Functional MRI - A pictorial review of eloquent cortical activation areas

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Learning Objectives

To review expected cortical activation areas during the four major paradigms typically utilised in clinical functional Magnetic Resonance Imaging (fMRI) with examples of pathological processes involving these areas.

Background

Functional Magnetic Resonance Imaging (fMRI) has transitioned from the research to the clinical realm, particularly in the setting of brain tumour and epilepsy surgery. Non-invasive pre-operative fMRI mapping can provide the neurosurgical team with additional information regarding the relationship between the surgical target and adjacent eloquent brain regions.

During a functional paradigm, neuronal activation causes regional increased cerebral blood flow that produces local magnetic susceptibility effect, increasing Magnetic Resonance signal via "blood oxygenation level dependent" (BOLD) contrast. The increased BOLD signal then undergoes statistical analysis to create functional maps.

Functional MRI is ideally performed with a 3Tesla magnet fitted with dedicated hardware and robust post-processing software operated by an experienced neuro-imaging team.

The information gained from a fMRI study can be combined with volumetric brain imaging and other advanced MRI techniques such as tractography (to map white matter tracks) and be incorporated into surgical stereotaxis software to guide target resection.

Images for this section:
Fig. 1: Hardware and software required to perform a fMRI study (the hardware shown is MRlx, which is used at our institution). A: The fMRI synchronisation control system coordinates paradigm presentation with image acquisition, behavioural response and physiological data. B: The eye tracker is used to detect subtle patient movement that may interfere with study accuracy. C: The scanner interface monitors behavioural and physiological data and calculates activation maps. D: The patient responds to visual/auditory input by using the thumb switch. E: The visor is mounted over the head coil to allow the patient to see the projected paradigm. F: An example of the language paradigm presented to a patient.
Paradigms used in clinical practice:

Language:

Language tasks typically consist of sentence reading followed by a cognitive response with activation of language and visual pathways as well as working memory. In visually impaired patients, the language paradigm can be performed using auditory stimuli resulting in language and auditory pathway activation.

Activation and laterality of Broca's area for language expression (pars triangularis and pars opercularis) and Wernicke's area for language comprehension (posterior aspect of the superior temporal sulcus, either superior or inferior bank) are assessed [Figure 2]. [1,2]

Most patients (left handed, right handed and ambidextrous) show left-dominant language activation, however, many variations occur [Figure 3]. [1,3,4]

There is also activation of an extensive visual and cognitive network involving the frontal eye fields (precentral sulcus), supplementary eye fields (medial frontal cortex), visuospatial attention region (intraparietal sulcus), visuospatial processing region (temperoparietal junction), visual motion detection (middle temporal lobe/V5), visual cortex (occipital lobes - V1 to V4) and executive working memory (dorso-lateral pre-frontal cortex) [Figure 4]. [1,2]

Memory:

Three different forms of memory are considered - episodic memory, working memory and semantic memory. In the clinical setting mainly episodic memory is tested (encoding and retrieval) with activation of the hippocampi (memory), mesial temporal lobes (memory), dorso-lateral prefrontal cortex (working memory, executive function) and anterior cingulate gyrus (attention) [Figure 5]. [1]

Working memory forms background awareness/decision making while performing other tasks and semantic memory relates to understanding context. [1,6]

Vision:
Visual saccades are tested by a flashing checker-board or a moving dot. This results in activation of the frontal eye fields (precentral sulcus), supplementary eye fields (medial frontal cortex), visual cortex (occipital lobe V1-V4), visual motion detection region (middle temporal cortex/V5), visuospatial attention (intra-parietal sulcus), visuospatial processing (temporoparietal junction) and lateral geniculate nuclei [Figure 6]. [1,7]

**Motor:**

Motor tasks are typically performed using the hand, foot or tongue/mouth movement signalled via a visual cue. The areas of activation include the respective homunculus primary motor cortex (pre-central gyrus), supplementary motor cortex (medial frontal lobe), frontal eye field (pre-central sulcus), supplementary eye field (medial frontal lobe anterior to the supplementary motor area) and motor co-ordination (thalamus and cerebellum) [Figure 7]. [1,8,9]

**Shortcomings and pitfalls:**

The success of a fMRI study is heavily reliant on patient compliance. Patient movement, language barriers, impaired task compliance and cognitive impairment can greatly limit study efficacy. Other factors that can interfere with cortical activation include steno-occlusive disease involving the arteries of the head or neck and magnetic field inhomogeneities (including blood product deposition and surgical clips) interfering with the BOLD signal. [1]

**Pre-operative imaging examples:**

Pathological processes can involve or displace eloquent cortical areas. fMRI can assist with non-invasive pre-operative cortical mapping, providing additional information for pre-surgical discussion and decision-making.

