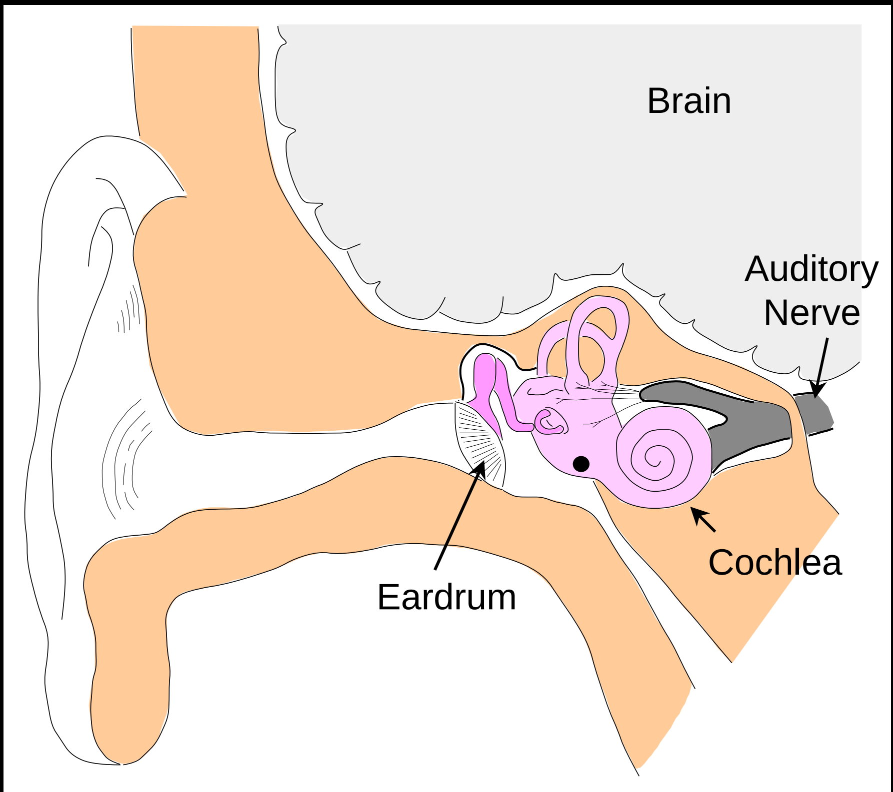
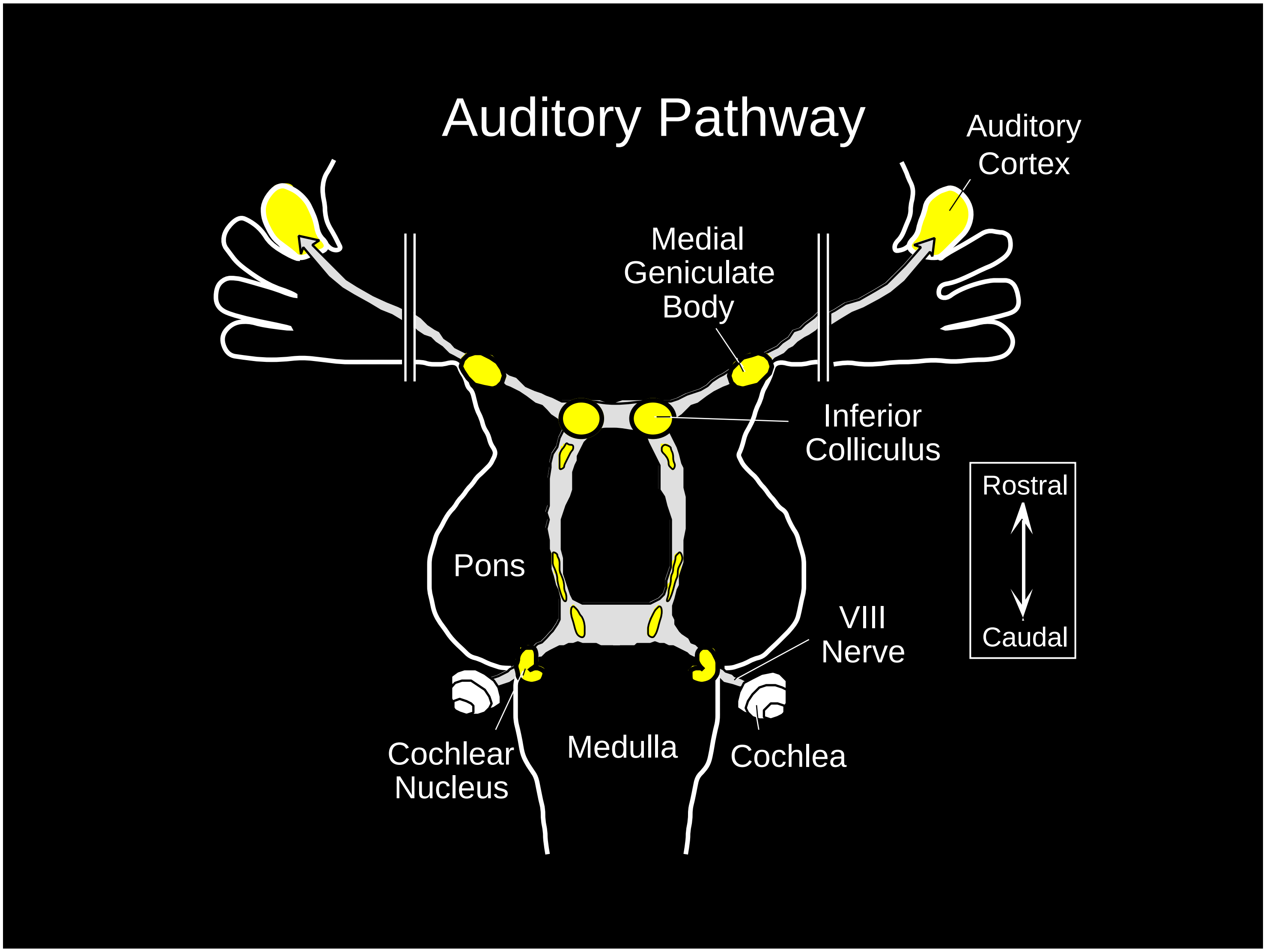
Improving fMRI signal detection using physiological data

