

PSGY4009

Experimental design for functional imaging

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1 Today

- Who am I? Who is everyone?
- A quick overview of the module.
- What to expect, assessment/coursework?
- 101 of functional MRI and experiment design.

2 Overview

Check via the [University of Nottingham timetable](#)

Timetable		
week	Lecturer	Lecture
02	D Schluppeck	Overview, fMRI & study design.
03	M Schürmann	Basic neu- roanatomy
04	K Dyke	Brain stimulation & study design.
05	W v Heuven	Language
06	D Schluppeck	Vision + brain imaging

Timetable week	Lecturer	Lecture
07	D Schluppeck	Q&A, experimental design, coursework
08	L Cragg	Developmental neuroimag- ing.
09	J Derrfuss	Cognitive control, attention, and working memory.
10	R Filik	Moral Cognition
11	D Schluppeck	Perceptual Decision making, Q&A for assignment

3 Assessment

- Written assignment (max 3000 words) including a 250 word abstract.
- Details on [moodle \(2023/24\)](#).

...

3.1 What? How?

How can fMRI and/or brain stimulation be used to study different neuroscience questions? Cover at least two topics and/or methods from the course.

4 Today's lecture

- A brief introduction to fMRI.
- Scope and limitations of the fMRI method.

- Principles of experimental design in psychology.
- Experimental design for fMRI.

5 Learning objectives

By the end of the lecture you should be able to:

- Understand what fMRI measures.
- Evaluate the strengths and weaknesses of fMRI.
- Evaluate different experimental designs.

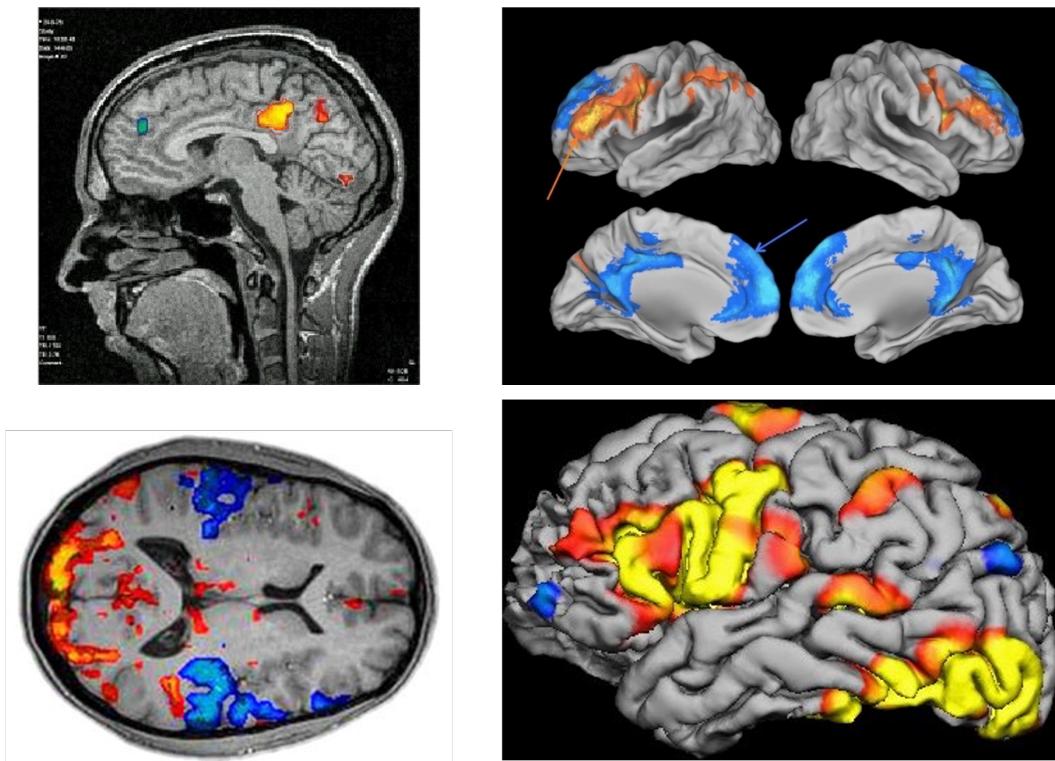


Figure 1: image of statistical maps on brains

6 LO

fMRI basics



Figure 2: person being positioned in an MRI scanner

7 fMRI basics



Figure 3: person being positioned in an MRI scanner

- MRI uses **static** and **oscillating** electromagnetic fields to detect different biological tissue properties.
- **functional MRI** measures changes in blood oxygenation over time.
- BOLD signal: blood oxygen level dependent

