How is fMRI data acquired?

Sunnybrook Neuroimaging Summer School 2025
Functional MRI Module

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Overview

- Brief overview of conventional fMRI acquisition methods
- Parsing the methods section of an fMRI paper
- Focus on providing basic definitions, practical, working knowledge and intuition for what things mean

Conventional functional MRI Acquisition

Conventional functional MRI Acquisition

2D Multi-Slice Gradient Echo EPI

2D Multi-Slice

Gradient Echo

EPI

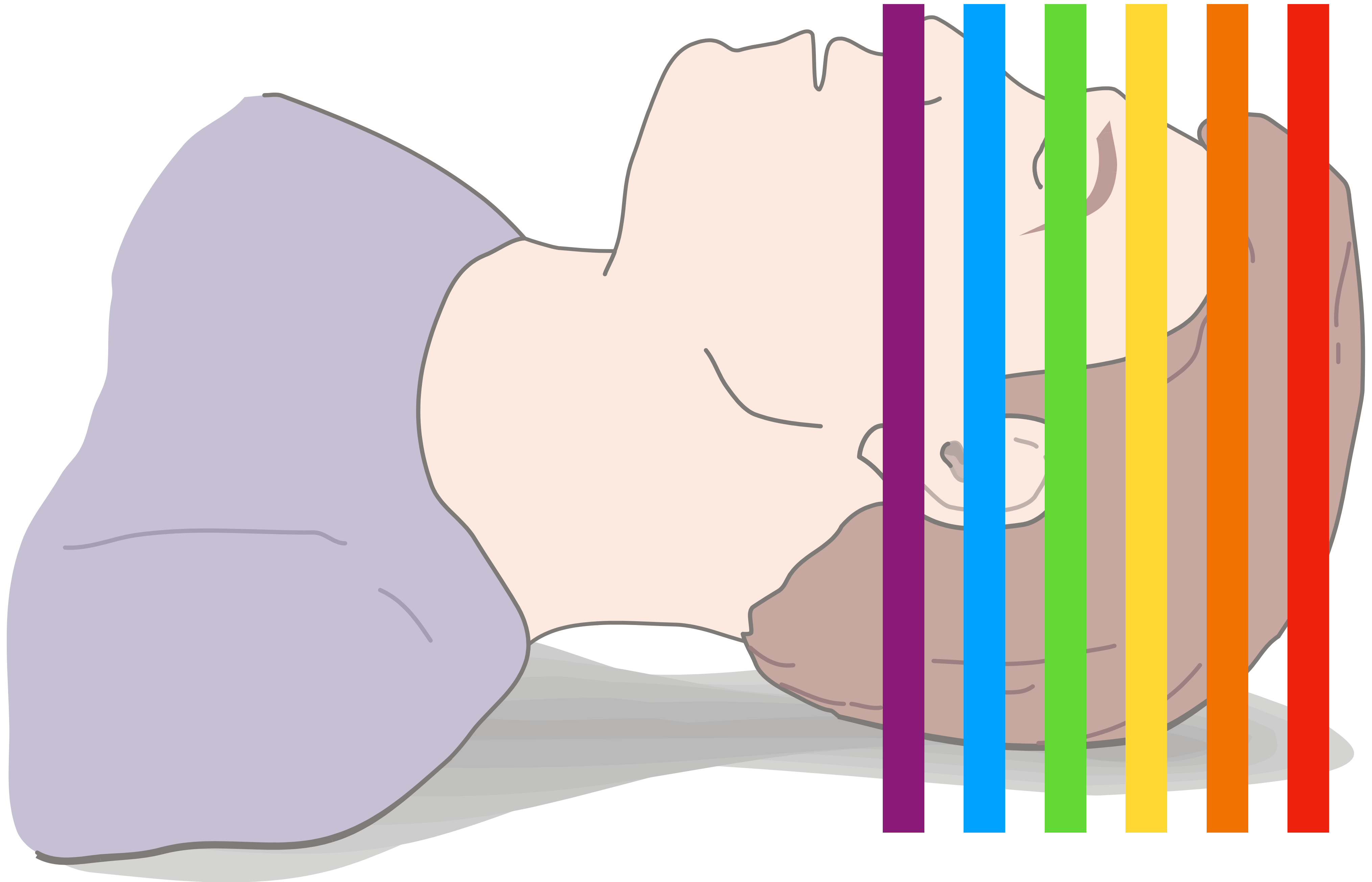
Conventional functional MRI Acquisition

2D Multi-Slice Gradient Echo EPI

2D Multi-Slice

2D Multi-slice imaging

2D Multi-Slice Gradient Echo EPI



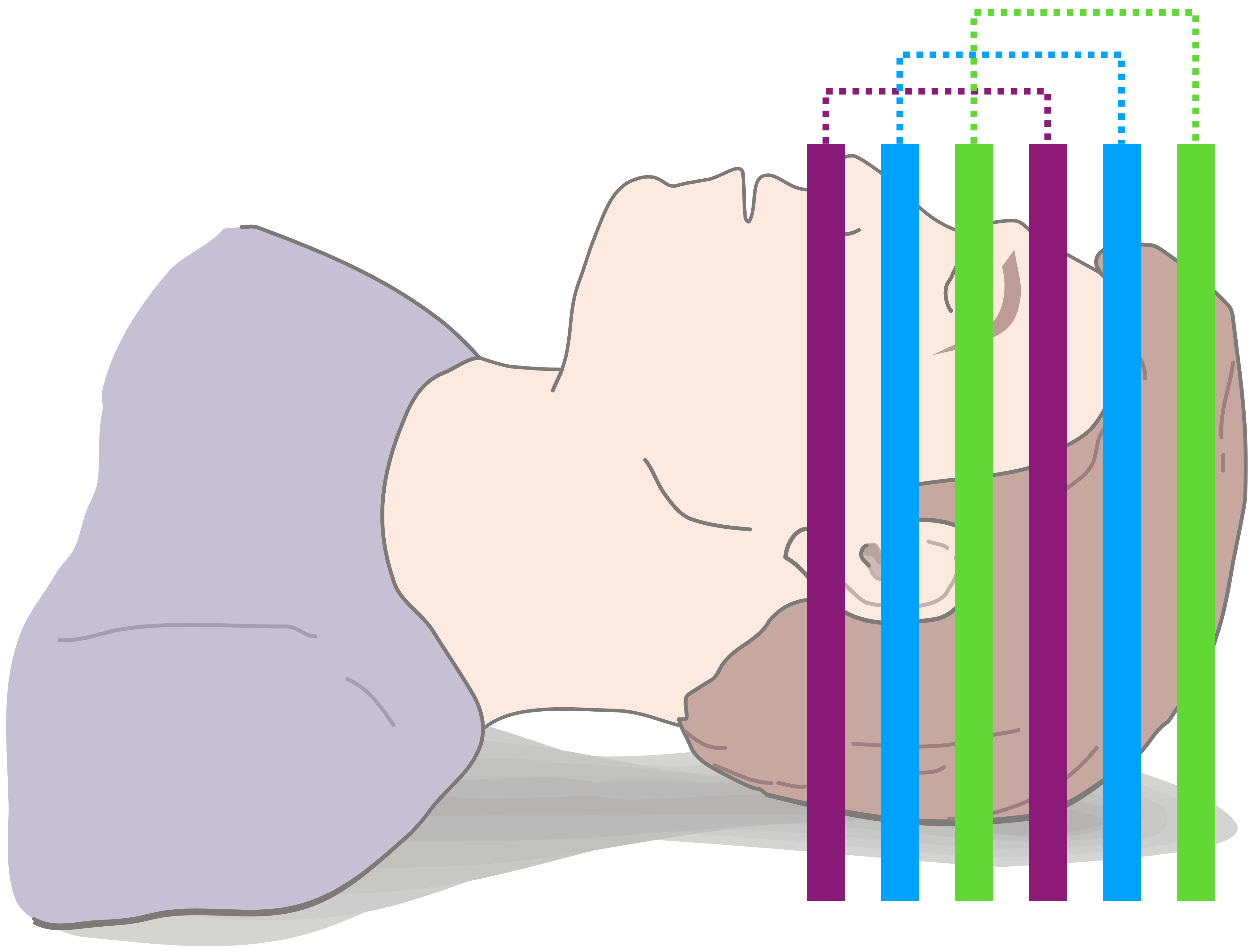
2D Imaging Considerations

2D Multi-Slice Gradient Echo EPI

- Slices are acquired sequentially one at a time
  - Slice timing effects and correction
- Slice profiles are not perfect rectangles, but can have wider than nominal extent
  - Slice interleaving and slice gaps address slice interaction effects
  - Slice thickness are typically 2-3 mm
- Slice orientation can be important for efficiency and artifact mitigation