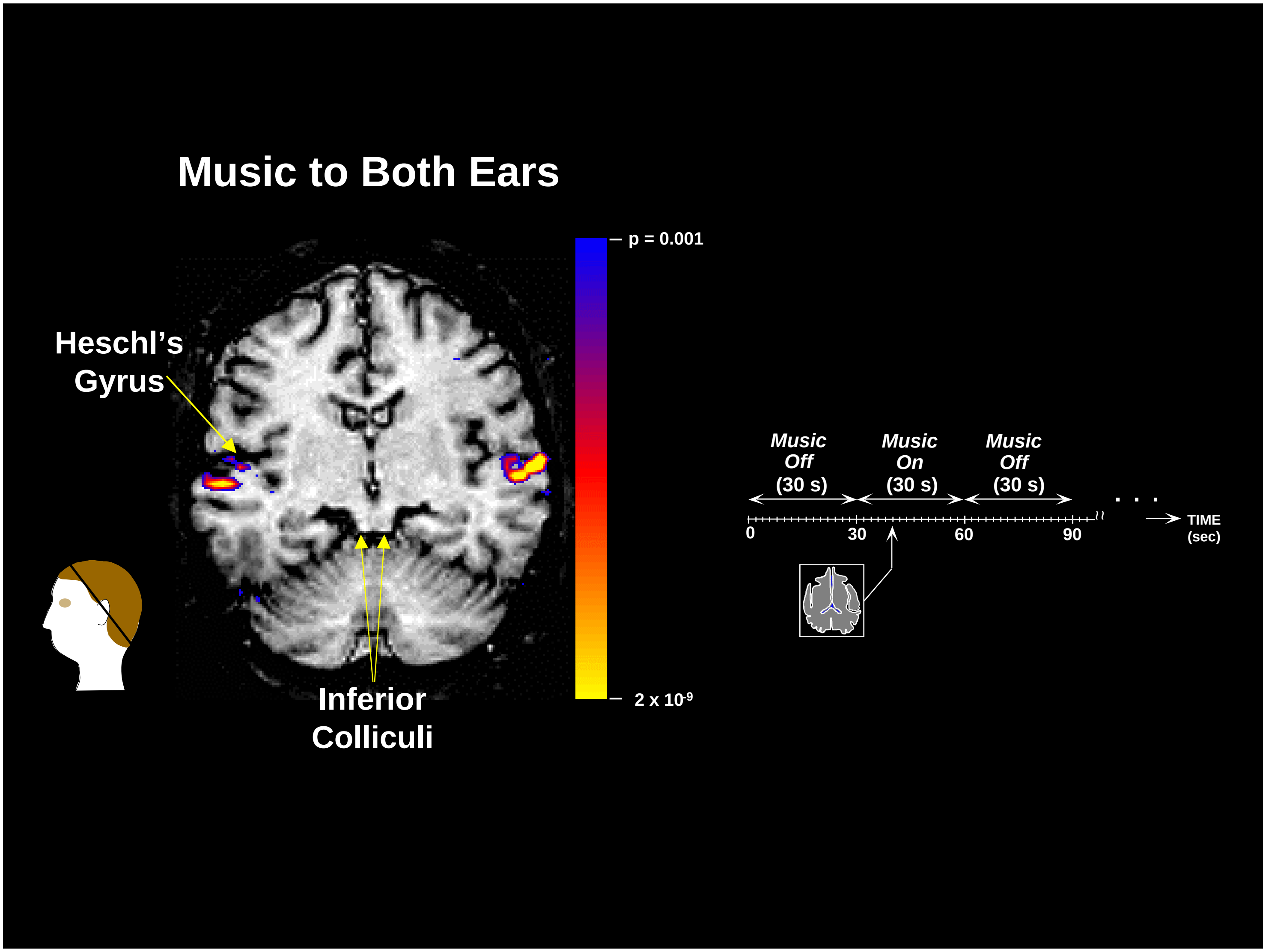
- **Cardiac gating** - to improve the detection of brainstem activation

