I research, therefore I am?

A purely scientific understanding of consciousness remains elusive, but the search for its neurological foundation continues

Philip Hunter

Consciousness is the heart of human existence, yet it has proven to be an elusive subject for scientific research and analysis. Its study has largely been left to philosophers, writers and artists who have spent centuries exploring the meaning of life. Existential questions such as ‘why am I me?’ are, by their nature, difficult to answer with empirical analysis. It is therefore perhaps unsurprising that natural science has found it difficult to add detail to René Descartes general principle: *cognito ergo sum*. From some quarters—particularly religious ones—there has also been resistance to the ‘profane’ tools of science probing the ‘sacred heart’ of human consciousness; Pope John Paul II is reported to have proclaimed during a conference at the Vatican in the 1980s, that while scientists can have the brain, the mind belongs to God (Lane, 2009).

Existential questions such as ‘why am I me?’ are, by their nature, difficult to answer with empirical analysis

The separation of mind and brain is fundamental to the study of consciousness, and requires elucidation of the relationship between the biological mechanisms of brain function and the higher-level processes—such as emotion or reason—that are enabled by them. Although the ultimate meaning of human existence remains elusive—assuming that there is one—research has begun to unravel the physical mechanisms that enable consciousness, by using brain imaging techniques together with an increasing understanding of the neuronal architecture of the brain. This approach has informed the quest to identify the neural

correlates of consciousness (Crick & Koch, 1990) that were first defined by Christof Koch, Professor of Biology and Engineering at the California Institute of Technology, and Francis Crick, who is better known for his codiscovery of the DNA double helix. These correlates are defined as the minimal set of neuronal mechanisms required for a particular conscious function or ability. Their identification would be useful for assessing levels of consciousness in animals, infants and adults with brain damage or disease, who are unable to express what they are feeling in words.

Koch explained that although neuronal mechanisms are necessary for consciousness, it is the information that they transmit and integrate that actually brings it into being; an idea that was first advanced by Giulio Tononi (2004), to which Koch has contributed. This theory, according to Koch, states that consciousness depends on the ability to coherently integrate information, irrespective of the information type. This has important implications: that consciousness is independent of language, vision or any other specific form of information, and can exist in any system with the required structure. From this, Koch has concluded that consciousness is not limited to humans, but could exist in a machine and many animals—a view that has led him to become a vegetarian. According to this theory, aspects of recent human evolution and culture—including language—are products of consciousness, rather than requirements for it.

According to Naomi Eilan, Director of the Consciousness and Self-Consciousness Research Centre at the University of Warwick, UK, the information flows and synchronization that enable consciousness

...consciousness is independent of language, vision or any other specific form of information, and can exist in any system with the required structure

are nevertheless dependent on the physical structure of the brain. “It’s mad to think that consciousness and the brain are independent [of one another],” she said. The extent of their interdependence, however, is hotly debated. According to Eilan, scientists generally take one of three positions on the subject: “[O]ne view [is that] the brain will tell us what consciousness is, but at the other [extreme] there’s the view that it’s neither here nor there and that the brain is one thing and consciousness quite another. I’m in the middle, where the brain presupposes consciousness but does not explain it. The brain will not tell you what consciousness is, but it does tell us how various aspects of it work.”

In evolutionary terms, consciousness is a phenotype with an underlying genotype. It is therefore subject to the pressures of natural selection, which act at the level of the genes encoding neurological structures. These structures probably first emerged in animals for specific functions and only later became integrated into a universal continuous consciousness, according to Antonio Damasio, Director of the Brain and Creativity Institute at the University of Southern California, Los Angeles, USA. “I believe most of the phenomena of consciousness emerged as a result of specific brain complexities which were required by an improved life regulation,” he said. “But once basic consciousness emerged, its adaptive value was so remarkable that natural selection made it prevail.”

