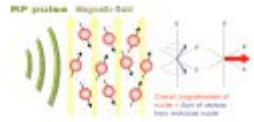
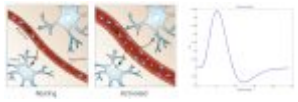
Psychophysics for fMRI

July 14, 2011
UCLA NITP Neuroimaging Summer Course
Agatha Lenartowicz, UCLA
alenarto@ucla.edu

let's measure brain function!



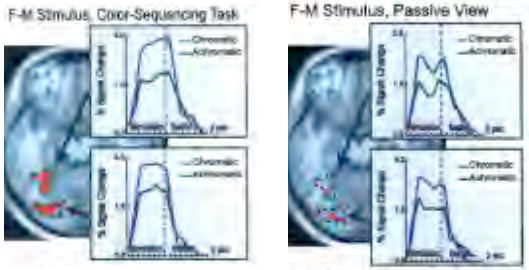


Biophysical Signal | BOLD Effect | Experimental Manipulation

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	BOLD response	Psychological Properties
- luminance - contrast - FOV	- reference - signal strength & interactions - HRF	- 5 vs 87 chips - forced choice - anxiety, fatigue

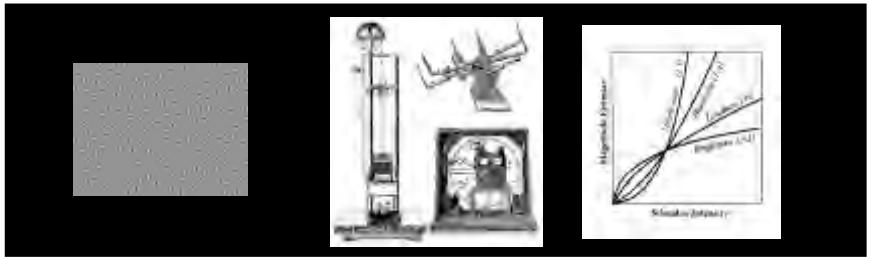
Beauchamp et al., 1999, Cerebral Cortex

"functional MRI is difficult"

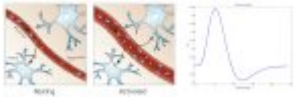
Savoy, RL (2005). Experimental design in brain activation MRI: Cautionary tales, Brain Res Bull 67, 361.

Physical Properties	BOLD response	Psychological Properties
- luminance - contrast - FOV	- reference - signal strength & interactions - HRF	- 3 vs 87 chips - forced choice - anxiety, fatigue

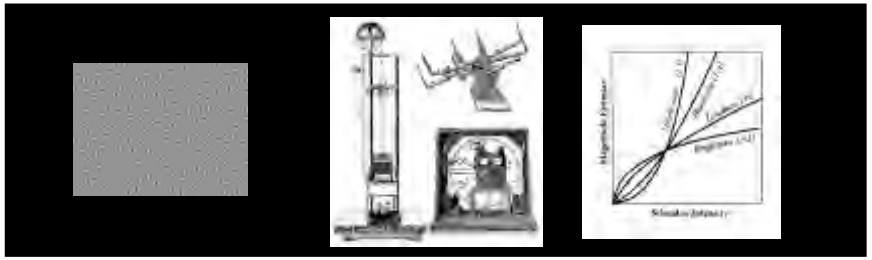
"Psychophysics" of fMRI



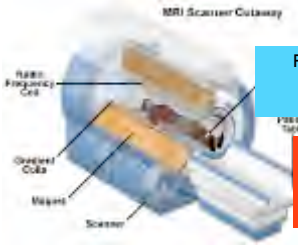
Experimental Manipulation



"Psychophysics" of fMRI



Experimental Manipulation



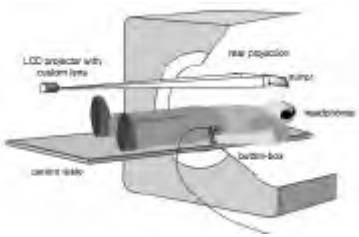
?

Physical Properties
- luminance
- contras

BOLD response
- reference
- signal strength & interactions

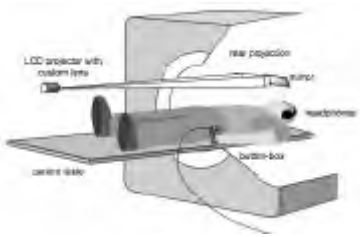
Psychol
- 3 vs 87 chips
- forced choice
- anxiety, fatigue

VISUAL LOUD STATIC ENVIRONMENT



Vision
Visual Cognition
[Internal States]

VISUAL ENVIRONMENT



Projection Systems

Cambridge Research Systems

Resonance Technologies Inc

VISUAL ENVIRONMENT

Specifications	Cambridge Research Systems	Resonance Technologies	Acer K11 Projector
Max Resolution	1920x1080	800 x 600	1440 x 600
Contrast Ratio	1000:1	NA	2000:1
Displayable Colors	16.7 mill	NA	16.7 mill
Field of View	variable	30 degree horizontal	varies (25”-11.2ft)
Refresh Rate	60 Hz	up to 85Hz	85 Hz
Eye-Tracking/Stereo	Yes/Yes	Yes (??)/Yes	No/SortOf

VISUAL ENVIRONMENT

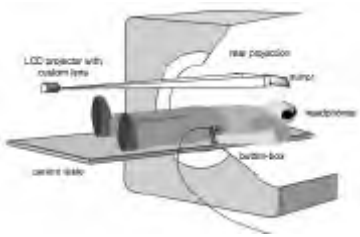
Specifications	Cambridge Research Systems	Resonance Technologies	Acer K11 Projector
Max Resolution	1920x1080	800 x 600	1440 x 600
Contrast Ratio	1000:1	NA	2000:1
Displayable Colors	16.7 mill	NA	16.7 mill
Field of View	variable	30 degree horizontal	varies (25”-11.2ft)
Refresh Rate	60 Hz	up to 85Hz	85 Hz
Eye-Tracking/Stereo	Yes/Yes	Yes (??)/Yes	No/SortOf

VISUAL ENVIRONMENT



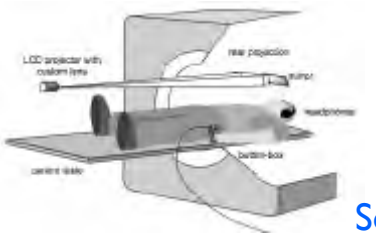
Specifications	Cambridge Research Systems	Resonance Technologies	Acer K11 Projector
Max Resolution	1920x1080	800 x 600	1440 x 600
Contrast Ratio	1000:1	NA	2000:1
Displayable Colors	16.7 mill	NA	16.7 mill
Field of View	variable	30 degree horizontal	varies (25”-11.2ft)
Refresh Rate	60 Hz	up to 85Hz	85 Hz
Eye-Tracking/Stereo	Yes/Yes	Yes (??)/Yes	No/SortOf

VISUAL LOUD STATIC ENVIRONMENT



Vision
Visual Cognition
[Internal States]

VISUAL LOUD STATIC ENVIRONMENT



Vision
Visual Cognition
[Internal States]
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)

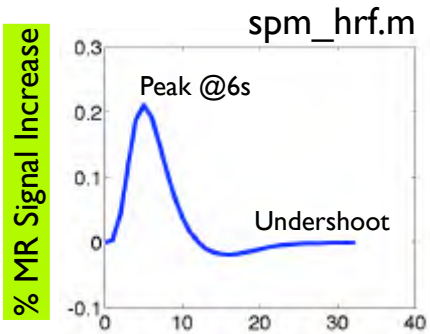
No walking, jumping, talking and interacting with the world.

