1 Inner space

SUSAN GREENFIELD

Consciousness: the inner space of the brain

Surely, the ultimate question is, not just for scientists, but also for any human being: 'How does the brain generate consciousness?' Consciousness, to date, has eluded formal definition. Perhaps the easiest would be 'the experience that you are going to lose this evening when you go to sleep, or when an anaesthetist bears down upon you'. Perhaps, for the time being, we could work with the informal idea that it is your own personal world – a world that only you can experience at first hand. If we are to approach, as scientists, how the brain generates this unique inner state, then we must assume that consciousness is generated by, for and of the brain. And yet, any scientific explanation must include the quintessential feature of consciousness: subjectivity.

Before we go any further, we should state what we are *not* going to attempt to do in this chapter. We will leave to one side the issue of how the physical matter of the brain generates the subjective state. We are not, in other words, going into the glamorous water into wine conversion problem of consciousness. Therein lies madness. Philosophers talk themselves round and round that question. What I would like to do instead is look for a correlation of consciousness. I am a pragmatic scientist, and I want to ask questions about consciousness on which we might make some progress. So what we are going to try and do is find whether there is something in the brain, something physical, some brain state that will match up with, or correlate with, different types of consciousness, different ways you feel.

How can we make progress? I would like to concentrate on finding a *neural correlation* of consciousness, one that is both necessary and sufficient. Let us

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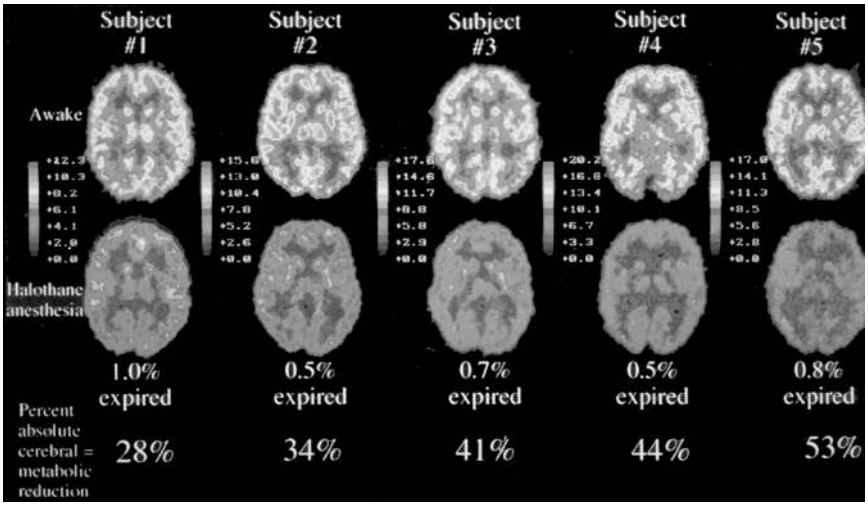

FIGURE 1.1 Effects of loss of consciousness with analysis of activity in different brain regions.

first therefore draw up a list of what we will require of the brain, if it is going to generate different types of consciousness.

One idea is that each brain region has its own set function – that the brain is really a collection of mini-brains. With this idea we would simply enter onto an infinite regress, however, where we miniaturised the problem, but did not solve it. Instead, we know that the brain functions rather like an orchestra, where different instruments of course each play a different part, or a bit like a stew or some complex food, where each ingredient makes its own contribution. With the advent of scanning techniques, this holistic organisation has become clear. Consider, for example, what such techniques have revealed about language and the brain. In one test, the subject was asked to view words passively, listen to words, speak words or generate verbs – all fairly subtle. Even a single 'function' like language, however, is, in terms of the brain, an umbrella for many different processes. Scans show that the brain divides up different aspects of the task to constellations of different brain regions. The important message here is that there is no single brain area lighting up for language, and there is certainly, even for aspects of language, no single brain area that is active. Instead, these regions are, again, working like instruments in an orchestra or like ingredients

of some complex dish. They operate all together – the whole is somehow more than the sum of its parts.

This holistic organisation certainly applies to consciousness. If you look at brain imaging again and give subjects anaesthesia, destroying their consciousness, then you can see that there is no single area that shuts down. There is no one area of the brain that has just stopped. There is no centre for consciousness.

If there is no centre for consciousness, where is it? It must arise from the participation of non-committed, non-specialised brain cells, or groups of brain cells that for one moment enter into some kind of state or configuration that allows for the generation of consciousness. A central factor in this model is that the degree of consciousness therefore is determined by the *size* of an assembly of neurons – the greater the *size* of the assembly, the higher the degree of consciousness. Since an assembly will have to vary dynamically, we need to look at the factors that will influence its formation, and therefore determine your degree of consciousness at any one moment.