© MedicalRF.com/Corbis

It is now almost universally agreed that consciousness is linked to the coherence of the electrical states of different groups of neurons, but the mechanisms underlying this are still disputed. Some researchers, such as the American psychologist Stuart Hameroff, argue that quantum mechanics must be involved through a phenomenon known as quantum coherence, which would correlate the states of subatomic particles across the brain (Hameroff, 1994). This hypothesis is questioned by others, but consciousness does seem to be generated by synchronized oscillations in the electrical states of neurons in different areas of the brain, as detected by electroencephalography.

...aspects of recent human evolution and culture—including language—are products of consciousness, rather than requirements for it

For electrical coherence to occur, structures that can synchronize disparate brain regions must have evolved at some stage.

Prime candidates are the calcium-binding (calbindin) positive cells in the thalamus—a structure that relays signals relating to spatial and motor awareness between the cerebral cortex and midbrain, as well as regulating sleep and alertness. Calbindin proteins modulate the flow of calcium within neurons, affecting synaptic activity and neuronal activation. The calbindin positive cells in the thalamus can thereby facilitate high-frequency oscillations in different regions of the cortex (Joliot *et al*, 1994). According to Koch, such cells might be crucial messengers for consciousness, enabling effective interactions between different cortical regions. In support of this, when calbindin positive thalamic cells lose their ability to activate other neurons—as a result of injury or disease—these patients are in a vegetative state even when their cortical tissue is intact.

The above observation is an example of how the study of brain-damaged patients can shed light on the underlying mechanisms of consciousness. It also led to the development of a possible treatment for such patients. Niko Schiff and

colleagues found that deep-brain electrical stimulation of the central thalamus restored some behavioural responsiveness in a patient who had been minimally conscious for 6 years (Schiff *et al*, 2007).

In evolutionary terms, consciousness is a phenotype with an underlying genotype

Sudden recovery from prolonged states of minimal consciousness can also indicate which structures of the brain are required for normal states of awareness and activity. A study by Henning Voss and colleagues in New York and New Zealand found evidence that axonal regrowth led to the dramatic recovery of speech in a patient who had been in a minimally conscious state for 19 years after a road accident in 1984 (Voss *et al*, 2006). Axonal regrowth was shown by use of a new imaging technique, Diffusion Tensor Imaging (DTI), as the patient quickly regained the ability to talk with increasing fluency over a period of a few days. DTI is a form of magnetic resonance imaging (MRI) that forms images by observing the Brownian

motion of water molecules. It showed axons sprouting from neurons in the intact part of the cortex. Further evidence came from positron emission tomography scans of the same brain areas, showing increased glucose metabolism that seemed to be linked with the neuronal regrowth, which would explain the patient's recovery.

Sudden recovery from prolonged states of minimal consciousness can also indicate which structures of the brain are required for normal states of awareness and activity

Koch noted that this and other neuroimaging studies of vegetative state or minimally conscious patients have found that even a prolonged loss of consciousness can be reversed. Another important question is whether consciousness can be detected when patients are in a persistent vegetative state and cannot communicate verbally or by movement. Observing responses to stimuli in specific brain areas is not sufficient to assess the level of consciousness, as these reactions can occur without consciousness, as they do during sleep.

To address this question, Adrian Owen and colleagues in the UK and Belgium conducted an ingenious experiment with a female patient who was incapable of responding to external stimuli. The researchers asked the patient to imagine playing tennis while they observed her in an MRI scanner. They found that the same cortical areas were activated as when normal individuals perform the same task (Owen *et al*, 2006). Koch points out that the task could not have been performed by unconscious processing of external stimuli, as the patient was only imagining the action.

This result does not conclusively show that the patient was conscious, as the neural correlates of thought processes remain unclear. However, the above observation suggests that the patient might be more than minimally conscious, as she had been diagnosed. Owen's colleague, Steven Laureys, has since been involved in several studies indicating that almost half of people with disorders of consciousness are wrongly diagnosed as being in a vegetative state. According to Laureys, these findings might indicate that some patients have had their life support turned off as a result of such

misdiagnoses, even though they could have subsequently regained consciousness, to some extent.

