

Medical constraints on the quantum mind

Nick Lane PhD

J R Soc Med 2000;93:571–575

Consciousness defines mankind. We each cherish a personal interpretation of what, as our most private possession, our own self, it might be. Our personal preferences carry over. Religious thinkers see consciousness as a direct line to God, philosophers as the crux of Cartesian dualism, linguists as an attribute of the language instinct. Historically, most biologists have preferred to ignore so vague a concept and get on with answering questions with more tangible answers, abandoning the field to the mathematicians and physicists—who lean towards a unifying explanation grounded in the fundamental laws of physics. A modern vogue is to discuss consciousness in terms of macro-quantum effects, and the greatest failing of this approach has been to turn a blind eye to the constraints imposed by medicine.

INVASION OF THE MIND SNATCHERS

Why is consciousness so attractive to quantum physicists? One reason stems from the impression that conventional molecular biology has failed to provide a physical basis for consciousness, therefore it cannot be considered physical in a classical sense. Put another way, since we do not (yet) understand consciousness in terms of familiar biological paradigms, we must look for something more outlandish. This is obviously a logical fallacy, but it is easy to succumb to the feeling that we are missing something. Compare the situation, for example, with that in embryology. We cannot pretend to understand the full workings of fetal development, but no serious biologist would argue that embryology is not ultimately intelligible in terms of gene expression. Not so with consciousness. Few neuroscientists would take a bet that consciousness will finally be explained without reference to the fundamental properties of matter. Unlike the physicists, however, most would at least like to try. Why introduce a new and even more baffling variable unless we really must?

A deeper and more mysterious connection between consciousness and quantum physics lies in the paradox of the observer. We have no way of measuring whether an ice cube feels sad as it melts; we just assume that because it is inanimate and shows no sign of pain it does not. Similarly, we cannot impute consciousness to a computer, a dog, or even another human being, except through reference to our

own experience. The paradox has led some to claim that consciousness can only be verified through its own existence and therefore cannot be a physical force. According to the mysteries of quantum mechanics, the world at large also needs an observer to make things real. Schrödinger's equation showed that the path of a wave-particle is indeterminate. The wave passes simultaneously through any conceivable, and no doubt many inconceivable, positions in space and time. The act of observation is assumed to resolve this underlying state of quantum indeterminacy, bringing about a 'collapse' of the wave function and a measurable outcome. In other words, an observer is necessary to precipitate an event (curiosity killed the cat). But even if we grant that consciousness and quantum mechanics both demand an observer, this seems a whimsical basis for asserting a fundamental link.

A more robust challenge to classical models of consciousness arises from some apparent oddities in our stream of consciousness. Neurosurgical experiments by Benjamin Libet and others indicate that sensory stimuli may take up to half a second to register consciously, and that we then 'refer' our awareness back in time to correspond to when the stimulus was actually applied¹. We 'think' it happened before we became consciously aware of it. Daniel Dennett compares the process with that of visual referral, whereby we project our internal neuronal construct of our surroundings back into the external environment². Thus, just as we perceive that a tree is not inside our head, so we perceive stimuli without an obvious time-lag. Greater difficulties are presented in the conscious initiation of events, which may take even longer. Time-lags as long as a second have been recorded between a conscious decision to flex a finger, say, and the actual muscular contraction¹. Roger Penrose has argued that such delays are incompatible with our sense of the world, and would prevent us from playing ping-pong or participating in a rapid verbal exchange³. Editing out time lapses in these cases cannot be achieved by temporal referral, so Penrose proposes that virtually instantaneous quantum processes must underlie conscious decision-making. But of course, nothing we do is instantaneous. Our response times in ping-pong are compatible with more or less unconscious reflexes; we are seldom consciously aware of sentence construction as we speak; and mental lapses of a few seconds in conversation, while a new point 'sinks in', are a frustratingly common experience. Any real need for quantum processing seems to be missing.

