Cognitive Neuroscience

Objectives

This course provides an introduction into the field of Cognitive Neuroscience. We will learn which methods a brain researcher can use to investigate the neuronal bases for different mental processes. This will enable us to better understand how the brain processes such fundamental functions like attention or memory.

Description of the course

Cognitive Neuroscience is a research field that originally emerged from a combination of traditional sciences such as philosophy, psychology, medicine and biology that all investigate the principles of perception, behavior and cognition from different perspectives.

As technical developments of different methods and tools in the field of cognitive neuroscience came forth, and as theoretical application of different mathematical and computer science-based models were used to explain neuronal functioning, additional disciplines, such as physics, mathematics, bioengineering and computer science materialized as an important part of this research field. Subsequently, an effective research project in cognitive neuroscience requires an interdisciplinary cooperation, in which each scientific discipline contributes its respective genuine theories, models, techniques and tools for the mutual investigation of the neuronal principles of perception, attention, memory, and cognition.

But can we really watch the brain at work? Are there ways to identify where exactly, and when exactly activation in the brain is needed to perform a specific mental process? This course will help to give some answers on the basic principles of brain research.

Tasks

Task 1: Measuring traces of the mind

Task 2: Brain waves

Task 3: Speaking of EEG

Task 4: Visualizing the brain

Task 5: Design is everything

Task 6: Visualizing vision

Task 7: Zapping the healthy human brain ….!?

Task 8: Dimming the spotlight

Task 9: Imagine!

Schedule

Week	**Tasks**	**Lecture**
1: 09-13 Apr	1: Measuring traces of mind 2: Brain waves	Introduction to Neuroscience
2: 16-20 Apr	3: Speaking of EEG 4: Visualizing the brain	EEG/MEG
3: 23-27 Apr	5: Design is everything 6: Visualizing vision	fMRI
4: 30 Apr - 04 May	7: Zapping the healthy human brain…!? **LABTOUR @ FPN**	Vision and Attention
5: 07-11 May	8: Dimming the spotlight	TMS
6: 14-18 May	**PRESENTATIONS** 9: Imagine!	
7: 21-25 May	last post-discussion	
8: 28 May – 01 Jun	**FINAL EXAM**	

General Information

Course planning group

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Exam

There will be one exam at the end of the course. The exam will consist of essay questions that are based on topics dealt with in the tasks, lectures, and reading materials. The score on the exam will make up 75% of your final grade.

Group presentation

The other 25% of your final grade consists of your score on a group presentation (10-15 minutes, 2-3 students). You are required to present a research idea that makes use of EEG/MEG, fMRI, or TMS. Think about an interesting research question, embedded in previous work, and explain how you would use those methods to answer it. What results do you expect and how would you interpret them? Check announcements for more details during the course.

Presentation date: **Thursday May 14th** (within the regular tutorial meeting time slot)

Attendance requirement

During the course there is the usual 85% attendance requirement. Please consult your student handbook on all matters concerning examination.

Prerequisite

SCI2034 Brain and Action and elementary knowledge of electricity and magnetism as stated under SCI-P.

(also see Prerequisites and recommendations section of the UCM Course guide)

Literature

Task 1: Measuring traces of the mind

- Gazzaniga, S. M., Ivry, R. B., Mangun, G. R. (2013). Chapter 3: Methods of Cognitive Neuroscience. In: Cognitive Neuroscience: the biology of the mind (4th ed). New York, NY: Norton & Co
- Gazzaniga, S. M. (2010). Neuroscience and the correct level of explanation for understanding the mind. *Trends in Cognitive Sciences*, 14(7), 291-292.
- https://neuroscimed.wordpress.com/2014/09/21/spatial-temporal-resolution-plots-for-neuroscience-methods/

Task 2: Brain waves

- Davidson, R. J., Jackson, D. C., & Larson, C. L. (2000). Human Electroencephalography. In J. T. Cacioppo & L. G. Tassinary & G. G. Berntson (Eds.), *Handbook of Psychophysiology* (pp. 27-52). Cambridge: Cambridge University Press.
- Luck, S. J. (2005). Chapter 1: An introduction to event-related potentials and their neural origins. In S. J. Luck (Ed.), *An introduction to the event-related potential technique* (pp. 1-50). Cambridge: MIT.

Task 3: Speaking of EEG

- Gazzaniga, S. M., Ivry, R. B., Mangun, G. R. (2013). Cognitive Neuroscience: the biology of the mind (4th ed). New York, NY: Norton & Co
- Cheour M, Ceponiene R, Lehtokoski A, Luuk A, Allik J, Alho K, Näätänen R. (1998). Development of language-specific phoneme representations in the infant brain. *Nat Neurosci.,* 1(5), 351-3.
- Osterhout, L., Nicols, J. (1999). On the distinctiveness, independence, and time course of brain responses to syntactic and semantic abnormalities. *Language and cognitive processes,* 14(3), 283-317.

Task 4: Visualizing the brain

- Papanicolaou, chapter 4 (fMRI)
- Menon RS, Kim S-G (1999) Spatial and temporal limits in cognitive neuroimaging with fMRI. *Trends Cogn Sci*, **3**, 207-216.
- Tutorials on http://www.fmri4newbies.com/
- Video intro to MRI Physics on http://www.mri-tutorial.com/

Task 5: Design is everything

- Huettel, S.A., Song A.W., McCarthy, G. (2004). Functional Magnetic Resonance Imaging, Sinauer Associates. Chapter 11: "Experimental Design". pp. 294-310.
- Donaldson DI, Buckner RL (2001) Effective paradigm design. In: Functional MRI - An Introduction to Methods. Jezzard P, Matthews PM and Smith SS. Oxford University Press. Pp. 177-193
- Matching two imagined clocks: The functional anatomy of spatial analysis in the absence of visual stimulation. L.Trojano, D. Grossi, D.E.J. Linden, E. Formisano, H. Hacker, F.E. Zanella , R. Goebel, F. Di Salle (2000) Cereb Cortex. 10(5):473-81.
- Tracking the mind's image in the brain I: time-resolved fMRI during visuospatial mental imagery. (2002) E. Formisano, D.E.J. Linden, F. Di Salle, L. Trojano, F. Esposito, A. Sack, D. Grossi, F.E. Zanella, R. Goebel. Neuron 35,185-194.

Task 6: Visualizing vision

- Gazzaniga, S. M., Ivry, R. B., Mangun, G. R. (2013). Cognitive Neuroscience: the biology of the mind (4th ed). New York, NY: Norton & Co
- Haynes, J.-D. & Rees, G. Decoding mental states from brain activity in humans. Nat Rev Neurosci 7, 523-534 (2006).
- Norman, K. A., Polyn, S. M., Detre, G. J. & Haxby, J. V. Beyond mind-reading: multi-voxel pattern analysis of fMRI data. Trends in Cognitive Sciences 10, 424-430, doi:http://dx.doi.org/10.1016/j.tics.2006.07.005 (2006).
- Miyawaki, Y., et al. (2008). Visual Image Reconstruction from Human Brain Activity using a Combination of Multiscale Local Image Decoders. *Neuron*, 60, 915-929.

Task 7: Zapping the healthy human brain ....!?

- Walsh, V., and Cowey, A. (2000). Transcranial Magnetic Stimulation and cognitive neuroscience. *Nature Neuroscience* 1, 73-79
- Hallett, M. (2000) Transcranial magnetic stimulation and the human brain. *Nature,* 406, 147-150.
- Robertson, E.M., Theoret, H., & Pascual-Leone, A. (2003). Studies in cognition: The problems solved and created by transcranial magnetic stimulation. *Journal of Cognitive Neuroscience,* 15, 948-960.

Task 8: Dimming the spotlight

- Gazzaniga, S. M., Ivry, R. B., Mangun, G. R. (2013). Cognitive Neuroscience: the biology of the mind (4th ed). New York, NY: Norton & Co
- Hilgetag CC, Théoret H, Pascual-Leone A. (2001) Enhanced visual spatial attention ipsilateral to rTMS-induced 'virtual lesions' of human parietal cortex. Nat Neurosci., 4(9), 953-7.
- Dambeck N, Sparing R, Meister IG, Wienemann M, Weidemann J, Topper R, Boroojerdi B. (2006). Interhemispheric imbalance during visuospatial attention investigated by unilateral and bilateral TMS over human parietal cortices. Brain Res., 1072(1), 194-9.

Task 9: Imagine!

