Psychophysics for fMRI

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UCLA NITP Neuroimaging Summer Course
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let's measure brain function!

Biophysical Signal  BOLD Effect  Experimental Manipulation

Farnsworth-Munsell Hue Test & Achromatopsia
Farnsworth (1957)

Beauchamp et al., 1999, Cerebral Cortex

Chromatic (C)  Fixation (F)  Achromatic (A)
Beauchamp et al., 1999, Cerebral Cortex

Physical Properties
- luminance
- contrast
- FOV

Psychological Properties
- 5 vs 87 chips
- forced choice
- HRF

BOLD response
- reference
- signal strength

Psychological Properties
- 3 vs 87 chips
- forced choice
- anxiety, fatigue

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“Psychophysics” of fMRI

Experimental Manipulation

“functional MRI is difficult”
**VISUAL LOUD STATIC ENVIRONMENT**

Vision
Visual Cognition
[Internal States]

**VISUAL ENVIRONMENT**

<table>
<thead>
<tr>
<th>Specifications</th>
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<th>Acer K11 Projector</th>
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<td>1440 x 600</td>
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<tr>
<td>Contrast Ratio</td>
<td>1000:1</td>
<td>NA</td>
<td>2000:1</td>
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<tr>
<td>Displayable Colors</td>
<td>16.7 mill</td>
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<tr>
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<td>variable</td>
<td>30 degree horizontal</td>
<td>varies (25&quot;-11.2ft)</td>
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**VISUAL LOUD STATIC ENVIRONMENT**

Vision
Visual Cognition
[Internal States]

No walking, jumping, talking and interacting with the world.

fMRI is a VISUAL modality (which will affect the kind of experiments you can do) but in general the visual environment is well within your control in MRI.

How does the (visual) BOLD response behave with stimulation?

Audition
Exploration (video vs. blind)
Social Interaction (confederates vs. body language)
Speech (confabulation)
Mobile Populations (Tourette, children)
Special Topics (motor coordination and learning, yoga, therapy)
"BOLD signal mainly reflects the incoming specific or association inputs into an area & the processing of this input information by the local cortical circuitry."

Friston et al (1998) MRM 39(1) 41-52

BOLD response shows nonlinearity for stimuli occurring with short separation (~<3sec).

stimulus input x2 ≠ BOLD signal x2

DURATION (assume infinite frequency) of stimulus has nonlinear results on BOLD response.

< .16Hz (T=6.25) BOLD can be simulated
> .21Hz (T=4.76) could not reconstruct

Immediate impact for fMRI is in terms of design and interpretation. If non-linearities are neuronal in nature they may be studied directly (with caution). If non-linearities are vascular in nature they may be avoided through experimental design.
Visual stimulation elicits neural activity, that decreases in magnitude with repetitive activation.

- Priming and noise suppression are candidate mechanisms.

Ubiquitous to contrast, color, and tilt but less understood in higher-order vision.

Consequences?
- trivial confound
- signal loss
- measurement tool
Adaptation/Carry-Over Effects

Adaptation can vary with stimulus duration AND region - carry-over effects are not necessarily trivial to control.

Fang et al., (2005), J Neurophys 94, 4188-4295

Steffener et al., (2010), NeuroImage 49, 2113-2122

VARIABILITY of HRF

Handwerker et al., (2004), NeuroImage 21, 1639-1651
VARIABILITY of HRF

1. HRF varies across regions (e.g., latency, undershoot)

2. HRF varies across individuals (diff in vasculature?)

3. HRF varies across measurements within individuals (**no so bad**).

4. HRF varies across time.

AUDITORY STIMULATION

30 dB quiet whisper (library)
60-70 dB normal conversation
88 dB motorcycle
~ 100 dB MRI (EPI, Spin-Echo)
110 dB power saw

**AUDITORY STIMULATION**

Magnitude of Noise in 1.5T vs. 3T

- 25 Pa = 122 dB
- 150 Pa = 137 dB

Noise Classes in 1.5T


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**AUDITORY RESPONSE**

Noise elicits neural activity (Bandettini et al., 1998)

Does this noise change the participants’ auditory experience in the scanner?


Scanner noise impairs frequency specific auditory discrimination.
Auditory response is not trivial to measure b/c by default it interacts with scanner noise.

