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## **Reith Lectures 2003: The Emerging Mind**

### **Lecture 4: Purple Numbers and Sharp Cheese**

In the 19th century, the Victorian scientist Francis Galton, who was a cousin of Charles Darwin, noticed something very peculiar. He found that certain people in the normal population who were otherwise perfectly normal had a certain peculiarity and that is every time they heard a specific tone, they would experience a specific colour. For example, C sharp might be red, F sharp might be blue, another tone might be indigo. And this curious mingling of the senses was called [synesthesia](#). Some of these people also see colours when they see numbers. Every time they see a black and white number like the number five printed on a white page, or a white five on a black page for that matter, they would see it tinged red so five might be red, six would be green, seven would be indigo, eight would be yellow and so on and so forth. Galton also pointed out this condition runs in families and more recently Simon Baron Cohen in Cambridge has confirmed this, that it does indeed run in families.

Now I think it's fair to say that even though people have known about synesthesia for over a hundred years, it's been by and large recorded as a curiosity by mainstream neuroscience and psychology but what I'd like to do today in fact is suggest that anomalies can be extremely important in science. If you know which anomaly to pick, you can completely change the direction of your research and generate what you would call scientific revolutions. But first let's look at the most common explanations that have been proposed to account for synesthesia and in fact there are four of these. The first explanation is the most obvious and that is that they're just crazy! Now the second explanation is maybe they're just acid junkies or pot heads, they've just been on drugs. Now this is not an entirely inappropriate criticism because synesthesia is more common among people who use LSD but to me that makes it more interesting, not less interesting. Why should some chemicals cause synesthesia, if indeed they do?

The third idea is that maybe these people are just remembering childhood memories. For example maybe they were playing with refrigerator magnets and five was red and six was blue and seven was green, and for some reason they're stuck with these memories but this never made much sense to me because why would it then run in families? You'd have to say they're passing the same magnets down, or the propensity to play with magnets runs in families or something like that. Anyway it didn't make much sense but it's something you have to bear in mind. The fourth explanation is more subtle and it invokes sensory metaphors. If you look at our ordinary language, it's replete with synesthetic metaphors, cross-sensory metaphors such as for example if you said cheddar cheese is sharp. Well cheese isn't sharp, you can take a piece of cheese and rub it on your skin, it's actually soft. So why do you say it's sharp? Well you say oh no no, what I mean is it tastes sharp, it's a metaphor. But this is circular - why do you use a tactile adjective, touch you know sharp, for a taste sensation?

Now the problem with this explanation is that in science you can never explain one mystery with another mystery. Saying that synesthesia is just a metaphor doesn't explain a damn thing because we don't know what a metaphor is or how it's represented in the brain. And indeed as we go along, what I'd like to do is to turn it

upside down and suggest the very opposite, that synesthesia is a sensory phenomenon whose neural basis you can discover in the brain and that in turn can give you an experimental foothold for understanding more elusive aspects of the mind such as what is a metaphor, so why has it been ignored? There's an important lesson here in the history of science. And I think in general it's fair to say that for a curious phenomenon, an anomaly to make it into mainstream science and have an impact, it has to fulfil three criteria, and that is first you have to show it's a real phenomenon. Second, you have to have a candidate mechanism that explains what it might be. And third it has to have broad implications. What's a big deal? So what, who cares? So for example if you take telepathy, OK telepathy has vast implications if true so the third criterion is fulfilled but the first criterion is not fulfilled, it's not repeatable. We don't even know if it's true, it's probably bogus. Another example would be bacterial transformation. If you take one species of bacteria - pneumococcus - and you incubate it with another species of bacterium, the second species actually becomes transformed into the first species and you can do this just extracting the chemical, the DNA, and then use that to induce the transformation and this was reliably repeatable. Many times it was repeated as published in a prestigious journal but people ignored it. OK why did they ignore it? Because nobody could think of a candidate mechanism. How can you possibly encode heredity in a chemical until Watson and Crick came along, described the double helical structure of DNA, described the genetic code and then people started accepting it, and recognised the importance of bacterial transformation.

So I'd like to do the same thing with synesthesia. First of all I'd like to show it's real, it's not bogus. Second, suggest candidate mechanisms, what's going on in the brain. And third, so what - why should I care? So I'm going to argue in fact synesthesia has very broad implications. It might tell you about things like metaphor and how language evolved in the brain, maybe even the emergence of abstract thought that us humans, human beings are very good at.