8 Example research questions

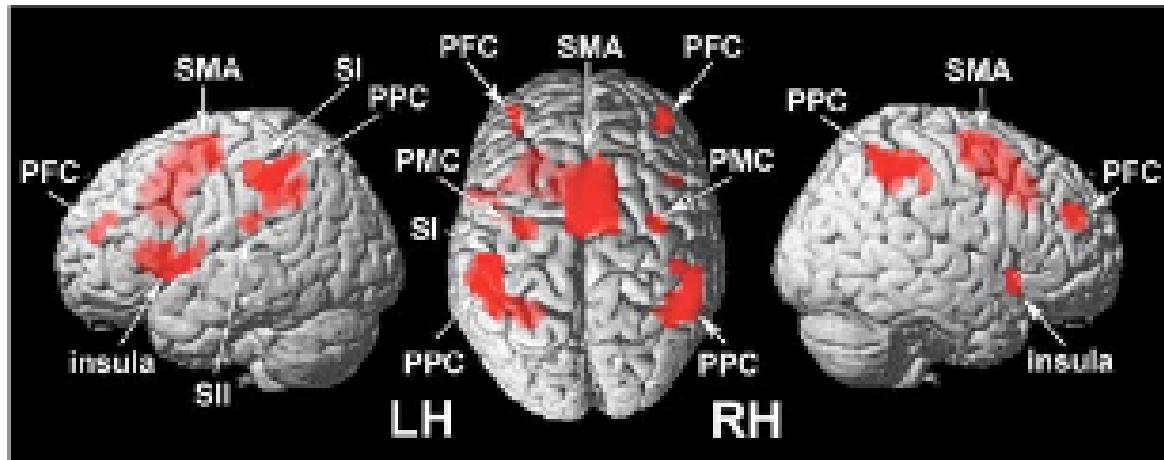
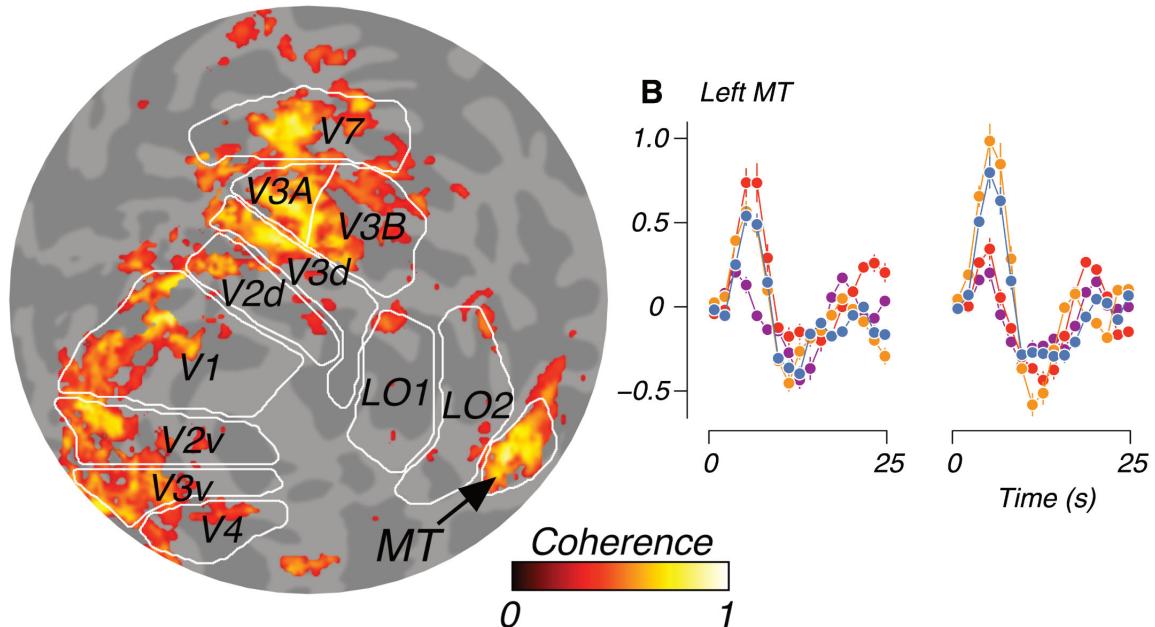


Figure 2. Cortical regions involved in frequency discrimination (contrast: discrimination trials > "null trials"). Significant signal changes were found in the SI and SII contralateral to the stimulated index finger. In addition, we found activation in the supplementary motor cortex (SMA), the premotor cortex (PMC), the posterior parietal cortex (PPC), the anterior insula, and the prefrontal cortex (PFC) of both hemispheres (MRI coordinates and t scores are listed in supplemental Table 1, available at www.jneurosci.org as supplemental material). LH, Left hemisphere; RH, right hemisphere.

Where are the areas more active in **Condition A** than in **Condition B**?

A Moving vs static dots



How do pre-defined **regions of interest** respond in different experimental conditions?

9 Experimental “pipeline”

Prepare

Theory ☐ Research Question ☐ Hypothesis

Plan & do

Experimental Design ☐ Piloting ☐ Data collection

Analyse & report

Preprocessing ☐ Analysis ☐ Interpretation

General overview of how imaging experiments often work / get designed.

10 Study

11 General thoughts (BOLD)

What does the blood-oxygen-level-dependent (BOLD) signal measure?

- neuronal activity?!
- populations of neurons (excitatory, inhibitory)
- spikes or (pre-)synaptic activity

12 General thoughts (Signal/Noise)

(fMRI) signals are weak + noisy.

- How does that limit voxel size?
- Short events, minimum durations?
- Need for averaging?
- Blocks versus “event-related” designs?

