2d | Brain Imaging Techniques

We're now going to talk about brain imaging techniques. In the previous section of this module we talked about how researchers were able to uncover some of the functions of the brain by looking at patients that had lesions or damage to specific regions of the cortex. By examining a group of individuals with similar lesions one can one can determine what cognitive ability is deficient and what is spared. For example, in the case of Paul Broca's research, he found that individuals that had a select lesion in the left inferior frontal cortex showed deficiencies in speech production. By showing that that relationship exists, one can then infer that that area of the cortex supports that cognitive function.

However, as important as this research is, it doesn't always tell us enough information about a normal functioning brain. For example, it's very difficult to make inferences about a normal functioning brain from a single case study of an individual with brain damage. Even in the case of multiple individuals that have similar brain damage, no two lesions are ever going to be identical. Luckily for us however, recent advances in technology have allowed us to look inside the functioning brain using non-invasive procedures.

These can broadly be broken down into two different categories: one being static imaging where you're looking at the structure of the brain, and the second being dynamic brain imaging where you're looking at the function of the working brain. First I'm going to talk about a couple of different static brain imaging techniques and then I'm going to spend the remainder of this section of the module talking about functional or dynamic brain imaging techniques.

Two popular structural neural imaging techniques are the CAT scan and the MRI scan. The CAT scan or computerized axial tomography is a technique in which highly focused converging beams of X-rays are passed through the head from many different angles. The differing types of brain tissues have differing densities and thus deflect the X-rays differently allowing visualization of the organ.

Recently MRI or Magnetic resonance imaging has become the tool of choice to measure the structure of the brain. This technique takes advantage of the different magnetic properties of tissues in the brain, that under a powerful magnetic field, produce an electromagnetic signal that the scanner detects, and then these electromagnetic signals allow the visualization of the underlying structure of the brain.

For neural imaging purposes, MRI scans are typically preferred over CAT scans and there are several reasons for this. Firstly, MRI requires no exposure to radiation. Secondly, MRI scans can often provide a more detailed image of the underlying structures of the brain. And thirdly, MRI has several other very powerful functions. Specifically, as we'll be talking about very shortly, you can also measure the dynamic or functional aspects of the brain with MRI. This you can not do with CAT scans.

The two previous techniques we talked about, CAT and MRI, provide static pictures of brain structures. Cognitive neuropsychologists and neuroscientists could use these static pictures to pinpoint brain damage and other abnormalities. However, these static images do not allow us to see how the functioning brain is working. For this we need functional neuroimaging.

Throughout this course you're going to be exposed to several different neuroimaging techniques. They all rely on two different types of activity that happens in the brain. First, when neurons fire in the brain they produce electrical activity. By placing metal electrodes on the scalp neuroscientists can measure this electrical activity and by measuring the time course of this activity and the source or location of this activity neuroscientists can make inferences about how the brain is responding to certain cognitive stimuli. The technique that is most commonly used to measure this electrical activity as a function of cognitive tasks is called Event-related potentials or ERP.

A second group of functional neuroimaging techniques measure the byproduct of this electrical activity. This byproduct of neuroactivity is metabolism or blood flow in the brain. Two functional neuroimaging techniques that measure this metabolism are Positron Emission Tomography or PET, and functional Magnetic resonance imaging or fMRI. I'm going to focus on this later technique, fMRI as it is by far the most popular technique in cognitive neuroscience.

Before we talk about fMRI I want to read you this quote by Donders in 1868: "As in all organs, the blood undergoes a change as a consequence of the nourishment of the brain. One discovers in comparing the incoming and outflowing blood that oxygen has been consumed."

It took over 100 years after Donders wrote these words for us to be able to have the technology to accurately measure this inflow and outflow of oxygenated blood in the brain. This technology is functional Magnetic resonance imaging, fMRI for short. Now recall previously when we talked about MRI or structural magnetic resonance imaging, what we were measuring there was the structural properties of the brain. In that case, MRI was able to provide us with pictures of the brain by taking advantage of the different magnetic properties of the tissues in the brain.

