Multisensory Integration and Visual Perception in the Human Brain Studied with Electrocorticography, fMRI and TMS

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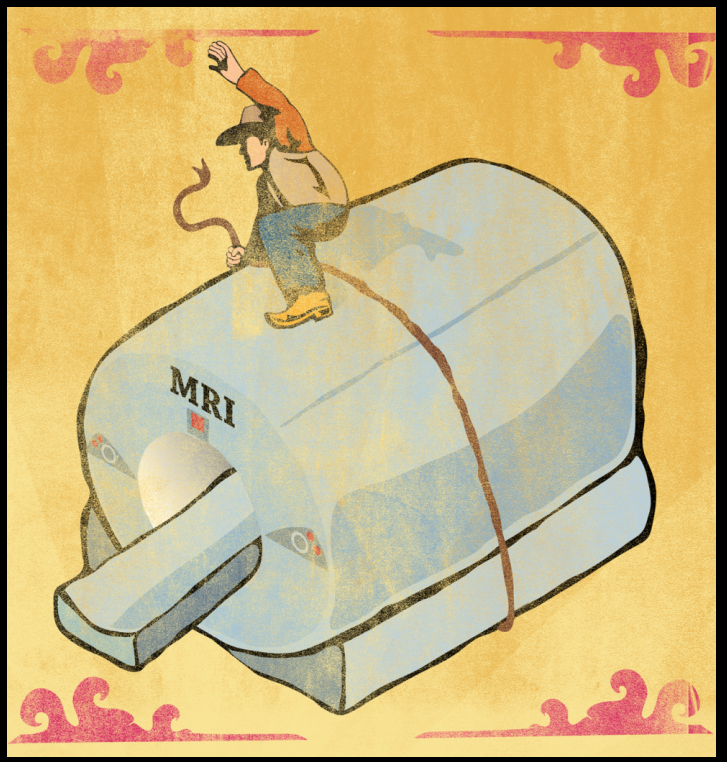

中国科学院心理研究所
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UTHealth
The University of Texas
Health Science Center at Houston

Thursday, June 14th

Overview
http://openwetware.org/wiki/Beauchamp

1) The STS, a hub for biological motion and multisensory integration

Beauchamp, et al., Neuron (2002); Beauchamp, et al., Journal of Cognitive Neuroscience (2003); Beauchamp, et al., Neuron (2004); Beauchamp, et al., Nature Neuroscience (2004)

2) Temporary Disruption of the STS impairs multisensory integration

Beauchamp, et al., Journal of Neuroscience (2010)

3) Interindividual Differences in the STS account for differences in multisensory integration

Nath, Fava, and Beauchamp, Journal of Neuroscience (2011), Nath and Beauchamp, Neuroimage (2011)

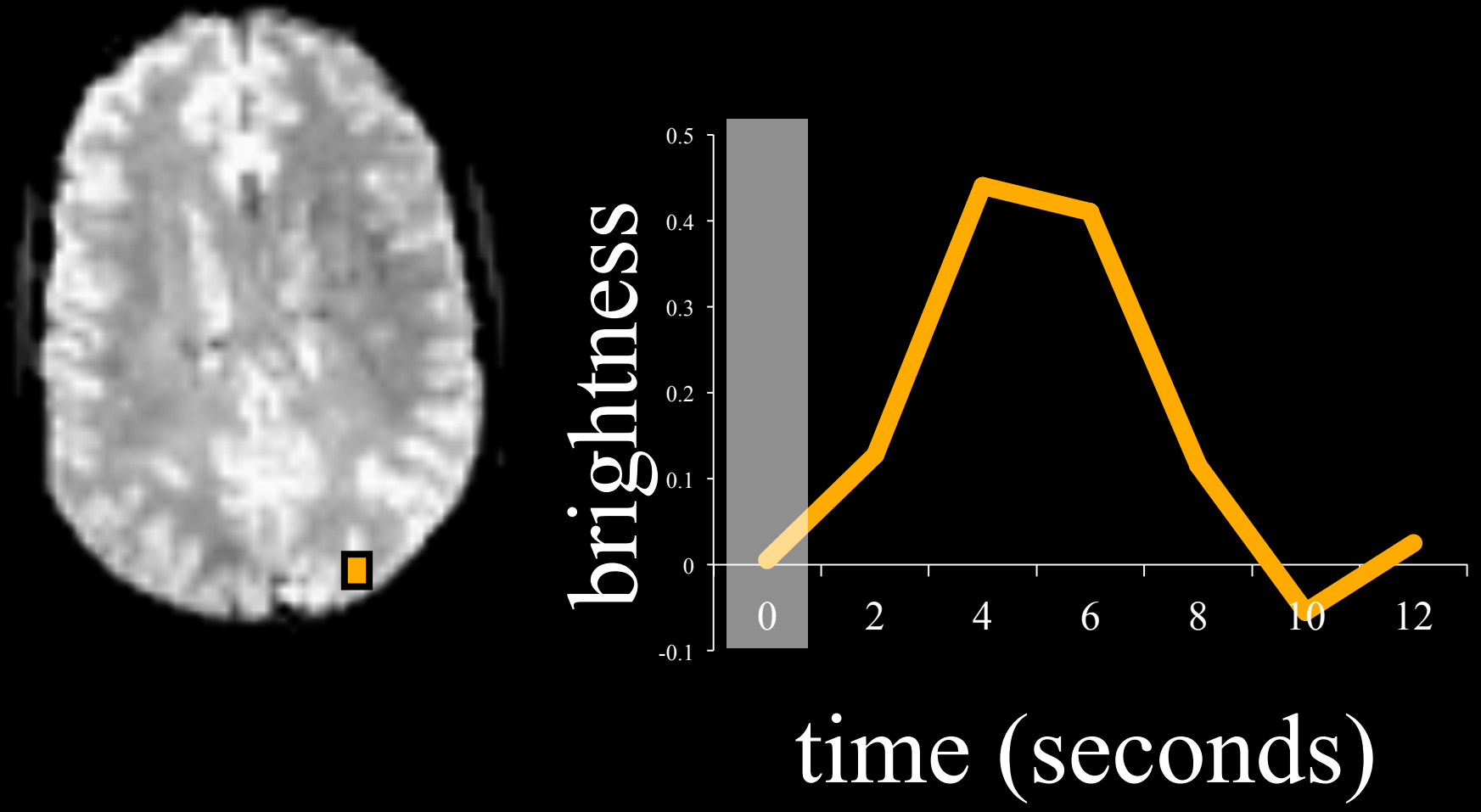
4) Neural mechanisms for Bayesian multisensory integration: STS connectivity

Nath and Beauchamp, Journal of Neuroscience (2011)

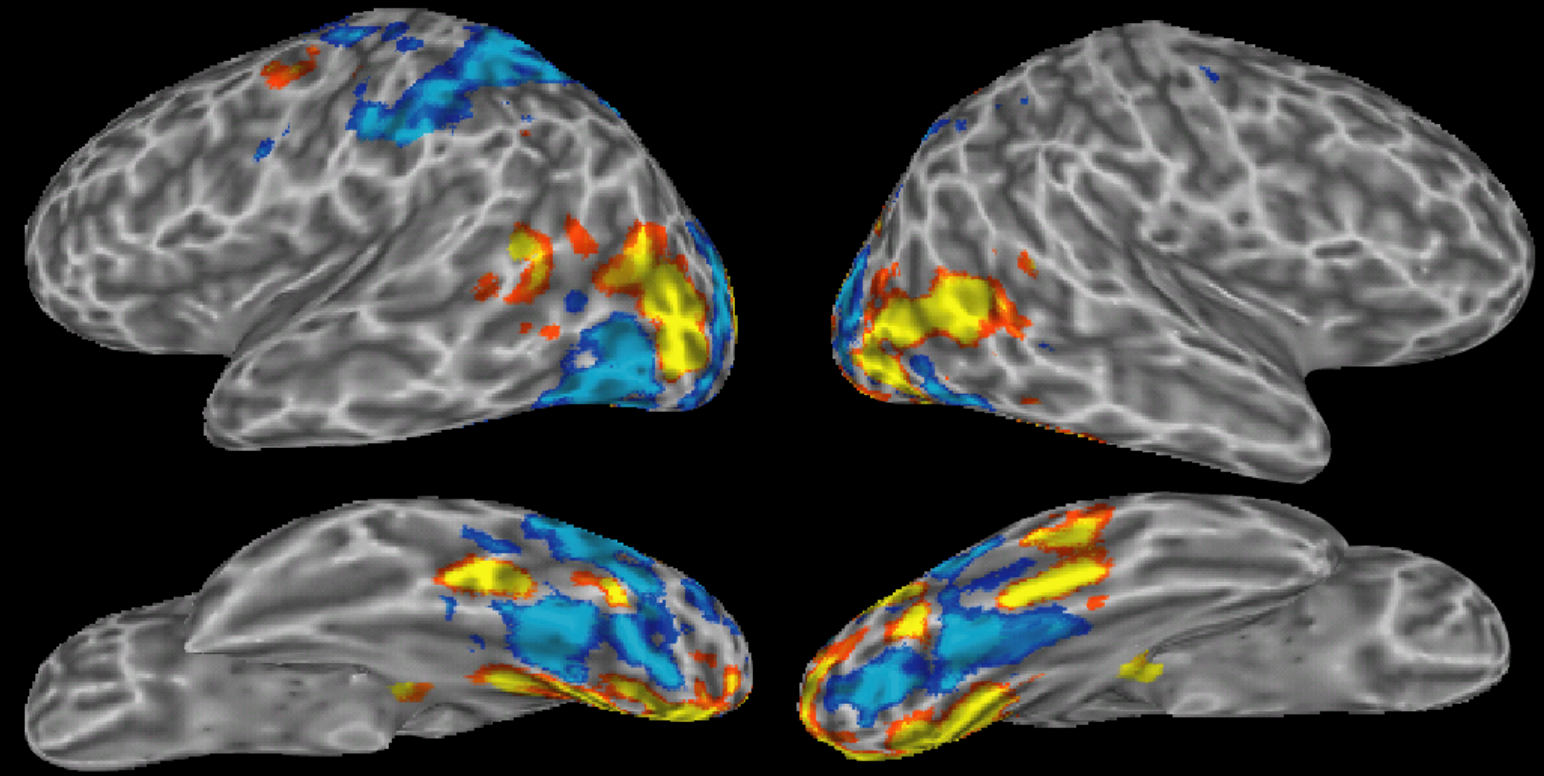
5) Conscious perception of visual stimuli in the temporo-parietal junction

Beauchamp, et al., Nature Neuroscience (2012)

Typical fMRI experiment



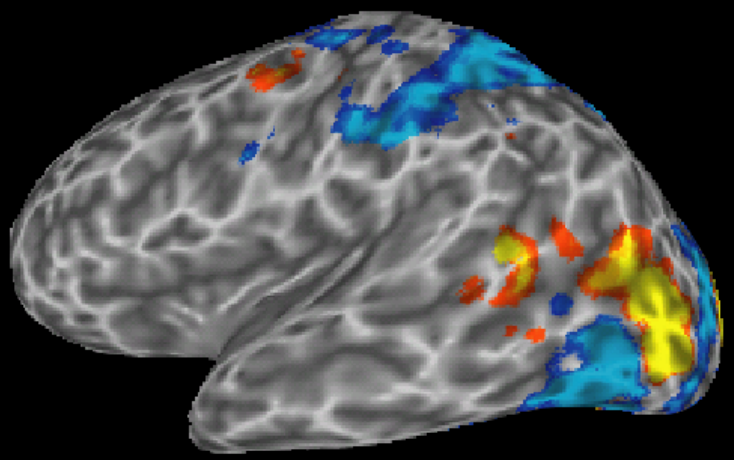
fMRI reveals large-scale brain networks

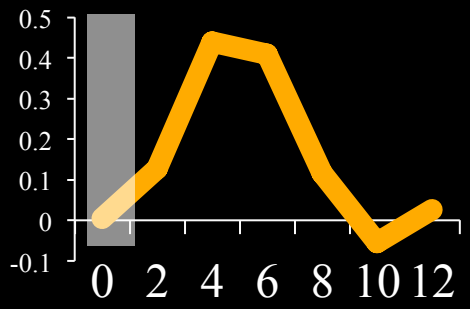


- Beauchamp, et al., Neuron (2002); Journal of Cognitive Neuroscience (2003)

General problems with fMRI

- What do the blobs mean?
  - Is activity in the area linked to behavior or perception?
  - Is activity in an area truly required for a cognitive function?
- Poor match between analysis (simple) and data (complex)
  - How do areas operate as a network?
- Slow temporal resolution
  - Neuronal responses are on a ~ms time scale, fMRI operates on a ~sec time scale





How we've tackled these problems

- What do the blobs mean?
  - Is activity in the area linked to behavior or perception?
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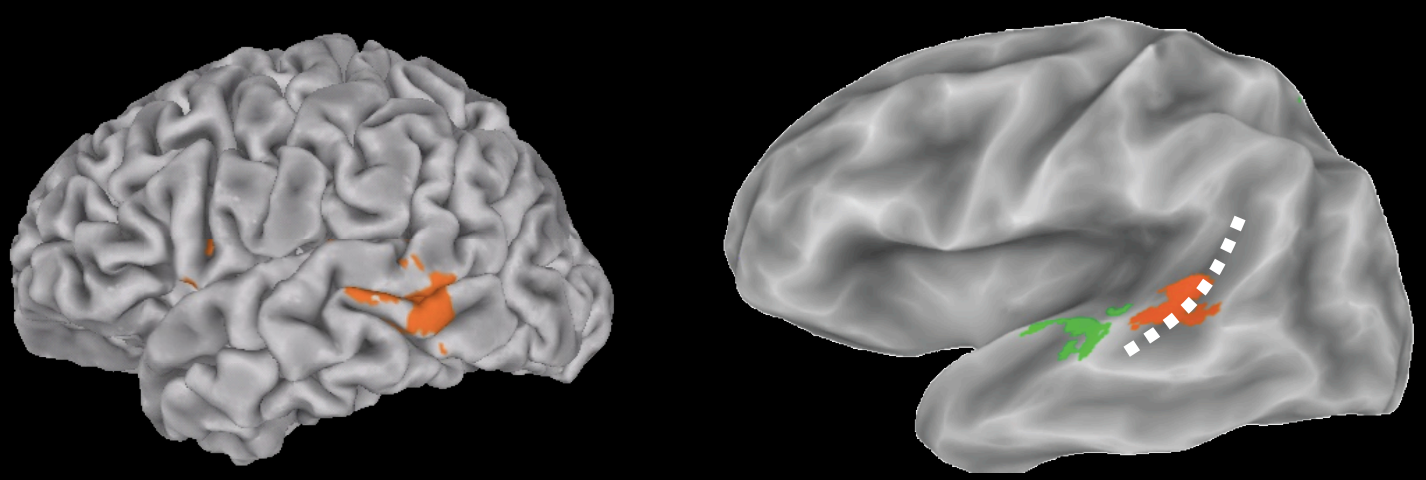
- Multisensory integration, esp. speech perception
- Temporary and permanent lesions of the STS
- Link between STS activity and perception of multisensory speech
- Connectivity of the STS during speech perception
- Electrocorticography with ms time resolution (TPJ)

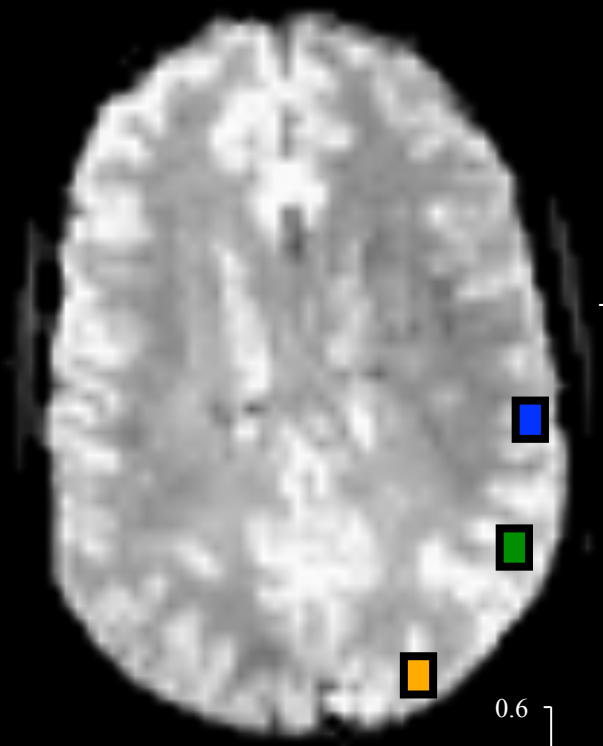
Superior Temporal Sulcus

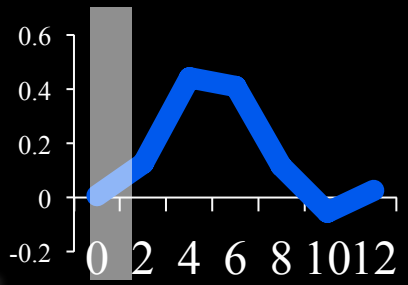
A brain hub for multisensory integration and biological motion perception

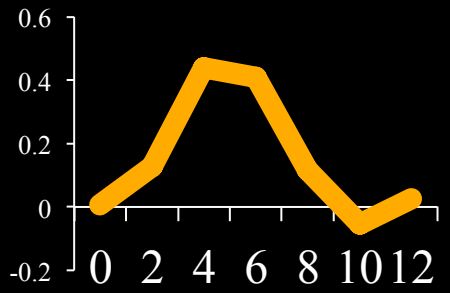


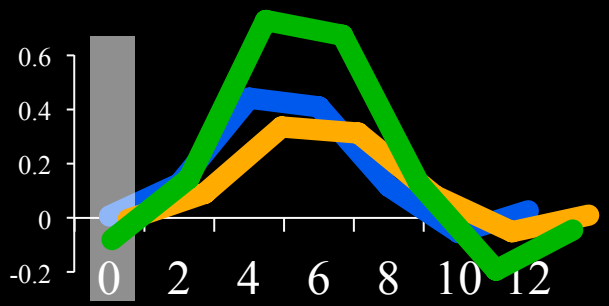
Beauchamp *et al*., *Neuron,* 2002; *Journal of Cognitive Neuroscience,* 2003, *Neuron,* 2004; *Nature Neuroscience,* 2004; *Neuroimage,* 2008; *Journal of Neuroscience,* 2010, *Journal of Neuroscience,* 2011a; *Neuroimage,* 2011, *Journal of Neuroscience,* 2011b

