Introduction to Functional Magnetic Resonance Imaging (fMRI)

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History of brain imaging

1890s 1970s 1970s 1980s 1990s
what is BOLD fMRI

why fMRI is performed

how to perform fMRI
what is BOLD fMRI

why fMRI is performed

how to perform fMRI
what is BOLD fMRI

- fMRI = functional magnetic resonance imaging
- MRI study that measures brain activity by detecting changes associated with blood flow
what does fMRI look like?

brain activation

anatomical image
what is BOLD fMRI

why fMRI is performed

how to perform fMRI
fMRI use

Clinical applications

Research
Clinical applications

- Presurgical planning for brain tumor resection or epilepsy surgery
- Pre-surgical identification of eloquent cortex
- Lateralization of hemispheric dominance

Research

- Study physiology and pathophysiology in brain diseases e.g. dementia, psychiatric disorders, traumatic brain injury, cerebrovascular diseases
Clinical applications:

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Research:

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Eloquent cortex

- Definition = brain areas that directly control function
- Damage to eloquent cortex generally causes major neurological deficits
Generally, brain function is localized to specific brain locations.
Generally, brain function is localized to specific brain locations. However, involvement of anatomical location by a tumor can cause cortical reorganization and displacement of the function to another location.
For safe surgery, the functional area needs to be identify
Intraoperative identification of eloquent cortex

Intraoperative electrocortical stimulation is gold standard

Limitations of electrocortical stimulation mapping

- perform during operation
- awake patient
- need patient co-operation
- can cause seizures
- time consuming

Ritaccio et al., Journal of Clinical Neurophysiology, March 2018
fMRI in presurgical mapping of eloquent cortex

fMRI can provide guidance for choosing electrocortical stimulation sites

De la Pena et al., Radiologia, 2013
fMRI in presurgical cortical mapping

**Value**
- provide preoperative guidance for choosing electrocortical stimulation sites
- shorten operation time

**Limitations**
- fMRI is not accurate enough to be used independently
- electrocortical stimulation remains the gold standard for localization of eloquent cortex

Ritaccio et al., Journal of Clinical Neurophysiology, March 2018
Clinical applications

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Research

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The two hemispheres of the human brain may look alike, but the function in each of the cerebral hemisphere is not the same.
Language and memory functions have dominance in one of the hemisphere.

The dominant hemisphere is usually the LEFT hemisphere.
There is an association between handedness and dominant hemisphere
Right-handed
left hemispheric dominance

95%

right hemispheric dominance

5%

Knecht et al., Brain 2000
Left-handed

https://thepetridish.my/2018/01/27/what-causes-left-handedness/
Left-handed people have a left hemispheric dominance of 70% and a right hemispheric dominance of 30%.

Knecht et al., Brain 2000
https://thepetridish.my/2018/01/27/what-causes-left-handedness/
Limitations of handedness to determine hemispheric dominance

- Handedness is a spectrum
  - Higher incidence of atypical dominance pattern in epilepsy patients
  - Handedness may not be the best predictor for hemispheric dominance
Wada test

Intracarotid Amobarbital test

- gold standard for lateralization of language and memory function
- invasive
- inject medication into one side of the internal carotid artery to paralyze one side of the brain
Wada test

Amobarbital injection

Paralyze one side of the brain
Patient would not be able to perform language task if the paralyzed side is the dominant hemisphere
Limitations of Wada test

- invasive procedure
- vascular connection between two cerebral hemispheres can cause cross paralysis in both sides of the brain
fMRI vs Wada test

- High concordance rate (about 90%) between language fMRI and Wada test for language lateralization

- Language fMRI may reduce the necessity of Wada test for language lateralization, especially in temporal lobe epilepsy

Woermann et al., Neurology 2003
Indications for language lateralization using fMRI

- Preoperative planning in patients with high incidence of atypical language dominance pattern e.g. epilepsy patient
- Preoperative planning in patients with brain tumor close to language areas
How does fMRI work?
Principles fMRI

BOLD = blood oxygen level
In 1990, Seiji Ogawa described that dark signal intensities can be seen on GRE images attributed to a magnetic susceptibility effect induced by paramagnetic deoxyhemoglobin in red cells.