Simultaneous Multi-Slice Imaging

2D Multi-Slice Gradient Echo EPI



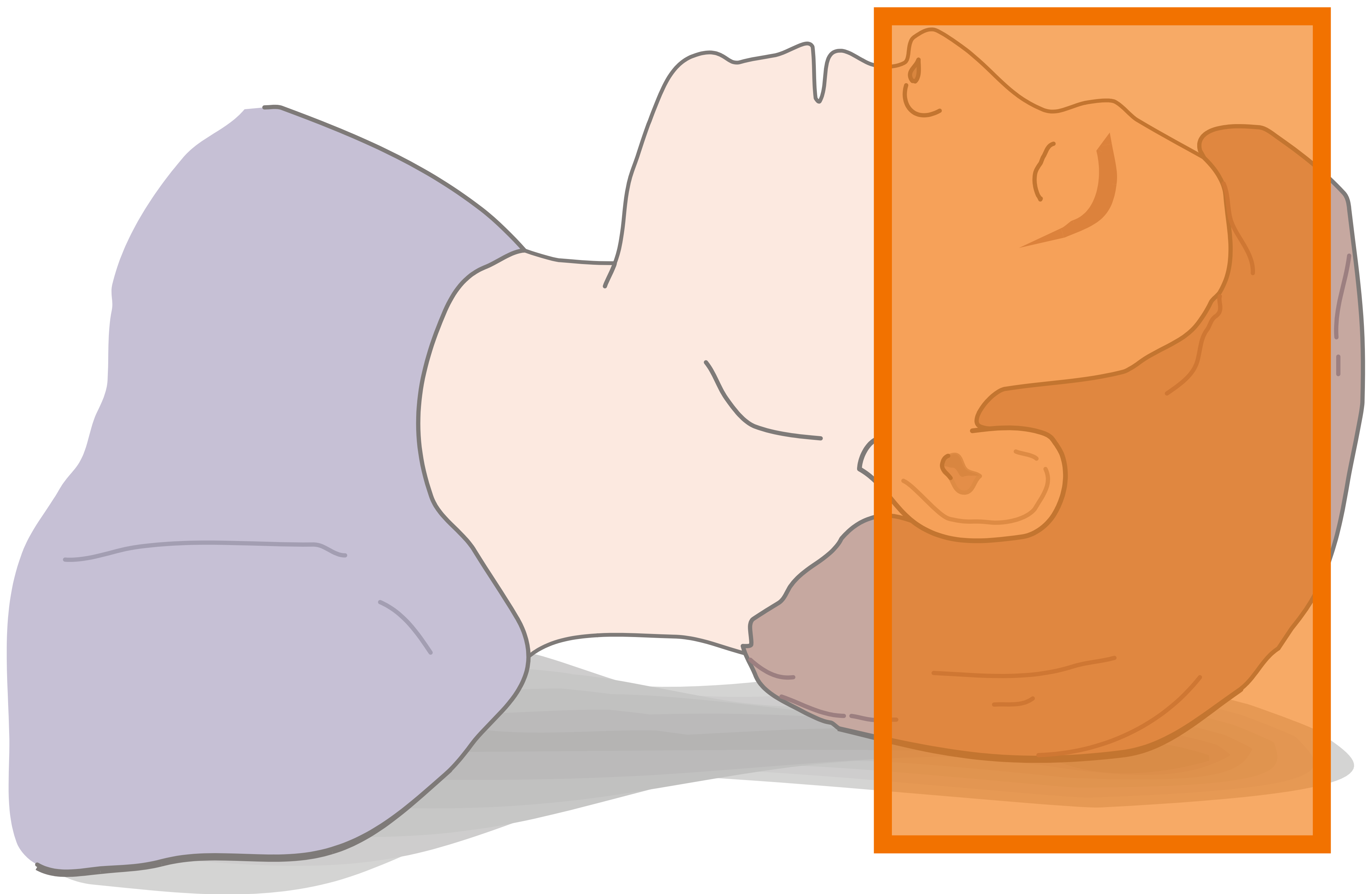
Simultaneous Multi-Slice Imaging

2D Multi-Slice Gradient Echo EPI

- Multiple slices acquired at the same time, otherwise similar to regular 2D multi-slice
- Introduced ~2010, really taking off after 2012
  - Moeller et al. *MRM* 2010, Feinberg et al. *PLoS ONE* 2010, Setsompop et al. *MRM* 2012
- Also sometimes referred to as “multiband” (MB) EPI
- Performance depends on multi-channel array coils, typical SMS/MB factors of 2-8
  - Optimal choice depends on context, analysis
- Cost is reduced SNR, or interslice “leakage” effects, at higher SMS factors

3D Volumetric Imaging

2D Multi-Slice Gradient Echo EPI



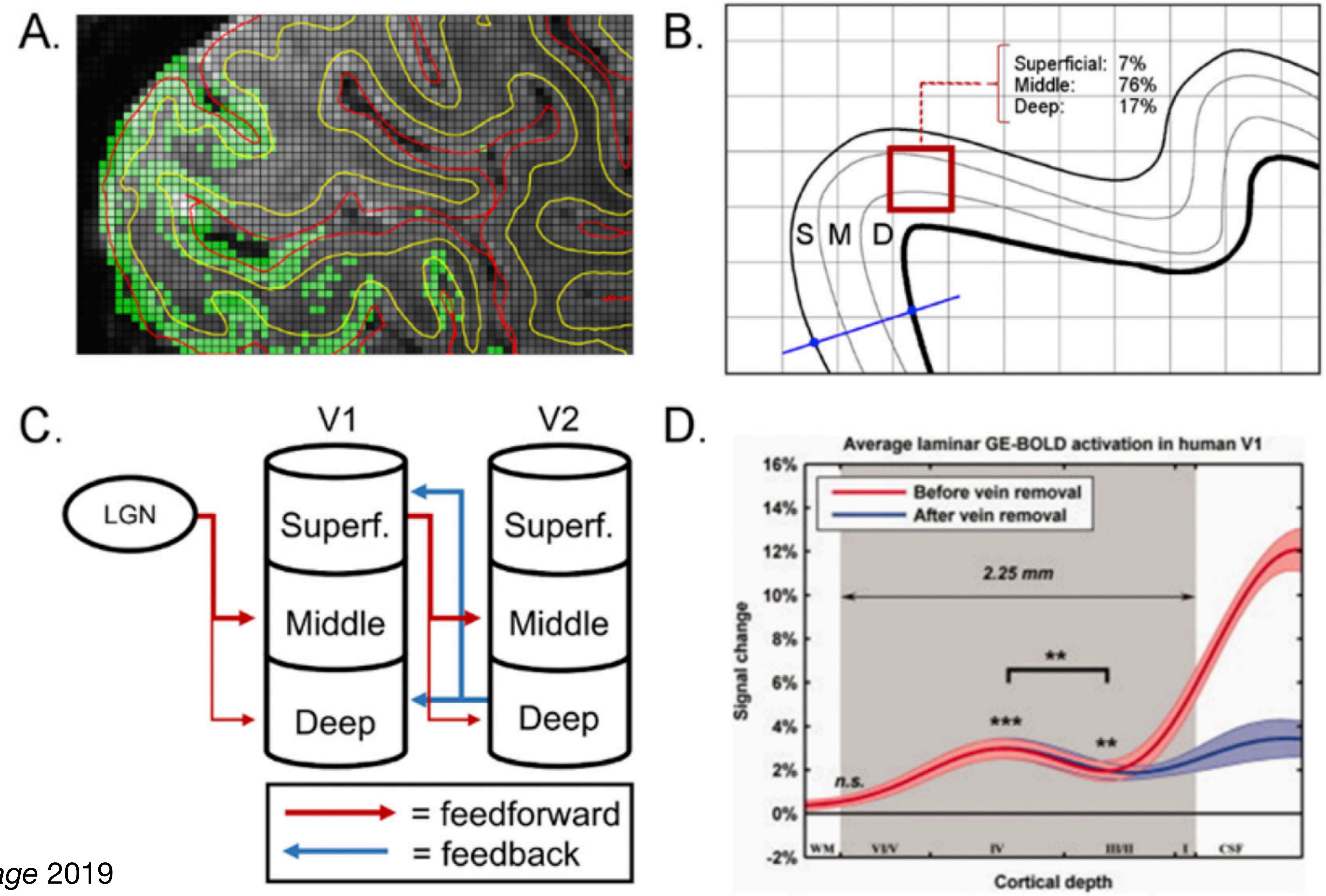
3D Volumetric Imaging

2D Multi-Slice Gradient Echo EPI

- 2D slices can only be so thin, due to hardware limitations
- To achieve thinner slices (e.g. ≤ 1mm), 3D imaging is the only solution
- For high isotropic resolution (< 1mm iso), 3D imaging is also better from an SNR perspective
- However, 3D doesn’t “freeze” motion in the same way as 2D imaging
- Also more susceptible to physiological fluctuations
- Used in specialized applications such as laminar/layer-specific fMRI