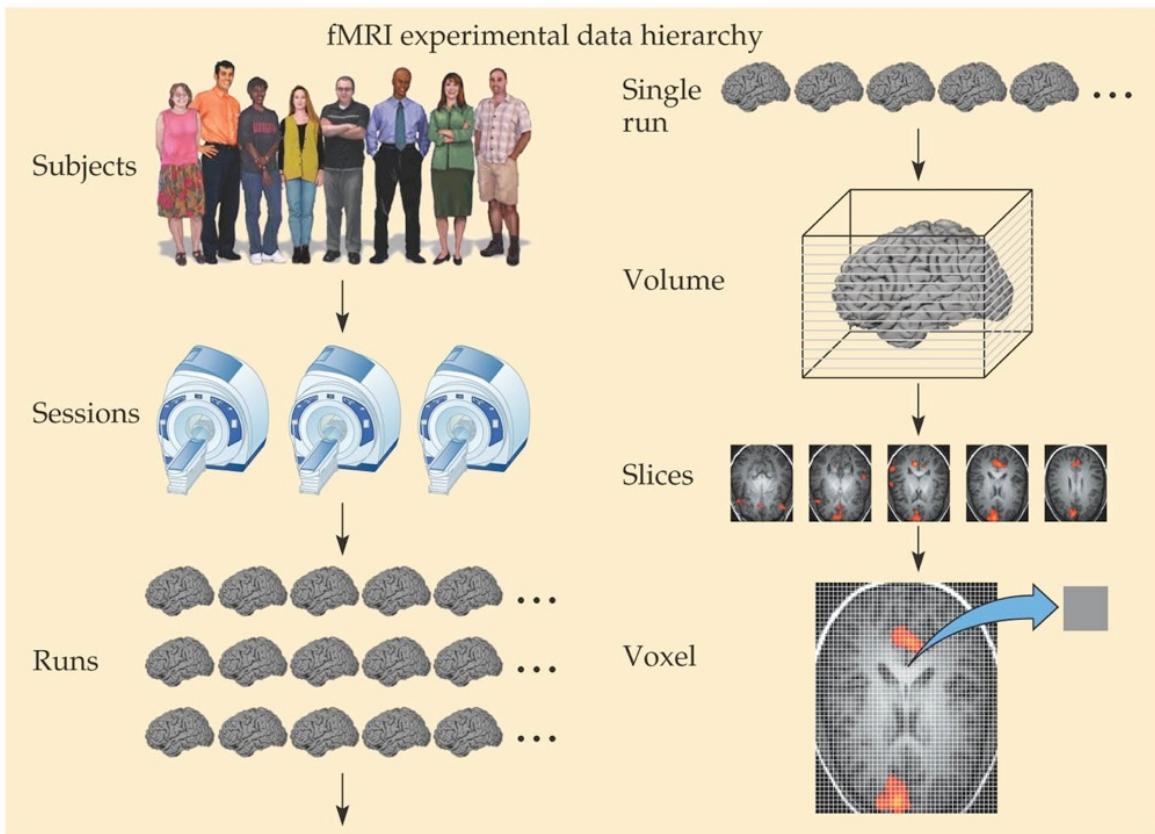


Figure 4: diagram from textbook showing study design ideas

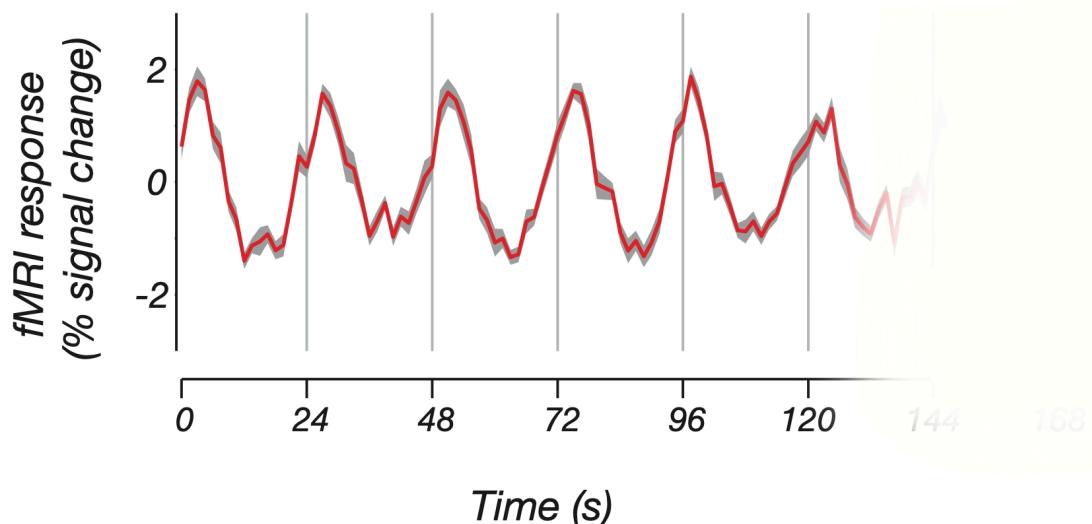
13 General thoughts (Variability)

Details of brain anatomy vary across individuals.

- What does this mean for group studies?
- Individual subjects results first?
- Data in 3d or 2d (cortical surface?)