Perhaps the most obvious issue is the degree of connections there in the first place. Let me compound that by introducing another concept. One source of resistance to this model is the common assumption that consciousness must be all or nothing. A little reflection shows us otherwise. Consider the consciousness of non-human animals. Is a dog conscious? If so, what is the difference between it and us? And how does that give us a clue as to what enables our brains to generate different degrees of consciousness?

More controversially, let us extend the riddle to that of the foetus. It is still a commonly held belief that the foetus is not conscious – if it is not conscious, when does it become conscious? When does a baby become conscious? At the time of birth? Fine, but when is a baby born? Some babies are born prematurely, and they are conscious. You would not for two months just ignore the baby in the incubator in the hospital and say, 'Ah, forty weeks are up, it is going to be conscious today. Now we can go and visit.' You would be Even less likely to do it after the birth and say, 'Ah, a few weeks have gone now, it is coming up to six months from birth, it might be conscious.' Or is it the manner of birth – squidging down the birth canal? That is tough on babies born by Caesarean section: because they will never be conscious. Clearly the manner of birth and the timing of birth, because they are so variable nowadays, cannot be the trigger for consciousness.

FIGURE 1.2 Shows that you often only see one thing at a time.

I think the big problem here, and one that stops us developing the idea, is normally that we think of consciousness as all or nothing. I myself defined it as 'the thing you are going to lose tonight'. But what if I was wrong? What if instead of consciousness being all or none, consciousness grew as brains grew? What if, therefore, it gradually developed? So a foetus would be conscious, but not *as* conscious as a child, and a baby conscious but not *as* conscious as an adult, and a cat conscious but not *as* conscious as a primate, and a monkey conscious but not *as* conscious as a human. If consciousness grows as brains grow, that raises an interesting issue. As an adult human being, we are more conscious at some times than at other times. If you think about it, we talk about 'raising' our consciousness or 'deepening' our consciousness – it does not matter which

way you go, you can go up or down; consciousness is then something that is variable. If that is the case, then science finally has a purchase on the problem – because, instead of looking for some magic brain region or gene or chemical, we can look for something that varies in degree, something we may be able to measure. We can look for something conceivably that ebbs and flows within your brain, something that changes in size within your brain. Now, what could that be?

Let us look at the properties of consciousness, therefore. We have seen there is no special brain region for it. It is spatially multiple, with many brain regions contributing to it. But you only have one consciousness at any one time. I would like to think that you only see one thing at one time. Even when what you see is a very complex pattern, you will still see it as a single pattern. In Fig. 1.2, there is both a young girl and an old crone – which is the true representation? Both are valid, but looking at it one way negates, for a moment, the other. You can only 'perceive' one at a time, rather than 'see'.

As a final item on our list, consider that we are always conscious of something. When we become very sophisticated of course we have an inner hope or fear or dream or thought or fantasy: you can close your eyes and have a trigger of consciousness occurring internally. In the simplest form we have momentary states triggered by the changing input from the sensory world.

A metaphor for consciousness

Let me suggest a metaphor to account for how these properties might be accommodated in the brain. Imagine a stone falling in a puddle. When a stone is thrown, just for a moment, it generates ripples that are highly transient, and that are vastly bigger in their extent than the size of the stone itself; and those ripples can vary enormously according to the size of the stone, the height from which it is thrown, the force with which it is thrown and the degree of competition from other stones coming in (see Fig. 1.3). All these different factors will determine the extent of the ripples.

What I am suggesting is that in the brain you do have the equivalent of puddles: hard-wired little circuits of brain cells, as we have seen, riddling your adult brain, that are sometimes accessed, sometimes not. The equivalent of throwing the stone would be, for example, me seeing my husband. Nerve impulses from my eyes would then go through certain parts of my brain and start activating the circuitry that is related purely to experiences with my husband. Still I

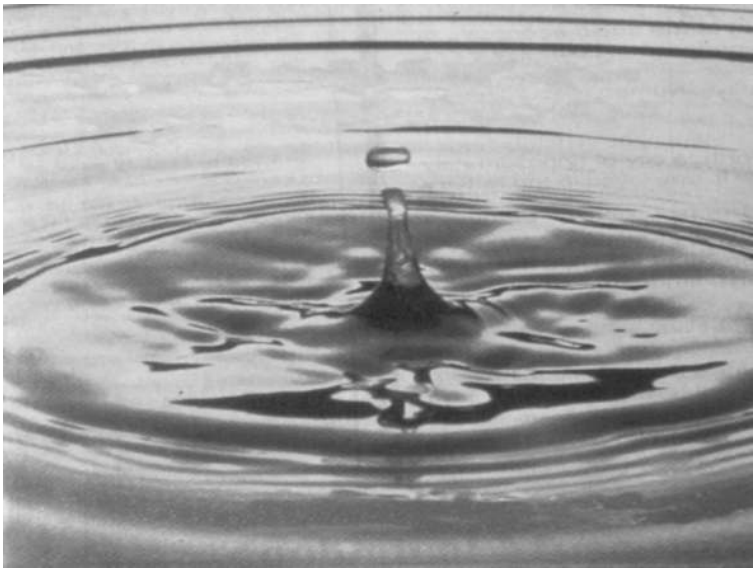

FIGURE 1.3 Metaphor for a transient neuronal assembly in the brain.

