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Seeing inside the brain

With the advent of brain scanning in the past twenty-five years, there has been nothing short of a revolution in our understanding of the brain. This brief chapter will describe the main forms of brain scanning that provide the basis for much of the evidence referred to in this book. Here you will learn more about:

- the principal forms of brain scanning;
- the evidence that is produced by different forms of scanning techniques;
- some possibilities for what we might learn to help pupils in the future and particularly those with special needs.

The context – two quotes

The following quotations suggest why scanning is important for our understanding of both the nature of the brain and of learning in the future. The first is from the neuroscientist and author Steven Rose:

> From physics and engineering come the new windows into the brain offered by the imaging systems: PET, fMRI, MEG and others – acronyms which conceal powerful machines offering insights into the dynamic electrical flux through which the living brain conducts its millisecond by millisecond business. (Rose, 2005)

The second is from the project on 'Learning Sciences and Brain Research' in the Organization for Economic Co-operation and Development.

> As with most advances in science, the key is the development of new technology. Techniques such as functional neuro – imaging, including functional Magnetic Resonance Imaging (fMRI) and Positron emission tomography (PET) together with Transcranial Magnetic Stimulation (TMS) are enabling scientists to understand more clearly the workings of the brain and the nature of the mind. In particular they can begin to shed new light on old questions about human learning and suggest ways in which educational provision and the practice of teaching can better help young and adult learners. (OECD, 2002)

In light of this comment from the OECD, it is possible to argue that more has been learned about the human brain in the past twenty five-years than in the whole of previous history because of the non-invasive techniques of brain scanning.

We are at the beginning of an era of brain information that will have many implications for teachers and learners. Brain studies will become an essential element of training for teachers, and I would argue that it should already be on the students' curriculum also. In the final chapter regarding the wellbeing of pupils in schools, the issue of the effects upon the brain of taking substances will be considered. Evidence from brain scans should play in important part in this debate.

Looking into the past

Neuroscience emerged at the interface between medicine, psychology and philosophy. As Steven Rose points out, its earliest rationale must have been in the attempts to treat or mitigate overt brain damage, presumably caused by head injuries. He notes that 'trepanning' – that is, making holes in or cutting out sections of the cranium – was practised by the Egyptians and 'maybe goes back much earlier if the surgical marks on prehistoric skulls found widely distributed across Europe are anything to go by'. (Rose, 2005). This practice was not confined to the West. In fact it was more widespread in the ancient world, for as he notes 10,000 trepanned skulls were found in Cuzco in Peru!

The problem for earlier civilisations was that until the advent of microscopy it was difficult to observe much of the structure of the brain beyond the division of white and grey tissues and the curious doubling of the hemispheres. So the Greek philosophers Plato and Hippocrates agreed that mind was located in the head, yet believed that the mind and body were separate. This belief persisted until Descartes who, as we will see in a later chapter, insisted that the mind and the body were entirely separate.

Some two hundred years later the German physiologist Johannes Muller showed that the perception of the senses takes place in the brain when he demonstrated that each of the sensory organs responds to stimuli in its own way:

> So, if the optic nerve leading from the eye to the brain is stimulated, we see a flash of light regardless of whether the light was the stimulus. (Greenfield, 1996)

Yet despite this emerging scientific understanding, the curious and sometimes dubious art of phrenology survived well into the twentieth century. Phrenology is based on the notion that the mind is intimately related to physical brain function. Hence phrenologists would feel the shape of the head, and the bumps that reflected supposed traits of ability and character, in order to give a reading. I remember as a child hearing about a relation who had had 'his bumps read'.

Present day practice

The revolution in diagnostic imaging that led to the wide range of safe practices that are available today began as recently as the 1970s. Early in this decade, the medical world was introduced to a remarkable imaging technique known formally as X-ray Computed Tomography, now usually termed X-ray CT. This technique passes a beam of x-rays through the tissue at many different angles in a selected plane. The result looks rather like a sliced section through the body. The computer was needed to process the vast amount of information that was necessary to create the actual images.