14 Example data / images

15 fMRI measures changes over time



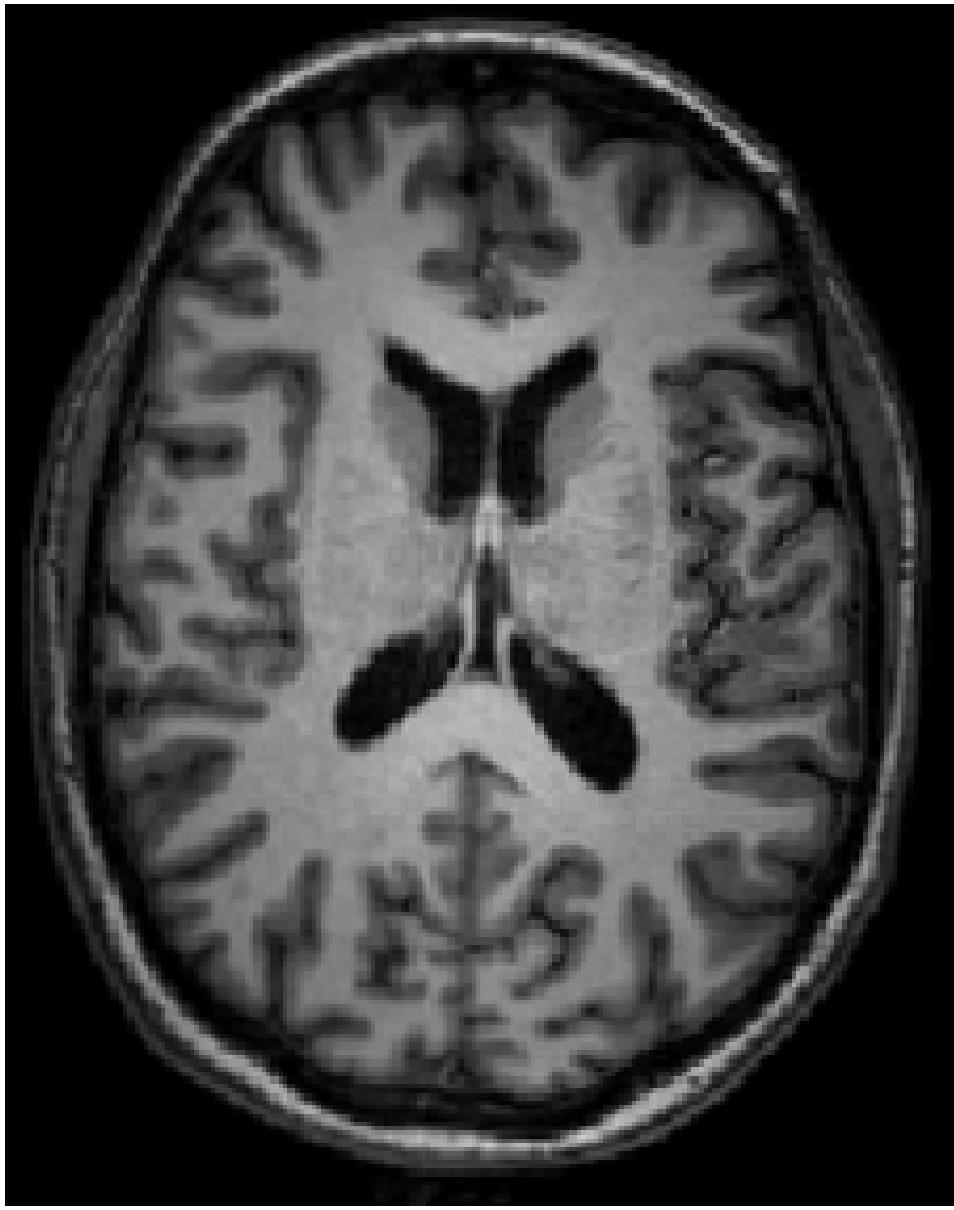


Figure 5: Anatomical image (T1w)

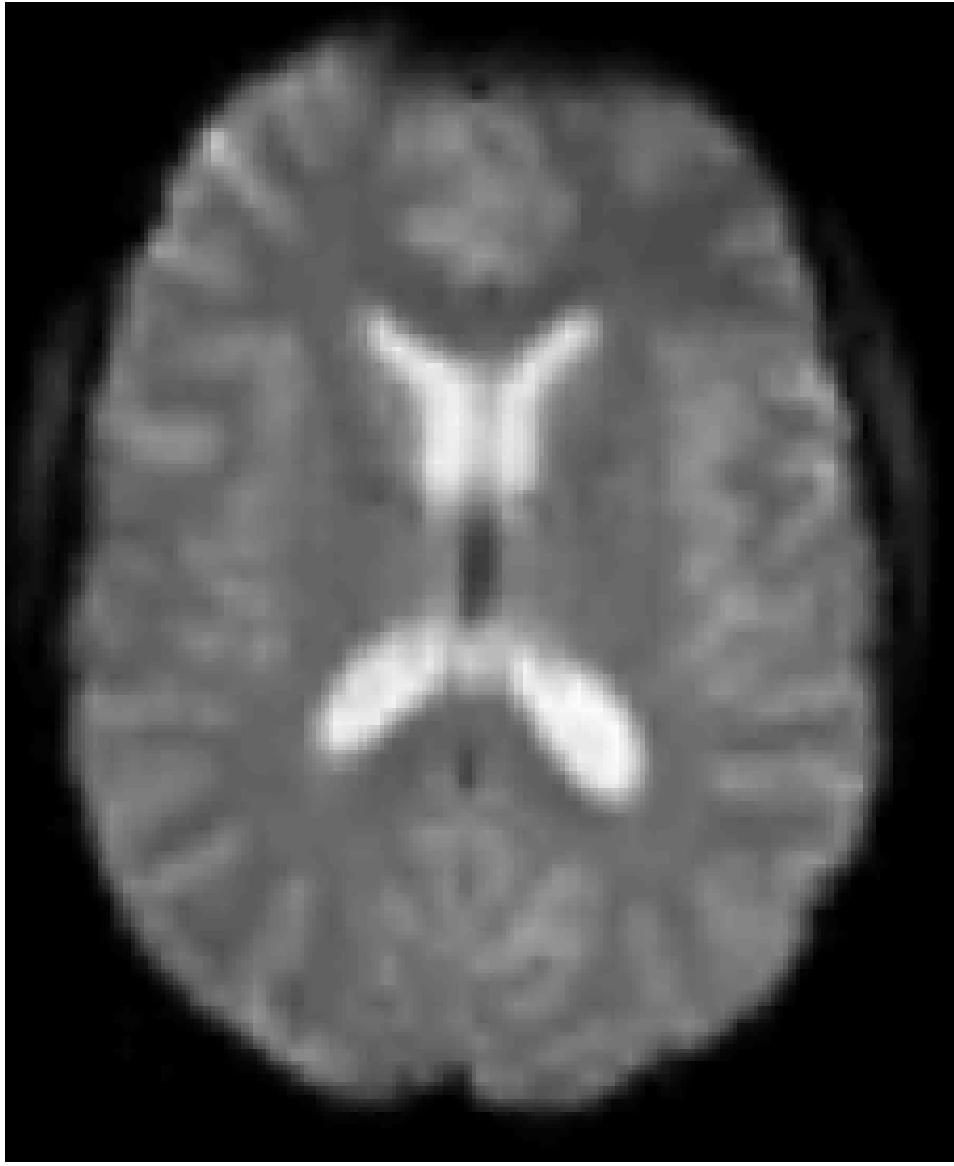


Figure 6: Functional image (T2*, EPI)

