

BRAIN IMAGING – ONE STEP CLOSER TO MIND READING

Dragan Marinković¹, PhD;

¹ University of Belgrade – Faculty of Special Education and Rehabilitation, Belgrade, Serbia,
dragan.marinkovic@hotmail.com

Abstract: *The new research methodology of brain imaging has aim to make link between vast complexity of human perceptual, emotional and cognitive processes on one hand, and the human brain on the other side. Numeral brain imaging techniques are nowadays accessible: Computerized Tomography, Positron Emission Tomography, Magnetoencephalography, Magnetic Resonance Imaging etc. The technique most frequently used in order to detect “brain in action” is functional magnetic resonance imaging (fMRI). fMRI detects a hemodynamic response, the reaction of the vascular system, to the enlarged necessity for oxygen of neurons in a activated area. The technique has many potential practical applications including reading of brain states, brain-computer interfaces, communicating with locked-in patients, lie detection, etc. In this paper some of the advances of application of fMRI in mind reading and their potential implication have been discussed.*

Keywords: *brain, neuroimaging, fMRI, mind reading*

INTRODUCTION

For centuries people have aspired to understand relations between mind and brain, in other words to comprehend the physical basis of what we experience subjectively as the mind. Cognitive neuroscience is science discipline working on this problem for last four decades. Developments in research methodology play a crucial part in the progress of cognitive neuroscience. The new research methodology has aim to make link between vast complexity of human perceptual and cognitive processes on one hand, and that of the human brain with approximately 10^{11} neurons and 10^{15} synapses on the other hand. The ultimate goal is clarifying the biological and neural basis of perceptual, cognitive and emotional functions in humans. Our capacity to link brain structure and function has been revolutionized since the mid-1970s because of the introduction of different brain imaging techniques.

Brain imaging techniques (neuroimaging techniques) are based on physical and physiological features of different tissues composing the brain. Depending on type of the information that they are providing brain imaging techniques could be classified as structural and functional. Structural brain imaging techniques could give us view to the static map of brain organization, while functional brain imaging deliver view in the “brain in action”. Prior to development of brain imaging techniques researchers had to wait for postmortem examination of the brain to pinpoint destruction that had occurred years or decades prior, or they had to predict the location of brain damage from limited medical records or from exams. Nowadays such imaging techniques are convenient to researchers using the lesion method because they permit the location of damage to be identified much more accurately than formerly possible in living patients. Advance in these non-invasive functional neuroimaging techniques has been very rapid. These techniques let us to record brain activity throughout presentation of different stimuli and execution of tasks in both healthy volunteers and patients. Modern brain imaging technology, alongside with refined signal analysis algorithms, offers possibilities for researchers that one could only have dreamt of a few decades ago. Today we can even detect such imaging patterns of brain activity that can be related with precise thoughts.

Numeral functional brain imaging techniques are accessible to examine the question of how and where in the brain specific perceptual and cognitive processes occur. Tasks or tests can be designed to place varying levels of demand on the cognitive, sensory or motor capacities of the participant that being tested. Performance of these tasks is then associated with physiological measurements, and on the basis of these results, we may attribute functions to areas of the brain. In this way functional brain imaging is linked to classical phrenology method. One has to be aware that none of the cognitive neuroscience methods existing today can deliver all the necessary information to solve the final question of neuroscience: how brain works. Each of these techniques provide us information that helps answering the final big question.

Brain imaging techniques vary in what specific feature of brain function they detect. Some of the techniques measure electric potentials (Single cell recordings and Electroencephalography) or magnetic fields (Magnetoencephalography and Magnetic resonance imaging) caused by huge populations of neurons. Some others measure the blood flow changes (functional Magnetic resonance imaging) that are tightly coupled with local changes in neuronal activity, or radioactivity of the radionuclide labeled probed injected in to blood flow of patients (Positron Emission Tomography).