Well, it turns out that oxygenated and de-oxygenated blood, also have different magnetic properties. So one can measure the inflow, and outflow of oxygenated blood in the brain by measuring the magnetic properties of that blood. The inflow and outflow of oxygenated and de-oxygenated blood in the brain is referred to as the blood oxygenation level dependent function or the BOLD function. This BOLD function is depicted in the following figure.

So what happens here is that as neurons fire in the brain blood flow increases as a function of that neural activity in the brain. This is a surprisingly slow process and that is actually depicted in the following picture. On the X axis here we have time and it shows a time scale of roughly

20 seconds. And on the Y axis we have signal strength and that's just the MRI signal strength as a function of the oxygenation level in the blood. At the point at the intersection of the X and Y axis of this graph would be when somebody started performing a cognitive task. And what initially happens is that those regions of the brain that are responsible for that task consume oxygen in that blood. What that does is that gives an initial dip in the BOLD function. After that there is a relatively slow influx of blood to that region and this peaks at around 10 or 15 seconds after the onset of that cognitive task. fMRI again picks up this BOLD function. As a researcher what you do is is you look around the brain and find those regions of the brain that show a BOLD function that is time-locked to the cognitive task that you're interested in. Once you find those regions that have that BOLD function you can then be confident that those regions are related to or correlated with performance on that task.

Now this sounds all well and good, however there is at least one caveat to this. When a person is performing a cognitive task and you're measuring the blood flow in the brain along with that cognitive task it's very difficult to know for sure what regions of the brain are specifically responsible for what aspects of that task. Specifically, every cognitive task that we do likely has many many underlying mechanisms that support that task and what we're often interested in in cognitive psychology is finding all those sub-components, all those combined mechanisms that support complex thinking.

So how is it that we can actually isolate and find those regions of the brain that are responsible for different components of different cognitive tasks? Once again, we have to give credit to Donders. He came up with what is referred to as Subtractive Logic. This idea originated with studies of reaction time differences. What the logic is is that in order to measure the time for a process to occur you need to compare two reaction times or two tasks: one which has the same components as the other, plus the process of interest.

So let's consider a very simple example. Let's just say you're interested in measuring the time it takes to make a decision about colour and in your experiment you just have a very simple choice decision task. Participants are presented with either a green light or a red light and what their task is is to hit the button when the light is green but not red. And for the sake of argument, let's just say you've performed this experiment and it takes around 250 milliseconds to perform this task. What your initial conclusion might be is, well it takes around 250 milliseconds to make a decision about colour. Sounds simple enough right? Well, not so fast, it's not that easy.

There are a number of different components to that decision task that also are contributing to the reaction time. There is indeed that decision time, that key process that you're interested in. However, there are also more basic components of that task. For example, there is a manual or motor component to the task. Just simply pushing a button takes time independent of having to make a decision about any stimuli. Ideally what you'd want to do is to gain access to that decision time or to be able to say something about decision time independent of the motor component of the task.

Well, using subtractive logic there's a way around this. What you can do is is have participants perform another simpler task that contains part of what that decision task is. For example, you could have participants just simply hit a button when they see any colour of light and take their responses to that more simple task and subtract them from your more complex task. So imagine that it took the participants around 200 milliseconds when the task was to simply hit the button when they saw any colour of light and it took participants around 250 milliseconds when their task was to hit a button when the light was green, but not red. Then what you can do is you can subtract the reaction times for these simpler tasks from reaction times for the more complex tasks leaving you with a difference of 50 milliseconds. That would be your best estimate of what the pure measure of decision time is independent of any sort of motor response.

Importantly, this logic is also applied to the analysis of functional neural imaging data. This allows us to isolate the brain regions contributing to a given underlying cognitive process. Specifically, the relative amount of activation in a particular brain region needed for a given cognitive task can be measured by subtracting a control state, for example responding to any colour of light in the last example, from a task state, like making a decision about two colours in the last example.

Throughout this course we're going to be covering a number of fMRI and PET studies and most of the time when you see a brain image picture what you're going to be seeing is the subtractive logic at work.