**Introduction**

Over the past fifteen or twenty years functional MRI has extended the boundaries of brain mapping from basic neuroscientific research into more sophisticated applications in neuroscience. More recently fMRI has begun to find further application in clinical science (e.g. neurological or psychiatric disorders) and in drug discovery. Functional MRI (fMRI) detects hemodynamic changes associated with neuronal brain activation during, for example, a visual, motor or cognitive stimuli. This neuronal activity drives local hemodynamic changes, such as increased local blood flow and blood volume, while generating relatively small changes in oxygen consumption. The resulting “endogenous” contrast mechanism (to which the functional MR signal is sensitive) is known as the Blood Oxygenation Level Dependent (BOLD) effect (Ogawa et al. 1990, Turner et al. 1991, Bandettini et al. 1992, Kwong et al. 1992, Ogawa et al. 1992).

Most fMRI studies utilize the BOLD effect as the contrast mechanism of choice to detect brain activity. In the BOLD effect, the magnetic properties of the blood change depending on blood oxygen levels as a consequence of the fact that oxygenated hemoglobin (Hb) molecules are diamagnetic while deoxygenated hemoglobin (dHb) is paramagnetic. The MR visible water, in and around the blood vessels, dephases in the presence of the inhomogeneous field pattern around the paramagnetic dHb. The dHb concentration dependent dephasing is seen in the images as an intensity change in a T2*-weighted imaging sequence. Given that increased neuronal activity drives increases in local blood flow and blood volume as well as smaller percentage changes in oxygen consumption, the dHb concentration decreases during activation. Thus, the BOLD effect is connected to a lengthening of the local value of T2* in activated tissue (brighter signal in the T2* weighted images). Because of the need to be sensitive to T2* and insensitive to motion artifacts, most fMRI studies utilize fast, single-shot T2*-weighted acquisitions based on gradient echo pulse sequences either using echo planar (Mansfield 1977) or spiral (Glover and Lee 1995) imaging. Given that the changes in image intensity associated with subtle brain activation in the fMRI experiment are relatively small, imaging parameters need to be optimally selected to maximize the fMRI contrast, improve sensitivity and encoding capabilities in functional MRI.

**Image Quality and Artifacts**

While fast image acquisitions capture sufficiently the BOLD effect, they are accompanied by some drawbacks. Ghosting artifacts in EPI, for example, result from phase differences during the acquisition of odd and even lines in k-space. Even more problematic artifacts arise from the effect of local susceptibility gradients on the EPI or spiral imaging. As discussed, the BOLD effect is based on microscopic alterations of the local magnetic field susceptibility gradients, at the macroscopic level. Thus we must make our sequences sensitive to local field alterations, however, the macroscopic magnetic susceptibility shifts arising at air and tissue interfaces results in image artifacts in fMRI acquisitions: (a) Signal loss due to within voxel dephasing (through plane susceptibility gradients) and (b) geometrical image distortions (e.g. signal compression or expansion in EPI) due to local in-plane susceptibility gradients or image blurring in spiral
acquisitions. We will discuss the origin of these artifacts and practical considerations in mitigating distortions for typical fMRI experiments (Jezzard and Balaban 1995, Merboldt et al. 2000, Andersson et al. 2001, Deichmann et al. 2002, Zaitsev et al. 2004, Weiskopf et al. 2006, Xiang and Ye 2007).

**Signal and Noise characteristics in fMRI**

Sensitivity in BOLD fMRI is characterized by only two fundamental parameters of the imaging sequence: 1) the sensitivity of the sequence to the $T_2$ or $T_2^*$ changes produced by the BOLD effect (this is simply determined by optimizing the TE of the acquisition); and 2) the Signal-to-Noise Ratio (SNR) of the time-series (tSNR), which contains fluctuations from thermal (image noise) and physiological noise sources. Alteration of an acquisition parameter that alters the MR signal level can affect the tSNR differently depending on the relative contribution of the physiological and thermal noise. Therefore, knowledge of this ratio is essential for optimizing fMRI acquisitions (Kruger and Glover 2001, Triantafyllou et al. 2005). As the MR signal increases (e.g., from higher field strengths, the use of array coils, or changes in voxel volume), the physiological noise increases proportionally. This is problematic since improving detection sensitivity, for example with array coils, will not translate to improved tSNR for fMRI if the time-series variance is dominated by physiological noise. In this talk, we will discuss how to translate the improved detection sensitivity toward other desirable directions, such as increased spatial resolution or additional parallel imaging acceleration (with reduced susceptibility-induced image distortion)(de Zwart et al. 2002, Triantafyllou et al. 2010).

In this lecture we will describe the physiology of the BOLD effect and need-to-know practical basics of the MR physics to enable brain function imaging at high spatial resolutions. Specifically, we will define common acquisition schemes describing important parameters such as pulse sequence selectivity and image reconstruction techniques. We will outline sources of image artifacts, and discuss corrective procedures regarding how they might affect functional activation maps. Finally, we will describe signal and noise characteristics in fMRI time-series and the limiting effects of spatial and temporal resolution on the SNR.

**Books**


**References**


Ogawa S, Lee TM, Kay AR, Tank DW. Brain magnetic resonance imaging with contrast dependent on blood oxygenation. Proc Natl Acad Sci U S A 87: 9868-72; 1990.