Multisensory fMRI experiment

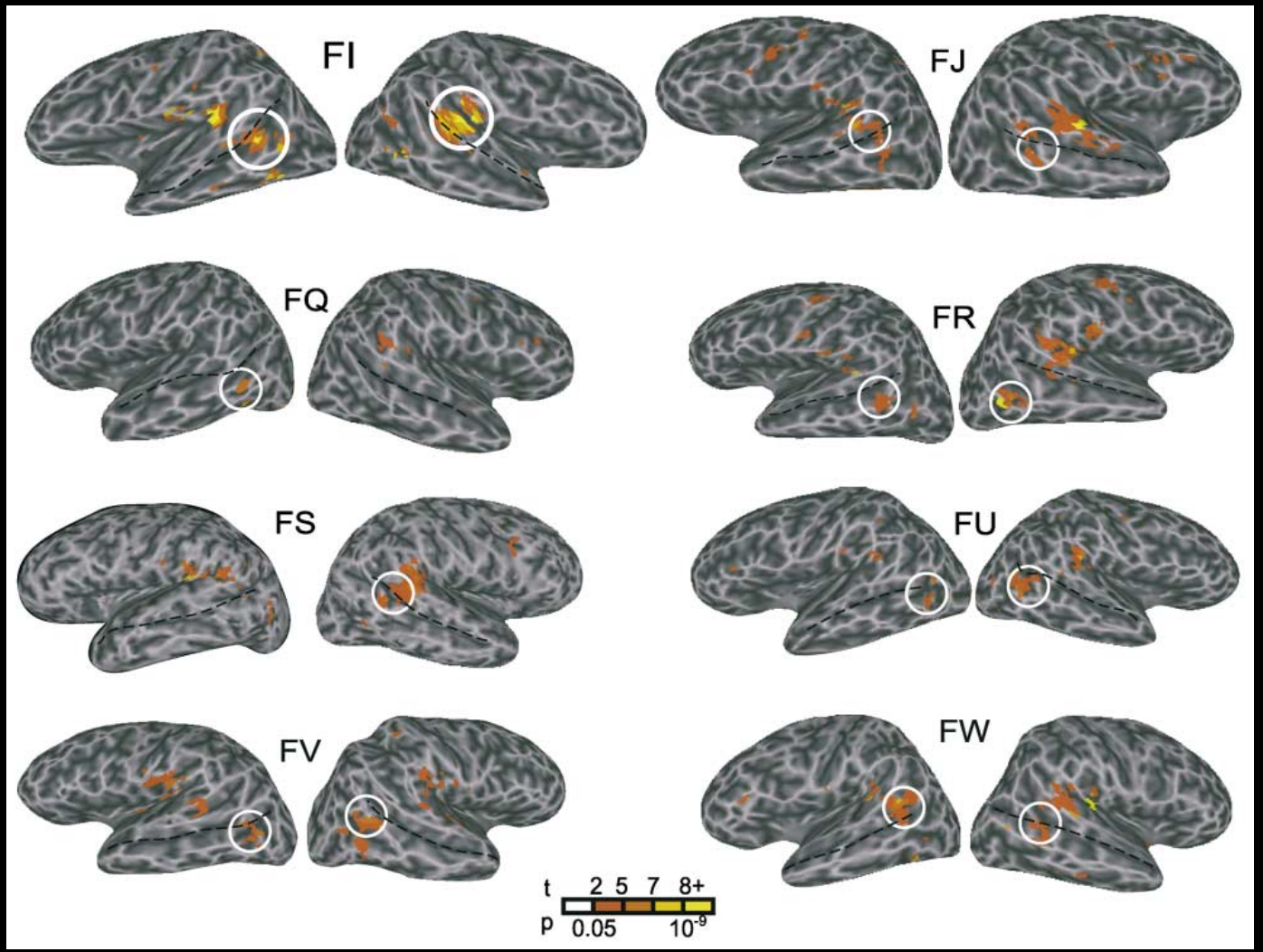




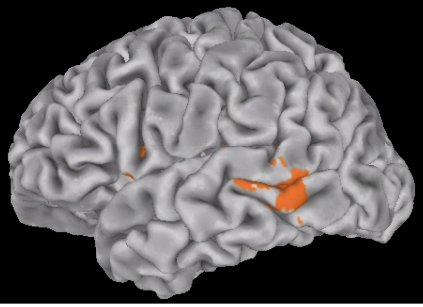


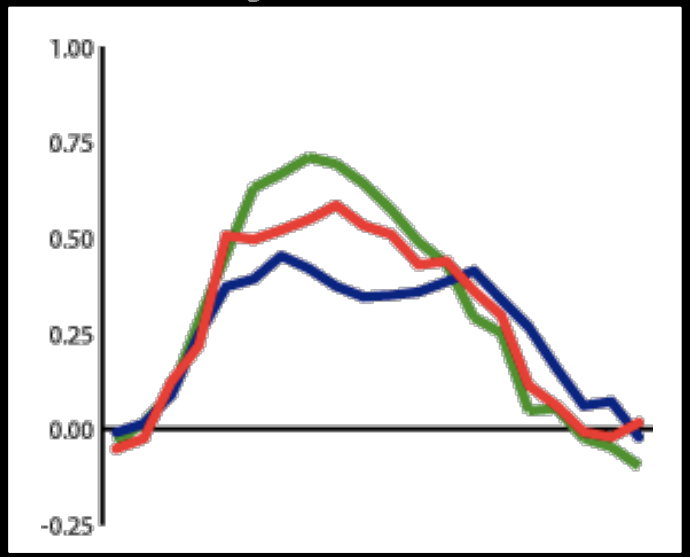


Multisensory enhancement across subjects

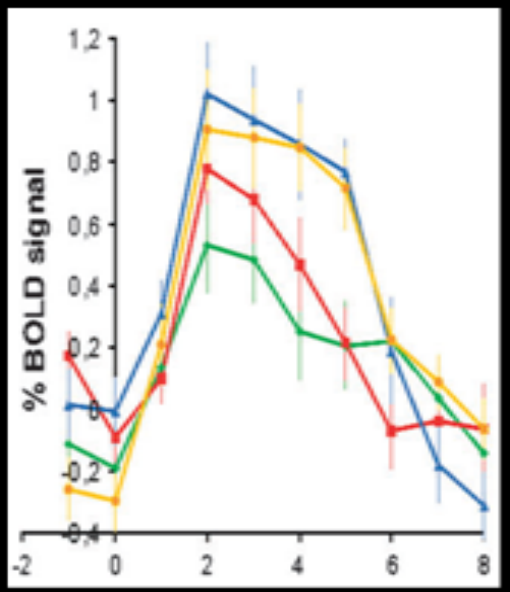


fMRI of multisensory integration in the STS

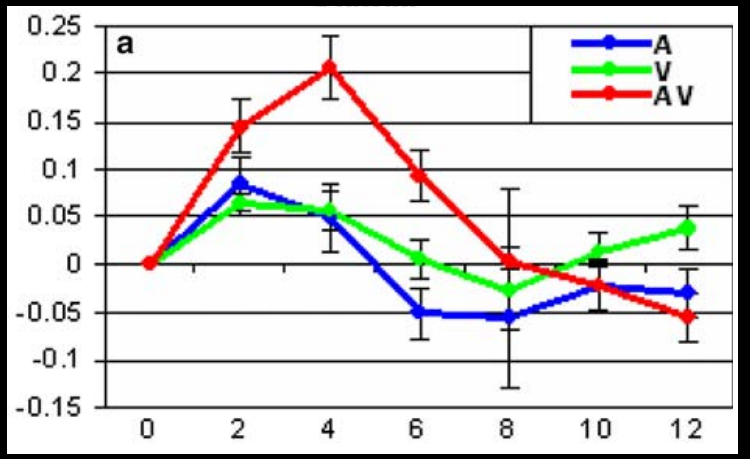




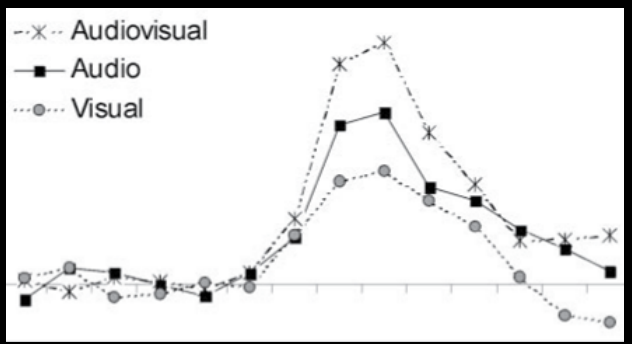
Beauchamp et al., *Neuron,* 2004



van Atteveldt et al., 2007

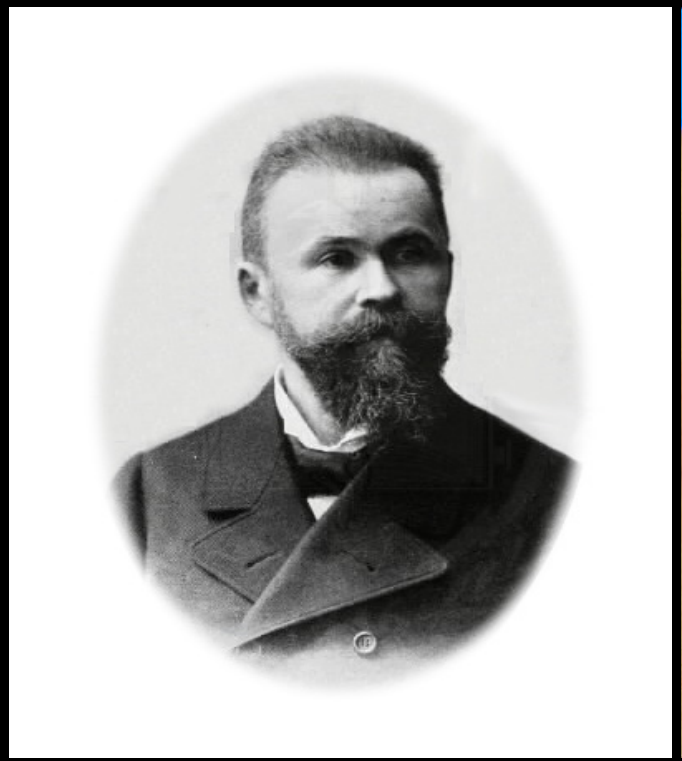


Stevenson et al., 2007



Wright et al., 2003

Speech perception

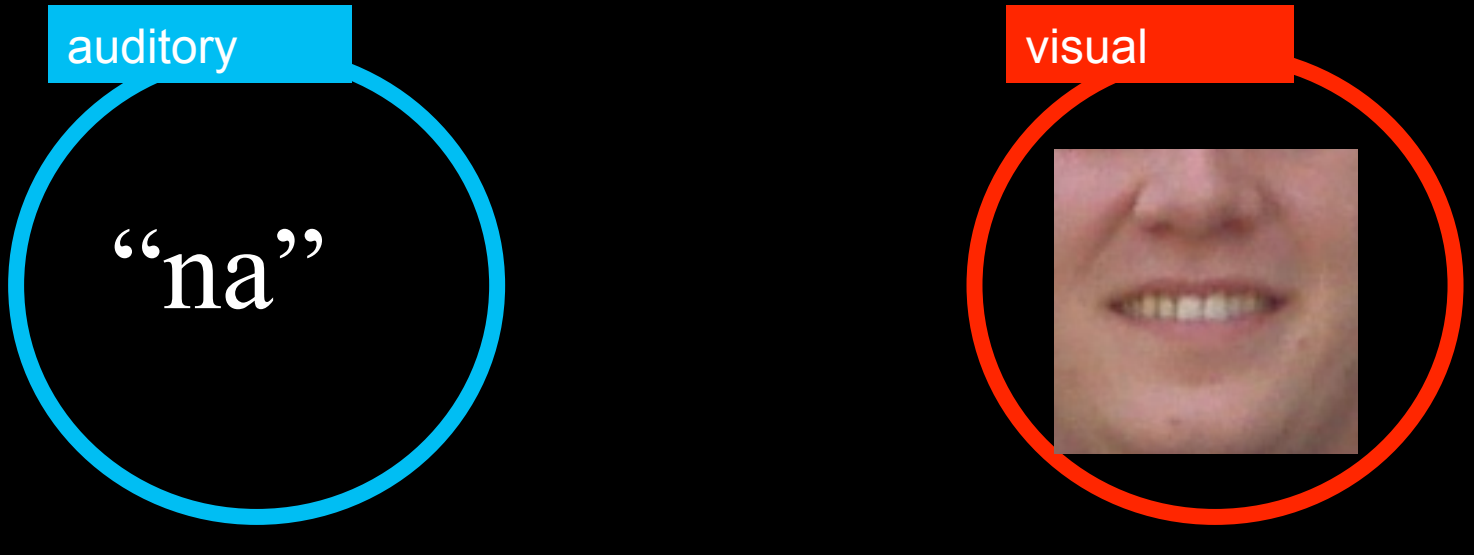


Wernicke's Area: Carl Wernicke, 1874

+ a network of areas (e.g. Scott & Johnsrude, 2003)

General utility of multisensory integration

- Independent sources of information about the world



L. Rosenblum, University of California Riverside

The McGurk-MacDonald effect, a multisensory speech illusion

Hearing lips and seeing voices

HARRY MCGURK
JOHN MACDONALD

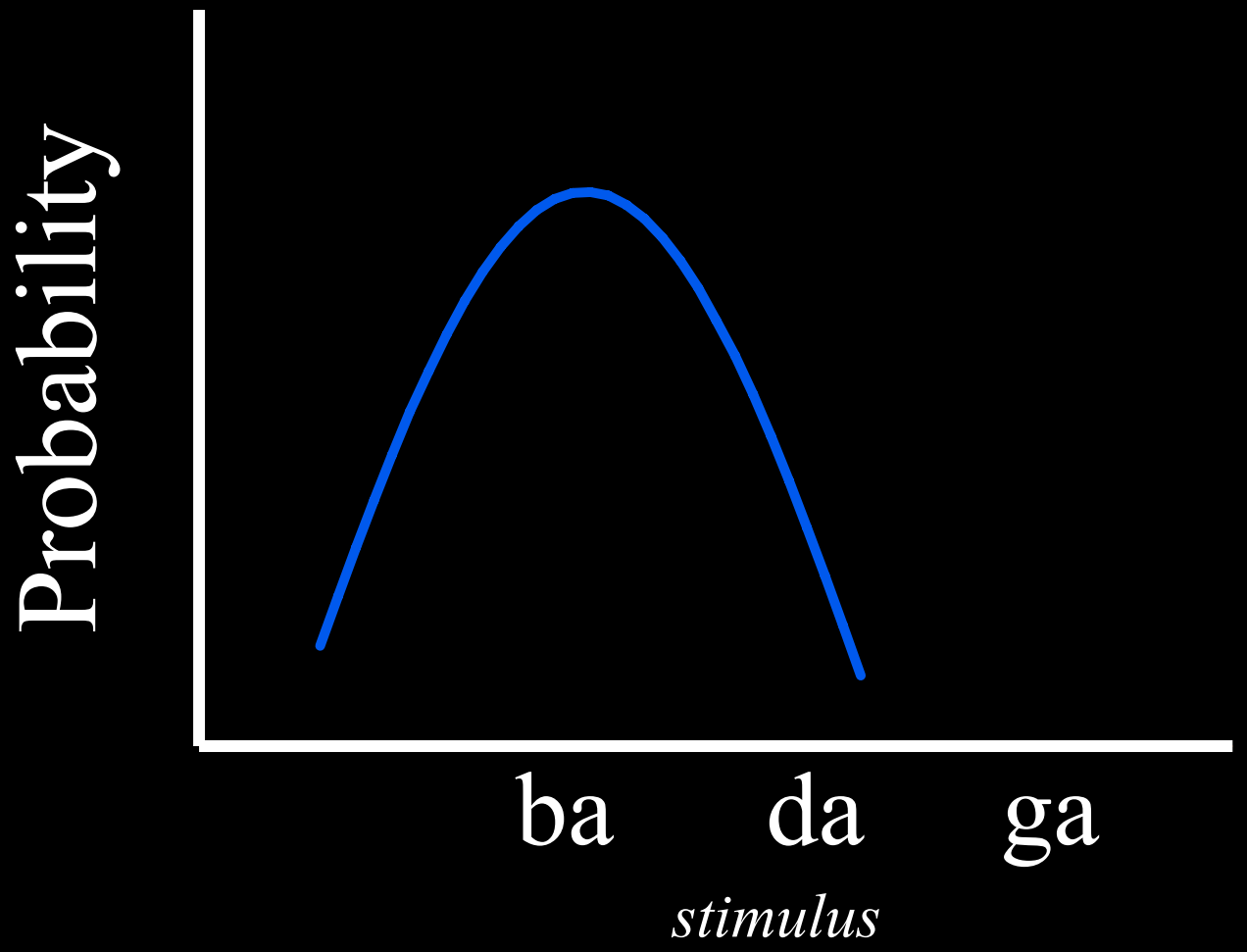
Nature Vol. 264 December 23/30 1976

Auditory-only McGurk

Summary

- Speech perception is multisensory: humans use both auditory and visual modalities
- Multisensory integration occurs in the superior temporal sulcus, which contains patches of neurons that respond to auditory stimuli, visual stimuli or both

Part 2: Is the STS necessary for multisensory speech perception?