Before invention of state of the art brain imaging techniques, behavioral studies have produced most of what is known about cognitive functions and their underlying neurobiological mechanisms. Progresses in physics have made accessible X-rays, radio waves and gamma rays which, coupled with computing power and software analysis that is based on some methodology borrowed from psychology, afford the means to image data measured from the brain. Some of the functional brain imaging techniques provide both detailed measures of brain structure and measures of when and where brain activity occurs during cognitive and emotional processes. Computerized analyzes and construction of the data allows the design of two-dimensional (2-D) or three-dimensional (3-D) images.

BRAIN IMAGING TECHNIQUES

Several brain imaging techniques could be used to image brain static structure. They differ in physical feature that is used to provide information about structure of intact brain in someone's head.

The density of brain structures can be determined with X-rays in a process called computerized tomography (CT) [1]. Technique is based on application of x rays in order to inspect density of tissues that they penetrate, but with improved possibility to make huge number of images that are analyzed using computer software. Collimated beams of X-rays are rotated around the head and pass through the brain, losing energy in proportion to the density of the various tissues (grey, white matter, cerebrospinal fluid and the skull). On images obtained using this technique, dense tissue such as bone appears white, whereas material with the least density, such as cerebrospinal fluid appears black. CT scans provide a series of 8-9 “slices” of the brain stacked one above the other. The advantage of CT technique is that is inexpensive and there are no restrictions on who can receive a CT scan, in contrast to other techniques.

Magnetic resonance imaging (MRI) activates using short-lived radiofrequency pulses the inherent distribution of hydrogen atoms that are present in the brain tissues, after they have lined up themselves in the strong magnetic field produced by a superconducting magnet placed around the subject's head. The information recorded about how long the hydrogen atoms take to recover from this distortion is then used to create an image of the anatomy of the brain. Because hydrogen atoms in different substances have different relaxation times, various parameters of the pulse sequence could be determined to maximize the ability to image certain brain tissues. The intensity of the signal received by the receiver coil indicates the concentration of the particular substance in the brain. MRI technique has two main advantages over CT. MRI do not require X-rays, so they do not involve transmitting high-energy ionizing radiation through the body, and the clarity of the picture (spatial resolution) is much better.

Although functional brain imaging techniques are often used to investigate patients with known or suspected brain damage due to development of the disease or collision, these techniques can also be used in neuroscience to study neurologically intact and healthy individuals. These techniques permit scientists to notice the grade to which a brain structure in a neurologically intact individual is activated by a specific cognitive task like object recognition or word pronouncing). This way contribution of certain brain region to task performance can be directly observed under normal circumstances. Neuroimaging techniques also allow scientists to detect the whole network of brain structures that act in performing a specific cognitive function, by revealing all brain regions that are active. Functional brain imaging techniques are opposite to lesion method, in which implications about a brain region's contribution to a task are made as a result of dysfunction.

Electroencephalography (EEG) is one of the oldest noninvasive technique for detection of brain activity. This technique reflects populations of synchronized and desynchronized oscillations of the brain's ongoing electrical activity that is mostly cortical dendritic activity [2]. Electroencephalography waves of different types (different frequency, amplitude and shape) like delta, theta, alpha, beta offer an index of diverse levels of arousal and activation. Event related potentials (ERPs), measured brain response that is the direct consequence of a specific sensory, cognitive, or motor event, reflect averaged momentary electrical potentials that are time-locked to the repeated presentation of discrete stimuli.

Magnetoencephalography (MEG) uses specialized superconducting detectors and sensing coils to detect and quantify magnetic fields that surround the currents that are basis for EEG technique. Actually, electric field is always accompanied with magnetic field, and together they represent electro/magnetic field. The magnetic fields mainly reflect currents induced within neurons that are orientated parallel to the skull. These fields have quite low intensity that in order to detect them strong magnetic field of the Earth should be blocked. Equipment used to

detect magnetic field is therefore more sophisticated and more expensive comparing to one used to detect electric field in EEG.