- **Clustered volume acquisition** - to reduce the impact of scanner acoustic noise during fMRI

The Peripheral Auditory System

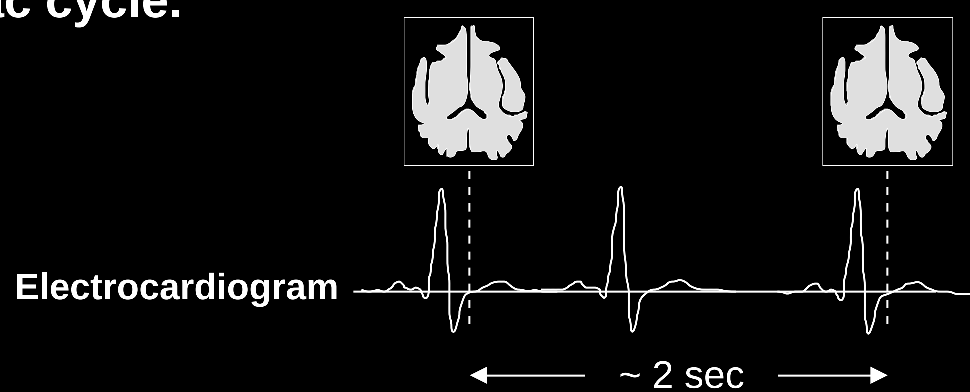



Auditory Pathway
Auditory Cortex
Medial Geniculate Body
Inferior Colliculus
Rostral
Caudal
Pons
VIII Nerve
Cochlear Nucleus
Medulla
Cochlea

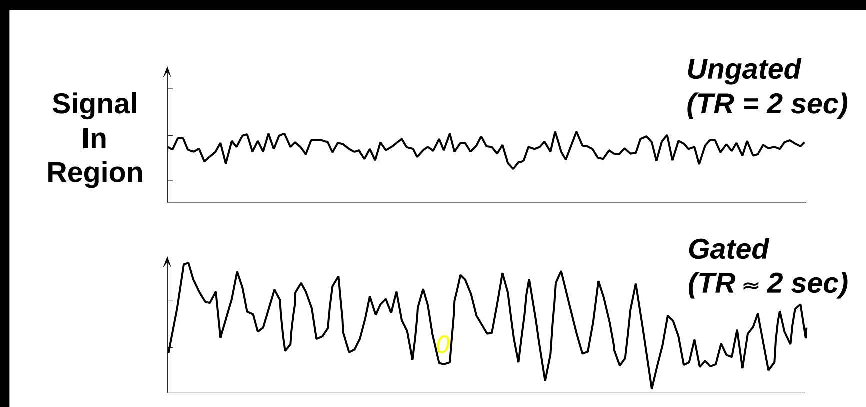

Music to Both Ears
Heschl's Gyrus
Inferior Colliculi
p = 0.001
2 x 10-9
Music Off (30 s)
Music On (30 s)
Music Off (30 s)
0
30
60
90
TIME (sec)

Cardiac Gating

- **Synchronize image acquisitions to the subject's cardiac cycle.**

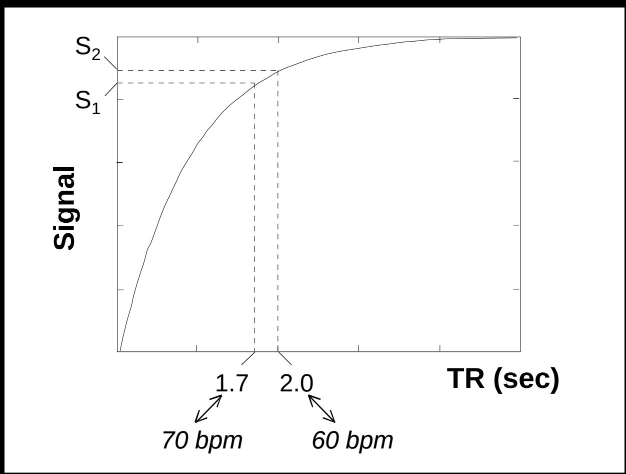


- Cardiac gating introduces signal variations.



Where do the signal variations come from?

- Signal ~ 1 - exp(-TR/T1)
- With gating, TR is not constant because heart rate fluctuates.
- The variations in TR cause image-to-image variations in signal.
- The signal variations are comparable to (or greater than) the changes associated with activation.



