Analysis of Functional Magnetic Resonance Imaging (fMRI)

Experimental Design

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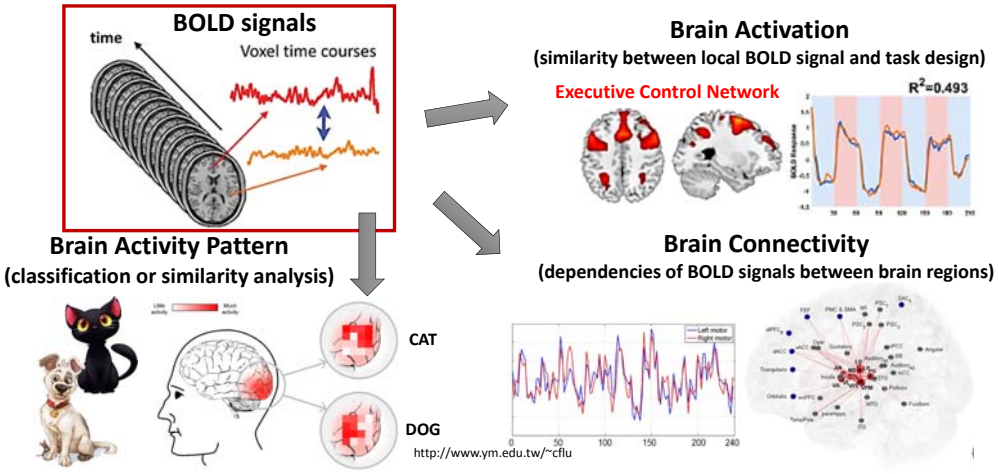
fMRI Analysis



Goal of Experimental Design

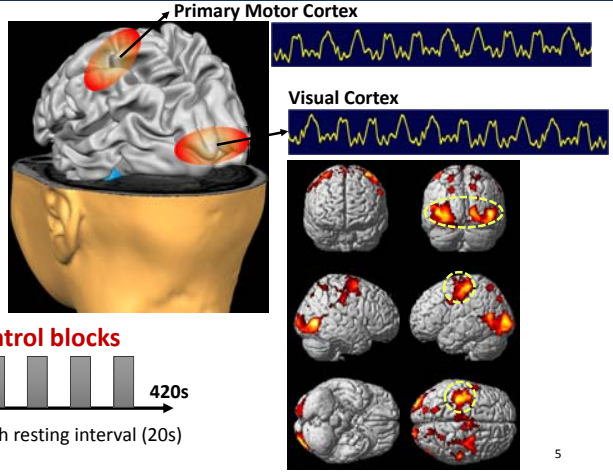
- To manipulate the participants experience and behavior in some way that is likely to produce a functionally specific neurovascular response.

- What can we manipulate?
  - **Stimulus properties** (what is presented?)
  - **Stimulus timing** (when is it presented?)
  - **Participant instructions** (what do subjects do with it?)

Types of Experimental Design

- **Simple Subtraction**
- **Categorical Design**
  - Cognitive subtraction: the assumption of pure insertion
- **Factorial Design**
  - Considering the interaction between multiple factors
- **Parametric Design**
  - Correlating behavior with brain activity

Simple Subtraction



Contrast: Motion – Control blocks

10 tasking blocks (duration = 20s) with resting interval (20s)

Categorical Design (1/3)

Comparing the brain activity between stimulus types.

Example:

- **Stimulus:** visual presentation of 12 common nouns.
- **Tasks:** decide for each noun whether it refers to an **animate** or **inanimate** object.

Categorical Design (2/3)

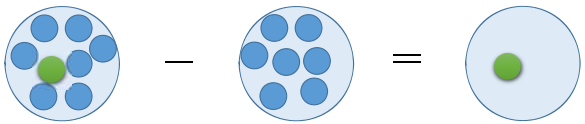
- **Cognitive subtraction**: the assumption of **pure insertion**

Aim

- Neural structures underlying a single process Y (e.g. face recognition)?

Procedure

- Contrast: [Task with Y] – [control task without Y] = Y



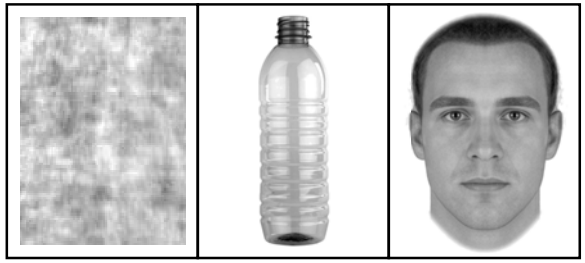
Categorical Design (3/3)

To identify the face recognition area…

Which one is the proper Control stimulus?