[Figure 8][Figure 9][Figure 10][Figure 11][Figure 12][Figure 13]

**Images for this section:**
Fig. 2: A and C: Dominant right (thick arrow) and non-dominant left (thin arrow) Broca’s area activation confirmed on laterality index calculation. B and D: Dominant left (thick arrow) Wernicke’s activation in the same right handed patient, confirmed with laterality index calculation.
Patient 1A-C: Right handed
Patient 2A-B: Ambidextrous
Patient 3A: Right handed
Patient 4A-C: Right handed
Patient 5A: Left handed
Fig. 3: fMRI maps demonstrating variation in laterality of speech centres - thick arrows high-lighting dominant speech area activation and thin arrows showing contra-lateral non-dominant activation (white arrows - Broca's areas and black arrows - Wernicke's areas). 1: Right-handed patient with right dominant Broca's area and co-dominant Wernicke's areas. 2: Ambidextrous patient with an intra-ventricular tumour demonstrating left dominant Broca's and Wernicke's areas. 3: Right handed patient with co-dominant Broca's areas and left dominant Wernicke's area. 4: Right handed patient with right dominant Broca's and Wernicke's areas. 5: Left handed patient with left dominant Broca's and Wernicke's areas.

Fig. 4: Although the language paradigm is primarily assessed, additional cognitive and visual activation is also demonstrated. A: Activation of bilateral Wernicke's areas (thick white arrows) as well as the primary visual fields V1-V4 (thin black arrows) and visual motion detection V5 (thick black arrow). B: Broca's area activation (thick white arrow) as well as V1-V4 (thin black arrows) and V5 (thick black arrow) activation. C: Frontal eye field activation (thick black arrows), supplementary eye field activation (thick white arrow head), visuospatial attention (thin black arrows) and cognitive processing/working memory (thin white arrow).
**Fig. 5:** Memory paradigm activation. A to C: Activation of bilateral hippocampi (thick arrows) as well as the mesial temporal lobes (thin arrows).

**Fig. 6:** Visual field activation. A: Activation is noted within the primary visual cortex V1-V4 (white arrows) as well as the motion detection cortex V5/MT (black arrows). B: Visuospatial attention (thick black arrows) and visuospatial processing (thin black arrow) activation. C: Activation of bilateral frontal eye fields (thick white arrows) as well as the supplementary eye fields (thin white arrow) with right dorso-lateral pre-frontal cortex activation (arrow head) related to working memory. D: Activation of the right lateral geniculate nucleus (black arrow).
**Fig. 7:** Motor paradigm activation. A: Activation of bilateral hand primary motor cortices (thin arrows) as well as activation of the supplementary motor cortex (thick arrow). B: Bilateral activation of the tongue/mouth primary motor cortex (thin black arrows) and primary left sensory cortex (thick white arrow). There is also activation of the left thalamus (thick black arrow) and bilateral basal ganglia (short thin white arrows) for motor integration and co-ordination.

**Fig. 8:** Functional MRI maps obtained as part of the pre-operative work-up of a left frontal protoplasmic astrocytoma (WHOII). A: Bilateral motor tongue activation demonstrated, on the left the tongue motor cortex contacts the posterior tumour margin. B: The dominant
left Broca’s area is displaced inferiorly by the tumour (thick black arrow) compared to the expected location noted on the right (thin black arrow). C: Left sided hand motor activation (arrow) is confirmed to be well away from tumour.

Fig. 9: Figure 9: Motor paradigms for hand and foot were performed to assess the motor strip in relation to this right fronto-parietal diffuse astrocytoma (WHOII). A: Bilateral primary hand motor activation is demonstrated (thick black arrows) - right sided activation contacts the lateral margin of the tumour. The supplementary motor area (thin white arrow) is seen antero-medial to the lesion. B: With the supplementary motor area identified during hand motion, new mesial frontal activation seen during foot motion confirmed an abnormally anteriorly displaced right hemispheric primary foot motor cortex (thick white arrow) relative to its normal position on the left (thin white arrow).
**Fig. 10:** A: Right amygdala dysplasia (arrow) resulting in treatment-refractory epilepsy. B, C and F: Despite the patient being right-handed, right sided Broca's dominance and Wernicke's co-dominance was demonstrated, suggesting an increased chance of post-operative memory-related word-finding difficulty. D and E: Bilateral hippocampal activation (arrows) as well as occipital visual cortex activation noted during memory testing.
**Fig. 11:** Language paradigm testing in a patient with a left temporal gangliogioma. A: In this right handed patient, the right sided Broca’s area (thin black arrow) and Wernicke’s area (thin white arrow) are non-dominant. B and C: The dominant left Broca’s area (thick black arrow) is displaced antero-superior by the tumour and there is marked postero-superior displacement of the dominant left Wernicke’s area (thick black arrow) as a result of mass effect.

![Image of brain scans](image)

**Fig. 12:** Language paradigm testing during pre-operative tumour work-up. A: Left fronto-temporal diffuse astrocytoma (WHOII) infiltrating the left dominant Broca’s area (arrow). B: A different patient with a left parieto-temporal glioblastoma multiforme - fMRI confirming that the dominant left Wernicke’s area (thin black arrow) is well anterior to the tumour margin (thin white arrow).
**Fig. 13:** A: Right temporal encephalomalacia secondary to prior herpes encephalitis causing treatment refractory seizures. B and C: Pre-operative fMRI demonstrates co-dominant Broca’s areas and left dominant Wernicke’s area.
Conclusion

In the clinical context, functional MRI can be used as an important non-invasive method to map eloquent brain regions during pre-operative work-up. The reporting radiologist needs to have a thorough knowledge of expected cortical activation during the four major clinical paradigms and be aware of potential imaging pitfalls that may affect the quality and accuracy of the investigation.

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References