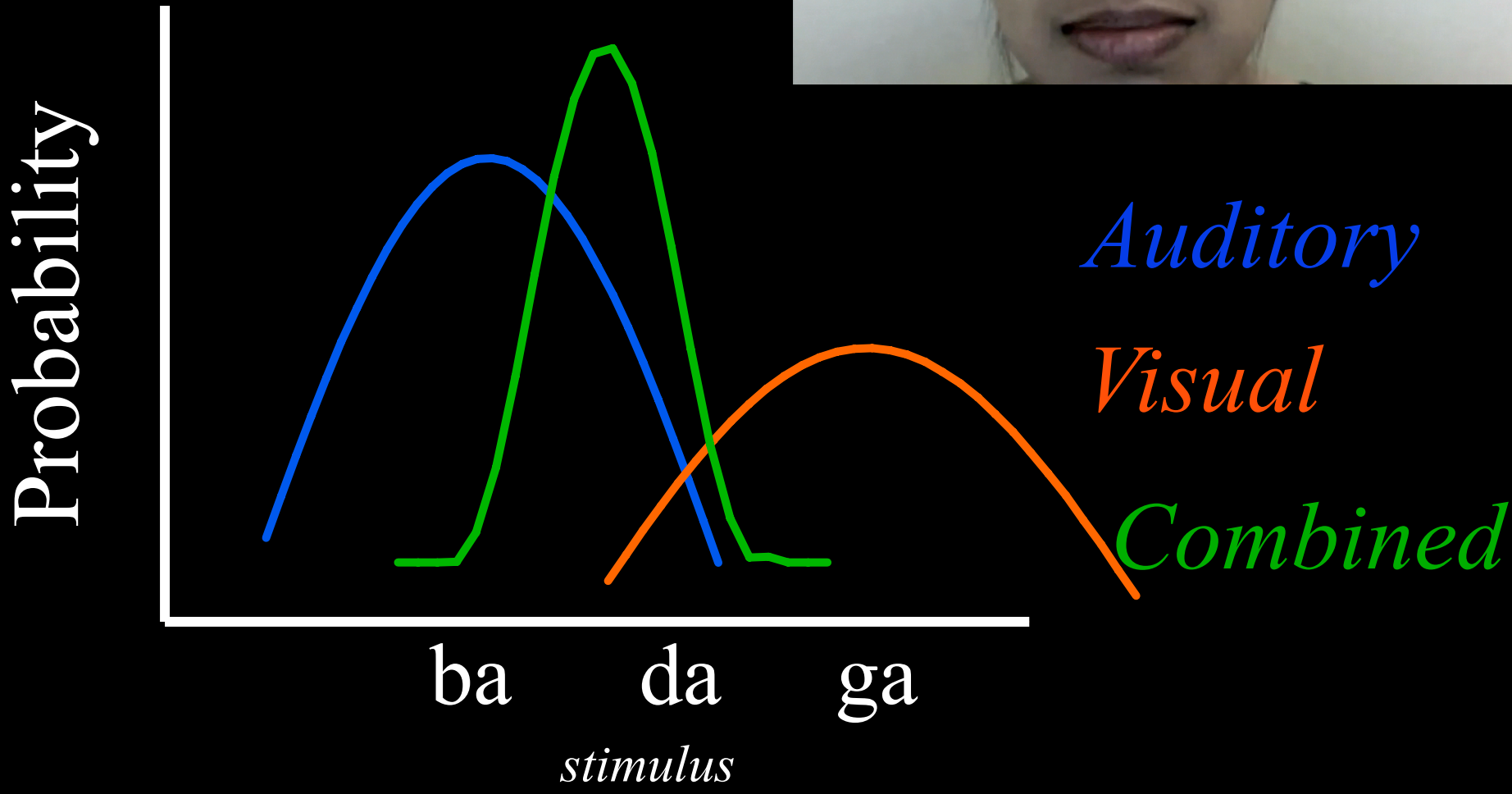
Auditory

Probability

Visual

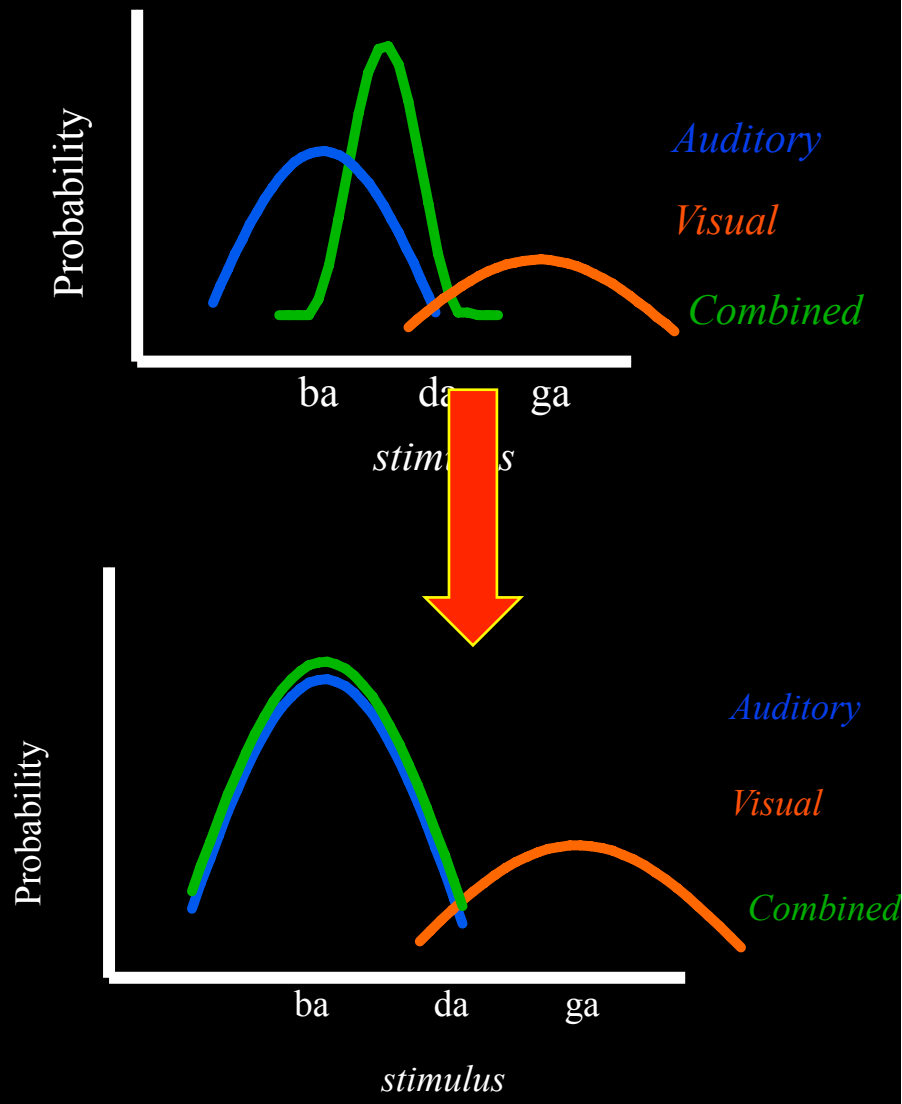
ba da ga

stimulus

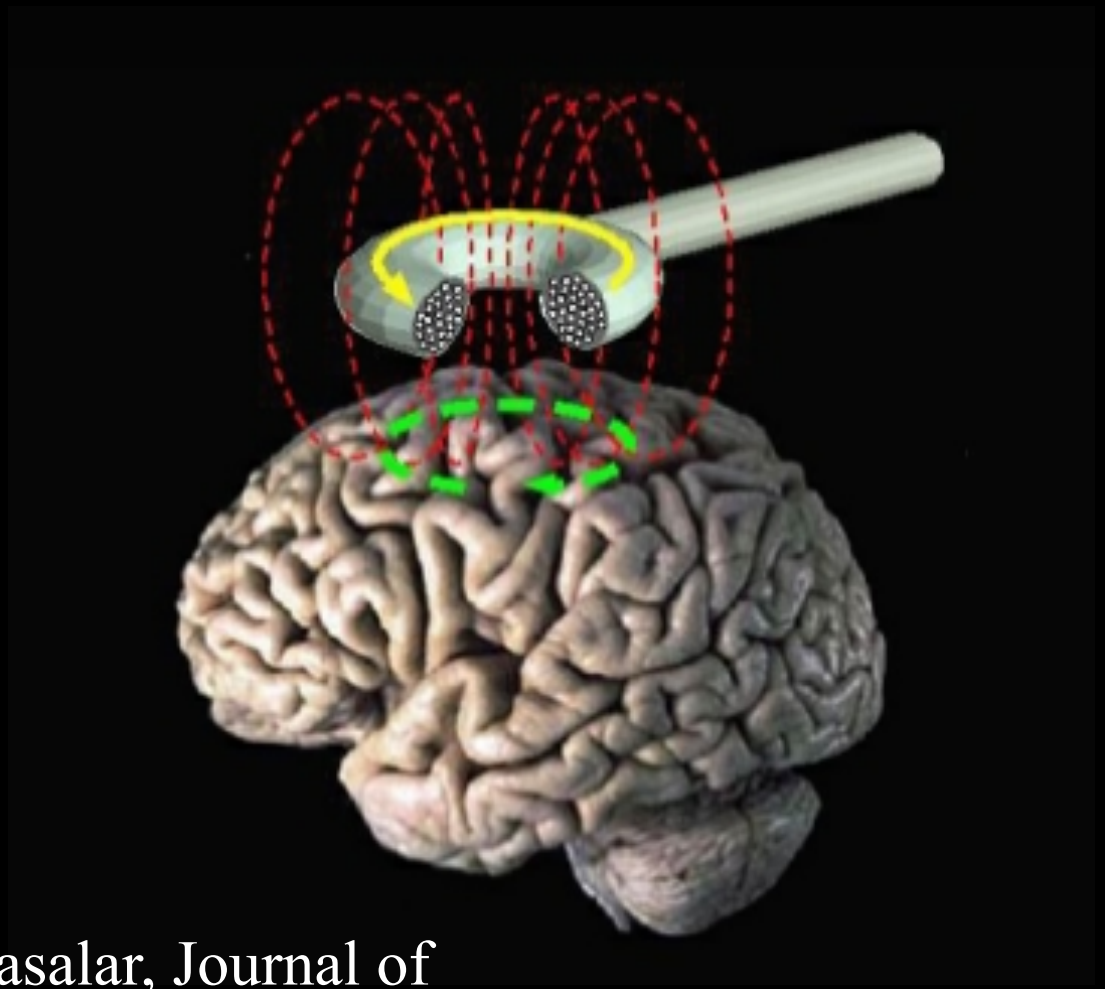

Probability
ba
da
ga
stimulus
Auditory
Visual
Combined

How can we prove that the STS is really critical for multisensory integration?

Hypothesis: disrupting STS should reduce multisensory integration



Transcranial Magnetic Stimulation (TMS)

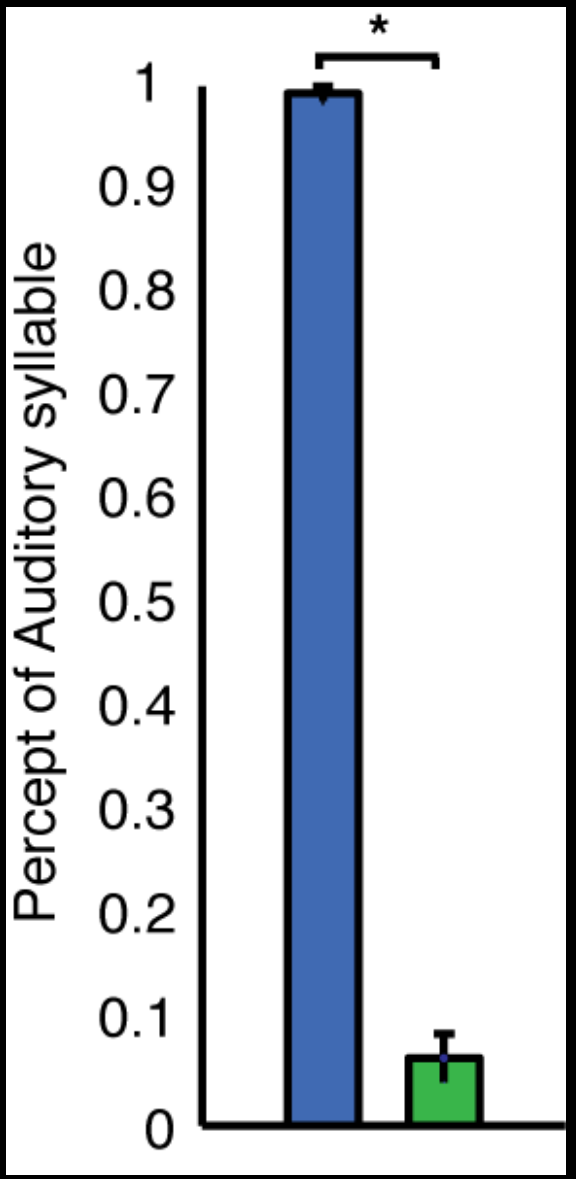


Beauchamp, Nath, Pasalar, Journal of Neuroscience, 2010

Behavioral Paradigm

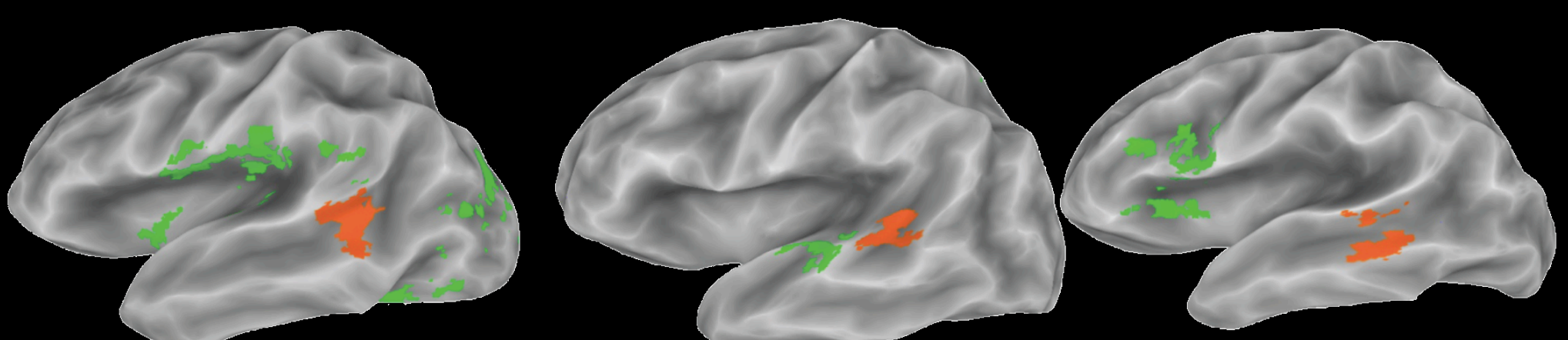
"ba" +

"ba" +



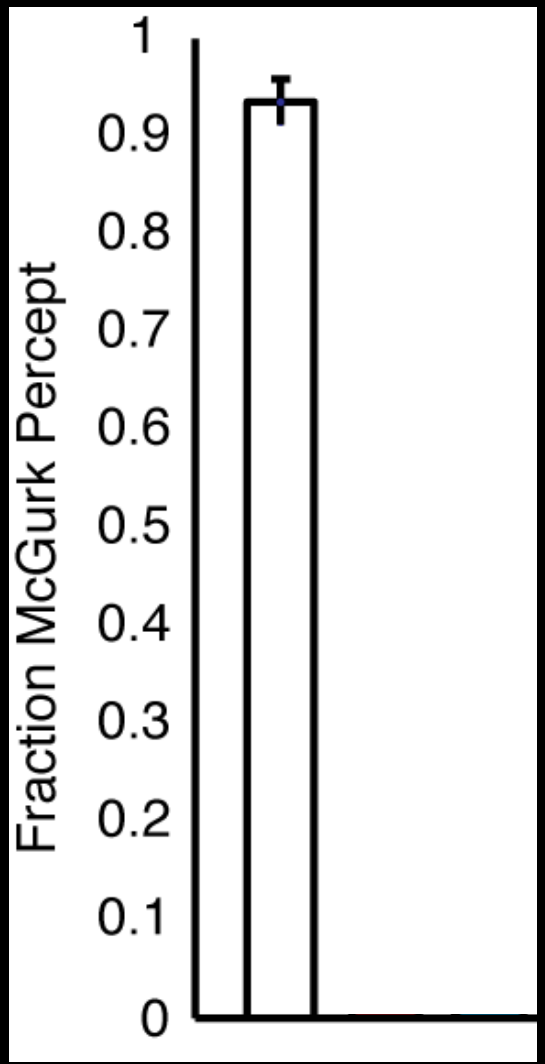
Method: combine fMRI with TMS

- First, scan subjects with fMRI to identify active brain areas
- Second, target these brain areas with TMS and examine behavior

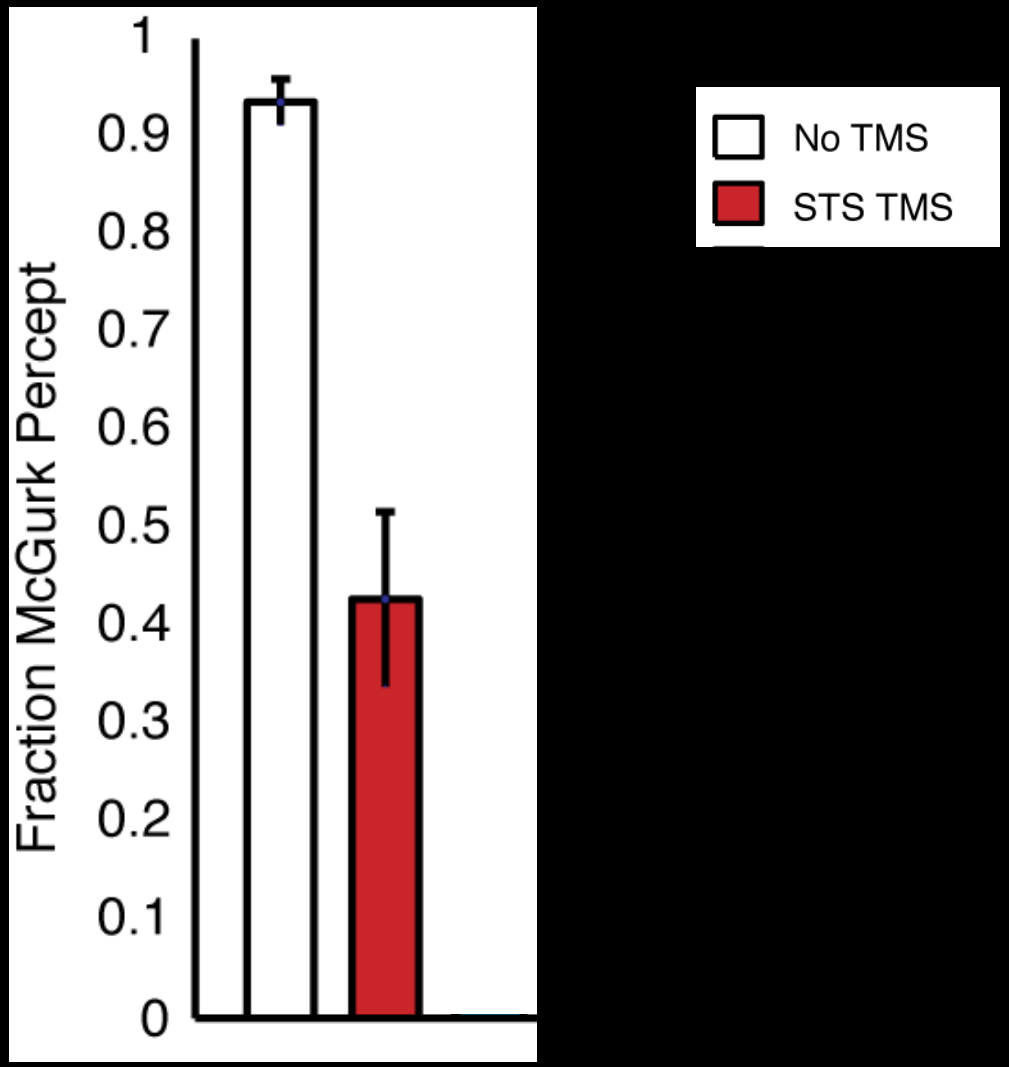


Experimental Paradigm

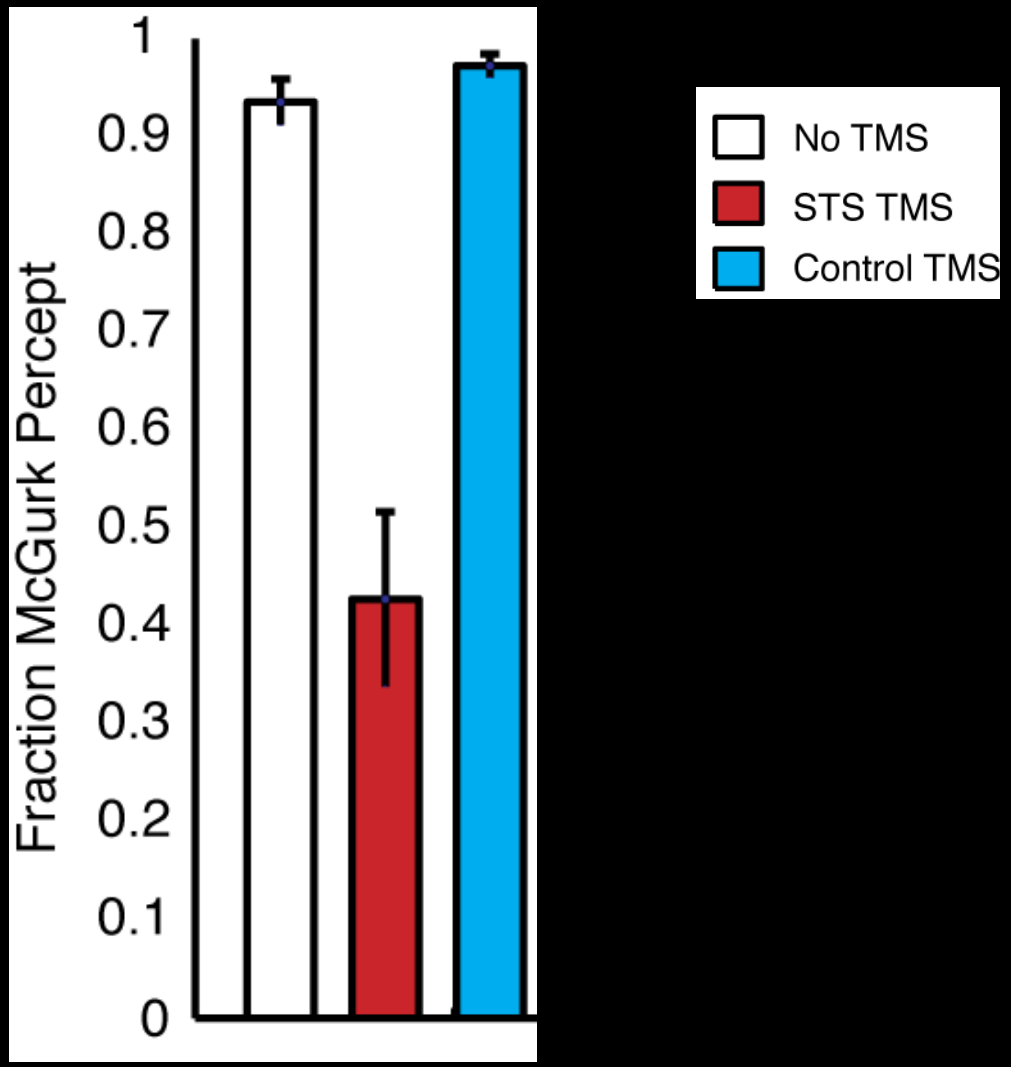
Experiment 1 (/ba/ + /ga/ ~= da)