Laminar fMRI

A brief aside



Lawrence et al., *Neuroimage* 2019

Conventional functional MRI Acquisition

2D Multi-Slice Gradient Echo EPI

Gradient Echo

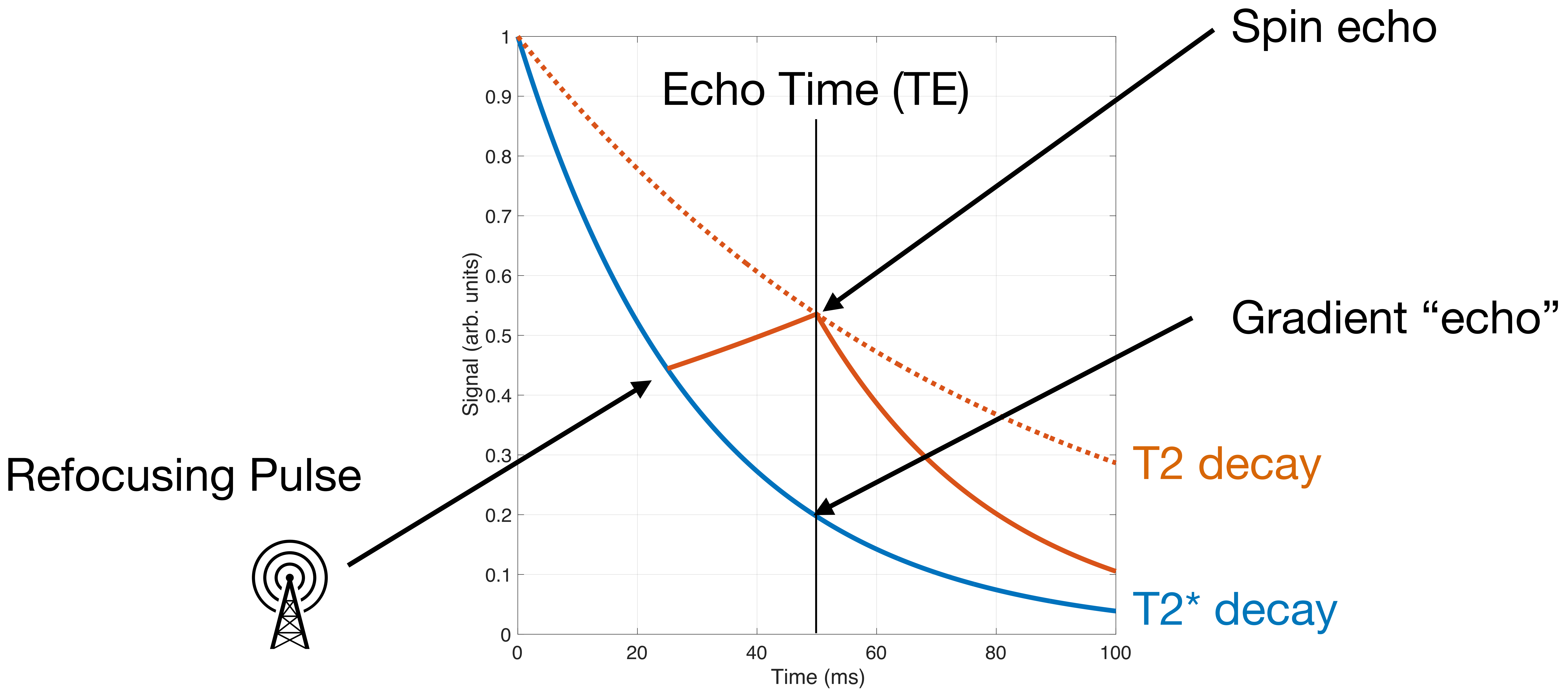
Conventional functional MRI Acquisition

2D Multi-Slice **Gradient Echo** EPI

- Gradient echo == T2* weighted —> signal decay due to all sources (reversible and irreversible)
    - The reversible decay component is due to large-scale, static magnetic field variations (such as those near larger draining veins)
- Spin echo == T2-weighted —> signal decay due only to intrinsic, irreversible sources
    - The spin echo reverses the effect of large-scale field variations, so we're left only with the irreversible component

