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Functional magnetic resonance imaging: Basic principles and application in the neurosciences☆

T. Labbé Atenas[a], E. Ciampi Díaz[b], J.P. Cruz Quiroga[c], S. Uribe Arancibia[c,d], C. Cárcamo Rodríguez[a,b,*]

[a] *Centro Interdisciplinario de Neurociencias, Facultad de Medicina, Pontificia Universidad Católica de Chile, Santiago, Chile*
[b] *Departamento de Neurología, Facultad de Medicina, Pontificia Universidad Católica de Chile, Santiago, Chile*
[c] *Departamento de Radiología, Facultad de Medicina, Pontificia Universidad Católica de Chile, Santiago, Chile*
[d] *Centro de Imágenes Biomédicas, Pontificia Universidad Católica de Chile, Santiago, Chile*

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Abstract Functional magnetic resonance imaging (fMRI) is an advanced tool for the study of brain functions in healthy subjects and in neuropsychiatric patients. This tool makes it possible to identify and locate specific phenomena related to neuronal metabolism and activity. Starting with the detection of changes in the blood supply to a region that participates in a function, more complex approaches have been developed to study the dynamics of neuronal networks. Studies examining the brain at rest or involved in different tasks have provided evidence related to the onset, development, and/or response to treatment in various diseases. The diversity of the possible artifacts associated with image registration as well as the complexity of the analytical experimental designs has generated abundant debate about the technique behind fMRI. This article aims to introduce readers to the fundamentals underlying fMRI, to explain how fMRI studies are interpreted, and to discuss fMRI's contributions to the study of the mechanisms underlying diverse diseases of the nervous system.

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* Corresponding author.
E-mail address: ccarcamo@med.puc.cl (C. Cárcamo Rodríguez).

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Resonancia magnética funcional: principios básicos y aplicaciones en neurociencias

Resumen La resonancia magnética funcional (RMf) es una herramienta avanzada para el estudio de las funciones cerebrales en sujetos sanos y pacientes neuropsiquiátricos, que logra identificar y localizar fenómenos específicos del metabolismo y la actividad neuronal. Comenzando por la detección de los cambios en la irrigación de una región que participa en una función, actualmente se han desarrollado aproximaciones más complejas que estudian la dinámica de las redes neuronales. Tanto en reposo como asociada a tareas, se ha aportado evidencia relativa al inicio, la evolución o la respuesta al tratamiento de diversas enfermedades. Los posibles artefactos asociados al registro y la complejidad de los diseños experimentales analíticos han generado abundante debate en torno a la técnica de la RMf. El objetivo del presente artículo es introducir al lector en las bases de la RMf, su interpretación y sus contribuciones al estudio de los mecanismos subyacentes a diversas afecciones del sistema nervioso.

Introduction

The attempt to attribute mental functions to specific areas of the brain started falling apart with Gall's phrenology; however, pathologists such as Broca and Wernicke showed cases of patients in whom local brain injuries caused specific functional disabilities.[1] Although these cases of regional symptoms, that are valid, have contributed to the ideas of localization in the subconscious of physicians and researchers, to this day, we know that the attribution of high-complexity functions to a specific area is extremely difficult or even inappropriate, because brain activity is based on the anatomic connections of different regions. Also, the same models of lesion, when interpreted from the perspective of functional disconnection, contribute to refute localizationism as a possible explanation of how the cerebral cortex actually works.

In an effort to try to give a more comprehensive explanation of the neural resources associated with the execution of certain cognitive functions, or the disintegration of such functions in the context of neurodegenerative conditions, the functional magnetic resonance imaging (fMRI) modality can be used to identify brain regions with specific functions and others that, although anatomically separated, are functionally connected configuring networks or connections.[2] Fig. 1 shows neural networks recruited while conducting different cognitive tests.

The goal of this paper is to introduce readers to the basics of fMRI, explain how fMRI studies are interpreted, and discuss how the fMRI contributes to the study of the mechanisms underneath different diseases of the central nervous system. At the same time, we propose here that this imaging modality provides multiple opportunities for radiological research, neurology, and neurosciences, and it can be used based on the interests, needs, and local reality of every particular researcher. Thus, one fMRI-based experimental paradigm provides a high degree of adaptation to the questions posed by research. Thus, acquisitions at rest can take less than 5 min (o much more than this) and require one standardized acquisition protocol that should take into account both technical details and decisions made based on the definition and instructions of the state of mental rest, eye opening, and strict motor control. On the other hand, more complex experimental designs can include motor or cognitive tests conducted during the acquisition and require the use of electronic devices compatible with the magnetic field, plus longer acquisition times and slower learning curves both for the researcher and the experimental subject.

The origin of the BOLD signal

fMRI studies are based on the acquisition of the BOLD signal (Blood Oxygen Level Dependent). The first papers published on this issue described signal changes based on the apparent transverse relaxation time T2* in a paradigm of visual stimulation. These changes that were objectified in the primary visual cortex were consistent with the idea that neural activation increases both the regional blood flow and oxygenation of venous blood, which in turn reduces the concentration of local deoxyhemoglobin that has paramagnetic properties.[3,4] During the last few years, we have been acquiring more knowledge on the mechanisms that enable this neurovascular connection. The actual model claims that the generation of potentials of action, synaptic activity, release of neuromodulators and neurotransmitters, and astrocyte activity, among other factors, increases the cerebral blood volume and flow, and the metabolic rate of the nervous tissue involved. However, the increase of blood flow is higher than the increase of metabolic rate, leading to a relative increase in oxygen availability and a reduced concentration of deoxyhemoglobin, meaning that the BOLD signal of the region involved will be higher compared to baseline state[5,6] (Fig. 2).