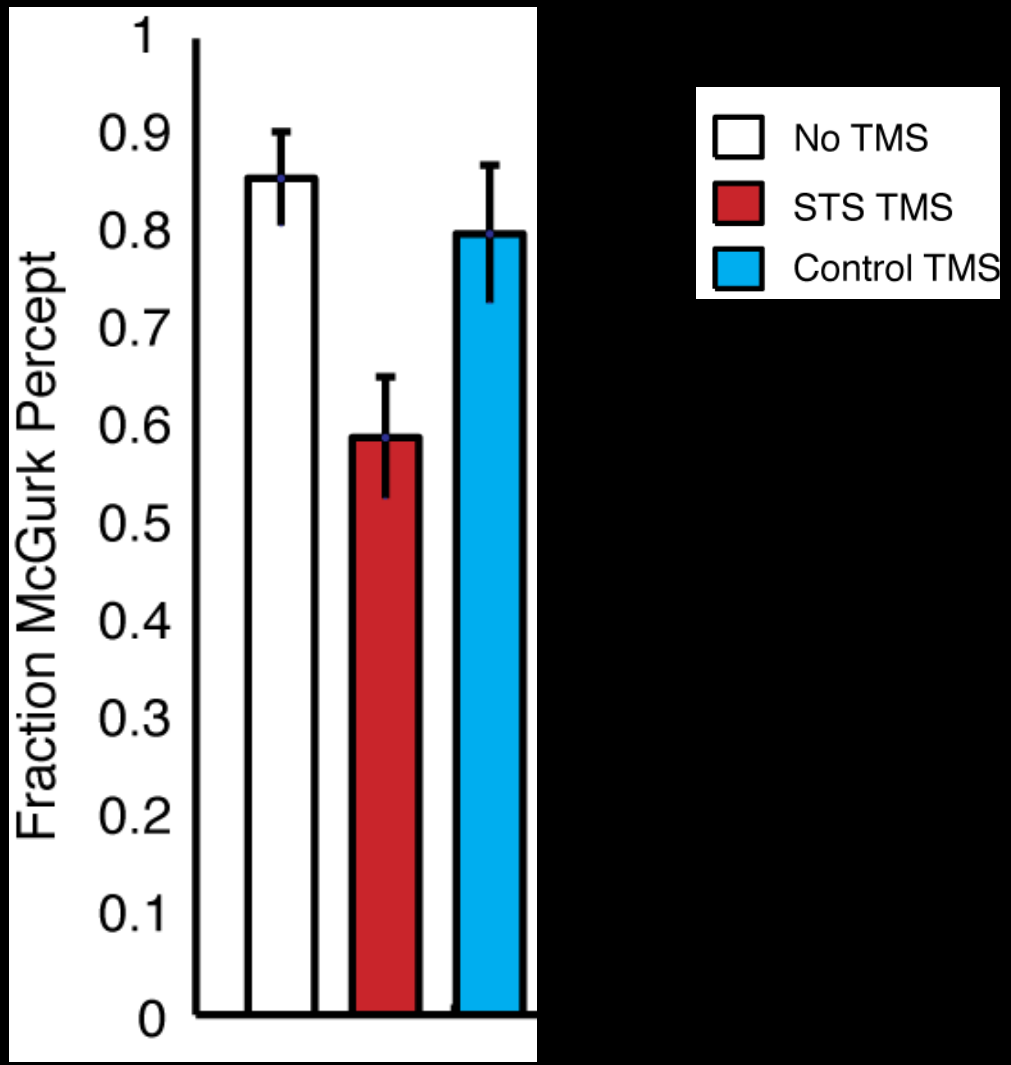
TMS Experiment 1



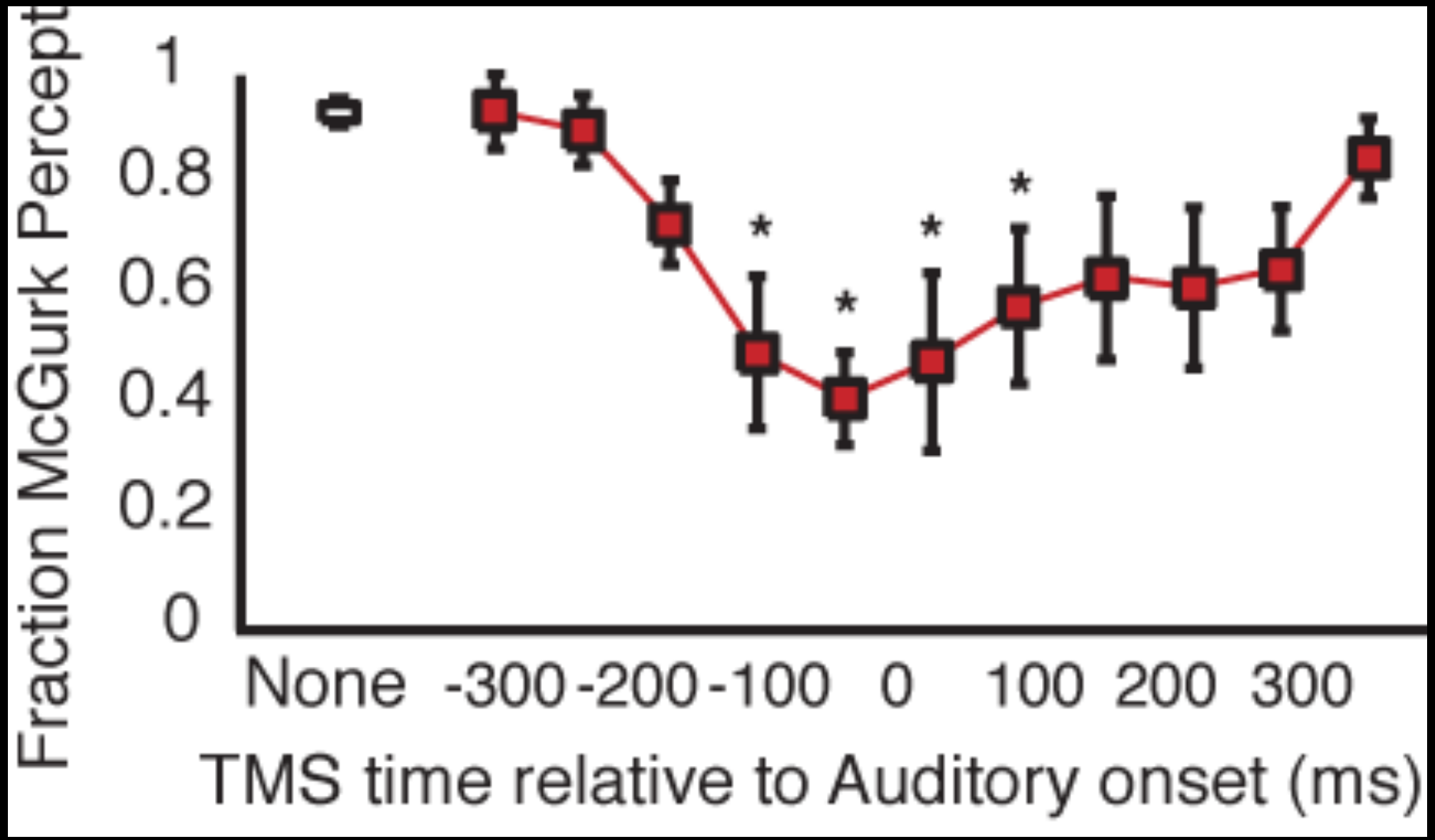
TMS Experiment 1



TMS Experiment 2 (/pa/ + /na/ ~= ta)



TMS Experiment 3



Part 2: Summary

- interfering with activity in the left STS interferes with the McGurk effect, showing a causal role for STS in auditory-visual integration in speech perception

Part 3: Interindividual differences in speech perception

Hearing lips and seeing voices

HARRY MCGURK
JOHN MACDONALD

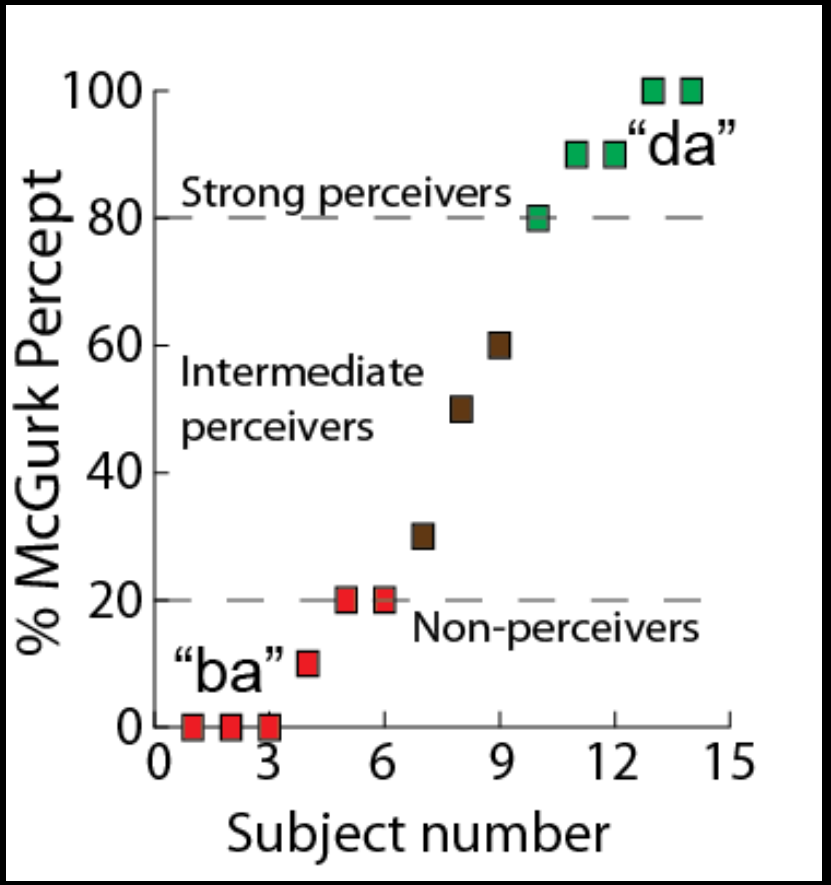
Stimuli					
Auditory	Visual	Subjects	Auditory	Visual	Responses Fused
ba-ba	ga-ga	18–40 yr ($n = 54$)	2	0	98

Table 2

Nature Vol. 264 December 23/30 1976

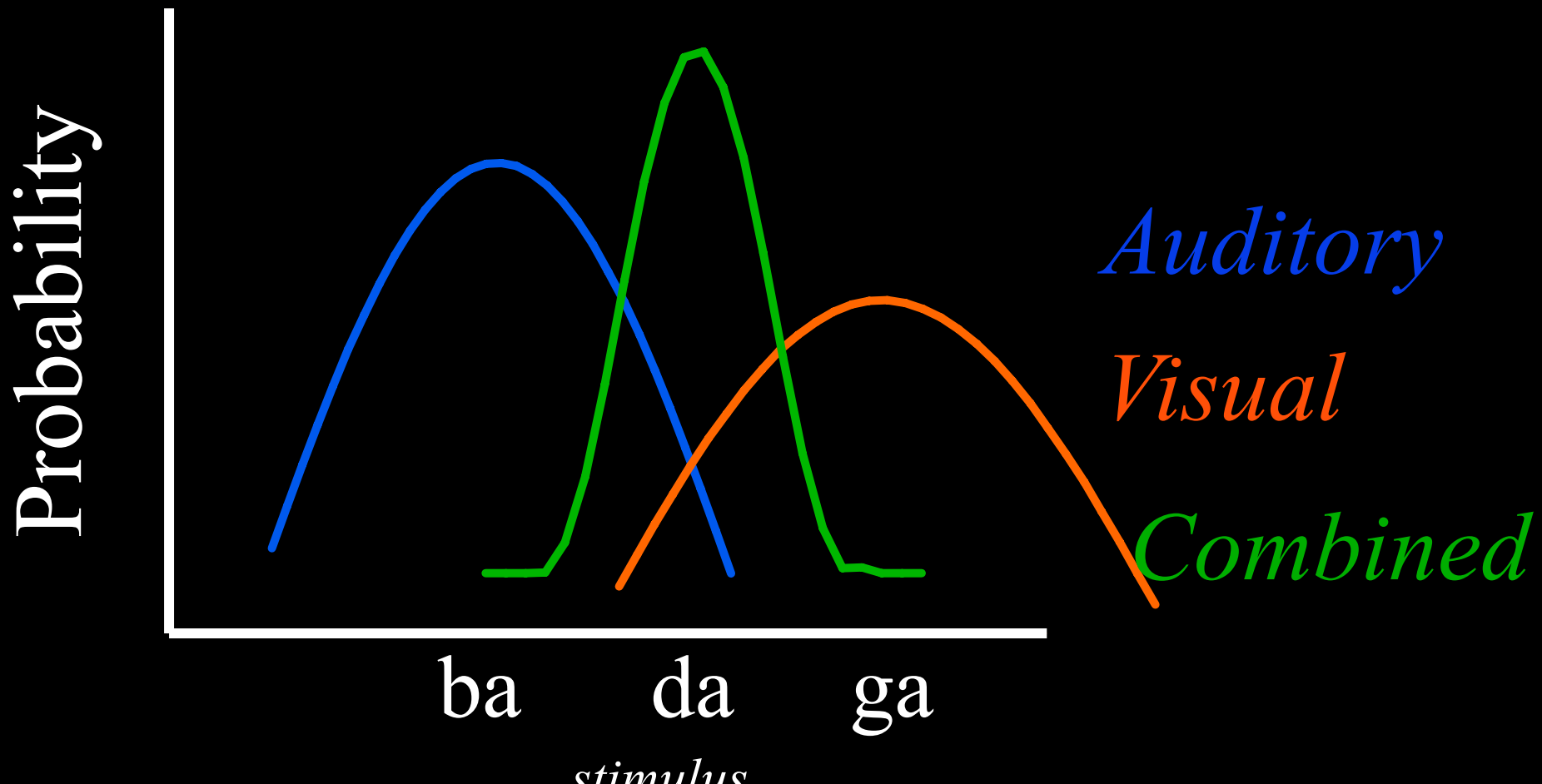
What about in this audience?

Intersubject Variability

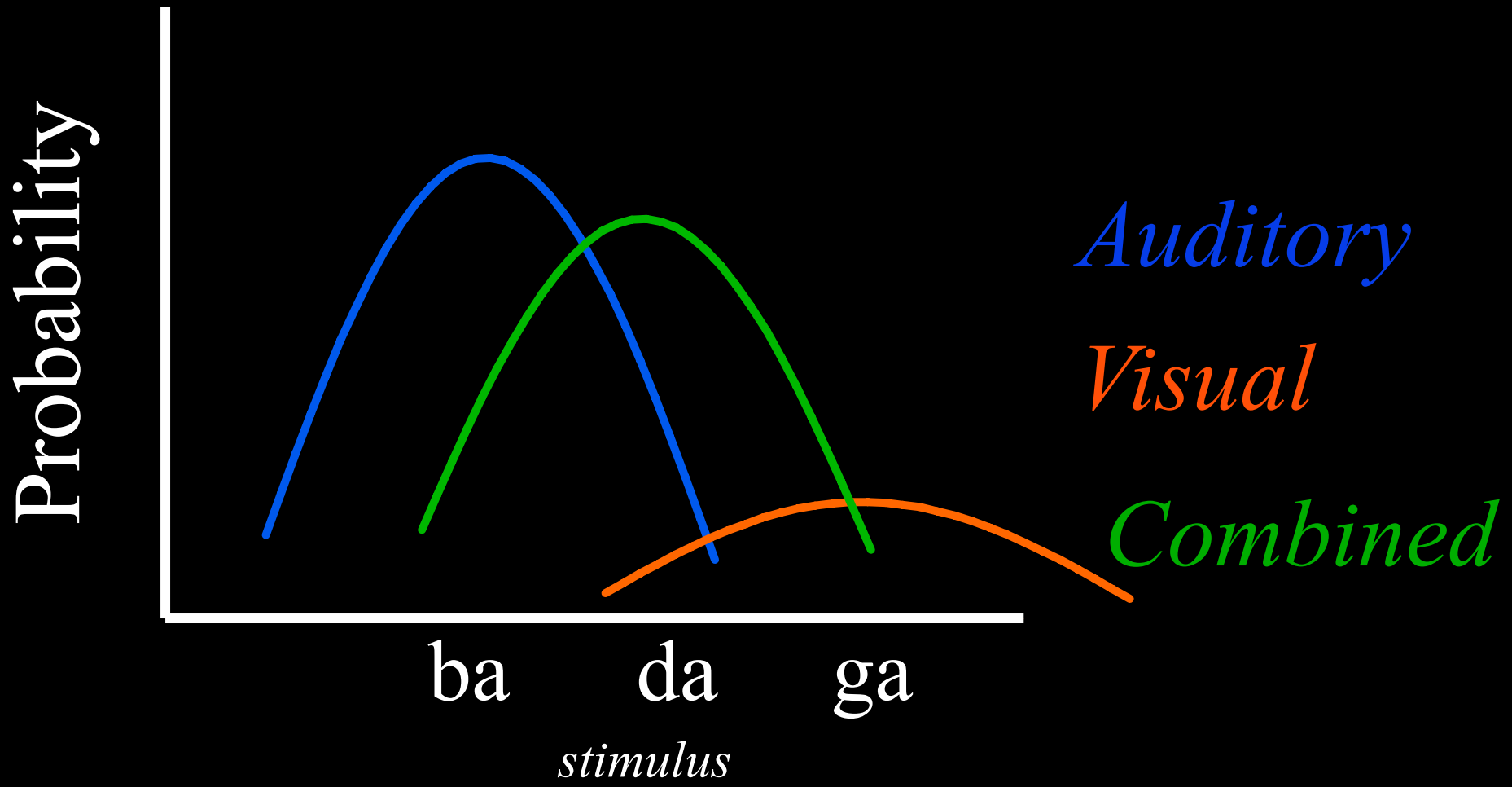


Nath, Fava, Beauchamp, Journal of Neuroscience, 2011
Nath and Beauchamp, Neuroimage, 2012

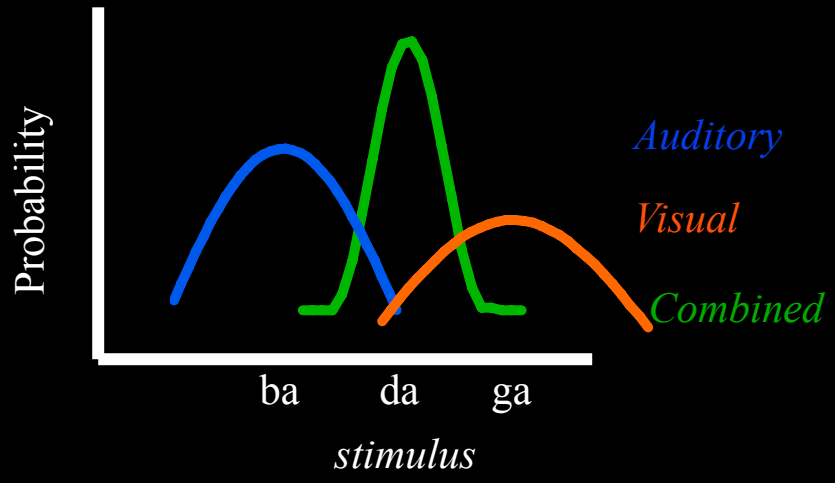
Strong Perceivers



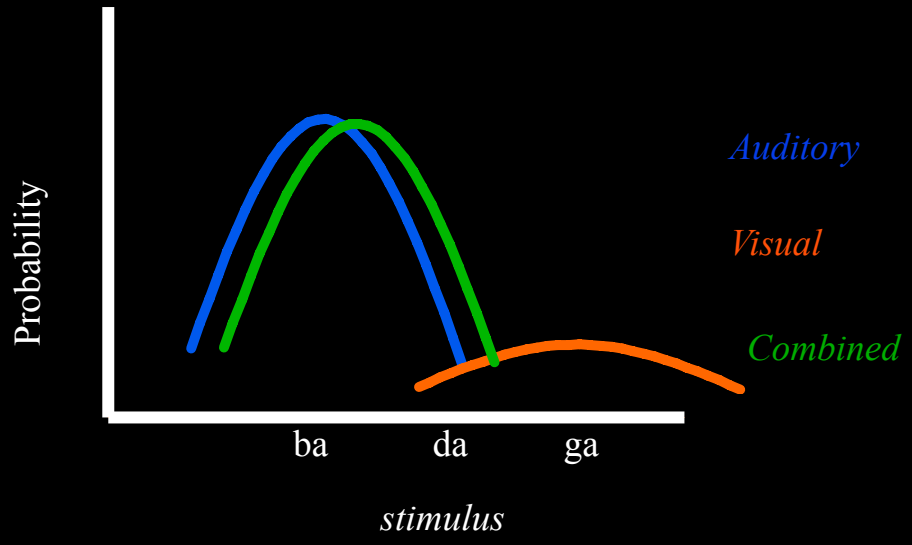
Non-perceivers



Perceivers

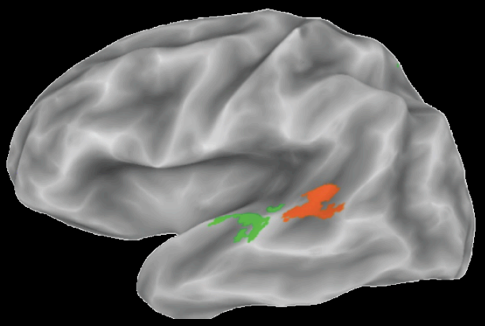


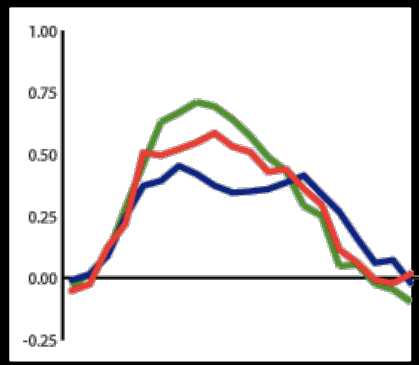
Non-perceivers



Hypothesis: perceivers integrate incongruent audiovisual speech, non-perceivers do not.