Ogawa et al, Magnetic resonance in medicine 16, 9-18 (1990)
Red blood cell

Hemoglobin = protein molecule in red blood cells that can carry oxygen
Oxygen use by tissue

Oxyhemoglobin

Deoxyhemoglobin
Oxyhemoglobin

Deoxyhemoglobin

Diamagnetic

Paramagnetic
Oxygen use by tissue

Oxyhemoglobin

O$_2$

Diamagnetic

Deoxyhemoglobin

Paramagnetic
Oxyhemoglobin

Deoxyhemoglobin

Oxygen use by tissue

Diamagnetic

Paramagnetic

BOLD = blood oxygen level dependent contrast
BOLD
Hemodynamic response function

http://mriquestions.com/does-boldbrain-activity.html
Neuronal activation

Increase oxygen use

Increase deoxyhemoglobin

Decrease BOLD signal
Increase deoxyhemoglobin

Increase cerebral blood flow and blood volume

Increase oxyhemoglobin & decrease deoxyhemoglobin

Increase BOLD signal
Cerebral blood volume starts to decrease while there is ongoing oxygen consumption.

- Increase deoxyhemoglobin
- Decrease BOLD signal
BOLD
Hemodynamic response function

http://mriquestions.com/does-boldbrain-activity.html
**BOLD**

**Hemodynamic response function**

![Graph showing BOLD response with labels for initial overshoot, initial dip, plateau, post stimulus undershoot, and repeated stimuli.](http://mriquestions.com/does-boldbrain-activity.html)
what is BOLD fMRI

why fMRI is performed

how to perform fMRI
MRI Scanner & fMRI software

3 Tesla MRI scanner
Types of fMRI

• Task-based fMRI
• Resting state fMRI
Accessory equipments

- Binoculars
- Headphones
- Binoculars
Task-based fMRI

- Block paradigm
- Event-related paradigm
fMRI paradigms

• Motor paradigms
• Language paradigms
Motor paradigms

- Finger tapping
- Fist clenching
- Button pressing
Motor paradigms

- smiling
- tongue moving
- toe wiggling
Finger tapping
Finger tapping

![Finger tapping diagram](image)
Toe wiggling
Toe wiggling
Activations in motor areas
precentral gyrus
Motor homunculus

One cerebral hemisphere controls the motor function of the body on the opposite side.
Language paradigm
Word generation paradigm

The patient is asked to think of words that start with each letter

- A —> apple, ant
- B —> boy, bird
- Think only, without having to move the mouth
Verb generation paradigm

The patient is asked to think of verbs that are related to a given noun

- bike —> ride, clean, sell
- drum —> play, borrow, show
The patient is asked to name the picture.

ชุดคำสั่งที่ 3 : จงคิดชื่อสิ่งของจากภาพ
เมื่อมีรูปภาพปรากฏขึ้นบนจอภาพ
ให้คิดชื่อสิ่งของที่อยู่ในภาพนั้นๆ
ตัวอย่าง

--- > ดอกไม้

ให้คิดในใจเท่านั้นไม่ต้องบอกเสียงหรือขยับปาก
Broca area

Pars opercularis and pars triangularis of the inferior frontal gyrus
Wernicke area

posterior superior temporal gyrus, just posterior to the Heschl gyrus
Secondary language areas

pre SMA (supplementary motor area) in superior frontal gyrus
Secondary language areas

middle frontal gyrus and inferior aspect of the precentral gyrus
Secondary language areas

- Anterior insula
- Visual word form area and fusiform face area in fusiform gyrus
Language lateralization

strong left lateralization
19 M, left-handed, right hippocampal sclerosis

lesion, right side

left hemispheric dominance
30 F, right-handed, DNET in left cerebral hemisphere

lesion, left side

left dominant
Resting state fMRI

- acquired in the absence of stimulus or task
- focus on spontaneous low-frequency BOLD signal alteration
- need sophisticated computational analysis
- rs-fMRI detects connectivity between different brain regions
- brain regions that have BOLD signal change at the same time are considered the same network

Wang et al, AJNR, 2018
Resting state fMRI

Default mode network
Post stroke recovery
brain tumor surgery
epilepsy
dementia
psychiatric disease
human cognition

fundamental knowledge of fMRI
brain plasticity
Limitations of fMRI

- task-based fMRI needs patient co-operation
- motion can cause data error
- lesion near skull base or lesion with susceptibility signal loss may cause false negative activation
- malignant tumor with hypervascularity may cause neurovascular uncoupling and false negative activation
Recap

- fMRI can detect brain activation
- T2*GRE EPI sequence
- BOLD signal
- no need for Gd injection
- Two types of fMRI; task-based and resting-state
- motion is a problem in fMRI
Thank you!