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Reith Lectures 2003: The Emerging Mind

Lecture 1: Phantoms in the Brain

The history of mankind in the last three hundred years has been punctuated by major upheavals in human thought that we call scientific revolutions - upheavals that have profoundly affected the way in which we view ourselves and our place in the cosmos. First there was the Copernican revolution - the notion that far from being the centre of the universe, our planet is a mere speck of dust revolving around the sun. Then there was the Darwinian revolution culminating in the view that we are not angels but merely hairless apes, as Huxley once pointed out in this very room. And third there was Freud's discovery of the "unconscious" - the idea that even though we claim to be in charge of our destinies, most of our behaviour is governed by a cauldron of motives and emotions which we are barely conscious of. Your conscious life, in short, is nothing but an elaborate post-hoc rationalisation of things you really do for other reasons.

But now we are poised for the greatest revolution of all - understanding the human brain. This will surely be a turning point in the history of the human species for, unlike those earlier revolutions in science, this one is not about the outside world, not about cosmology or biology or physics, but about ourselves, about the very organ that made those earlier revolutions possible. And I want to emphasize that these insights into the human brain will have a profound impact not just on us scientists but also on the humanities, and indeed they may even help us bridge what CP Snow called the two cultures - science on the one hand and arts, philosophy and humanities on the other.

I would like to thank the BBC for inviting me to give the 2003 Reith lectures. I hope the lectures will appeal to a broad audience, fulfilling Lord Reith's original mission. Given the enormous amount of research on the brain, all I can do is to provide a very impressionistic survey rather than try to be comprehensive. Of course by doing this, I will be oversimplifying many of the issues involved and run the risk of annoying some of my specialist colleagues. But, as Lord Reith himself once said, "There are some people whom it is one's duty to offend!"

Although the lectures will cover a very wide spectrum of topics, there will be two recurring themes that run through all of them. The first broad theme is that by studying neurological syndromes that have been largely ignored as curiosities or mere anomalies we can sometimes acquire novel insights into the functions of the normal brain - how the normal brain works. The second theme is that many of the functions of the brain are best understood from an evolutionary vantage point.

The human brain, it has been said, is the most complexly organised structure in the universe and to appreciate this you just have to look at some numbers. The brain is made up of one hundred billion nerve cells or **"neurons"** which is the basic structural and functional units of the nervous system. Each neuron makes something like a thousand to ten thousand contacts with other neurons and these points of contact are called **synapses** where exchange of information occurs. And based on this information, someone has calculated that the number of possible permutations and combinations of brain activity, in other words the numbers of brain states, exceeds the number of elementary particles in the known universe.

Even though its common knowledge these days, it never ceases to amaze me that all the richness of our mental life - all our feelings, our emotions, our thoughts, our ambitions, our love life, our religious sentiments and even what each of us regards us his own intimate private self - is simply the activity of these little specks of jelly in your head, in your brain. There is nothing else.

Given the staggering complexity, where do you even begin? Well let's start with some basic anatomy. It's the 21st century and most people here have a rough idea what the brain looks like. It's got two mirror-image halves, called the **cerebral hemispheres**, so it looks like a walnut sitting on top of a stalk, called the **brain stem**, and each hemisphere is divided into four lobes, the **frontal lobe**, the **parietal lobe**, the occipital lobe and the **temporal lobe**. The occipital lobe in the back is concerned with vision. If it's damaged, you become blind. The temporal lobe is concerned with things like hearing, with emotions and certain aspects of perception. The parietal lobes of the brain are concerned with - at the sides of the head - they are concerned with creating a three-dimensional representation of the spatial layout of the external world, and also of your own body in that three-dimensional representation. And lastly the frontal lobes, in the front, are the most mysterious of all. They are concerned with some very enigmatic aspects of human mind and human behaviour such as your moral sense, your wisdom, your ambition and other activities of the mind which we know very little about.

Now there are several ways of studying the brain but my approach is to look at people who have had some sort of damage to a small part of the brain, or some change in a small part of the brain, and interestingly when you look at these people who have had a small lesion in a specific part of the brain, what you see is not an across-the-board reduction in all their cognitive capacities, not a blunting of their mind. What you see is often a highly selective loss of one specific function with other functions being preserved intact, and this gives you some confidence in asserting that that part of the brain is somehow involved in mediating that function.