VISUAL ENVIRONMENT

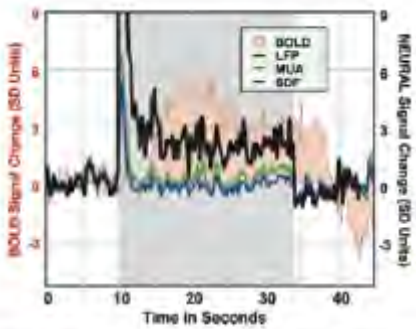
fMRI is a VISUAL modality (which will affect the kind of experiments you can do) but in general the visual environment is well within your control in MRI.

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

VISUAL BOLD RESPONSE

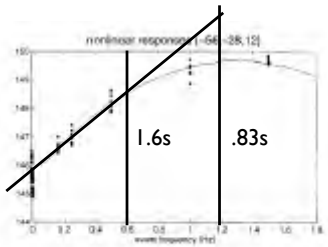


Logothetis (2003) JNeuro 23(10) 3963-3971



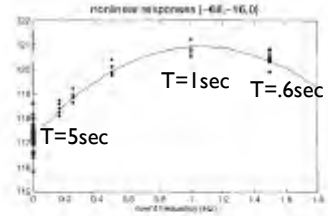
'BOLD signal mainly reflects the incoming specific or association inputs into an area & the processing of this input information by the local cortical circuitry'

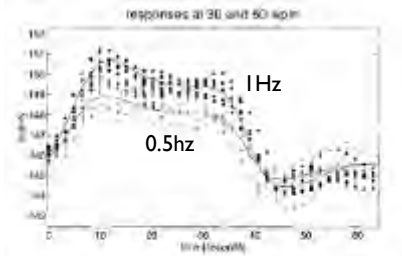
VISUAL BOLD RESPONSE



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

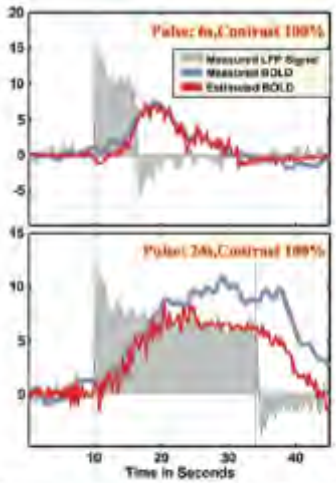
stimulus input x2 ≠ BOLD signal x2





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

VISUAL BOLD RESPONSE



Logothetis (2003) JNeuro 23(10) 3963-3971

BOLD response shows nonlinearities 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

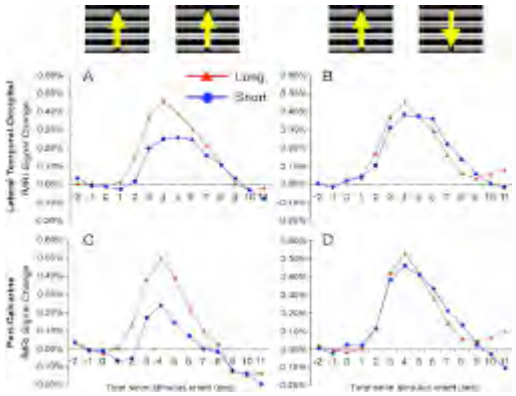
VISUAL BOLD RESPONSE

Proposed explanations have included vascular (e.g., baseline state), metabolic (e.g., oxygen extraction fraction), and neuronal sources (e.g., LFP).

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.

Adaptation/Carry-Over Effects

Visual stimulation elicits neural activity, that decreases in magnitude with repetitive activation.

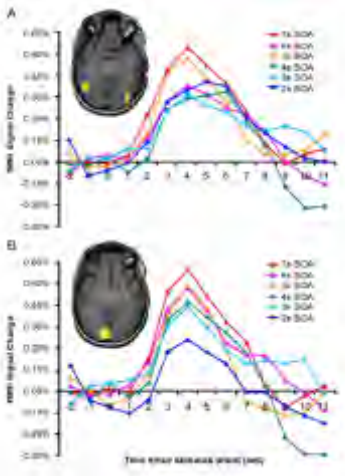


Huettel et al., (2004), NeuroImage 23(1)

Adaptation/Carry-Over Effects

Visual stimulation elicits neural activity, that decreases in magnitude with repetitive activation.

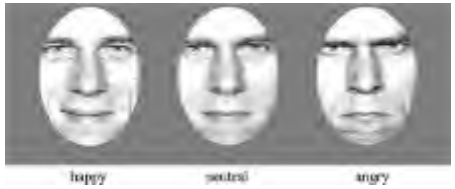
Priming and noise suppression are candidate mechanisms.



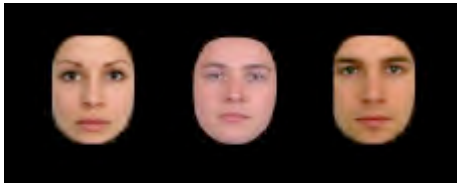
Huettel et al., (2004), NeuroImage 23(1)

