Clinical Functional Magnetic Resonance Imaging (fMRI)
Suitable Protocols for Motor, Somatosensory and Language Function
Christoph Stippich¹

Abstract
The clinical application of functional magnetic resonance imaging (fMRI) makes the implementation of dedicated imaging protocols mandatory that measure specific functions of the human brain validly in short scanning times. Clinical fMRI requires – in contrast to research applications – the analysis of data from individual patients to achieve an fMRI diagnosis. To this end, the paradigms need to be applicable also in patients with neurologic, linguistic or other cognitive deficits. Clinical fMRI protocols typically consist of a set of different paradigms to better assess complex brain functions (e.g., language, memory) and/or to enhance the validity of the fMRI results through reproduction. In this paper, optimized clinical fMRI protocols for motor, somatosensory and language function are proposed.

Key Words: Clinical fMRI · Motor · Somatosensory · Language

Introduction to Blood Oxygen Level-Dependent (BOLD) fMRI
Functional magnetic resonance imaging (fMRI) measures and locates specific functions of the human brain noninvasively without the use of ionizing radiation.

¹Research Group for Structural & Functional Neuroimaging, Division of Neuroradiology, Department of Neurology, University of Heidelberg Medical Center, Germany.

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To this end, the corresponding neurofunctional systems must receive targeted stimulation, which is usually done using specific stimulation schedules called paradigms. The stimulation leads to increased synaptic activity in the functional area with increased demands for energy and oxygen of the neurons, which are not only met but overcompensated by local hemodynamic changes. There is a rise in the regional cerebral blood volume, blood flow, and oxygen content. Finally, blood oxygenation level-dependent (BOLD) fMRI is used to produce the image contrast originating from the different magnetic properties of oxygenated hemoglobin (oxy-Hb) and deoxygenated hemoglobin (deoxy-Hb) [1]. Paramagnetic deoxy-Hb disturbs the magnetic field and produces a drop in signal on susceptibility-weighted (T2*) MR sequences, while oxy-Hb is magnetically “neutral” (diamagnetic). A few seconds after beginning the stimulation, the “washout” of oxygen-starved blood by oxygen-rich blood leads to a drop in the relative deoxy-Hb concentration, with a measurable drop in local field inhomogeneity in the functional area corresponding to an increase in the BOLD signal. BOLD fMRI [2] has become widely accepted for neurofunctional imaging of the human brain compared to the other MR techniques available (bolus tracking [3], arterial spin labeling [4]). The blood itself serves as an intrinsic contrast agent rendering the intravenous administration of paramagnetic contrast agents or radioactive substances unnecessary. By statistical correlation of the measured BOLD signal time course to the hemodynamic reference function (hrf), those areas of the brain can be identified which exhibit task-synchronous hemodynamic changes; they follow neuronal activation with a time lag of several seconds [5] (Figure 1). Even if the physiology of the underlying neurovascular coupling is not yet conclusively understood, there is very good agreement between the location of the BOLD signal and the actual site of neuronal activation [6]. BOLD measurements are generally carried out with ultrafast single-shot echo-planar imaging sequences as a gradient echo (GE) or spin echo (SE) [2]. GE sequences achieve higher BOLD signals of primarily venous origin, while SE sequences better reflect the capillary bed of the parenchyma [7]. The temporal resolution using paradigms in the block design or parametric design, corresponds to the length of the blocks (typically > 15 s). With event-related measurements, < 100 ms can be achieved [8]. The temporal resolution capability of fMRI is thus lower than that of electroencephalography or magnetoencephalography [9]. However, the outlay on technical methods is lower and the location accuracy higher due to the direct relation of the fMR images to surface anatomy. The signal intensity and the achievable spatial resolution change with the strength of the main magnetic field. MR tomographs with field strengths < 1.0 T are not suitable for BOLD imaging. 1.5-T machines with efficient gradients permit the reliable measurement of cortical activations, while the new clinical high-field MR imagers with 3.0 T (or more) also permit functional imaging of subcortical structures and the brain stem [10]. Because of the low signal-noise ratio many similar stimulations must be carried out during fMRI in order to obtain enough BOLD signal. This also makes statistical postprocessing of fMRI data necessary. This is typically carried out after the fMRI measurements with commercial or freely available software [11–14], most programs not being licensed for medical applications. Nowadays, the manufacturers of clinical high-field MR imagers offer optional programs for “online” evaluation of fMRI data (“real-time fMRI”) [15]. The functionality of the different programs, however, varies greatly, so the selection of suitable programs is usually made depending...