Example:

heart rate = 60 - 70 bpm

S_1 = signal at 70 bpm

S_2 = signal at 60 bpm

$$\text{Percent Change} = \frac{S_2 - S_1}{S_1} \times 100 = 5\%$$

How can gating-related signal variations be removed?

- Model the signal variations

For any given voxel,

$$S_n = A_n\,[1 - \exp(-TR_n/T1)] \qquad (1)$$

S_n is the signal in the nth image.
TR_n is the inter-image interval (measured during experiment).
A_n includes signal changes associated with activation.

- Consider a correction that removes these variations.

$$\text{Corrected } S_n = S_n \frac{[1 - \exp(-TR_{av}/T1)]}{[1 - \exp(-TR_n/T1)]} \qquad (2)$$

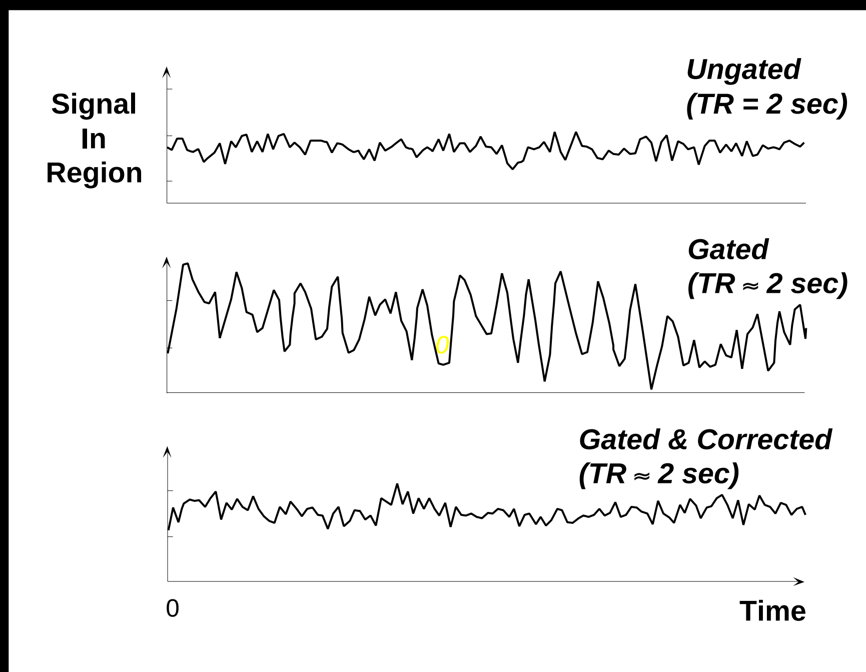
TR_{av} = the average inter-image interval during the experiment
T1 is chosen to minimize variations in the corrected signal.

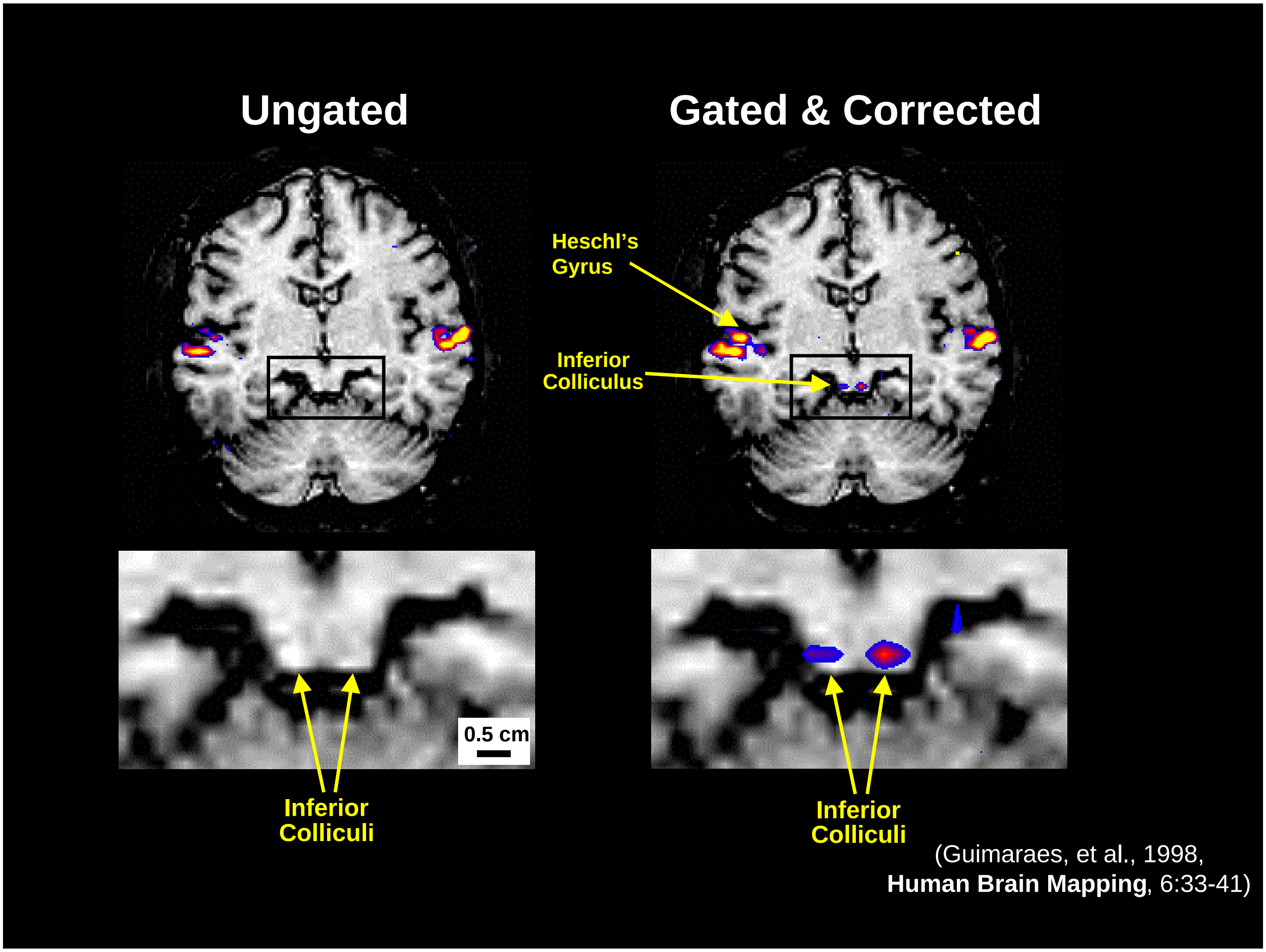
- Correct the signal based on the model (use eq. (2)).

