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Reith Lectures 2003: The Emerging Mind

Lecture 2: Synapses and the Self

Our ability to perceive the world around us seems so effortless that we tend to take it for granted. But just think of what's involved. You have two tiny upside down distorted images inside your eyeballs but what you see is a vivid three-dimensional world out there in front of you and this transformation is nothing short of a miracle. How does it come about?

One common fallacy is to assume there is an image inside your eyeball, the optical image, exciting photoreceptors on your retina and then that image is transmitted faithfully along a cable called the optic nerve and displayed on a screen called the visual cortex. Now this is obviously a logical fallacy because if you have a screen and an image displayed on a screen in the brain, then you need another little chap in there watching that image, and there is no little chap in your head. And if you think about it, that wouldn't solve the problem either because then you'd need another little guy in his head looking at the image in his brain and so on and so forth, and you get an endless regress of eyes and images and little people without really solving the problem of perception.

So the first thing you have to do to understand perception is to get rid of the idea of images in the brain and think instead of transforms or symbolic representations of objects and events in the external world. Just as little squiggles of ink, print or writing, or dots and dashes in the Morse code can symbolize or represent something even they don't physically resemble what they are representing, similarly the action of nerve cells in your brain, the patterns of firing, represent objects and events in the external world even though they don't in any way resemble what's out there in the world. Neuroscientists are like cryptographers trying to crack an alien script, an alien code, in this case the code used by the nervous system to represent objects and events in the external world.

So today's lecture will be about the process we call seeing - about how you become consciously aware of things around you. As in our last lecture, I'll begin by telling you about patients with strange visual defects and then explore the wider implications of these syndromes for understanding the nature of conscious experience, how the activity of mere specks of jelly in the visual areas of your brain gives rise to all the richness of your conscious experience, the redness of red, your ability to recognize a burglar or your lover, and how does that happen.

We primates are highly visual creatures and it turns out we have not just one visual area, the visual cortex, but thirty areas in the back of our brains which enable us to see, perceive the world. It's not clear why we need so many, why do you need thirty areas, why not just one area? But perhaps each of these areas is specialised for a different aspect of vision. For example, one area called V4 seems to be concerned mainly with processing colour information, seeing colours, whereas another area in the **parietal lobe** called MT or the middle temporal area is concerned mainly with seeing motion. How do we know this? Well the most striking evidence comes from patients with tiny lesions that damage just V4, the colour area, or just MT, the motion area.

So for example, when V4 is damaged on both sides of the brain, you end up with a syndrome called cortical colour blindness or achromatopsia, and patients with cortical achromatopsia see the world in shades of grey, like a black and white movie, but they have no problem reading a newspaper or recognising people's faces or seeing direction of movement. Conversely if MT, the middle temporal area is damaged, the patient becomes motion blind. She can still read books and see colours but can't tell you which direction something is moving or how fast.

For example there was a woman in Zurich who had this problem, she was terrified to cross the street because unlike of us here, she saw the cars on the street not as moving but as a series of static images as though lit by a strobe light in a discotheque. She couldn't tell how fast a car was approaching even though she could read its number plate or tell you what colour it was. Even pouring wine into a glass was an ordeal; you and I gauge the rate at which the wine level is rising and slow down appropriately but she can't do this - so the wine always overflows. All of these abilities that seem so simple and effortless to all of us normal people -- it's only when something goes wrong we realize how extraordinarily subtle the mechanisms of vision really are and how complex a process it really is.

Now even though the anatomy of these thirty "visual" areas, the "seeing areas" in the brain looks bewildering at first, there is an overall pattern which I will now describe. The message from the eyeball on the retina goes though the optic nerve and goes to two major visual centers in the brain. One of these I'll call it the old system, the old visual centre, it's the evolutionary ancient centre, the old pathway that's in the brain stem and it's called the superior colliculus. The second pathway goes to the cortex, the visual cortex in the back of the brain and it's called the new pathway. The new pathway in the cortex is doing most of what we usually think of as vision, like recognizing objects, consciously. The old pathway, on the other hand, is involved in locating objects in the visual field, so that you can orient to it, swivel your eyeballs towards it, rotate your head towards it. Thereby directing your high acuity central foveal region of the retina towards the object so then you can deploy the new visual pathway and then proceed to identify what the object is and then generate the appropriate behaviour for that object.

Let me now tell you now about an extraordinary neurological syndrome called **Blindsight** discovered by Larry Weiscrantz and Alan Cowey at Oxford. It's been known for more than a century that if the visual cortex which is part of the new visual pathway, if that's damaged you become blind. For example if the right visual cortex is damaged you're completely blind on the left side if you look straight everything to the left side of your nose, you're completely blind to.

