functional Magnetic Resonance Imaging – Methods

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1/4

Next 4 lectures

1. Spatial and temporal properties of fMRI
   (+ linearity, convolution)
2. Signal and Noise
   (+ Fourier domain)
3. Preprocessing of fMRI data
   (+ common software tools)
4. Statistics + experimental design
   (+ linear regression, GLM, multiple comparisons)

Preamble

Argh!

I saw some equations and weird mathematical symbols in the course materials...

$$A\hat{u} = \left[\mathbf{A}(\mathbf{A^T}\mathbf{A})^{-1}\mathbf{A^T}\right]b$$

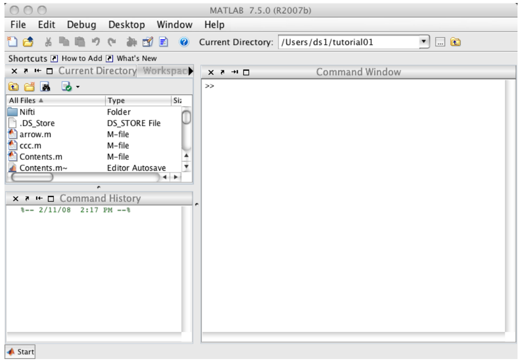
$$\beta, \epsilon, \int_0^\infty f(x)dx \qquad \bar{y} = \frac{1}{n}\sum_{i=1}^{n} y_i$$

... you'll be fine.

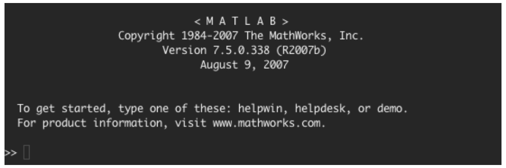
Matlab

*if you have **any** spare time... borrow a book and do a tutorial!*

University has a site license & a personal student version is cheap!



desktop



command line
[from terminal]

Matlab = life skill

*"The successful candidate should have a PhD. **Candidates with strong analytical skills,** and with research experience in visual neuroscience, cognitive neuroscience, computational methods, or functional MRI are encouraged to apply."*

*"Applicants should have a background in MRI analysis techniques (FSL, SPM, **Matlab** etc.), programming and statistics. Interest in clinical neuroscience and cognitive function would be appreciated..."*

*"Candidates should hold (or expect) a Diploma or Masters degree in a relevant discipline (e.g. Psychology, Neuroscience, Physiology, biology, Computer Science). **Programming experience with Matlab is a plus.***

Ads for Phd / Post-doc positions...

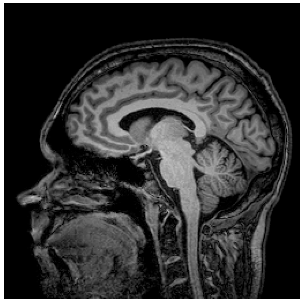
(Online) Resources

- please stop me if you are confused
- please take (some) notes
- hand-outs will be on course webpage
  (but my slides tend to have little text)
- *ditto:* links to Matlab information
- Huettel, Song & McCarthy (ch. 8-12)
- denis.schluppeck@nottingham.ac.uk
  (e-mail questions for '10 minute clinic')

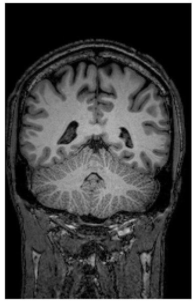
Glossary

- **1D, 2D, 3D, nD:** dimensionality
  line (1D), plane (2D), cube (3D), ...
- **voxel:** volume element, 3D version of a **pixel**
- **slice:** plane of *x* by *y* voxels (x, y often 2^n: 64, 128, 256)
- **volume:** made up of *z* slices (so $x \cdot y \cdot z$ voxels)
- **scan/run:** series of *t* volumes collected (~5-10 minutes)
- **session:** several scans for which one subject goes into the scanner