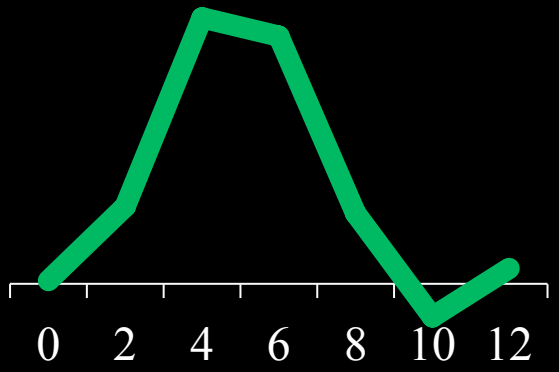
Test hypothesis with fMRI of the STS



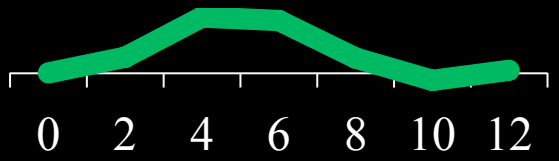


Beauchamp et al., *Neuron,* 2004

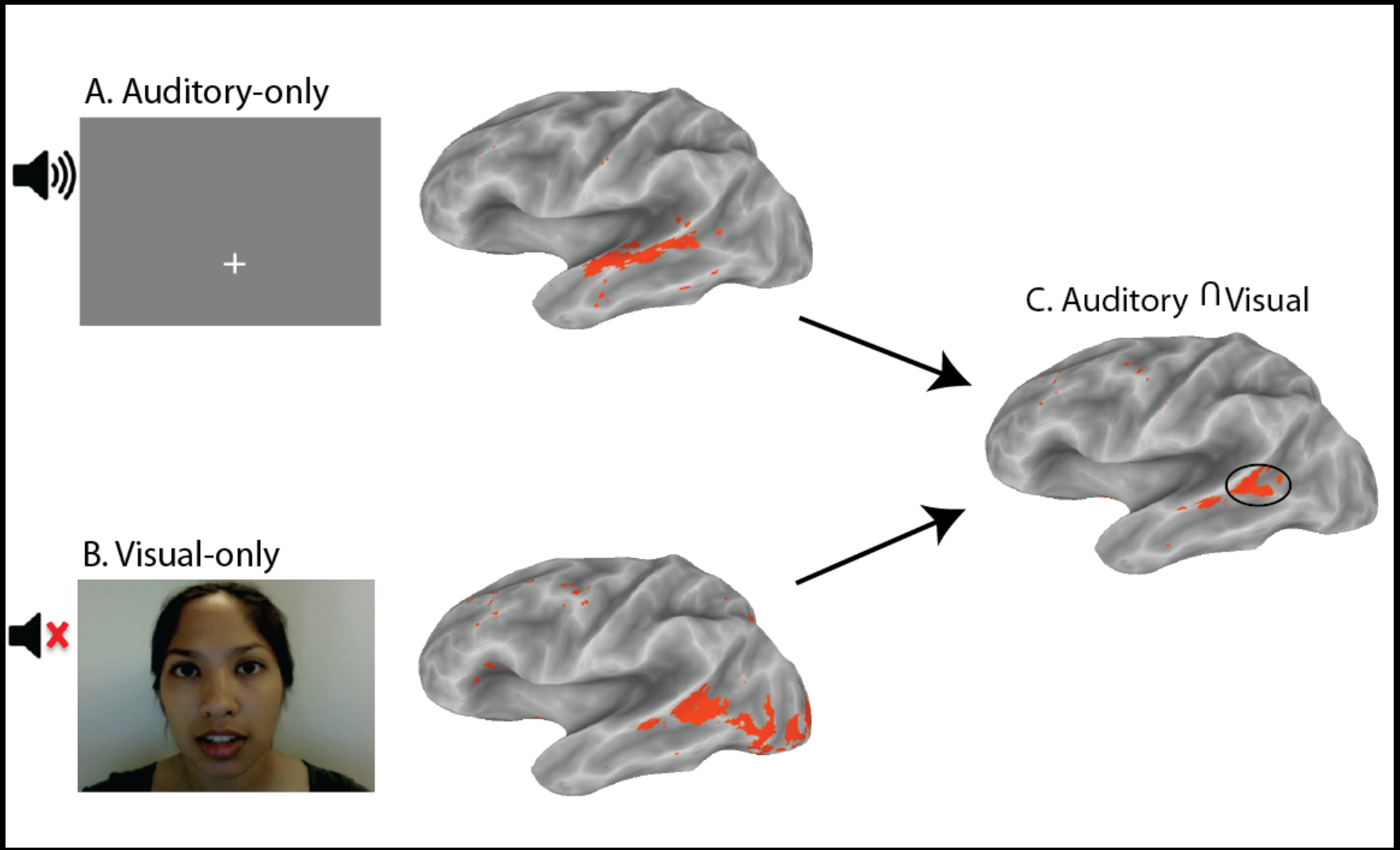
Perceivers



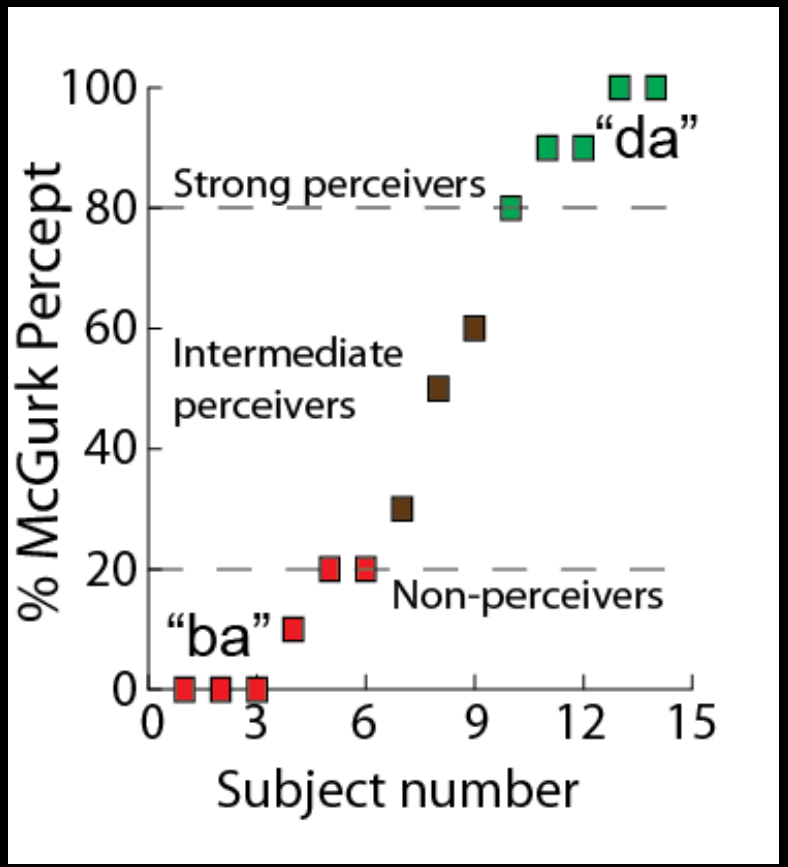
Non-perceivers

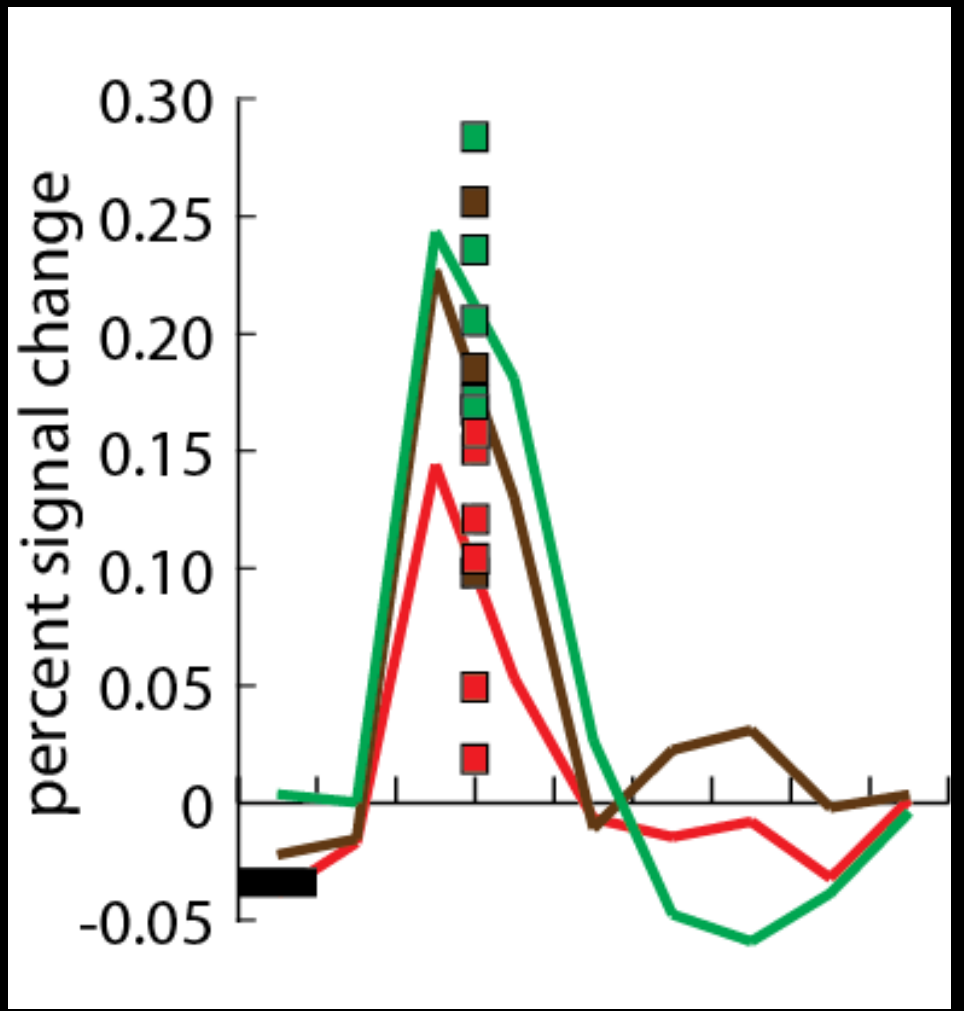


Independent Functional Localizers to avoid “voodoo correlations”

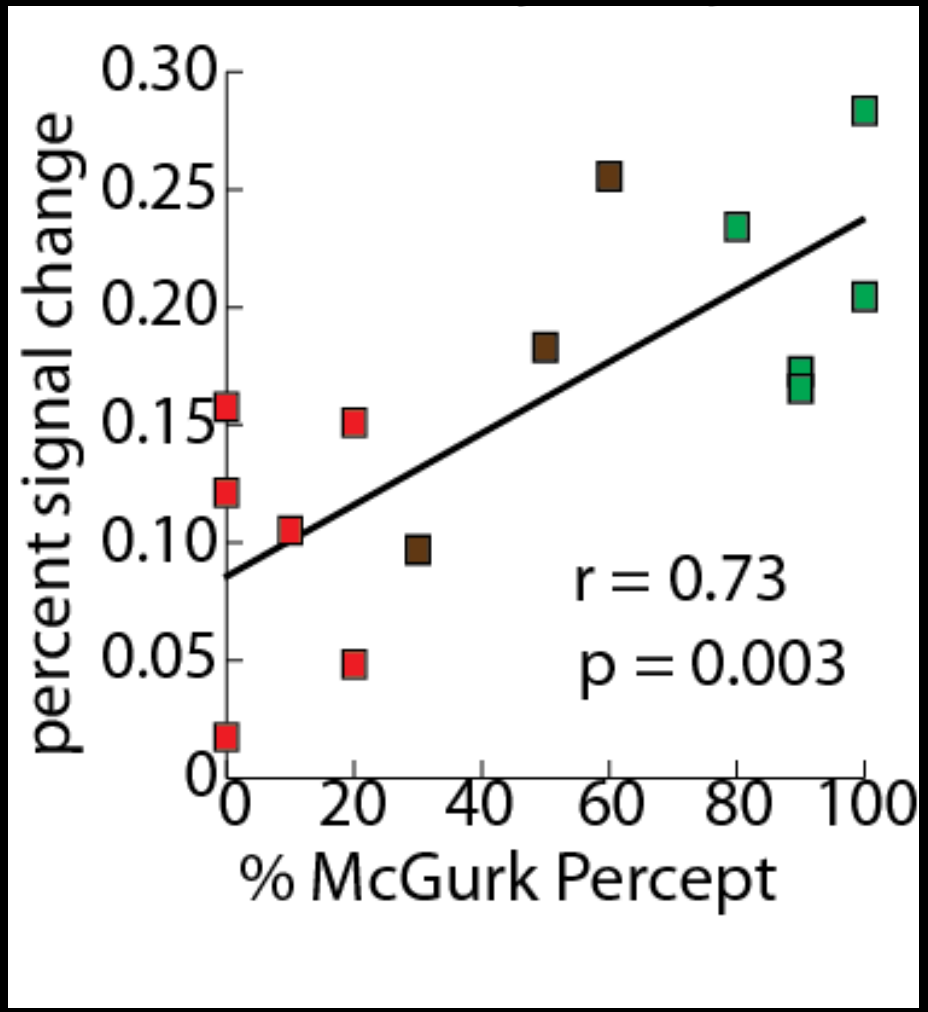


Measure fMRI Response to Incongruent Speech

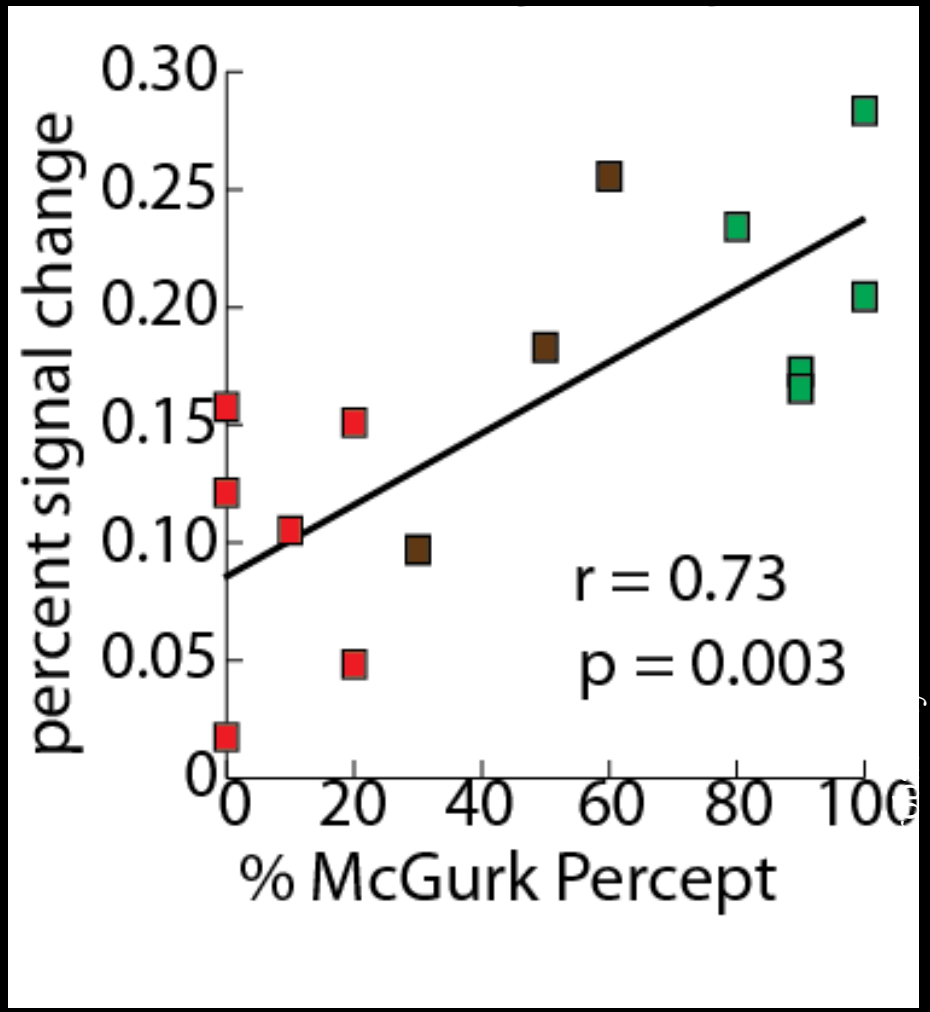


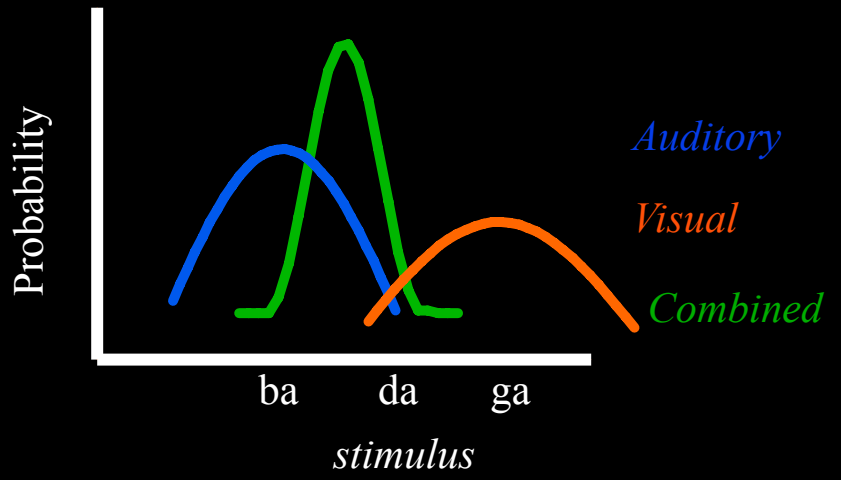


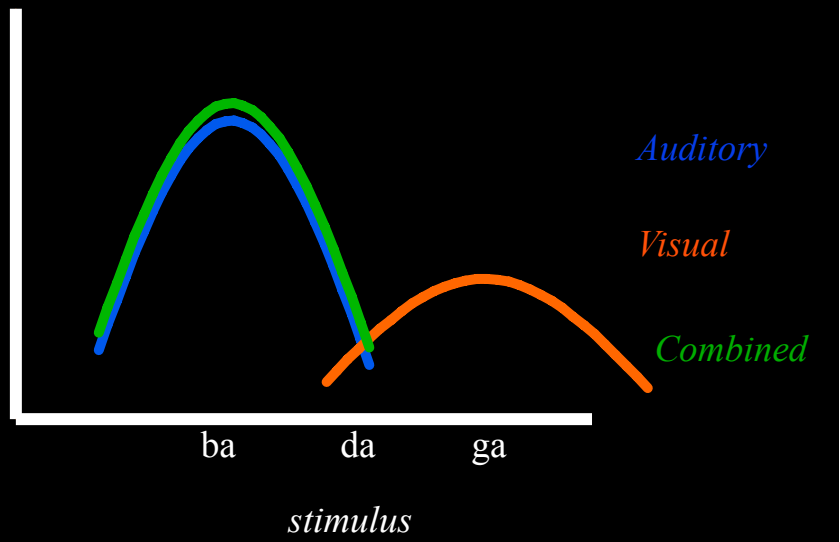
Correlation with perception



Correlation with perception







Part 3: Summary

- Activity in the STS predicts perception of auditory-visual incongruent speech

Part 4: Neural mechanisms for Bayesian multisensory integration: STS connectivity

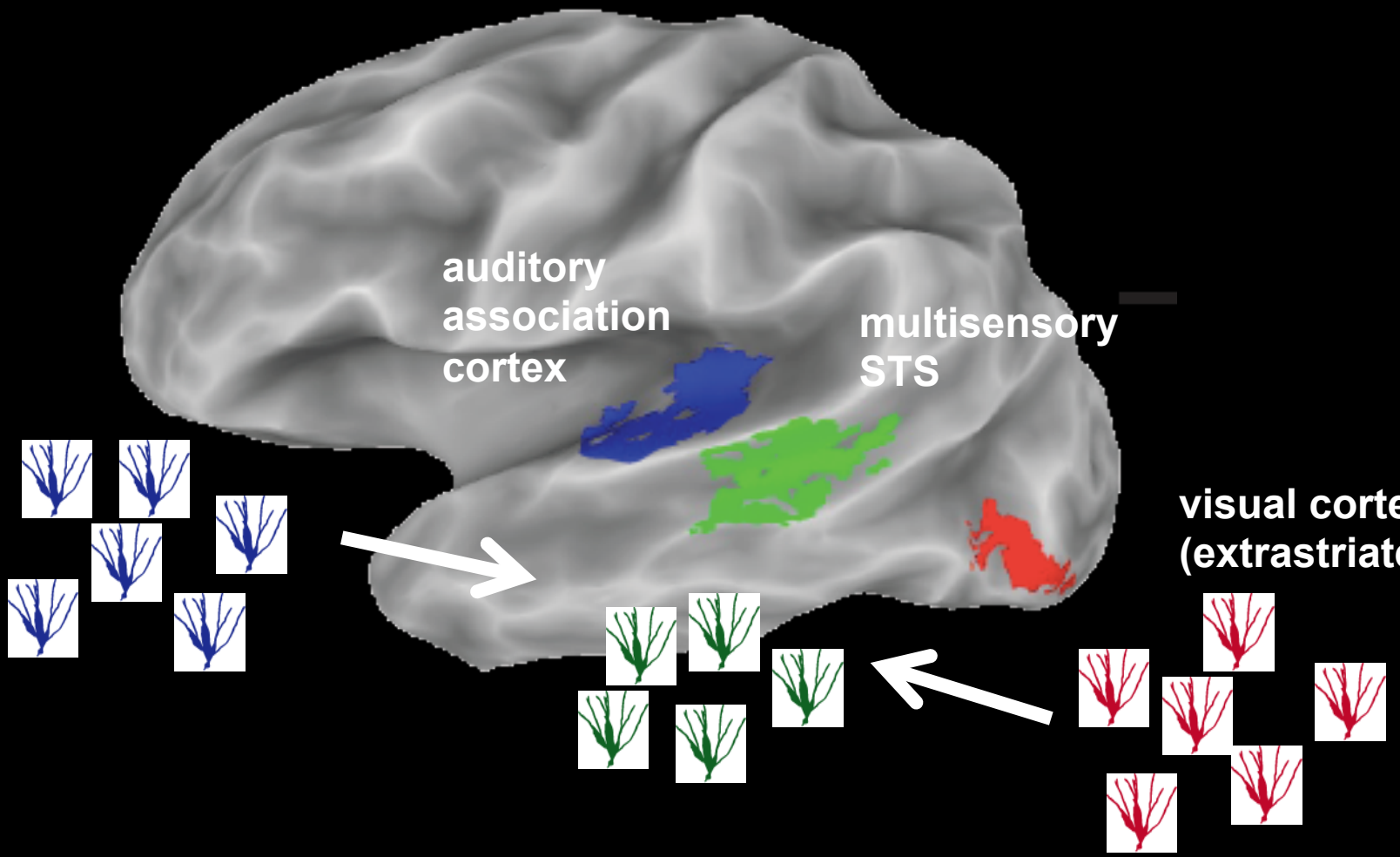
Speech Multisensory Integration: Auditory Only

- *e.g.* Sumby and Pollack (1954)