The correction effectively removes any signal variations explained by the model.

- Cardiac gating introduces signal variations.

- However, these can be removed.




Ungated
Gated & Corrected
Heschl's Gyrus
Inferior Colliculus
0.5 cm
Inferior Colliculi
Inferior Colliculi
(Guimaraes, et al., 1998,
Human Brain Mapping, 6:33-41)

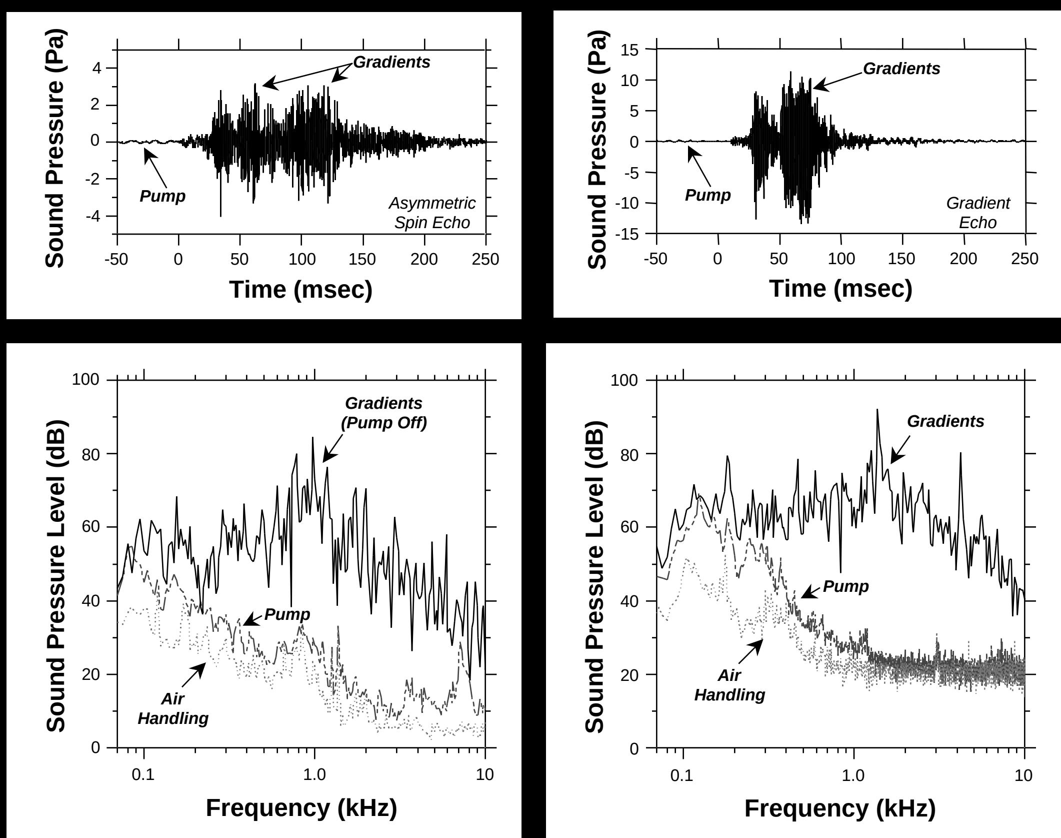
Acoustic Noise During fMRI:

