Excerpt from Chapter 4 of Chris Frith's (2007) *Making up the mind: How the brain creates our mental world* (pp. 101 – 110). Oxford, UK: Blackwell Publishing Ltd.

The self and the world

So how do I experience myself in the world? Consider a very simple action like walking round the room as I try to think of the next sentence. There is me, and there is the world I am moving through, which is not me. The big difference is that I move and the world stays exactly where it is. And this is very odd because every time I move, this movement produces dramatic changes in what my brain senses about the world. Even just moving my eyes has a dramatic effect. On my retina, and again on my visual cortex at the back of my brain a picture of the world is projected. But if I move my eyes this projection will change completely. As I move my eye from left to right across the fir tree in the garden, the projection of the fir tree moves from the right side to the left side of my retina. This is a dramatic change of sensation. And it raises a problem for my brain - is there a change in sensation because my eye is moving or because the fir tree is moving?

We have all experienced how ambiguous movement can be when travelling by train. I think my train has started moving again and then find it was the train on the next platform going the other way. But we rarely experience any ambiguity about whether it's the tree moving past my eye or me moving my eye past the tree. More than 100 years ago Helmholtz was worried about this problem. He showed that we can sometimes be unsure even about our own eye movements. He showed that if he moved his eye by poking it with his finger then the world appeared to jerk from side to side[1]. So why does the world remain stable when we move our eyes in the normal way?

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[1] As long as you don't poke your eye too hard this is an experiment that can be tried out at home. It really works.

Helmholtz realised that our brain already has detailed information about an eye movement before the movement occurs. This is because it is our brain that sends the signals to the eye muscles that cause the movement. These signals can be used to predict exactly how our visual sensations will change when an eye movement occurs[2]. Here again the brain learns important things about the world through prediction.

Our brain can use this prediction to make us perceive the world as stable even though the image of the world is jumping around on our retina as we move our eyes. This illusion of stability is important for our survival. All animals are very sensitive to sudden changes of visual sensation. Any sudden change in sensation is likely to be caused by the movement of a small animal that we want to catch or a large animal that we want to avoid. But visual changes caused by our own movements are of no relevance at all. By predicting these unimportant changes of sensation the brain can suppress our response to them. We can then devote all our attention to things happening in the outside world.

Why we can't tickle ourselves

There was a time when scientists were very serious people, masters of specialist knowledge that ordinary people did not expect to understand. Scientists are not like this today. We have to be publicly accountable. Our research must be relevant, understandable and, best of all, fun[3]. So, if there are many different

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[2] So why can't the brain predict exactly what will happen when we poke our eye with a finger? Well firstly our brain has very little experience of this action and hasn't had a chance to learn how to predict. And secondly each time we poke our eye we are likely to put our finger in a slightly different place so the prediction will never be quite the same.

[3] In other words, likely to be taken up by the popular press. But be warned. If it's too much fun you may get an igNobel prize. These prizes are for a) 'research that makes you laugh and then makes you think' b) 'research that cannot and should not be reproduced'.

ways to study the process of interest, why not choose the one that is most fun. With this in mind Sarah-Jayne Blakemore and I decided to study tickling. It was already well established by general experience, even backed up by science, that we can't tickle ourselves. The reason lies in prediction. Our brain can predict what we are going to feel because our brain is sending the commands to the fingers that cause the tickling sensation.

There are receptors on our skin that detect when our body is being touched. These receptors send signals to areas of the cortex that are dedicated to representing touch (the primary and secondary somatosensory areas: see Figure 3.7). If I start stroking the palm of your hand while you are having your brain scanned, then I can observe a dramatic increase of neural activity in these brain regions as they respond to the touch. But if you stroked your own palm in just the same way[4], then I will observe very little increase in activity. When you touch yourself your brain suppresses your response.

Figure 4.6 Brain activity associated with tickling

The Professor of English removes her hand just as I am trying to tickle it. 'That's not very surprising', she says. 'It feels much less intense when I tickle my own hand. Obviously, my brain activity will correspond with my subjective experience. You keep telling me that my experience depends upon my brain.'

[4] You rightly ask how can I be sure that you stroke your own palm in *exactly* the same way that I stroke it. We use a combination of sensitive movement detectors and robot arms. A computer records the movements that you make and then reproduces them exactly by controlling a robot arm which tickles you.

What the imaging study shows is the location in our brain where the suppression occurs. It occurs in the region of the cortex where the sensations of touch first arrive. For this to happen our brain must be predicting the activity so that it is ready to counteract the signal as soon as it arrives.

There is nothing special about tickling. We cause sensations whenever we move even if we are not touching ourselves or anything else. There are receptors in our muscles and joints that detect how tense our muscles are and also measure the angles of our joints. These receptors are stimulated whenever we move our limbs, but the brain’s responses to this stimulation are suppressed when we move the limb ourselves. If someone else moves our limb (a passive limb movement) then the cortical responses are much greater. Our brain cannot predict what is going to happen when someone else moves our limb, and so our sensations of movement are not suppressed.

