Psychology Factsheets

www.curriculum-press.co.uk Number 213

Using Technology to Investigate Cognitive Processes

This Factsheet explores two types of neuroimaging technology used in cognitive research. Guidance is given on writing effective examination answers on this topic and terms in bold are explained in the glossary. There is a worksheet that allows you to test your knowledge in exam style questions.

Why do psychologists use neuroimaging technology?

Cognitive neuroscientists use neuroimaging technology in order to capture and analyse brain activity (especially cortical activity), while someone performs a cognitive task such as solving a mental arithmetic problem. The main value of neuroimaging technology for psychologists is that it can suggest how the different brain regions involved in a particular mental activity co-operate with each other. This Factsheet describes two of these technologies and gives examples of their use in cognitive research.

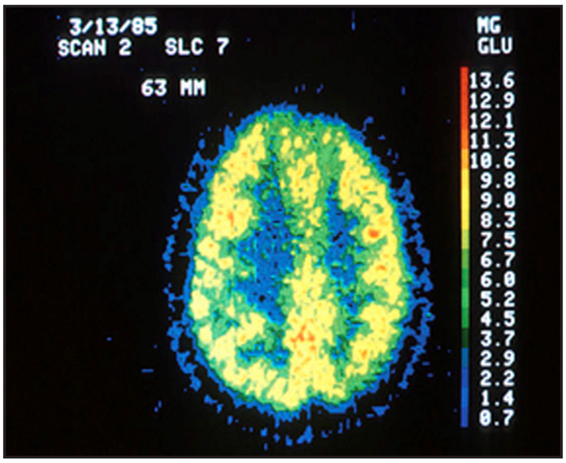
Positron Emission Tomography (PET)

Most of the cognitive research that has employed PET scanning technology has used cerebral blood flow as a measure of brain activity. The result of a PET scan is a **false-colour image** of the brain, which can be viewed as a set of discrete "slices" taken vertically, horizontally or at any angle in between. The false colour identifies high (red), intermediate (yellow and green) and low (blue) activity areas of the brain. When this information is correlated with instructions to the subject to engage in a particular cognitive activity, such as reading or looking at pictures, the scanner shows which parts of the brain were most active when that activity was performed.

A typical PET scan facility

Photographer: J Maus

Public domain (http:// jens-maus.de)



PET scan showing no evidence of pathological change

Source: NIMH USA

The design of research using PET scanning

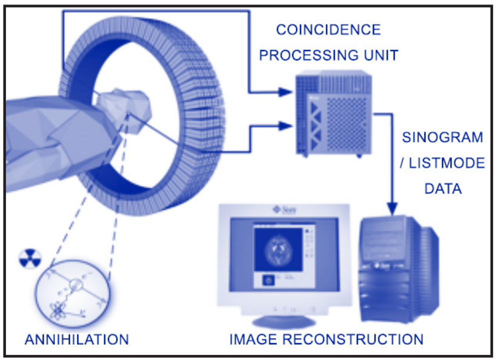
A typical experiment uses 6-10 scans per subject made 10-15 minutes apart and then averaged over all subjects in the same experimental condition. Two conditions are used: a **target condition** and a **reference condition**, which differ in terms of the cognitive process that is being studied. The measure of brain activity associated with that process is obtained by subtracting the activity observed in the reference condition from that in the target condition. Hence this method is known as the **subtraction method**. The higher level of blood flow typically found during the target task is called "activation".

How is the scanned image obtained?

First, a radioactive tracer in a glucose carrier is injected into the subject's bloodstream, which carries radioactivity to the brain. The tracer is typically a radioactive **isotope** of oxygen i.e. an unstable atom which has a **half-life** of 2 minutes. This isotope will quickly decay, thus minimising the possible harm to the subject. The PET scanner is able to detect the distribution of this tracer substance in the brain as it provides an index of cerebral blood flow and thus the pattern of brain activity. Because the more active areas of the brain convert glucose into energy at faster rates than less active areas, more radioactive material is taken up by the active regions.

> ***Exam Hint:*** *It is unlikely that you will be expected to provide this level of detail on the workings of the PET scanner. The essential points to understand are (a) the presence of radioactivity and (b) the fact that it can be used to show which areas are most active.*

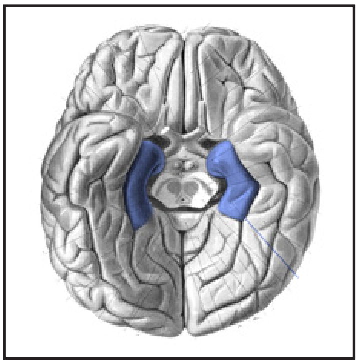
The radioactive material emits subatomic particles called **positrons**. Each positron only travels through tissue for a short distance, typically less than 1 mm, and as it travels it loses energy until it collides with a nearby **electron**. Both electrons and positrons are destroyed by the collision, but each annihilation produces a pair of **photons** that move in approximately opposite directions. When these photons reach the scanner, they can be detected. The data is stored on a computer. The subtraction method is then used to establish which parts of the brain were active while cognitive activity was taking place. Each test is usually run twice; once as the reference condition, once as the target condition, and the two sets of results are compared.