- Farah, M.J (1989). The neural basis of mental imagery. *Trends in Neurosciences*, 12(10), 395-399.
- Kosslyn, S.M., Pascual-Leone, A., Felician, O., Camposano, S., Keenan, J.P., Thompson, W.L., Ganis, G., Sukel, K.E. and Alpert, N.M. (1999): The role of Area 17 in visual imagery: convergent evidence from PET and rTMS. *Science* 284, 167–170.
- Stokes, M., Thompson, R., Cusack, R., & Duncan, J. (2009). Top-down activation of shape-specific population codes in visual cortex during mental imagery. *Journal of Neuroscience*, 29(5), 1565-1572.
- Sack, A.T., Sperling, J., Prvulovic, D., Formisano, E., Goebel, R., Di Salle, F., Dierks, T., Linden, D.E.J. (2002). Tracking the mind's image in the brain II: Differential effects of repetitive transcranial magnetic stimulation of the right and left parietal lobe. *Neuron* 35: 195-204.
- Sack, A.T., Camprodon, J.A., Pascual-Leone, A., & Goebel, R. (2005). The dynamics of interhemispheric compensatory processes in mental imagery. *Science*, 308, 702-704

Tasks

TASK 1: Measuring traces of the mind

A

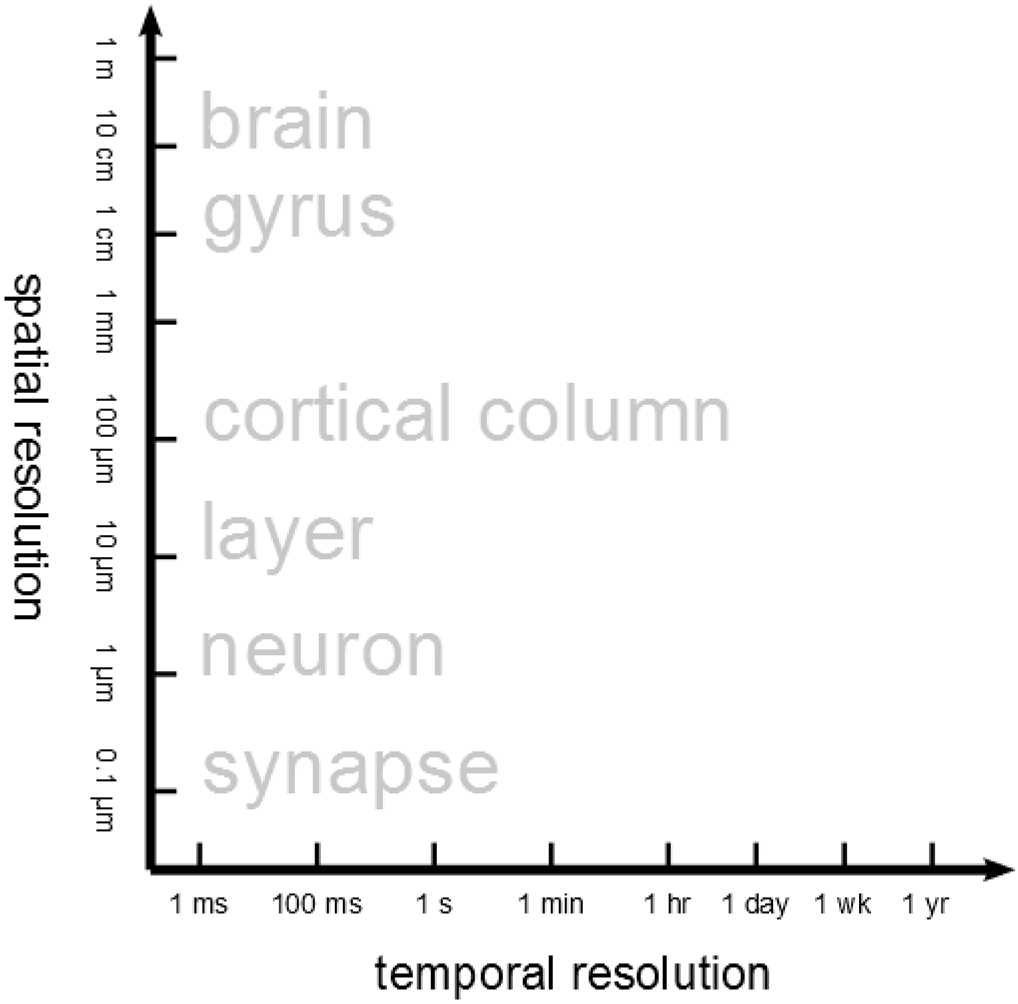
There is a range of techniques in cognitive neuroscience that provide “windows” into the brain. Unfortunately, there is not a single method that can capture all aspects of brain anatomy and function. Instead, each method has its particular strengths and weaknesses that are important to consider when conducting your own research or evaluating the work of others. To get started, we will focus on the big picture to gain a general understanding of how various methods relate to each other. Later tasks will then focus on the most important methods in more detail.

Here is a collection of methods commonly used in cognitive neuroscience. Feel free to add other methods that you have heard of that are missing! Then, give a general description of how these methods work and try to cluster them. Which dimensions could you use to compare them with each other?

transcranial current stimulation
magnetoencephalography
functional MRI
transcranial magnetic stimulation
positron emission tomography
microstimulation
computer tomography
lesions
single cell recording
electroencephalography
magnetic resonance imaging
drug manipulation

B

Try to put all methods from the previous part into the coordinate system below…



C

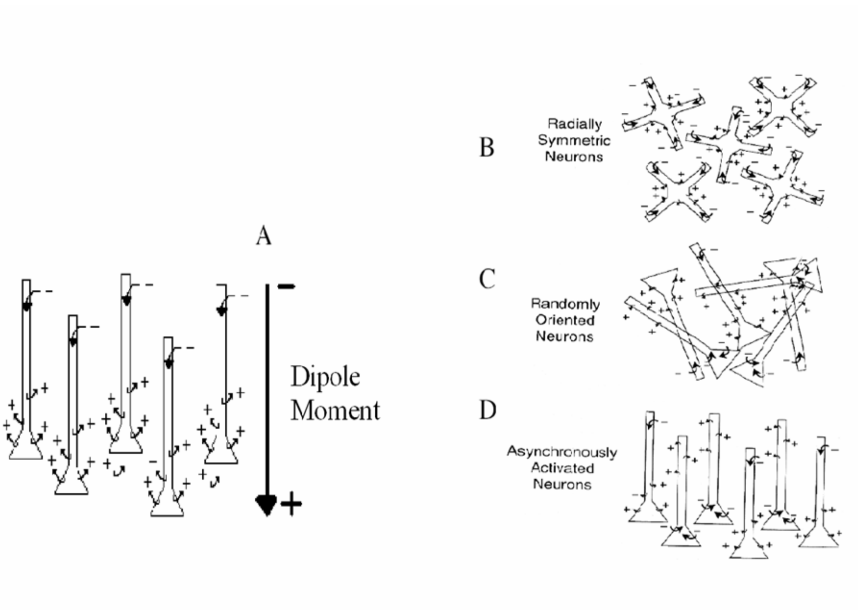
And now try to rank them according to how invasive these methods are…

D

And finally, suppose you could measure the activity of each and every neuron at any moment in time? Do you think this would be sufficient for understanding how the brain works and would this be the dream scenario for explaining the human mind?