The impact of this work was twofold. First, it avoided the need for radiological examinations which were unpleasant and sometimes dangerous for patients, and second it opened up fresh possibilities for scientists with new ways of imaging the body 'using the same basic mathematical and computer strategies for image reconstruction' (Posner, 1999).

PET scans

The next major change to follow X-ray CT was Positron Emission Tomography, or PET scans for short. This is a nuclear technique that produces an image of the distribution of radioactivity in the human body following the administration of a substance containing radioactive atoms. The resulting pictures are in vivid colour, with the lightest colours reflecting the areas of greatest brain activity. My first encounter with PET scans was in 1994, when watching the Christmas television lectures for children delivered by Susan Greenfield. She demonstrated which parts of the brain were active during activities such as reading out loud, working out numerical problems and reading silently. Although the scans didn't yield a great deal of information, they provided a fascinating insight into the brain and were an interesting indicator of where the work might be heading in the future.

A celebrated study using PET scanning showed the plasticity of the adult brain. (McGuire et al., 1997). In this study, London taxi drivers of many years experience were scanned while they recalled complex routes around the city, and the results were compared with a control group. It was found that the posterior hippocampi of the taxi drivers were significantly larger than those of the control subjects, and that the hippocampal volume correlated with the amount of time spent as a taxi driver. Clearly, the taxi drivers had elaborated their spatial representation of the environment as adults, reflecting the plasticity of the adult brain.

MRI – Magnetic Resonance Imaging

The next major technique to be developed was Magnetic Resonance Imaging or MRI. This approach exploits the fact that many atoms in the presence of a magnetic field behave like little bar magnets or compass needles. By skilfully manipulating the atoms in a magnetic field, scientists can line up the atoms just as the needle of a compass lines up in the earth's magnetic field. When radio wave pulses are applied to a sample whose atoms have been so aligned, the sample will emit detectable radio signals that are characteristic of the number of particular atoms present and of their chemical environment. The resultant images of organ anatomy provide much better detail than the two earlier procedures.

Benefits of fMRI scans

A further development led to the process often used today and known as functional Magnetic Resonance Imaging or fMRI. It uses MRI to capture the quick, tiny metabolic changes that take place in an active part of the brain. 'Essentially fMRI shows up the areas where there is most oxygen' (Carter, 1998). In routine practice, fMRI studies are frequently used in planning brain surgery, since it can help physicians to monitor normal brain functions as well as any disturbed patterns. Currently it appears that fMRI can also help to assess the effects of stroke, trauma or degenerative disease. The conventional fMRI unit is a cylindrical magnet in which the patient must lie still for several seconds at a time, and it can feel claustrophobic to some (especially children, one might imagine).

fMRI images of the brain and other head structures are clearer and more detailed than those obtained by other methods. The medical applications are still developing, and include:

- identifying the location of normal brain function in order to allow surgeons to attempt to avoid these areas during brain surgery;

- enabling the detection of a stroke at a very early stage so physicians can initiate effective treatments;

- helping physicians to monitor the growth and function of brain tumours to guide the planning of radiation therapy or surgical treatment.

Scanning jugglers

There are wider applications of fMRI scanning that yield some evidence about learning. For example, a study at the University of Regensburg using fMRI explored the changes that took place in the brain while volunteers were juggling. Researchers split 24 students into two groups, one of which was given three months to learn a classic three ball cascade juggling routine, the other was a control group. When the jugglers had acquired enough skill to perform for at least a minute, brain scans were carried out on both sets of volunteers.

The scans revealed an increase in grey matter in the visual regions of the brains of the jugglers. In particular, the posterior hippocampi of the jugglers were significantly larger than those of the control subjects. However, after another three months without juggling, the amount of extra grey matter in the jugglers' brains had diminished. This evidence contributes to our understanding of the brain's plasticity, as it shows how the structure of the brain alters in response to environmental demands (Draganski, 2004). The researchers explained that the effect could be due to increased cell production or changes in the connections between neurons.