Formation of a brain image using PET

Example of research using the PET scan

Sergent et al(1992) were interested in investigating whether different regions of the brain were involved when subjects were viewing different types of images. The task involved deciding whether an object was living or non-living or whether images of unfamiliar faces belonged to males or females. The reference task required participants to decide whether a set of parallel lines was oriented vertically or horizontally. The researchers found that activation in response to the target tasks occurred in different and distinct regions of the **cerebral cortex**. There was a strong tendency for the processing of objects to be found in the left hemisphere only, while processing of faces occurred on both sides of the brain. These results provided the first evidence about the crucial role in face recognition that is played by one particular area, the **parahippocampal gyrus** of the right hemisphere.



The para-hippocampal gyrus is shaded in this view of the brain

Sobotta's Textbook and Atlas of Human Anatomy 1908 / Sobo 1909 630.png

Strengths and limitations

The development of the PET scan meant that researchers could obtain a visual image of localised brain activity taken from a fully conscious research subject. This means that subjects can be directed to engage in specific cognitive tasks and can give immediate feedback to the researcher.

Its other main strengths are:

- It offers an economical way of using research time since it allows for re-testing and multiple trials.
- PET scans are unaffected by small movements of the body such as the jaw movements that occur when reading aloud. Therefore, the range of research topics that can be investigated is not limited by the technology.
- The half-life of the oxygen isotope is only two minutes so the amount of radiation exposure involved is small.

PET scanning technology also has a number of significant limitations:

- A PET scan lasts from 40 to 70 seconds so all neural activity during the scanning period appears in the same brain image. If the experimental task lasts only a few seconds a PET scan cannot measure the brain activity that is specifically associated with one trial but only the total brain activity that takes place during the scan.
- A weakness of the subtraction method is that it does not identify all the brain regions involved in a certain behaviour but only those that show a significant change in activity between reference and target tasks.
- The target and reference tasks must differ only in respect of the single cognitive process that is of interest in order to achieve **internal validity**.
- PET scan technology is expensive. It not only requires a machine located in a dedicated facility and operated by highly trained personnel but it requires radioactive isotopes which are costly to use.
- Safety issues with the radioactive material mean that longitudinal studies are not possible because the radioactive isotope cannot be administered more than a small number of times.
- There is a potential to miss small but significant changes occurring in the brain.
- The **ethical standards** of medical practitioners and psychological researchers discourages invasive procedures which have the potential to cause harm.

> ***Exam Hint:*** *Try to focus on those limitations that may have most effect on the research. For example, cost is less important than low temporal resolution of the scanning process.*

Functional Magnetic Resonance Imaging (fMRI)

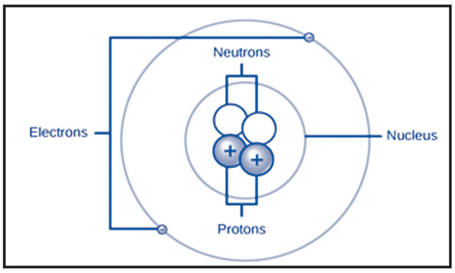
fMRI provides a non-invasive and safe alternative to the PET scan. It produces a similar image of localised brain activity but works in a different way. It involves exploiting the magnetic properties of oxygen-rich arterial blood compared to oxygen-poor venous blood. Blood flow and blood oxygenation levels are strongly connected to levels of neural activity and these variables are used by the fMRI system to give an indirect measure of neural activity. Brain activity shows up on the scan as a false- colour image in which the more active regions are brighter colours such as yellow and red and the less active are darker colours such as blue.

How does it work?

This system utilises the response of the hydrogen atom to strong magnetism. The scanner generates a magnetic field about 50,000 times stronger than the Earth's magnetic field. Magnetism at this strength is so powerful that it affects the behaviour of the **nuclei** of hydrogen atoms in the blood.

Normally these nuclei, which consist of both **protons** and **neutrons**, are oriented in random directions but when a human body is placed in the magnetic field the nuclei align themselves with the direction of the magnetic field; the stronger the field, the closer the alignment. When pointing in the same direction, the minute magnetic signals from the hydrogen nuclei combine to provide a signal that can be detected and measured. Because blood is composed of approximately 90% water (H_20), the signal can be used to track changes to cerebral bloodflow. Such changes can be used as an indicator of neural activity.