So first we need to show synesthesia is a real phenomenon. What we did was essentially develop a clinical test for discovering closet synesthetes, and how do you do that? First of all we found two synesthetes and these people saw numbers as colour, for example five as red and two as green, so we produced a computerised display on the screen which had a random jumble of fives on the screen and embedded among these fives are a number of twos, and the twos are arranged to form a shape like a triangle or a square or a circle. Now when you and I, anybody here in the audience who is not a synesthete looks at this display, it takes several seconds, as much as twenty or thirty seconds before you say oh I see all the twos, they are arranged to form a triangle or a square. Now when we showed this sample display to the two synesthetes, they immediately or very quickly saw the triangle or the square because the numbers are actually coloured for them, they see them conspicuously popping up from the background so this demolishes the idea that they're just crazy because if they're crazy, how come they're better at it than all of you normals? It also suggests that it's a genuine sensory effect because if it's just a memory association or something high level, how come they actually see the triangle? So we know the phenomenon is real and using this test and other similar tests, we are able to show that it's much more common than people have assumed in the past. In fact people have claimed that it's one in ten thousand. We find it's one in two hundred, probably two or three of you here in the audience who don't want to admit it.

So next what causes synesthesia? Well my students and I, especially Ed Hubbard, he and I were looking at brain atlases and we found if you look at a structure called the fusiform gyrus in the [temporal lobes](#) of the brain, it turns out that the fusiform gyrus has the colour area V4 which is described by Semir Zeki. This is the area which processes colour information but we were struck by the fact that the number area of the brain which represents visual numbers as shown by brain imaging studies, that number area is right next to it, almost touching the colour area of the brain so we said this can't be a coincidence, how come the most common type of synesthesia is number/colour and the number area and colour area are almost touching each other right next to each other in the same part of the brain? Maybe what's going on is these people have some accidental cross-talk, or cross-wiring, just as in my experiments on [phantom limbs](#) in my London lecture I showed that the face area becomes cross-wired with the hand area in the cortex, except in this case it happens not because of amputation but because of some genetic change in the brain. And now we've done imaging experiments on people with synesthesia and showed that if you show just black and white numbers, they get activation in the colour area.

Now the next question is why does this cross-wiring or cross-activation occur? Well remember I said it runs in families. Well this suggests there's a gene or set of genes involved. What might this gene be doing, this bad gene? Well one possibility is we are all born with excess connections in the brain. In the foetus there are many more redundant connections than you need and then you prune away the excess connections to produce the modular architecture characteristic of the adult brain, like Michelangelo chipped away everything that doesn't look like David to produce David. That's how you generate a brain. So I think what's happened in these people is that gene is defective and therefore there's defective pruning so there's cross-activation between adjacent areas of the brain - or there could be some kind of chemical imbalance that produced cross-activation between adjacent parts of the brain that are normally only loosely connected and this produces a hyperconnectivity between these parts of the brain.

Now what we found next was even more amazing. Take the same two synesthetes. Instead of showing them Arabic numbers- actually I should call them Indian numbers but it doesn't matter - Indian/Arabic numbers, you show them Roman numbers, Roman V which looks like a V or a 6. Guess what happens? They say oh I know it's a five but it doesn't look coloured, it's black and white so Roman numbers don't give colours. Now what does that prove? It's very important because it shows it's not the numerical concept that drives the colour but the visual appearance of the Indian/Arabic number and it fits with what I'm saying because the fusiform gyrus represents the visual appearance of numbers and letters and things like that, not the abstract concept of sequence or ordinality.

Where does that occur, the abstract idea of number? We don't know but a good guess is angular gyrus in the left hemisphere. We know that because when that's damaged in patients they can no longer - they're fluent in conversation, they are intelligent and all of that but they can't do even simple arithmetic. You say what's seventeen minus three, he'll say oh is it nine? Gets it completely wrong. So we think that abstract number concepts are represented in the angular gyrus and remember this chap's cross-wiring, is in the fusiform gyrus but in the visual appearance of a number and the colour.