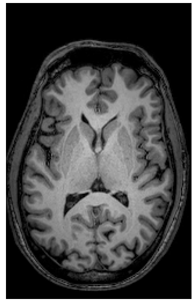
Orientations



sagittal



coronal

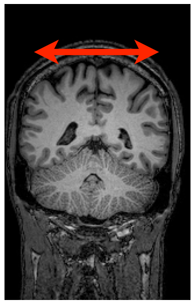


axial, horizontal, transverse

Orientations

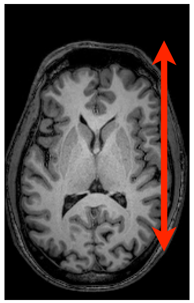
sagittal

foot-head FH



coronal

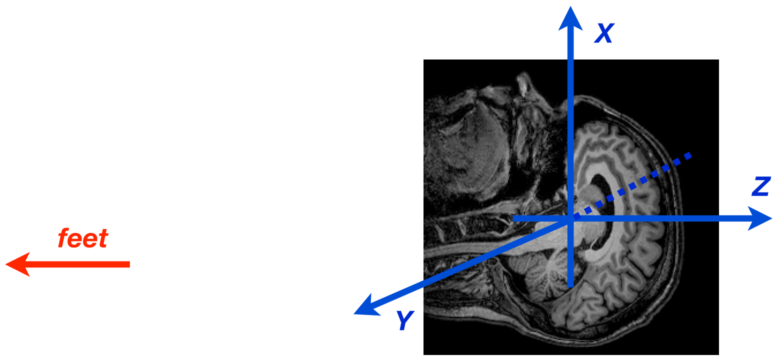
right-left RL



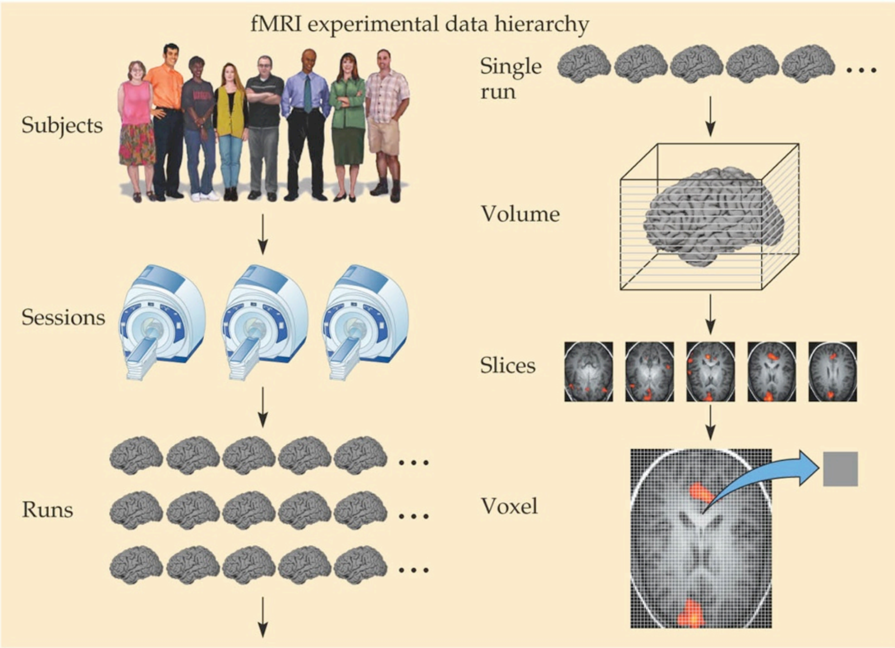
axial. horizontal. transverse

anterior-posterior AP

Orientations / scanner

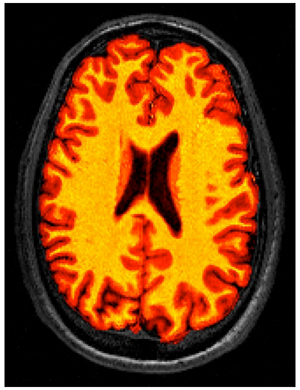


Subjects often go into the scanner:
head-first-supine *(HFS)*

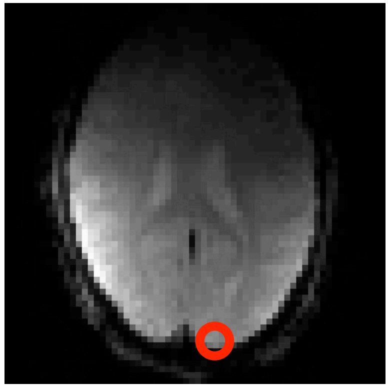


Example Images

Anatomy: 1·1·1mm^3 | *Functional: 3·3·3mm^3*