When examining a patient named GY who had this type of visual deficit, one half of the visual field completely missing, where he was blind, Weizcrantz noticed something really strange. He showed the patient a little spot of light in the Blind region. Weiscrantz asked him "what do you see"? The patient said "nothing" and that's what you would expect given that he was blind but now he told the patient "I know you can't see it but please reach out and touch it" The patient said well that's very strange - he must have thought this is a very eccentric request. I mean, point to this thing which he can't see.

So the patient said, you know I can't, I can't see it how can I point to it? Weiscrantz said well just try anyway, take a guess. The patient then reaches out to touch the object and imagine the researcher's surprise when the patient reaches out and points to it accurately, points to the dot that he cannot consciously perceive. After hundreds of trials it became obvious that he could point accurately on 99% of trials even though he claimed on each trial that he was just guessing. He said he didn't know if he was getting it right or not. From his point of view it might as well have been an experiment on ESP. The staggering implication of this is that the patient was accurately able to point to an object that he denied being able to see. How is this possible? How do you explain his ability to infer the location of an invisible object and point to it accurately?

The answer is obvious. As I said GY has damage to his visual cortex - the new pathway - which is why he is blind. But remember he still has the other old pathway, the other pathway going through his brain stem and superior colliculus as a back-up. So even though the message from the eyes and optic nerves doesn't reach the visual cortex, given that the visual cortex is damaged, they take the parallel route to the superior colliculus which allows him to locate the object in space and the message then gets relayed to higher brain centres in the parietal lobes that guide the hand movement accurately to point to the invisible object! It's as if even though GY the person, the human being is oblivious to what's going on, there's another unconscious zombie trapped in him who can guide the hand movement with uncanny accuracy.

This explanation suggests that only the new pathway is conscious - events in the old pathway, going though the colliculus and guiding the hand movement can occur without you the person being conscious of it! Why? Why should one pathway alone or its computational style perhaps lead to conscious awareness, whereas neurons in a parallel part of the brain, the old pathway can carry out even complex computations without being conscious. Why should any brain event be associated with conscious awareness given the "existence proof" that the old pathway through the colliculus can do its job perfectly well without being conscious? Why can't the rest of the brain do without consciousness? Why can't it all be blindsight in other words?

We can't answer this question directly yet but as scientists the best we can do is to establish correlations and try and home in on the answer. We can make a list of all brain events that reach consciousness and a list of those brain events that don't. We can then compare the two lists and ask, is there a common denominator in each list that distinguishes it from the other? Is it only certain styles of computation that lead to consciousness? Or perhaps certain anatomical locations that are linked to being conscious? That's a tractable empirical question and once we have tackled that, it might get us closer to answering what the function of consciousness might be, if any, and why it evolved.

Now I should add that the blindsight syndrome in GY seemed so bizarre, when it was first discovered that it was greeted with scepticism and some of my colleagues don't believe that it even exists. Well partly this is because the syndrome is very rare but also partly because it seems to violate common sense. How can you point to something you don't see? But actually that's not a good reason for rejecting it because in a sense we all suffer from blindsight. Now that sounds cryptic so let me explain that.

Imagine you are driving your car and having a lively animated intimate conversation with your friend sitting next to you. Your attention is entirely on the conversation, it's what you're conscious of. But in parallel you are negotiating traffic, avoiding the pavement, avoiding pedestrians, not running red lights and performing all these very complex elaborate computations without being really conscious of any of it unless something strange happens, like you see an actual zebra instead of just a zebra crossing! So in a sense you are not any different from GY all of you here, you have "blindsight" for driving and negotiating traffic. What we see in GY is simply an especially florid version of blindsight unmasked by disease, but his predicament is not fundamentally different from yours and mine.

Intriguingly you cannot imagine the converse scenario. Paying conscious attention to driving and negotiating traffic while unconsciously having a creative conversation with your friend. This may sound trivial but it is a thought experiment and it is already telling you something valuable, that computations involved in the meaningful use of language require consciousness but those involved in driving, however complicated, don't involve consciousness.

I believe this approach to consciousness will take us a long way toward answering the riddle of what consciousness buys you and why it evolved. My own philosophical position about consciousness accords with the view proposed by the first Reith lecturer, Bertrand Russell, there is no separate "mind stuff" and "physical stuff" in the universe, the two are one in the same, the formal term for this is neutral monism.

So we have talked about the messages in the new visual pathway. But now let us turn to the other pathway, the old pathway which goes to the colliculus, mediates blindsight. That projects to the parietal lobe in the sides of the brain. The parietal lobes are concerned with creating a three dimensional representation, a symbolic representation of the special lay-out of the external world so the ability that we call spatial navigation, avoiding bumping into things, dodging a missile that's hurled at you, catching something that's thrown at you all of these abilities depend crucially on the parietal lobes.