Now, however, we then found this is not true of all synesthetes. All synesthetes are not made equal. We then ran into other synesthetes where it's not merely a number that evokes colour but even days of the week evoke colours. Monday is red, Tuesday is indigo, Wednesday is blue, months of the year evoke colour, December is yellow, January is red, February is indigo. No wonder people thought they were crazy! But remember, if you're a clinician you know when somebody sounds crazy it usually means you're not smart enough to figure it out. He isn't crazy. What do calendars, what do days of the week, months of the year and numbers have in common? What they all have in common is the abstract idea of sequence or ordinality. So what I am claiming is that's represented in the angular gyrus, higher up in the TPO junction, temporal parietal occipital junction in the vicinity of the angular gyrus, and guess what? The next colour area in the sequence is higher up in the general vicinity of the TPO junction, not far from the angular gyrus so what I'm arguing is - in these people the cross-wiring is higher up in the angular gyrus. Then you get a higher synesthete, so if the faulty gene is selectively expressed in the fusiform gyrus, lower at an earlier stage in processing, you get a lower synesthete driven by the visual appearance. If it's expressed selectively higher up in the vicinity of the angular gyrus, you get a higher synesthete driven by the numerical concept rather than by the visual appearance.

OK next question - why did this gene survive? One in two hundred people have this peculiarity of seeing coloured numbers and it's completely useless so why hasn't it vanished from the population and I'm going to suggest it's a bit like sickle cell anaemia - there's a hidden agenda. These genes are doing something else important. What? Well one of the odd facts about synesthesia which been known for a long time and again been ignored, is the fact that synesthesia is much more common among artists, poets, novelists, you know flaky types! So now why is it much more common? Well one view is that - in fact according to one study it's seven times more common among artists poets and novelists and the reason is what do artists, poets and novelists all have in common? Just think about it. What they all have in common is they're very good at metaphor, namely linking seemingly unrelated concepts in their brain, such as if you say "out out brief candle", so it's life, why do you call it a candle? Is it because life is like a long white thing? Obviously not. You don't take the metaphor literally, although schizophrenics do and we won't go into that. So why do you that? Well it's brief like a candle, it can be snuffed out like a candle, it illumines like a candle very briefly. Your brain makes all the right links and Shakespeare of course was a master of doing this. Now imagine one further assumption - if this gene is expressed more diffusely instead of being just expressed in the fusiform or in the angular, if it's expressed in the fusiform you get a lower synesthete, in the angular gyrus TPO junction you get a higher synesthete. If it's expressed everywhere you get greater hyperconnectivity throughout the brain making you more prone to metaphor, links seemingly unrelated things because after all concepts are also represented in brain maps. This may be seem counter-intuitive but after all a number, there's nothing more abstract than a number. You can have five pigs, five donkeys, five chairs - it's fiveness - and that's represented in a fairly small region namely the angular gyrus so it's possible that concepts are also represented in brain maps and these people have excess connections so they can make these associations much more fluidly and effortlessly than all of us less-gifted people.

Now, remember I said the third thing you have to do in science is show that this is not just some quirk. It has vast implications. Well what implications does synesthesia have? I'm going to show all of you that synesthesia is not just a quirk in some people's brain. All of you here are synesthetes, and I'm going to do an experiment. I want all of you to imagine in front of you, to visualise in front of you a bulbous amoeboid shape which looks a bit, has lots of curves on it, undulating curves. And right next to it imagine a jagged, like a piece of shattered glass with jagged shapes. And just for fun, I'm going to tell you this is Martian alphabet. Just as in English alphabet, A is a, B is b, you've got each shape with the particular sound, this is Martian alphabet and one of these shapes is kiki and the other is booba, and I want you to tell me which is which. How many of you think the bulbous shape is the kiki, raise your hands? Well there's one mutation there. In fact what you find is if you do this experiment, 98% of people say the jagged shape, the shattered glass is kiki, and the bulbous amoeboid shape is a booba. Now why is that? You never learnt Martian and nobody here is a Martian. The answer is you're all synesthetes but you're in denial about it. And I'll explain. Look at the kiki and look at the sound kiki. They both share one property, the kiki visual shape has a sharp inflexion and the sound kiki represented in your auditory cortex, in the hearing centres in the brain also has a sharp sudden inflexion of the sound and the brain performs a cross-modal synesthetic abstraction saying the only thing they have in common is the property of jaggedness. Let me extract that property, that's why they're both kiki. So what? Well I'll explain.