would not be conscious of him. What would happen then? How could we now get ripples occurring in the brain? Amazingly enough, you have something very special in your brain: not just circuits, but chemical fountains. These chemical fountains actually emanate from primitive parts of your brain and access the cortex and many other areas. The cortex is the outer folded layer of the cerebrum. These are the chemicals that are targeted, for example, by Ecstasy or by Prozac, and these are the chemicals that vary during sleep–wakefulness and during high arousal: they fulfil a very special function, in that they put brain cells on red alert.

So, imagine I see my husband. That is the equivalent of throwing the stone. It activates a hub of hard-wired circuitry, established, in the example of my husband, over long experience of married life. If that is coincidental with a group of brain cells being sprayed upon by a fountain of chemicals related to arousal, then the process would predispose those adjacent cells to be corralled up just for that moment; and just for that moment a very active hub will then activate a much, much bigger group of cells; and that big group of cells will determine the extent of my consciousness at that particular moment. That is the model.

A correlate of consciousness?

An increasing body of experimental and other data suggests the stone-and-ripple model is correct. Some of these data have come from Arnivam Grinvald's laboratory at the Weizmann Institute in Israel. I was very fortunate in being able to visit Grinvald's lab and see his important experiments at first hand. He showed me experiments – not on humans, because the research is invasive – using optical dyes that register the voltage of brain cells. Arnivam showed that, even to a flash of light, there is indeed the neuron equivalent of ripples. These ripples – in this particular experiment to a simple flash of light – extend over 10 million neurons, and they extend very quickly, in about 230 milliseconds, less than a quarter of a second. So this means that in your brain you can have tens, even hundreds, of millions of brain cells corralled up into a highly transient working assembly in less than a quarter of a second, just like a ripple. That, in my view, is the best place to look if we are trying to find out about consciousness.

You have up to 100 000 connections onto any one brain cell. If you were to count them at one a second in the outer layer of the brain, in the cortex alone, it would take you 32 million years. If you wanted to work out the permutations and combinations, it would exceed the particles in the universe.

Connections are really important, because they work at a level mid-way between genes and larger brain regions. Why are they so important? Let us go back again to see where they fit in. The number of genes you have is about 30 000. Even if one makes the really unlikely assumption that every single gene in your body accounted for a brain connection – even if that was the case – here you have about 10^{15} brain connections (that is 10 followed by 15 zeros), so you would be out by 10^{10}. You just do not have enough genes to determine your brain connectivity. People who hope one day to manipulate their genes so that they are good at housekeeping, or being witty or not being shy – all these other things that people fondly hope that they can start targeting with molecular biology – should, I think, bear this number in mind. There is far more to your brain than your genes.

I am not saying for one moment that genes are not important, and I am not saying that if a gene goes wrong you will not have some kind of terrible malfunction – of course these things can happen: but there is far more above and beyond the single genes that is really important. We are talking here, of course, about nurture, not just nature. The most marvellous thing about humans

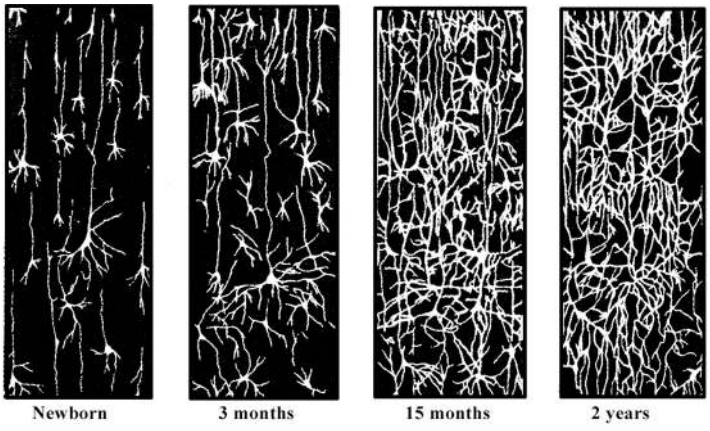

FIGURE 1.4 Development of the connections in the first two years of life.

beings and other animals is that as we grow our brain connections grow as well. So, although we are born with pretty much all the brain cells we will ever have, it is the growth of the connections after birth which accounts for the growth of our brains (see Fig. 1.4).