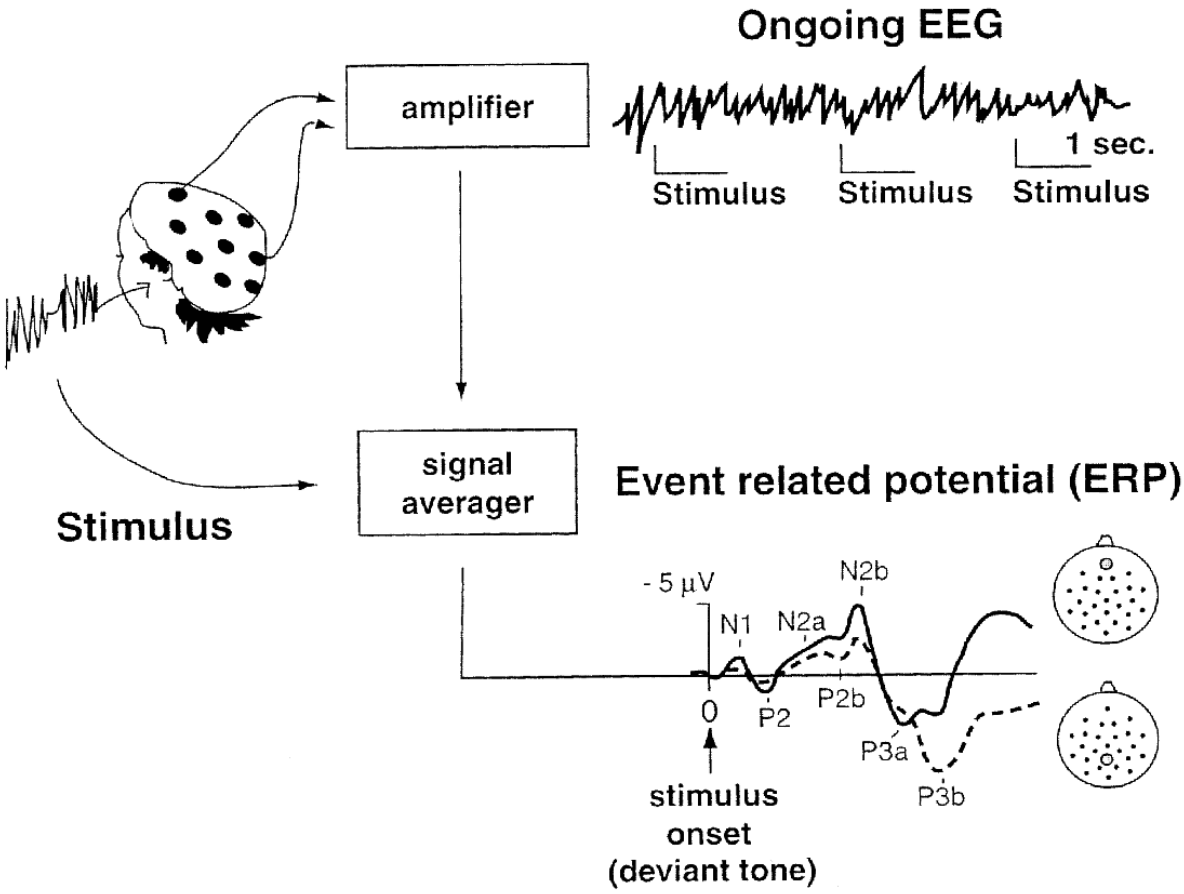
TASK 2: Brain waves

Even though hemodynamic methods like fMRI result in beautiful images of the working brain, they are a rather indirect ways of investigating brain function. Fortunately, electrophysiological methods offer a more direct recording of neuronal activity. Electroencephalography (EEG), for instance, records the electrical signal on the skull generated by neuronal populations in the brain. There are, however, some drawbacks with this method intrinsic to the nature of the electrical signal. Perhaps you remember some features of electrical current from your physics class…



The brain signal we eventually gather with EEG typically looks like this:

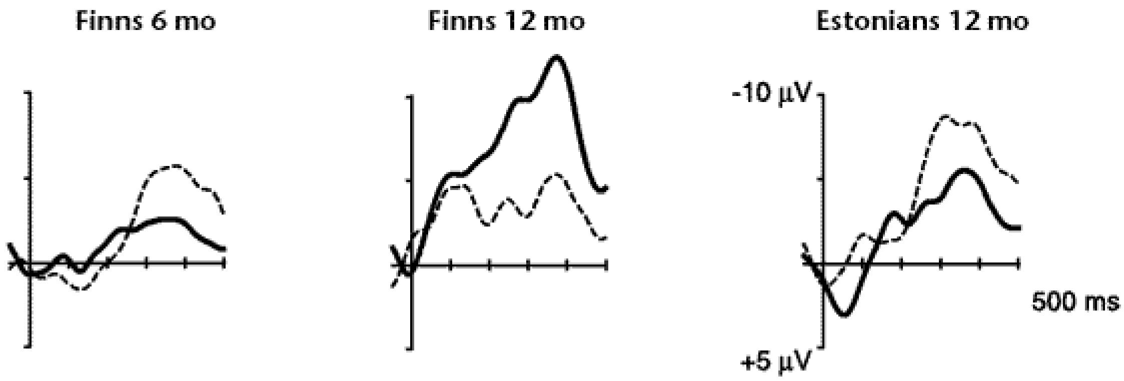
As the main interest of cognitive neuroscience lies in the relationship between brain function and specific cognitive operations, an ongoing signal like this is not very informative. Most studies in the field applying EEG will report ERPs, i.e. event-related potentials. The following picture might give you some idea on the way ERPs are calculated. As you can see, the ERP wave looks much less noisy than the EEG signal displayed above. But what do the rise and fall of the wave at certain latencies mean? What does N1, P2 etc. mean?



TASK 3: Speaking of EEG

As we have seen in task 1, the methods in cognitive neuroscience differ on various dimensions, which makes a given research method more suitable to answer certain kinds of research questions over others. In task 2 you learned something about the properties of EEG/ERP as a neuroscientific tool. Based on this, you might already know what kinds of research questions EEG is particularly suited for…?

In this experiment by Cheour et al. (1998), Estonian and Finnish infants were presented with different speech sounds. The standard stimulus was the Finnish and Estonian vowel /e/. The deviant stimulus /ö/ was a vowel shared by both languages; the deviant stimulus /õ/ is a vowel only in Estonian. Acoustically, /e/ and /ö/ are more similar than /e/ and /ö/.
The graph below depicts the MMN for the /õ/ and /ö/ stimuli in different groups of infants.



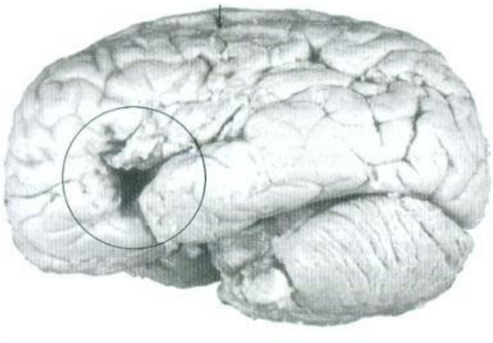
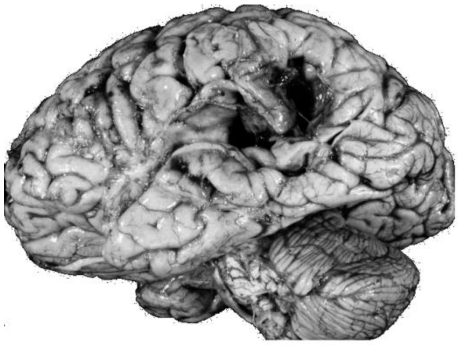
———— standard /e/ - deviant /ö/, a vowel shared by Finnish and Estonian languages,
--------- standard /e/ - deviant /õ/, an Estonian vowel

Apparently, our ability to discriminate between vowels is influences by the language we grow up with. Why did the researchers choose to investigate this with EEG, rather than any other method?

There is more to language than mere sound processing of course. In order to understand spoken or written language, one needs to have a basic understanding of syntactic rules and semantics.

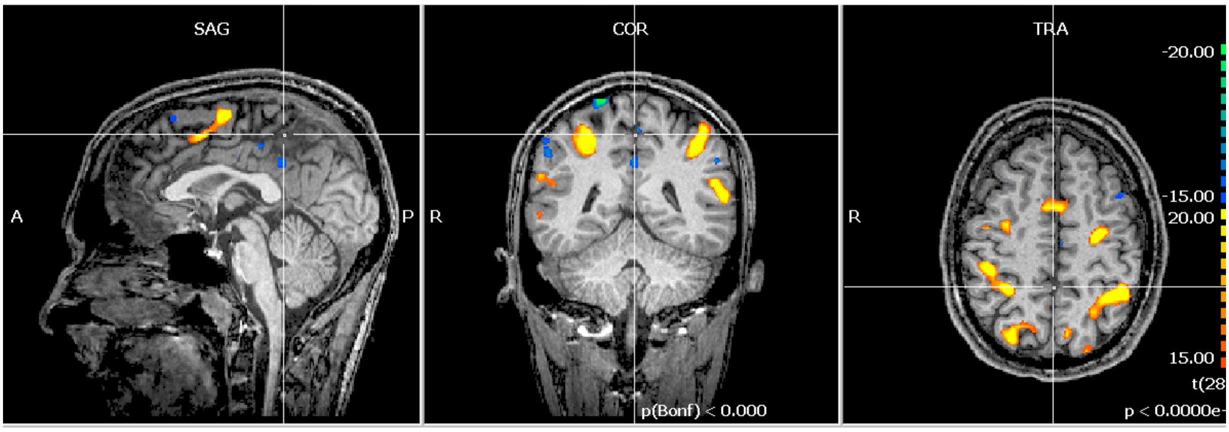
1) The cat won't *eat* the food that Mary leaves them.
2) The cat won't *eating* the food that Mary leaves them.
3) The cat won't *bake* the food that Mary leaves them.
4) The cat won't *baking* the food that Mary leaves them.