Positron emission tomography (PET) is based on the use of high-energy ionizing radiation, although in this event the radiation is emitted by a substance introduced into the body rather than by radiation passing through it [1]. In PET imaging, molecules altered to have a radioactive atom are introduced into the blood supply and carried to the brain. Brain areas of high metabolic activity emit many photons of light from the radionuclides, whereas those that are less active emit less. From data obtained by the detectors, computers extrapolate backward to determine the point from which the photons emanated, allowing the activity of various brain regions to be determined. PET has two main advantages. First, it allows researchers to examine how the brain uses specific molecules like metabolites or neurotransmitters, and PET provides information on absolute levels of brain metabolism. Increased neural activity is associated with local changes in blood flow, oxygen use, and glucose metabolism all of which can be measured with PET. In other words PET measure brain activity in brain regions active during certain cognitive or emotional process. PET has been eclipsed by fMRI for a variety of reasons. First, like CT, PET includes ionizing radiation and therefore the number of scans an individual can undergo per year is limited. Second, the temporal and spatial resolution of PET is lower comparing to functional MRI. Although PET has many restrictions, it is still the preferred technique for examining neurotransmitter function in the brain.

FUNCTIONAL MAGNETIC RESONANCE IMAGING (fMRI)

Without any doubt, the technique most frequently used by cognitive neuroscientists in order to detect “brain in action” is functional magnetic resonance imaging (fMRI). fMRI is based on the fact that local blood flow increases during activation of the brain regions involved in perceptual, emotional and cognitive processes. With functional magnetic resonance imaging, neuroimagers are able to map the following types of physiological information: baseline cerebral blood volume, changes in cerebral blood volume, quantitative measures of baseline and changes in cerebral perfusion, changes in cerebral blood oxygenation, the resting-state cerebral oxygen extraction fraction, and changes in the cerebral metabolic rate for oxygen [3].

The procedure and device are basically same to the one used in conventional MRI. Emitted radio waves cause the hydrogen atoms (protons) to oscillate, and a detector of the device measures local energy fields that are emitted as the protons return to the orientation of the magnetic field created by the device [4]. However, with fMRI technique imaging is focused on the magnetic properties of the deoxygenated form of hemoglobin (deoxyhemoglobin) that is transported by blood circulation to the active parts of the brain. Deoxyhemoglobin is paramagnetic and has weak magnetic features in the presence of a magnetic field, whereas oxygenated hemoglobin has not.

Detectors of the fMRI measure the ratio of oxygenated to deoxygenated hemoglobin. fMRI results are reported as an increase in the ratio of oxygenated to deoxygenated hemoglobin. This change occurs because, as a region of the brain becomes active, the amount of blood being directed to that area increases. The neural tissue is unable to absorb all of the excess oxygen. Detected value is referred as the BOLD, blood oxygen level-dependent, effect. When a specific brain area is active, the local increase in oxygen-rich blood is greater than the amount of oxygen that can be extracted by the brain tissue. Consequently, the relative fraction of oxygenated blood to deoxygenated blood increases in that activated brain region, and decrease in deoxygenated blood permits increased signal clarity from which a picture of brain activity can be derived.

Application of fMRI involves always comparing of two conditions, the condition of interest that correspond specific brain region activation, and baseline that correspond to basic and unspecific activity of the brain [2]. The selection of the appropriate baseline is crucial for clarification of the results. In example, if someone needs to determine brain regions specifically involved in processing faces above and beyond other nonface objects, then brain activation while viewing faces must be compared to a baseline of brain activation while viewing nonface objects. In contrast, if the someone wants to determine all the brain regions involved in visually analyzing a face, then brain activation while viewing faces has to be compared to a baseline of brain activation while viewing a very basic visual form such as a cross.