You are going to see many examples of this in my lectures but just to give you a flavour for this kind of research, I'm just going to mention two or three of my favourite examples. One of my favourites is prosopognosia, or face blindness. When there is damage to a structure called the fusiform gyrus in the temporal lobes on both sides of the brain, what you get is a patient who can no longer recognise people's faces. Now the patient isn't blind because he can still read a book and he's not psychotic or obviously mentally disturbed but he can no longer recognise faces by looking at people. Now that syndrome is very well known but there is another syndrome that is quite rare and that's what we call the **Capgras Syndrome**, and I'll give you an example of this. A patient I saw not long ago who had been in a car accident, had sustained a head injury and was in a coma for about a couple of weeks. Then he came out of this coma and he was quite intact neurologically when I examined him. But he had one profound delusion - he would look at his mother and say "Doctor, this woman looks exactly like my mother but she isn't, she is an imposter".

Now why would this happen? Now the important thing is this patient who I will call David is completely intact in other respects. Now to understand this disorder, you have to first realise that vision is not a simple process. When you open your eyes in the morning, it's all out there in front of you. It's easy to assume that it's effortless and instantaneous but in fact you have this distorted upside down image in your retina exciting the photoreceptors and the messages then go through the optic nerve to the brain and then they are analysed in thirty different visual areas, in the back of your brain. And then you finally after analysing all the individual features, you identify what you're looking at. Is it your mother, is it a snake, is it a pig, what is it? And that process of identification takes place in a place which we call the fusiform gyrus which as we have seen is damaged in patients with face blindness or prosopognosia.

So once the image is recognised, then the message goes to a structure called the **amygdala** which is sometimes called the gateway to the **limbic system** which is the emotional core of your brain, which allows you to gauge the emotional significance of what you are looking at. Is this a predator, is it a lion or a tiger? Is it a prey which I can chase? Is it a mate that I can chase? Or is it my departmental chairman I have to worry about, or is it a stranger who is not important to me, or something utterly trivial like a piece of driftwood? What is it?

Now what's happened in this patient? What we suggest is that maybe what's gone wrong is that the fusiform gyrus and all the visual areas are completely normal in this patient. That's why when he looks at his mother, he says "oh yeah, it looks like my mother", but the wire, to put it crudely, the wire that goes from the amygdala to the limbic system, to the emotional centres, is cut by the accident. So he looks at his mother and he says - "hey, it looks just like my mother, but if it's my mother why is it I don't experience this warm glow of affection (or terror, as the case may be). There's something strange here, this can't possibly be my mother, it's some other strange woman pretending to be my mother". It's the only interpretation that makes sense to his brain given the peculiar disconnection.

Now how do you test an outlandish idea like this? My student Bill Hirstein and I in La Jolla, and Haydn Ellis and Andrew Young here in England, did some very simple experiments measuring galvanic skin response which I'll talk about in detail in my last lecture, and we found - sure enough - there has been this disconnection between vision and emotion as predicted by our theory, just as we had thought. Now what's even more amazing is when David, this patient who when his mother said she's an imposter, an hour later his mother phones him and he picks up the phone and answers the phone and he says "mum, how are you, where are you?" Instantly he recognises her. There is no delusion. An hour later the mother walks into the room and he says "who are you? You look just like my mother but you're an imposter, you're not my mother". Now why does this happen? Well it turns out there's a separate pathway going from the auditory cortex in the superior temporal gyrus to the amygdala, and that pathway perhaps is not cut by the accident. That's why when he listens to his mother on the phone, he says "oh my god, this is my mum, where are you?" But when he sees her, the delusion kicks in immediately and he says "who are you"?

Now, there are many other twists to this story which I'm going to tell you about in my last lecture on neuropsychiatry, but I thought I'd just mention it briefly today because it's a lovely example of the sort of thing we do, of cognitive neuroscience in action.

Now we have talked about visual response to visual images, your emotional response to visual images. Obviously this response is vital for your survival but the existence of connections between visual brain centres and the limbic system or emotional core of the brain also raises another interesting question, and that is what is art? How does the brain response to beauty? Given that these connections are between vision and emotion, and art involves an aesthetic emotional response to visual images, surely these connections must be involved, and this is a topic I'll take up my lecture in Birmingham.

Now we've been talking about all these intricate connections in the brain, in the limbic system, in the visual centres, in the amygdala. An obvious question is the question of nature versus nurture. In other words, are these connections laid down by the genome in the foetus, or are they acquired in early infancy as the infant interacts with the world, the so-called nature/nurture debate. This takes me to the next syndrome I'd like to talk to you about and that is **phantom limbs**.