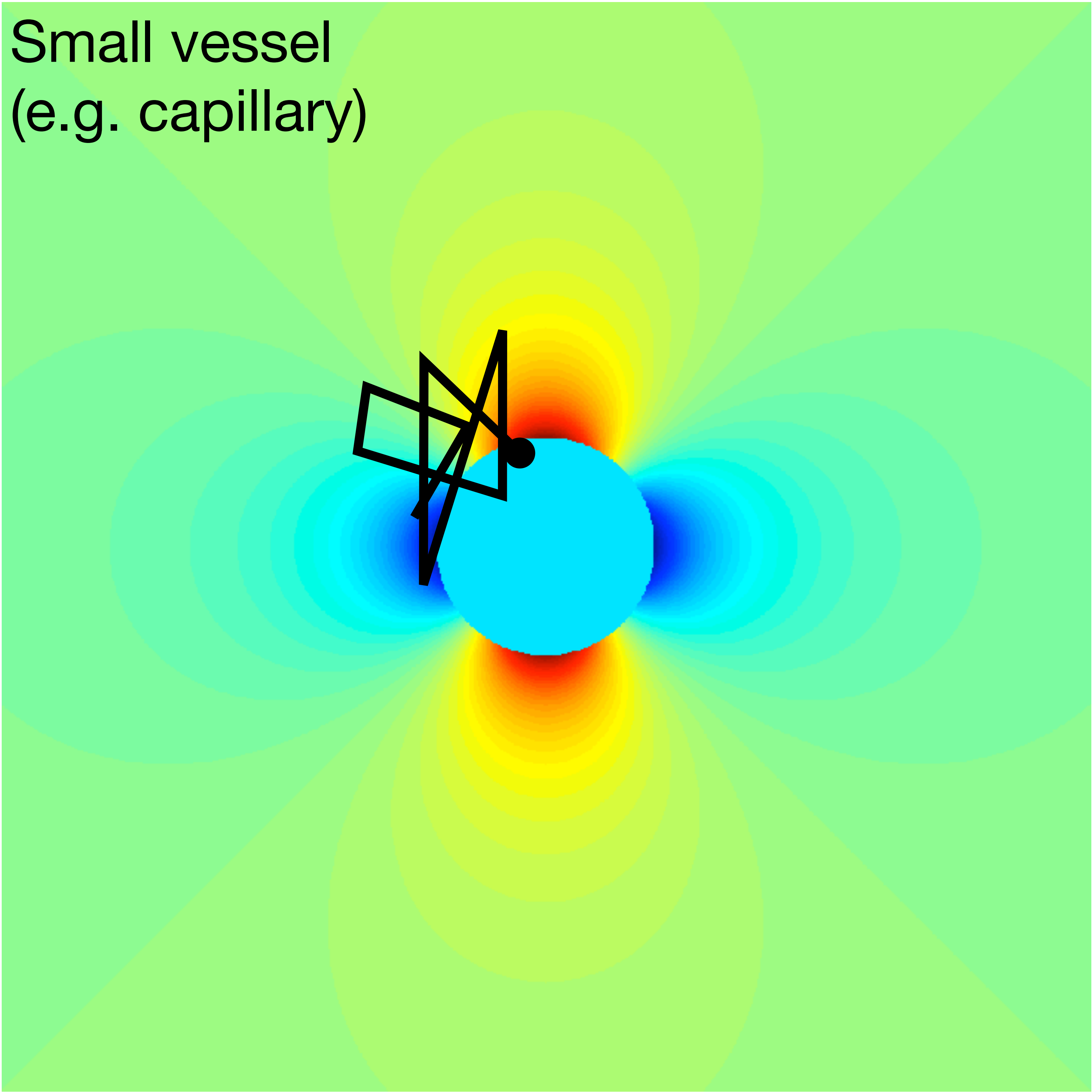
Conventional functional MRI Acquisition

2D Multi-Slice **Gradient Echo** EPI

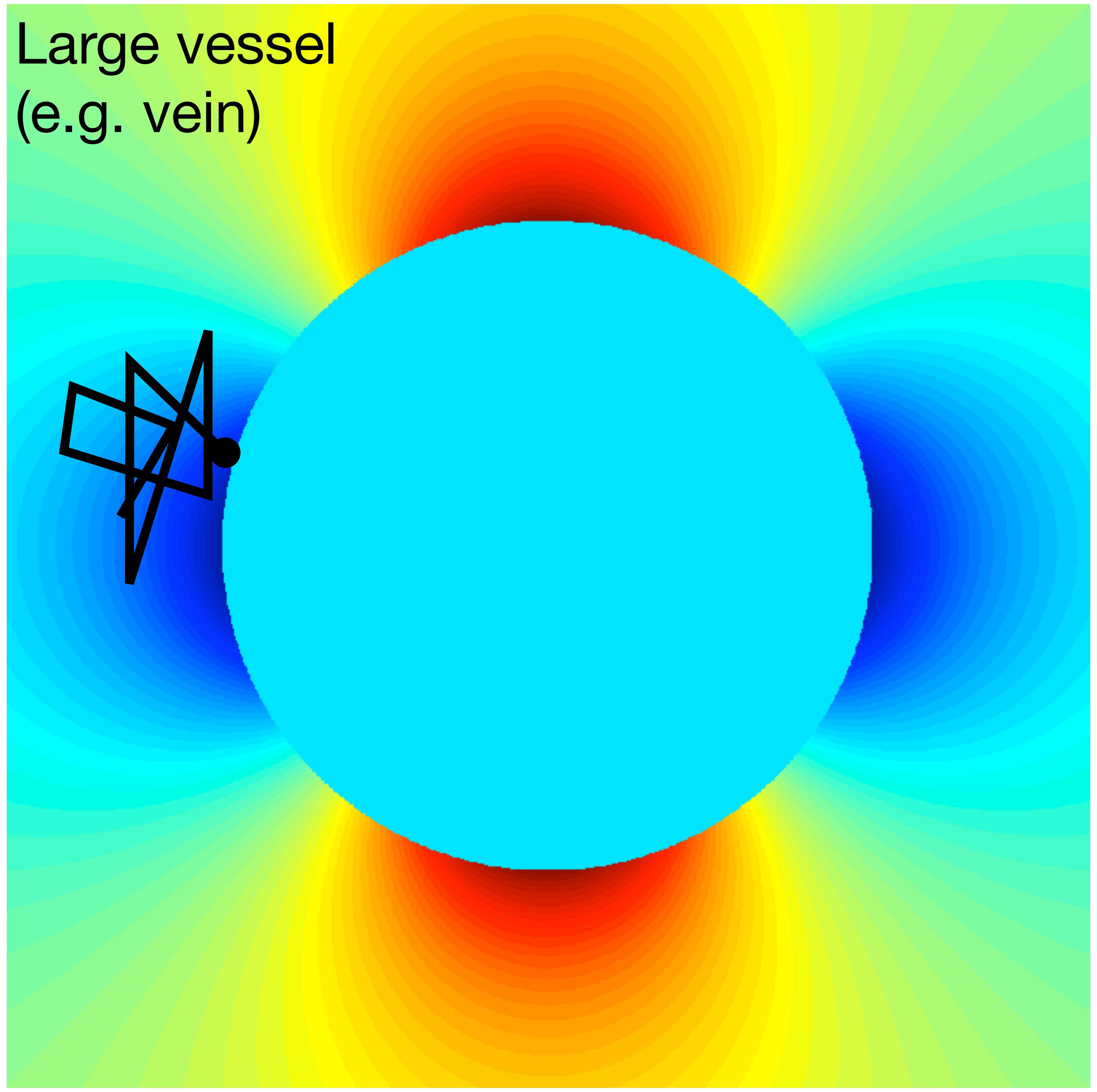


Conventional functional MRI Acquisition

2D Multi-Slice **Gradient Echo** EPI



Random motion “sees” many different magnetic fields, not easily reversible



Random motion “sees” consistent magnetic field, more easily reversible

Conventional functional MRI Acquisition

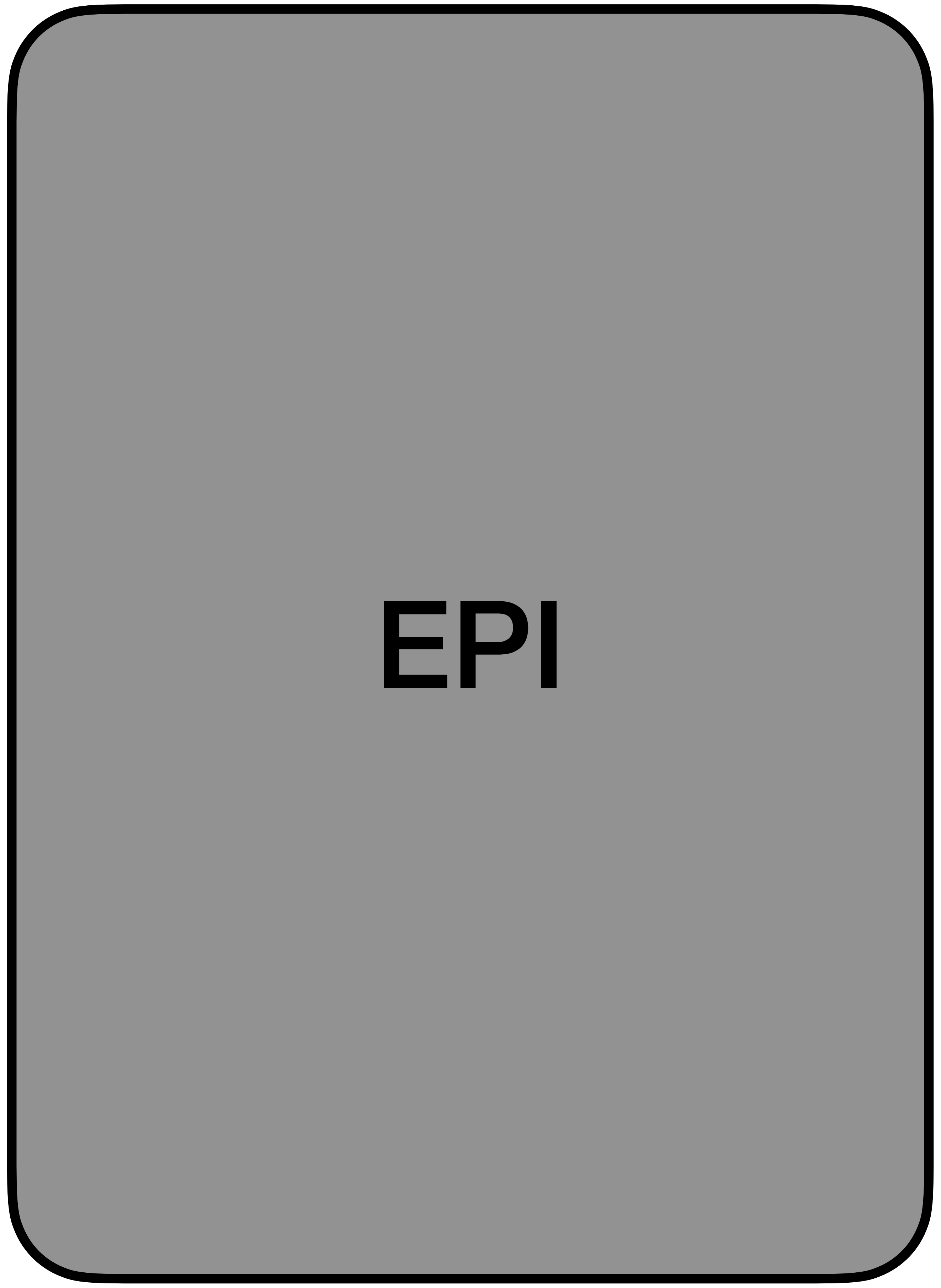
2D Multi-Slice **Gradient Echo** EPI

- Gradient echo fMRI (T2*-weighted)
  - High sensitivity (lots of signal), but weighted towards draining veins
  - Much more common

- Spin echo fMRI (T2-weighted)
  - Much less signal, but more specific to capillary bed
  - More niche