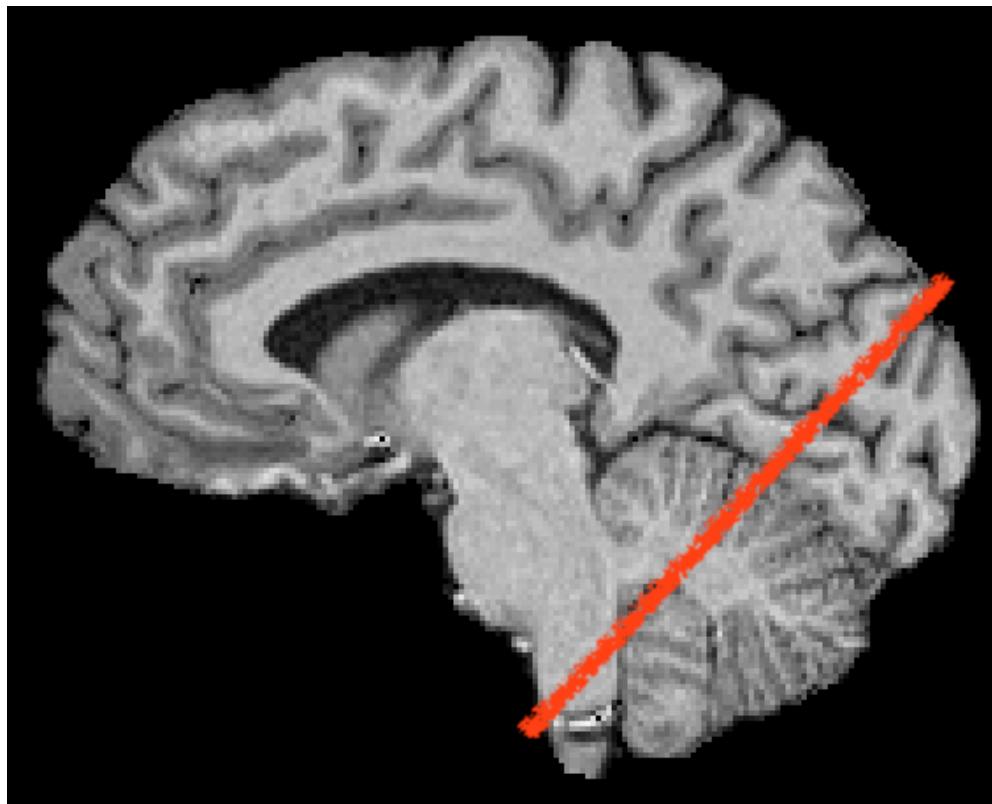


Figure 7: anatomical image with position of fMRI slice

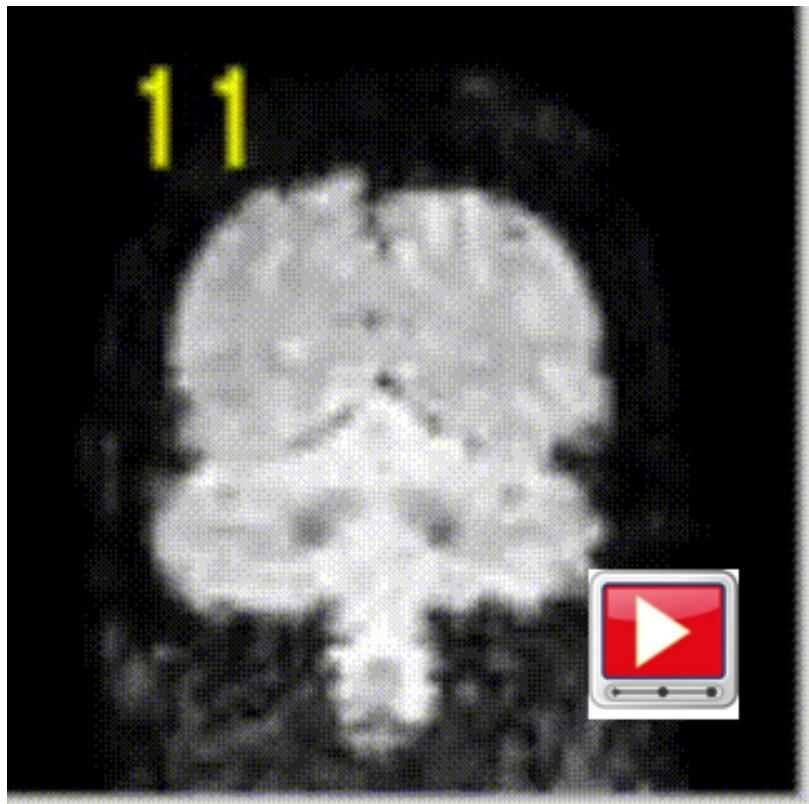
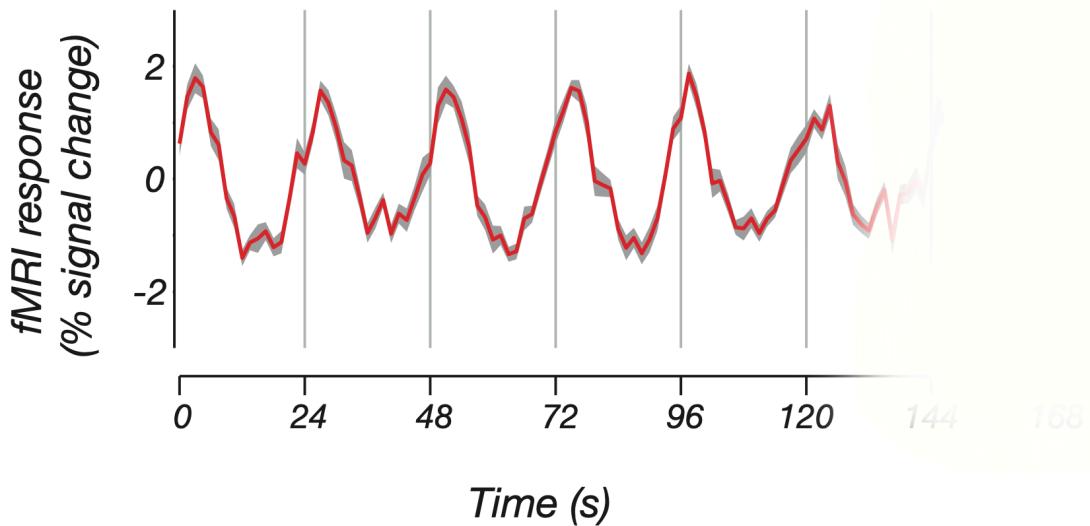