Your brain needs to process all the phonological, syntactical and semantic information captured in a single sentence for you to understand the meaning of a sentence. The brain is also responsible for the reverse process of speaking, the production of language. Different neuropsychological syndromes that are characterized by specific language deficits have been described.

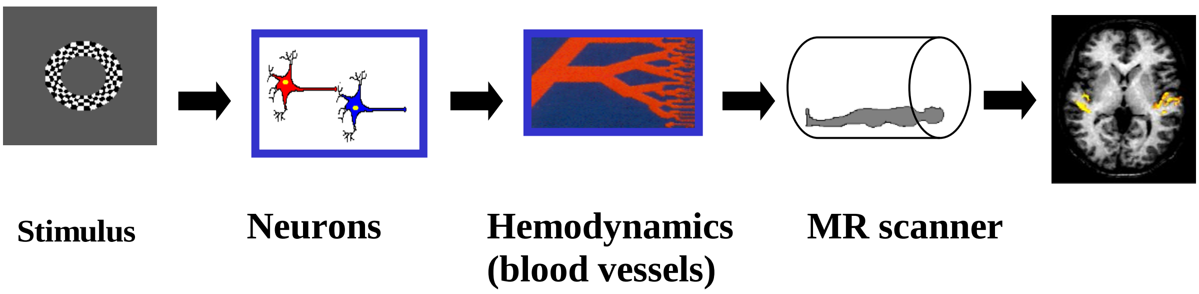
TASK 4: Visualizing the brain

The pictures below should look familiar to you after studying task 1. Can you indicate whether they are MRI or fMRI images?



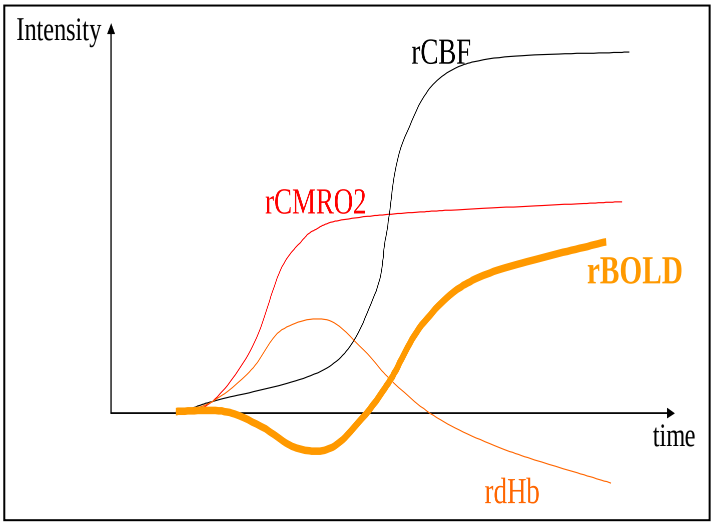
In the last two decades, the introduction of functional Magnetic Resonance Imaging (fMRI) has influenced tremendously the way psychologists and cognitive neuroscientists investigate the functional specialization of the human brain. Using fMRI, not only anatomical but also *functional* images of the living brain can be collected and brain regions that respond to a sensory, motor or cognitive stimulus can be highlighted.

Obviously, the MR scanner is not a camera or camcorder. So the images you see above must be translated from another type of signal. In fMRI this signal (Blood Oxygenation Level Dependent or BOLD signal) is no direct measure of brain activity since it does not measure the actual firing of neurons, but rather a metabolic consequence of neuronal firing. This has important implications for fMRI's temporal resolution. From the schema below it should become clear what the dependent variable in fMRI research actually is.



The MR Scanner consists of an extremely strong magnet (approx. 10,000 the earth's magnetic field strength!!!). Therefore, the signal recorded in MR scanning must have some magnetic properties.

This graph below shows the details of a time course of the BOLD signal. The small *r* always stands for regional, meaning it is restricted to a specific area in the brain. *CBF* is the Cerebral Blood Flow, *CMRO2* the Cerebral Metabolic Rate of Oxygen, and *dHB* refers to the relative amount of deoxygenated Hemoglobin.



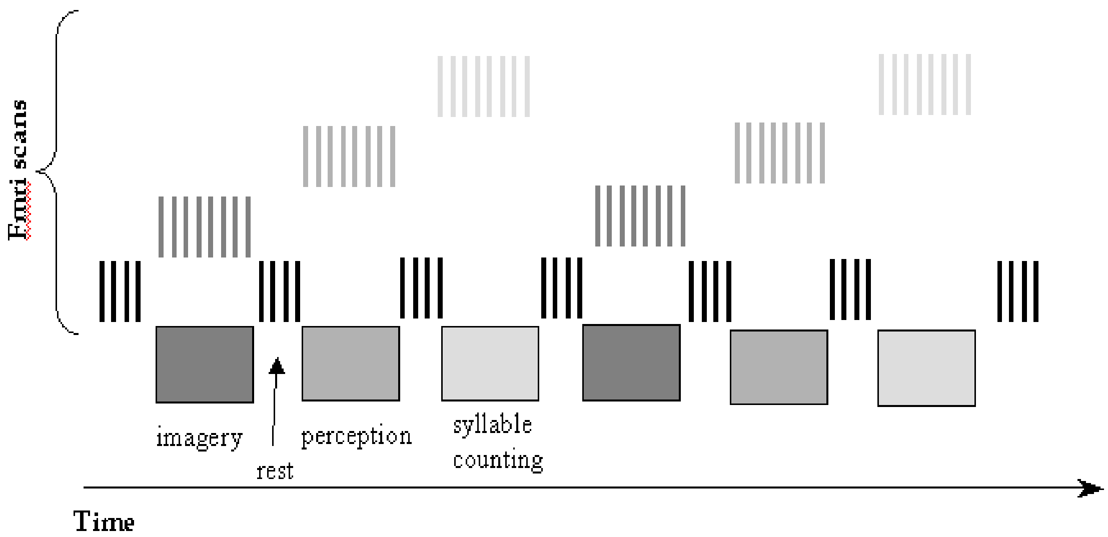
After reading all this, do you have an idea what the blue and yellow particles are in the brain of the person depicted in figure 1?

TASK 5: Design is everything

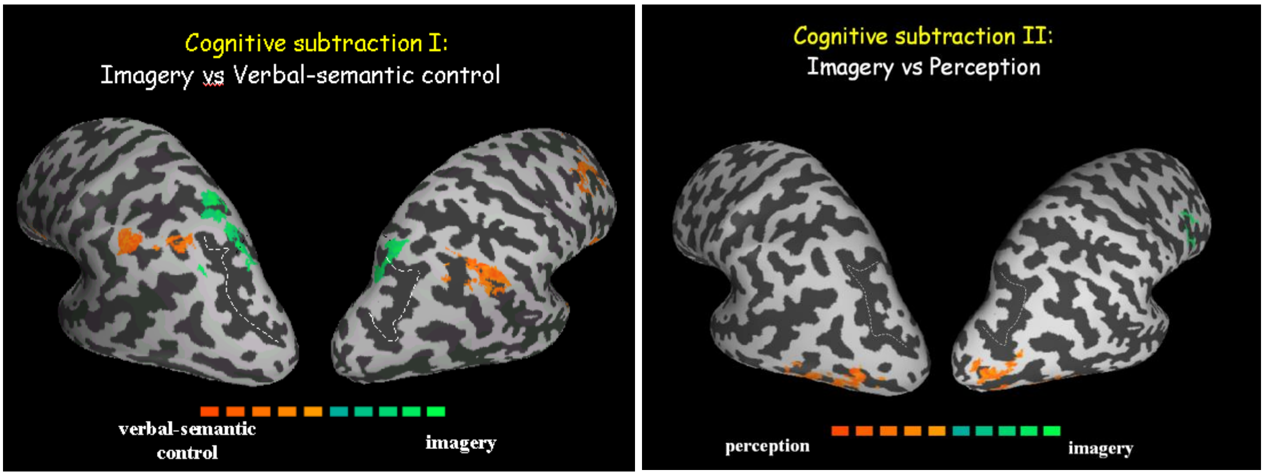
A picture of the brain areas that are active during a cognitive task can be obtained easily in experiments that take a few minutes. Despite this apparent simplicity, the way experiments are designed and performed and the way data are analyzed have a great influence on what the empirical results can really tell us.