Conventional functional MRI Acquisition

2D Multi-Slice Gradient Echo EPI



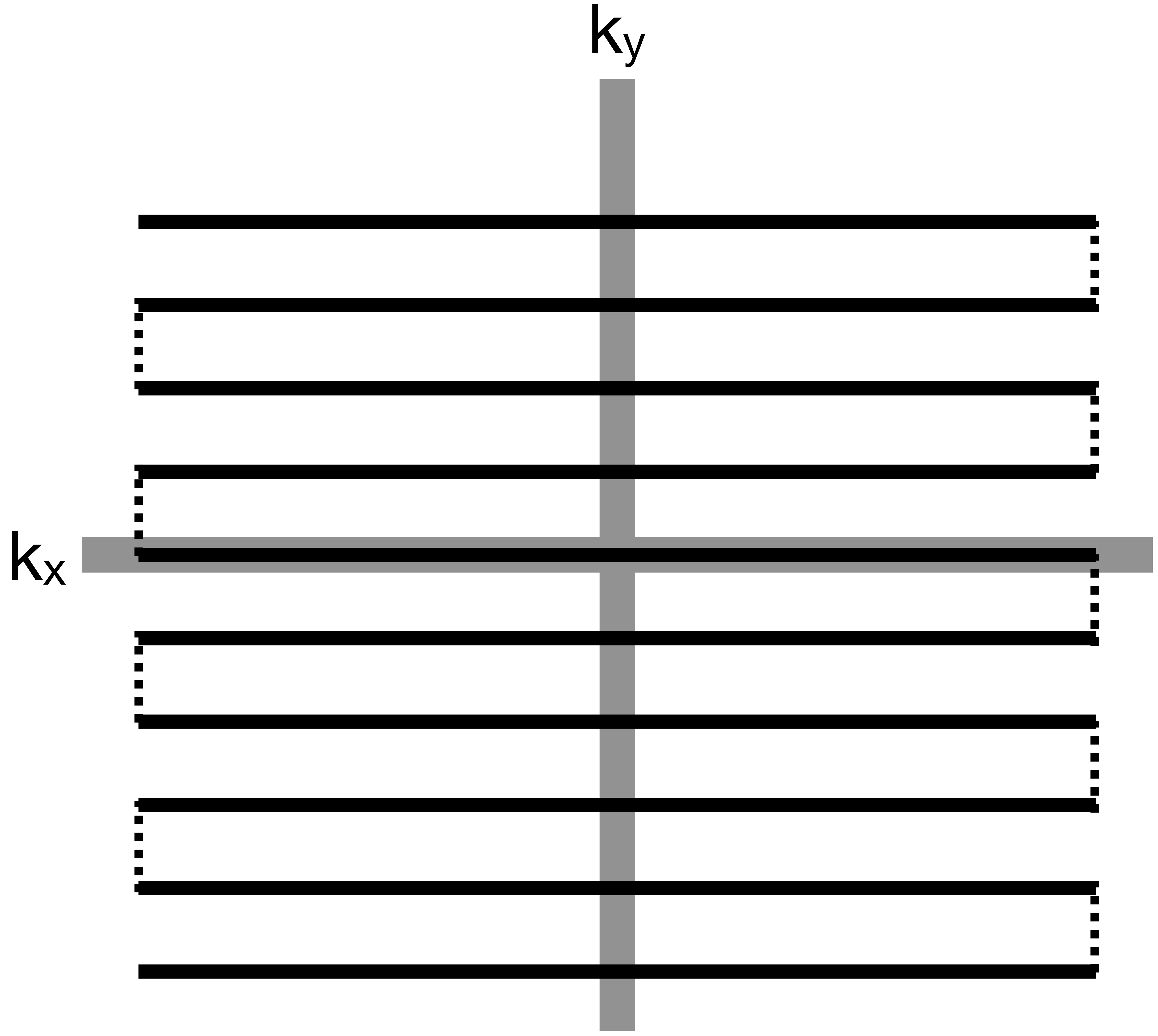
Sampling in MRI

2D Multi-Slice Gradient Echo **EPI**

- Old cameras capture information onto film negatives, which have to be processed to create your photo
- Similarly MRI doesn't acquire our image directly, but captures information in an abstract "k-space", which has to be processed to create your image

EPI Trajectory

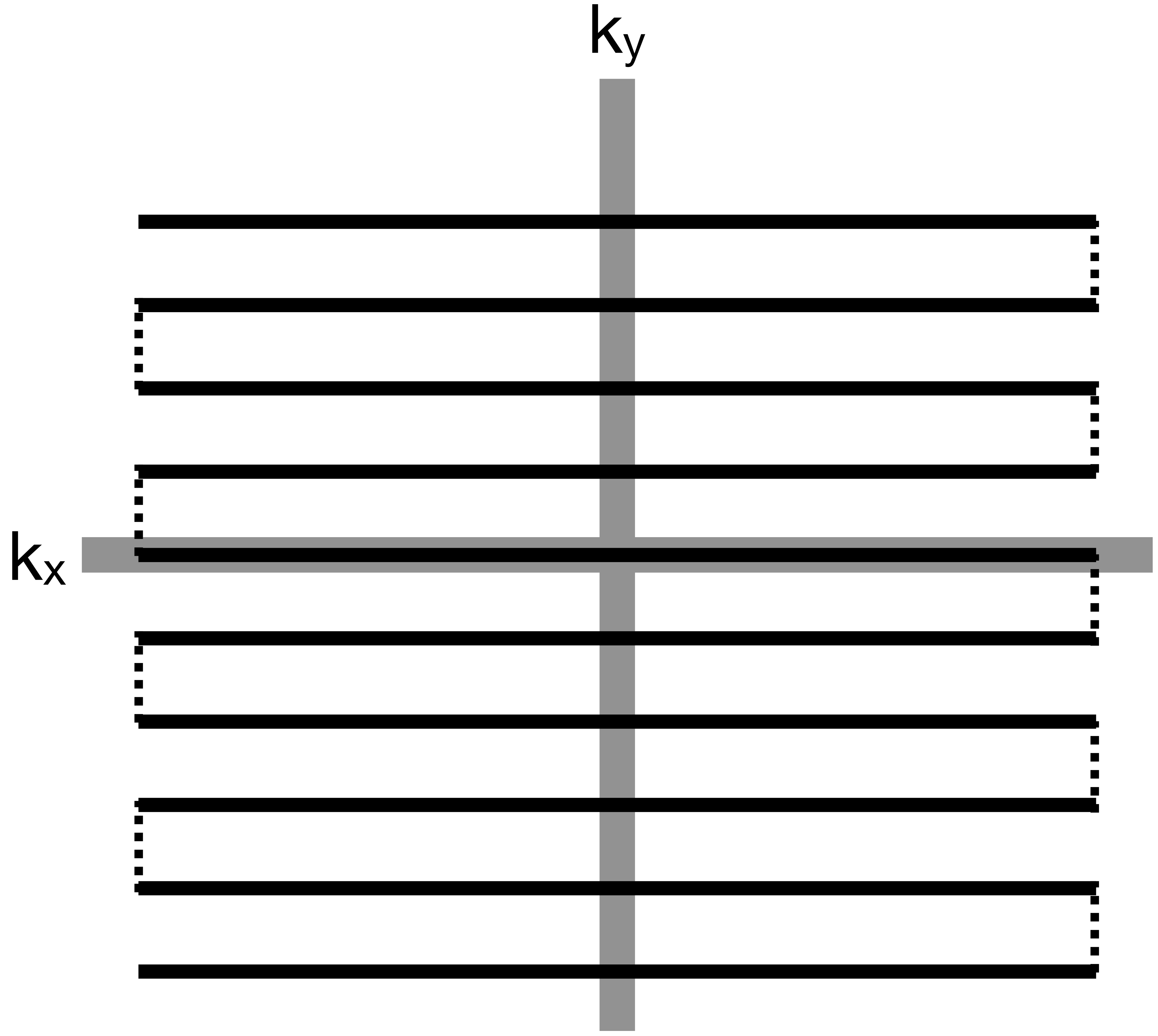
2D Multi-Slice Gradient Echo **EPI**



- We have a 2D “plane” of samples to acquire
- Echo Planar Imaging (EPI) describes the scheme on the left, rastering back and forth across to sample every point
- Far and away the most popular way to acquire data for fMRI

