One of my scientific heroes is Semir Zeki. I think he's been substantially wrong on almost everything, but his contribution to science has been far bigger than those who haven't had the intellectual smarts or courage to put new ideas into the literature. This is no side swipe, I actually think Zeki should have shared the 1982 Nobel prize: he had completely rewritten the architecture of the visual cortex by 1978. The best most of us can hope for is to be fruitfully wrong — and you need to be damned clever and courageous to be so. I can only dream of getting things as intelligently wrong, but there's time.

Do you really mean that? Yes, I mean it with knobs on actually. The view comes from my love of the history of science. I get really angry when people say nonsense like "Gall was discredited" or "Let's not make the phrenological error". I even heard someone say that "Newton has been discredited". Such things display a deep ignorance of what Gall contributed and of how history proceeds (the point being that it isn't a procession of course). Some people think that knowledge of the history of the subject is some kind of optional indulgence but it's not, it's essential and it's also the gateway to humility.

We really haven't kept up with the general pace as a science. If you reincarnated Gall and explained to him where we are up to, you could bring him up to speed over a pint. If you did the same with a physicist or cell biologist from the same period, the poor buggers' brains would be throwing sparks by 1905, spewing smoke by 1930 and be in total meltdown by 1953 — and that's when the pace really picked up! Being interestingly wrong is so underrated. Galileo's ridiculously premature attempt to measure the speed of light is one of my favourite experiments in the whole of science — it was based on great thought, not on tweaking a variable.

How do you run your research group? Er "run"? I think I run after it most of the time. I try to help people in my group get the best out of themselves and that often means leading from behind. I'm exhilarated rather than intimidated by knowing less about a project than my students — I get to learn more that way. Right now I have people doing great stuff on synaesthesia, faces, numbers, visual search, eye movements, plasticity, sleep, time perception and probably some things they haven't deigned to tell me about yet. There's no group purpose, everyone owns their own project and there's no place to shelter. A colleague once told me that I run my group more like an artist's studio than a scientific lab. It wasn't meant as a compliment, but that is exactly how I'd like to think of it.

What do you think is the next big thing in cognitive neuroscience? Let's try a bit of humility and see where it gets us. I bought a book last week and read that "It seems possible that external events can enter awareness and memory in the absence of attention" and then gave some great examples. Very interesting, but the book was written in 1818 — almost 200 years ago. Conceptually, cognitive neuroscience has not delivered, and I think that is because we have been up our own jacksies about our wonderful techniques. But they don't replace thinking and I think we need to get ready to jettison some cherished cargo. I also think we need to start demanding different skills and greater breadth from post-grads and post-docs — one shouldn't be able to get a PhD in cognitive neuroscience and think that an astrocyte is a celestial body.

I think the transition of science into a normal profession wherein people pander to business values perpetuates conservative thinking and leads to papers being more highly valued than ideas. So I think the next strategic move for cognitive neuroscience is to get all these conservative, impact factor accountants into a field and club them to death. Do you think I could get a grant for it?

What are your future plans? I think I should go back to the record shop business. They are closing down distressingly fast and, as a way of meeting and discussing with other musinerds, there isn't anything to replace them.

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Quick guide

Mirror neurons

Christian Keysers

What are mirror neurons? Mirror neurons are multimodal association neurons that increase their activity during the execution of certain actions and while hearing or seeing corresponding actions being performed by others. Neurons responding to the sound or sight of some actions, but only to the execution of different actions, are not mirror neurons.

Where are mirror neurons found? Three research groups have reported the existence of mirror neurons in three regions of the macaque cortex (Figure 1). Pending systematic explorations, we do not know whether mirror neurons exist elsewhere in the macaque brain. Recently, mirror neurons have also been reported in the song-bird.