- pump noise - produced by the liquid helium pump

- gradient noise - produced by the gradient coils each time an image is acquired

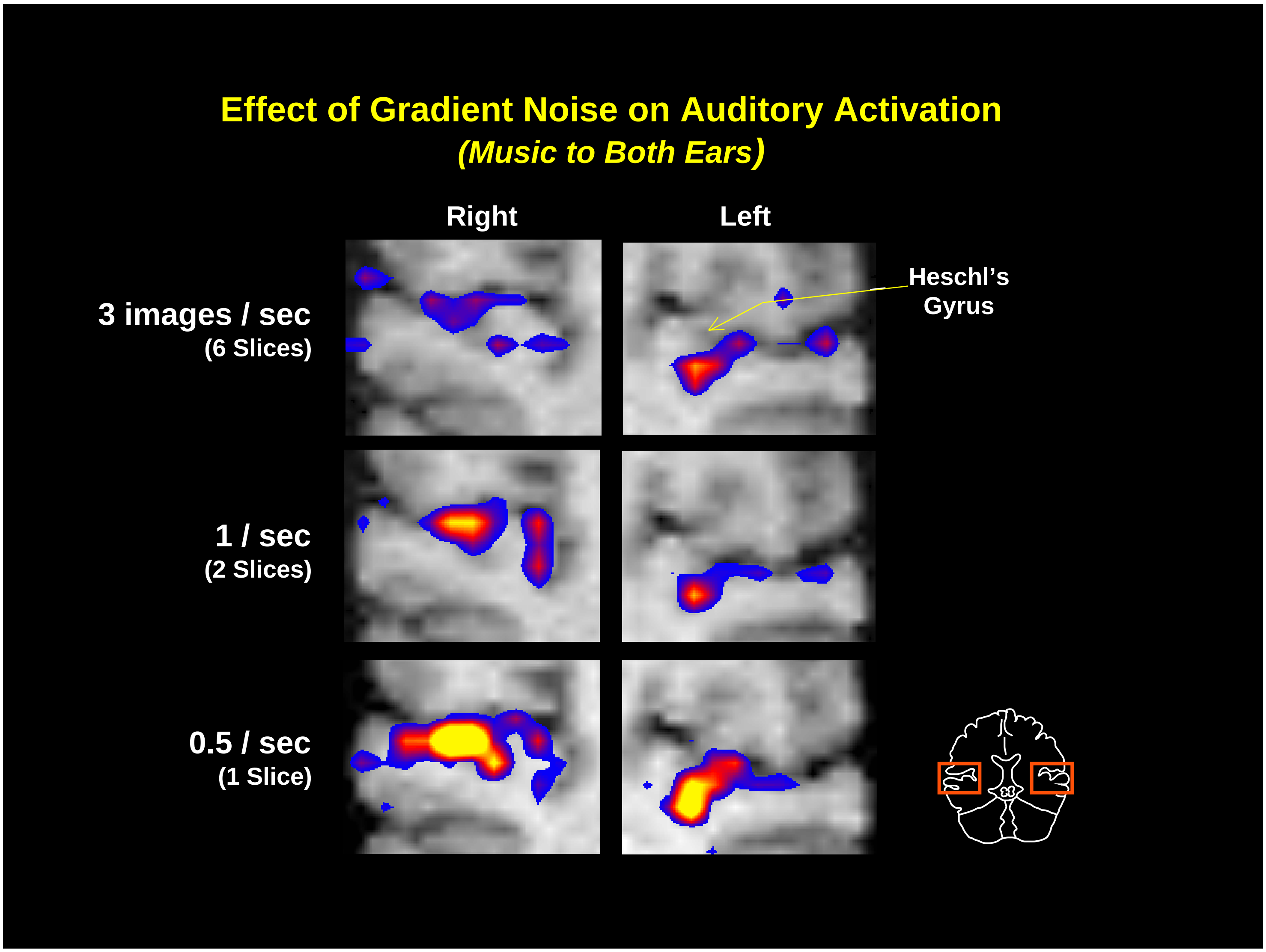
Acoustic Noise

1.5 T **3 T**

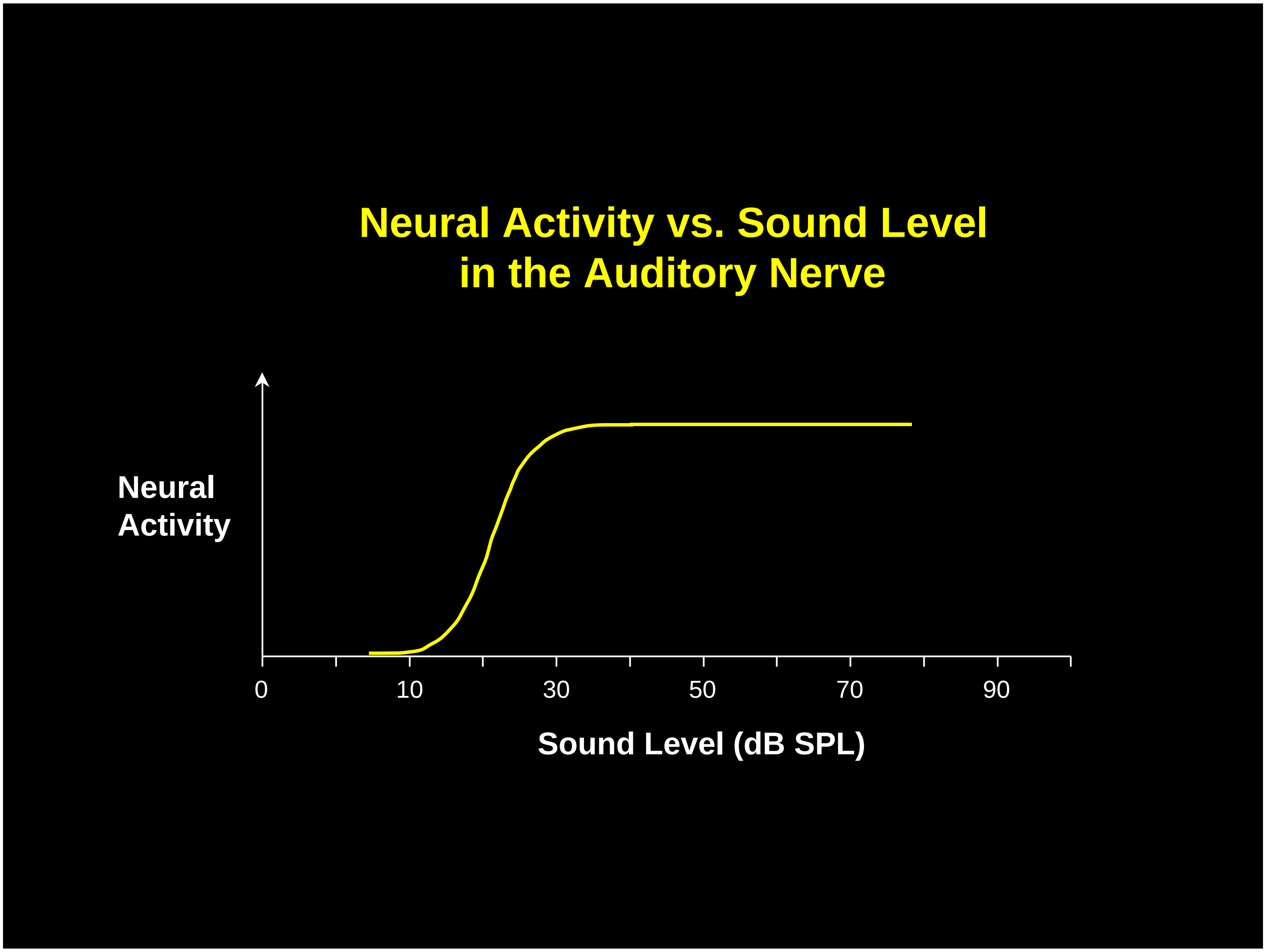


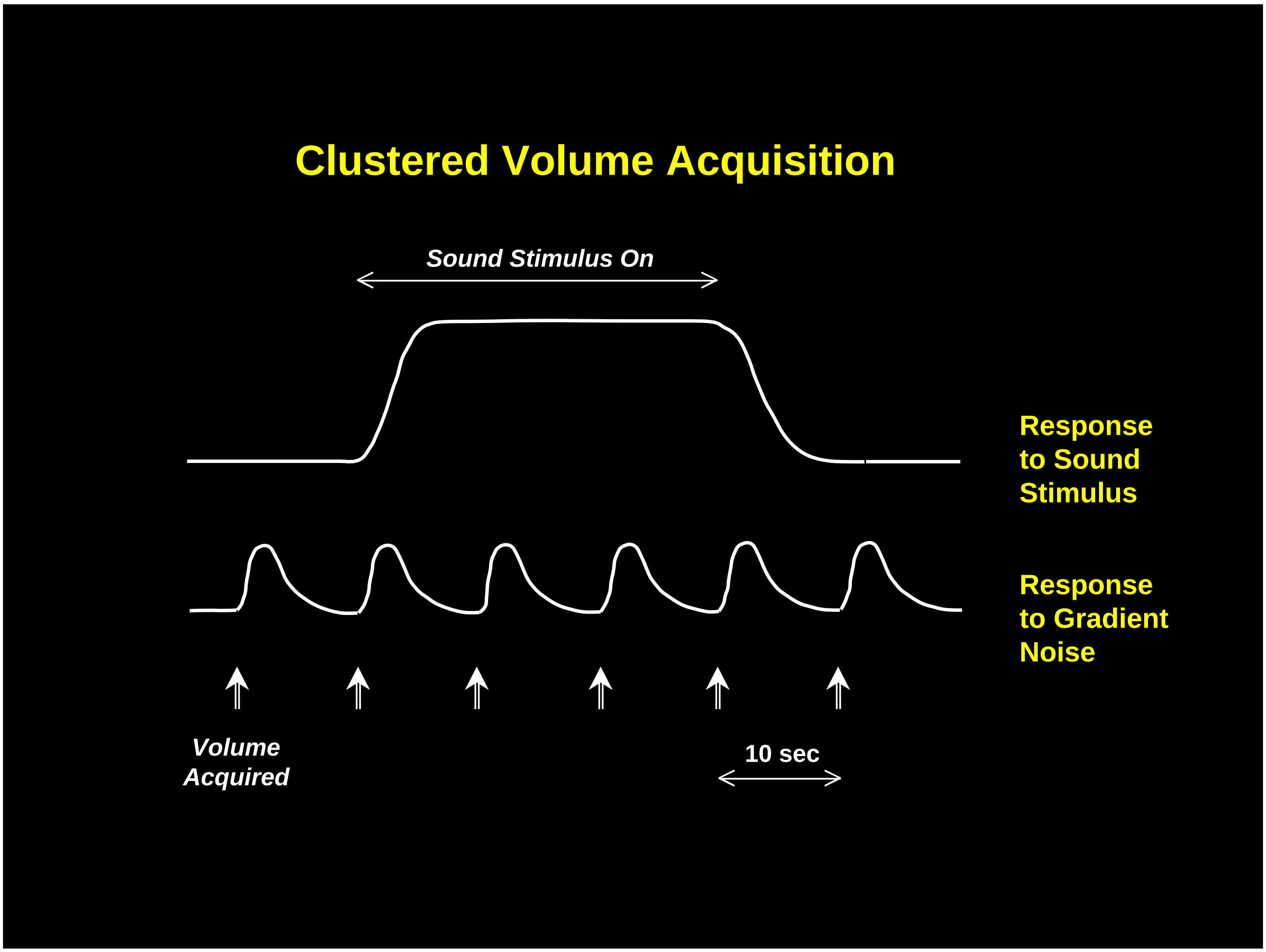
Problems Posed by Acoustic Noise:

- Difficulties hearing sound stimuli