EPI Trajectory

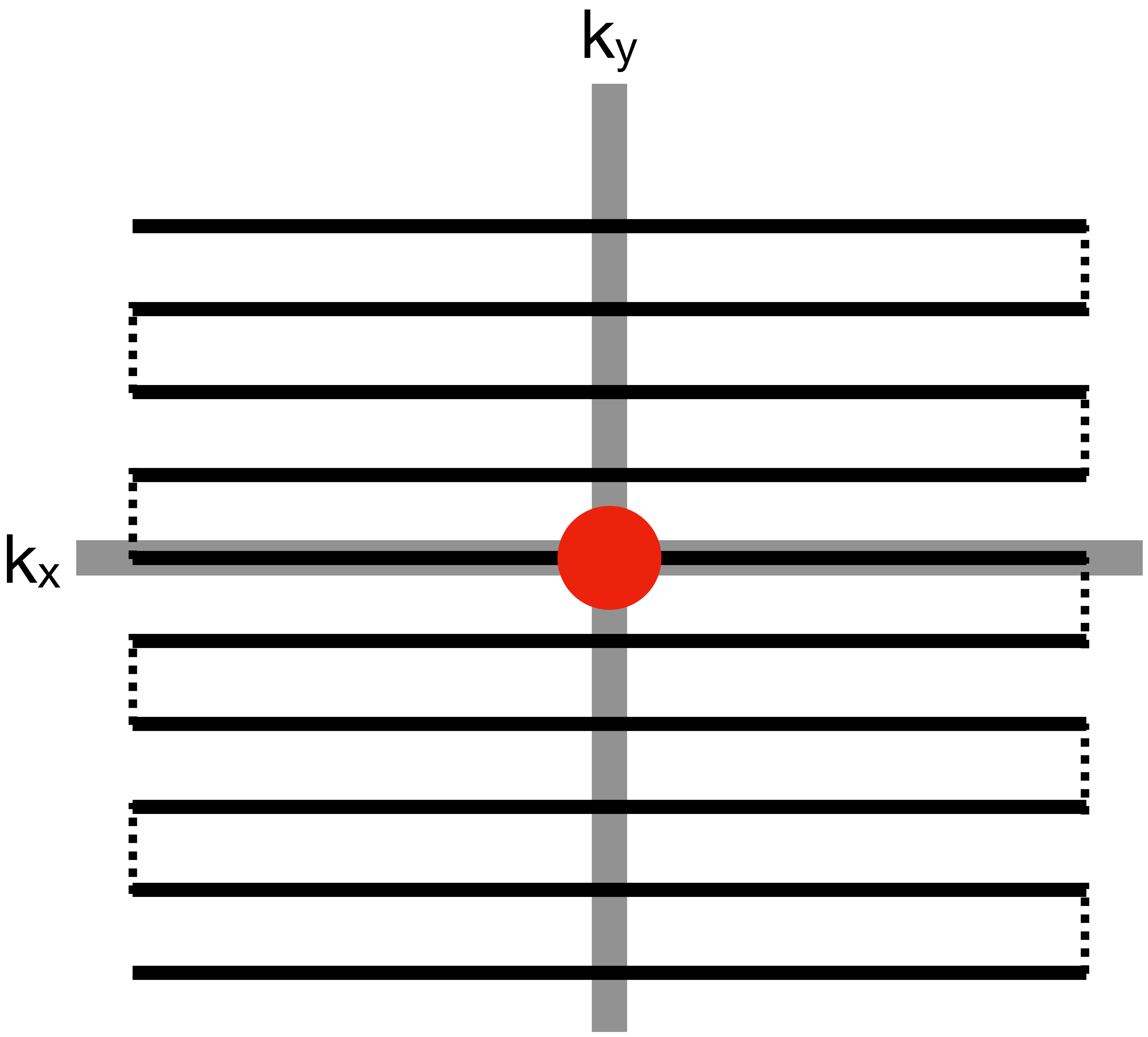
2D Multi-Slice Gradient Echo **EPI**



- The “within line” direction (left/right in this image) is referred to as the “readout” or “frequency encoding” direction
- The “across lines” direction (up/down) is called the “phase encoding” direction
- These can also be referred to as the “fast” and “slow” encoding directions, respectively

EPI Trajectory

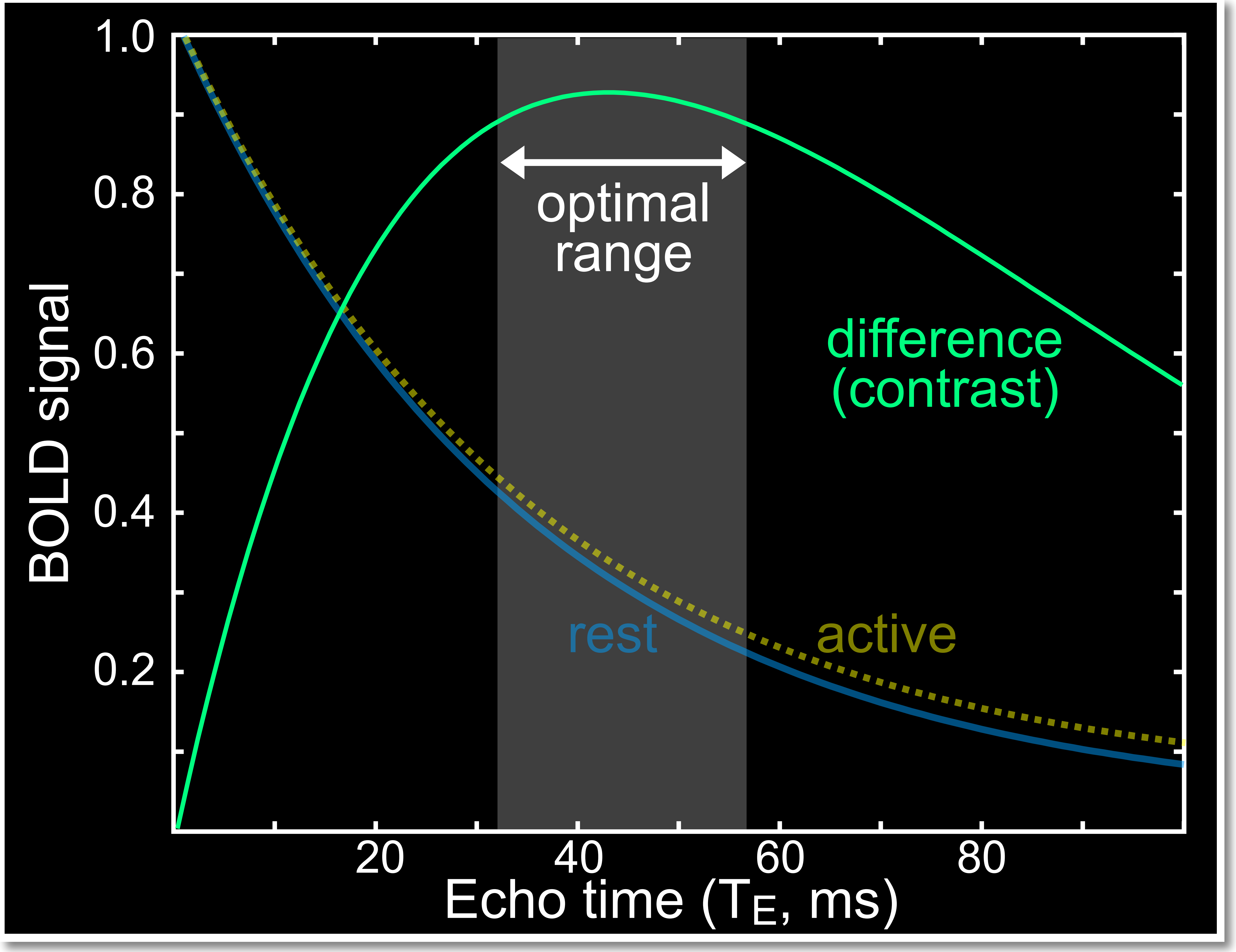
2D Multi-Slice Gradient Echo **EPI**



- EPI is very fast compared to “line-by-line” acquisitions
- Acquire a 2D image in ~50 ms
- Contrast in images is related to the time at which the centre of k-space is sampled (red circle)
- In gradient echo EPI, we call this time the TE

