensually attested) entities solely in terms of the metaphors or other psychological operations that underpin their presentation to consciousness.

It further contends that the main problem underlying construal of the "spiritual' is the same as that which has destroyed the normative aspect of political experience in favor of an over-used "rights-based" approach. To wit, this is skepticism about the existence of an algorithmically compact level of description, the noetic level, which gives the correct entrée into an area of discourse. Once we have such an entrée, and with it the confidence that we are construing the area veridically, we can be more sure of our spiritual insights, our political calls to arms, and our scientific intuitions.

The noetic stance refers to how a discipline - be it a conventional academic discipline, spiritual perspective, a political call to arms, or a technical skill – should be apprehended. It is distinguishable from the cognitive description, which is a post hoc attempt to map onto the structures of cognitive science including recursion, schemes and so on. The noetic description is more algorithmically compact than the cognitive such. Finally, this summary can be perhaps read as the appropriate interrelation of the cognitive and the noetic stance,

For example, folk psychology – explanation of behaviour in terms of motives, desires and so on – is a noetic description and is psychologically prior to the eschatological hope of eliminative materialism that we can dispense with all these terms through neuroscience. Similarly, as exemplified in the famous break-up scene with Sheldon and Amy in the "Big bang theory", the noetic description of the physical domain is couched in the language of mathematical physics and no description in terms of neurobiology will be more elliptical or veridical – a point Sheldon , the "genius physicist" ,fails to make in this hilarious scene.

Yet even physics requires a causal notion of information; not only can addition of a bit change the area of a black hole, as demonstrated inter alia by Susskind, but the observer can cause state-vector reduction. The noetic level of physics must acknowledge this by including, suitably nuanced, the idea that "a bit gives it". Similarly, the noetic level of biology includes the fact that syntax IS indeed intrinsic to the biology, if (as Searle, following Kripke argued) not the Physics) and the $billions that have gone into projects like the HGP that ignore this fact have largely been wasted. Indeed, one result has been the absurdity of a genome with over 99% thereof, while preserved for millions of years by evolution, somehow seen as "non-coding". Once we accept the existence of different ontological layers in nature – so far the physical and biological - our science gets a lot better.

We come now to the cognitive level – as mentioned the structures of cognitive science including recursion, schemes and so on. This area must also explain the structures of our physical and biological theory, and by the mid explain the mind. Yet it is constrained by the structures of these theories in ways that have not really been made clear. If Einstein could use a fourth-order tensor to produce general relativity, then clearly fmri with its scalars (0 order tensors) is not an appropriate formalism.

Indeed, cognitive science has spawned the area of consciousness studies. This can best be seen as an attempt to extend the objectivist, third-person explanation pattern in science to primitive aspects of subjective experience like visual illusions and sensorimotor experience. Consciousness studies, as exemplified by the work of the late Jim Newman and John Taylor (see our 1997 collection) can be interpreted as providing support for the notion that the phenomena of attention on which we have based so much of the argument of this paper may not hold out any promise for quantum mind. It is indeed the case that attention results in a simple yes/no question, a la maniere de Von Neumann being put to nature; but, argues Taylor, that is simply because the nuclei reticularis thalami gate every access to attention, and will allow only one item in at a time.

Now we come to the punch line of this final argument. If Taylor is correct about the gating mechanism's existence, it may buttress the quantum mind idea in an unexpected way. It may just as well be argued that the structure of the mammalian brain has conformed to the requirement, implicit from Von Neumann, that there be a single yes/no question imminent from whatever process has grabbed the resources of attention. Luckily, this single serial stream of consciousness is what's needed also for dealing with the classical, macroscopic world, and control of action therein.

We can go further. This yes/no question will inevitably change the superposition manifest in the processing stream by removing information, precisely as in state-vector reduction. Given a similarly superimposed object – and such may occur in visual processing in particular – that too will change, as we know occurs in photosynthesis. A bit gives it; information is causal, and the mind has capacities that we will only slowly discover.

8. Summary

The health of the quantum mind hypothesis, even subjected to a robust devil's advocate as here in this paper, is surprisingly robust. We find that it is compatible with best practice in experimental and computational neuroscience, and the classical Von Neumann QM approach. That is not to say that it is proved.

This leads to a surprising hypothesis – that it is those streams of cortical processing that are attended to are those to which the quantum description in terms of superposition, and the Quantum Zeno effect apply. Once a stream is attended to, it will be broadcast to the entire nervous system through a mechanism in which the fast gamma oscillations are modulated – in the manner of FM radio – to convey information to the rest of the nervous system, and this is susceptible to classical description. It makes evolutionary sense that superposition should be reserved for only some processes , the better to exploit the kind of processing now being modeled in quantum computation while yet maintaining the single serial stream of consciousness that we need to engage the world when the wave-function collapses.