At present, this suggestion is controversial and does no more than provide a source of acute uncertainty for the families and doctors of such patients. In future, however, brain imaging could help clinicians to make more accurate diagnoses. In one of the most striking examples so far, Christine Ecker and colleagues at King's College and University College, London, UK, have identified characteristic structural features of the brain that can be used to reliably diagnose autism spectrum disorder (ASD; Ecker *et al*, 2010). They used MRI to measure certain brain features in patients with ASD—such as the thickness and degree of folding in particular areas of the cortex—and combined this information to obtain a correlate picture of the brain changes that are unique to ASD. This was an important development, as ASD is complex and associated with many cortical features that have previously been difficult to categorize. By using this new approach, ASD can now be clearly distinguished from other conditions and accurate, rapid diagnosis in early life could make a notable difference for sufferers.

“the study of consciousness is now moving from the domain of philosophy and metaphysics into the empirical domain of science”

This work might also guide research on the genetic and neurological bases of ASD, by identifying the anatomical features and ultimately individual proteins that are implicated in the disorder. Some of the cortical regions involved seem to be unique, which resonates with more general research into various aspects of consciousness.

This type of applied research into consciousness is at the opposite end of the spectrum to the ongoing attempts to unite the scientific and philosophical approaches to studying the subject. Indeed, as Koch noted, “the study of consciousness is now moving from the domain of philosophy and metaphysics into the empirical domain of science.”

This move is creating the ultimate challenge for multidisciplinary research; it requires the interaction of two fields with little history or experience of collaboration. According to Bill Brewer, who

specializes in the philosophy of perception at Warwick University, UK, “this is a massive philosophical question in itself: what is the relationship between philosophical and scientific approaches to mental phenomena in general and conscious experience in particular?” Brewer believes that such efforts will ultimately prove successful; “My own opinion, having been part of a number of interdisciplinary projects concerned with such matters, is that there is no general abstract recipe for fruitful collaboration. It requires long periods of open-minded mutual learning, teaching and open-ended discussion of very specific questions and issues in the various different fields until it eventually becomes clear that a good deal in the disciplinary boundaries is arbitrary and all parties are actually concerned with the same fundamental problems in ways that merge into a continuum of approaches.”

Whether this will lead to a full understanding of consciousness and whether science has something to say about the ‘meaning’ of our existence remains to be seen.

REFERENCES

- Crick F, Koch C (1990) Towards a neurobiological theory of consciousness. *Semin Neurosci* **2**: 263–275
- Ecker C *et al* (2010) Describing the brain in autism in five dimensions—magnetic resonance imaging-assisted diagnosis of autism spectrum disorder using a multiparameter classification approach. *J Neurosci* **30**: 10612–10623
- Hameroff SR (1994) Quantum coherence in microtubules: A neural basis for emergent consciousness? *J Consciousness Stud* **1**: 91–118
- Joliot M, Ribary U, Llinas R (1994) Human oscillatory brain activity near 40 Hz coexists with cognitive temporal binding. *Proc Natl Acad Sci USA* **91**: 11748–11751
- Lane N (2009) *Life Ascending: the Ten Great Inventions of Evolution*. New York, NY, USA: WW Norton
- Owen AM, Coleman MR, Boly M, Davis MH, Laureys S, Pickard JD (2006) Detecting awareness in the vegetative state. *Science* **313**: 1402
- Schiff ND *et al* (2007) Behavioural improvements with thalamic stimulation after severe traumatic brain injury. *Nature* **448**: 600–603
- Tononi G (2004) An information integration theory of consciousness. *BMC Neurosci* **5**: 42
- Voss HU *et al* (2006) Possible axonal regrowth in late recovery from the minimally conscious state. *J Clin Invest* **116**: 2005–2011

Philip Hunter is a freelance journalist in London, UK.

EMBO reports (2010) **11**, 827–829.
doi:10.1038/embor.2010.162