Everyone here knows what a phantom limb is. A patient has an arm amputated because there's a tumour, malignant tumour on the arm or there's been a car accident and the arm has to be amputated, but the patient continues to vividly feel the presence of that arm. Some of you here, this being England, would now about Lord Nelson who vividly felt a phantom arm. I'll tell you about an experiment we did on these patients. So we have a patient with a phantom left arm. His arm had been amputated above the left elbow so I had him sitting in my office blindfolded and I took a Q tip and touched different parts of the body and asked him what do you feel? I touched his shoulder and he said oh you're touching my shoulder. I touched his belly and he said oh you're touching my belly. I touched his chest and he said you're touching my chest - not surprising. But the amazing thing is when I touched his face, the left side of his face - remember his left arm is amputated so he has a phantom on the left side - when I touched his cheek he said oh my god doctor, you're touching my left thumb, my missing phantom thumb and he seemed as surprised as I was. Then I touched him on the upper lip and he said oh my god you're touching my phantom index finger, and then on his lower jaw and he said you're touching my phantom pinkie, my little finger.

So why does this happen? There was a complete map, a systematic map of the missing phantom hand on his face, draped on his face. So you have a medical mystery of sorts, the sort of mystery we saw with David, the patient with the Capgras syndrome, the sort of mystery that would have intrigued Sherlock Holmes, Conan Doyle or Berton Rouché. So what's going on?

To answer this question, you have to look at the anatomy of the brain again. The entire skin surface, touch signals, all the skin surface on the left side of the brain is mapped on to the right cerebral hemisphere on a vertical strip of cortical tissue called the post-central gyrus. Actually there are several maps but I'll simplify them and pretend there's only one map called the post-central gyrus. Now this a faithful representation of the entire body surface. It's almost as though you have a little person draped on the surface of the brain. It's called the Penfield homunculus, and for the most part it's continuous which is what you mean by a map, but there is one peculiarity and that is the representation of the face on this map on the surface of the brain is right next to the representation of the hand on this map, instead of being near the neck where it should be, so it's dislocated. Now nobody knows why, something to do with the phylogeny or the way in which the brain develops in early foetal life or in early infancy, but that's the way the map is.

So I realised that what's going on here is when you amputate the arm, the part of the cortex of the brain corresponding to the hand is not receiving any signals because you've removed the hand. So it's hungry for sensory input. So what happens is the sensory input from the face skin now invades the vacated territory corresponding to the missing hand, and that then is misinterpreted by higher centres in the brain and arising from the missing phantom hand. And that's why the patient says, every time you touch his face he says oh that's my phantom thumb you're touching, that's my phantom index finger, that's my phantom pinkie. In fact you can even put an ice cube on the face and the patient will say oh my thumb is ice cold. You can put a drop of hot water, in fact you put a drop of hot water and the water started trickling down the face, the patient will trace the trickle on his phantom with his normal hand following its path. On one occasion we had the patient raise his phantom and he was amazed to feel the trickle going uphill which is against the law of physics.

Now that's just a hypothesis but to test this idea, we used the brain imaging technique called MEG or magnetoencephalography which allows you to see which parts of the brain light up when you touch different parts of the body, and sure enough what we found was in this patient, Victor, unlike the normal brain when you touch his face, it activated not only the face area in the brain but also activated the hand region of the Penfield map in the brain. So there has obviously been this cross-wiring in the brain of this patient. And this is important because it allows you to link changes in brain anatomy, changes in brain maps, in the sensory map, with phenomenology, allows you to link physiology and psychology which is one of the goals of cognitive neuroscience, this discipline we're talking about.

The discovery also has broader implications. One of the things we were all taught as medical students is that connections in the brain are laid down in the foetus or in early infancy, and once they are laid down, there is nothing much you can do to change these connections in the adult and that's why when there's damage to the nervous system as in a stroke, there is such little recovery of function and why neurological ailments are so notoriously difficult to treat. What I am saying is that's wrong. In fact there's a tremendous amount of plasticity or malleability even in the adult brain, and you can demonstrate this in a five minute experiment in a patient with a phantom limb. Now how you go about harnessing this ability in the clinic may be to help patients recover from stroke or indeed from phantom limb pain is a question that we don't have time to go into but we can take up during discussions.

OK so we have seen that after our arm amputation, the patient's brain gets cross-wired. The face input now innervates the hand region of the brain. Now that happens because of amputation. It turns out that the same thing can happen because of a mutation, if there is something wrong with your genes. Instead of the brain modules remaining segregated, you get this accidental cross-wiring and then you get a curious condition called **synesthesia**, which we have now been studying. This is going to be a topic of my lecture in Oxford. Briefly it was described by Francis Galton or clearly documented by him in the 19th century. He pointed out that some people who are perfectly normal in other respects have one peculiar symptom, if you want to call it a symptom, and that is these people who are otherwise completely normal, they get their senses mixed up and that is every time they hear a particular tone they see a particular colour. So C sharp is red, F sharp is blue. Another tone might be indigo, OK? And this phenomenon, this mingling of senses is synesthesia. Galton pointed out also that it runs in families. We and others have confirmed this, including Simon Baron-Cohen.