Adaptation/Carry-Over Effects

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

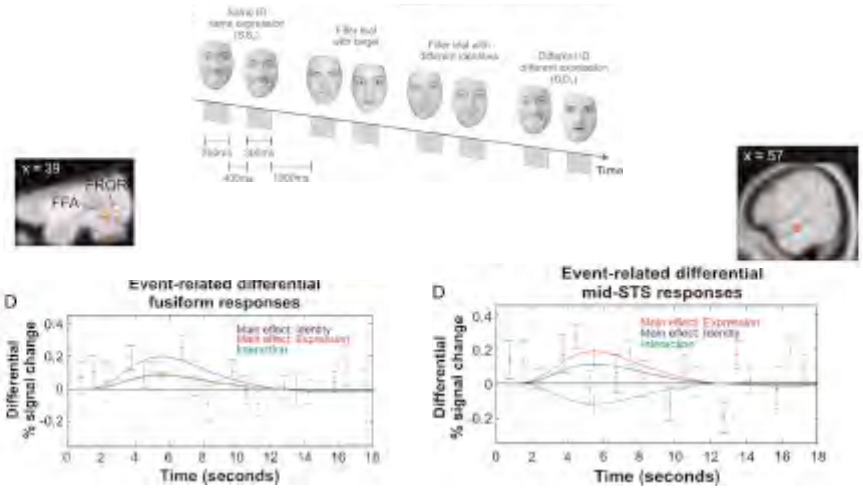


Consequences?
- trivial confound
- signal loss
- measurement tool



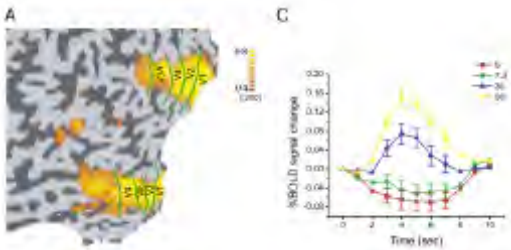
Adaptation/Carry-Over Effects

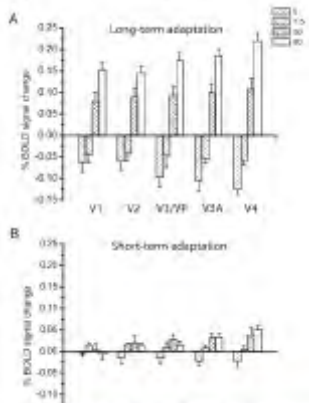
Winston et al., (2004), J Neurophys 92, 1830-1839



Adaptation/Carry-Over Effects

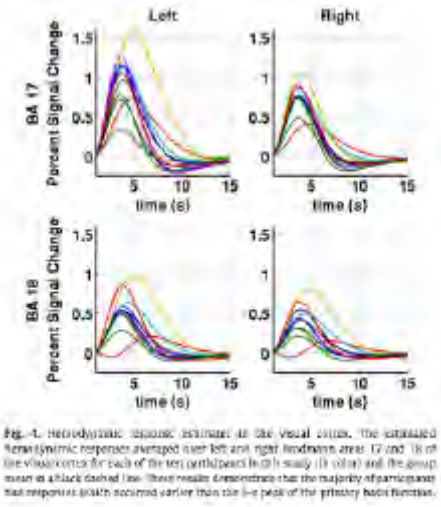
Fang et al., (2005), J Neurophys 94, 4188-4295





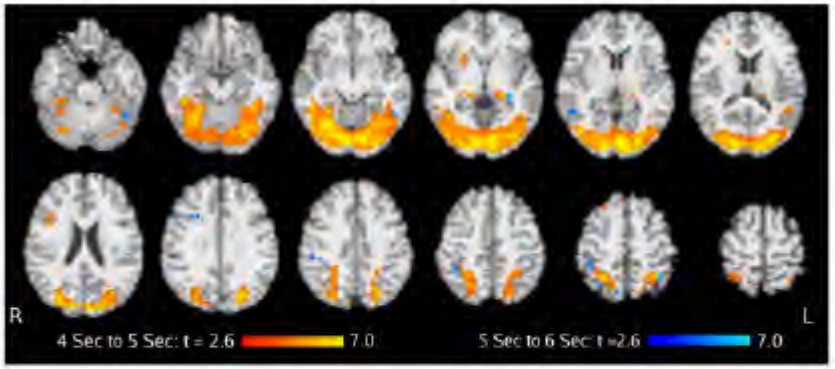
Adaptation can vary with stimulus duration AND region - carry-over effects are not necessarily trivial to control.

VARIABILITY of HRF



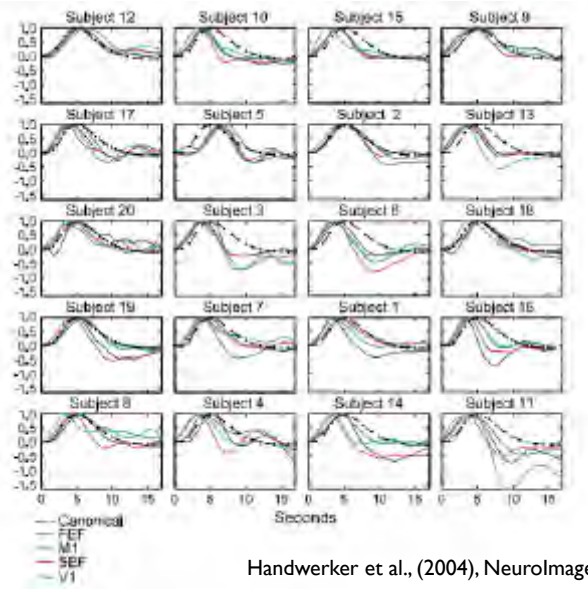
Steffener et al., (2010), NeuroImage 49, 2113-2122

VARIABILITY of HRF



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

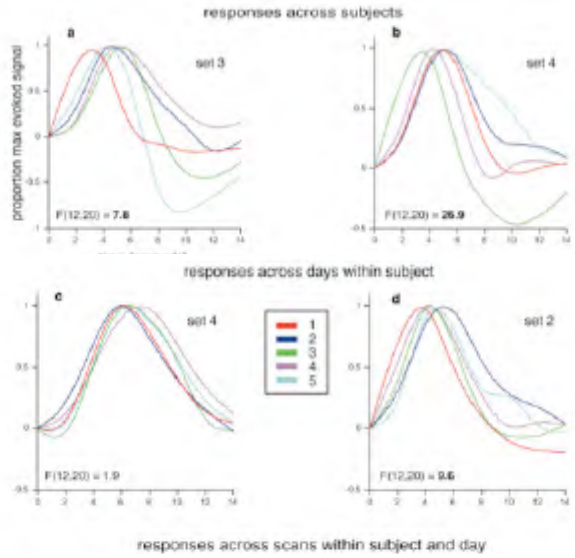
VARIABILITY of HRF



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

VARIABILITY of HRF

Central Sulcus Variability



Aguirre et al., (1998), NeuroImage 8, 360-369

VARIABILITY of HRF

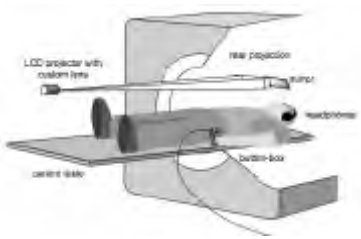
1. HRF varies across regions (e.g., latency, undershoot)

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

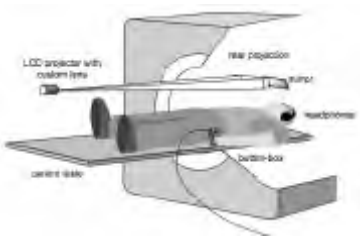
3. HRF varies across measurements within individuals (**no so bad**).