Electroencephalography (EEG) – electrical recordings of the brain

Techniques that we have encountered so far such as PET and MRI have the potential to enlighten us about where the activity is occurring in the brain while it is performing various tasks. What is not available from these methods alone is the duration of activity in the active areas and the sequence of their activation. Neurons communicate in only milliseconds, but 'it requires about forty seconds to obtain the data necessary to construct a PET image of blood flow in the human brain' (Posner and Raichle, 1999). Therefore, in order to capture the moment-to-moment changes in activity in the brain, scientists turned to other methods, particularly electroencephalography (EEG).

EEG technique 'measures brainwaves – the electrical patterns created by the rhythmic oscillations of neurons' (Carter, 1998). These waves show characteristic changes according to the type of brain activity that is taking place. EEG measures these waves by picking up signals via electrodes placed in the skull. As Posner explains:

> Using geodesic electrode nets, we have examined the effects of tasks similar to those used in PET studies, such as the presentation of visual words. So for example if we want to know when the brain first distinguishes between words and consonant strings, we can compare the wave forms recorded at each of sixty four electrode sites and find out when they begin to depart from each other. (Posner and Raichle, 1999)

An EEG then, is a recording of signals from the brain made by hooking up electrodes to the subject's scalp. The main drawback of EEG is that it provides less spatial resolution than PET scans. The biggest advantage is speed, since EEG can record complex patterns of neural activity occurring within the brain as soon as a stimulus has been administered. Another significant advantage is that it can be used with children, and there are an increasing number of university and other centres around the world focusing on various aspects of the development of the infant's brain using this technique.

Baby labs and geodesic brain hats

These infant brain research centres, often termed 'Babylabs', are yielding a great deal of information that is important to our understanding of the learning process. One of the best known centres is Birkbeck's Centre for Brain and Cognitive Development, where they focus on how babies learn and develop during the first two years of life. They also study atypical patterns of mental development as seen, for example, in autism. In particular, Birkbeck has focused on the themes of:

- how babies recognise faces;
- how they learn to pay attention to some things and not to others;
- how they learn to understand what other people do and think;
- how their language and understanding of the world develop;
- why and how some children develop disorders such as autism.

The researchers in the centres commonly use a geodesic hairnet which fits over the infant's head and has 64 points of contact on the scalp to provide the EEG information.

A brief survey of some of the infant 'Babylab' study centres around the world found the following themes being researched and studied.

- Cornell, USA: the development of communication, cognition and language;
- Western Sydney, Australia: how infants perceive speech from its vowels to its tones, how infants listen to music, and whether infants are attuned to the 'Aussie' accent;
- Lincoln, UK: categorisation and conceptual development, speech perception, language acquisition, word learning and early grammar;
- Oxford, UK: early word learning, visual perceptual development and understanding of the world of objects;
- Stanford, USA: the origins of communication in infancy and early childhood and how young children develop competence in understanding spoken language;
- Uppsala, Sweden: identifying early deficits in social behaviour, children who are neurologically at risk and autistic disorders.

This is not a systematic review, but it does indicate the range and depth of the early learning studies taking place with EEG and other scanning technologies. As these develop, they will yield even more evidence about the early stages of life and the acquisition of skills that will inform provision for child care and early learning.

When this evidence is coupled with that from neuro-scientific research centres at universities across the globe, we have a picture of a huge evidence base that is only possible because of the non-invasive techniques of scanning that are currently in use. The priority now is that of harnessing these findings and disseminating it to those who need such information – not least parents and teachers.

Research using brain scanning

The following examples of brain scanning show particular relevance for learning and indicate the quality and range of evidence that is developing through scanning techniques. They also show the huge value of the emerging evidence base about learning and important related social issues across the globe.

Some differences between learning Chinese and English

The first example is cross-cultural and from San Diego University. The title is 'How Chinese language and learning pathways differ from alphabet-based languages like English'. In this experiment, the researchers worked with 16 Beijing schoolchildren who were ten to twelve years-old. Eight were dyslexic and the rest were normal readers. The children took turns being placed in an MRI machine as sets of Chinese characters were flashed electronically on a screen. They saw the characters briefly and had to choose an answer by pressing a key with their index finger. During the test, the MRI took snapshots of oxygen-rich blood flowing to the portions of their brain in action.