Target Face

Scrambled **A Bottle** **Male Face**



Factorial Design (1/2)

- Combining two or more factors within a task and looking at the effect of one factor on the response to other factor.

- **Main effects**
  - Main effect of task:
    (A1+B1) – (A2+B2)
  - Main effect of stimuli:
    (A1+A2) – (B1+B2)

Stimuli (A/B)

	Task (1/2)	
	Viewing	Naming
Gray-level	A1	A2
Color	B1	B2

Factorial Design (2/2)

- Combining two or more factors within a task and looking at the effect of one factor on the response to other factor.

- **Interaction of task and stimuli**
  - (A1 – B1) – (A2 – B2)

Does not make the assumption of pure insertion.

Stimuli (A/B)

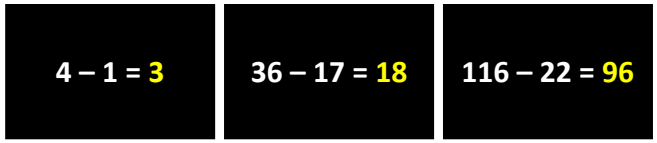
	Task (1/2)	
	Viewing	Naming
Gray-level	A1	A2
Color	B1	B2

Parametric Design

Exploring systematic changes in brain responses according to some performance attributes of the task.

Parametric designs use **continuous rather than categorical design**.

For example, we could **correlate response times with brain activity.**

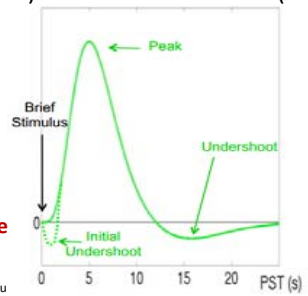


Stimulus Delivery

- **MRI compatible hardware**
  - In-room viewing monitor/projector
  - Goggles with integrated EyeTracking cameras
  - Audio system
  - Response pads/grips/buttons
  - Trigger/synchronization box (MR scanner ⇔ stimulus presentation software)
- **Stimulus presentation software**
  - E-prime (BIOPAC Systems)
  - Presentation (Neurobehavioral Systems)

BOLD and HRF characteristics

- The relationship between neural activation and BOLD signal
  - Neuronal firing and postsynaptic potentials occur very soon (tens to hundreds of milliseconds)
  - BOLD: initial dip (~1s) → maximal value (4~6s) → return to baseline (~20s)
- **Hemodynamic response function (HRF)**

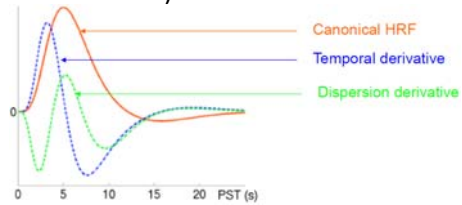


BOLD Impulse response

Friston et al, Neuroimage, 1995, 1998.

HRF and its derivatives

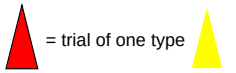
- The HRF characteristics can differ between
  - Brain regions within one subject (inter-region difference)
  - Subjects (inter-subject difference)
- The adaption of HRF in
  - The onset time (temporal derivative)
  - Dispersion/width of curve (dispersion derivative)

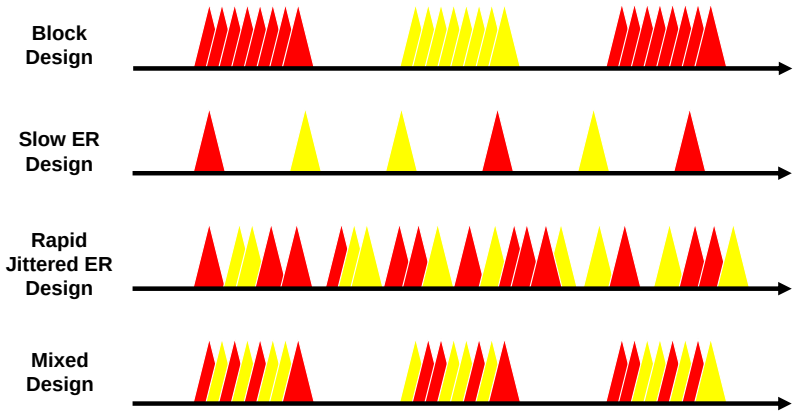


Stimulus Timing Design

- **Block design**
  - Combine BOLD response to a number of continuous trials (events)
- **Event-related (ER) design**
  - Obtain the BOLD response to a single event
- The more *efficient* a design, the less scan time is needed to achieve sufficient *power*.