The fMRI system also tracks the way oxygenated blood is exchanged for de-oxygenated blood. When neurons become active, local blood flow to those brain regions increases and oxygen-rich blood begins to displace oxygen-depleted blood. This increase rises to a peak after about 4–6 seconds, and then falls back to the original level and these changes to cerebral blood flow in response to changing demands for oxygenated blood are known as the **haemodynamic response**.

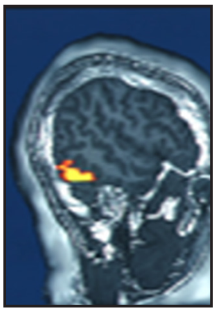


The structure of a typical atom

The successful tracking of blood oxygenation depends on the magnetic properties of the **haemoglobin** molecule. Deoxygenated haemoglobin is more magnetic than oxygenated haemoglobin, which is virtually resistant to magnetism. It is this difference in magnetic properties that produces differences in the signal obtained by the scanner. And, by indicating the various levels of oxygenation it can show the different levels of activity in different parts of the brain in more detail.

Exam Hint: *fMRI tracks changes to both cerebral blood flow and blood oxygenation in order to produce an image and an exam answer should refer to both aspects of this technology.*

Like the PET scan, research using fMRI scans typically report data that have resulted from the subtraction method. For example, the results of an fMRI scan of a subject who has been looking at faces can be obtained by taking the result of a scan obtained while the subject was not looking at faces and subtracting those data from the data obtained while the subject *was* looking at face.



fMRI scan of a subject who has been asked to look at faces.

Strengths and limitations

fMRI scanning offers researchers a way of obtaining images of brain activity by means of a technology that has a number of strengths including:

- Fast, non-invasive and completely without risk to subjects.
- Opportunity for testing under controlled conditions, with the possibility of repeated testing.

On the other hand, there are limitation to the usefulness of fMRI as a research tool:

- Costly to use and maintain.
- Those who can be scanned excludes those with metallic implants and those who cannot tolerate the scanning process.
- Changes to blood oxygen levels provide only an indirect indicator of neural activity and may be affected by non-neural factors.
- Changes in the blood supply, which are the basis of fMRI, are much slower than the electrical signals in the nervous system, so the scanner may not register extremely short bursts of activity.
- fMRI suffers from a poor **signal-to-noise ratio** in the output from the scanner. This is usually dealt with by using software to minimise the problematic "noise". Some software assumes that "noise" will be uniform across the whole brain, thereby making neural activity appear more uniform than it really is.
- fMRI has been criticised for encouraging an over-simplified view of how the brain works. It shows localised activation of one or more specific regions of the brain and therefore implies that the activity in a particular area is caused by a particular cognitive process.

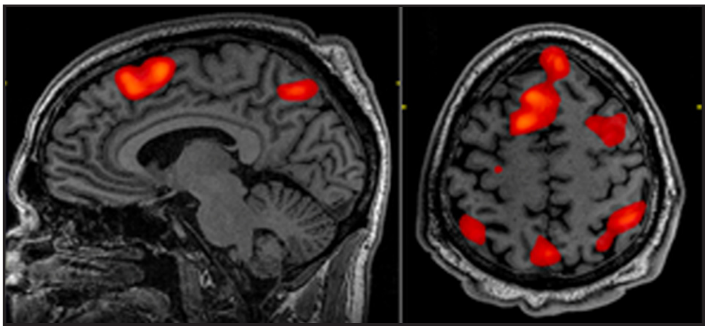
Exam Hint: *The limitations of fMRI can appear more numerous than its advantages but this should not lead you to argue that it is a poor technology for research purposes.*

Examples of research fMRI

Kozel et al (2005) used fMRI to show that specific regions of the brain were activated when subjects lied. Participants took part in a staged mock crime in which they stole either a ring or a watch. They were questioned about their activities while undergoing an fMRI scan. They were instructed to deny taking either of the valuables, thereby telling the truth in some of their responses and lying in others. The test for the researchers was whether they could correctly distinguish the truthful responses from lies on the basis of the fMRI scan. They found that they could correctly identify the truthful answers in 90% of trials

Corkin et al. (1997) used fMRI scanning to investigate memory loss caused by childhood trauma. The patient HM suffered a head injury at age 7 when he fell off his bicycle, injured his head and began to have epileptic seizures. By the age of 27 the epileptic attacks prevented him from living a normal life and surgery was performed to remove parts of his temporal lobes in an attempt to stop the seizures. The surgery was successful in that the seizures no longer occurred, but H.M. suffered from memory problems for the rest of his life. Most of his memories from before the operation remained, known as partial **retrograde amnesia**, but he could no longer store new memories, known as **anterograde amnesia**. HM could no longer process new **semantic** and **episodic memories** although his ability to form **procedural memories** appeared unaffected. Fifty years later Corkin et al used fMRI scanning to investigate the extent of damage to HM's brain. The scan showed that in addition to the expected temporal lobe damage, most of the hippocampus had also been destroyed by the operation and there was too little left to support normal memory function. This study was one of the first to use modern scanning technology to identify the biological basis of cognition.