The results of the study suggest that the brains of Chinese schoolchildren with reading problems misfire in a different region than the one used in reading alphabet-based languages like English. This demonstrates that the learning disorder dyslexia is not the same in every culture and therefore does not have a universal biological cause. Neurologists described these results as 'very important and innovative'. They assert that while dyslexia has certain common roots, they now have proof that this kind of functional problem plays out differently according to the particular demands that western and eastern languages place on the brain's wiring and processing centres.

This kind of study is only possible through the use of scanning technology and it has led to more recent research on a connected theme: 'Dyslexia in Chinese: Thinking in Tongues' (*Nature*, January 2007). The original study here is Siok, 2004.

Supporting premature babies

The second study, by researchers at Imperial College, concerns a new test that can identify premature babies who are at risk of developing learning difficulties. The study used MRI scans to measure the brain growth of 113 babies born between 22 and 29 weeks gestation – a baby is normally born at 40 weeks. The babies were scanned up to the point where they would have been eight weeks old if born at full term. The mental development of 63 of the children was then assessed when they were aged about two.

The research showed that the slower the rate of growth of brain surface and the smoother it was compared to brain volume, the more likely it was for a child's development to be delayed. The most premature babies and boys were most likely to be affected.

If the results are confirmed in future studies, the researchers say that it might be possible to use brain scans to identify which children might need development support and even trial treatments. The director of the study, Dr David Edwards, said: 'Now we know what we are looking for, we can try a treatment. We are looking at using melatonin, which is a powerful neuro-protector'. This work could be of great importance for the future of some premature babies (see Kappelou, 2006).

Memory competence in old versus young

A third example investigates factors affecting learning in older adults. The study from Toronto University considers 'The relation between brain activity during memory tasks and years of education in young and older adults'. It is well established that those who experience higher education suffer less age-related decline in cognitive function, but little is known about the mechanism for the protective effect. The research team examined the effect of age on the relation between education and brain activity by correlating years of education with activity measured using functional MRI during memory tasks in young and older adults. In the younger adults, education was negatively correlated with frontal brain activity, whereas in older adults education was positively correlated with frontal activity. The team suggest that the frontal cortex is engaged by older adults, particularly by the highly educated, as an alternative network that may be engaged to aid cognitive function. So, the team conclude that education protects memory by contributing to flexible mental strategies.

Again, this is a rich field of interest and studies in this area are still developing at Toronto University (Grady, 2005).

A two-stage model of learning

The final and most recent example concerns the actual nature of learning and involves the use of advanced imaging techniques with fMRI. The researchers at Georgetown University studied how humans use both higher and lower brain processes to learn novel tasks (see Riesenhuber, 2007).

The team provided the first evidence for a two-stage model of how a person learns to place objects into categories. They showed how we can discriminate between a green apple and a green ball, and assign only the apple to the category of food. They describe the process as a complex interplay between neurons: those that recognise and process the basic shapes and other more sophisticated brain areas that discriminate between these shapes to categorise and label that information – a mixture of 'bottom-up' and 'top-down'.

The researchers theorised that a very simple yet efficient way of doing this kind of learning would be for the brain to first learn how objects vary in shape and then in a second stage to learn which shapes go with which labels. So for example, a green apple and a green tennis ball are both round, but the apple can be eaten while the ball belongs to a sport.

The team therefore asked volunteers to undertake a series of tasks presented to them on a computer screen. All of the tasks involved cars that were generated by a computer graphics morphing system that allowed the researchers to generate thousands of cars with subtle shape differences. In the beginning, all of the cars looked very similar because the participants did not have any experience with sorting them.

In the first experiment, the participants looked at series of cars presented in different parts of the screen and produced simple judgements about the positions of particular images. At the same time their brain activity was measured using an advanced fMRI technique that made it possible to more directly probe neuronal tuning than in previous studies. Researchers found that the cars activated a particular region in the participants' brains, namely the lateral occipital cortex, which had also been found by other studies to be important for object recognition.

Then the volunteers were given several hours of training using images of the cars. In these sessions, participants had to learn how to group the cars into two distinct categories. This was easy at first, because the cars were obviously not alike, but as the experiment progressed the researchers made the task more difficult by making the two categories increasingly similar. Over the course of the training, the participants got better at finer category discriminations.