As an example, consider two fMRI studies of mental imagery (Trojano et al. 2000, Formisano et al. 2002). These two studies are based on the same mental imagery task: the *'mental clock task'*. In this task, subjects are asked to imagine pairs of clock faces on the basis of acoustically presented times (e.g., "nine thirty, eight o'clock..."), to compare the mental images, and to report in which of the two faces the clock hands form the greater angle.

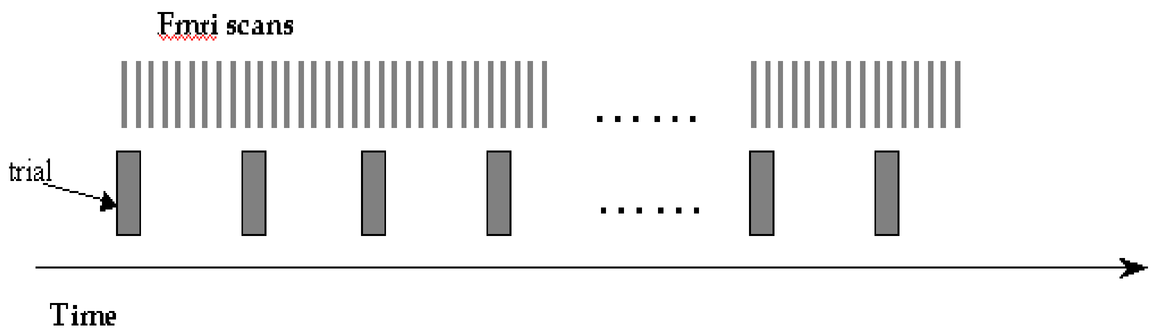
The two studies employed two different experimental designs. The experiments in Trojano et al. (2000) followed a so-called *blocked paradigm*. During the collection of functional images, "blocks" in which subjects performed eight trials of the mental clock task (*imagery*) were alternated with blocks in which subjects performed one of two control tasks (*syllable counting* or *perception*). Short blocks of rest (baseline) separated the three experimental conditions.



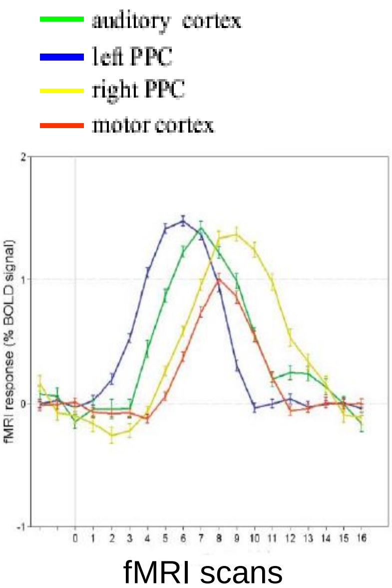
The activation maps obtained by comparing the images collected in the three conditions are superimposed to an "inflated" representation of the brain.

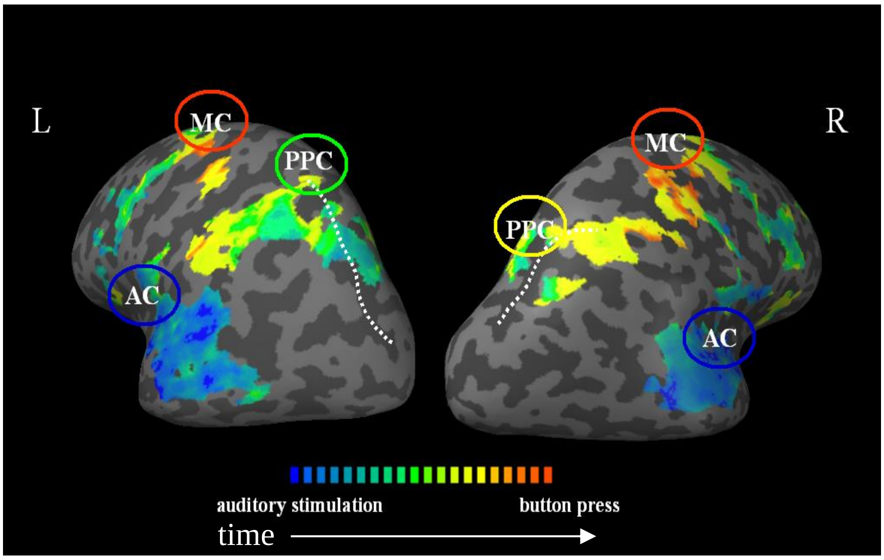


In Formisano et al. (2002), a so-called *event related* paradigm was employed. During fMRI measurements, pairs of times were presented every 16 s Subjects were instructed to imagine the corresponding analog clock faces and to push a button to report their response.



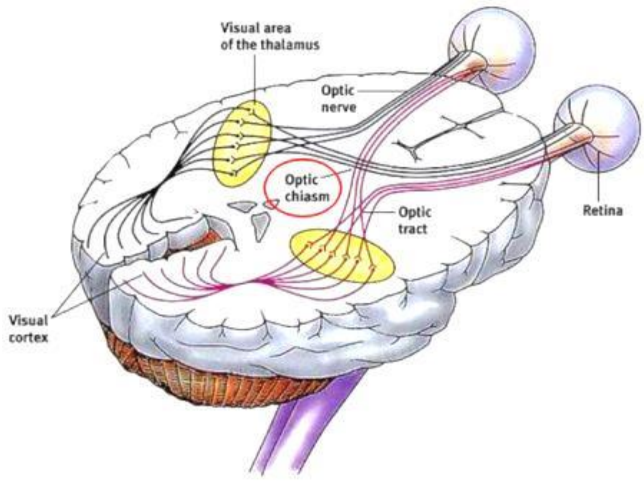
The data acquired from this experiment look somewhat different from the Trojano experiment.



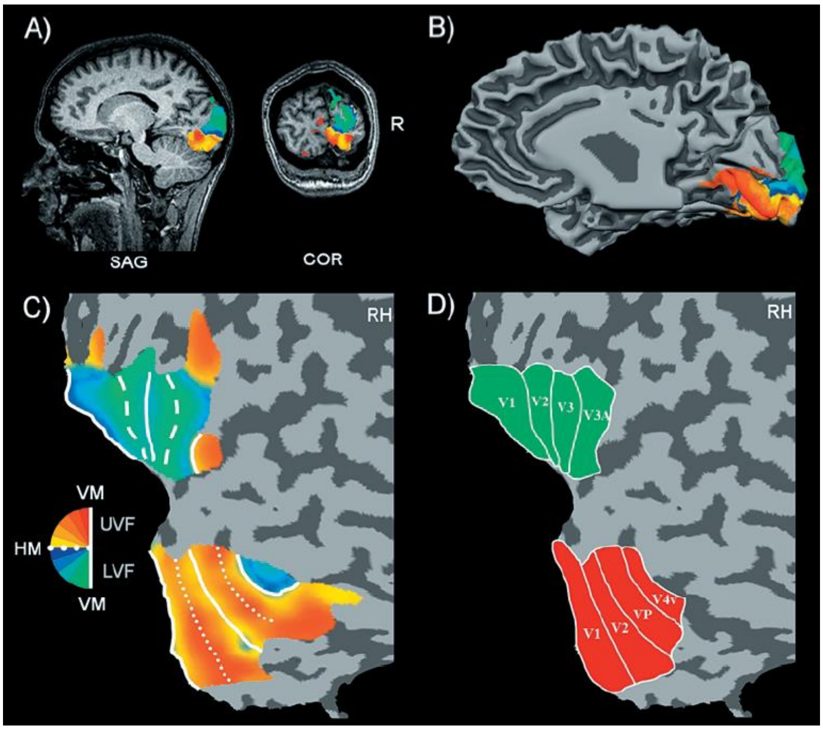


TASK 6: Visualizing vision

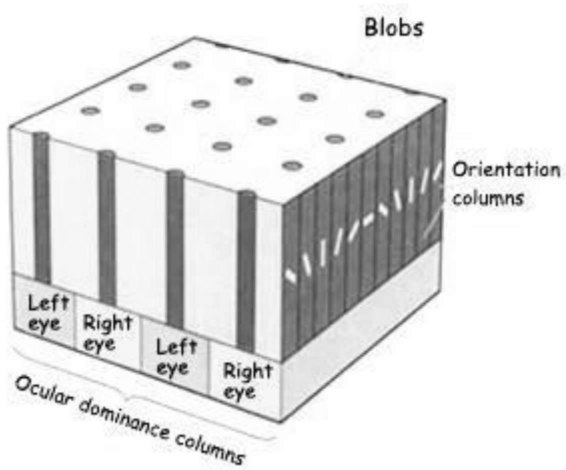
The visual system has the amazing capability of transforming the light reflected by an external object into an image in our minds. Decades of research have revealed the astonishing complexity of this sensory system, ranging from the first processing steps in our eyes to higher-order processes in the cortex. Several important characteristics of the visual system are depicted below.