EPI Trajectory

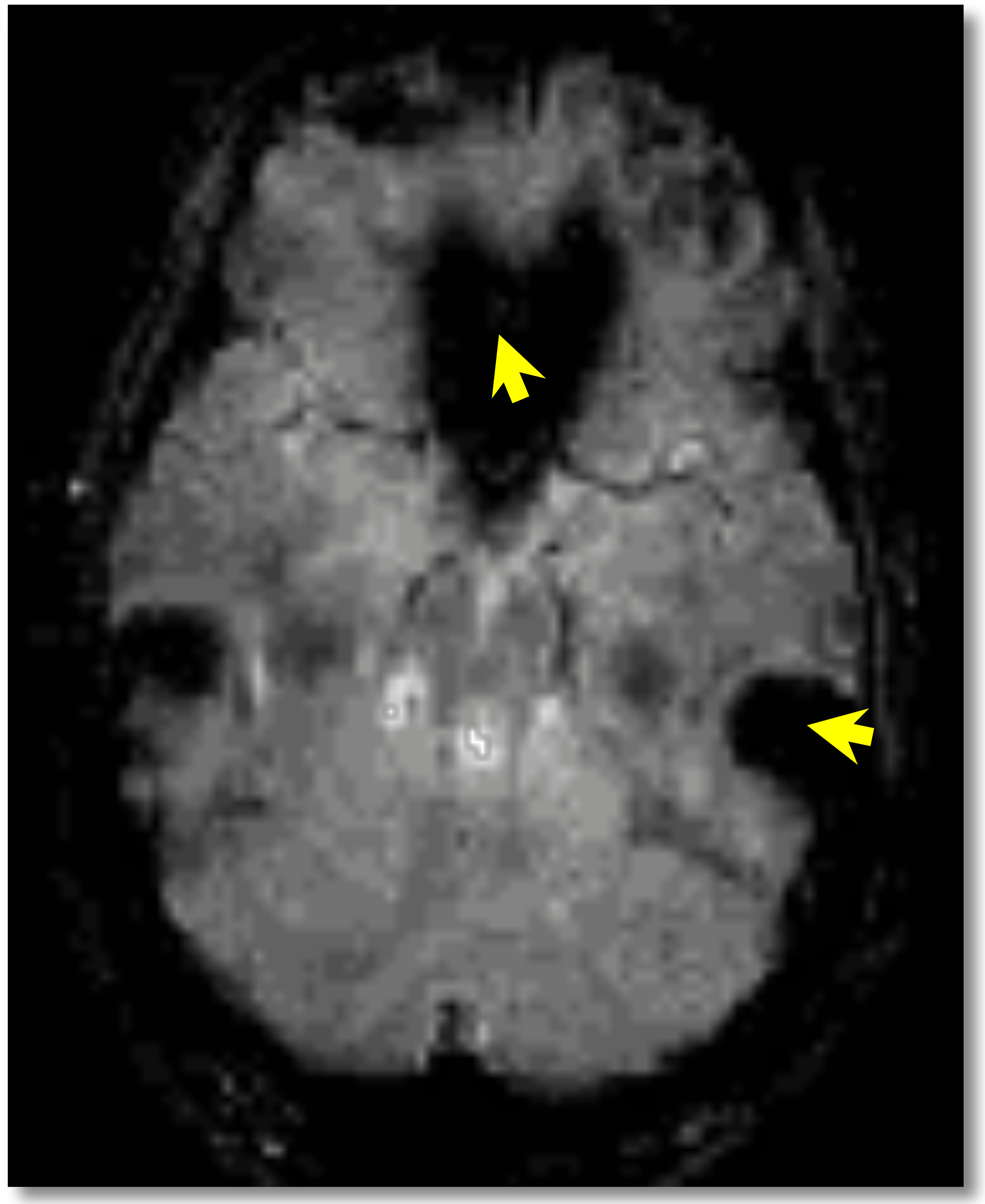
2D Multi-Slice Gradient Echo **EPI**



Considerations of EPI

2D Multi-Slice Gradient Echo EPI

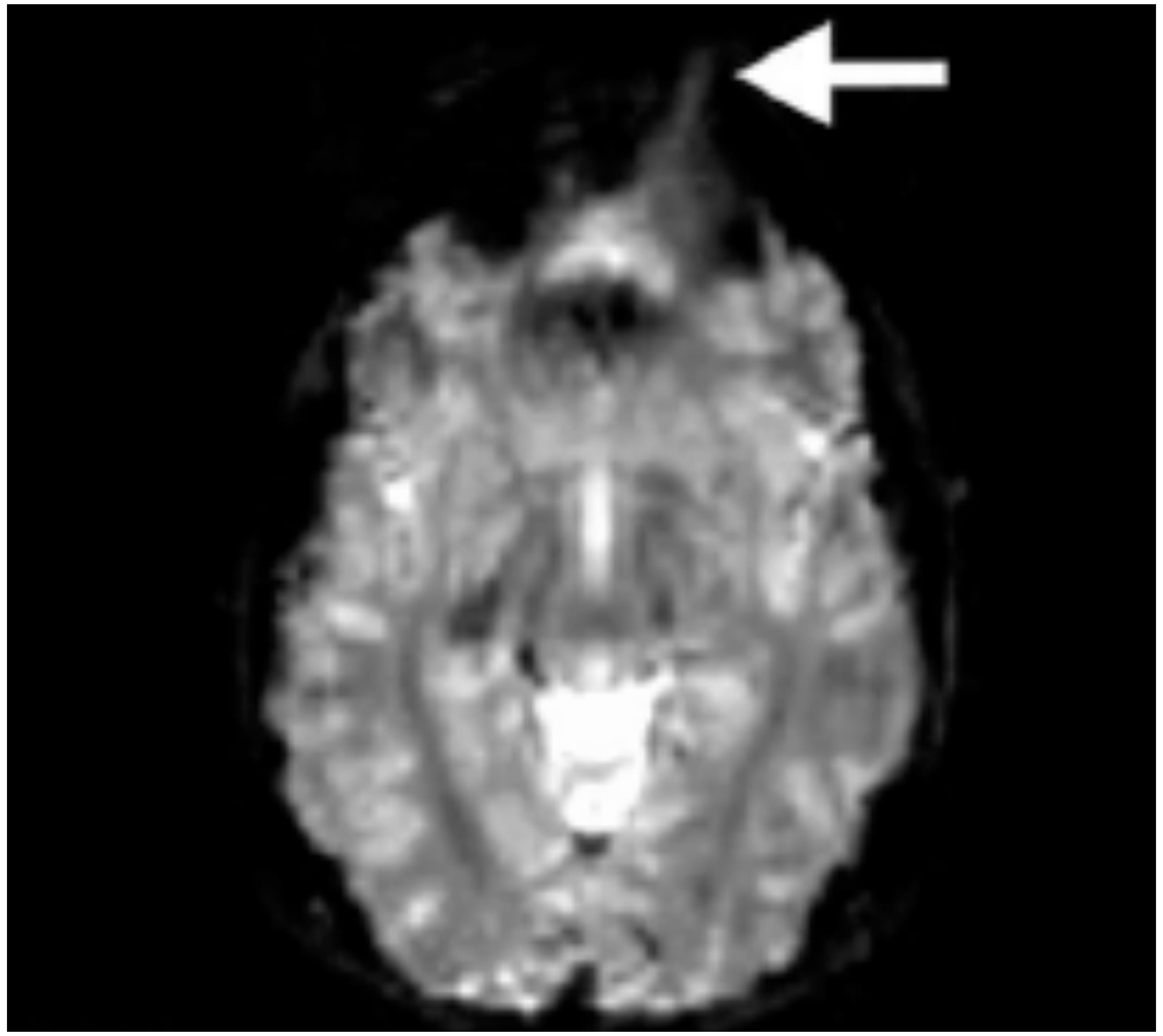
- EPI is susceptible to many artifacts (image problems), including:
- Dropout (signal loss)
  - depends on TE
  - Longer TE, more dropout
  - Shorter TE, less dropout, but reduces BOLD contrast



Considerations of EPI

2D Multi-Slice Gradient Echo EPI

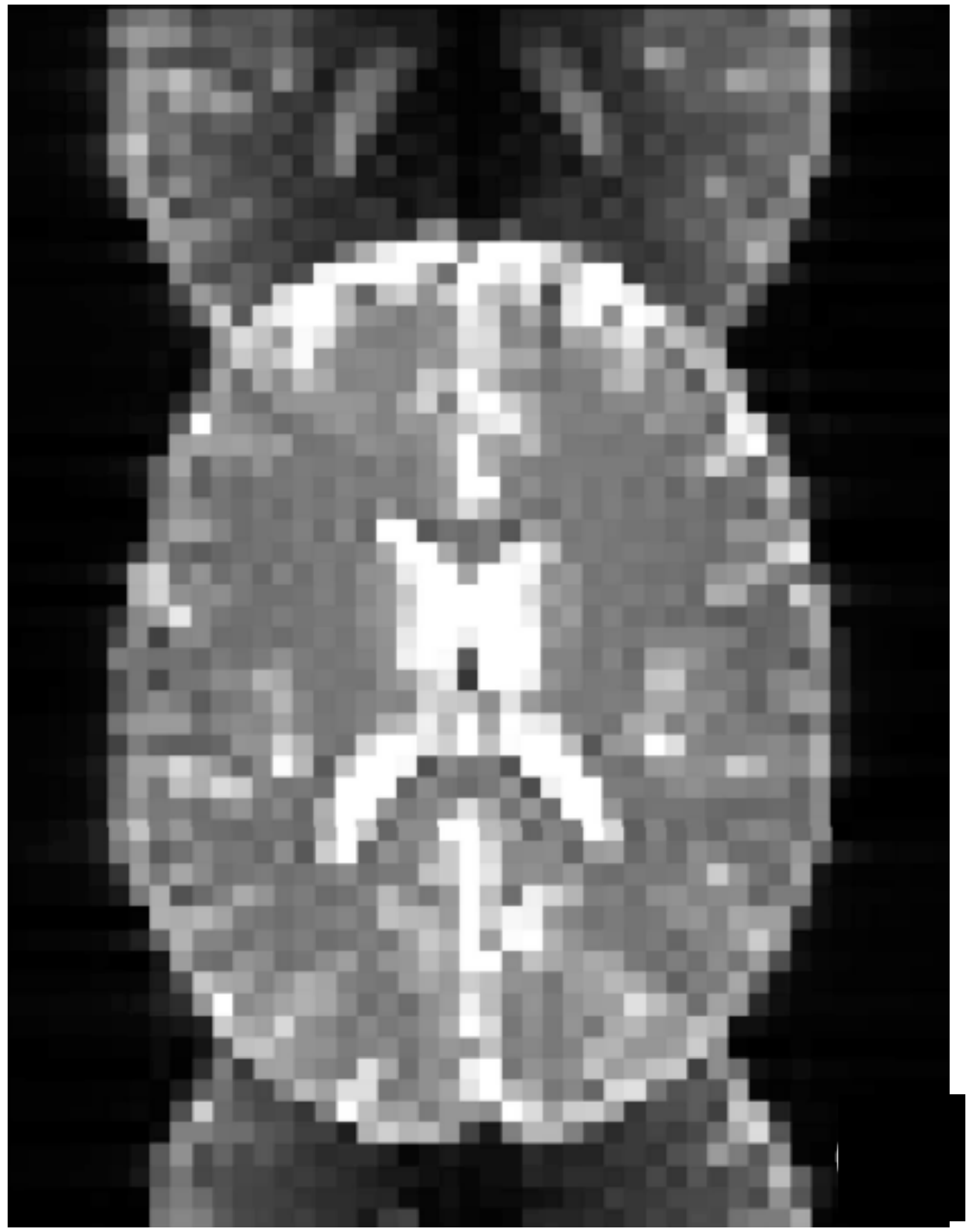
- EPI is susceptible to many artifacts (image problems), including:
- Distortion (image warping)
    - Due to magnetic field inhomogeneity
    - Depends on the imaging speed (bandwidth)
    - Occurs mainly in the phase-encode direction
    - Bandwidth is hardware (gradient) limited
    - Also sometimes physiologically limited (PNS)
    - Acceleration (parallel imaging) reduces distortion