Exam Hint: *Make sure you explain why your example research makes good use of the capabilities of the fMRI system to uncover new information about cognitive functioning.*



Two views of the brain during a working memory task

Conclusion

The PET scan was a state-of-the art technology in the late 1980s when it was first developed. It has been handicapped by the fact that it involves both exposure to radiation and an invasive process, which render it ethically problematic as a research tool. It has since been largely superseded by non-invasive and cheaper techniques such as fMRI. While rapid progress has been made, scanning technology is still relatively undeveloped and is currently unable to detect the very subtle brain activity which must be present and which would offer great promise of increasing our understanding of cognition. Until further strides are made in improving the resolution of scanning technology our knowledge and understanding of how the brain works will remain incomplete.

GLOSSARY

Anterograde amnesia: The inability to remember events that happen after a particular point in time; an inability to create new memories.

Cerebral cortex: The outer layer of the brain.

Cognitive neuroscience: The branch of psychology that aims to construct a detailed knowledge of what is happening in the brain during cognitive processes.

Electron: A subatomic particle carrying a negative electrical charge.

Episodic memory: Memory for events.

Ethical standards: The set of guidelines that are intended to ensure the physical safety and psychological well-being of participants.

False-colour image: An image of the brain in which different levels of activity are indicated by different colours which have been digitally added to the data after the scanning process has been completed.

Functional Magnetic Resonance Imaging (fMRI): The method of obtaining an image of brain activity by tracking the magnetic properties of blood.

Functionally induced change: A change in the level of brain activity that occurs as a result of normal cognitive functions such as remembering or perceiving.

Haemodynamic response: Variations in the brain's demands for oxygenated blood that produce changes to cerebral blood flow.

Haemoglobin: The blood component that is responsible for the transport of oxygen.

Half-life: The time taken for an isotope to lose half its radioactivity.

Internal validity: Is the extent to which a study examines what it set out to examine.

Neutron: A sub-atomic particle that carries no electric charge.

Nuclei (of atoms): The central core of an atom consisting of both protons and neutrons.

Parahippocampal gyrus: Area of the brain close to the hippocampus.

Photon: An elementary particle of light.

Proton: A subatomic particle that carries a positive electrical charge.

Positron: A subatomic particle that has the same mass as an electron but has a positive electric charge.

Positron Emission Tomography: A scanning technology that uses the behaviour of the positron subatomic particle to generate an image of the brain (see also **Tomography**).

Procedural memory: Memory for processes.

Reference condition: The equivalent of the control condition in experimental research.

Retrograde amnesia: The inability to recall existing memories.

Semantic memory: Memory for the meaning of words.

Signal-to-noise ratio: The ratio between the useful or coherent information in a signal and the simultaneously present level of background interference.

Spatial resolution: A measure of the ability of the scanning system to distinguish small areas of the brain.

Subtraction method: A technique which allows seeing which areas of the brain were active during the experimental task. Because the brain is active all the time it is necessary to subtract reference condition data from target condition data to remove the effects of irrelevant activity.

Target condition: The equivalent of the experimental condition in an experiment.

Temporal resolution: A measure of the ability of the scanning system to distinguish events of short duration such as a nerve impulse.

Tomography: Technology that uses penetrating waves to construct a view of an object, such as a brain, as a series of slices or sections.

Acknowledgements: *This **Psychology Factsheet** was researched and written by **Colin Dyer**, edited by **Jeanine Connor** and published in **September 2017** by **Curriculum Press**.* ***ISSN 1351-5136***

Worksheet: Technology and Cognitive Processes

Name: ____

1. Describe how **EITHER** PET scanning **OR** fMRI scanning is able to produce an image of the brain.

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2. Why do ethical difficulties arise in the use of PET scans in research?

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3. Which advantages of the PET scan are likely to be most useful to a research psychologist investigating cognition, and which limitation(s) are likely to be of most concern? Give reasons for your choices.

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4. Briefly outline three limitations of fMRI scanning. How do these affect the conclusions that may be drawn from a scan?

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5. Describe one piece of research that has used fMRI scanning and suggest why that technology was employed.

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