Once the volunteers had learned how to categorise small shape changes, they were shown the cars from the first experiment while again being scanned. This allowed the researchers to compare how training had enhanced the brain's ability to process car shapes. They found again that the cars selectively activated an area in the lateral occipital cortex, but that now neurons in that area appeared to be finely tuned to small car shape differences.

During a third and final scan, the investigators asked subjects to categorise the same car images shown in the other scans. This time two areas of the brain, the now familiar area of the occipital cortex as well as an area of the lateral pre-frontal cortex, were found to be active when processing the images. The lateral pre-frontal cortex is known to be the centre of cognitive control. It is where the brain connects physical input to an action or response, deciding what task to do and how to respond to a stimulus. In essence then, the fMRI showed that both the higher and lower brain regions had worked together to learn the task. The research team now hope that the findings will be helpful in understanding disorders such as autism or schizophrenia that involve differences in the interaction of bottom-up and top-down information in the brain.

It is clear then that the new scanning technologies are helping us to gain new insights into the functioning of the brain and in some cases to enhance our understanding of the learning process. There is cause for optimism that the vast amount of work taking place in this area will provide us with new and valuable knowledge for pupils with special needs that will also improve the provision for all pupils learning in schools.

Scanning in the future – looking forward

It is certain that the quality and detail of the images from scanning will continue to improve, and that it will be possible to see the brain in action more clearly than current technology allows. In terms of educational applications there should be great strides of progress in our understanding of some aspects of special needs. Some pupils may bring brain scans as parts of their educational profile to help the school better understand how to teach them. This will generate its own ethical issues and it will require teachers to have a better understanding of the brain than most do at present. There is likely to be a wealth of information about each student's brain that will be available in the future to support learning. We are at the beginning of an era of brain information that will have many implications for teachers and learners.

Moving objects through brain activity

There are some wonderful possibilities for the future for those pupils who have severe physical disabilities. For example, a new technology from Japan could let pupils control electronic devices without the need for any physical activity. The brain machine interface being developed by a Japanese company analyses slight changes in the brain's blood flow and translates brain motion into electronic signals. A cap, rather like those used by infants in Babylabs and mentioned earlier in this chapter, is connected by optical fibres to a mapping device. This in turn is connected to a computer. Underlying this technology is a process called 'optical topography', which sends a small amount of infra-red light through the brain's surface to map out small changes in blood flow. I saw this demonstrated by a reporter operating a model of an electrical train. As she did small calculations in her brain the train moved forwards, apparently indicating activity in the brain's frontal cortex which handles problem solving. The company has manufactured a device that monitors brain activity in paralysed patients so that they can answer simple questions, for example by doing mental calculations to indicate 'yes' or thinking of nothing in particular to indicate 'no'. The beauty of this advance is that it is non-invasive and only requires a small helmet, rather than having a chip inserted into the brain.

An altogether different use for brain scanning in the future is already creating an ethical debate. A team of leading neuroscientists at the Max Planck Institute in Germany has developed a powerful technique that allows them to look deep inside a person's brain and to read their intentions before they act. The research breaks controversial new ground, potentially increasing scientists' ability to read the thoughts of others, and raises serious ethical issues about how brain-reading maybe used in the future.

The team used high-resolution brain scans to identify patterns of activity before translating them into meaningful thoughts, revealing what a person is planning to do in the near future. It is the first time that scientists have succeeded in reading intentions in this way. The researchers describe the process as looking around the brain for information 'like shining a torch around and looking for writing on a wall'.

During the study, the researchers asked the volunteers to decide whether to add or subtract two numbers they were later shown on a screen. Before the numbers flashed up they were given a brain scan using fMRI. The researchers then used software that had been designed to spot subtle differences in brain activity to predict the person's intentions with 70 per cent accuracy. The study revealed signatures of activity in a marble-sized part of the brain called the medial prefrontal cortex that changed when a person intended to add the numbers or subtract them. Professor Colin Blakemore, a much respected neuroscientist, noted that these techniques could offer much to education and diagnosis in the future. He also observed that 'we will have more and more ability to probe people's intentions, minds, background thoughts, hopes and emotions' (Sample, 2007).