fMRI is not the technique that measures directly activation of neurons that are responsible for the cognitive processes. Rather, it detect a hemodynamic response, the reaction of the vascular system to the enlarged necessity for oxygen of neurons in a local area. This fact has at least two consequences. First, although there is strong correlation between hemodynamic response and activity of specific brain region in cognitive action, it is only correlation. Thus, fMRI does not measure directly someone thoughts but rather give us indirect information of possible involvement and response of certain brain region in some cognitive function. Second, due to necessary time for blood circulation this response is slow, starting about 2 seconds after a stimulus is presented, peaking at about 6–8 seconds, and falling back to baseline by about 14–16 seconds. Temporal resolution of fMRI is much faster comparing to PET, although it is slow compared to some other methods, such as EEG that measures direct activation of neurons.

There are several advantages in application of functional magnetic resonance imaging for observing brain in action. fMRI is performed using regular clinical MRI machines that have the appropriate hardware and software to

enable the procedure. Importantly, it is noninvasive technique, because no high-energy radiation is involved in the procedure. Using fMRI multiple scans can be performed on a single individual, which allow researches to examine changes in the brain over time like during the process of learning. Clinicians could also observe changes that occurs during recovery of illness as a result of medical treatment. fMRI also provides a measure of brain activity over seconds rather than minutes as is the case with PET. Finally, the precision of scans obtained from fMRI enables examination of brain-behavior relationships in individuals, which makes fMRI particularly useful for clinical interventions such as neurosurgery. Because MRI can be tuned to specific atoms, it can also be utilized to examine the concentration of other biologically active substances via a method known as magnetic resonance spectroscopy [5]. A primary struggle in fMRI is to increase sensitivity which is achieved by increasing the magnitude of the signal change or by decreasing the effects of noise [3].

Other processing steps for increasing sensitivity include temporal and spatial smoothing which is achieved by repeating experiments for several times and applying statistical processing of data using software. Once images are collected, and after motion correction is performed, a time series analysis is carried out voxel by voxel.

Functional imaging techniques such as PET and fMRI have certain limitations that are of great importance to anyone that want to study perceptual, emotional and cognitive processes of the brain. One of the main obstacles is poor temporal resolution of PET and fMRI compared with direct electrophysiological techniques like single-cell recordings. PET is constrained by the decay rate of the radioactive agent, and fMRI is dependent on the hemodynamic changes that underlie the BOLD response. Half-life of the radioactive probe could be only a few minute, while hemodynamic response changes in only a few seconds. A second difficulty arises from the fact that data sets from an imaging study are massive. A huge amount of data make interpretation of the data from a PET and fMRI studies a complicated and doable only using software. Quite often the comparison of experimental and control conditions produces many differences [4]. In example, asking someone to generate a verb associated with a noun (experimental task) involves many more cognitive operations than just saying the noun (control task). Therefore, it is not easy to make inferences about each area's functional contribution from neuroimaging data. At the end, importantly, correlation does not imply causation. Rather than focus on local changes in activity, the data from an fMRI study can be used to ask whether the activation changes in one brain area are correlated with activation changes in another brain area. In this manner, fMRI data can be used to describe networks associated with particular cognitive operations [4].

Even though fMRI is restricted to a lesser degree by scanner technology and to a greater degree by the unknowns regarding the spatial, temporal, and magnitude relationships between neuronal activity and hemodynamic signal changes, progress is being made in overcoming these limitations. A principal avenue by which the limitations of functional magnetic resonance imaging can be overcome is integration with other brain activation assessment techniques [3].

fMRI AS A TOOL FOR MIND READING

In challenges to generate 'maps' of the functional roles of different brain regions that are applicable to all people, neuroimaging measurements have typically been pooled and averaged across many individuals and across many repetitions of a task [6]. Developments in neuroimaging are now being translated into many new potential practical applications, including the reading of brain states, brain-computer interfaces, communicating with locked-in patients, lie detection, and learning control over brain activation to modulate cognition or even treat disease. Mind reading, the ability to understand another person's thoughts, intentions, and feelings [7], is the one of the potential applications.