Figure 8: one slice over 160 repeated measurements (every 1.5s)

16 Example: visual cortex

17 Example: visual cortex (movie)

18 fMRI measures changes over time



19 “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...

20 Why do we need high spatial resolution?

- brain structures of interest are ~mm in size, sometimes separated by ~cm; need appropriate sampling
- smaller voxels: less mixing of grey matter, white matter, CSF, veins, ... reduced partial voluming

21 Appropriate sampling

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

FUNCTIONAL MAGNETIC RESONANCE IMAGING, Table 8.1 © 2004 Sinauer Associates, Inc.

Figure 9: Table of structures / sizes

22 Volume → no. of cells

... if packing density in grey matter of cortex is ~50,000 cells / mm³

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

23 PVE

24 Partial volume effects

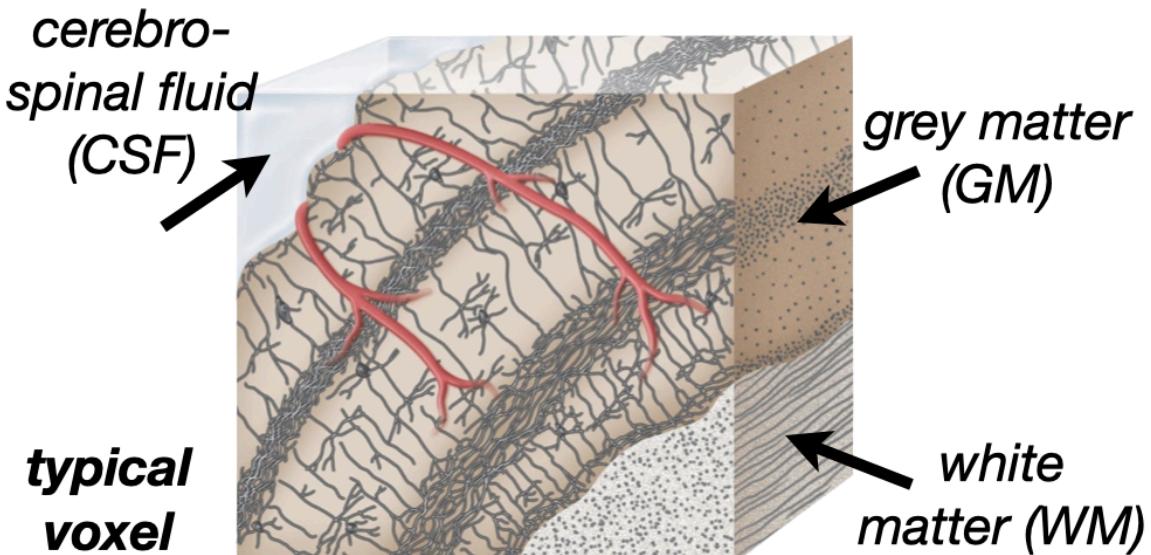


Figure 10: A typical 3mm voxel contains a mixture of tissues

25 What limits (spatial) resolution

hardware (the scanner)

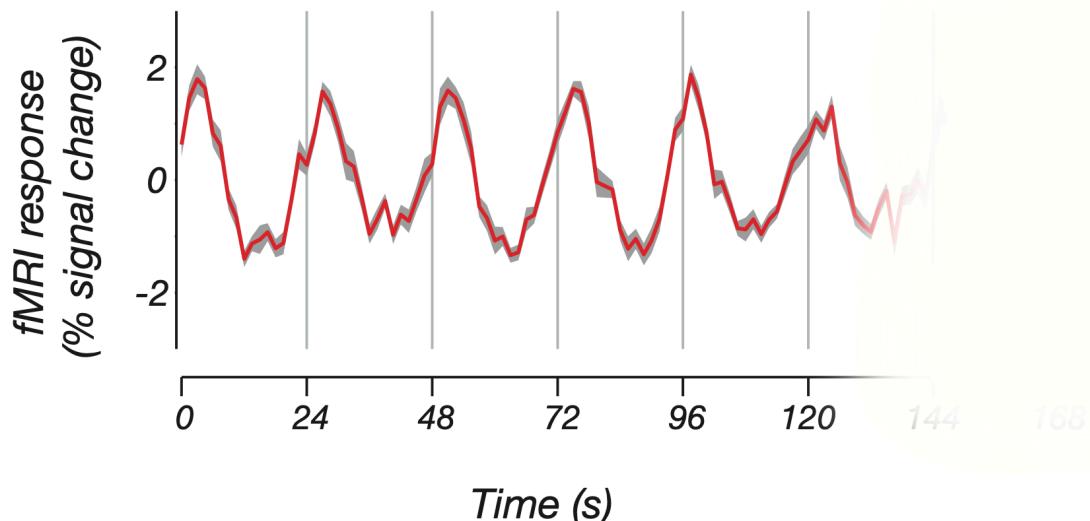
the subjects

- peripheral nerve stimulation PNS
- specific absorption rate SAR limits
- time in scanner (>1.5h is not fun)

signal-to-noise ratio - smaller voxels = proportionally more noise head motion, physiology,

...