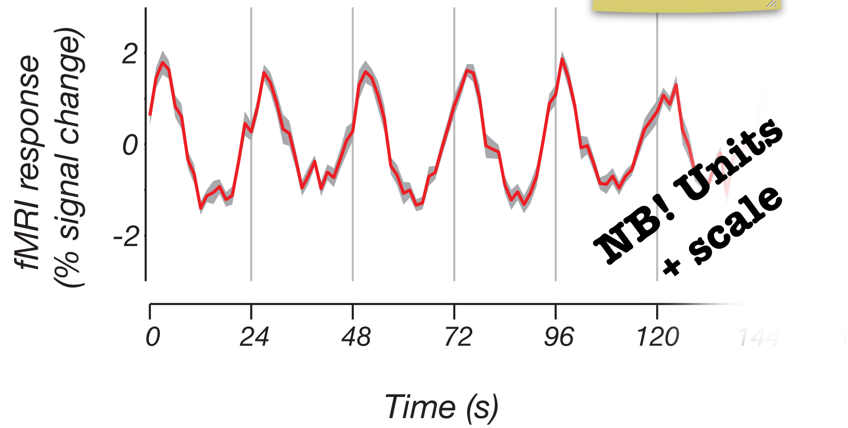
T1 MPRAGE (3T)
[minutes]



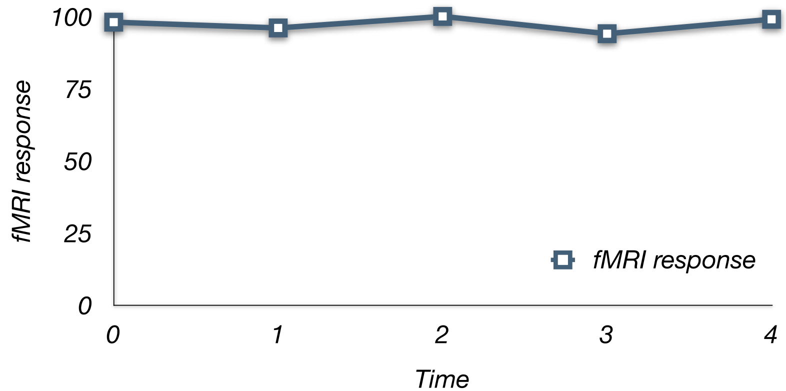
T2 EPI (3T)*
[ms, s]

fMRI measures changes over ti

interesting temporal structure which we will discuss in much more detail later.



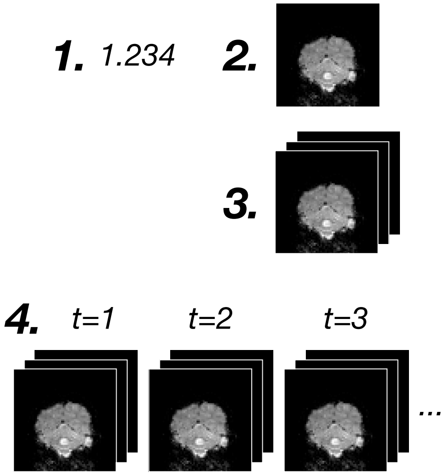
Size of fMRI response



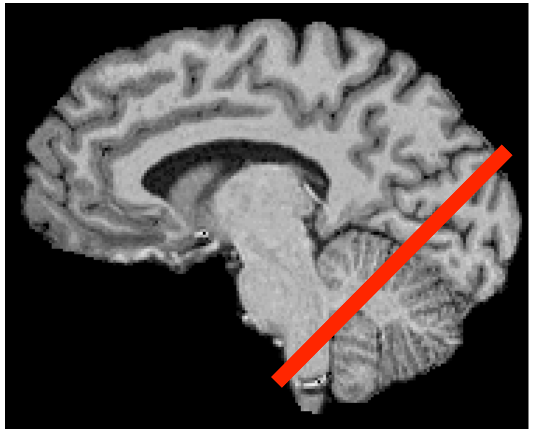
(see Lecture 4, Statistics)

Quick recap: data

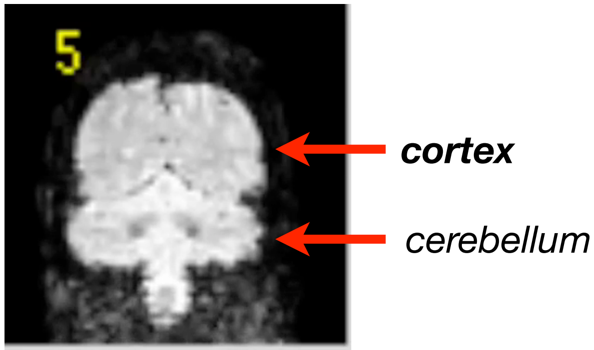
1. numbers (=pixel/voxel)
2. a bunch of numbers on a grid (=slice)
3. a collection of slices (=volume)
4. many volumes over time, acquired every TR (=timeseries)