4. HRF varies across time.

AUDITORY STIMULATION



AUDITORY STIMULATION



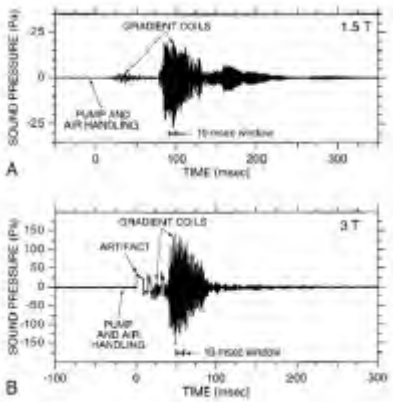
30 dB quiet whisper (library)
60-70 dB normal conversation
88 dB motorcycle
~ 100 dB MRI (EPI, Spin-Echo)
110 dB power saw

Counter et al., (1997) JMRI, 7(3), McJury & Shellock (2000) JMRI 12

AUDITORY STIMULATION

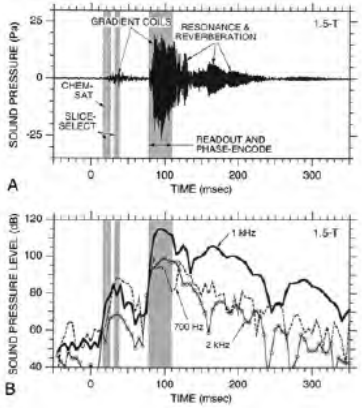
Magnitude of Noise in 1.5T vs. 3T

25 Pa = 122 dB



150 Pa = 137 dB

Noise Classes in 1.5T

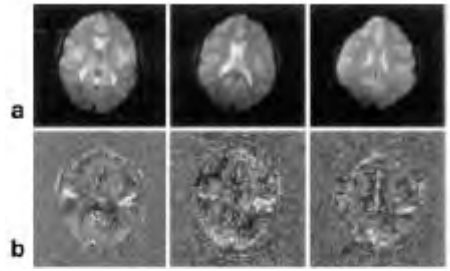


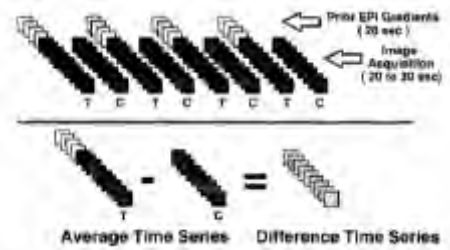
Ravicz et al., (2000), J Acoust Soc Am 108(4)

AUDITORY RESPONSE

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

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

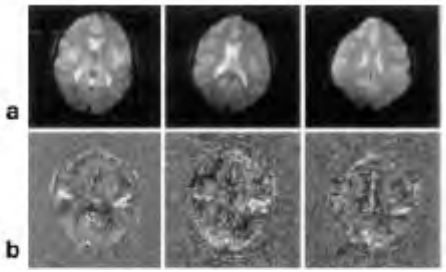


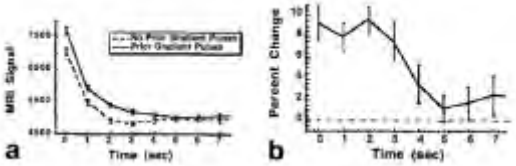


AUDITORY RESPONSE

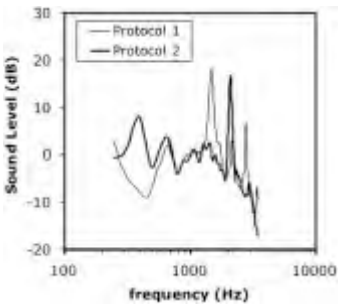
Noise elicits neural activity (Bandettini et al., 1998)

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

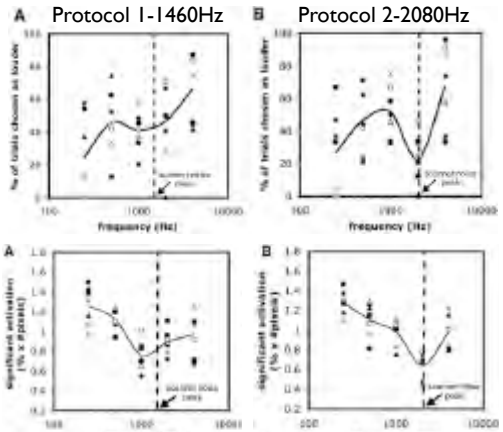




AUDITORY RESPONSE



Scarff et al, (2004) HBM, 22, 341-349



Scanner noise impairs frequency specific auditory discrimination.

AUDITORY RESPONSE

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

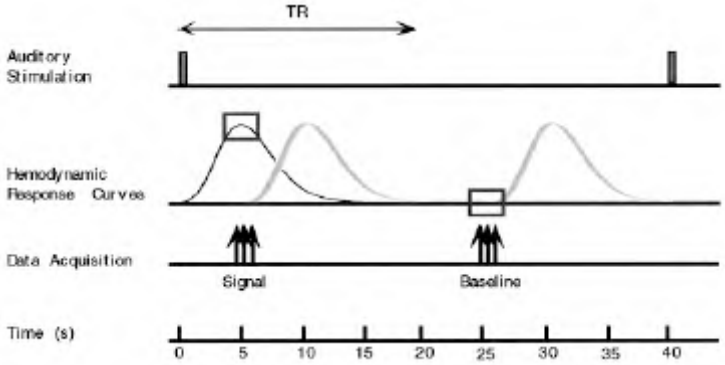
Active Attenuation
(active noise cancellation e.g., Chambers et al, 2001)
- 12 dB reduction (but noise travels through body)

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

SPARSE SAMPLING as a SOLUTION?

