fMRI in humans consists of collecting images on a subject while (s)he is in the MRI, typically performing a stimulus-guided task. Here we will discuss the basic components of human fMRI, from issues of informed consent of the subject and institutional ethics board approval to the acquisition and analysis of the data. We will primarily draw examples from 3 Tesla BOLD fMRI.

Stimulus presentation and behavioral recording

Delivering multi-sensory stimuli (audio, video, tactile, etc.) and recording behavioral responses (button presses, voice recordings, physiology, etc.) is possible, but challenging. We will discuss the use of wave-guides and filters to deliver stimuli and record responses, issues of MR compatibility, and the physical constraints of the magnet’s bore and other equipment. We will also discuss the computer control of this process and synchronization with the MRI. The timing and time spacing of stimulus trials has important implications on the types of experiments that can be done, the fMRI signal the stimuli elicit, and how the data are analyzed. Therefore, we will discuss block and event-related designs. As an important special case, we will also discuss resting state studies, in which no external stimulus/task is presented. One advantage of human fMRI is that relatively complex tasks can be communicated to and performed by the subject. Further, it is possible to get self-report data. Another reason that fMRI has become such a major tool in cognitive neuroscience is that more invasive methods are not possible on healthy human subjects. fMRI is currently the best available method for whole-brain, non-invasive measurements of the human brain.

Imaging parameters

A number of tradeoffs exist for fMRI imaging parameters. This lecture will discuss common pulse sequences and their parameters such as TR, TE, flip angle, number of slices, and slice thickness. We will also discuss the length of experiments from a statistical perspective as well as from a subject comfort perspective.

Institutional/ethics review

Research involving human participants need to be review and approved by an independent ethics committee (IEC) or institutional review board (IRB). IRBs assure that appropriate steps are taken to protect the rights and welfare of humans participating in research.

fMRI analysis

We will discuss basic spatiotemporal properties of fMRI data, focusing on how these impact statistical analysis. The BOLD signal can be approximated as the convolution of neuronal activity with a hemodynamic response function (HRF). The effect of the HRF is to temporally blur the neuronal time series. Based on the temporal properties of the hemodynamic response, most analysis approaches make use of the fact that knowing the timing of stimulus/task conditions leads to correlated BOLD signal increases. This leads to univariate/time series approaches such as correlating of every brain voxel’s time series with an ideal time series, and extensions of this approach that are termed the general linear model (GLM). Knowing the stimulus/task timing in fMRI also allows multivariate approaches, such as multi-voxel pattern analysis. Finally, we will discuss independent components analysis (ICA). ICA is an unsupervised learning method that assumes neither knowledge of the stimulus/task design nor the expected functional maps. Various preprocessing steps are usually required before performing any of the analysis techniques mentioned above. The goal of preprocessing is to get the data “ready”. So preprocessing starts with any image reconstruction and data conversions (e.g. NIfTI) required by the statistical software, but the majority of preprocessing focuses on correcting for any deficiencies in the acquired data. Preprocessing can also involve applying spatial transformations to bring the images into a standard space that allow for group analyses and “standardized” reporting of spatial coordinates. As with most types of data analysis, preprocessing is critical and often much more time consuming than the ultimate statistical analysis.

Tools and resources

The lecture will briefly mention common software packages that are available to the fMRI community such as SPM, BrainVoyager, FSL, AFNI, and the NITRC website.