Auditory + Visual

Anatomical and Functional Connections of the STS

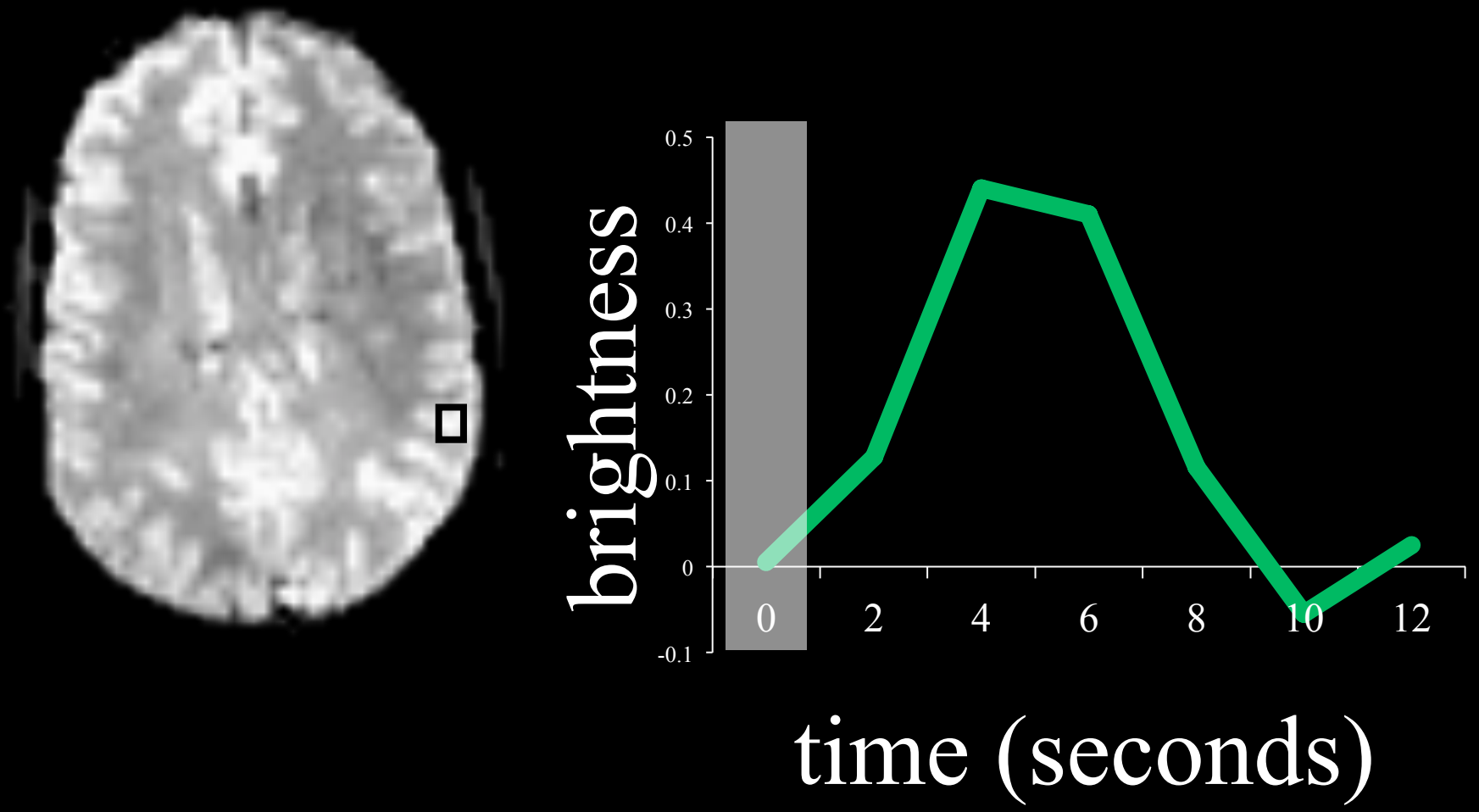
e.g. Cusick et al., Seltzer at al., Lewis and Van Essen



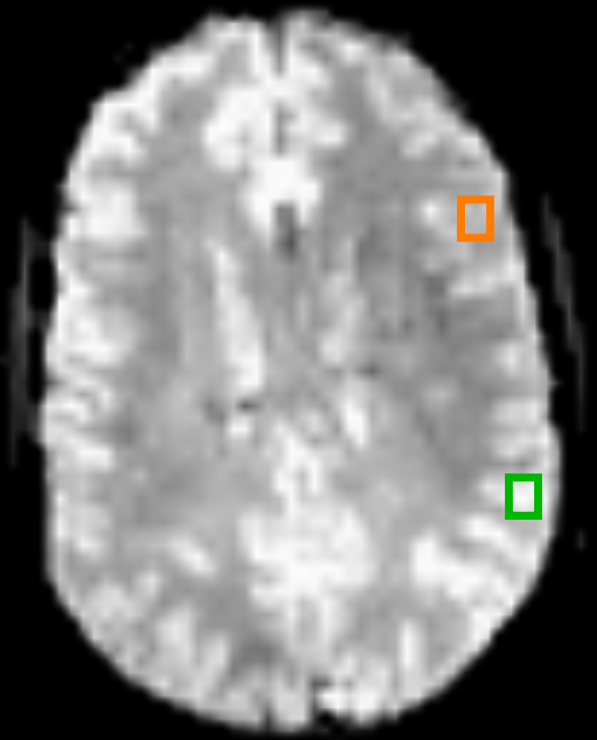
How do we measure functional connections?

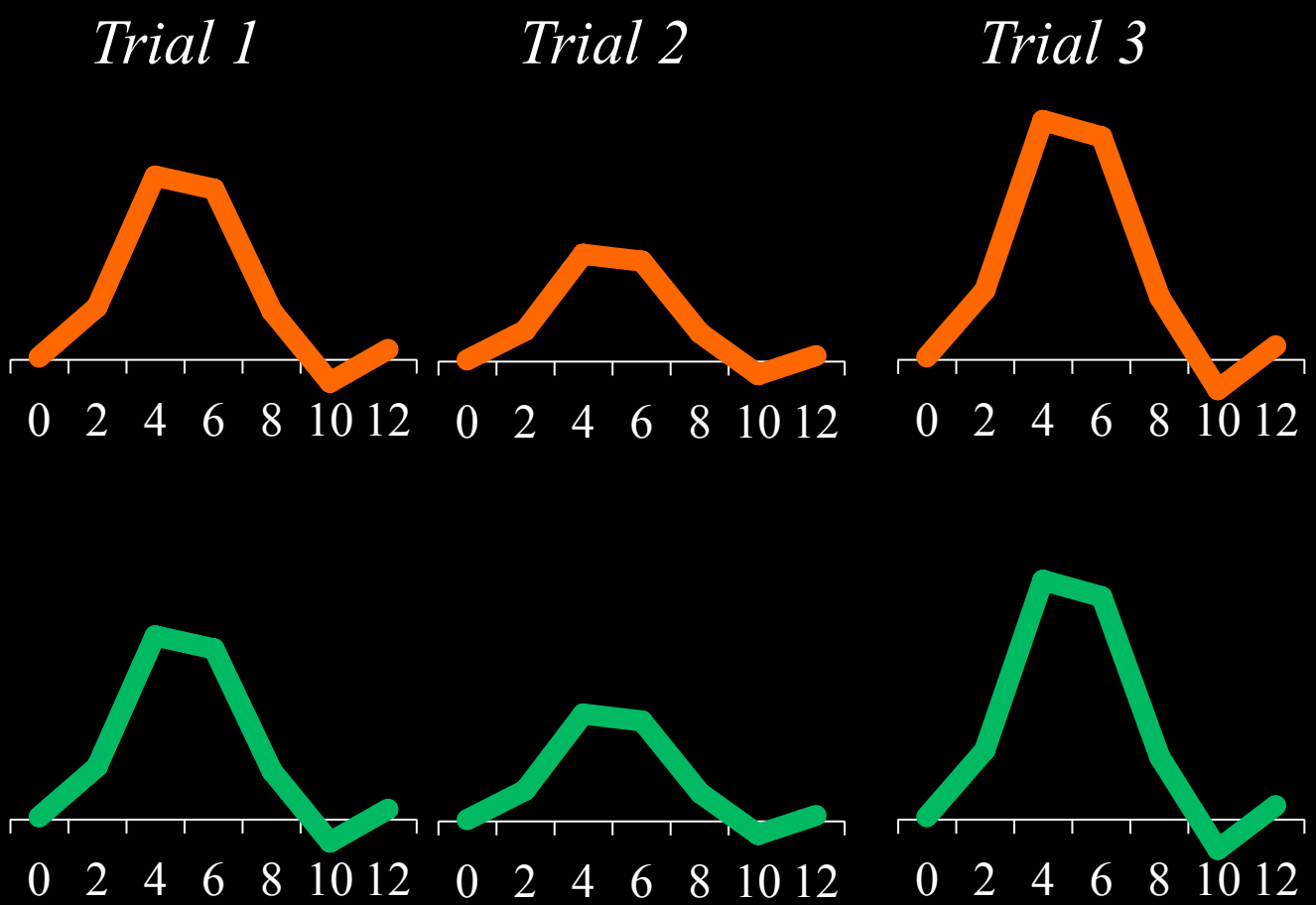
- Functional imaging to measure functional connectivity in the human brain
- McIntosh et al (1994); Horwitz et al., (1995); Friston etal., (1995)

Basic fMRI experiment

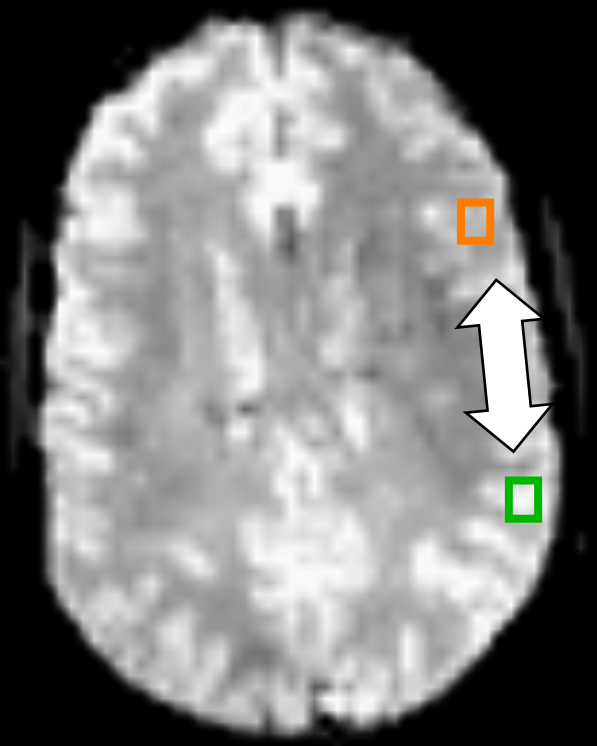


Connectivity fMRI ("fcMRI") experiment

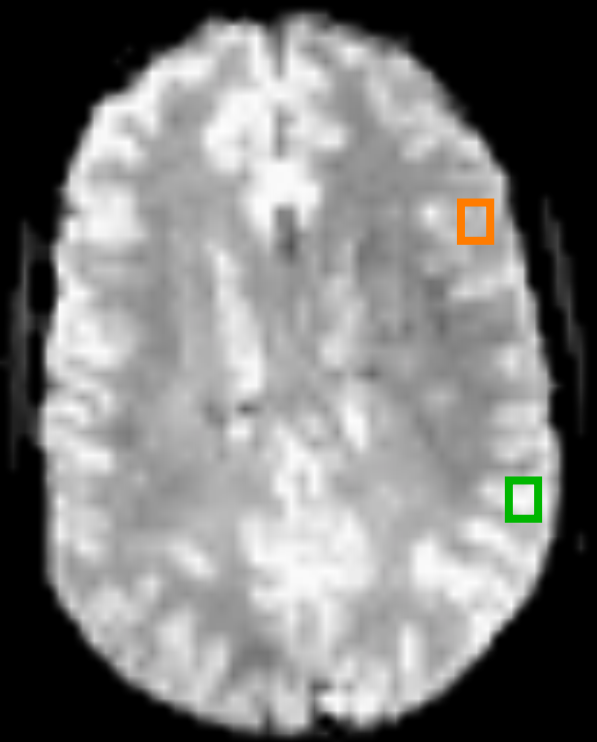


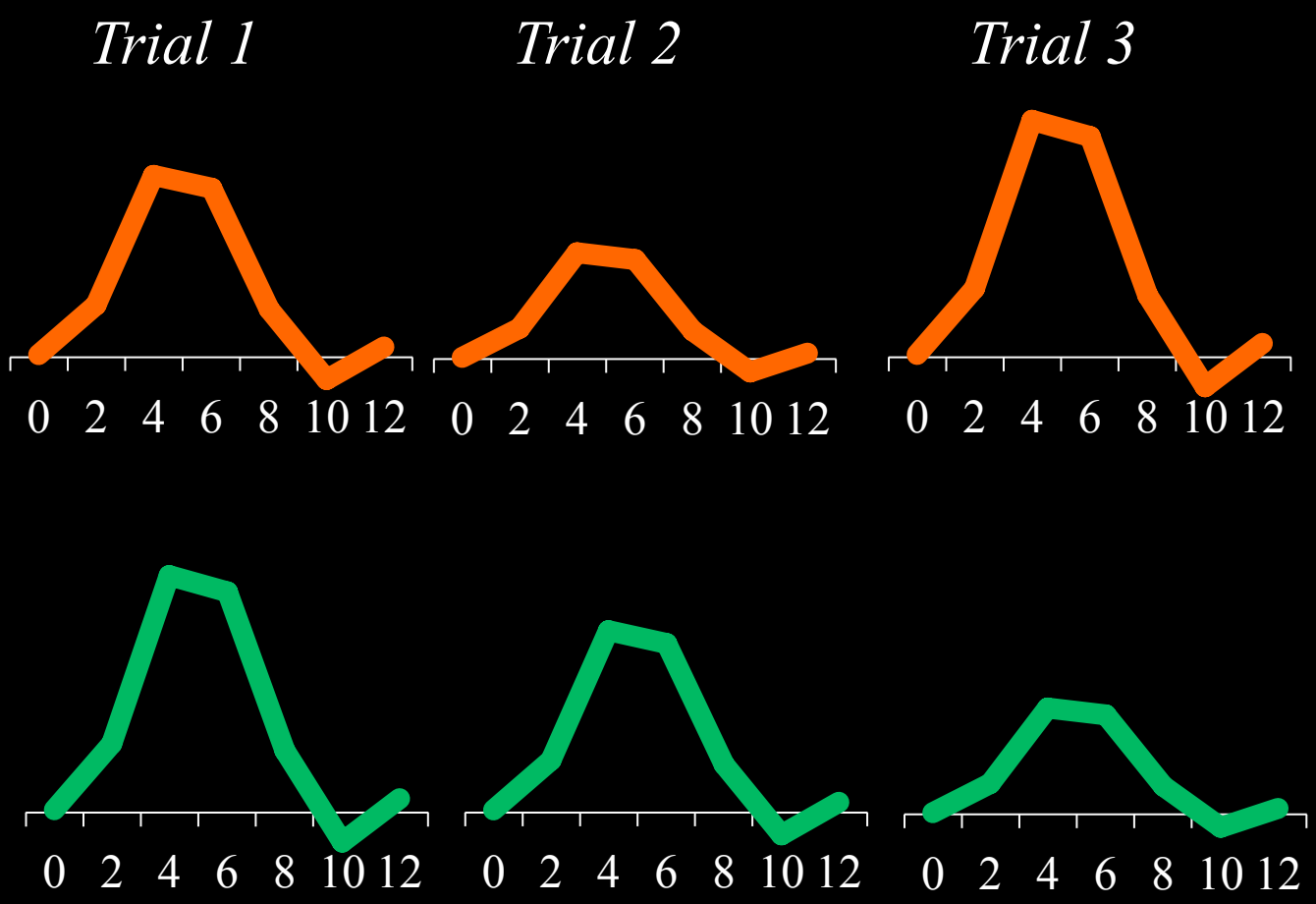


Connectivity fMRI experiment: connected regions

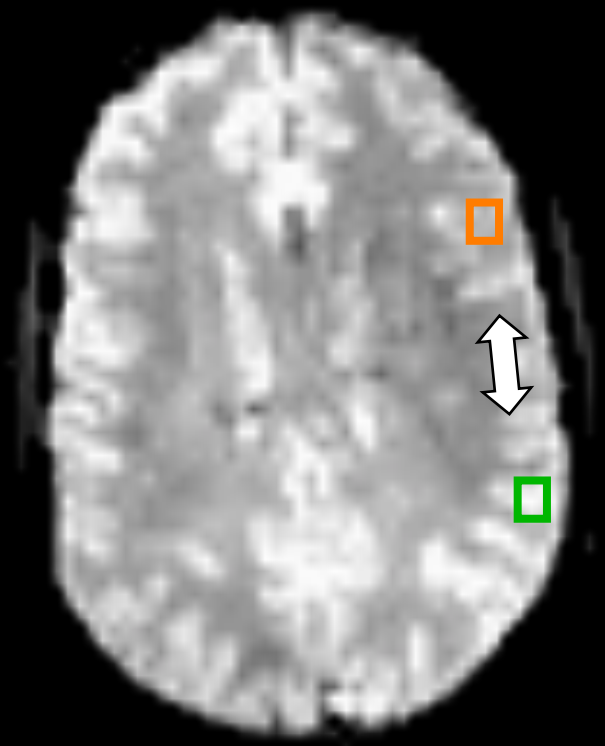


Connectivity fMRI ("fcMRI") experiment

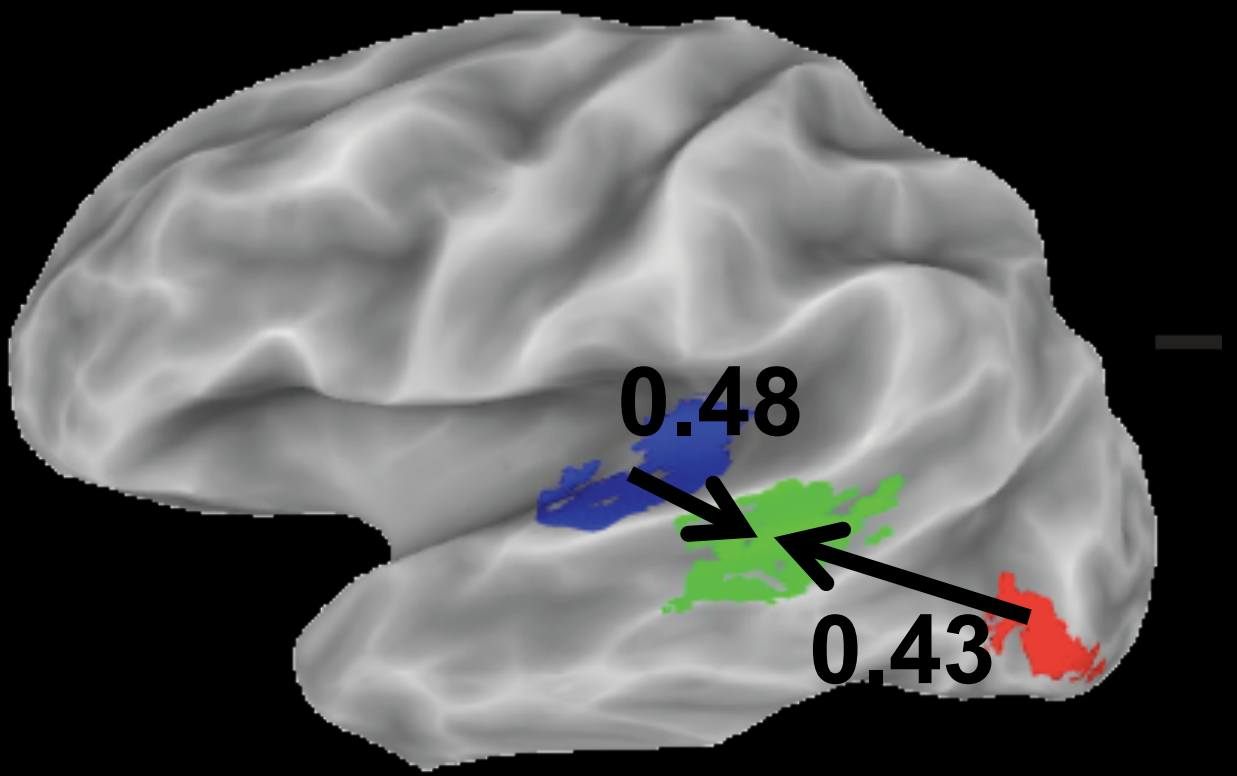




Connectivity fMRI experiment

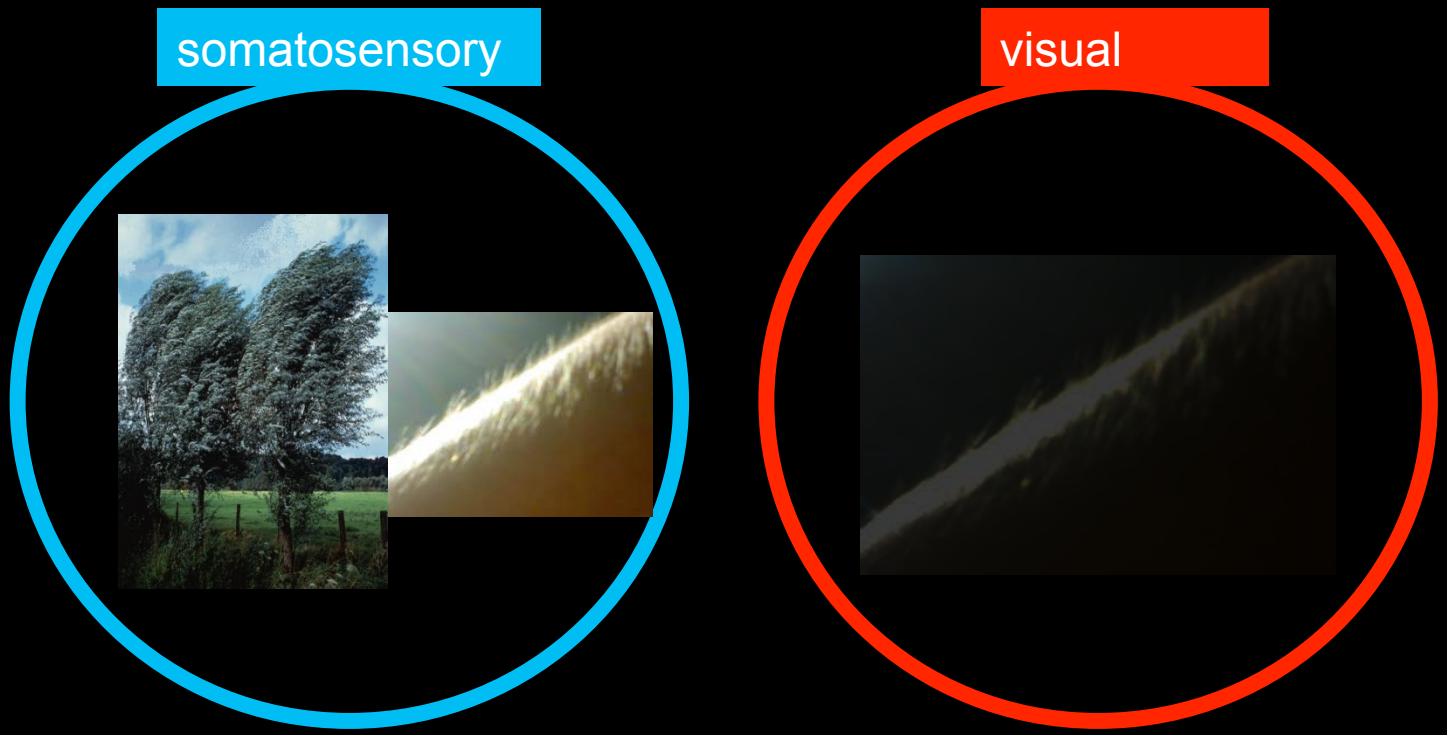


Result I: Strong functional connectivity between extrastriate visual cortex, auditory association cortex, and STS