Now when the right parietal lobe is damaged, you get a fascinating syndrome, called neglect, in a sense the converse of blindsight. The patient can no longer move his eyes towards the object, which is looming towards him and he can no longer reach out and point to it or grab it. Now bear in mind he isn't blind to events on the left side of the world because if you draw his attention he can see it perfectly clearly and he'll identify it, he'll tell you what it is. So he's not blind. So you can think of neglect, I think the best description of it is, it's an indifference to the left side of the world. That's why you call it neglect.

If he's eating from a plate of food, he'll eat only from the right side of the plate and completely leave the left side of the plate uneaten. Then you draw his attention he will say "Oh my God, that's a nice avocado" and he'll take it. So when you draw his attention he can see it but otherwise he ignores it. If he is shaving he will only shave from the right side of his face, or if she's a woman only apply make-up on the right side of the face and that looks quite bizarre, as you can imagine.

Now as I said neglect is caused by damage to the right hemisphere. The patient is also usually paralysed on the left side because the right hemisphere of the brain controls the left side of the body. I wondered if it would be possible to "cure" neglect? Can you treat this patient, making him pay attention to the left side of the world he's ignoring?

So I hit on the idea of using a mirror, as in the case of phantom limbs in my previous lecture. So all I did was I had the patient sitting on a chair and then I stood to the right side of the patient and held a mirror like that so that when the patient rotated his head to the right he would be looking directly into the mirror that I was holding on his right side.

Now the question is, how does he react to this? Obviously he is not neglecting the right side, he's only neglecting the left side of the world so clearly he can see the mirror but he's going to see the reflection of the left side of the world inside the mirror. The question is how is he going to react to that? Well one possibility is he's going to say: "Hey my God, that is a reflection. There's a whole left side of the world that I have been ignoring, let me pay attention" and turn around and pay attention -- in which case you have cured neglect instantly with a mirror. Or he could say, "Well look the reflection is on my right side, so the objects are on my left but hey, left doesn't exist in my universe I'm supposed to neglect it so I'll just ignore it" so he ignores the reflection. What happens?

Well what happened actually as often happens in science - neither! OK? I stood on her right, so she is sitting here in her wheelchair I was sitting, standing on her right side, holding up a mirror, she looked inside the mirror, and on her left side was my student standing with a pen, holding a pen. And I asked the patient what do you see? What am I holding? The patient says, oh you're holding a mirror. I said, how do you know? She said well I can see my reflection in and it's cracked on the top -- which is true.

And I said, what do you see in the mirror? She said oh I see your student John, he's holding a pen. I said, OK I would now like you to use your right hand - remember her right hand is not paralysed - to reach out, grab the pen and then write your name on the pad that's on your lap. Now of course you try this on a normal person and actually I have tried it on a normal colleague. You know you just reach, you know you see the reflection in the mirror of the person holding the pen, you turn to the left, grab the pen and write your name on the pad. What did the patient do?

It's absolutely astonishing. The patient looked in the mirror, reaches out into the mirror for the reflection, bang, bang, bang, starts clawing the surface of the mirror, or on some occasions reaches behind the mirror trying to grab the reflection sometime yanking my tie, grabbing my belt buckle, remember I was holding the mirror on the patient's right side. And I said, what are you doing Mrs D, the patient's name?

The patient said, oh I am trying to reaching for the pen. I said, no, no, no I don't mean the reflection, I mean the real pen where is the real pen? The patient says: "The real pen is inside the mirror, Doctor," or on another occasion: " The pen is behind the darn mirror, Doctor." OK? Now this is absolutely astonishing because we have tried this on a three year old child so the child is sitting here on a chair, you hold the mirror on the right side of the child and you have an assistant holding a candy and you tell the child reach out, reach and grab the candy. The child realizes this is some kind of game, giggles and reaches correctly for the candy on the left side and takes it. Even a chimpanzee can do this, doesn't get confused a mirror image for a real object but the older and wiser Mrs D - seventy years of experience with mirrors - reaches straight into the mirror, bang, bang, bang. Why does this happen? We call it "mirror agnosia" or " looking glass syndrome" in honour of Alice who actually walked into the mirror thinking it was a real world. Why does it happen?

Well I think what happens is this patient's brain is saying, speaking metaphorically, look that's a mirror, I know it's a mirror, that's a reflection, therefore the object is on my left but left doesn't exist in my universe. Therefore the object must be inside the mirror, however absurd it seems to all of you chaps, and therefore I'll reach into the mirror, bang, bang, bang. All of that abstract knowledge about the laws of optics and mirrors is now distorted to accommodate this strange new sensory world that the patient finds herself trapped in.