Example: visual cortex



Example: visual cortex



one slice over 160 repeated measurements (every 1.5s)

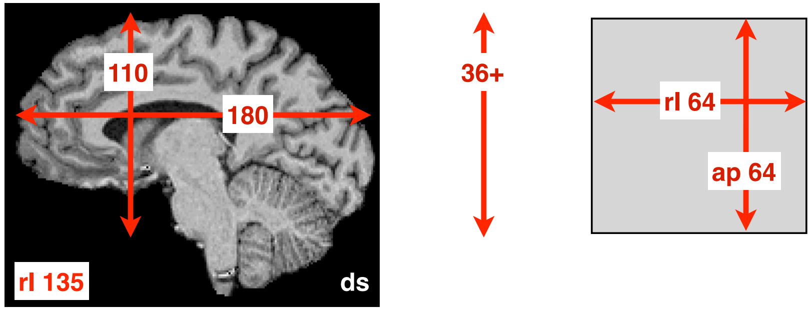
"There is no free lunch!"

- both, **spatial** resolution and **temporal** resolution, are limited
- often, experimenter has to trade off one against the other
- so, different choices for different applications...

What limits spatial resolution?

- hardware (the scanner)
- the subjects
  - peripheral nerve stimulation [PNS]
  - specific absorption rate [SAR] limits
  - time in scanner (>1.5h is not fun)
- signal-to-noise ratio (see lecture 2)
  - smaller voxels = proportionally more noise
  - head motion, physiology, ...

Example: Scanner limits

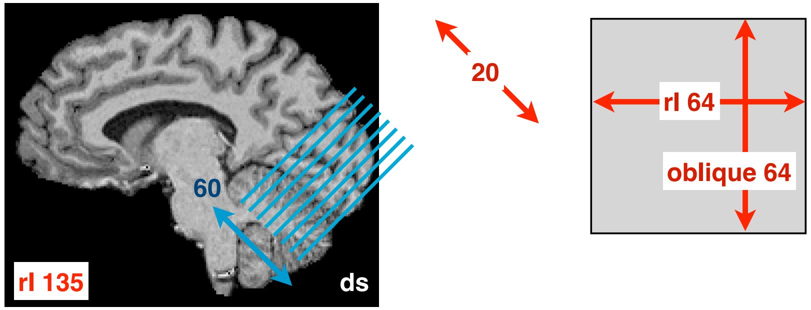


~brain dimensions (mm) ~# of slices ~# of voxels

64×3mm=**192mm**

❖ *our 3T scanner can do ~13slices/s for these settings with SENSE r=2 so min[TR] for 36 slices with 3mm voxels = ~3s*

One solution: partial coverage

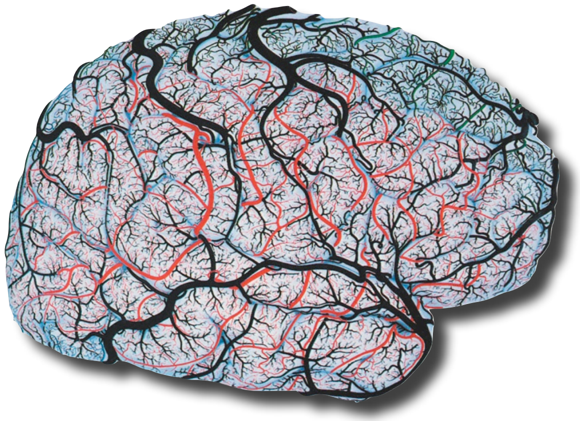


~dimensions (mm) ~# of slices ~# of voxels

64×3mm=**192mm**

❖ *~13slices/s, so can run with a TR of ~1.5s*

Why do we need (high) spatial resolution?