26 fMRI measures changes over time



27 What limits (temporal) resolution

! physiology

basis of the blood-oxygen-level-dependent (BOLD) signal

- BOLD is **haemodynamic**, an indirect measure of neural activity (+ still hotly debated)
- BOLD signal is **delayed and blurred** in space, but also in time

28 Haemodynamic response

the shape of the response to a brief event is called the haemodynamic response function (HRF)

e.g. haemodynamic response to a 1s visual stimulus peaks several seconds later and is spread out

29 Intermediate summary

- Overview of the fMRI method.
- How to interpret fMRI data.
- Limiting factors of fMRI.
- Trade-off between temporal and spatial resolution.

Thinking about **temporal resolution** particularly important when designing fMRI experiments

30 Some principles of experimental design

Why do we need to worry about designing experiments?

break

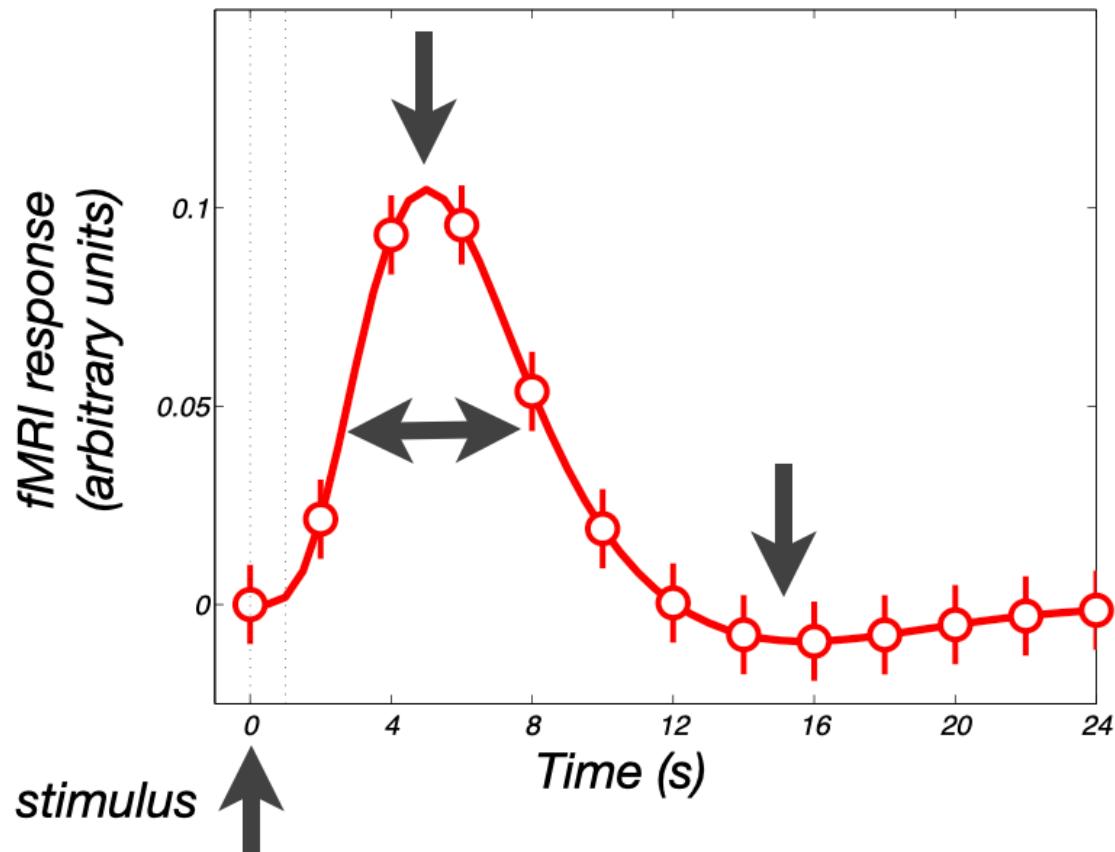


Figure 11: haemodynamic response

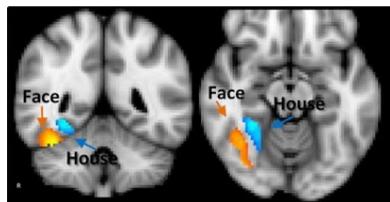
31 Terminology

Independent Variable: variable which is intentionally manipulated (different manipulations are called conditions / levels)

Dependent Variable: measured variable

Confound: a property that co-varies with the IV

32 eg. this experiment



33 Dealing with confounds

Counterbalancing: a process for removing confounds by ensuring they have equal influence at each level of the IV

Randomization: removing confounds by making sure they vary randomly at each level of the IV

34 Within or between subjects?

Within-subjects designs are stronger as they control for:

- Age Gender.
- Experience.
- Individual Difference.
- Brain size / shape.

Between-subjects designs are sometime unavoidable

- Diagnostic comparisons
- Gender effects

Match the design to the research question...

35 ... and for fMRI?

All the above, plus...

- Selecting an appropriate IV
- Selecting an appropriate control condition
- Types of experimental design
- Stimulus presentation timing

36 Many studies: cognitive subtraction

Compare two very similar conditions that are assumed to differ only in one property.