Considerations of EPI

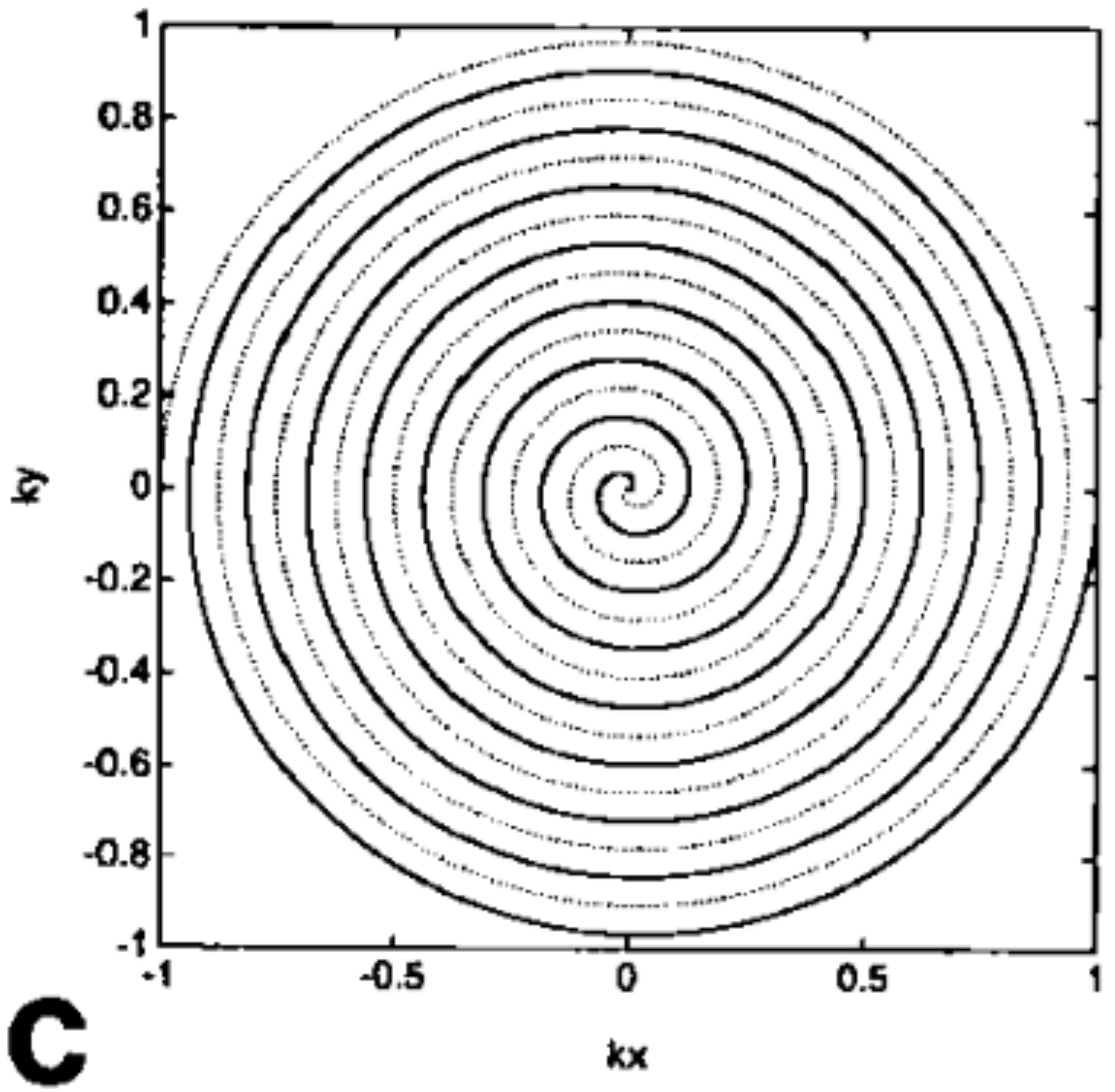
2D Multi-Slice Gradient Echo EPI

- EPI is susceptible to many artifacts (image problems), including:
- Ghosting (image duplicates)
  - caused by mismatch in acquired even/odd lines
  - manifests in the phase encoding direction
  - usually correctable



Other trajectories

2D Multi-Slice Gradient Echo **EPI**



- There are other types of sampling trajectories that are possible
- Spiral trajectories, for example, are also possible
- However, these are more niche, are harder to implement and reconstruct
- Artifacts manifest mainly as blurring

Glover et al., *Magn Reson Med* 1995

Parsing the methods sections of fMRI papers

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B

Phil. Trans. R. Soc. B (2005) **360**, 1001–1013
doi:10.1098/rstb.2005.1634
Published online 29 May 2005

Investigations into resting-state connectivity using independent component analysis

Christian F. Beckmann*, Marilena DeLuca, Joseph T. Devlin and Stephen M. Smith

Oxford Centre for Functional Magnetic Resonance Imaging of the Brain (FMRIB), University of Oxford, John Radcliffe Hospital, Oxford OX3 9DU, UK

Finally, to investigate the spatial consistency of resting-state patterns across subjects, data were collected from 10 subjects during rest. For each, 200 volumes of whole head functional data were acquired at 3T with typical fMRI resolution ($3\times3\times3$ mm, TR$=3.4$ s, TE$=40$ ms). In addition, a high-resolution T1-weighted reference scan ($1\times1\times1.5$ mm resolution) was also acquired for the purpose of anatomical localization.

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Imaging Methods. ***Stanford University data.*** Functional images were acquired on a 3-T General Electric Signa scanner using a standard whole-head coil. The following spiral pulse sequence parameters were used: repeat time, 2,000 ms; echo time, 30 ms; flip angle, 80°; and one interleave. To aid in the localization of

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UK Biobank Brain Imaging Documentation

Version 1.10
May 2024

primary documentation authors:
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Oxford Centre for Functional MRI of the Brain (FMRIB/WIN), Oxford University on behalf of UK Biobank

2.5 Resting-state functional MRI

Resolution: 2.4x2.4x2.4 mm
Field-of-view: 88x88x64 matrix
Duration: 6 minutes (490 timepoints)
TR: 0.735 s
TE: 39ms
GE-EPI with x8 multislice acceleration, no iPAT, flip angle 52°, fat saturation

As implemented in the CMRR multiband acquisition, a separate "single-band reference scan" is also acquired. This has the same geometry (including EPI distortion) as the timeseries data, but has higher between-tissue contrast to noise, and is used as the reference scan in head motion correction and alignment to other modalities.

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HUMAN Connectome PROJECT

WU-Minn HCP 1200 Subjects Release: Reference Manual

Resting-state fMRI (rfMRI)

rfMRI data were acquired in four runs of approximately 15 minutes each, two runs in one session and two in another session, with eyes open with relaxed fixation on a projected bright cross-hair on a dark background (and presented in a darkened room). Within each session, oblique axial acquisitions alternated between phase encoding in a right-to-left (RL) direction in one run and phase encoding in a left-to-right (LR) direction in the other run.

Resting state images were collected with the following parameters:

Parameter	Value
Sequence	Gradient-echo EPI
TR	720 ms
TE	33.1 ms
flip angle	52 deg
FOV	208x180 mm (RO x PE)
Matrix	104x90 (RO x PE)
Slice thickness	2.0 mm; 72 slices; 2.0 mm isotropic voxels
Multiband factor	8
Echo spacing	0.58 ms
BW	2290 Hz/Px

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Questions?

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