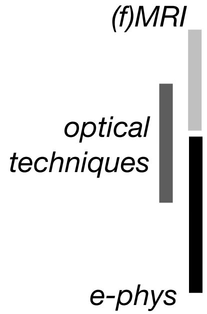


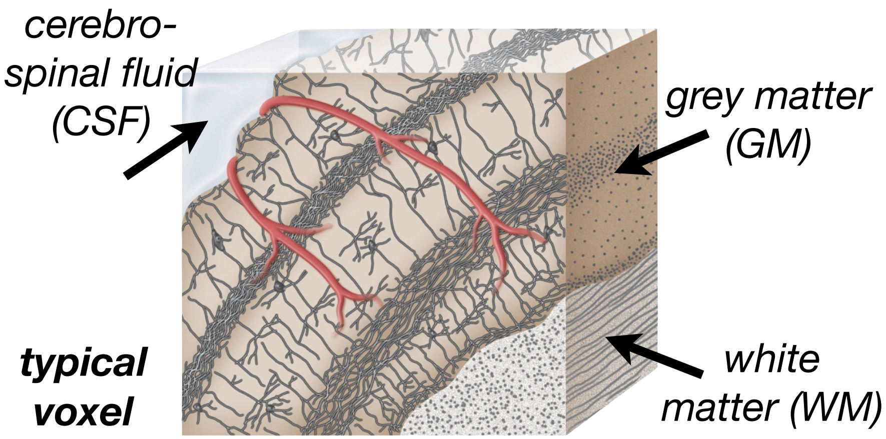
TABLE 8.1 Different Spatial Scales in the Human Brain	
Structure	**Scale**
Brain	100 mm
Gyri	10 mm
Dominance column	1 mm
Neuron	0.01 mm
Synapse	0.001 mm
Ion channel	0.00001 mm

for fMRI, voxel sizes usually (3-5mm)^3 but as small as (1mm)^3

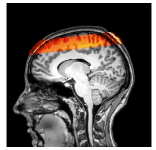
Why do we need (high) spatial resolution?

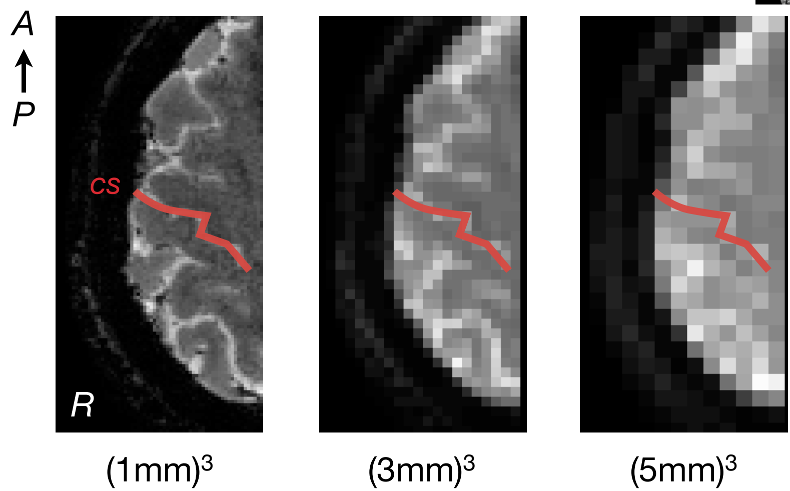
- brain structures of interest are ~mm in size, sometimes separated by ~cm; need appropriate **sampling** (see Sampling/Nyquist, lecture 2)
- smaller voxels: less mixing of grey matter, white matter, CSF, veins, ... reduced **partial voluming**

Why do we need (high) spatial resolution?



Spatial resolution



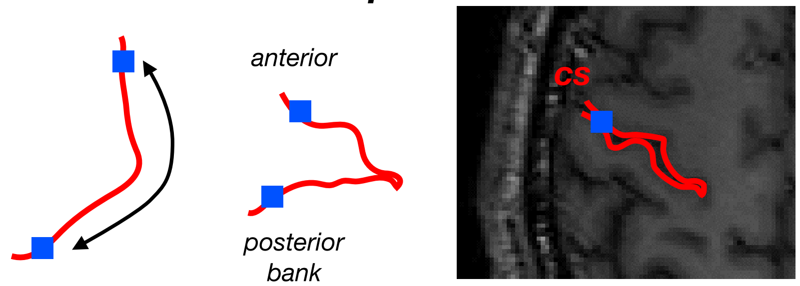


Volume: # of cells

if packing density in grey matter of cortex is ~50,000 cells / mm^3

edge (mm)	***volume (mm^3)***	***#cells in pure GM***
1	1	50k
3	27	1.35M
5	125	6.25M