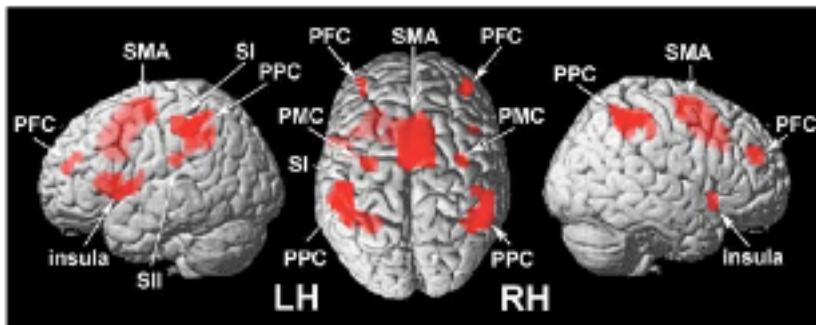


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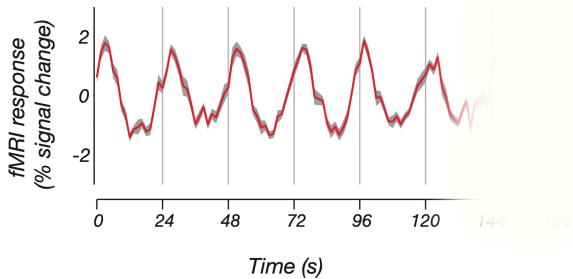
37 Control conditions are important



38 fMRI designs

- Block Designs – trials appear in alternating blocks (Task A, Task B)
- Event Related Designs – stimuli are presented one-at-a-time in a random order
- Mixed Designs – alternating blocks of tasks but with mixed trials
- (resting state fMRI) - no task

39 Block designs



- Powerful for detecting signal changes if a good control is selected.
- Not very good for estimating the shape of the HRF.
- Sensitive to noise (scanner drift)
- The block length is very important to consider

40 Event-related designs

come in two “flavours”

- Slow – stimulus followed by long inter-trial intervals (eg 10-15s rest)
- Fast/Rapid variable – rapid stimulus presentation with variable, but short ISI (2s)

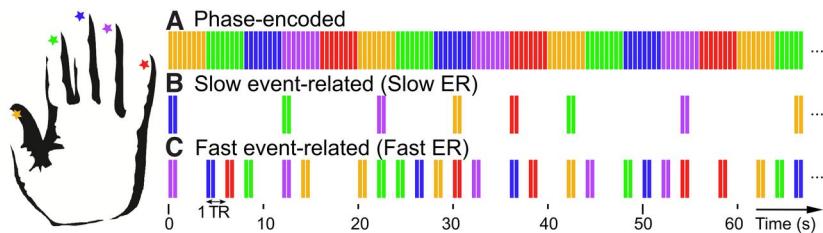


Figure 12: figure showing timing of events in touch experiment

41

42

43 Summary

Principles of experimental psychology apply to good fMRI study design also.

- Consider how the hypotheses make predictions about space and time (and do they align with the scope of what fMRI can measure).
- The experimental design should be appropriate for the research question.
- Timing of stimulus presentation is key!

44 Thanks

See you soon!

45 Colophon

- This presentation was made with `quarto` and `revealjs`.
- Uses a font called `Atkinson Hyerlegible`, which was designed to work better for people with low vision: available via [google fonts](#).

HRF & temporal precision

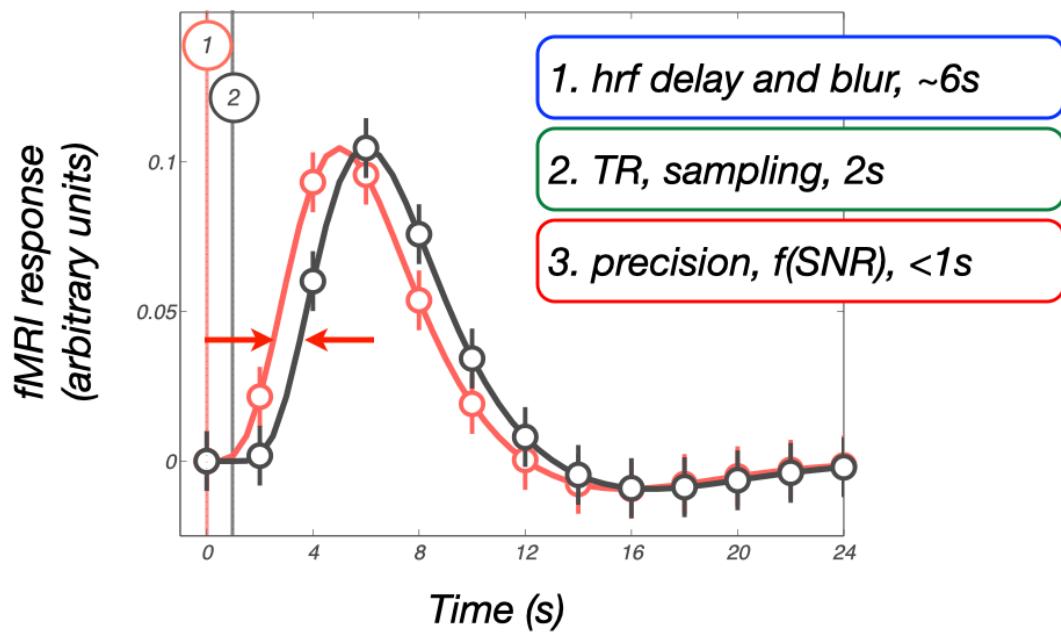


Figure 13: figure illustrating different aspects of temporal precision in fMRI experiments