Module:
Techniques in Neuroscience

Week 1
Understanding the brain:
Who we study, how and why?

Topic 1
The living brain
– Part 2 of 3

Dr Vincent Giampietro
Senior Lecturer, Department of Neuroimaging, King's College London

Slide 3:

This section focuses on functional imaging, i.e. in mapping brain activity. The main technologies currently used to image brain function will be briefly described before being contrasted on three axes: spatial resolution (which is the amount of details in the images), temporal resolution (the speed of detail acquisition) and the level of tolerance needed.

Slide 4:

EEG, electroencephalography, is the oldest functional neuroimaging technique available. It is non-invasive - the syringe that you can see in the picture is only used to apply conductive gel to ensure good contact between the scalp and the electrodes. So, it's non-invasive and it records brain activity through measuring electrical activity on the surface of the scalp. The signal is picked up by multiple electrodes in different locations, and the signal source is then inferred mathematically, which is called the inverse problem. The main advantages of EEG are that it is cheap, somewhat portable and that it can measure brain activity at the millisecond scale. On the other hand, the signal is measured only at the surface of the scalp in relatively few locations and does not, therefore, provide accurate localisation of brain function.

Slide 5:

EEG has the lowest spatial resolution of the functioning imaging technologies I'm presenting here, the highest temporal resolution and the lowest level of tolerance needed.

Slide 6:

MEG, magnetoencephalography, is closely associated to EEG, in that the former measures the tiny magnetic fields generated by brain activity on the scalp, while the latter measures electrical activity. So, EEG and MEG are

complementary techniques. In MEG, the subject has to position their head under a helmet-shaped dewar - which is vacuum-filled - that contains hundreds of magnetometers. A vat of liquid helium is used to cool down the ultra-sensitive detectors making up the bulk of the scanner. Like EEG, MEG suffers from low spatial resolution due to the fact that it measures signal on the surface of the skull and then infers mathematically where the source of the signal is coming from. But, the two technologies certainly have the highest temporal resolution, able to measure brain activity at the millisecond level. In the picture seen here, the subject is in a sitting position, but the scanner can actually be rotated so that the subject is scanned lying down.

Slide 7:

Like EEG, MEG has the lowest of the spatial resolution of the techniques I'm talking about here, the highest temporal resolution and it's got a medium-level of tolerance needed, as you have to sit under or lie under this big helmet, so it's less participant-friendly than EEG is.

Slide 8:

PET, positron emission tomography, is an invasive neuroimaging technique that uses radiopharmaceuticals to measure physiological processes. Tissue tracer concentration and location can be computed by detecting the gamma rays emitted as a byproduct of the decay of the injected radioactive tracer. For example, fluorine-18 fluorodeoxyglucose, FDG, is one of the most widely-used tracers and is employed as a marker of glucose metabolism. The picture you can see here is of the fluorodopa, F-DOPA, tracer that is used to characterise the distribution of dopamine in the brain of a healthy subjects, on the left, and on a patient with Parkinson's disease, on the right. The tracers need to have a short half-life so they decay quickly. So, they have to be produced onsite by a cyclotron, substantially raising the costs of PET and making it the most expensive neuroimaging technique.

Slide 9:

Though, in terms of spatial resolution, PET has a high spatial resolution and we measure the whole brain on a millimetre scale. In terms of temporal resolution, PET has the lowest temple resolution of all the methods I am presenting here, because it's only able to measure brain function in like 10/20-second scales. And to the tolerance needed, it's of course the highest one because it's an invasive method and you're injecting radioactive tracers.

Slide 10:

Functional near-infrared spectroscopy - fNIRS, as some people say - is a non-invasive optical imaging technique that aims to detect changes in brain activity for neurovascular coupling using near-infrared light. fNIRS is based on the BOLD effect - blood oxygenation level dependent is what BOLD means. The differential need for red absorption spectra of oxy- and deoxyhaemoglobin is used to indirectly measure changes in blood flow, blood oxygenation levels and blood volume. The main limitation of fNIRS is that near-infrared light does not penetrate deep through the skull and through the brain- about five centimetres- so this has limited spatial resolution, due to a relatively small number of sensors as well. This makes fNIRS particularly suited to the image the infant brain, because the infant brain is really small and the skull is nearly transparent because it is really thin.