Hall et al., (1999) HBM, 7, 213-233

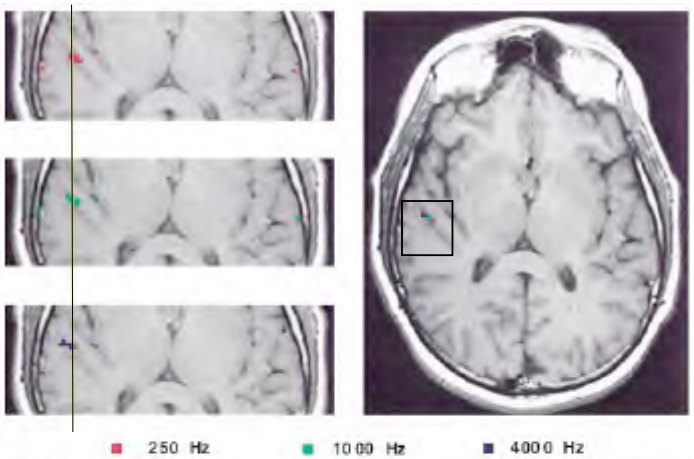
Yang et al., (2000) MR in Medicine, 43, 185-190
TR > TA



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

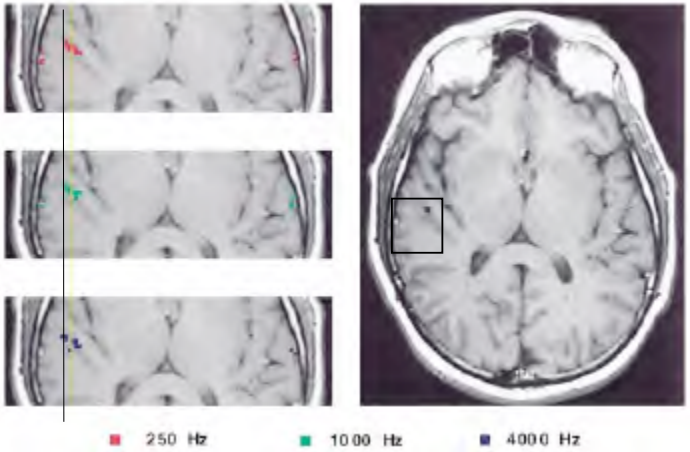
SILENT



COST: note fewer slices and time points acquired

SPARSE SAMPLING as a SOLUTION?

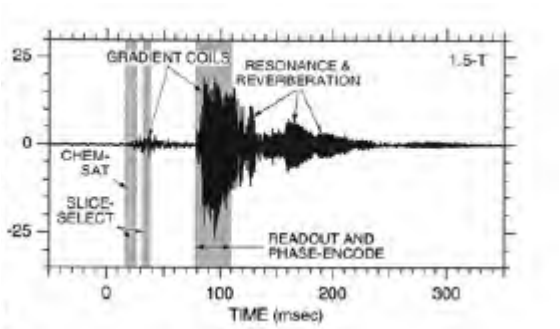
medial to lateral shift in Heschl's gyrus corresponding to a low-to-high frequency shift, specific for stimulated laterality - ABSENT!



TRADITIONAL

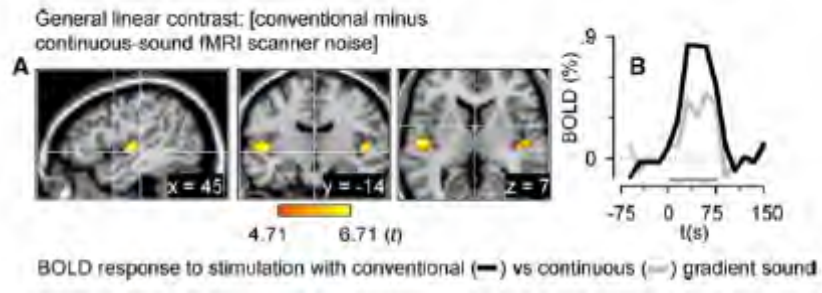
COST: note fewer slices and time points acquired

SPARSE SAMPLING as a SOLUTION?



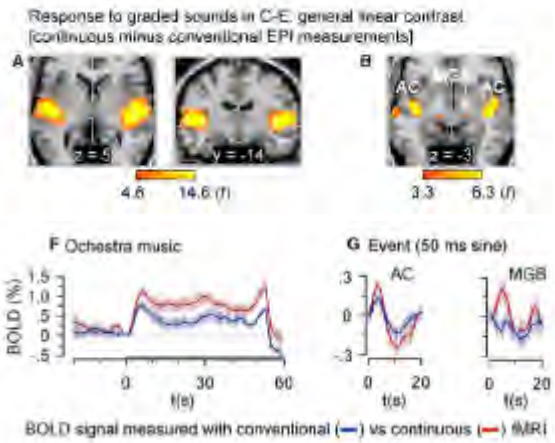
MOST OF NOISE IS FROM READOUT & PHASE-ENCODING STEPS. CAN WE MODIFY GRADIENT SEQUENCE TO ATTENUATE SOUND?

SPARSE SAMPLING as a SOLUTION?



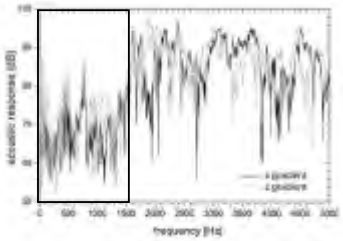
Seifriz et al., (2006) NeuroImage, 29, 1013-1022
- modified readout gradients to follow a quasi-continuous pattern, which produced a sound frequency that appeared as continuous sound (rather than pulsed)

SPARSE SAMPLING as a SOLUTION?



Seifriz et al., (2006) NeuroImage, 29, 1013-1022
- modified readout gradients to follow a quasi-continuous pattern, which produced a sound frequency that appeared as continuous sound (rather than pulsed)

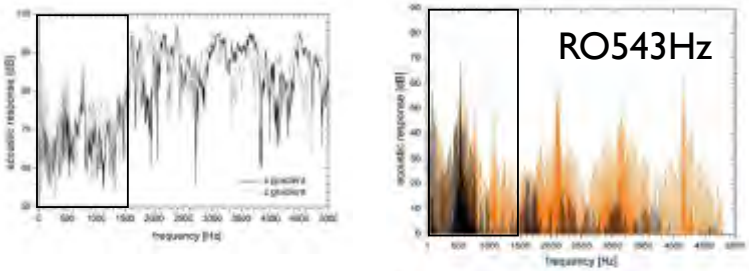
SPARSE SAMPLING as a SOLUTION?



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

SPARSE SAMPLING as a SOLUTION?



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

SPARSE SAMPLING as a SOLUTION?