Volume: anatomical space



$\mathcal{E}$: ~cm ← ***$\mathcal{E}$: ~mm***

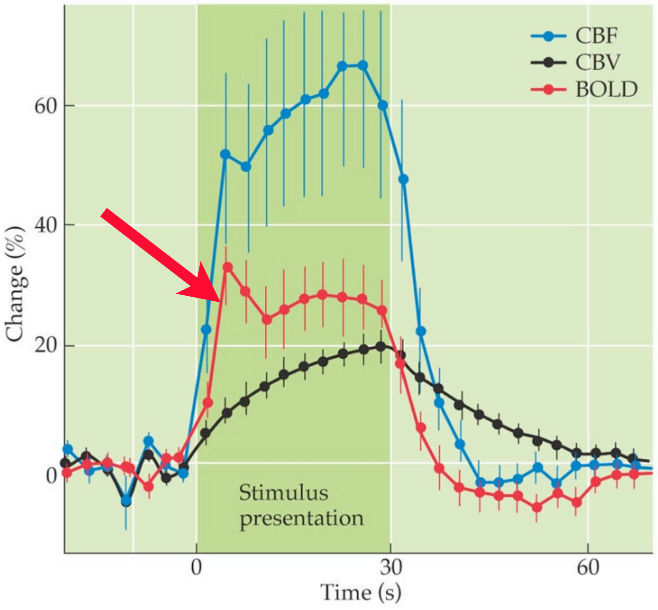
projection from x,y,z to vertices on surface

Temporal resolution

- you had lectures about the blood-oxygen-level-dependent (BOLD) signal
- BOLD is **haemodynamic**, an indirect measure of neural activity (+ hotly debated)
- BOLD signal is blurred in space, and also in **time**

What limits temporal resolution?

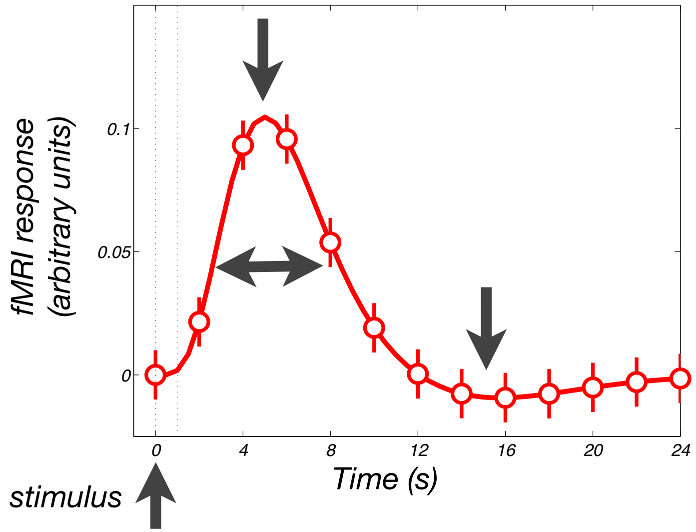
- haemodynamics!
- hardware (the scanner) - not so much
- signal-to-noise ratio (see lecture 2)
  - for TR < 2.0s, can't use 90º flipangle
- the subjects
  - specific absorption rate [SAR] limits
  - time in scanner (>1.5h is not fun)
with reduced SNR, need more repeats



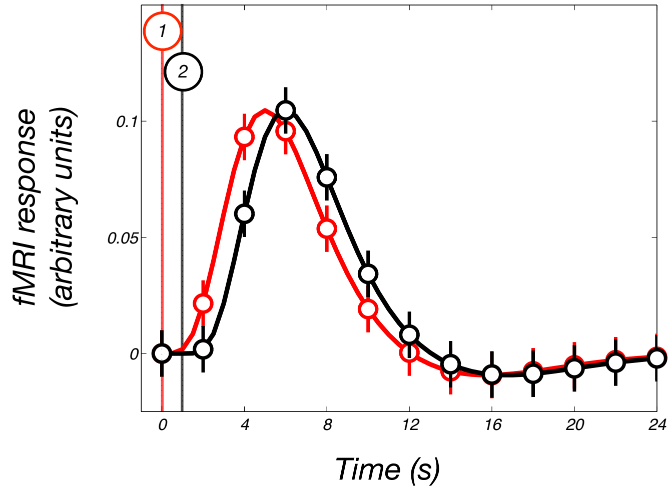
HRF

- the shape of the response to a brief impulse (e.g. visual stimulus) is called the haemodynamic response function (HRF)
- haemodynamic impulse response function (HIRF, HRF, IRF, ...)
- this is an important concept (see 2nd part of lecture)
- e.g. haemodynamic response to a 1s visual stimulus peaks several seconds later and is spread out