IN TWO MINDS ABOUT THE BASICS

Although consciousness cannot be explained by waves of gene expression (which are far too slow to constitute changes in mood or awareness) there is no *prima facie* reason to suppose that the phenomenon cannot be explained by a combination of classical neurochemistry and massively parallel brain circuitry. This amounts to a statement of faith. So too does the view that consciousness can only be explained by reference to quantum mechanics. I prefer the first view, if only because I am a biologist; but can we begin to discriminate? I think we can. A quantum mechanical theory of consciousness demands some very special properties of matter—macroquantum effects are not to be found all around us, after all—whereas a classical biological explanation demands an extraordinary organization of rather ordinary matter.

If we accept that consciousness is an emergent property of very complex nervous systems we can define a few of the features that must be expressed for the system to generate consciousness. For a classical explanation, this is conceptually simple: all we must do is show that an enormously complex parallel processing system, comprising a hundred billion neuron-equivalents, coupled to a multifaceted and profoundly integrated sensory system, and an ability to remember and learn, is capable of giving rise to consciousness. In other words, we have to prove that consciousness will emerge from a (sophisticated) robot. That might take a while. Meanwhile, what features of the nervous system are needed to support a quantum mechanical theory of consciousness? And what happens when these features break down?

A MIXED OFFERING

For a purportedly unifying theory, there is surprisingly little unity about what might constitute the quantum mechanical mind. The overarching assumption is that consciousness is some type of macroquantum effect, but under this umbrella there is little to choose between a number of possibilities. Macroquantum effects known to occur at temperatures above absolute zero include superfluidity and superconductivity, but neither seems to have an obvious equivalent in the brain. Certainly there is nothing structurally comparable to the delocalization of electrons in a piece of copper wire, or to suggest that the brain can sustain a state of zero resistance to the movement of electrons across space.

The closest we come to superconductivity is the theory of Evan Walker, who argues that the onset of consciousness is produced by the connections of delocalized electrons, which supposedly hop along neurons using cytoplasmic RNA as stepping stones, and 'tunnel' through the synapses (quantum tunnelling refers to the

ability of particles to cross solid barriers)⁴. Walker backs his theory by arguing that synaptic morphology corresponds closely to that predicted by quantum tunnelling calculations, based on the likelihood of post-synaptic firing⁴. But this hardly proves the point. Something similar is obviously required for conventional neurotransmission.

Roger Penrose has put forward similar arguments to those of Walker, proposing that, rather than cytoplasmic RNA, the microtubules provide the intracellular architecture required for quantum delocalization across neurons. Penrose and Stuart Hameroff cite the accumulation of anaesthetic agents within the microtubules as support for their importance in sustaining consciousness^{3,5}. Yet there is little evidence that the action of anaesthetic agents is related to their accumulation in the microtubules rather than, for example, their various effects on ion channel function, calcium influx, synaptic transmission or lipid bilayer integrity. Indeed, despite the long search for a unitary theory of anaesthesia, there is no reason to suppose that all anaesthetic agents work in the same way. They produce a spectrum of activity in the central nervous system, and different agents produce different patterns of activity. Conversely, several agents known to affect the microtubules, such as colchicine (used in the treatment of gout), have no measurable effect on consciousness. The microtubular theory smacks of a physics-orientated 'theory of everything' rather than a serious biological proposition.

The most widely accepted quantum theory of mind was proposed by Ian Marshall in 1989, who argued that consciousness might be a type of quantum coherence maintained by the so-called Fröhlich effect⁶. Quantum coherence is a state of energy delocalization, in which large numbers of particles share a single quantum state, losing their own individuality in the same way that, in an orchestra, the individual violins merge into a single sound. Herbert Fröhlich, one of the pioneers of superstate physics, described a system in which the natural oscillation of proteins could produce a coherent state if metabolic energy was supplied at a constant rate⁷. The metabolic energy is used to pump changes in protein conformation. As the proteins relax, they emit vibrational energy in the form of phonons (the sound equivalent of photons) with their wavelength in phase synchrony. A coherent, non-local order emerges.