Why is this post-birth growth so important? The answer, and the reason I have been emphasising that genes do not determine brain connections, is that, if brain connections are growing as you are growing, then your brain will mirror what happens to you. Even if you are a clone (that is to say, even if you are an identical twin) you will have a unique configuration of brain cell connections that will shape your reactions to things and will mirror your experiences; so you will see the whole world in terms of your personalised brain cell connections.

Brain plasticity

Let us look at some evidence for this. London taxi drivers, as you may know, are masters at remembering. Every single working day they have to remember how to get from one place to another – and not only the configurations of the streets; they also have to remember the one-way systems and how best to navigate round the streets of London. In one particularly fascinating study, scientists scanned the brains of London taxi drivers and compared them with scans of other people of a similar age. Surprisingly enough, they found that the hippocampus was enlarged in taxi drivers compared to people of a similar

age. Now, could it be that people with an enlarged hippocampus are disposed to become taxi drivers? No, because it was found that the longer they had been plying their trade, the more marked this structural difference was. It was what they were doing, their daily activities, that had physically changed their brains.

Your brain will relate to whatever you do. Consider another very simple example: in another study, human subjects were asked to practise five-finger piano exercises. With physical practice, even within five days, there was an enormous enhancement in areas of the brain relating to the digits, just by doing five-finger piano exercises. More remarkable still is that there was a comparable change in brain territory when people were not practising the piano, but were *imagining* they were practising. In real terms you can see that brain territory is reflecting even mental processes, and it is physically measurable.

Nowadays few subscribe to the silly distinction between mental activity and brain activity, as if airy-fairy thoughts were something that floated free, beamed in from Planet Zog. Everything that happens to you, everything you are thinking, has some kind of physical basis rooted in your physical brain. What we are realising now is how exquisitely sensitive the brain is to your experiences and what you do, and therefore how it makes you the individual you are.

Even into old age, one's brain remains continuously 'plastic'; that is to say, it is constantly dynamic, it is constantly evolving and changing, mirroring whatever happens to you. Sadly, what can be created over a lifetime can also be destroyed. Old age often brings with it a reduction in brain connectivity, and consequent losses in inner life and outward functioning. I would like to stress that dementia (which is a name for the confusion and memory loss which characterise Alzheimer's disease) is *not* a natural consequence of ageing; however, when it does strike, it is because the branches with which brain cells make contact with other cells have atrophied. Neurally as well as mentally, therefore, if one becomes senile, it is almost like becoming a child again. As the brain connections are dismantled, you reverse development; and where, in childhood, the world means more and more, so this time the world means less and less. 'Means less': that is to say, you cannot see things in terms of other things any more, because the connections are no longer there.

Mind versus consciousness

When we reflect on the mind of a child, or a senile adult, it is natural to ask: what is a mind? We are clear what brains are, so why do people now talk about minds as opposed to brains? I myself do not subscribe to the idea that the mind is some non-material alternative to the biological squalor that scientists work with. I would like to suggest to you that 'mind' has a very clear physical basis in the brain. We have seen that we are born with pretty much all our brain cells. The growth of the connections between cells accounts for the growth of the brain after birth. These connections, as we have seen, reflect your experience, and in turn they influence your further perception, so you see the world in terms of what has happened to you.

I think this is what the 'mind' is: it is no more and no less than the personalisation of the brain. You are born, in the words of the great William James, into a world that is a 'booming, buzzing confusion', where you judge the world, and objects in it, as to how sweet things are, how fast, how cold, how hot, how loud, how bright. You evaluate it in terms of its pure sensory qualities. As you get older, these sweet, bright, noisy, loud, fast, cold, hot things acquire labels; they become objects or people or processes or phenomena. They have labels, and then they have memories and associations attached to them, so gradually you can no longer deconstruct the world (unless you are some brilliant artist) in terms of colours and noises and abstract shapes; instead you see it with a meaning, a meaning that is special to you. That is how it continues to occur, and, as we have seen, the connections that sub-serve these processes remain highly dynamic. So, as you go through life, the world acquires a highly personalised significance, built up by 'hard-wired' circuits in the brain.

Although we have this mind rooted in personalised circuits in the brain and we therefore see the world in a certain way, this organisation is not always accessed. Let us consider 'blowing the mind'. Sadly, the patient with dementia is losing their mind on a permanent basis, but, amazingly, some people pay money to lose their minds or 'let themselves go' at raves. The very word Ecstasy means 'to stand outside of yourself'. I think phrases like 'lose your mind', 'blow your mind', 'out of your mind', 'let yourself go' are exactly what we are talking about – although of course, one is still conscious. Conversely, tonight, when you lose your consciousness, I imagine you are not expecting to lose your mind.