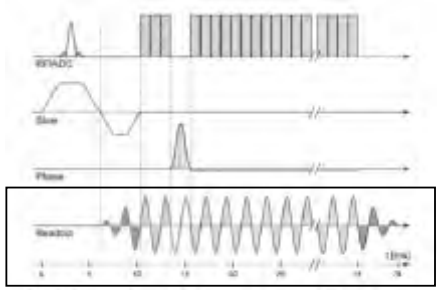
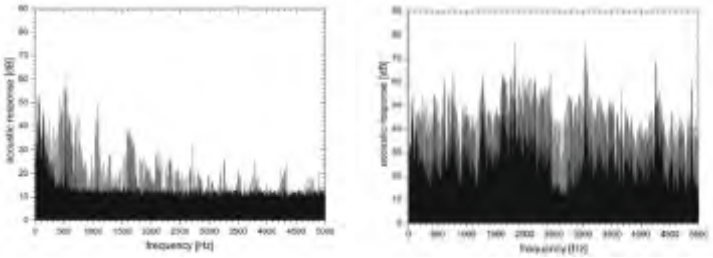


Fig. 1 Timing scheme of the low-noise sequence. Three areas are indicated: *dark gray* RO dephaser, *shaded* phase correction scans, *light gray* EPI RO train. During the PE dephaser switching, the oscillating RO gradient switching is maintained

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

SPARSE SAMPLING as a SOLUTION?



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

SPARSE SAMPLING as a SOLUTION?

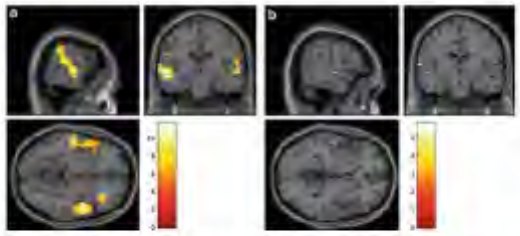


Fig. 8 Axial statistical maps ($t > 5.2$, $P_{corr} < 0.01$) of subject 5. The images were acquired with the low-noise sequence (a) and the standard manufacturer EPI sequence (b), respectively. Significant activation can be observed in the auditory cortices of both sides when the low-noise sequence is applied. The standard EPI sequence reveals only few voxels above the threshold with a lower peak t-value of 2.8 compared to a peak t-value of 11.7 acquired by the low-noise sequence. All images are displayed in neurological orientation

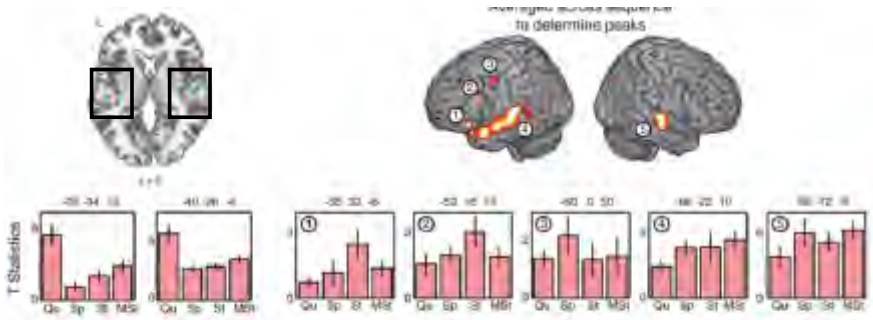
Schmitter et al., (2008) MRMP, 21, 317-325 *Silent echo-planar imaging for auditory fMRI.*

- 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

SPARSE SAMPLING as a SOLUTION?

aud noise > baseline

sentences > aud noise



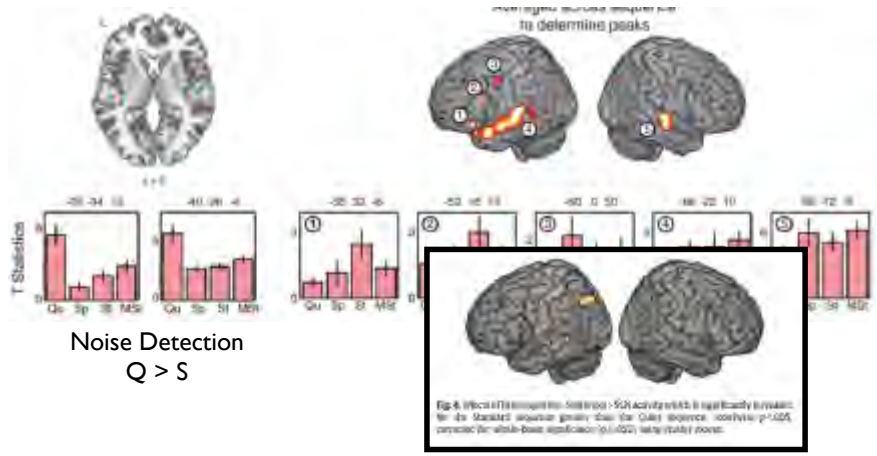
Noise Detection
Q > S

Sentences > Noise
Q = S and Q < S

*dropout in iTL

Peele et al., (2010) Neuroimage, 52, 1410-1419

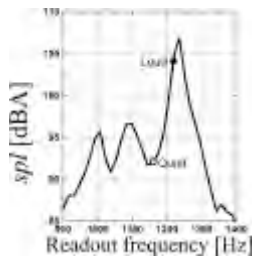
SPARSE SAMPLING as a SOLUTION?



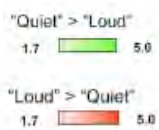
Noise Detection
Q > S

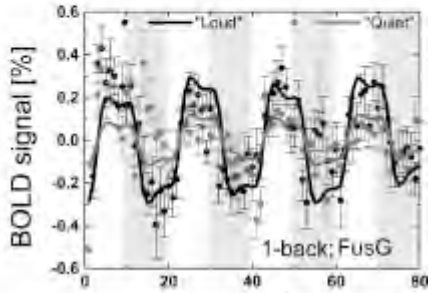
Peele et al., (2010) Neuroimage, 52, 1410-1419

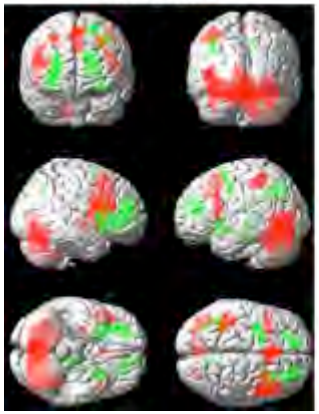
PSYCHOLOGICAL EFFECTS of NOISE



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

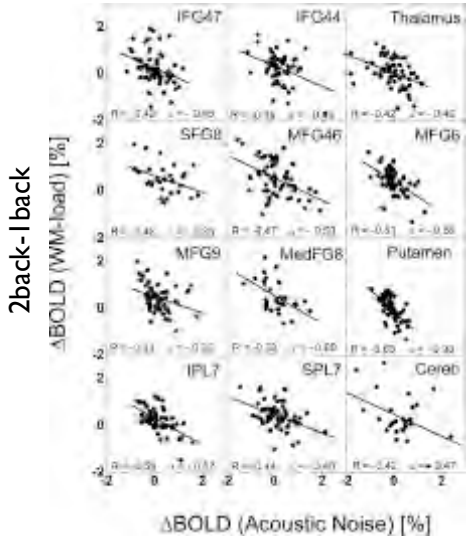




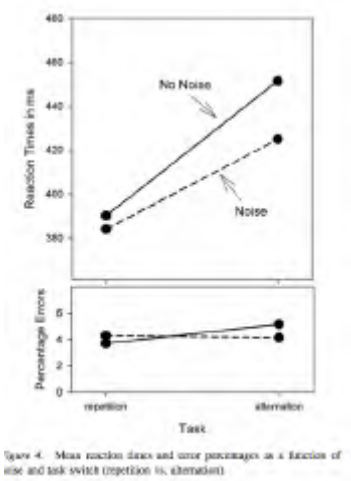


PSYCHOLOGICAL EFFECTS of NOISE

Scanner noise increases cognitive working load & simultaneously decreases amount of activation change.