Reliability-weighted multisensory integration

- Independent sources→independently varying noise levels

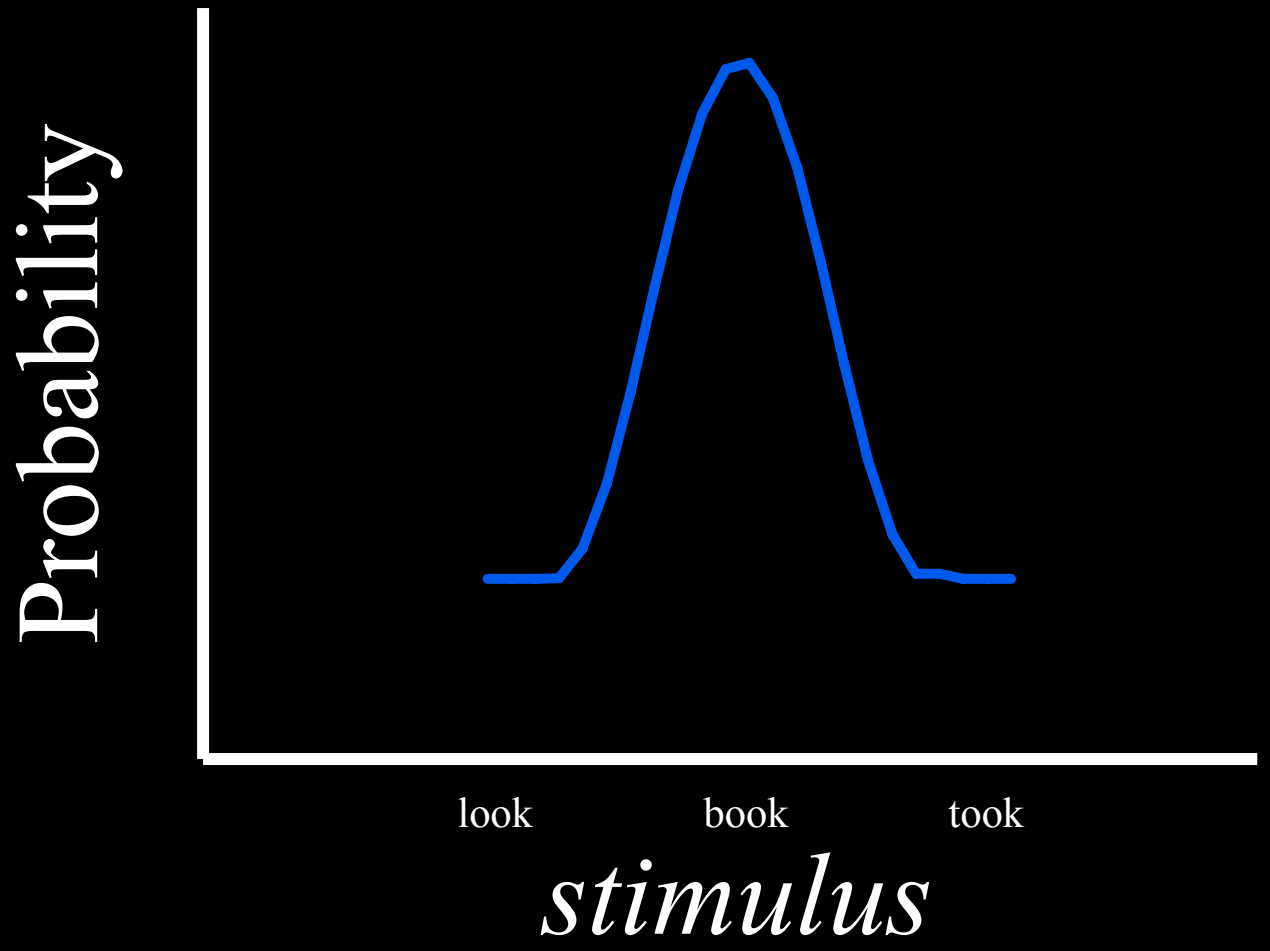


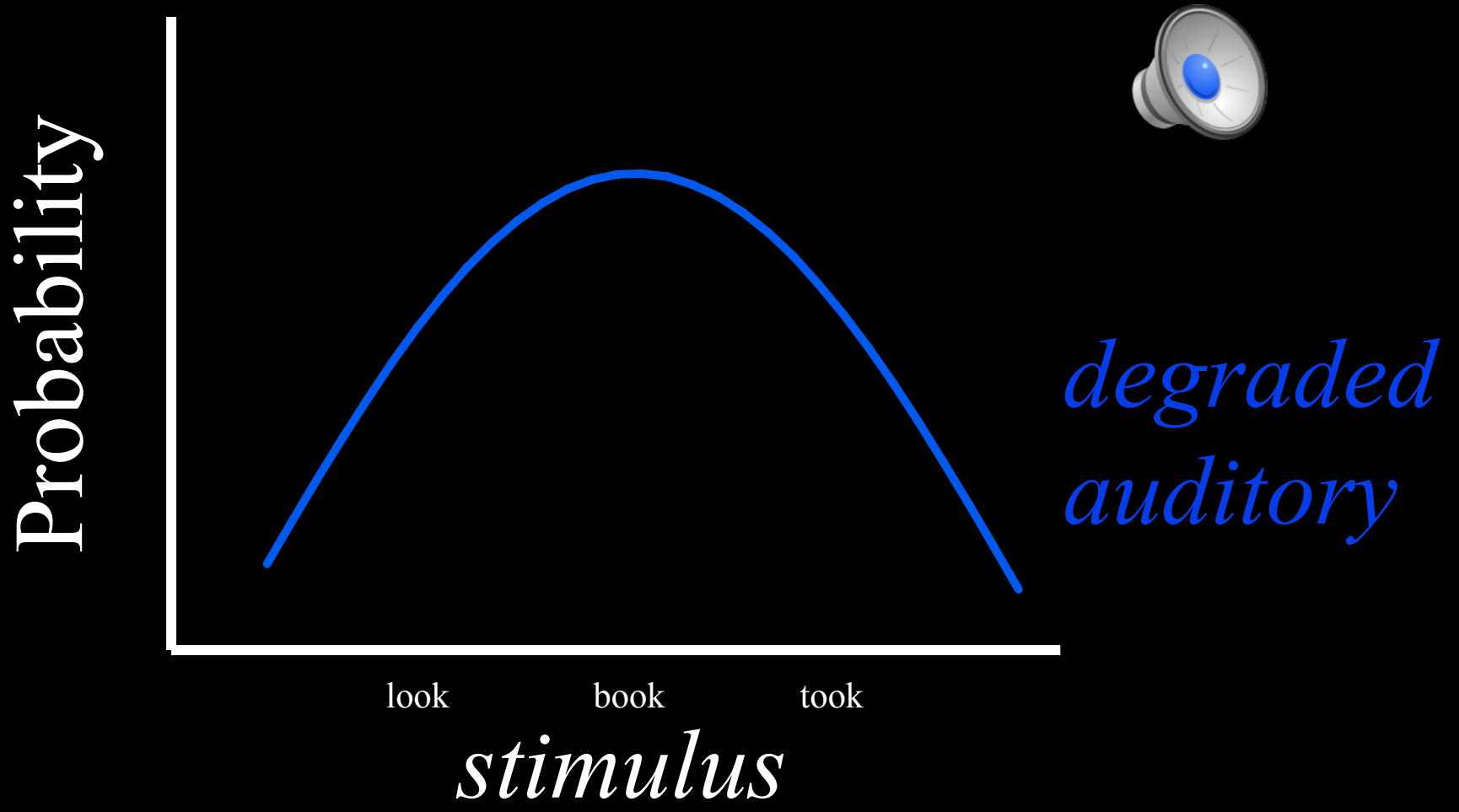
Ernst and Banks (2002); Alais and Burr (2004); Battaglia at el (2003); Pouget et al (2004); Ma et al (2006)
Saunders, Knill, Jacobs (1999); Young et al. (1993); Landy & Kojima (2001)

Bayesian approach

- Bayesian Approach: Statistical Inference for Optimal Perception
- calculate probability of a real-world event given an observation, combined with information about prior probability of the event
- Ernst and Banks (2002); Alais and Burr (2004); Battaglia at el (2003); Pouget et al (2004); Ma et al (2006)
- also known as cue integration; maximum-likelihood estimation
- Saunders, Knill, Jacobs (1999); Young et al. (1993); Landy & Kojima (2001)

Bayesian Approach



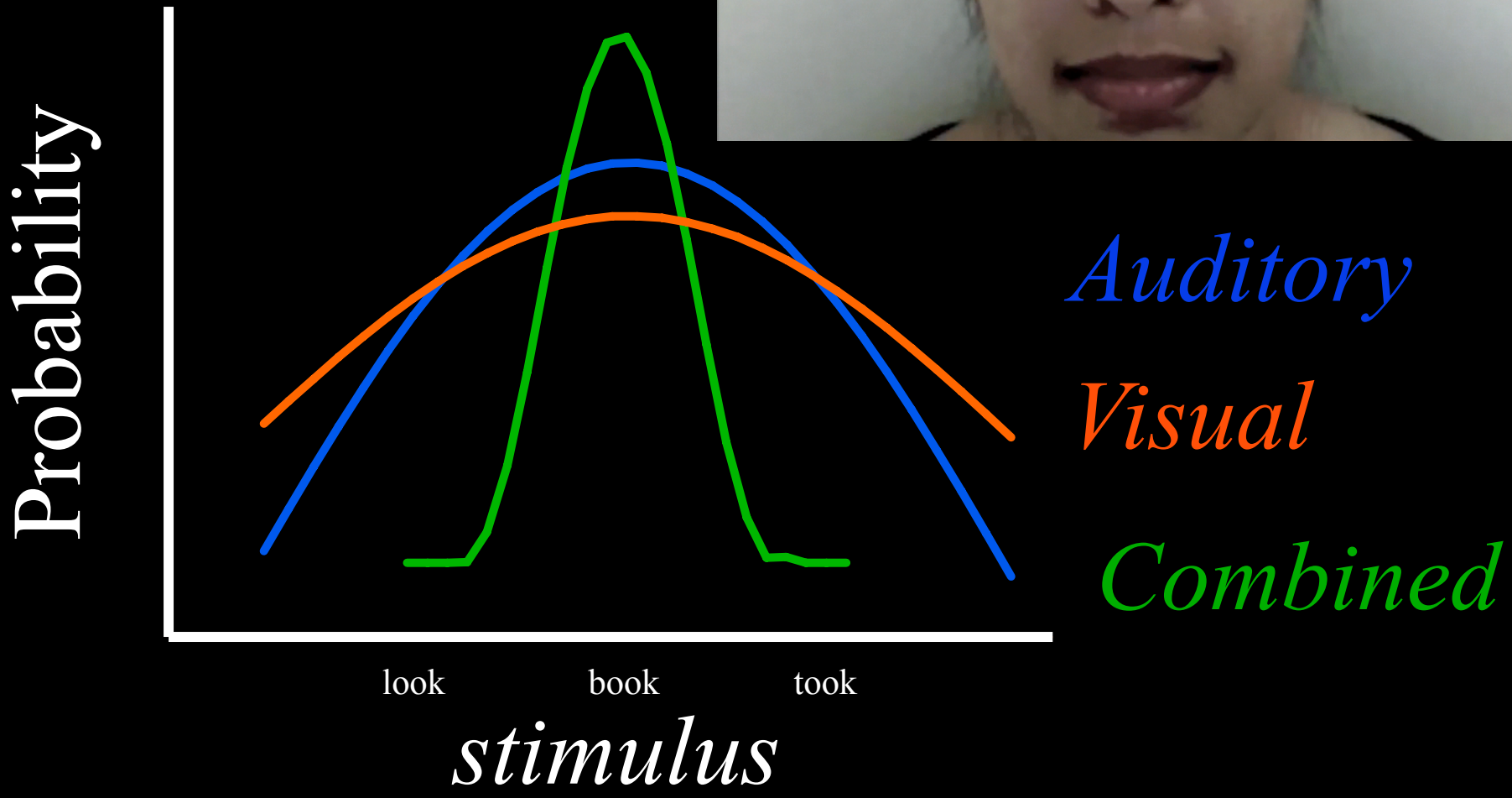

Probability
look
book
took
stimulus
degraded
auditory

Probability

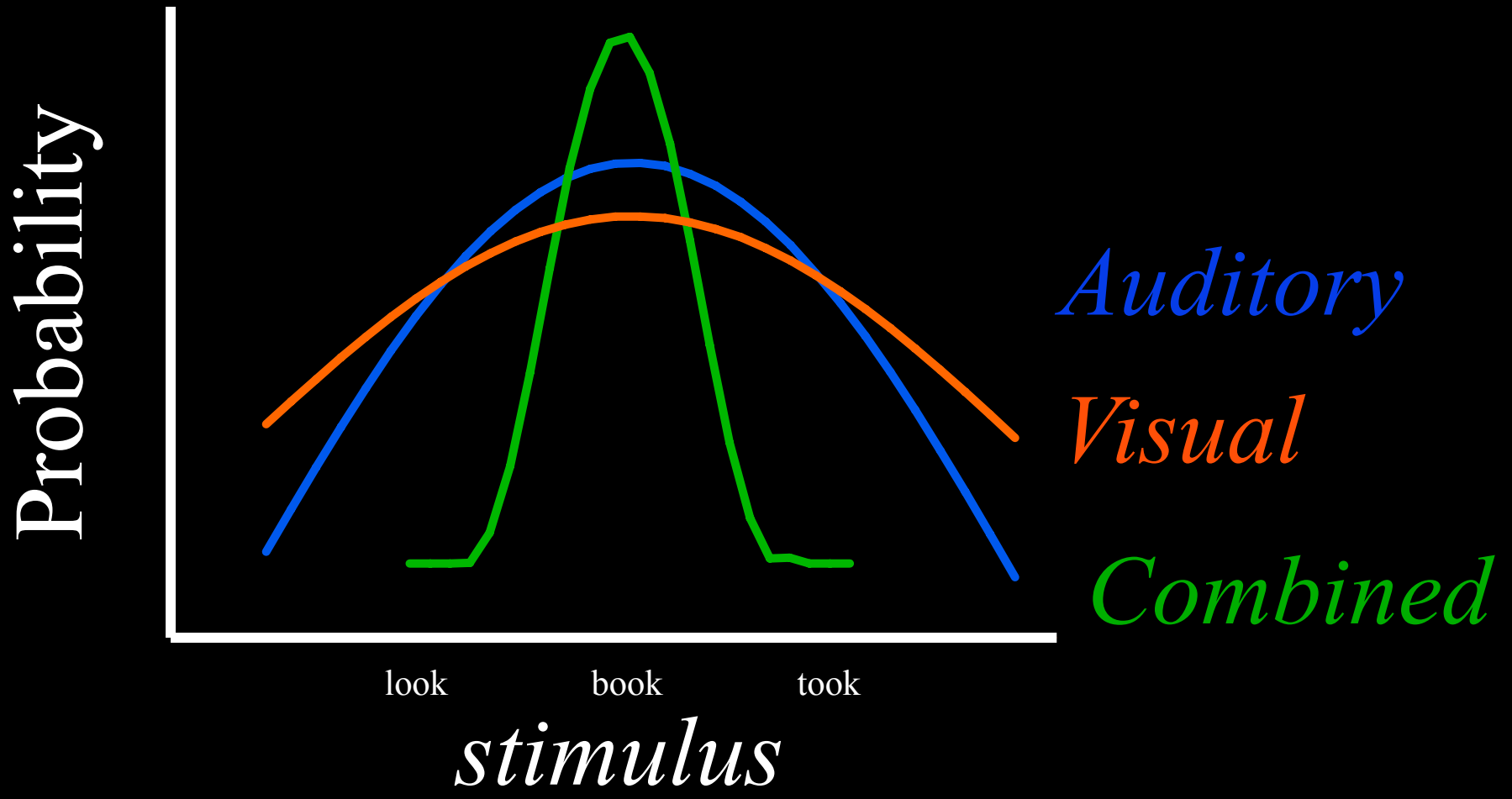
look book took

stimulus

Visual


Probability
look
book
took
stimulus
Auditory
Visual
Combined

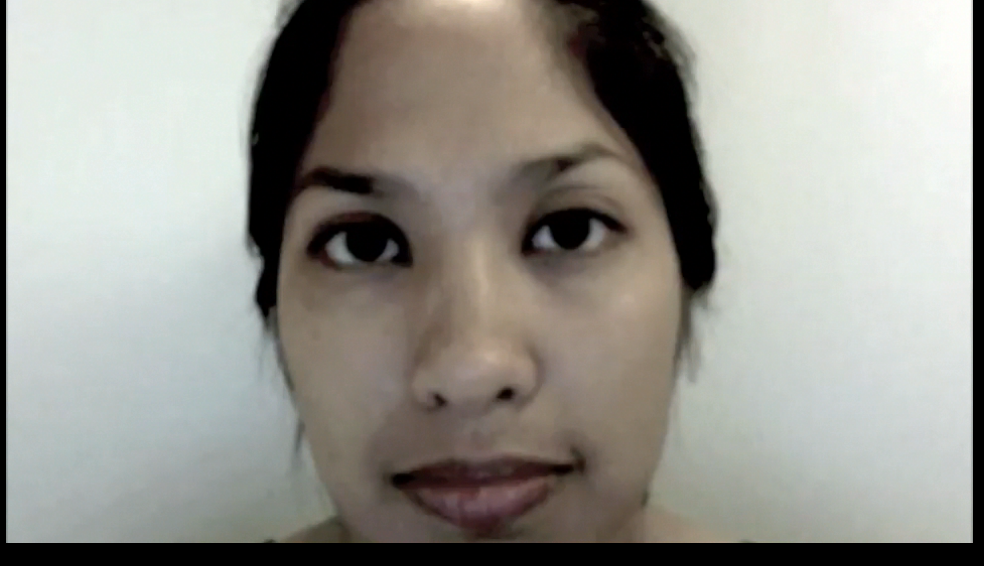
$$\sigma_{AB}^2 = \frac{\sigma_A^2 \sigma_B^2}{\sigma_A^2 + \sigma_B^2}$$