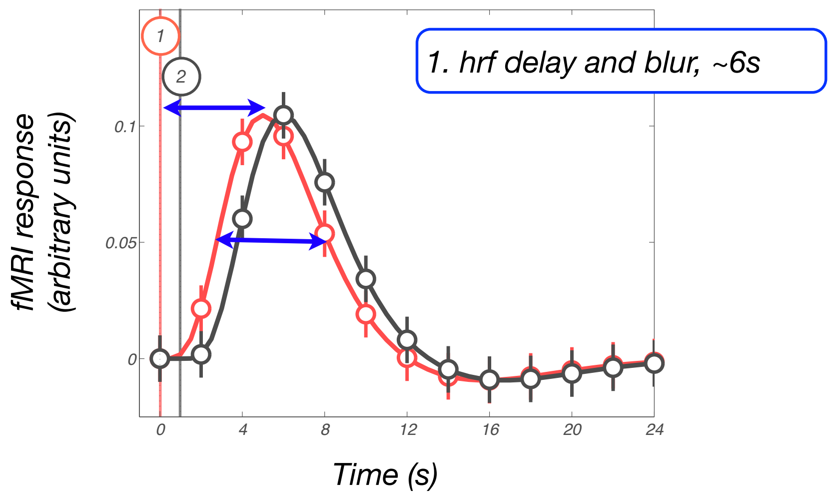
HRF



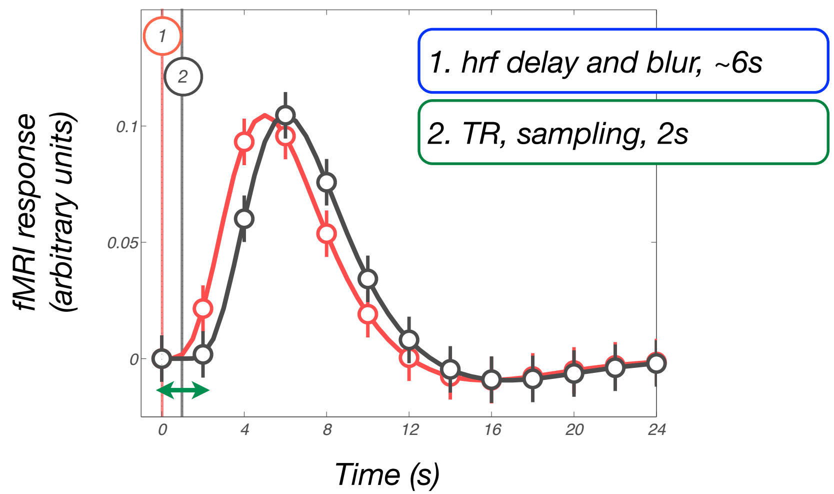
HRF & temporal precision



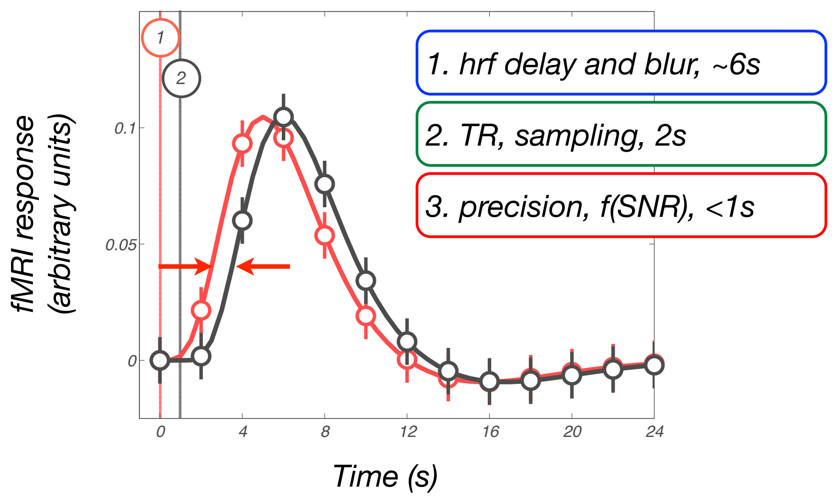
HRF & temporal precision



HRF & temporal precision

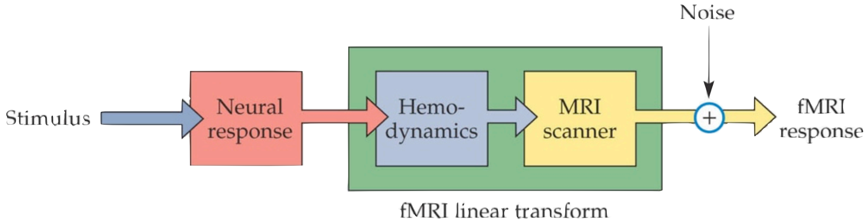


HRF & temporal precision



1b – Linear Systems, Convolution

fMRI response as a linear system



input *output*

Boynton et al (1996)