Design Types





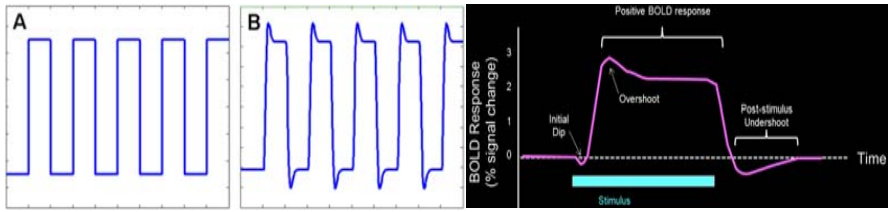
fMRI slides from http://culhamlab.ssc.uwo.ca/fmri4newbies/Tutorials.html

Block Design

- A design in which the task is presented in so-called blocks (15~30s), alternated with resting blocks.
- The number of scans should be equal in all conditions, so that the variance in all factors is the same.
- The longer the blocks are, the more chance there is for a correlation with low-frequency noise.
- The strength of the brain signal can decrease over time.

Block Design

- **Box-car function**
  - A 0 for no-task and a 1 for task period
- **Hemodynamic (BOLD) changes don not suddenly activate and stop activating in the way modeled by the box-car function.**
  - A better estimation by convolving the box-car input function with an HRF.



Matthijs Vink, Preprocessing and analysis of functional MRI data, 2007.

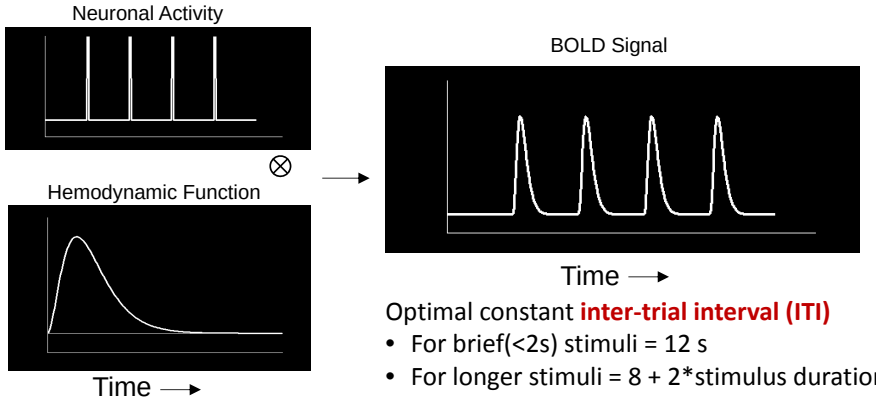
Pros of Block Designs

- high detection power of activated voxel/region
- has been the most widely used approach for fMRI studies
- accurate estimation of hemodynamic response function is not as critical as with event-related designs

Cons of Block Designs

- poor estimation power to differentiate the time courses in response to different conditions
- very predictable for subject
- Can't look at effects of single events
- becomes unmanageable with too many conditions (e.g., more than 4 conditions + baseline)

Slow Event-Related (ER) designs



Optimal constant **inter-trial interval (ITI)**

- For brief(<2s) stimuli = 12 s
- For longer stimuli = 8 + 2*stimulus duration

Pros of Slow ER Designs

- excellent estimation of BOLD changes
- useful for studies with delay periods
- very useful for designs with motion artifacts because you can tease out artifacts

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Cons of Slow ER Designs

- poor detection power because of very few trials per condition
- subjects can get VERY bored and sleepy with long ITI.

How about making it fast?

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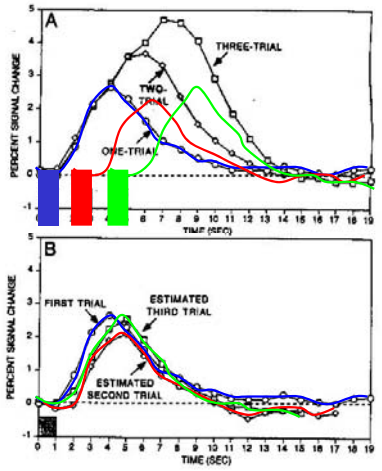
Linearity of BOLD signal



Linearity:
"Do things add up?"

red = 2 - 1

green = 3 - 2

Sync each trial response to start of trial

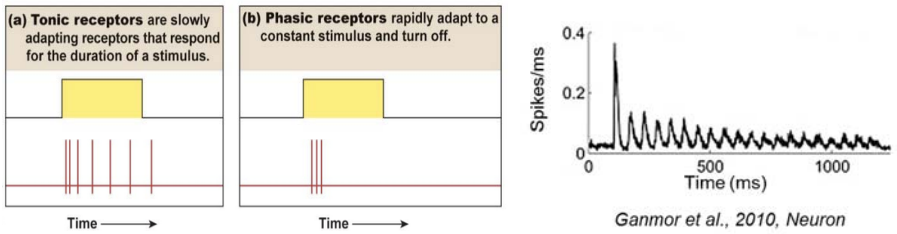
Not quite linear but good enough!