Real-time functional MRI (rtfMRI), a new improved version of fMRI is exploring the possibility of watching one's own brain activation 'live'. Real-time fMRI permits instant admission to experimental results by exploring information as fast as they are obtained and can thus be used to guide a person's cognitive processes, an experimenter's parameter selections or a clinician's interventions. The accessibility of results throughout enduring experiment facilitates a diversity of applications such as quality assurance or fast functional localization. RtfMRI can also be used as a brain-computer interface (BCI) with high spatial resolution and whole-brain coverage, overcoming limitations of EEG based BCIs. rtfMRI has increased potential to fundamentally alter our ability to 'read' mental states by decoding this information in real time. Thus, modernization of existing brain imaging techniques and potential development of the new ones bring us one step closer to potential mind reading.

So, what would be the mechanism of mind reading using techniques like fMRI or improved version of rtfMRI? When someone is thinking about something, i.e. other person like grandmother, fMRI can show which voxels of the brain are activated i.e. voxels 13-22-15 and 24-22-22. Mind reading through functional MRI is inverting this relationship: if fMRI demonstrates that the subject has active voxels 13-22-15 and 24-22-22, researchers can guess that this person is thinking about a grandmother. Decoding techniques interrogate more of the information in the brain scan. Rather than examining which brain regions respond most intensely to faces, they use both strong and weak responses to identify more subtle patterns of activity. Studies that objects are encoded not just by one small very active area, but by a much more distributed array. These recordings are fed into a 'pattern classifier', a computer algorithm that learns the patterns related with each picture or concept. Once the program has seen enough samples, it can start to deduce what the

person is looking at or thinking about. Until today there have been several research groups that have taken up similar type of procedure to infer subjects' thoughts or actions from patterns of pixels triggered in fMRI images.

Haynes et al. applied pattern classification algorithms to guess the subject's intention to accomplish either an addition or a subtraction of two numbers [8]. By decoding the activity in the anterior medial prefrontal cortex this group was capable to predict the subject's intention with 71% correctness. Decoding of intentions was most robust from the medial prefrontal cortex, which is consistent with a specific role of this region when subjects reflect on their own mental states.

Hassabis and associates [9] asked subjects to virtually move between 8 locations within 2 rooms. By means of a pattern grouping algorithm to analyze the fMRI results, Hassabis and associates were able to guess at which location a subject was standing at a given moment, from the pattern of activation of specific voxels in the hippocampus and parahippocampal gyrus. Hippocampus and parahippocampal gyrus are brain regions involved in spatial memory.

Kay and associates develop a decoding method based on quantitative receptive-field models that characterize the relationship between visual stimuli and fMRI activity in early visual areas [10]. They established how the activity of each voxel in the visual cortex responded to locations, orientations and spatial frequencies presented in 1750 images. During image identification step, they presented images out of a set which was not used during the training session. They were able to guess which image was actually seen by the subject, by previous measuring the response of each voxel to the novel image, and comparing it with the predicted response for each image out of this new set. Their results suggest that it may soon be possible to reconstruct a picture of a person's visual experience from measurements of brain activity alone. A step further was made when the same group developed a decoder that could produce primitive-looking movies of what the participant was viewing based on brain activity.

Horikawa and associates published their efforts at dream decoding [11]. They presented a neural decoding approach in which machine-learning models predict the contents of visual imagery during the sleep-onset period, given measured brain activity, by discovering links between human functional magnetic resonance imaging patterns and verbal reports with the assistance of lexical and image databases. They let participants fall asleep in the scanner and then woke them occasionally, asking them to recall what they had seen. The team tried first to reconstruct the actual visual information in dreams, but eventually resorted to word categories. Their program was able to predict with 60% accuracy what categories of objects, such as cars, text, men or women, featured in people's dreams. Findings of this research group demonstrated that specific visual experience during sleep is represented by brain activity patterns shared by stimulus perception, providing a means to uncover subjective contents of dreaming using objective neural measurement.