The feeling of being in control

There are many reasons why prediction is a good thing. If we know what is going to happen then we can relax. We don’t have to keep making new plans about what to do. We only need to change our plans when something unexpected happens. Also if we know what is going to happen then we feel that we are in control.

We all like the feeling of being in control. And the thing we control best is our own body. Yet, paradoxically, because our brain suppresses the bodily sensations it can predict, we feel most in control when we don’t feel anything. I reach for my glass and all I experience is the look and taste of the wine as I drink it. I don’t experience the various corrections made to the movements as my brain navigates my arm through the various obstacles on the table to reach the wine glass. I don't experience the change in the angles of my elbow or the feel of the glass on my fingertips as they adjust perfectly to the size of the stem. I feel in control of myself because I know what I want to do (have a drink) and I can achieve this aim without any apparent effort. As long as I stay in control I don't have to bother with the physical world of actions and sensations. I can stay in the subjective world of desires and pleasures.

The world of the imagination

The Professor of English thinks I am talking nonsense. 'You may move through the world like a Zombie', she says, 'But I am certainly aware of what I am doing.' 'No', I reply. 'Most of the time you are not aware of you are doing. What you are aware of is what you *intend* to do. As long as your intentions are fulfilled, you are not aware of what movements you are actually making.' Remember Pierre Fourneret's experiment from chapter 3 (Figure 3.3)? The participants in this experiment thought they were moving their hand in a straight line when, in fact, their hand was deviating to the side. They intended to move their hand in a straight line in order to reach the target. And they did reach the target. They were not aware of the deviations their hand had to make in order to reach the target. All they were aware of was the intended movement.

We can live in this world of intentions, this imaginary world, because our brain can predict the consequences of our movements. Our brain knows in advance how long a movement will take, what our hand will look like at the end and what the movement should feel like. And even if we do not move at all, we can imagine making movements.

Since the advent of behaviourism, psychologists have been very suspicious of the imagination. We don't quite trust subjective reports. We want some sort of objective measure in support. We are therefore pleased because we can show that when someone imagines making a movement they take the same time to do it as when they really make that movement. We are even more pleased when we can show that, when someone imagines making movements, we can see activity in the relevant motor regions of their brain. And we get really excited when we can show that imagining making movements can actually increase our skill with real, objective movements.

Yue & Cole asked one group of volunteers to train the muscle that controls the little finger (the hypothenar muscle) for 4 weeks, five sessions per week. Another group only imagined making these contractions, also for 5 sessions a week. A third group, the control group, did not do any training at all. After five weeks, the average force that could be exerted by the little finger had increased by 30% in the real training group and by 22% in the imaginary training group. The change in the control group was a trivial 2.3%. This study shows that practicing movements in the imagination can increase strength almost as much as real training. How is this possible?

We learn by prediction. My brain predicts what is going to happen when I move and uses the error in its prediction to do better next time[5]. But if we don't move there is no final outcome to compare with the prediction. There is no error. So how can I learn by simply imaging making a movement? Learning in the

[5] I continue with my convention of saying, 'my brain does …' to indicate those situations where I am not aware of what my brain is doing. In contrast, 'I do …' indicates those situations where I am aware of what my brain is doing. But the 'I' in this case is still my brain (see the Epilogue).

imagination is possible because my brain makes two different predictions about my movements. First, it can predict which particular sequence of commands sent to my muscles will generate the movement I want to make. This prediction is called the *inverse model* because my brain has to reason backwards from the output of my motor system (my moving finger) to its input (the commands sent to my finger muscles). Second, my brain can predict which exact movements will occur if it sends a certain sequence of commands to my muscles. This prediction is called the *forward model* since my brain has to reason forwards from input (the commands to the muscles) to output (the finger movements). My brain cannot test how good either of these predictions are without making movements. But we don't need to make movements to test whether or not the two predictions are consistent with one another. The prediction from the forward model, which finger movements will occur, should match the starting point of the inverse model, which fingers movements I want to make. My brain can make these two predictions and adjust them until they match without my making any actual finger movements. As a result of such purely mental practice my ability to make the real movements will improve[6].

When the system fails

Moving through the world and reaching for the things we want seems easy. We take it for granted. In the normal state our feeling of being in control of our actions is marked by a lack of awareness of the details of the actions we are performing.

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[6] Machines can also learn to recognise objects in this way (see chapter 5). These are sometimes called Helmholtz machines because they use the same 'unconscious inferences' about which Helmholtz speculated. They use a technique called the wake-sleep algorithm, which also makes two kinds of prediction: *recognition*; predicting what object would cause these sensations (the inverse model) and *generation*; predicting what sensations this object would cause (the forward model). There is speculation that, in the brain, dreaming occurs during harmonisation of the two kinds of predictions. This happens during sleep when there are no sensory inputs.