We have taken the same patterns I have just told you about, the booba/kiki, and shown them to patients who have damage, very small lesion in the angular gyrus of the left hemisphere and guess what? If you show them these two shapes and ask them to associate kiki with the two shapes, kiki and booba, they're random and by the way we don't use just these two shapes. We have a whole set of them and they cannot do this cross-modal associations even though they're fluent in conversation, they're intelligent, they seem normal in other respects. This makes perfect sense because the angular gyrus is strategically located at the crossroads between the [parietal lobe](#) (concerned with touch and proprioception) the [temporal lobe](#) (concerned with hearing), occipital lobe (concerned with vision) so it is strategically placed to allow a convergence of different sense modalities to create abstract modality-free representations of things around you. Now think of what this involves. Think of the jagged shape and the sound, kiki. They have nothing in common. One is photons hitting the retina in parallel, and the other is a sharp sound hitting the hair cells sequentially but the brain abstracts the common denominator saying - but jaggedness is common, or the property of undulation is common, so what you're seeing here in the angular gyrus is the beginnings of a property that we call abstraction that us human beings excel in. And another point I'd like to make is why did this ability evolve in humans in the first place, cross-modal abstraction? Well it turns out if you look at lower mammals, compare them with monkeys, then compare them with the great apes and then with humans, there's a progressive enlargement of the TPO junction and angular gyrus, almost an explosive development and it's especially large in us humans. Why? Well I think this ability evolved because imagine your ancestors scurrying up on the treetops trying to grab branches, jumping from branch to branch, they've got a visual horizontal branch and then they have to adjust the angle of the arm and the fingers so that the proprioceptive map has to match the horizontality of the visual appearance and that's why the angular gyrus became larger and larger. But once you develop this ability to engage in cross-modal abstraction, that structure in

turn became an exaptation for other types of abstraction that us humans excel in, be it metaphor or any other type of abstraction, so that's the claim being made here.

Now finally I would like to turn to language, how did language evolve? This has always been a very controversial topic and the question is look, here we have this amazing ability called language with all the nesting of clauses, this hierarchical structure of language, this recursive embedding of clauses, our enormous lexicon and it's an extraordinarily sophisticated mechanism. How could it possibly have evolved through the blind workings of chance through natural selection? How did we evolve from the grunts and howls and groans of our ape-like ancestors to all the sophistication of a Shakespeare or a George Bush? Now there have been several theories about this. Alfred Russell Wallace said the mechanism is so complicated it couldn't have evolved through natural selection. It was done by god, divine intervention. Maybe he's right but we can't test it so let's throw it away. Next theory was by Chomsky. Chomsky said actually something quite similar although he doesn't use the word god. He said this mechanism is so sophisticated and elaborate it couldn't have emerged through natural selection, through the blind workings of chance but god knows what happens if you pack one hundred billion nerve cells in such a tiny space, you may get new laws of physics emerging. Aha, that's how you explain language so he almost says it's a miracle although he doesn't use the word miracle. Now even if that's true we can't test it so let's throw it away. So then what actually happened? How did language evolve? I suggest the clue, the vital clue comes from the booba/kiki example, from synesthesia and I'd like to replace this idea with what I call the synesthetic boot-strapping theory of language origins, and I'll get to that in a minute.

So the next idea is Pinker's idea and his idea is look there's no big mystery here. You're seeing the final result of evolution, of language but you don't know what the intermediate steps are so it always looks mysterious but of course it evolved through natural selection even though we don't know what the steps were. Now I think he's right but he doesn't go far enough because as a biologist, we want the devils and the details. We want to know what those intermediate steps are, not merely that it could have happened through natural selection. Of course it happened through natural selection. There is nothing else so let's take the lexicon, words. How did we evolve such a wonderful huge repertoire of words, thousands of words? Did our ancestral hominoids sit near the fireplace and say, let's look at that. OK, everybody call it an axe, say everybody axe. Of course not! I mean you do that in kindergarten but that's not what they did. If they didn't do that, what did they do? Well what I'm arguing is that the booba/kiki example provides the clue. It shows there is a pre-existing translation between the visual appearance of the object represented in the fusiform gyrus and the auditory representation in the auditory cortex. In other words there's already a synesthetic cross-modal abstraction going on, a pre-existing translation if you like between the visual appearance and the auditory representation. Now admittedly this is a very small bias, but that's all you need in evolution to get it started and then you can start embellishing it.