All mentioned experiments described first step towards mind reading. Till today, researchers have been developing decoders for various tasks: for visual imagery, in which participants imagine a scene; for working memory, where they hold a fact or figure in mind; and for intention, often tested as the decision whether to add or subtract two numbers. Using a first-person, combat-themed video game called *Counterstrike*, the researchers tried to see if they could decode an intention to go left or right, chase an enemy or fire a gun. Inventing a decoding model that can generalize across brains, and even for the same brain across time, is a complex problem. Decoders are generally built on individual brains, unless they're computing something relatively simple such as a binary choice [12].

In spite of their experimental complexity, the scenarios described stay relatively simple: it is a matter of predicting what you are seeing, doing or planifying within a pre-defined set of possibilities. On the other hand the number of thoughts is infinite, and the mind reading experiment in a broader context would be much more complex. Furthermore, all of these experiments are based on a straight bond between a feature of the stimulus and a neuroanatomical location. This relationship is clear for some functions (somatotopy, retinotopy, tonotopy), but it is more than uncertain for other functions.

CONCLUSION

Functional MRI is a promising tool for potentially reading a mind. The possible applications go beyond the imaginable: reading unconscious thoughts; mind reading in a patient with an altered state of consciousness; lie detector; and so on. This is a powerful kind of tool, which deals with the most private aspect of Self, hence it must be manipulated with care and ethics. Although companies are starting to pursue brain decoding for a few applications, such as market research and lie detection, scientists are far more interested in using this process to learn about the brain itself. Once the mind reading machine appear on the commercial market a new question will arise. Who is allowed to read someone's mind? For what purpose? Is it moral? Is it legal?...

REFERENCES

- [1] Banich, T. M., & Compton, J. R. (2010). *Cognitive Neuroscience*: Wadsworth Publishing.
- [2] Gordon, E. Brain imaging technologies: how, what, when and why? *Aust NZ J Psychiatry*. 1999 apr;33(2):187-96.
- [3] Senior, C., Russell, T., & Gazzaniga, S. M. (2006). *Methods in Mind* (1st ed.). London: The MIT Press.

- [4] Gazzaniga, S. M., Ivry, B. R., & Mangun, R. G. (2013). *Cognitive Neuroscience: The Biology of the Mind* (4th Ed ed.). New York: W. W. Norton & Company.
- [5] Gujar SK, Maheshwari S, Bjorkman-Burtscher I, Sundgren PC. Magnetic resonance spectroscopy. *J Neuro-Ophthalmol* 2005;25:217–226.
- [6] deCharms, R.C. Applications of real-time fMRI. *Nat Rev Neurosci*. 2008 Sep;9(9):720-9.
- [7] Andrew, W. *Natural Theories of Mind: Evolution, Development and Simulation of Everyday Mindreading*. Oxford: Basil Blackwell, 1991
- [8] Haynes JD, Sakai K, Rees G, Gilbert S, Frith C, Passingham RE. Reading Hidden Intentions in the Human Brain. *Curr Biol*. 2007 Feb 20;17(4):323-8.
- [9] Hassabis, D., Chu, C., Rees, G., Weiskopf, N., Molyneux, D.P. and Maguire, A.E. Decoding Neuronal Ensembles in the Human Hippocampus. *Curr Biol*. 2009 Apr 14; 19(7-3): 546–554.
- [10] Kay KN, Naselaris T, Prenger RJ, Gallant JL. Identifying natural images from human brain activity. *Nature*. 2008 Mar 20;452(7185):352-5.
- [11] Horikawa, T., Tamaki, M., Miyawaki, Y. & Kamitani, Y. *Science* **340**, 639–642 (2013).
- [12] Smith, K. Brain decoding: Reading minds. *Nature* 502, 428–430 (24 October 2013)