Slide 11:

In terms in spatial resolution, optical imaging through fNIRS has a low spatial resolution - so, with more detectors than an EEG, so it's a bit higher spatial resolution, but we're still only measuring at the surface and on few detectors. In terms of temporal resolution, it's got really high temporal resolution. Not as high as EEG and MEG, but much higher than PET and fMRI. In terms of tolerance needed, it's quite a participant- and patient-friendly technique, so it requires a low level of tolerance.

Slide 12:

Amongst the functional neuroimaging techniques, functional magnetic resonance imaging – fMRI - is currently the most widely used. Like fNIRS, fMRI is based on the BOLD effect (I will repeat, this is the blood oxygenation level dependent), what is here measured for the fact that oxy- and deoxyhaemoglobin have different magnetic properties. In optical imaging, it was the fact that oxy- and deoxyhaemoglobin are slightly different colours, so they reflect and refracted light in different ways. In this case, we make use of the fact that oxy- and deoxyhaemoglobin have different magnetic properties: oxyhaemoglobin is diamagnetic, which means it's barely magnetic, while deoxyhaemoglobin is paramagnetic. So, deoxyhaemoglobin interacts more strongly with the magnetic field of the MRI scanner, making it possible to distinguish both blood types. This has been used to indirectly measure brain activity for regional changes in magnetism. fMRI has been used to study a wide range of psychiatric and neurological disorders, as well as to investigate healthy brain processes.

Slide 13:

FMRI has the highest spatial resolution of all the techniques I mentioned above, it's the one that gives you the most detailed picture of the brain, if you want. It's got quite a low temporal resolution because it only measures brain activity every couple of seconds, which is much slower than EEG and MEG which can measure at the millisecond level. It's got a medium level of tolerance - so basically you have to lie down in the MRI scanner, you're strapped and everything, you're not supposed to move - but at least you have no radioactivity injected, so it's better than PET.

Slide 14:

Let's contrast two of the most common neuroimaging methods, EEG and fMRI. In terms of temporal resolution, we can see from the pictures here that an EEG cap consists of only a few dozen electrodes measuring the small electrical current generated by the brain activity on the scalp. By contrast, fMRI's measuring brain activity in tens of thousands of locations in the brain - these are called voxels. So, that's why we say that the spatial resolution of EEG is therefore much lower than that of fMRI. But, in terms of temporal resolution, we can see from the two graphs at the bottom that EEG acquires hundreds of measurements within two seconds, which is the scale in the x-axis, while it takes two seconds for an fMRI volume to be acquired, for an fMRI snapshot of brain activity to be acquired, it takes seconds. So, the temporal resolution of EEG is therefore much higher than that of fMRI.

Slide 15:

This graph is a good summary of what I've mentioned before in this section, in that it contrasts, graphically, the most common neuroimaging methods in terms of spatial resolution, temporal resolution and degree of tolerance, specifically to do with infants in this case.

Slide 16:

This graph here shows the initial investment costs of the most common neuroimaging technologies, ranked from the cheapest on the left to the most expensive on the right. The cheapest techniques, EEG and optical imaging, are several orders of magnitudes cheaper than the other three, but require bulky scanners and in the case of PET, an in-house cyclotron. So, we're talking from about £20,000 for a research-grade EEG up until a couple of million pounds for a PET camera plus the cost of a cyclotron, enough for all the room around.

Slide 17:

In terms of running costs, still EEG and optical imaging are the cheapest, and the prices you can see on the other three techniques are the London prices, if you want. For MEG scanning, it's about £250 an hour, for fMRI, most of the places in London, it's about £500 an hour, and the minimum price you would pay for PET scan is about £2000 - I mean, £1500- £2000 - and it can go up to £15,000 per hour of scanning for PET imaging.