Neuroimaging

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Introduction

Neuroimaging[1] is a term for several different techniques that are used to visualize the brain or brain parts and brain activities. The development of those techniques was extremely helpful in studying the brain since for the first time it allowed us to look at and take measurements from living and working brains.

Before Neuroimaging came along most information from the brain was gathered by destructive techniques, like vivisection. The problem with this was that you either had to rely on animals or use dead humans. So it was nearly impossible to study topics like brain development or how external influences take effect on the brain. Neuroimaging changed that and now allows us to conduct experiments on humans without inflicting stress, pain or injuries and at the same time to get a unique insight into the workings of the human mind.

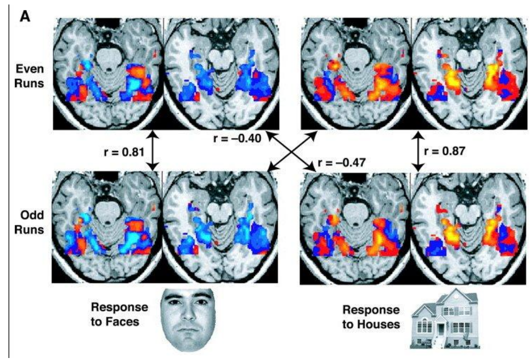

Figure 1: fMRI images from a study about human responses to images

Neuroimaging can be divided into two groups, structural and functional neuroimaging. Structural neuroimaging techniques are Computed Tomography (CT) and Magnetic Resonance Imaging (MRI). They allow insight into anatomic details of the brain for example to locate tumors or brain injuries. Functional techniques are Single Photon Emission Tomography[2] (SPECT), Positron Emission Tomography[3] (PET), Magneto Encephalography[4] (MEG) and functional MRI[5] (fMRI). They can give insight into how the brain forms thoughts by visualizing changes in the metabolism, electric current and blood flow in the brain. This can go as deep as visualizing how semiochemical particles are used to communicate between neurons. Both techniques can be combined in order to show where exactly functional changes in the brain are located anatomically.

The remainder of this report will present different functional neuroimaging techniques and how they work and show application areas where they have been used. This is followed by a discussion of the problems of the technology.

How Neuroimaging works

Even so the techniques are different they rely on similar principles. The brain is "sliced" into many layers and each layer is then divided into cubes, called voxels. The brain brain activity in each of the voxels is measured and the results are visualized using different colors (See Figure 1). The main difference is how the different techniques measure the brain activity. There are two categories here. The first one makes use of existing materials or phenomena in the body (E.g. electrical currents) to measure brain activity. The second category adds tracing materials into the body that can then be detected by the scanners.

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[1] http://en.wikipedia.org/wiki/Neuroimaging
[2] http://en.wikipedia.org/wiki/SPECT
[3] http://en.wikipedia.org/wiki/Positron_emission_tomography
[4] http://en.wikipedia.org/wiki/Magnetoencephalography
[5] http://en.wikipedia.org/wiki/Fmri

fMRI is a modified version of the traditional MRI technique. MRI makes use of a physical phenomenon called Nuclear Magnetic Resonance (NMR). The effect is that magnetic nuclei that are exposed to a magnetic field absorb and emit electromagnetic-radiation at different strength, which is dependent on the isotope of the atoms. The MRI machine emits such magnetic fields and can detect the changes of some nuclei in response to the field. This information can then be used to construct 2D and 3D images of the scanned objects (E.g. brains, hearts). It is very good for creating images of soft tissue like the one in the brain.

	Temporal Resolutio	Spatial Resolution	Detects	Uses Tracers?
fMRI[1]	2-5 sec	1-1.5 mm	Hemoglobin in the blood	No
MEG[1]	1 msec	5 mm	Magnetic Fields caused by electrical currents	No
SPECT[1]	> 60 sec	6-8 mm	Positrons	Yes
PET[1]	45 sec	4 mm	Positrons	Yes

Table 1: Comparison of different functional neuroimaging techniques

fMRI uses the MRI technique to visualize neural activity in the brain. Neural activity in the brain increases the demand for oxygen in the active part of the brain, which in turn causes oxygen rich blood to flow into the active parts. This is called the Blood-Oxygen-Level Dependent (BOLD) effect and can be detected via an fMRI by detecting the Hemoglobin in the blood flow. Depending on the application other markers besides Hemoglobin can be used. This technique offers good spatial resolution but the temporal resolution is limited by the reaction of the body, since the effects of the increased oxygen are not instantaneously measurable.

MEG uses very sophisticated magnetometers to detect the magnetic fields that are created by electrical currents in the neurons. Its spatial resolution is not as good as the one from fMRI, but since it tracks electrical currents instead of elements in the blood it has a much higher temporal resolution due to the fast expansion of the electrical signals in the brain. MEG works with very weak magnetic signals and is very prone to background noise. The aperture for a MEG has therefore to be housed in a highly magnetically shielded room, which makes it very immobile.

SPECT and PET rely on infusions of gamma emitting radioisotopes into bloodstream. While in the body the tracing material emits positrons which can be detected by the scanner and turned into images of the affected area.

Since fMRI and MEG do not rely on harmful ionizing radiation and doesn't need injection of a contrast medium it is very useful for human studies. Experiments can be easily repeated without harm to the patients due to long term exposure to ionizing radiation which can destroy human tissue.

Applications areas of Neuroimaging

Neuroimaging has been used in a wide range of human studies. Researchers are particularly interested in studying attention, memory, comprehension, language, perception and reasoning [2]. The authors of [3] give an overview about a series of studies done with non-responsive patients. The goal of these studies was to research the different states of consciousness and awareness of patients. For this researches looked at the brain activity of patients (E.g vegetative patients, sedated patients) and how it changes in response to external stimuli (E.g. their names). They showed that several patients who are unable to give any physical responses still show responses in brain activity similar to healthy patients. This information could be used in the future to communicate with people in a vegetative state.

Learning and memory is another topic with a lot of research activity. [2] analyzes recent studies about learning. According to the authors researches are particularly interested in trying to analyze how information is organized and stored in the brain and how it is recalled. Decision making is an issue in neuroeconomics and neuromarketing. They are interested in the decision making process in context with economics and marketing and use these to improve economic models or trying to sell products.

Another field that makes use of neuroimaging is Neurophilosophy which uses studies to research the philosophy of mind, especially in the debate about freedom of will. Results here show that mental processes are correlated with brain activity and that most mental processes are unconscious[2]. The experiment from Libet and later follow ups are one of the most influential experiments and indicate that decisions happen unconsciously and we are only aware of the decision later on[4][5].

Problems of Neuroimaging

Besides the technical limitations which are mainly the spatial and temporal resolution and the size of the machinery which makes them very immobile and not always perfect for human studies (E.g. Limited movement) there are also ethical problems with this technology. Spatial resolution is increasing more and more and is becoming less of a limiting factor, but it is still not possible to single out neurons but only groups of them inside a voxel. There are some inherent limitations when it comes to temporal resolution, namely reaction time of the body functions that are measured.

Ethical concerns are mainly focused on privacy and self-determination. People are raising concern that researches in neuromarketing for example can find something like a “buy button” that could cause people to act against their will and buy products even if they don’t want to. Privacy is a big concern when it comes to research into “mind reading” where neuroimaging is used to try to extract information from people. Main advocates of this technology are police and intelligence agencies.

References

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