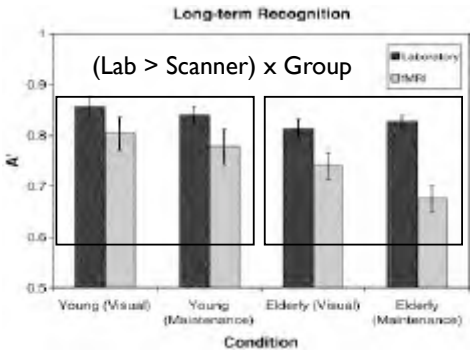
PSYCHOLOGICAL EFFECTS of NOISE?

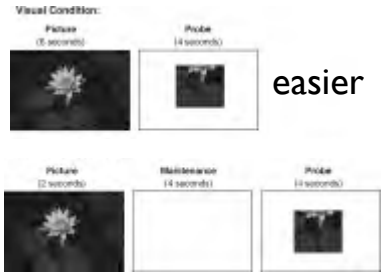


Hommel et al, 2012, JEP:HPP, 38(2), 290-301

PSYCHOLOGICAL EFFECTS of NOISE?

Gutchess & Park, 2006, Br Res, 133-140





easier

harder

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)

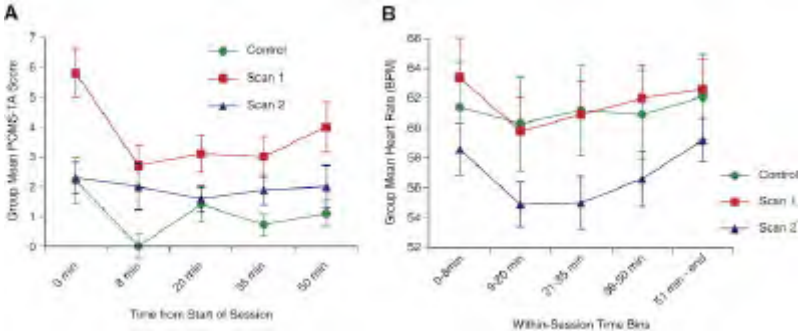
- sensory deprivation (you can't see the experimenter, you can't be heard during the scan)

- 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

Chapman et al, 2010, Psych Res: Neuroimaging

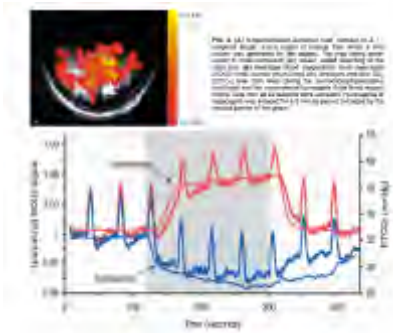


Earlier and first scans will produce a different experience than later scans.

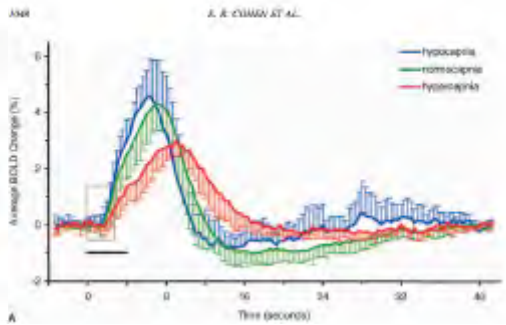
HYPOCAPNIA

- anxiety can be associated with hypocapnia (decreases CO2/hyperventilation)

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



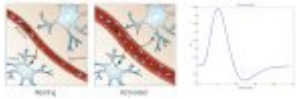
CBF



BOLD change to Visual Stimulus

NON-SPECIFIC PSYCHOLOGICAL EFFECTS

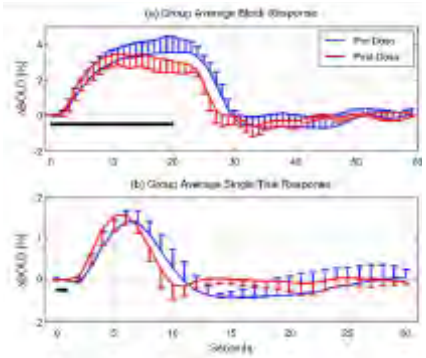
Oxygen
Acetazolamide
Caffeine
Alcohol
Cocaine
Adrenaline
Anesthetic Agents



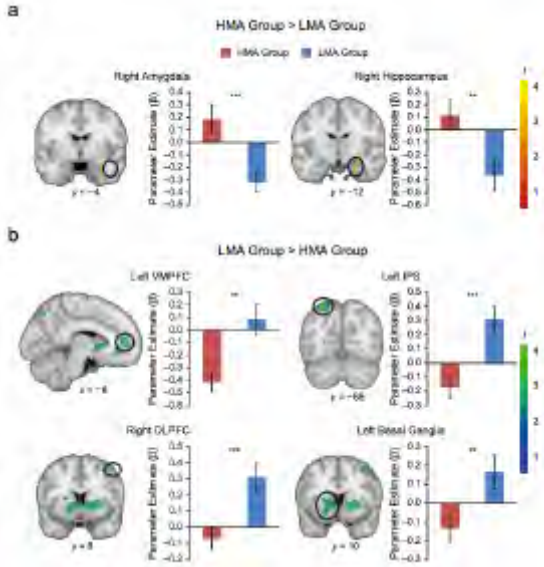
(CBF differs by region)