The model thus suggests that the brain s hybrid quantum-classical in its assignment of attentional resources. Superposition occurs in a manner that indeed allows the possibility of conscious processing in a manner redolent of quantum computation, and indeed it is not controversial to suggest that many of the finest results in mathematics (a la Poincaré's famous discovery as he got on a bus) seem to arise in consciousness almost effortlessly. Only decohered streams of thought can so appear; once there, they may be broadcast to the rest of the nervous system through the mechanism of consciousness. Our work (Freeman et al, 2008) indicates that this mechanism in discontinuous and has perhaps 10 events per second and in this is consistent with the findings that the conscious moment is around 80 to 100 ms.

Streams of processing that have decohered compete for conscious resources, and the total of 10 events per second are each also a chance for another stream to get on stage and broadcast to the nervous system. It is also uncontroversial to suggest that meditation, where an attempt is made to enthrone one innocuous stream on stage for some time at the expense of more informational-rich streams, has health benefits and seems to allow the gamma oscillations to remain more coherent as the focus of awareness is changed less often.

The consequences for free will are consistent with common-sense intuitions, psychology, and Von Neumann's work in that our freedom may above all be the ability to regulate the focus of our attention, and thus action, over time. It is not claimed that every act is absolutely “free”; however, human beings are capable of modifying the objects that become foci of attention as what initially were acts of will become habits of the nervous system. The degree of this freedom will vary between individuals.

In summary, then a paradoxical situation obtains with respect to attention and superposition. On the one had, attention may be seen as turning a mixture into a superposition (Jiang et al 2009), The counter-argument may be made that this is an artificial situation, with dichoptic stimuli manipulated in a way that does not occur in nature. On the other hand, it seems to be the case that attention decoheres/decorrelates input streams, and this reduces response variability (Mitchell et al, 2009). Yet such processes occur even in dendrites in the hippocampus as a way of sparsifying signals.

The final situation, then is one on which quantum superposition is one of many mechanisms used by the brain. In some cases, it appears to be the case that attention works with only decohered signals as a way of decreasing response variability. Yet decorrelation is used elsewhere in the brain as a way of sparsifying signals, without any attention.

It is therefore plausible to suggest that attention causes some signals to decohere from a state that resembles a superposition, rather than a mixture. Moreover, this process can occur for areas like concept-formation and decision-making as for perception. Our inability to maintain focal consciousness on any particular item for very long may be the result of such consciousness as being dependent on state-vector reduction happening. Human voluntary action, as opposed to involuntary action that is the subject of attention, can be thought of as subject to the Quantum zeno effect and therefore of a different kind to animals' reactions to their environment

The existence of coherent quantum states at physiological temperatures in biological systems is no longer in doubt, which buttresses the position that it is plausible to suggest that attention works as one of many decohering processes in the brain.

Reynolds is currently working on a model in which voltage modulation in ion channels can produce a huge gain change in attention. This may be suitably sensitive to and/or causative of quantum effects in the manner of quantum effects in transistors; also the Ahranov-Bohm effect, inter alia, shows that the electrical field potential can change a quantum state.

In particular, only processing streams of sufficient duration in time to be susceptible of becoming the focus of consciousness seem candidates for superposition and state-vector reduction. Attention may be merely one of many mechanisms in the brain for state-vector reduction; alternatively, it may be the case that we can become aware only of sufficiently durable such processes.

References

Aerts, D. (2009), Quantum structure in cognition. Journal of Mathematical Psychology, 53, 314-348.

Atmanspacher, H., Bach, M., Filk, T., Kornmeier, J., Römer H. (2008), "Cognitive time scales in a Necker-Zeno model for bistable perception". *Open Cybernetics and Systemics Journal* 2, 234–251.

Ball (2011) "Physics of life: The dawn of quantum biology" *Nature* 474, 272-274 (2011) |doi:10.1038/474272a Published online 15 June 2011 News Feature

Branco, Tiago, Beverley A. Clark, and Michael Häusser (2010) "Dendritic Discrimination of Temporal Input Sequences in Cortical Neurons" *Science* 24 September 2010: Vol. 329 no. 5999 pp. 1671-1675 DOI: 10.1126/science.1189664

Bressler DW, Silver MA (2010) "Spatial attention improves reliability of fMRI retinotopic mapping signals in occipital and parietal cortex" *Neuroimage.* 2010 Nov 1;53(2):526-33. doi: 10.1016/j.neuroimage.2010.06.063. Epub 2010 Jul 1.

Bressler DW, Fortenbaugh FC, Robertson LC, Silver MA. (2013) "Visual spatial attention enhances the amplitude of positive and negative fMRI responses to visual stimulation in an eccentricity-dependent manner" *Vision Res.* 2013 Jun 7;85:104-12. doi: 10.1016/j.visres.2013.03.009. Epub 2013 Apr 3.

Cohen M & John H R Maunsell (2009) "Attention improves performance primarily by reducing interneuronal correlations" *Nature Neuroscience* 12, 1594 - 1600 (2009)

de Barros, J.A. & Suppes, P. (2009). Quantum mechanics, interference, and the brain. *Journal of Mathematical Psychology*, 53 (5), 306-313.