- Acoustic conditions differ from most auditory studies
- Suppression of fMRI activation in auditory areas



Effect of Gradient Noise on Auditory Activation
(Music to Both Ears)
Right
Left
Heschl's
Gyrus
3 images / sec
(6 Slices)
1 / sec
(2 Slices)
0.5 / sec
(1 Slice)

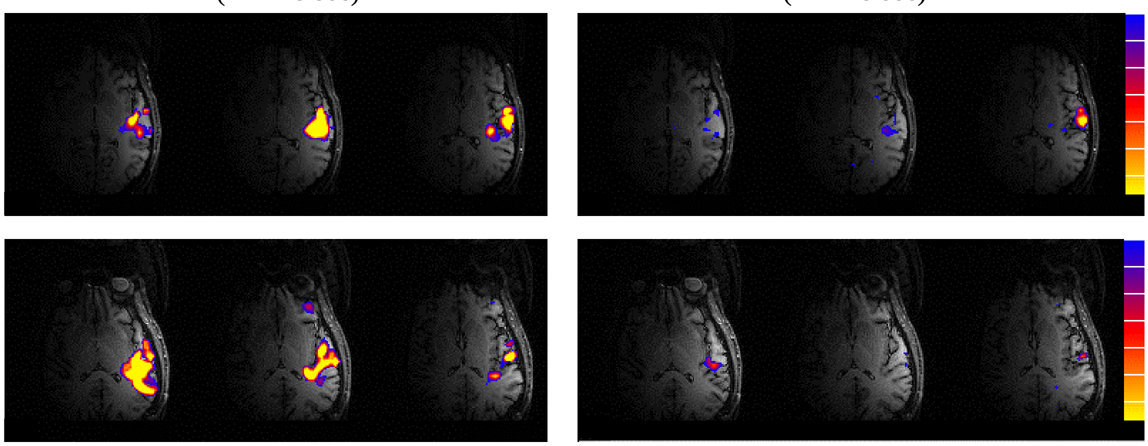

Neural Activity vs. Sound Level
in the Auditory Nerve
Neural
Activity
0
10
30
50
70
90
Sound Level (dB SPL)


Clustered Volume Acquisition
Sound Stimulus On
Response to Sound Stimulus
Response to Gradient Noise
Volume Acquired
10 sec

Clustered Volume Acquisition (TR = 8 sec) | Distributed Volume Acquisition (TR = 8 sec)

Subject 1

Subject 2



Apapted from Edmister et al.
Human Brain Mapping 7: 89-97 (1999)