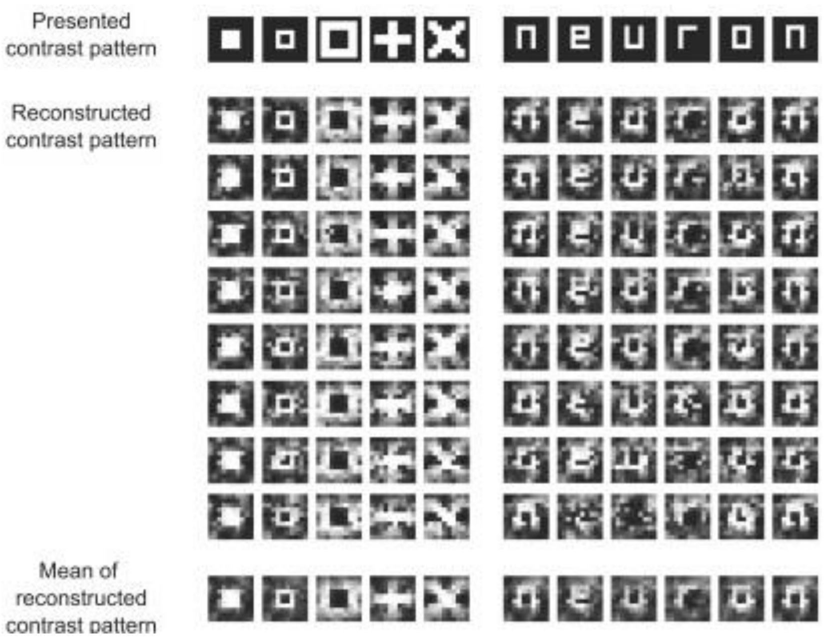
In visual cortex, additional organizational principles emerge. The most obvious one is called retinotopy, meaning that there is a particular spatial relationship between points on the retina and visual cortex… (please note the small legend in the lower left corner)



As Information travels from one brain area to the next, the processing becomes increasingly complex. In the beginning, neurons are tuned to very simple features of the visual input while higher-order brain areas are more involved in object recognition. What kind of basic features do you think are relevant for visual processing and how could these features serve as starting point for highly advanced tasks such as face perception?

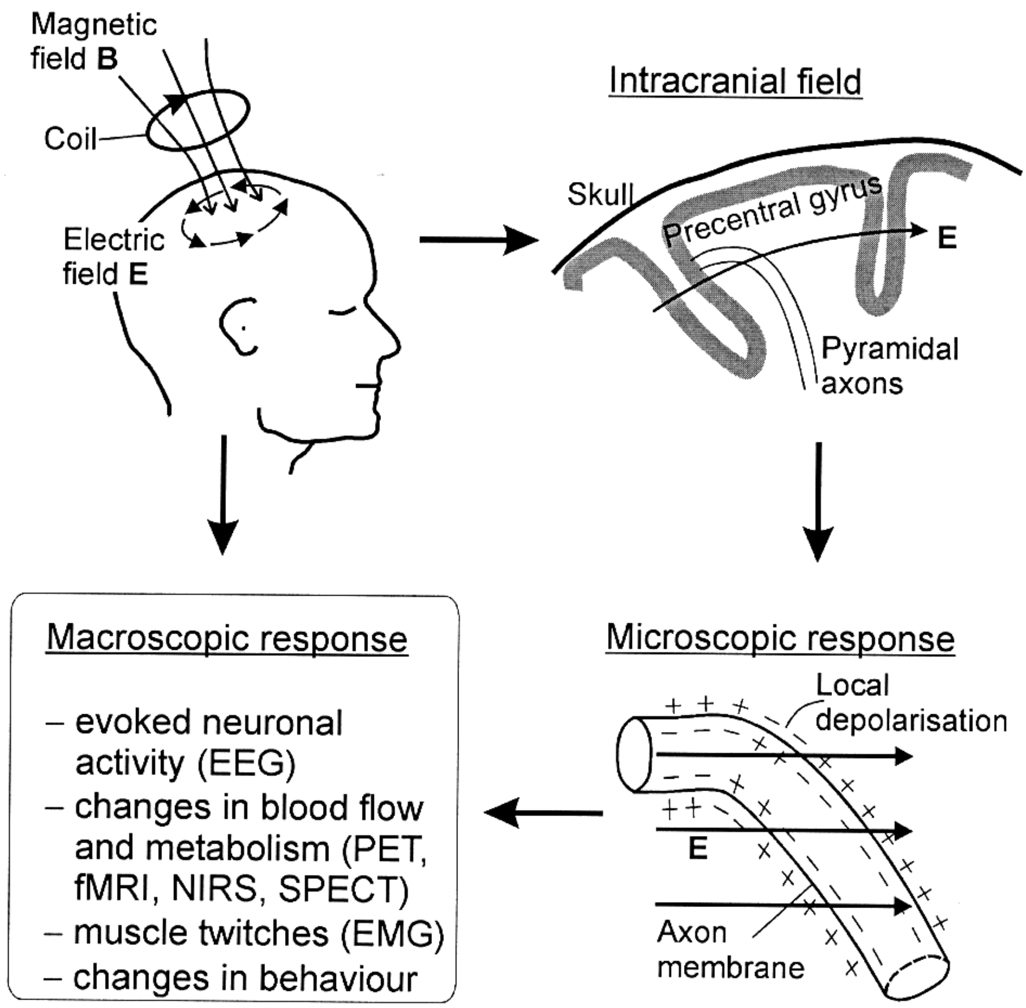


Finally, due to the inherent organization of the visual system, it is actually possible to decode the information processed by the visual system based on brain activity. That is, show me the activity in your visual system and I will know what you see, at least sometimes!
Also, follow this link for another example: https://www.youtube.com/watch?v=nsjDnYxJ0bo



TASK 7: Zapping the healthy human brain ....!?

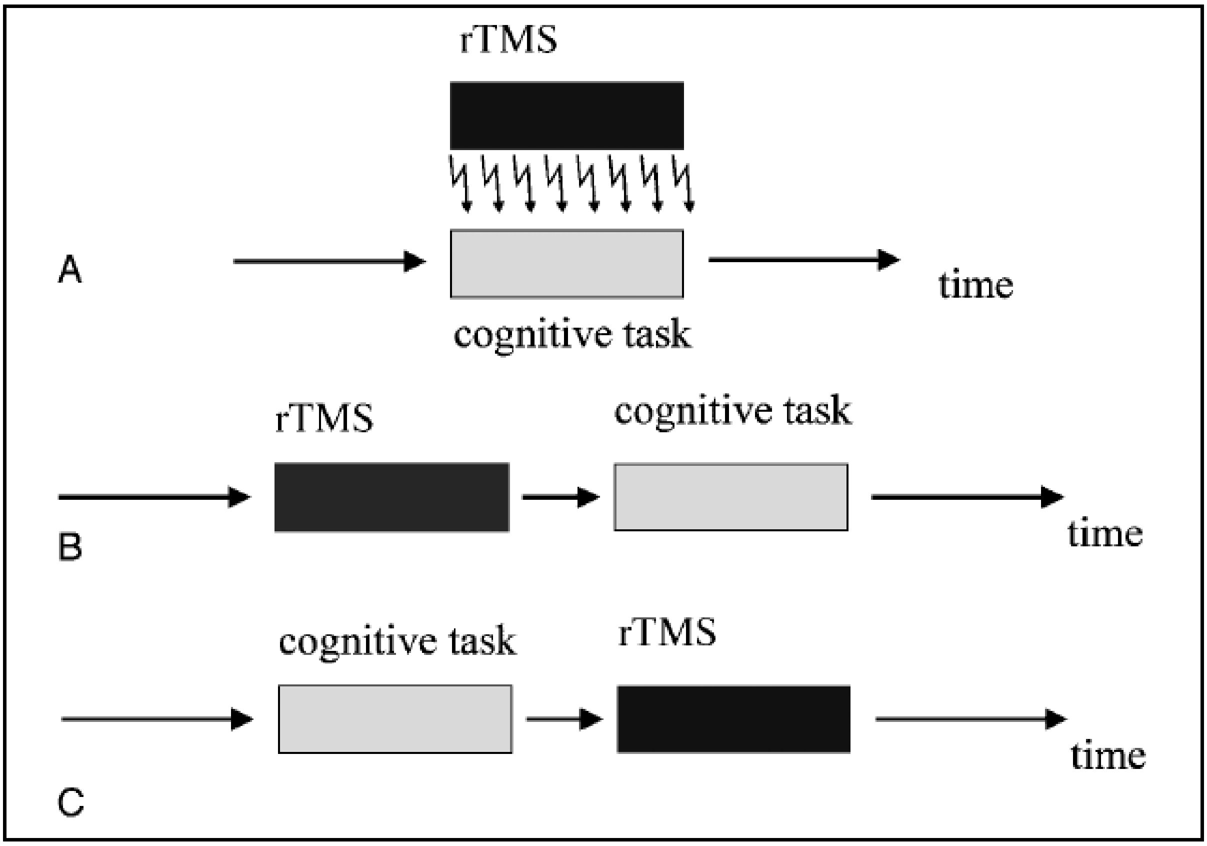
In neuropsychology, lesion studies have proven to be a useful tool in localizing the neural source of different types of behavior. For obvious reasons, subjects are limited and in most cases no records exist of previous performance on the damaged function. From a research perspective these are some, among other, limitations on the use of human lesioned subjects. Since the development of Transcranial Magnetic Stimulation (TMS) these drawbacks can be circumvented, because it offers the opportunity to induce temporal disturbances in healthy individuals with a spatial resolution in the millimeter range. Simply from its name, one can already deduce the way TMS works. The following picture sheds even more light on its properties.