Do humans have mirror neurons? This issue has been highly contentious, with no individual piece of evidence generally accepted as definitive, but quite a lot of indirect evidence for human mirror neurons has been reported. First, if a subject moves, the power of the mu-rhythm in the electro-encephalogram (EEG) recorded from his or her brain decreases. Similarly, the EEG rhythm desynchronizes when the subject observes somebody else move. Second, behavioral experiments indicate that the execution of an action is facilitated by viewing someone else execute a similar action, but hindered by viewing an incompatible action. Moreover, transcranial magnetic stimulation (TMS) studies evidence that watching performance of an action facilitates the motor cortical representation of the muscles involved in doing the same action. This shows that some neurons involved in performing an action are indeed selectively activated by seeing a similar action — in other words, mirror neurons do exist somewhere in the human brain.

If humans do have mirror neurons, where are they? Disrupting activity

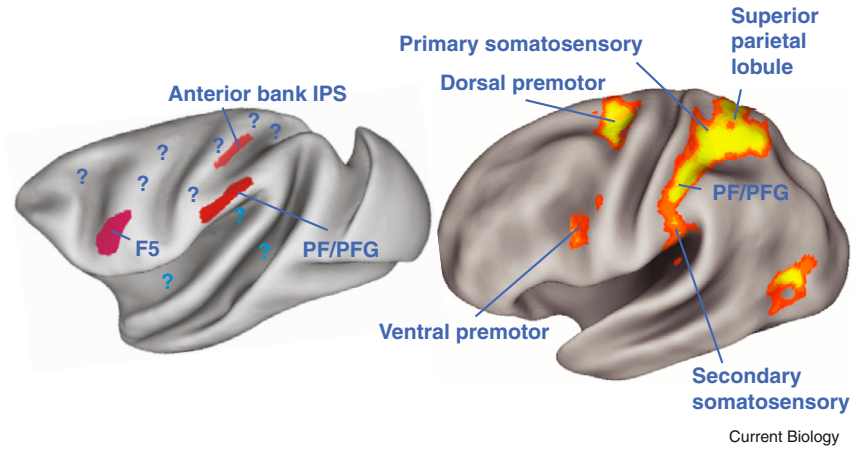

Figure 1. Mirror neurons.

Left: regions in which mirror neurons have been recorded in the macaque; and right, voxels showing activity both during observation and execution in the human brain (from Gazzola and Keysers (2009)). Both brains have been partially inflated to reveal the sulci. Many brain regions have not yet been explored for mirror neurons in the monkey, hence the '?'s. IPS, intraparietal sulcus; PF/PFG, areas of the inferior parietal lobule.

in the ventral premotor cortex using repetitive TMS reduces the effect of viewing other people perform an action. Functional magnetic resonance imaging (fMRI) has shown that a great number of locations in the brain that are active during the execution of an action are also active when the same action is seen or heard; these include the premotor and parietal regions in which mirror neurons are found in monkeys (Figure 1). Unless one abandons the concept of evolutionary continuity, the conclusion that mirror neurons akin to those found in monkeys (and birds) exist at least in these regions of the human brain is most parsimonious.

The results of fMRI experiments, however, suggest that a number of additional brain regions have mirror properties in the human brain, including the dorsal premotor, supplementary motor, the primary and secondary somatosensory cortex, the posterior middle temporal gyrus and parts of the cerebellum (Figure 1). Whether these shared activations indeed reflect the activity of mirror neurons in *each* of these regions remains to be established: some could also contain distinct populations of neurons active during the perception and the execution of actions that just happen to share the same voxel. Pending further single cell recordings, it would seem best to refer to these human brain regions as parts of a *putative* mirror neuron *system*.

Is there evidence against the existence of mirror neurons in humans? Not really: for each experiment that fails to find evidence for mirror neurons in humans there is at least one that succeeds. For example, recent experiments used fMRI to test the prediction that, for a brain region that is part of the mirror neuron system, repeated viewing of an action would lead to reduced activation during subsequent execution of the same action (and *vice versa*): three of the four experiments that tried found such an effect. Given statistics that limit false positives to <5%, this ratio of 3:4 is strong evidence for the existence of human mirror neurons. But if there are mirror neurons, shouldn't all experiments find evidence for them? A basic power analysis falsifies this intuition: using the typical voxelwise thresholds of $p < 0.001$ in fMRI, one would expect even large effect sizes to remain undetected over 50% of the time.

