

Title: fMRI Basics

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Highlights

- fMRI measures local changes in cerebral hemodynamics associated with neuronal activation
- Blood-Oxygenation-Level-Dependent (BOLD) is the most widely used fMRI contrast
- BOLD fMRI data are typically acquired while subjects perform a (cognitive) task
- BOLD specificity and sensitivity varies with acquisition strategy

Target audience: Technical or clinical audience with little or no background in fMRI

Outcome: After this lecture participants will be able to understand the physiological and MR mechanisms that contribute to fMRI signals and design and implement a simple fMRI experiment.

Functional Magnetic resonance imaging (fMRI) is the primary tool used to measure brain function non-invasively in humans, for both neuroscience and in the clinic. Since its emergence about 20 years ago, it has offered unprecedented advances in our understanding of brain function, currently yielding more than 7 peer reviewed manuscripts per day. fMRI measures local changes in cerebral blood volume (CBV), flow (CBF), and oxygenation that arise from local increases in oxidative metabolism ($CMRO_2$) associated with neuronal (and glial) activity (1,2). Hemodynamics thus provide the necessary oxygen in the target region. The most widely used fMRI technique to measure these hemodynamic changes is based on the Blood-Oxygenation-Level-Dependent (BOLD) contrast (3). BOLD capitalizes on the magnetic properties of deoxygenated hemoglobin (deoxy-Hb) in the blood, specifically in the venous side of the vasculature (capillaries, intracortical veins, pial vessels). Deoxy-Hb causes a distortion of the magnetic field in (intra-vascular) and around (extra-vascular) the vessels which alters the T2 and T2* decay of the MR signal in that region. This effect can be detected with either gradient-echo (GE; T2*-weighted) or spin-echo (SE; T2-weighted) contrast. The physiological mechanism is somewhat counter-intuitive. With increases in neuronal activity there is an oversupply of oxygenated blood. Because not all oxygen is absorbed in the tissue this results in a *decrease* of deoxy-Hb in the venous vasculature. This in turn lengthens the T2(*) yielding an increase in the MR signal intensity. An optimal BOLD functional contrast is obtained for a TE comparable to the T2(*) of gray matter. Ideally, this functional contrast would be specific to the capillary bed that serves active neuronal sites. However, extra- and intra-vascular signals from the larger vasculature can have a prominent contribution; this contribution varies with field strength (eg 3T vs 7T) and is different for extra- and intra-vascular signals as well as GE and SE based sequences (4).

A typical fMRI experiment involves acquiring a time series of GE volumes with a fast imaging technique (e.g. EPI) while the subject performs a given task. Tasks can range from passive viewing of visual stimuli to more complex cognitive manipulations such as pattern memorization. fMRI signals can be observed by alternating task periods with periods of rest in a regular manner (block design) or, more commonly, with a random alternation between task and rest, or between different task conditions (event-related design). The latter offers advantages in time efficiency and higher sampling of hemodynamic signal changes. Hemodynamic responses however endure for several seconds beyond cessation of neuronal activation, even for very brief stimuli (few ms). Thus the speed of alternation, i.e. the efficacy in differentiating signals between task periods or conditions, depends on the duration of the hemodynamic response. On the acquisition side, several parameters can be manipulated (e.g. spatial resolution, averaging, TR, parallel imaging, pulse sequence, field strength) and can yield different fMRI sensitivity, specificity and efficiency. Though this apparent freedom can be confusing, parameters can be chosen depending on the requirements at hand (e.g. whole brain coverage for a 10 min scan at 3T) and the acceptable signal to noise ratio. One thing to note is that the fMRI sensitivity depends on the temporal signal to noise ratio (5); fMRI signals can also be susceptible to respiration, heart-rate, or motion.

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