NON-SPECIFIC PSYCHOLOGICAL EFFECTS

Oxygen
Acetazolamide
Caffeine
Alcohol
Cocaine
Adrenaline
Anesthetic Agents



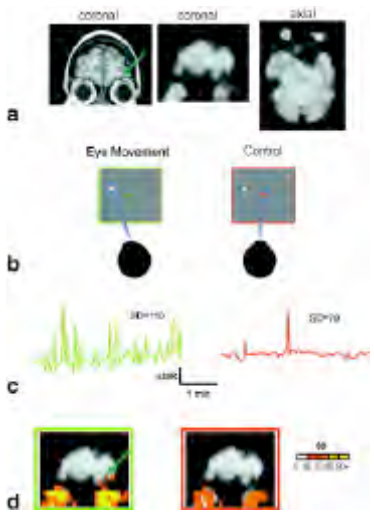
NETWORK MODIFICATION



Young et al (2012) Psy Sci

Other Unusual Sources of Variability: Eyes

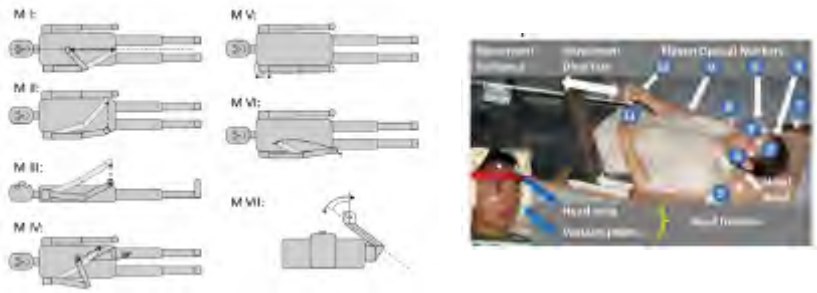
Eye movements can lead to signal variability in surrounding signal producing false positive activations in frontal orbital regions.



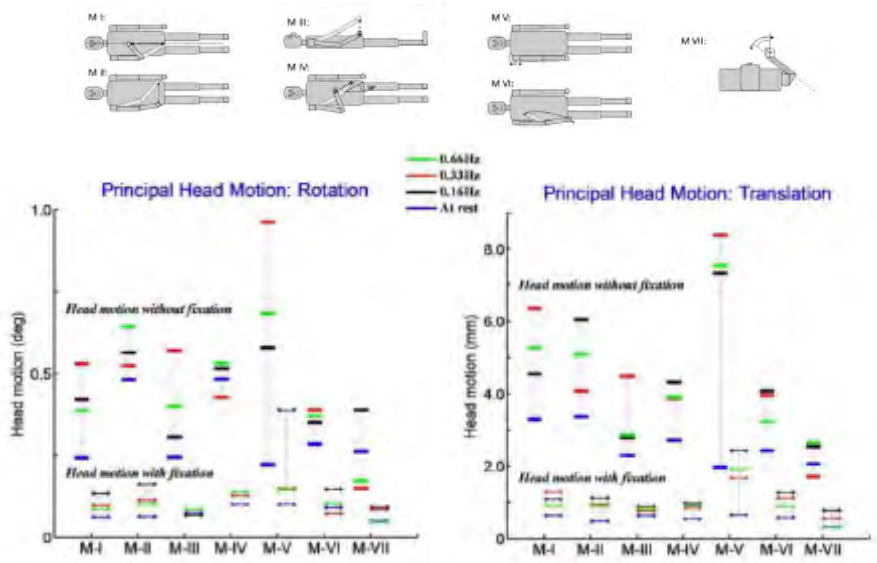
Beauchamp, 2003

Other Unusual Sources of Variability: Body

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

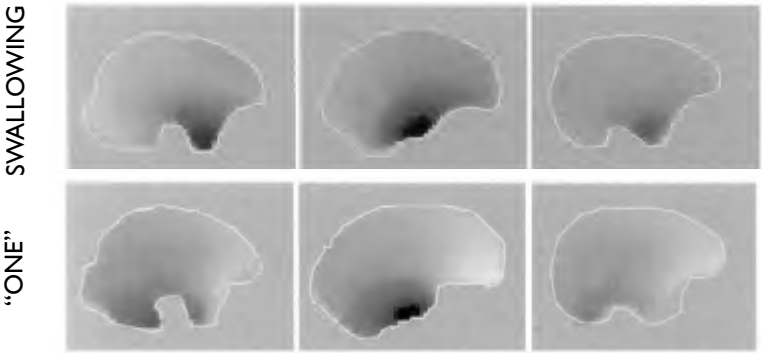


Other Unusual Sources of Variability: Body



Other Unusual Sources of Variability: Mouth

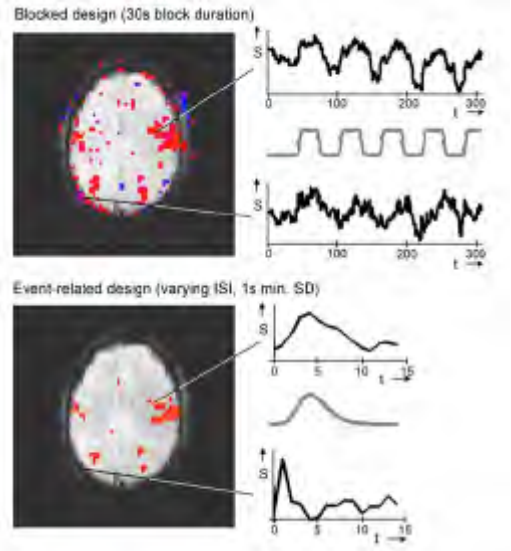
Verbal responses can also introduce motion artefacts through: movement of jaw, tongue, swallowing, opening of air cavity, air pressure changes with vocalization



Birn et. al., 1998

Other Unusual Sources of Variability: Mouth

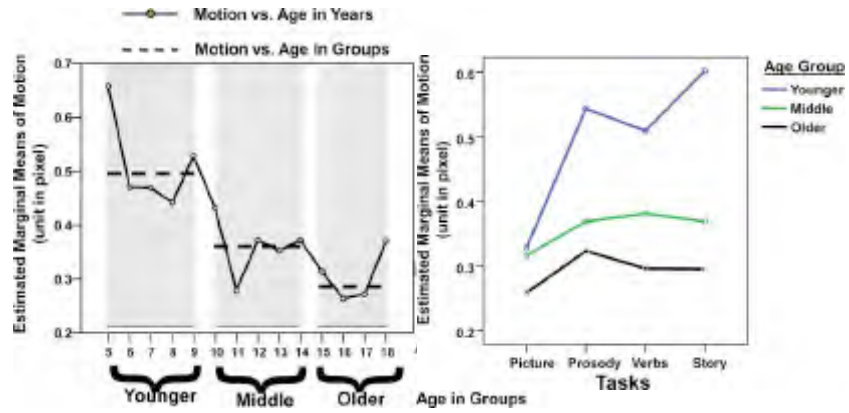
Partial Solution: Artefact and HRF have different time courses and so can be dissociated by using an event related design & separating artefact TRs from task.



Birn et. al., 2004

Why care about noise due to motion?

- special populations (children, elderly, neuropsychiatric patients)



Yuan et al. (2009) HBM 30:1481-1489

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)