Session: fMRI: From Basic to Intermediate Brain Connectivity, Part 1

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Target audience: Both new and experienced fMRI users interested to learn more about the technique behind the images they use in their research.

After the lecture, the audience should be able to:

- Explain why single shot Echo Planar Imaging (ssEPI) is the 'natural choice' for BOLD imaging.
- Explain how ssEPI images are acquired and reconstructed.
- Recognize the most common artifacts and explain how they are related to image acquisition and/or reconstruction

Title: Acquisition, Reconstruction and Artifacts

BOLD imaging: requirements

Most of todays fMRI studies are using the Blood Oxygenation Level Dependent (BOLD) effect to map brain activity. The method is based on changes in deoxyhemoglobine concentration in venous blood during execution of a task. This leads to a change in the local magnetic field in and around the venous structures of the brain. In terms of requirements for BOLD imaging this means that the method used to image the brain should be sensitive to changes in field homogeneity. The most sensitive method to do this utilizes changes in T2*. This means that the most effective way of measuring the BOLD effect is based on a gradient echo sequence (to be sensitive to changes in T2*).

A second requirement for BOLD imaging comes from the fact that the signal changes due to brain activity are small relative to the MR signal. Therefore, either the SNR of the data has to be high enough, or averaging of data is needed, to be able to pickup the signal changes.

The third requirement has to do with the time available for data acquisition. The hemodynamic response to a short stimulus peaks at about 2-8 seconds after stimulus onset and returns after approximately 20 seconds to baseline. To be able to visualize this curve, a temporal resolution in the order of a few (1-4) seconds is wanted in combination with jittering of the stimulus onset time relative to the data acquisition. This results in a data set every 1-4 seconds which covers the desired area of the brain (requirement 4). The latter can vary, from single slice to whole brain including the cerebellum. Taking the worst case is would mean whole brain coverage in around 3 seconds.

The fifth and last requirement has to do with the spatial resolution. To be able to locate the functional activity a resolution of 1-4 mm in every direction is usually sufficient.

In conclusion, *we need a gradient echo sequence with an acquisition matrix of 64x64x30 (3.5 mm isotropic resolution) for whole brain coverage in about 3 seconds*. For a multi-slice acquisition this means one slice every 100ms. The question is whether this is fast or slow in terms of MR acquisition time.

MR acquisition time

To be able to answer this question we take a closer look at what determines the

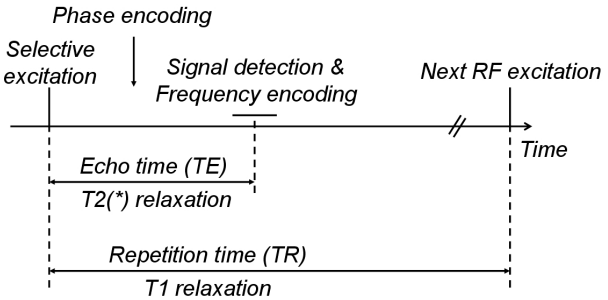

Figure1: Basic MR sequence

acquisition time of an MR sequence. If we concentrate on a basic 2D gradient echo sequence without the use of parallel imaging techniques, the time to acquire a single slice is the repetition time (TR) times the number of phase encoding steps (see figure 1).
The latter is determined by the resolution in combination with the field of view and is reflected in the acquisition matrix. From the requirements we conclude that we need at least 64 phase encoding steps. So the total imaging time for a slice is TRx64. The minimal TR is determined by the echo time (TE) because TR>TE. By comparing the T2* signal decay during 'rest' and 'task' it becomes clear that the optimal echo time for BOLD imaging is around TE ~ T2* tissue. At 3 tesla T2* is around 50 ms in the brain. Therefore the time required for a single slice using a basic gradient echo sequence is: 50x64 = 3.2 seconds! Even if we use a lower and less optimal echo-time of 25 ms we still would need 1.6 seconds for a single slice. This is way to long for whole brain BOLD imaging. The 'natural solution' to this problem is to acquire multiple phase encoding steps per excitation (see figure 2). For gradient echo images the pulse sequence of choice is single shot Echo Planar Imaging (ssEPI). The readout (Gx) and phase encoding (Gy) gradient for ssEPI along with the resulting k-space trajectory are shown in figure 3.

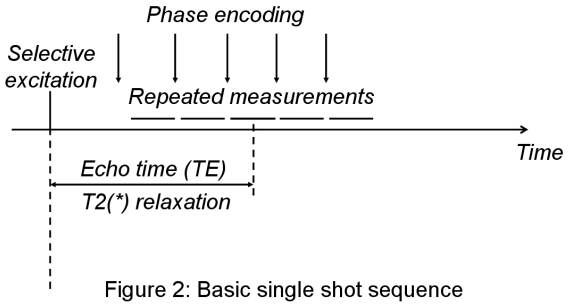

Figure 2: Basic single shot sequence

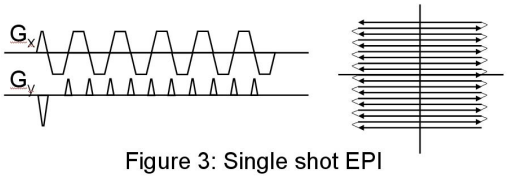

Figure 3: Single shot EPI

EPI reconstruction & artifacts

EPI images are reconstructed from k-space data by a 2D Fourier transformation. A consequence of using both positive and negative readout gradients (figure 3) is that the position of the echo-top might differ between the odd and even lines in k-space. If this is not corrected for in reconstruction, a so-called N/2 ghost will appear in the image. Other typical EPI artifacts (figure 4) are signal dropout and image deformation. The first one manifests itself in tissue above the nose and ear areas due to susceptibility differences between air and tissue. The second is visible as a compression and stretching of the brain in the phase encoding direction. For a detailed discussion on EPI image reconstruction and artifacts the book edited by Schmitt, Stehling and Turner [1] is recommended (especially chapter 4 on reconstruction and chapter 5 on artifacts). During the lecture basic image reconstruction will be explained and typical EPI artifacts will be shown and discussed in relation to acquisition and reconstruction.

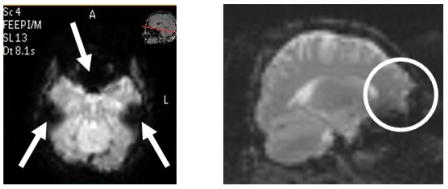
Figure 4: Typical EPI artifacts

References

[1] F. Schmitt, M.K.Stehling and R. Turner, Echo-Planar Imaging Theory, Technique and Application.