Linear system

A linear system has two basic properties:

1. **scaling** (homogeneity)
2. **superposition**

engineers: linear system,
linear time-invariant (LTI) system

Linear system

input → $\mathcal{L}$ → *output*

$x = [1\ 2\ 3]$ $y = [2\ 4\ 6]$

Scaling

input → $\mathcal{L}$ → *output*

ax ay

Superposition

input → $\mathcal{L}$ → *output*

input	output
x_1	y_1
x_2	y_2
(x_1+x_2)	(y_1+y_2)

Examples

input → $\mathcal{L}$ → *output*

multiply by a number ✔

$y = 3x$

Examples

input → $\mathcal{L}$ → *output*

squaring input ✗ *no*

$y = x^2$

Examples

input → $\mathcal{L}$ → *output*

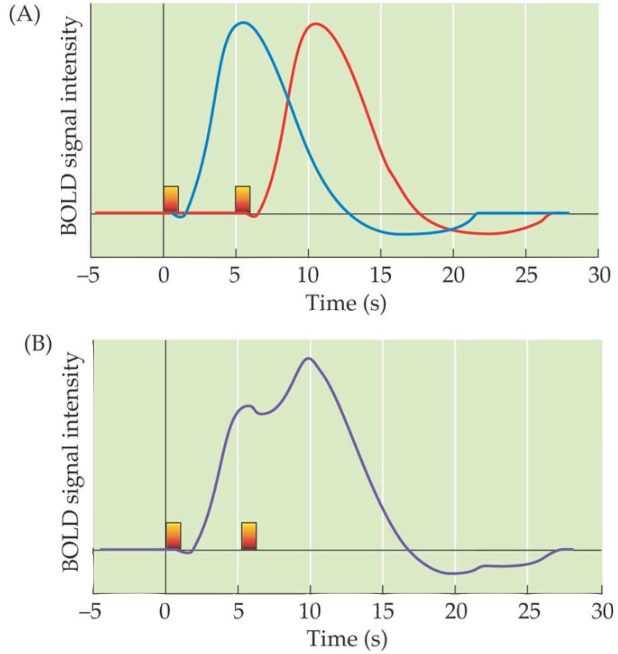
adding a number ✗ *no*

$y = x+2.5$

Linear system

1. If we a system is **linear**, then the impulse response function **fully** describes it
2. e.g. given the response to a brief stimulus (impulse), we can predict response to arbitrary inputs
3. mathematical operation of **convolution** is central to those predictions (lecture 2,4)

Superposition



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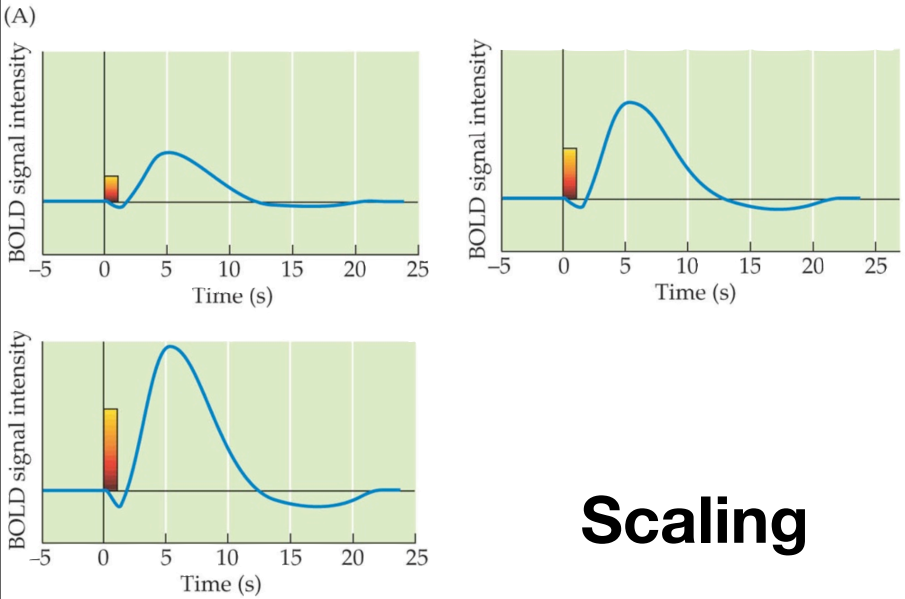
Scaling



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Summary

- new vocabulary
- **Matlab**
- what our fMRI data look like
- spatial resolution
- temporal resolution
- concept of HRF