Do mirror neurons help us perceive the actions of others? Experiments in which brain areas thought to contain mirror neurons were disrupted, either using repetitive TMS or as a result of localized brain damage, have demonstrated a drop in the accuracy with which participants can report what action another individual has performed — particularly for those actions they can no longer perform accurately themselves. Often, however, the accuracy remains above chance. These results indicate that brain areas thought to contain mirror neurons are indeed *contributing* to our perception of the actions of others, but that they are unlikely to be the only player.

Can we develop new mirror neurons? Hebbian learning suggests that performing an action while seeing and hearing oneself perform it should be enough for neurons involved in performance to start responding to the sight and sound of the same action. The fact that five hours of piano lessons suffice for the premotor cortex to start responding to piano music supports this view.

Is the mirror system broken in patients with social deficits? Given that the mirror neuron system is implicated in understanding the actions of others, it has been widely suggested that defects in the system may play a part in neurological disorders characterised by social deficits, in particular autism. While some studies do show that, in individuals with autism, the putative mirror neuron system is activated less than usual while they view the emotions or actions of others, other studies do not. We now need to find out *when* autistic individuals may activate this system less, and examine whether this can help us understand this disorder.

Are mirror neurons the neural basis of mind reading, empathy and language? Activations in brain regions involved in executing actions have been measured while people try to read the minds of others, empathize with them or listen to spoken language. Examining how much of that activity really stems from mirror neurons, and in particular to what extent there is a *causal* link between this activity and these mental functions is a key challenge for future research and will require TMS and lesion studies.

Do we have mirror neurons for emotions or sensations? A handful of experiments suggest that brain regions involved in the experience of emotions and sensations become reactivated while we view the emotions and sensations of others. These regions *might* therefore contain mirror-like neurons for emotions and sensations. Pending single cell

recordings, this conclusion remains tentative, though it is an influential idea.

Why is the mirror neuron system so controversial? About a dozen papers have reported direct evidence for mirror neuron activity in monkeys and birds. Approximately 100 times as many papers refer to mirror neurons without directly recording their activity, often implying a link between mirror neurons and higher cognitive functions. While the existence of mirror neurons in animals is beyond doubt, the causal relationship between these neurons and phenomena such as empathy, mind reading, language, autism, esthetics, morals and politics is so poorly established, that the frequency with which the term mirror neuron is encountered in the literature *should* trigger some unease.

So what is next? After the initial enthusiasm for the discovery of mirror neurons, and the stimulating wave of speculation that followed, we now need to concentrate on developing methods that can: localize these neurons in the human brain; examine what information they convey about the actions of others; test for a causal relationship between putative mirror neurons in various nodes of the system and higher brain functions in humans; and try to understand the evolution of this system. Mirror neurons give us a fascinating glimpse into the neural basis of social cognition — let us use careful experimentation instead of wild speculations and controversies to transform this glimpse into solid scientific understanding.

Where can I find out more?

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Image awards

The Wellcome Image Awards are now a well-established event. The focus has been on dramatic micrography over recent years but included in this year's winning pictures is an image of a Tibetan doctor, Amchi Tala, clutching a set of Tibetan medical manuscripts that were written in the 12th century. In a remote region of western Tibet, Tala holds the Gyu Shi (Four Tantras), the fundamental Tibetan medical classic, and a manuscript on compounding medicines, written by previous generations of Tala's medical family.

The photographer was Theresia Hofer, a social and medical anthropologist currently working at the Centre for the History of Medicine at University College London.

Nineteen images have been chosen by a panel of judges based on the ability of the picture to communicate the wonder and fascination of science.

The selected images are now on display at the Wellcome Collection in London and the Image Awards website, which explains the stories behind the pictures: how the images were created, what they add to scientific understanding and why the judges picked them out as the best images this year.

Nigel Williams

Award: Amchi Tala, a Tibetan doctor, holding copies of 12th century medical manuscripts. (Photo: Wellcome Trust.)