The idea is a pleasing one: consciousness is the melody of proteins singing together. Song captures the essence of mood, and the emotional nuances of music seem more akin to the states of consciousness than the circuit boards of a computer will ever do. Graham Cairns-Smith elaborates on the idea, suggesting that fluxing 'musical' wave patterns across the white matter might equate to the stream of consciousness⁸. A nice idea, then, and one that hardly

requires interpretation in quantum terms; but is there any evidence that it actually happens? Sadly not. As Jiri Pokorny put it last year, 'Experimental verification of energy condensation and coherent vibrations... is still missing'⁹. Proteins, *in vivo* at least, just do not seem to vibrate in this way. And if they did, I cannot help wondering whether microwaves and radiowaves from radar systems, cellular telephones, television transmitters, satellites and microwave ovens ought not interfere with consciousness. There is, of course, concern in some quarters that they do, but the supposed effects are explained in terms of the heat generated by microwave irradiation rather than quantum incoherence¹⁰.

EVOLUTION AND QUANTUM BROADCASTING

For all their disparity, these quantum theories of mind are linked in one important respect, allowing a more medical commentary. All require molecular stepping stones of the sort posited by Walker. Walker's own theory requires that cytoplasmic RNA should be positioned at 100 Å intervals along the axons, with glycosylated proteins bridging the synaptic gaps. Similarly, Penrose and Hameroff require intact microtubules, while the Fröhlich effect is dependent on tiny gaps between vibrating proteins to produce a coherent state, whether these proteins are in the microtubules or in the cell membranes. In other words, a dedicated, repetitive, microscopic infrastructure seems to be necessary to generate a state of quantum coherence, via discrete 'broadcasting' steps.

From an evolutionary perspective, this dedicated infrastructure must have evolved from pre-existing structures, and these structures must have had sufficient evolutionary plasticity to permit adaptation without seriously compromising their existing function. This is an important point that applies more to quantum theories of consciousness than to 'classical' theories. From a classical point of view, if consciousness is an emergent property of highly organized nervous systems, fashioned by language and cultural evolution, then there is no requirement for a separately evolved infrastructure to sustain consciousness, merely sufficient neuronal plasticity. But from a quantum broadcasting point of view, the machinery required to sustain consciousness must have evolved without compromising the computing function of the nervous system. Cells as highly specialized as neurons, which have evolved to a high degree of complexity even in organisms with little recognizable consciousness, cannot have much remaining flexibility to support the evolution of a new infrastructure for consciousness. In the same way, a hand, perfectly adapted to perform complex manipulative tasks, cannot turn into a flipper for swimming without jeopardizing its original skill. For these reasons, Cairns-Smith argues that

consciousness may not arise from the highly adapted neurons at all, but rather from the (presumably) less specialized glial cells—oligodendrocytes in the white matter, or astrocytes in their support network throughout the brain⁸.

SETTING THE SNARE

Before progressing further, we should define consciousness more precisely. The word has a tendency to mean all things to all men. I shall try to keep a broad perspective, while focusing the term sufficiently to allow some specific questions to be asked. For consciousness, then, I mean awareness or sentience, both of our own self and of our relationship to the world around us. Within this general definition, I will follow the standard medical subdivision of consciousness into level and content.

The level of consciousness is easily graded by means of scales such as the Glasgow Coma Scale, encompassing the degrees of drowsiness from a clear mind, through stupor, to coma. The content of consciousness is more difficult to quantify. Traditionally, the content is considered to be the sum of cognitive plus affective domains, but this definition may be a little too wide to allow us to draw meaningful conclusions. Instead, I will consider the extent to which people with apparently unclouded consciousness are truly aware of themselves and of their interactions with the environment.