We have little awareness of our sensation when we move and we are rarely aware of having to make corrections to our movements even though we are making them all the time. But, in the background, our brain is working hard to achieve this sense of ease.

A daily marathon

IW, as the result of a viral infection, has lost all the sensations in his limbs, apart from feeling temperature and fatigue. He only knows about the positions of his limbs through his eyes. After such damage people usually do not move even though they still have control over their muscles. This is because our brain depends upon bodily sensations to control our movements. In order to issue the right commands to the muscles our brain needs to know where our hand is before the movement begins and whether it has reached the right position after the movement has finished. For people like IW this information is no longer available, except through vision.

IW is very unusual. After years of effort and hard work he has learned to walk again, but falls over if the lights go out. He has learned to pick up objects as long as he can see both the object and his hand. He depends on his vision to know where his hand is before the start of a movement and he has to look to check that it has reached the right place when the movement has finished. This is not the normal way that the brain controls movements.

The control that IW has achieved does not happen automatically. He has to think carefully about his movements all the time. No automatic corrections occur. He has to think continuously about controlling his movement through the whole course of an action.

This is quite different from our normal feeling of being in control. Perhaps the nearest we can get to understanding what this might be like for IW is when we force ourselves to move in spite of extreme tiredness. Every inch of movement requires an extreme effort. This is how IW himself describes the experience. He says his life is a daily marathon.

Alien forces

PH suffers from schizophrenia. One of her most disturbing symptoms is the feeling that she is not controlling her own actions. '*My fingers pick up the pen, but I don't control them. What they do is nothing to do with me*.' Psychiatrists call this a 'delusion of control' because the person believes that her actions are being controlled by alien forces. Of course many of us might say that our actions are not under our own control. We may feel constrained by the government or our employers. There is a perfectly real sense in which many of my actions are controlled by the Wellcome Trust[7]. PH's feeling of being controlled is much more direct than this. When she moves her arms it feels to her as if she is not controlling it.

PH's experience is quite different from that of IW. She can control her movements without too much thought. Her brain makes all the automatic corrections that are needed when she reaches for an object. So why does she say that her movements are controlled by alien forces?

[7] That wonderful medical charity which has funded my research for the last 10 years.

In the early part of the 20th century Karl Jasper suggested that many of the experiences described by psychiatric patients were simply not understandable. Anxiety and depression are more extreme versions of states that all of us have experienced, but having our actions and thoughts directly controlled by other people is beyond any experience most of us have ever had. Karl Jaspers was critical of claims linking brain function to psychological processes. These claims were 'brain mythology' that would not help us to understand the experiences of psychiatric patients.

'He's right,' interjects the Professor of English. 'You need psychological theories to explain psychological experiences'. I take pleasure in reminding that her that Jaspers also criticised the 'mythology of psychoanalysis.'

I believe we can now achieve some understanding of PH's experiences because of what we have discovered about the brain. In our normal state we are hardly aware of the sensations that occur whenever we move. This is because our brain can predict these sensations and suppress our awareness of them. But what would it be like if something went wrong with the prediction and we became aware of the sensations? Normally I am only aware of the sensations when someone else moves my hand. Such a brain abnormality could explain why PH feels as if her arm is being moved by someone else. She is abnormally aware of her bodily sensations when she moves her hand. For her it really does feel as if someone else were moving her hand.

The Professor of English looks very sceptical. 'Are you going to tell me that PH can tickle herself?'

'Exactly'. I am delighted that she has hit on the key experiment. In the lab we found that PH and people like her could tickle themselves. It made no difference to them whether they stroked their palm themselves or the experimenter stroked it. They reported that the tickliness of the sensation felt the same. We may not yet fully understand the underlying brain abnormality, but we are beginning to understand what the experience of movement is like for these people. Their brains no longer suppress awareness of the sensations that inevitably accompany movements. For them it really does feel as if someone else was moving their limbs.

The invisible actor at the centre of the world.

Through its ability to learn and predict, my brain ties me to the world with many strong threads. Because of these threads the world's not a buzzing, confusing mass of sensations; instead, everything around me exerts a push or a pull because my brain has learned to attach values to them. And my brain creates more than mere pushes and pulls. It even specifies all the actions I might need to perform to reach some things and avoid others. But I am not aware of these strong connections - my brain creates the illusion that I am an independent being quite separate from this physical world.

Whenever I act in the world, moving my limbs and moving myself from one place to another, I cause massive changes in the signals striking my senses. The pattern of sensations on the retina at the back of my eye changes completely every few seconds. But the world outside has not really changed. And my brain manages to create for me the experience of a constant, unchanging world through which I move. I can choose to attend to the various parts of my body, and then they too become part of this external world. But most of the time I, the actor, move through the world invisibly, a shadow that one can sometimes catch a glimpse of from the corner of one's eye before it moves on.

Through associative learning our brains discover the valuable things in the world and what actions we need to take to get them.