But that's only part of the story, part one. Part two, I'm going to argue, there's also a pre-existing built-in cross-activation. Just as there is between visual and auditory, the booba/kiki effect, there's also between visual in the fusiform and the motor brocas area in the front of the brain that controls the sequence of activations of muscles of vocalisation, phonation and articulation - lips, tongue and mouth. How do I know

that? Well let's take an example. Let's take the example of something tiny, say teeny weeny, un peu, diminutive - look at what my lips are doing. The amazing thing is they're actually physically mimicking the visual appearance of the object - versus enormous, large. We're actually physically mimicking the visual appearance of the object so what I'm arguing is that also again a pre-existing bias to map certain visual shapes onto certain sounds in the motor maps in the [brocas area](#).

Lastly, the third factor - I think there's also a pre-existing cross-activation between the hand area and the mouth area because they are right next to each other in the Penfield motor map in the brain and let me give you an example, and I got scooped. Charles Darwin first described this. What he showed was when people cut with a pair of scissors you clench and unclench your jaws unconsciously as if to echo or mimic the movements of the fingers. He didn't explain why but I'd like to give it a name. I call it synkinesia - and that's because the hand and mouth areas are right next to each other and maybe there is some spill-over of signals. Now so what? Well, imagine your ancestral hominids evolving a system of gestures for communication, and this would have been important because vocalisation, you can't engage them in your hunting. Now the right hemisphere produces guttural emotional utterances along with the anterior singular. Now your mouth and tongue are already, there's a pre-existing translation of the visual symbols into mouth lip and tongue movements. Combine that with guttural utterances coming from the right hemisphere and anterior cingulate, what do you get? You get the first words, you get proto-words.

So now you've got three things in place - hand to mouth, mouth in brocas area to visual appearance in the fusiform and auditory cortex, and auditory to visual, the booba/kiki effect. Each of these is a small effect but acting together there's a synergistic boot-strapping effect going on and an avalanche effect, culminating in the emergence of language. Finally you say well what about the hierarchical structure of syntax? How do you explain that? Well I think like when you say he knows that I know that he knows that I know that I had an affair with his wife. How do you do this hierarchic embedding in language? Well partly I think that comes from semantics, from the region of the TPO where I said you'd engage in abstraction and I already explained how abstraction might have evolved, so partly abstraction feeds into syntactic structure, but partly from tool use. Early hominids were very good at tool use and especially what I call the sub-assembly technique in tool use where you take a piece of flint, make it into a head - step one. Then you haft it onto a handle - step two, and then the whole thing becomes one entity which is then used to hit you the subject, you hit the object. You do something to the object and this bears a certain operational analogy with the embedding of noun clauses. So what I'm arguing is what evolved for tool use in the hand area is now exapted and assimilated in the brocas area to be used in syntactic hierarchic embedding. So now look, each of these has a small bias but acting in conjunction they culminate in language. It's very different from Steve Pinker's idea which is that language is a specific adaptation which evolved step by step for the sole purpose of communication. What I'm arguing here is no, it's the fortuitous synergistic combination of a number of mechanisms which evolved for other purposes initially and then became assimilated into the mechanism that we call language. This often happens in evolution but it's a style of thinking that has yet to permeate neurology and psychology and it's very odd that neurologists don't usually think of evolution given that nothing in biology makes any sense except in the light of evolution as Dobzhansky once said.

So let me summarise what we've done. We begin with a disorder that's been known for a century but treated as a curiosity. And then we showed that the phenomenon is real, what the underlying brain mechanisms might be, and lastly spelt out what the broader implications of this curious phenomenon might be. So what have we done here with synesthesia? Let's take a look. One day we might be able to clone the gene or genes, because if you find a large enough family you might be able to do this. Then we can go on to the brain anatomy and say look, it's expressed in the fusiform gyrus and you get lower synesthesia. You go to angular gyrus you get higher synesthesia. If it's expressed all over you get artsy types! Then from the brain anatomy you go to detailed perceptual psychophysics. Either the pop-out effect, you know the 2s against the 5s which you can measure, and then finally all the way to understanding abstract thought and how it might have emerged, metaphor, Shakespeare, even the evolution of language - all of this in this one little quirk that people used to call synesthesia. So I agree wholeheartedly with what Huxley said in the last century just across the road here at the University Museum, contrary to Benjamin Disraeli's views and the views of Bishop Wilberforce. We are not angels, we are merely sophisticated apes. Yet we feel like angels trapped inside the bodies of beasts, craving transcendence and all the time trying to spread our wings and fly off, and it's really a very odd predicament to be in, if you think about it.

Thank you!