Patterns of success in chess players

Some ten years ago, Posner and Raichle, both experts in the field of imaging, predicted changes in the future for scanning technologies. They mentioned the work of Herbert Simon, who argued that 50,000 hours or more of practice allows the chess master to develop the highly elaborated semantic memory structure necessary to play at the highest level. This semantic structure allows the master to reproduce, after a mere glance, the more than 30 pieces that occupy the chess board in the middle stages of a master level game. This level of performance far surpasses that of a good chess player, yet the memory of the master for a random chess board configuration or for other kinds of information is only average. Practice has given the chess master a way of representing information that comes into play rapidly and effortlessly. The key question here is: how has the brain of the master changed? Might it be possible for sensitive and non-invasive scanning to illuminate the changes in the brains of experts that would enable others to improve their skills? The answer is almost certainly yes, and it seems only a matter of time before it happens.

Posner and Raichle note that:

> uncovering such developmental changes will help us to address many questions about how the brain acquires and attends to new skills, and the methods used may be applied to discover how adults learn second languages and acquire other types of skill.(Posner and Raichle, 1999)

The aspiration is still that the cognitive study of expertise and the neuro-scientific study of learning will merge to produce new levels of understanding of the relation between brain and mind.

'How beauteous mankind is! O brave new world, That has such people in't' (*The Tempest*, 5.1)

One final possibility for the future is suggested in a beautifully illustrated book which seeks an understanding of the mind through the art of Shakespeare and the science of brain imaging (Matthews, 2003). Inevitably, in an area of rapid technological growth such as imaging there is the urge to move forward without always referring to and connecting with the past. These writers relate their arguments to Shakespeare, noting that he was concerned not only with the normal brain, but 'he also observed keenly brain diseases which challenge us now'. So, for example, he probed aspects of madness with Hamlet, Ophelia and Lady Macbeth, and in King Lear he addressed the problems of aging and dementia that are so critical in the twenty-first century, while in Julius Caesar, he shows how the crowd wondered at Caesar having had a fit in the market square. Shakespeare also observed the way drugs change the mind and behaviour, and these words of Cassio are just as relevant to contemporary society as they were to the Elizabethans:

> O, God, that men should put an enemy in their mouths to steal away their brains! That we should with joy, pleasance, revel and applause, transform ourselves into beasts!

This book, *The Bard on the Brain*, would be a powerful introduction for students to the worlds of both Shakespeare and the modern science of brain imaging. One page in particular would hold their interest, where it shows the juxtaposition of PET scans of normal brains and those of murderers! Pupils would find the arguments about diminished responsibility because of poorly functioning frontal lobes very interesting, rather as Richard III appeals to the audience that his evil acts are due to his deformities (Matthews and McQuain, 2003).

There are wonderful images from brain scanning which are easily found on the web. Here are two books which provide useful and interesting information on this theme.

Images of Mind – Posner and Raichle (1999)

Although the field of brain imaging has moved on since this prize-winning book was written, it nevertheless provides a sound background to the techniques of scanning. The authors provide a rich interpretation of the networks of anatomical areas that become active during the performance of mental tasks. They provide a clear visual picture of the ways in which we are beginning to measure human thought processes, while acknowledging that we are at the beginning of a journey which has yet to include the impact of multiple assemblies of cells within the brain. The book provides clear and readable explanations of the foundations of cognitive neuroscience.

The Bard on the Brain: Understanding the Brain Through the Art of Shakespeare and the Science of Brain Imaging – Matthews and McQuain (2003)

This wonderful collaboration blends the beauty and mystery of the human mind with new insights into its workings. The writers combine 35 beautiful passages from Shakespeare's plays with images of the brain. The themes are challenging both for teachers and students. There are sections on 'Minds and Brains' with quotations from *Hamlet* and *The Tempest*, 'Drugs and the Brain' with Falstaff in praise of alcohol, and Juliet's farewell. A must for any student of art or science!