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Functional Magnetic Resonance Imaging

Jayakumar PN*

Senior Consultant & Head, Department of Radiology, Sultan Qaboos Hospital, Oman

Corresponding Author:** ***Jayakumar PN, *Senior Consultant & Head, Department of Radiology, Sultan Qaboos Hospital, Oman,* ***Email:*** *jayakumarpn@yahoo.com*

Functional magnetic resonance imaging (fMRI) is the most commonly used functional MR neuroimaging technique. It takes advantage of the tight link between local neuronal activity and blood flow, called neurovascular coupling as a result of which, there is a relative decrease of paramagnetic deoxygenated haemoglobin which in turn leads to an increase of MR signal in those areas of the brain that are active. Since such signal changes (hemodynamic response function ,HRF) are small and relative, many measurements need to be made, typically during an alternation of active and baseline conditions in a task that aims to activate the functional brain region of interest. A statistical model is created to assess the correlation of the measured signal changes with the task which is overlaid in colour on a high-resolution anatomical image of the same subject. This is the typical colour "activation" map produced by an fMRI image processing software, which is merely a combination of anatomical and statistical information very indirectly representing neuronal activation.

Significant progress has been made from the earliest clinical studies of evaluation of the visual cortex and the primary motor cortex in 1992. fMRI has been used both to understand how the normal, diseased or injured brain works in terms of the functions of the anatomically distinct regions and their functional connectivity. More specifically, the functional mapping of the brain such as cerebral dominance and asymmetry in language and memory has improved the safety of therapeutic neurosurgical or radiotherapeutic ablation due to pre-procedural planning in tumor excision or lesionectomy in patients with intractable epilepsy.

Task-based fMRI is used almost exclusively for clinical applications and are two types; Block design and Event-related design. During the performance of a task by the subject in the scanner, rapid imaging of the brain is performed. In the block design, the entire brain is scanned at intervals of 3–5 s for duration of about 5 min during equal alternating periods of performing a specified task (active) and periods of rest when not performing any task. In an event-related task design, individual stimuli, each representing a specific condition, are presented in random order and rapid succession. While such a task design offers the possibility to evaluate multiple stimuli referring to different conditions it is statistically less robust and hence blocked designs are generally preferred in clinical studies.

The choice of active and rest (baseline) conditions is determined by the brain function of interest. Somatotopic mapping of the motor cortex is usually done with motor activation tasks such as finger tapping, wrist flexion, foot tapping, and lip pouting. Language is usually studied by verb-to-noun generation, passive listening, and picture naming. It is known to activate eloquent areas (Broca's and Wernicke's) of speech planning and execution in the dominant, and sometimes non-dominant, hemisphere. . The n-back task is a widely-used in studies of working memory brain circuitry, and has been shown to activate a number of areas in the frontal and parietal cortices, in particular the dorsolateral-prefrontal cortex (DLPFC). The limbic system including structures such as the amygdala and hippocampus.has been studied using a set of gender specific emotionally-charged pictures (aggressive, erotic or stressful) with pictures of neutral content, such as geometric figures or furniture as control condition.

Research and application is slowly and predictably moving from Task related fMRI to Resting state fMRI (rsfMRI). Unlike task based fMRI where activity is based on relative changes of the BOLD signal from baseline during the performance of a task or in response to a stimulus, rsfMRI investigates synchronous activations between regions that are spatially distinct, occurring in the absence of a task or stimulus These activities observed in multiple distinct regions are presumed to indicate functional connectivity within and between the highly organized neuroanatomical networks. Unlike the task-based fMRI, the subject is instructed to lie in the scanner and think of nothing in particular. rsfMRI can be performed even when subjects are asleep or anaesthetized, and more easily in small children, restless patients or cognitively impaired subjects as there is no dependency on patient cooperation, on task design or task performance.

Traditionally fMRI has been used most frequently in patients with brain tumors in terms of displacement or involvement of functional cortex and thereby improve the safety and prognosis. Synthesis of diffusion tractography (DTI), rsfMRI data and Electrical Cortical Mapping has only further improved the outcome of the neurosurgical procedures. rsfMRI has improved our understanding of stroke and has shown the possibility of contributing to acute stroke management and also stroke rehabilitation. Recent studies of rsfMRI in patients with acute stroke has shown decrease in neural connectivity with a few hours and even before motor impairment only to be re-established in those who recovered, suggesting that rsfMRI may be useful as a tool for selecting appropriate stroke therapies and monitoring. Although structural damage from stroke is focal, remote dysfunction can occur in regions connected to the area of lesion. Disruption of inter-hemispheric connectivity in the somatomotor network and the dorsal attention network has been found to be more strongly associated with behavioral impairment. Decreased inter-hemispheric connectivity has been found to be an important contributor to neuromotor impairment after stroke.

fMRI has been used as a part of the investigating algorithm in patients with intractable epilepsy. Recent advances in rsfMRI, due to its spatial resolution being better than EEG, could provide a better localization of the functional areas in patients with lesions close to the eloquent regions of the brain such as the sensorymotor cortex and the mesial temporal lobe. Degenerative disorders have been well studied and have identified multiple brain network abnormalities and hippocampal clustering in patients with Alzheimer Disease, mild cognitive impairment and frontotemporal dementia as compared to controlled normal population groups. fMRI is being used in a number of ways to improve our understanding of psychiatric disorders. Some of the clinical applications include; helping to redefine clinical diagnoses on a less subjective, biological basis; identifying important psychological processes to initiate psychological interventions in major depressive disorders and schizophrenia. Recent work has demonstrated the ability of Resting State fMRI (rsfMRI) to assist in the diagnosis of disorders of consciousness, demonstrating a negative correlation between the connectivity of the brain networks and the level of impairment of consciousness. rsfMRI has also been used to identify patients with autism and attention deficit/hyperactivity disorder and is also being tried to address novel targeting in psychopharmacological interventions and clarifying the heterogeneity and comorbidity of many diseases. Pharmacological fMRI, assaying brain activity after drug administration is being tried to assess blood –brain barrier penetration and evaluate dose vs effect information of the medication.

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