The level of consciousness reveals little of mechanism. Patterns of sleep and wakefulness are controlled by the reticular activating system (RAS), which regulates the overall activity of the cerebral cortex. A threshold electrical activity (around 40 Hz according to Francis Crick) is required to maintain wakefulness, irrespective of the precise neurological mechanism. Focal injury to the RAS, as in brainstem stroke, depresses overall cortical activity and will often lead to coma, whereas focal injury to the cortex rarely does. Serious perturbations in cortical function leading to loss of consciousness, such as epilepsy or syncope, usually involve concerted shifts in the electrical activity of the entire cortex. Little is known about the involvement (or otherwise) of a microscopic infrastructure of mind in these conditions.

Some familiar conditions in which the state of consciousness is altered rather than depressed are also unhelpful in terms of discriminating between quantum and classical theories of mind. A good example is schizophrenia. By definition, schizophrenia involves altered states of consciousness. To the extent that it can be controlled with antipsychotic drugs, schizophrenia obviously involves neurotransmitter systems. But neurotransmitters are upstream in the communications loop. Depolarization of a neuron by a neurotransmitter is required for the neuron

to fire as part of a conventional neural network, but is also likely to be required to stimulate the metabolic machinery needed to pump phonons and start proteins singing. The difficulty with schizophrenia is that the detailed pathophysiology remains obscure. Neuroimaging studies suggest that, at a gross level, the disease is associated with enlarged ventricles and cerebral atrophy, but consistent structural alterations at the subcellular level have not been reported. Similar difficulties arise in the interpretation of other conditions, such as delirium or manic depressive disorder. Everything 'looks' fine.

Given the limitations of our present understanding, the best place to begin a structural analysis of consciousness seems to be neurodegenerative disease. Here, at least, we have a general idea of which microscopic structures degenerate. Admittedly, very few studies have set out to examine consciousness as such; we will need to read between the lines a little. Specifically, we are looking for a correlation between damage to the microscopic infrastructure, comprising the microtubules, astrocytes or oligodendrocytes, and changes in awareness of self or environment.

THREE WAYS OF LOSING YOUR MIND

The most obvious example of a specific attack on oligodendrocytes in the white matter is multiple sclerosis (MS). If the white matter sustains consciousness we might expect to find an erosion of awareness progressing in step with motor or cognitive decline, or with demyelination as measured by magnetic resonance imaging, but this kind of relationship does not emerge from the data available. In the absence of direct studies, a reasonable surrogate for consciousness in MS is the ability of patients to grade their own disability and quality of life. This skill requires a close awareness of self and of interactions with the environment. Several studies, examining a total of a few hundred patients, have correlated self-assessments with blinded neurological ratings of health status^{11,12}. Patients and neurologists agreed to within one point on the expanded disability status scale (EDSS) in 72–86% of cases. The inter-rater agreement between neurologists is also about 85% (again on the basis of a one-point difference on the EDSS)¹³, so it seems that MS patients do have a clear-headed view of their predicament, despite possibly extensive demyelination.

A progressive condition in which self-awareness is unquestionably lost is Alzheimer's disease. In the final stages of dementia, many patients show no glimmer of self-recognition in a mirror, even if coaxed verbally. The early symptoms of Alzheimer's disease correlate with the burden of neurofibrillary tangles in the neocortical association areas of the temporal lobe, but by this stage there may be

numerous tangles in other parts of the cortex. Tangles are but the ghosts of microtubules. If the microtubules really are critical to consciousness, and are lost in large numbers at the outset of Alzheimer's disease, we might expect self-awareness to decline early on. It does not. One study, based on conversational analysis, showed that even patients with advanced Alzheimer's disease (mean Mini-Mental State Examination score of 10.65) continued to use first-person constructions freely and coherently, were aware of their cognitive deficits, and responded to changes taking place during the conversation¹⁴. The authors concluded that self-awareness persists into the middle and late stages of Alzheimer's disease. Other studies suggest that perceptions of memory impairment are similar in early Alzheimer's disease and normal ageing¹⁵.