Now, another aspect of this syndrome is whenever you hear a particular tone you see a particular colour. Some of these people also when they see numbers in black and white, like the number five or the number six or the number seven, what we call Arabic numerals - Indian numerals strictly speaking - when you see these numbers, every time you see a number it evokes a particular colour so 5 is always red, 6 is always green. It's always tinged green. 7 is always indigo, 8 is always yellow, so this again is another example of synesthesia and it's very common. We find it's about one in two hundred people have this so it's not as rare as people have thought it to be in the past.

Now why does this happen? Why does this mixing of signals occur? Well we, a student of mine, Ed Hubbard and I were looking at brain atlases, brain maps and we were struck by the fact that if you look at the fusiform gyrus, that's where the colour information is analysed. But amazingly the number area of the brain which represents visual graphemes of numbers, 5 6 7 8 and all of that, is right next to it also in the fusiform gyrus, almost touching it. So we said this can't be a coincidence. Maybe in some people there is some accidental cross-wiring. Just as after amputation we get cross-wiring between the face and the hand, in these people maybe there's a cross-wiring between the number and colour area in the fusiform gyrus. Of course the key difference is in the case of phantom limbs, it's the amputation that causes the reorganisation whereas in synesthesia given that it runs in families, we think it's caused by a gene or a set of genes which causes abnormal connections between adjacent brain regions, in this case between numbers and colours so every time he sees a specific number it evokes a particular colour.

First of all many neurologists, neuroscientists in the past, even though the phenomenon was described by Galton a hundred years ago, it's been regarded mainly as a curiosity. It sounds crazy. They're just crazy or they're just faking it to draw attention to themselves, or maybe it's childhood memories. You played with refrigerator magnets, 5 was red, 6 was blue, 7 was green. Now it never made much sense to me because why does it then run in families? You have to say maybe the same magnets were passed round. So first thing we wanted to show this is a real phenomenon, it's the person genuinely sees red when he sees 5. It's not just imagination or memory. How do you show that?

So we devised a simple display on the computer screen, a number of 5s scattered on the screen, black 5s, just black and white. Embedded among those 5s are a number of 2s and these 2s form a shape like a triangle, a hidden shape, a triangle or a square. Now when all of us here, any one of us normals or less gifted individuals, looks at this pattern, you see nothing. But when a synesthete looks at it, who sees numbers as colour, he sees the 5s as red and the 2s as green so he looks at it and he says my god, instantly the 2s pop out and he says oh they're forming a triangle, they're forming a square. And they are much better at doing this than normal people so it's a clinical test for discovering synesthetes.

Now, the fact that synesthetes are actually better at this than normal people suggests that they can't be crazy. If they're crazy, how come they're better at it? So this shows this is a genuine sensory phenomenon. It also shows that it can't be memory association or something cognitive or a metaphor because - if that were true, how come he's able to see the triangle or the square pop out from the background? OK we have shown that this phenomenon is real, we in La Joya and as well as Jeffrey Gray and Mike Morgan and others here in London have done experiments to test the idea there's actual cross-wiring in the brain and have shown that in fact there's activation of the fusiform gyrus in the colour area just showing numbers to these people.

But then the next question is OK, here are some people with some quirk in the brain. They see numbers as colours so what's the big deal, why should I care? Well now I'm going to show you that you're all synesthetes but you're in denial about it. So what I want you to do is I want you all to imagine two shapes in front of you. I wish I had a slide but of course this is radio. One of them imagine is a shattered piece of glass with jagged edges, the other is like an amoeba, it's got undulating curvy shapes. And one of them I'm going to call a bouba, and the other is kiki - which is which? Now the amazing thing is 98% of people will pick the shattered piece of glass with the jagged edges, and say oh that's a kiki, and the undulating amoeboid shape, oh that's a bouba, even though they have never seen the shape before.

Why does this happen? Well I suggest it happens - I am going to talk about this in detail in my Oxford lecture - because you're all synesthetes.

Now we have talked about several syndromes, phantom limb, synesthesia, Capgras syndrome and these are quite bizarre and we have tried to explain it in terms of neural circuitry in the brain but there is a syndrome that is even more bizarre, and this is pain asymbolia. I'll tell you about a patient I saw in Vellore in India about ten years ago. He was quite normal, intellectually normal, mentally quite lucid, alert, attentive, his memory was normal, perception, everything was fine except I took a needle and pricked him with a needle to determine the intact, not to be sadistic but to determine the intactness of his pain pathways, to determine his pain sensations, and every time I poked him, of course, all of you here would say, ouch. He started giggling, telling me doctor, I feel the pain but it doesn't hurt. It feels very funny, like a tickle and he would start laughing uncontrollably.