Hu, H &Wu, M. (2010) "Current Landscape and Future Direction of Theoretical & Experimental Quantum Brain/Mind/Consciousness Research" *Journal of Consciousness Exploration & Research* |November 2010 Vol. 1 Issue 8 pp. 888-897

Freeman, W., S. O'Nuallain and J Rodriguez(2008) "Simulating cortical background electrocortigram at rest with filtered noise" *Journal of integrated neuroscience*,7 (3)Page: 337 - 344 Sept 2008

Stephan Hoyer, Akihito Ishizaki, K. Birgitta Whaley (2012) "Spatial propagation of excitonic coherence enables ratcheted energy transfer" *Phys. Rev. E* 86, 041911 (2012)

Jiang Y, Patricia Costello ,Fang Fang ,Miner Huang , and Sheng He (2006) "A gender- and sexual orientation-dependent spatial attentional effect of invisible images" *PNAS* vol. 103 no. 45 17048–17052

B. Libet, C. A. Gleason, E. W. Wright, and D. K. Pearl, Time of Conscious Intension to Act, In Relation to Onset of Cerebral Activity (readiness Potential) (1983) *Brain*, 106, 623-642.

JF Mitchell, KA Sundberg, JH Reynolds (2009) " Spatial attention decorrelates intrinsic activity fluctuations in macaque area V4 " *Neuron*, 2009, 63. 879-888

O'Nuallain S "The Search for Mind" (*Ablex*, 1995; 2nd ed *Intellect*, 2002; Third edition *Intellect*, 2003)

O'Nualláin, Seán (1997), "Two Sciences of Mind" (principal co-editor) (*Benjamins*)

O'Nuallain, S CSLI, Stanford and T. Doris(2004) http://bcats.stanford.edu/previous_bcats/bcats04/html/nuallain.html

O'Nualláin, Seán (2009), "Zero power and selflessness" *Cognitive sciences* 4(2).

O'Nualláin, Seán (2012), "God's unlikely comeback" *Cosmos and History* Vol 8, No 1 (2012) The Future of Philosophy Pp 339-382.

O'Nualláin, Seán (2008)"Subjects and Objects" *Biosemiotics journal*, Volume 2, Pp. 239-251

O'Nualláin, Seán and T. Doris (2010) "What is neural resonance for?" *Chaos and complexity letters* 4(2). Reprinted in the collection "mondforce"

O'Nualláin, Seán (2010) "Ask not what you can do for yourself: Cartesian chaos, neural dynamics, and immunological cognition*"* *Biosemiotics* Vol 3 Issue 1, 2010 DOI 10.1007/s12304-009-9070-4

O'Nualláin, Seán and T. Doris (2011) "Consciousness is cheap" Biosemiotics journal DOI: 10.1007/s12304-011-9136-y online; Hardcopy 2012 Biosemiotics journal 5(2) Pp 193-210

Reimers, Jeffrey R.; McKemmish, Laura K.; McKenzie, Ross H.; Mark, Alan E.; Hush, Noel S. (2009)."Weak, strong, and coherent regimes of Fröhlich condensation and their applications to terahertz medicine and quantum consciousness". *PNAS* **106** (11): 4219–4224. doi:10.1073/pnas.0806273106.

Shepherd GM, Grillner S. 2010. Handbook of Brain Microcircuits. New York: *Oxford University Press*

Stapp H (forthcoming, 2013) "Quantum Theory of Mind" In *Contemporary Dualism A Defense* Edited by Andrea Lavazza, Howard Robinson Routledge Studies in Contemporary Philosophy Series" November 2013

Stapp, H (2009) "A model of the Quantum-Classical and Mind-Brain Connections, and of the Role of the Quantum Zeno Effect in the Physical Implementation of Conscious Intent." http://arXiv.org/abs/0803.1633 CH 14 in *Minds Machines &QM* 3rd edition 2009

Suppes, P., J. Acacio de Barros, and G. Oas (2012). Phase-oscillator computations as neural models of stimulus–response conditioning and response selection. *Journal of Mathematical Psychology*, 56(2): 95–117, April 2012.

Tegmark, M. (2000). "Importance of quantum decoherence in brain processes". *Physical Review E* **61** (4): 4194–4206. arXiv:quant-ph/9907009

Zangenehpour S, Ghazanfar AA, Lewkowicz DJ, Zatorre RJ (2009) Heterochrony and Cross-Species Intersensory Matching by Infant Vervet Monkeys. *PLoS ONE* 4(1):e4302.doi:10.1371/journal.pone.0004302

Zhang, P Keith Jamison, Stephen Engel, Bin He, Sheng He (2011) "Binocular Rivalry Requires Visual Attention" *Neuron*, Volume 71, Issue 2, 362-369, 28 July 2011.