Dale & Buckner, 1997

fMRI slides from http://culhamlab.ssc.uwo.ca/fmri4newbies/

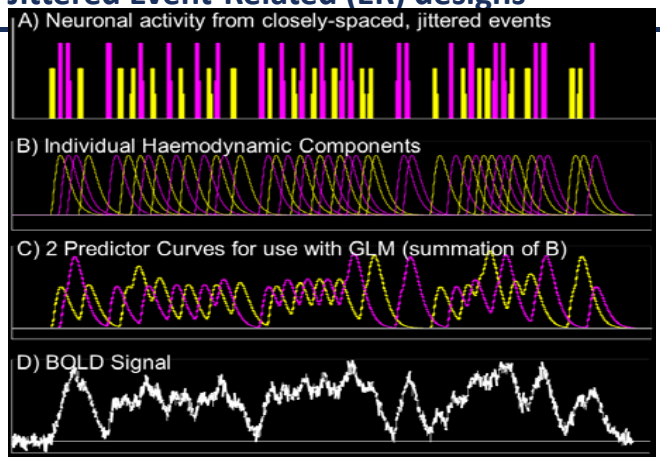
BOLD isn't totally linear

- Linearity of BOLD is sufficient for events with **at least 4s of ITI**.
- Phasic neural responses
- Adaption or habituation depends on stimulus duration and intensity.



Ganmor et al., 2010, Neuron

Rapid Jittered Event-Related (ER) designs



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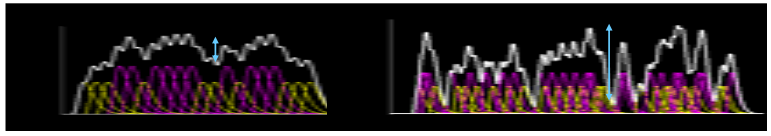
Why jitter?

- Yields larger **fluctuations** in signal



When pink is on, yellow is off
→ pink and yellow are anticorrelated

Includes cases when both pink and yellow are off
→ less anticorrelation

- Without jittering predictors from different trial types are strongly **anticorrelated.**
  - As we know, the GLM doesn't do so well when predictors are correlated (or anticorrelated)

fMRI slides from http://culhamlab.ssc.uwo.ca/fmri4newbies/Tutorials.html

Pros of Rapid-ER Designs

- high detection power
- trials can be put in unpredictable order
- subjects don't get so bored

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Cons of Rapid-ER Designs

- reduced detection compared to block designs
- requires stronger assumptions about linearity
  - BOLD is non-linear with inter-event intervals < 4 sec.
  - Nonlinearity becomes severe under 2 sec.
- errors in HRF model can introduce errors in activation estimates

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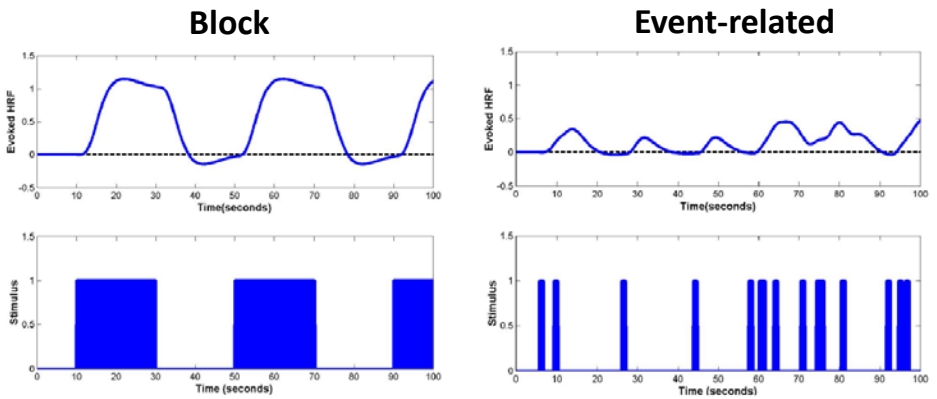
Block vs. Event-Related Design



Summary of Experiment Design

- **Rules of thumb**
  - **Blocked Designs:**
    - Powerful for detecting activation
    - Useful for examining state changes
  - **Event-Related Designs:**
    - Powerful for estimating time course of activity
    - Allows determination of baseline activity
    - Best for post hoc trial sorting
  - **Mixed Designs**
    - Best combination of detection and estimation
    - Much more complicated analyses

Quoted from Yingying's slide.

THE END

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Teaching Materials: http://www.ym.edu.tw/~cflu/CFLu_course_fMRIana.html