Perhaps the brain learns to compensate for gradual loss. A more dynamic example may illustrate the possible role of astrocytes in sustaining consciousness—acute ischaemic stroke. Here, the token evidence is intriguing and might be open to a quantum interpretation. Focal stroke normally produces focal necrosis and focal deficits, but may induce widespread astrocyte depolarization and migration, disrupting the finely tuned network. Is there then a discrepancy between changes in awareness and overall neurological deficit? There may be. In 1995, James Grotta and Patti Bratina described the subjective experiences of 24 patients who recovered dramatically from stroke during a thrombolysis trial¹⁶. Most patients recalled the exact circumstances of the onset of their stroke, yet seemed unaware of the magnitude of their neurological deficit. Strikingly, only 6 of the 24 patients were aware of their improvement, dramatic as it was, when it happened. The authors commented that 'most patients seemed peculiarly unaware or blasé about their deficit and improvement'. Of course this may not have anything to do with a sluggish recovery of the astrocyte network, but these data are not incompatible with Cairns-Smith's idea that consciousness might be a product of quantum delocalization in astrocytes.

WHY SHOULD WE CARE ABOUT QUANTUM THEORIES OF CONSCIOUSNESS?

Given the importance of altered conscious states in disease, and the tools now at our disposal, perhaps it is time for the medical profession to take a more focused look at consciousness. If diseases of consciousness turn out to be a quantum problem, we will need to bring a radically different approach to treatment. The puzzling lack of awareness in stroke shows that the idea of a quantum mind is not invalidated by current medical evidence. The consciousness question seems to me to be approachable

with current technology, and is too important to leave to the speculations of physicists.

REFERENCES

- 1 Libet B. The neural time factor in conscious and unconscious events. *Ciba Found Symp* 1993;**174**:123–37
- 2 Dennett D. *Consciousness Explained*. Harmondsworth: Penguin, 1993
- 3 Penrose R. *Shadows of the Mind*. Oxford: Oxford University Press, 1994
- 4 Walker EH. Quantum mechanical tunneling in synaptic and ephaptic transmission. *Int J Quantum Chem* 1977;**11**:103–27
- 5 Hameroff S. Anesthesia, consciousness and hydrophobic pockets—a unitary quantum hypothesis of anesthetic action. *Toxicol Lett* 1998; **100–101**:31–9
- 6 Marshall IN. Consciousness and Bose–Einstein condensates. *New Ideas in Psychology* 1989;**7**:73–83
- 7 Fröhlich H. Long-range coherence and energy storage in biological systems. *Int J Quantum Chem* 1968;**2**:641–9
- 8 Cairns-Smith AG. *Evolving the Mind*. Cambridge, UK: Cambridge University Press, 1996
- 9 Pokorny J. Conditions for coherent vibrations in the cytoskeleton. *Bioelectrochem Bioenerg* 1999;**48**:267–71
- 10 D’Andrea JA. Behavioral evaluation of microwave irradiation. *Bioelectromagnetics* 1999;Suppl 4:64–74
- 11 Gulick EE, Cook SD, Troiano R. Comparison of patient and staff assessment of MS patients’ health status. *Acta Neurol Scand* 1993;**88**:87–93
- 12 Verdier-Taillefer MH, Roullet E, Cesaro P, Alperovitch A. Validation of self-reported neurological disability in multiple sclerosis. *Int J Epidemiol* 1994;**23**:148–54
- 13 Amato MP, Fratiglioni L, Groppi C, Siracusa G, Amaducci L. Interrater reliability in assessing functional systems and disability on the Kurtzke scale in multiple sclerosis. *Arch Neurol* 1988;**45**:746–8
- 14 Tappen RM, Williams C, Fishman S, Touhy T. Persistence of self in advanced Alzheimer’s disease. *Image J Nurs Sch* 1999;**31**:121–5
- 15 Brustrom JE, Ober BA. Predictors of perceived memory impairment: do they differ in Alzheimer’s disease versus normal aging? *J Clin Exp Neuropsychol* 1998;**20**:402–12
- 16 Grotta J, Bratina P. Subjective experiences of 24 patients dramatically recovering from stroke. *Stroke* 1995;**26**:1285–8