TMS does not measure brain function, like e.g. fMRI or EEG, but rather manipulates it. This fact has consequences for the data type gained in TMS research and more importantly, for the conclusions one can draw on the basis of TMS results. It needs to be taken into consideration from a safety perspective as well. Some health risks are associated with TMS, like the induction of epileptic seizures.

As a researcher using TMS the most important decision to make is which brain area to stimulate, given the cognitive or perceptual function under investigation. After determining the stimulation site, it can be quite tricky to position the coil at the right spot on the skull. There are several ways to tackle this problem, for instance by using the anatomy of the subject's skull or brain.

Apart from the "where" there is also the "when" question. When does it make sense to apply TMS?



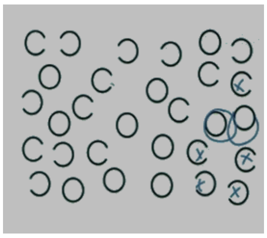
Can you think of any other parameters a researcher needs to decide upon (multitude of pulses, timing between pulses etc.)?

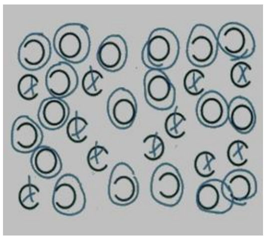
TASK 8: Dimming the spotlight

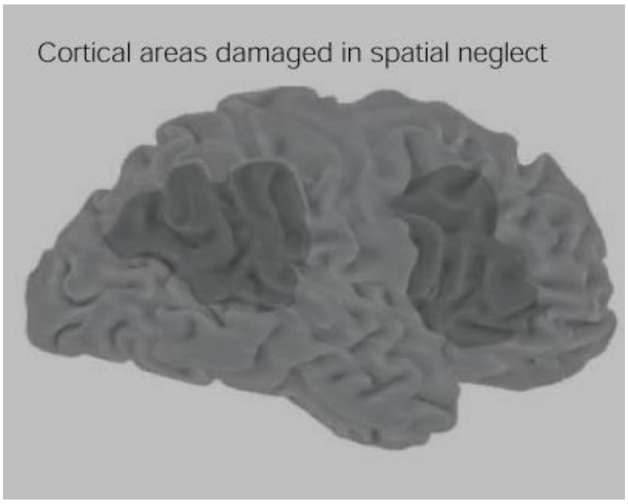
Imagine coming back from holidays and being picked up at the airport by a friend. As you pass through the gates hundreds of people swarm around in the terminal. Your goal is to find your friend as quickly as possible among them. How do you achieve this?

This airport scene makes clear how we use our attention to select certain items in our external environment. Cognitive psychologists have developed theoretical models on the different types and cognitive processed of attention. Selective attention is the process that favors one of multiple competing stimuli for limited processing resources. Attention can function as a 'spotlight' in the sense that it can filter out all the irrelevant incoming information and highlight the stimuli your attention is directed at. The question is how this conceptual idea on human selective attention manifests itself in the brain.

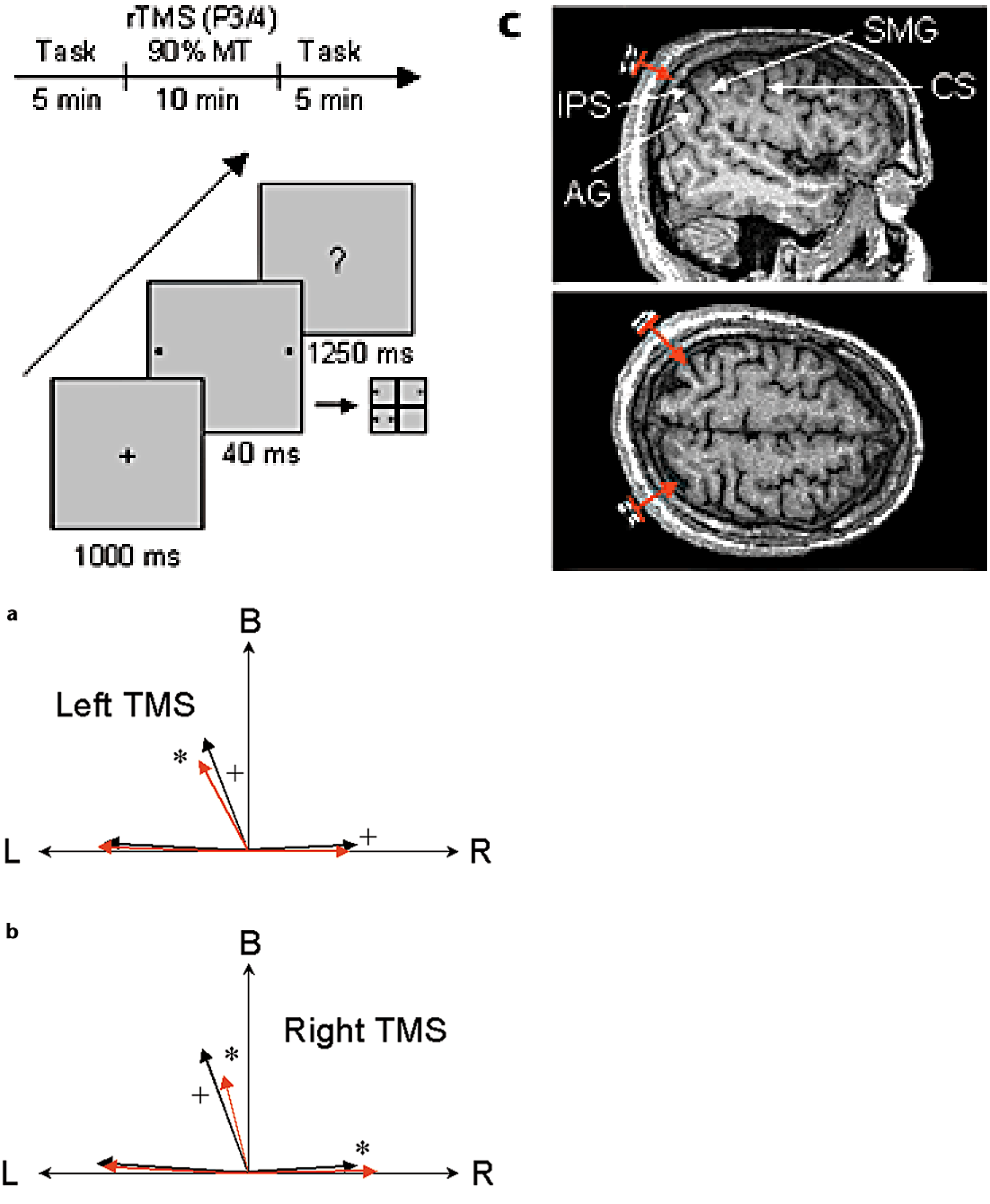
The neuropsychological syndrome of visuospatial hemineglect is characterized by the failure to attend, explore and act on the contralesional side. There are two types of neglect, corresponding with different types of attention.