Here is the ultimate irony - a human being laughing in the face of pain. OK, why would the patient do this? Well, seeing this patient made me ask an even more basic question, why does anybody laugh? Why do all of you here laugh, OK? Now a martian ethologist watching all of you here would be very suprised every now and then. It is a species-specific trait, laughter. Every now and then all of you here stop what you're doing, shake your head, make this funny staccato rhythmic sound, hyena-like sound. Why do you do it? Now clearly laughter is hard-wired, it's a "universal" trait. You see it every society, every civilization, every culture, society, has some form of laughter and humour - except the Germans.

So this suggests strongly it's hard-wired in the brain and this raises an interesting question. Why did it evolve in the brain, OK, how did it evolve through natural selection? When you look at all jokes and humour across societies, the common denominator of all jokes and humour despite all the diversity is that you take a person along a garden path of expectation and at the very end you suddenly introduce au unexpected twist that entails a complete re-interpretation of all the previous facts. That's called a punch-line of the joke. Now obviously that is not sufficient for laughter because then every great scientific discovery or every "paradigm shift" would be funny, and my scientific colleagues wouldn't find it amusing if I said their discoveries were funny.

OK, the key ingredient here is, it's not merely sufficient that you introduce a re-interpretation but the re-interpretation, the new model you have come up with should be inconsequential, it should be of trivial consequence. It sounds a bit abstract so let me illustrate with a concrete example. Here is a portly gentleman walking along, he is trying to reach his destination, but before he does that he slips on a banana peel and falls. And then he breaks his head and blood spills out and obviously you are not going to laugh. You are going to rush to the telephone and call the ambulance. But imagine instead of that, he walks along, slips on the banana peel, falls, wipes off the goo from his face, looks around him everywhere, and and then gets up, then you start laughing. The reason is I claim is because now you know it's inconsequential, you say, oh it's no big deal, there's no real danger here. So what I'm arguing is, laughter is nature's false alarm. Why is this useful from an evolutionary standpoint? So what you are doing with this rhythmic stocatto sound of laughter is informing your kin who share your genes, don't waste your precious resources rushing to this person's aid, it's a false alarm everything is OK. OK, so it's nature's OK signal.

OK, now what does this got to do with my patient in Vellore? Let me explain. When we examined his brain, when we do the CT scan we found there was damage to the region called the insular cortex on the sides of the brain. The insular cortex receives pain signals from the viscera and from the skin. That's where you experience the raw sensation of pain but it turns out there are many layers to pain. It's not just a unitary thing. From the insular cortex the message goes to the amygdala, which we encountered earlier in the context of the Capgras syndrome and then to the rest of the limbic system, and especially the anterior cingulate, where you respond emotionally to the pain, to the agony of pain and take the appropriate action. So my idea was, maybe what's happened on this patient is, the insular cortex is normal. That's why he says, doctor I can feel the pain, but the message, the wire that goes from the insular to the rest of the limbic system and the anterior cingulate is cut.

Therefore you have the two key ingredients you need for laughter and humour, namely one part of the brain signalling a potential danger, my god there is something painful here, but the very next instant the anterior cingulate says but I'm not getting any signal. Big deal, there is no danger here, forget it, OK. So you got the two key ingredients and the patient starts laughing and giggling uncontrollably, OK. So it is a disconnection similar to what we saw with the Capgras patient.

So we have seen several syndromes here which suggest that you can look at neurological oddities, neurological syndrome and learn a great deal about the functions of the normal brain. I would like to conclude with a quotation from my previous book, *Phantoms in the Brain*, "There is something distinctly odd about a hairless, neotenous primate that has evolved into a species that can look back over its own shoulder to ponder its own origins. Odder still, the brain cannot only discover how other brains work but also ask questions about itself, who am I? What is the meaning of my existence, especially if you are from India? Why do I laugh? Why do I dream, why do I enjoy art, music and poetry? Does my mind consist entirely of the activity of neurons in my brain? If so, what scope is there for free will? It is the peculiar recursive quality of these questions as the brain struggles to understand itself that makes neurology so fascinating. The prospect of answering these questions in the next millennium is both exhilarating and disquieting, but it's surely the greatest adventure that our species has ever embarked upon."

So I hope you'll stay with me for all the remaining lectures, thank you very much.