Visual Mapping Using Blood Oxygen Level Dependent Functional Magnetic Resonance Imaging

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KEYWORDS

• Human • Functional MR imaging • Brain mapping • Visual cortex • Cancer
• Arteriovenous malformation • Epilepsy

KEY POINTS

- Functional MR (fMR) can be used to map the visual cortex and identify healthy brain tissue near a site of operable brain abnormality.
- fMR mapping using an advanced stimulus/task paradigm permits identification of brain subregions supporting central vision that is critical for reading and other visual functions.
- Novel functional field map (FFMap) displays permit instant appreciation of the behavioral relevance of visual cortex activation, especially with respect to existing and treatment-induced visual field deficits.
- Neurovascular uncoupling (NVU) can complicate the interpretation of fMRI data, but this can be ameliorated by use of new methods to detect and map NVU.
- Resting-state fMRI can be used to map the visual cortex in patients who are behaviorally compromised.

INTRODUCTION

Being the most essential of our senses, the intricacy and brilliance of vision are perhaps most appreciated when compromised by damage or disease. Although a comprehensive account of the processes by which quanta of light falling on the retinae are translated into subjective visual experience is lacking, recent advances, particularly from functional neuroimaging, have allowed researchers to sketch out the functional organization of the human visual system, and thus provide a framework for understanding the sensory and perceptual effects of central vision pathology. For instance, it is now known that vision-related cortex, once thought to reside primarily in the calcarine fissure of the occipital lobe, extends throughout the entire lobe and into adjoining portions of the temporal and parietal lobes (**Fig. 1**) and even to remote locations in the frontal lobes.[1–4] Though highly interconnected, this extensive network can be subdivided into more than a dozen functionally distinct visual areas which, if selectively damaged, can result in deficits ranging from simple scotomata (localized regions of blindness) to complex agnosias and higher-order perceptual deficiencies.[5–12] For the clinician, staying abreast of all these developments can be daunting and of questionable therapeutic value given their limited ability to "cure" central nervous system damage. However, there are clinical applications, such as the guidance of neurosurgery and the documentation of disease progression, for which detailed assessment of visual system involvement may be warranted to avoid potentially

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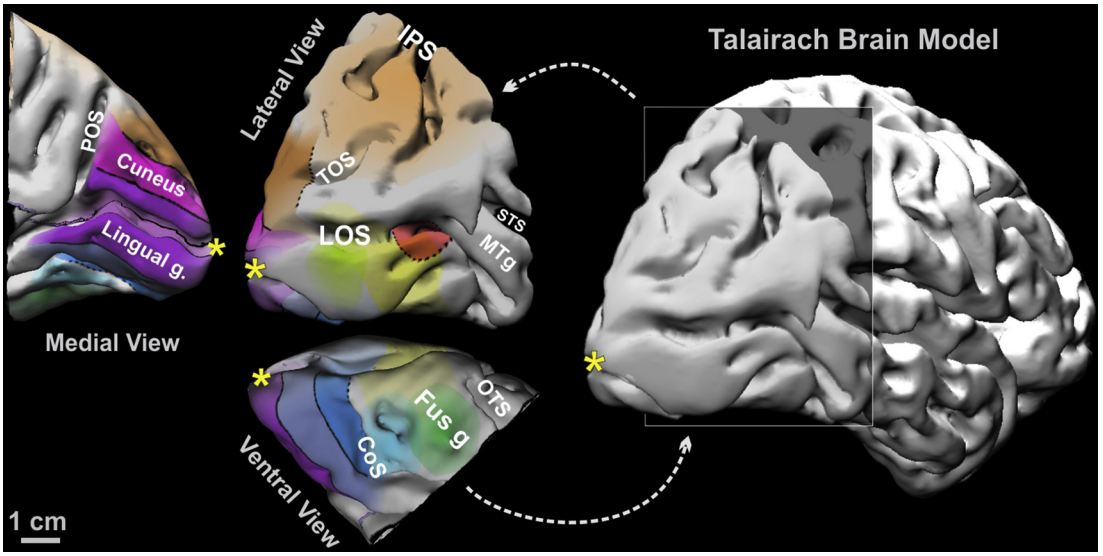

Fig. 1. Subdivisions of human visual cortex displayed on a surface model of the standard brain of Talairach and Tournoux.[59] Whole brain at right shows plane used to create a separate occipital lobe model. Yellow asterisks mark the tip of the occipital pole. Colored patches on occipital models mark the approximate locations of functionally distinct visual areas. (*Medial view*) Pink with yellow asterisk: primary visual cortex, V1, which is flanked above and below by purple V2. Magenta (cuneus): dorsal division of V3. (*Ventral view*) Blue-gray: ventral division of V3. Dark blue: V4. Light blue: ventral occipital complex.[3] Dark green: fusiform face area.[60] (*Lateral view*) Red in LOS-TOS complex.[3] Yellow: lateral occipital complex.[61,62] CoS, collateral sulcus; Fus g, fusiform gyrus; IPS, intraparietal sulcus; LOS, lateral occipital sulcus; MTg, middle temporal gyrus; OTS, occipitotemporal sulcus; POS, parietal occipital sulcus; STS, superior temporal sulcus; TOS, transverse occipital sulcus.

debilitating vision deficits. Accordingly, this article outlines some of the more clinically relevant tools developed in the last decade for mapping the human visual system, and highlights key interpretational issues and future trends.

From a clinical applications perspective, it is noteworthy that some of the earliest accounts of vision loss attributable to brain damage noted the relationship between the anatomic site of damage and the location and severity of a visual scotoma within the patient's field of view.[13–19] This perspective is reiterated today in the use of functional magnetic resonance imaging (fMRI) to provide retinotopic maps of the visual cortex potentially at risk from invasive surgical and radiation treatment of nearby brain tumors, arteriovenous malformations, or epileptic foci. fMRI is used to map eloquent neural responses evoked by sensory, motor, or cognitive tasks by measuring localized changes in the oxygenation of blood hemoglobin that are triggered by focal changes in neural activity. Although fMRI is, therefore, an indirect measure of neuronal function, it is noninvasive, well tolerated by patients, rapidly acquired in as little as 20 minutes, and can provide extensive maps of eloquent brain tissue that, if damaged, could result in a posttreatment visual deficit.

VISUAL MAPPING PARADIGM AND ANALYSIS

Early approaches to mapping human visual cortex were as simple as turning the lights on and off, or flashing a large checkerboard. Although such stimuli can evoke activation of the visual cortex, the resulting fMRI maps do not reveal even the most rudimentary features of functional organization such as the distinction between the cortical representations of peripheral versus central vision, the latter being particularly critical for many day-to-day visual tasks such as reading. Today, more comprehensive and informative approaches are available. (For detailed reviews of methodology and the functional organization of the visual cortex, see Gill and colleagues[20] and DeYoe and colleagues[21]). Mapping of visual field eccentricity and angular position using fMRI scans of approximately 4 minutes each can yield more informative cortical maps that delineate multiple, functionally distinct, visual areas and differentiate subregions supporting central versus peripheral vision. This mapping can be done efficiently through sequential display of a slowly expanding checkered annulus and a slowly rotating checkered wedge, respectively (**Fig. 2**). The checkerboard patterns are composed of high-contrast, black and white checks that counterphase flicker at 8 Hz, resulting