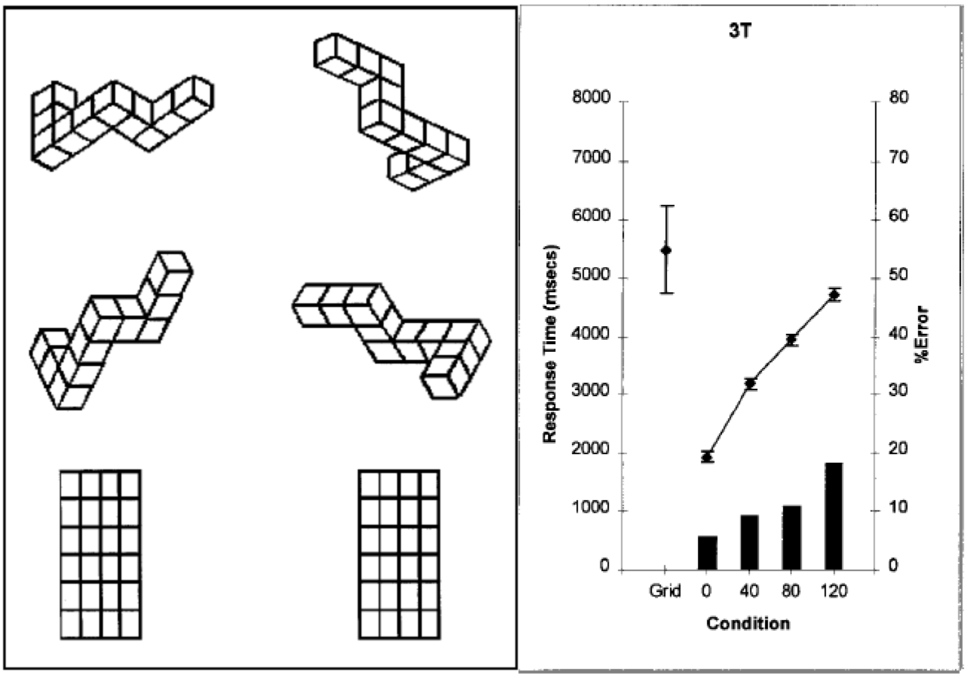
These symptoms can be mimicked in healthy volunteers:



These results imply hemispheric specialization in visuospatial attention.

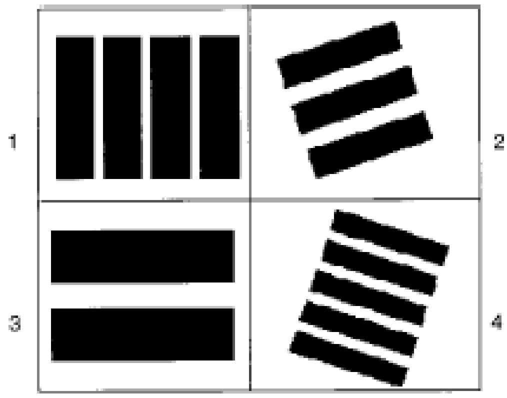
TASK 9: All methods agree….

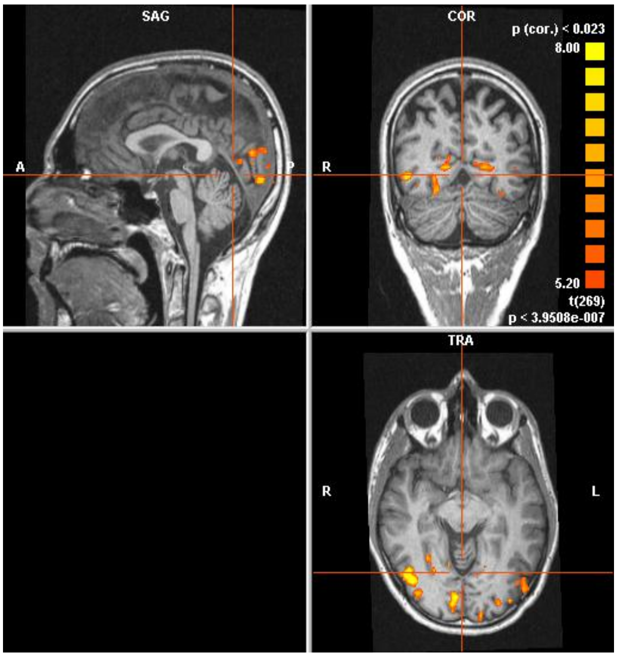
From the beginning of scientific psychology there has been debate on the quality of visual imagination, specifically on whether it relies on a depictive representation (Kosslyn, 1994) or whether its functional basis is an abstract code which can also be found in language (Pylyshyn, 1973). Even though there has always been consent on the existence of mental images, the question, if the pictorial aspects of imagery are functionally necessary in the process of imagination, remained unresolved.

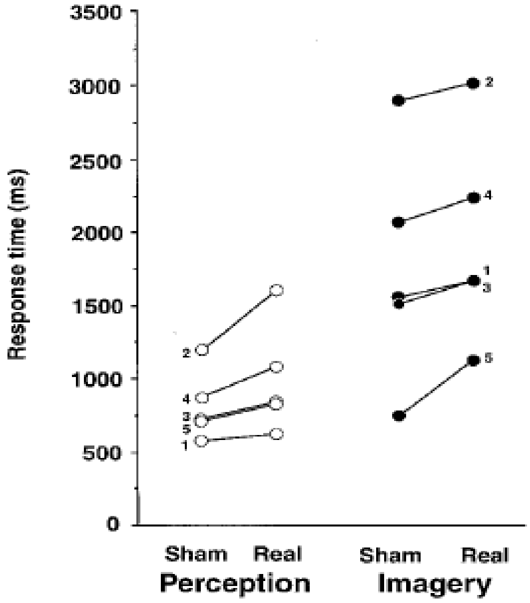


The field of cognitive neurosciences provided a set of new instruments to resolve the imagery debate and even go beyond the question of the existence of depictive representations.
Does visual mental imagery rely on the same neuronal structures as visual perception?

In an experiment that combined two main methods of cognitive neuroscience, Kosslyn et al. (1999) used a visual imagery task that required subjects to compare stripe pattern of four visual stimuli. After having memorized the four stimuli, subjects were put in the scanner and received an *acoustic* cue that indicated which two stimuli had to be mentally imagined. Depending on the instruction, subjects had to compare the imagined stimuli with regard to a specific feature, e.g. lengths of the stripes.

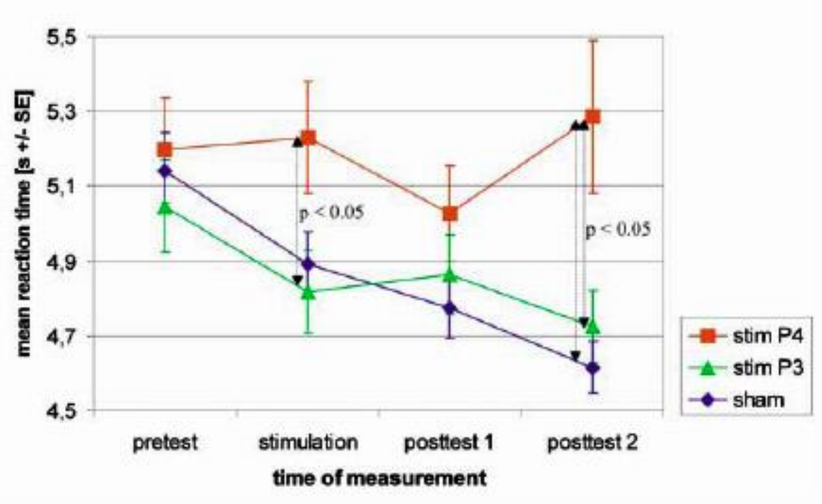






The results achieved with these methods nicely contribute to the same conclusion. Results acquired with different neuroscientific methods can also build on each other, stepwise unraveling the way in which the brain executes a given task. Perhaps you reminder the mental clock task from task 5.

As a result of the Formisano et al. (2002) study we know that bilateral parietal cortex is involved in the execution of the mental clock task. In an rTMS paradigm, Sack et al. (2002) subsequently investigated the contribution of the parietal cortex of both hemispheres. The results led to an interesting conclusion on the functional relevance of both unilateral regions for mental imagery.



The mental clock task requires the execution of a couple of cognitive operations. The hemispheric differences Sack et al. (2002) discovered might reflect the specific mental sub processes left and right parietal cortex take part in. Another mental imagery study was conducted in which clever use was made of a mixed repetitive and event-related TMS design.