Passive attenuation (i.e., headphones + earplugs): -31-38 and 25-29 dB of attenuation respectively -38-43 dB at 1-1.4 kHz of attenuation together

Active Attenuation (active noise cancellation e.g., Chambers et al, 2001) - 12 dB reduction (but noise travels through body)

Hardware Modification - modification of coils, use of rotating coils & placement of coils in vacuum have been proposed (not easy to implement)

AUDITORY RESPONSE

SPARSE SAMPLING as a SOLUTION?

Hall et al., (1999) HBM, 7, 213-233
Yang et al., (2000) MR in Medicine, 43, 185-190
TR > TA

SPARSE SAMPLING as a SOLUTION?

medial to lateral shift in Heschl's gyrus corresponding to a low-to-high frequency shift, specific for stimulated laterality

SILENT

COST: note fewer slices and time points acquired

TRADITIONAL

COST: note fewer slices and time points acquired
SPARSE SAMPLING as a SOLUTION?

Most of noise is from readout & phase-encoding steps. Can we modify gradient sequence to attenuate sound?

- modified readout gradients to follow a quasi-continuous pattern, which produced a sound frequency that appeared as continuous sound (rather than pulsed)

Schmitter et al., (2008) MRMP, 21, 317-325 Silent echo-planar imaging for auditory fMRI
- sinusoidal readout gradients with narrow band acoustic frequency spectrum that can be shifted to make it coincide with minima of scanner’s frequency response function
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- sinusoidal readout gradients with narrow band acoustic frequency spectrum that can be shifted to make it coincide with minima of scanner’s frequency response function
Noise Detection

\[ Q > S \]

Sentences > Noise

\[ Q = S \text{ and } Q < S \]

*dropout in iTL

SPARSE SAMPLING as a SOLUTION?


PSYCHOLOGICAL EFFECTS of NOISE

Tomasi et al., (2005), NeuroImage, 27(2).

Scanner noise increases cognitive working load & simultaneously decreases amount of activation change.
PSYCHOLOGICAL EFFECTS of NOISE?

Hommel et al., 2012, JEP:HPP, 38(2), 290-301

Both behavioral and neural measures suggest that scanner noise changes cognitive performance - effect direction can vary.

NON-SPECIFIC PSYCHOLOGICAL EFFECTS

EXAMPLE: The MRI experience

Raz et al., 2005, NeuroImage
- novel, intimidating environment (pre-test procedures, metal/safety screening, metal wand, ear buds, head-movement, constraints on movement/head restraint, and emergency squeeze ball)
- sensory deprivation (you can’t see the experimenter, you can’t be heard during the scan)
- lack of control over environment (head-first in scanner, confined space, pressure to perform)

ANXIETY

- occurs in ~30% of scanned subjects, with 5-10% experiencing significant anxiety (Robinson 1996) e.g., heavy breathing, heart palpitations, blood pressure, dizziness


Earlier and first scans will produce a different experience than later scans.
HYPOCAPNIA
- anxiety can be associated with hypocapnia (decreases CO2/hyperventilation)

Cohen E et al, 2002, JCBFM, 22, 1042-1053

NON-SPECIFIC PSYCHOLOGICAL EFFECTS
- Oxygen
- Acetazolamide
- Caffeine
- Alcohol
- Cocaine
- Adrenaline
- Anesthetic Agents

(CBF differs by region)

NETWORK MODIFICATION

Eye movements can lead to signal variability in surrounding signal producing false positive activations in frontal orbital regions.

Beauchamp, 2003

Upper body movements introduce motion artefacts (joysticks?) e.g., Yu et al., (2009), IEEE 11th International Conference on Rehab Robotics

Verbal responses can also introduce motion artefacts through: movement of jaw, tongue, swallowing, opening of air cavity, air pressure changes with vocalization

Birn et al., 1998
Partial Solution: Artefact and HRF have different time courses and so can be dissociated by using an event related design & separating artefact TRs from task.

Other Unusual Sources of Variability: Mouth

Partial Solution: Artefact and HRF have different time courses and so can be dissociated by using an event related design & separating artefact TRs from task.

Why care about noise due to motion?

- special populations (children, elderly, neuropsychiatric patients)

IN SUM

- the BOLD signal that you measure depends on your ability to create the correct environment (physical & psychological) and elicit a detectable & interpretable BOLD response

- BOLD is subject to variability that can in some cases be controlled by careful experimental design (adaptation, anxiety) or analysis (functional connectivity) and sometimes not (audio noise)

- in all cases fMRI requires careful thought in design and analysis as BOLD response is not always what it may seem (pay very very careful attention to the next 24 hrs of talks)