Technical Considerations for Functional Magnetic Resonance Imaging Analysis

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KEYWORDS

• fMRI • BOLD • Realignment • Normalization • Smoothing • Statistical inference

KEY POINTS

- Blood oxygenation level–dependent (BOLD) functional magnetic resonance imaging has gained clinical relevance in the past decade. However, acquiring BOLD data is straightforward, there are numerous considerations with regard to experimental design and analysis.
- Analysis has 2 distinct sections: preprocessing and postprocessing.
- The preprocessing steps relate to the spatial transformations and operations that ensure the data are properly aligned and in the same coordinate space.
- With the data properly rendered, postprocessing techniques are applied to infer statistically significant physiologic changes.
- As the field continues to evolve at a rapid pace and newer algorithms are developed it is inevitable that measurement and analysis of BOLD will improve in the years to come.

LEARNING OBJECTIVES

1. Discuss the preprocessing pipeline typically used in clinical blood oxygenation level–dependent (BOLD) functional magnetic resonance imaging (fMRI).
2. Highlight the importance of preprocessing BOLD fMRI data before statistical inference.
3. Discuss the significance of quality assurance of clinical BOLD fMRI data.
4. Understanding different statistical tests and algorithms to increase the confidence of fMRI results.

INTRODUCTION

fMRI has become ubiquitous in modern cognitive research and clinical imaging communities. Not only is fMRI being used by neuroscientists, psychologists, economists, marketers, and others to enhance clinicians' understanding of the brain, it has also progressed into several clinicians' protocols; for example, presurgical brain mappings of language and sensorimotor cortex. The statistical activation maps generated after analysis of functional data can help decrease patient morbidity while facilitating the neurosurgeon's surgical

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planning for tumor resection in an effort to improve patient outcome. Acquisition of BOLD fMRI data relies heavily on the T2* changes in blood oxygenation levels, as initially observed by Thulborn and colleagues[1] in test tube samples and later called BOLD by Ogawa and colleagues[2] through in-vivo demonstration with rats. Later it was Kwong and colleagues[3] who showed this effect in human brains. The BOLD effect can be summarized as follows: given the paramagnetic nature of deoxyhemoglobin it is possible to quantify the decrease in MR signal caused by a deficiency in oxygen. In essence, the susceptibility differences between deoxyhemoglobin and surrounding tissue lead to a rapid dephasing of regional spins, thereby decreasing the overall MR imaging signal. In contrast, an increase in oxyhemoglobin or decrease in deoxyhemoglobin leads to an increase in MR imaging signal. This process is the seminal principle involved with BOLD fMRI, and it can be detected using a fast susceptibility sensitivity MR imaging pulse sequence such as a gradient echo (GRE) echoplanar imaging sequence. However, the relative change in signal is only between 3% and 5% on scanners with a field strength of 1.5 T, which makes it difficult to distinguish between brain activation and noise (physiologic and scanner). The implication of this result necessitates the construction of higher field strength scanners (to increase signal) and the use of novel statistical techniques to parse out real signals of interest that represent signals that are different enough from background noise to be classified as significant.

This article focuses on the analysis of BOLD fMRI data. Once acquired, there are many preprocessing steps to temper the data in preparation for statistical testing. The processing procedure includes motion correction, coregistration of functional images to structural, segmentation, normalization to a standard space, and smoothing to increase signal/noise ratio (SNR) and decrease the number of multiple comparisons. The combination of all these steps yields a data set ready for statistical estimation and presentation of the maps of brain activations. **Fig. 1** shows an overall work flow chart describing the various steps involved in the BOLD image analysis. In the rest of the article these various steps are explained in detail.

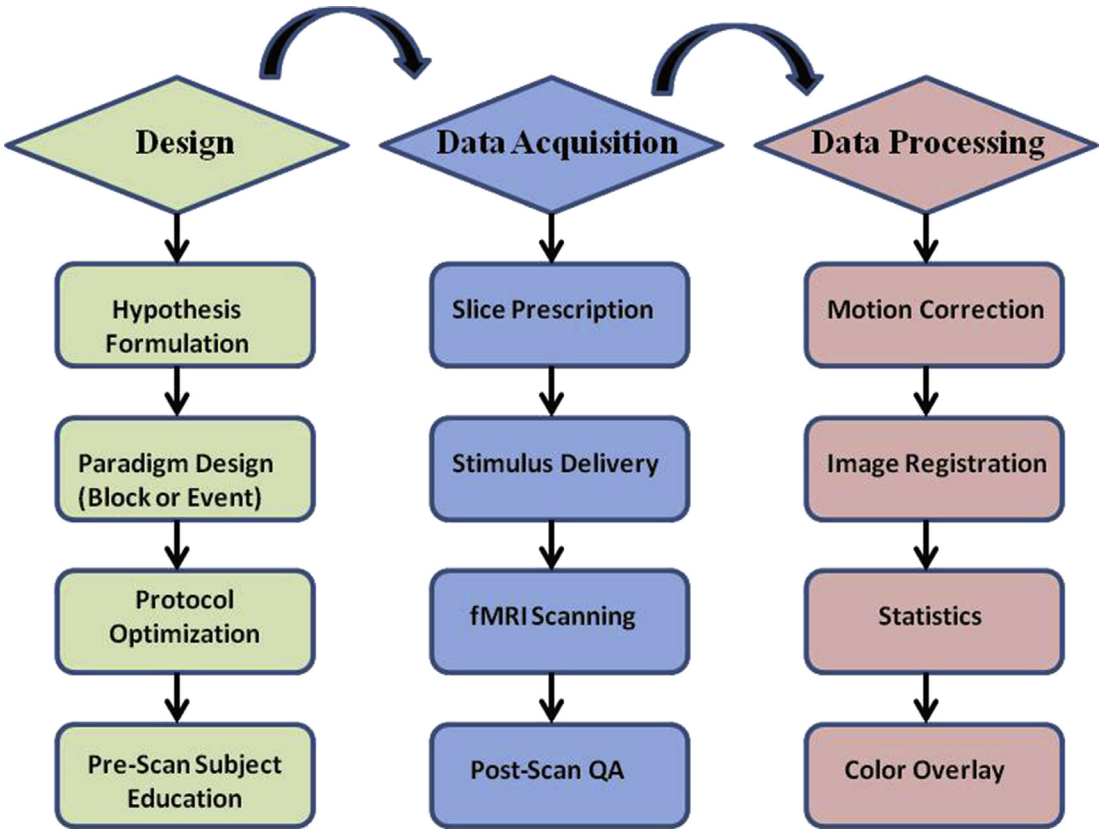

Fig. 1. Workflow pipeline outlining the key steps in the postprocessing of BOLD fMRI data. QA, quality assurance.