Now I'll turn to another disorder which is also caused by damage to the right parietal and that is even more extraordinary. It's called denial or **anosognosia**. Remember most of these patients with right parietal damage also have some damage to the internal capsule so they are completely paralyzed on the left side of the body. It's what you mean by a stroke, this complete paralysis of the left side of the body, and most of them complain about this as indeed they should. They say when am I going to get better, my arm doesn't work. But a subset of them, a small percentage of them will vehemently deny that their left arm is paralyzed, and these are patients who don't have any neglect. They'll say doctor, it's moving fine. Why does this happen?

It's not clear but it is only seen when the right parietal is damaged, rarely seen when the left parietal is damaged and that gives out a clue. It tells you that the denial syndrome has something to do with hemispheric specialization. The manner in which the two cerebral hemispheres deal with the external world, especially the manner in which they deal with discrepancies in sensory input and discrepancies in beliefs. Specifically I would like to suggest when confronted with a discrepancy, the left hemisphere's coping style is to smooth over the discrepancy, pretend it doesn't exist and forge ahead. The right hemisphere's coping style is the exact opposite. It's highly sensitive to discrepancies so I call it the anomaly detector.

Now imagine a patient with a right hemisphere stroke left side paralyzed. The patient is sending a command to move the arm, he is getting a visual signal saying it is not moving so there is a discrepancy. His right hemisphere is damaged, his left hemisphere goes about its job of denial and confabulation smoothing over the discrepancy and saying, all is fine, don't worry. On the other hand, if the left hemisphere is damaged and the right side is paralyzed the right hemisphere is functioning fine, notices the discrepancy between the motor command and the lack of visual feedback and says, my god you are paralyzed. This was an outlandish idea but it's now been tested with brain imaging experiments and shown to be essentially correct.

Now this syndrome is quite bizarre - a person denying that he or she is paralyzed - but what we found about seven or eight years ago something even more amazing. Some of these patients will deny that another patient is paralyzed so the patient is sitting here. We saw the patient, another patient sitting in a wheelchair - I'll call him patient B - and I've told patient B move your arm. Patient B of course is paralyzed, doesn't move. And then I ask my patient - is that patient moving his arm? And the patient says yes of course he is moving his arm. He is engaging in denial of other people's disabilities.

Now at first this didn't make any sense to me then I came across some studies by Giaccomo Rizzollati, experiments done on monkeys. If you record from parts of the frontal lobes which are concerned with motor commands you find there are cells which fire when the monkey performs certain specific movements, like one cell will fire when the monkey reaches out and grabs a peanut, another cell will fire when the monkey pulls something, yet another cell when the monkey pushes something. That's well known. These are **motor command neurons**. But Rizzollati found that some of these neurons will also fire when the monkey watches another monkey performing the same action, so you find a peanut-grabbing neuron which fires when the monkey grabs a peanut. When the monkey watches another monkey grab a peanut, it fires. It's quite extraordinary because the visual image of somebody else grabbing the peanut is utterly different so you have to do this internal mental transformation to do that computation and for that neuron to fire and Rizzollati calls these mirror neurons. Another name for them is monkey-see monkey-do neurons and these neurons I think are the ones that are damaged in these patients.

Because think about what's involved in your judging somebody else's movements. Maybe you need to do a virtual reality internal simulation of what that person is doing, and that may involve the activity of these very same neurons, these mirror neurons. So these mirror neurons, instead of being some kind of curiosity, hold important implications for understanding many aspects of human nature like how do you read somebody else's movements, their intentions, their actions. Many aspects of what you called a theory of other minds, a sophisticated theory of other people's behaviour. We think it is this system of neurons that is damaged in these patients. The patient can therefore no longer construct an internal model of somebody else's actions.

I also want to argue that these neurons may have played an important role in human evolution and I am going to talk about this at length in my Oxford lecture on the emergence of language and abstract thinking, because think about it. One of the hallmarks of our species is what we call culture. And culture depends crucially on imitation of your parents, of your teachers and the imitation of complex skills may require the participation of mirror neurons. So what I'm arguing is somewhere around 50,000 years ago maybe the mirror neurons system became sufficiently sophisticated that there was an explosive evolution of this ability to mime complex actions, in turn leading to cultural transmission of information which is what characterises us humans.

Now let me conclude by emphasising once again that although the studies on patients are intriguing in themselves, our real agenda here is to understand in terms of brain function, us normal humans, how our brains work, the whole spectrum of abilities that we call human nature, whether it is body image or culture or language or abstract thinking and I hope to convince you that such a deeper understanding of the brain will have a profound impact not just on the sciences but on the humanities as well. Lofty questions about the mind are fascinating to ask, philosophers have been asking them for three millennia both in India where I am from and here in the West - but it is only in the brain that we can eventually hope to find the answers.

Thank you very much.