Reliability-Weighted Integration

Auditory-only

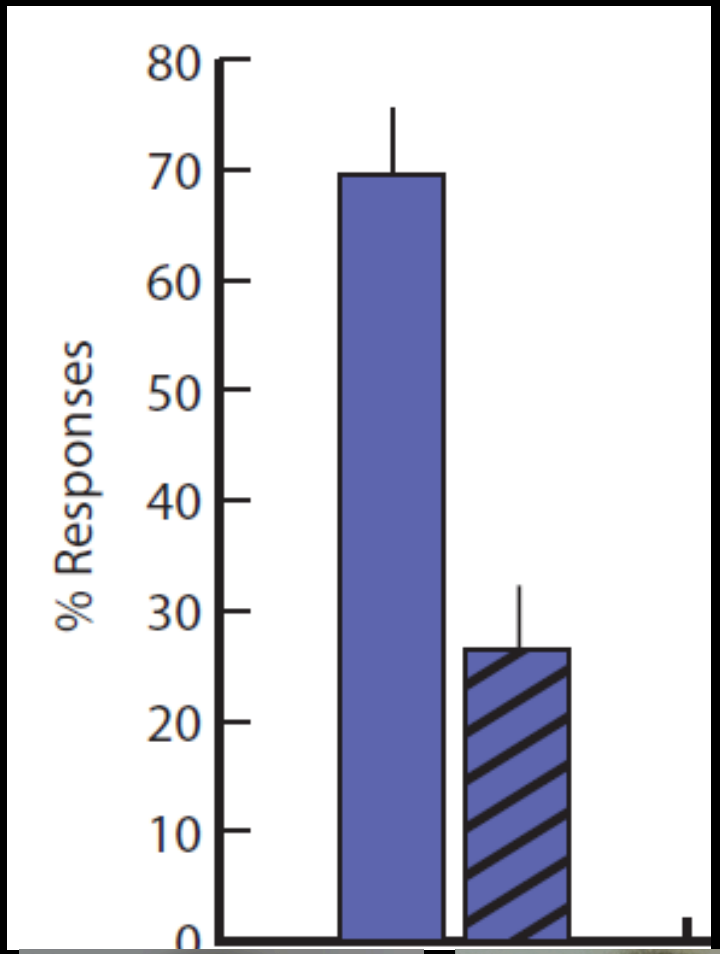
Visual-only

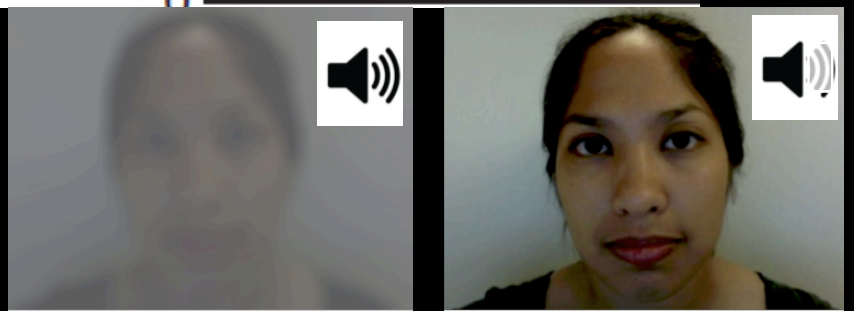


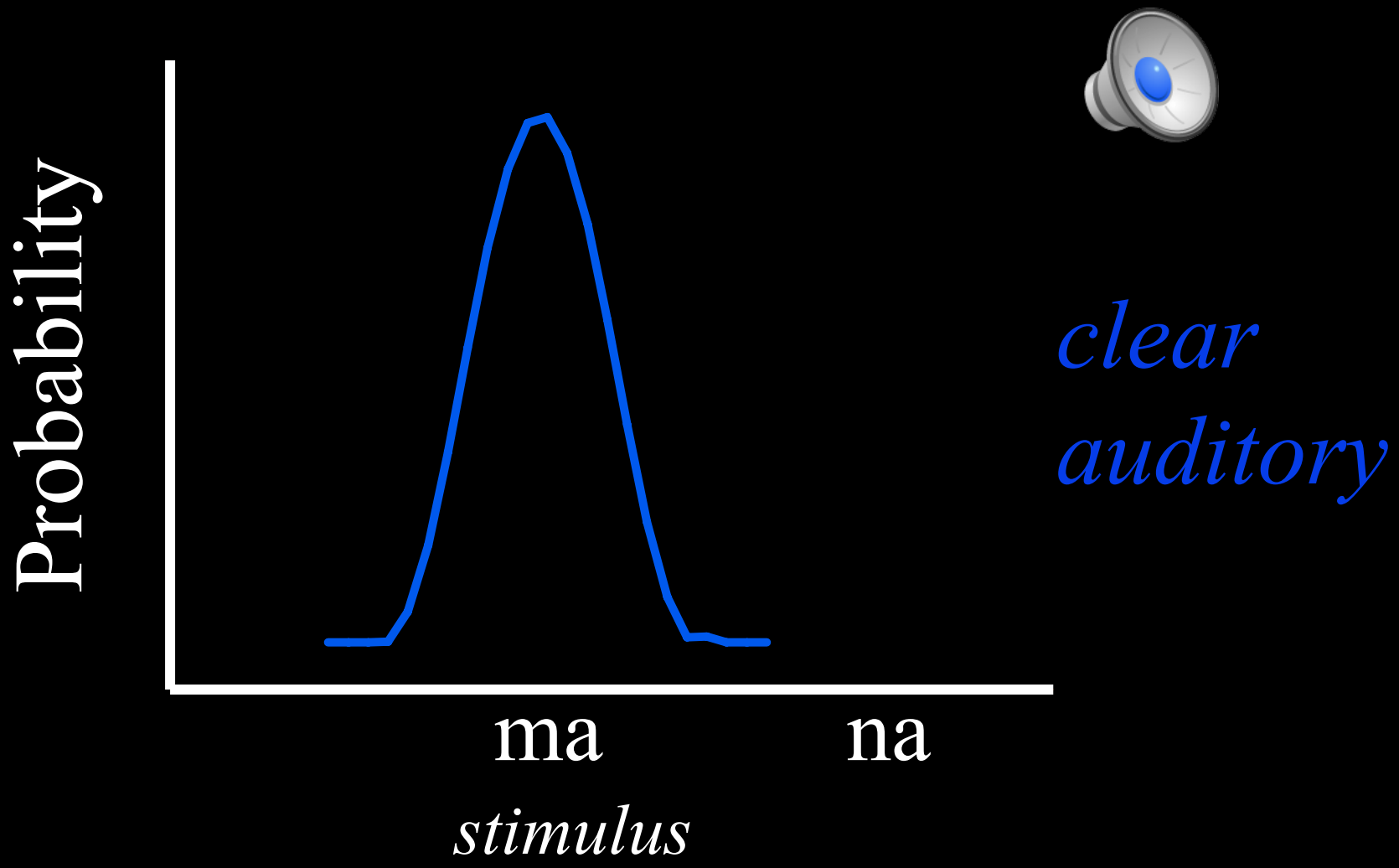
Degraded Auditory

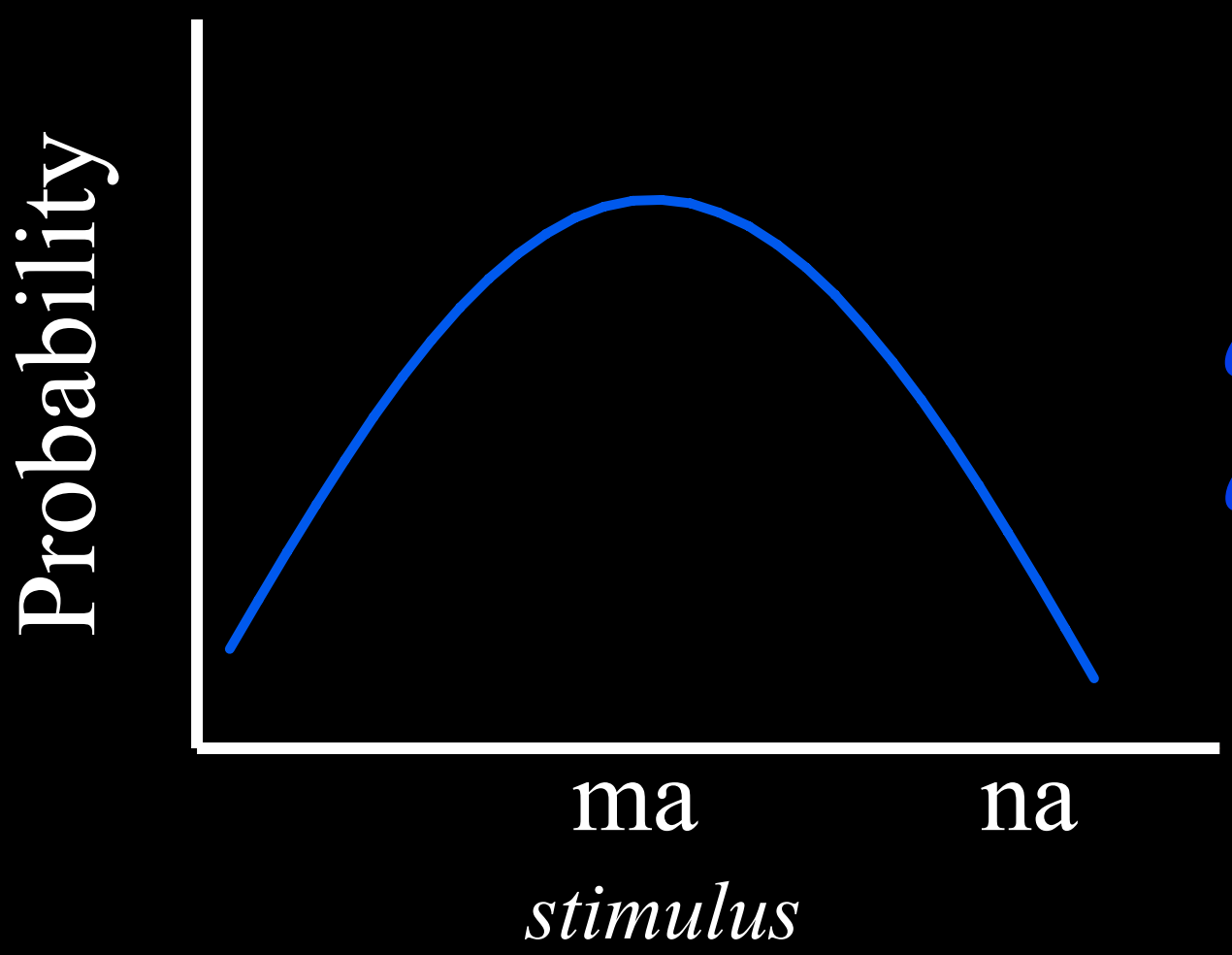
Incongruent auditory-visual stimuli

Incongruent auditory-visual stimuli






Probability
ma
na
stimulus
clear
auditory



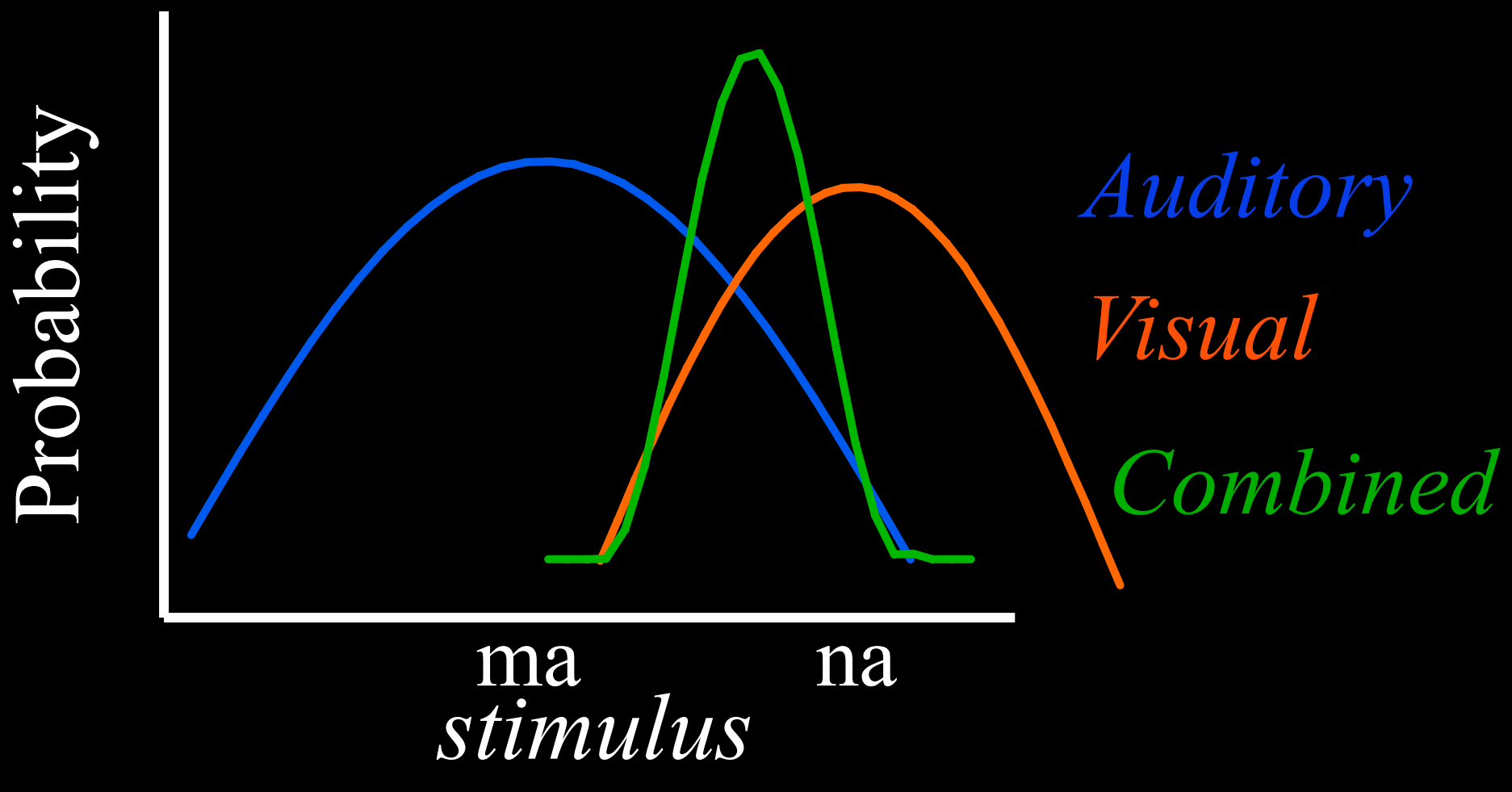
degraded auditory

Probability

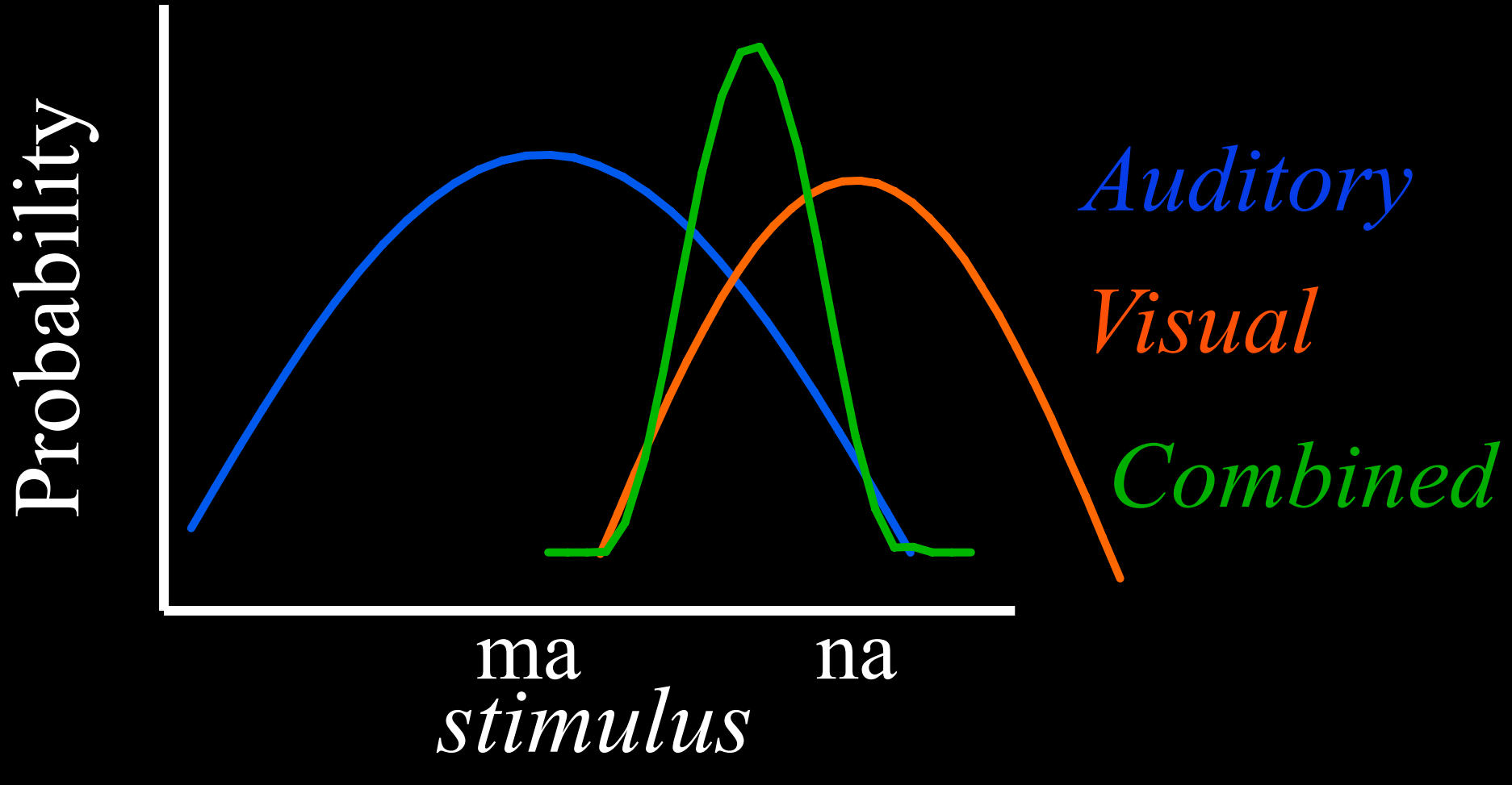
Visual

ma na

stimulus

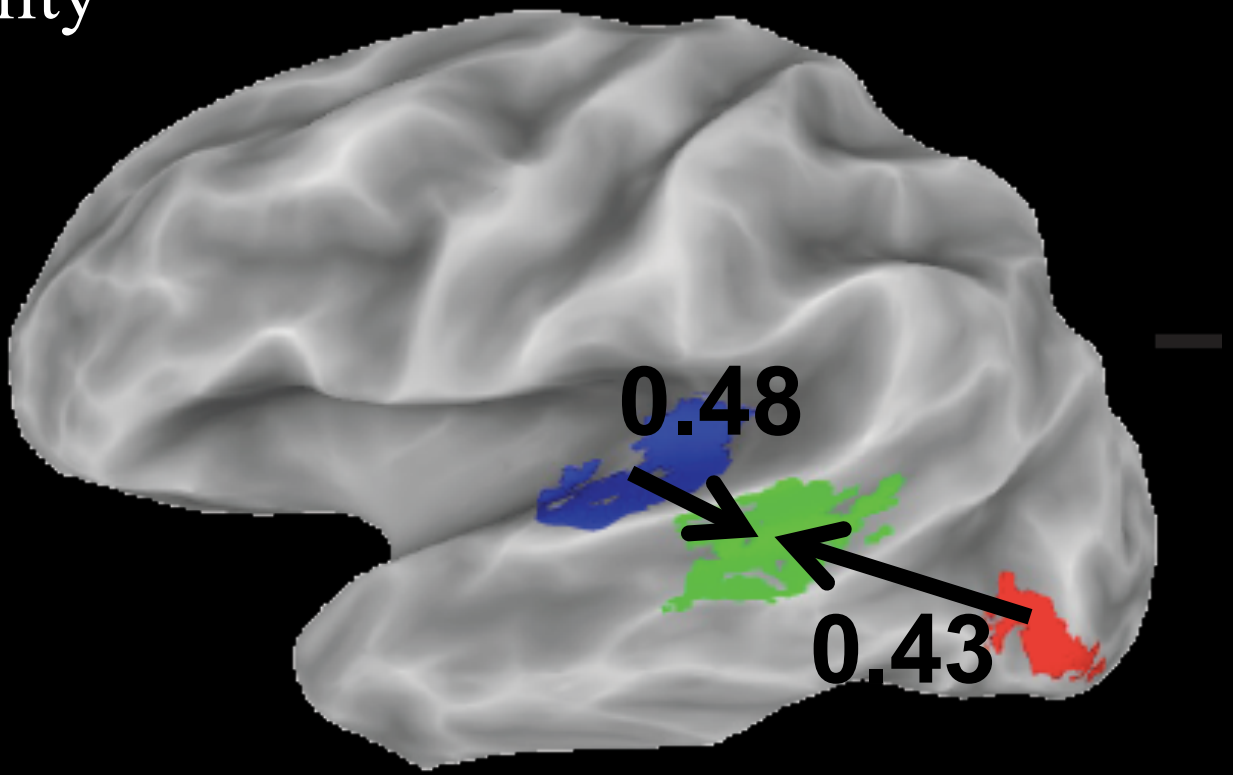

Probability
Auditory
Visual
Combined
ma
na
stimulus

$$\hat{S} = \sum_i w_i \hat{S}_i \quad w_i = \frac{1/\sigma_i^2}{\sum_j 1/\sigma_j^2}$$

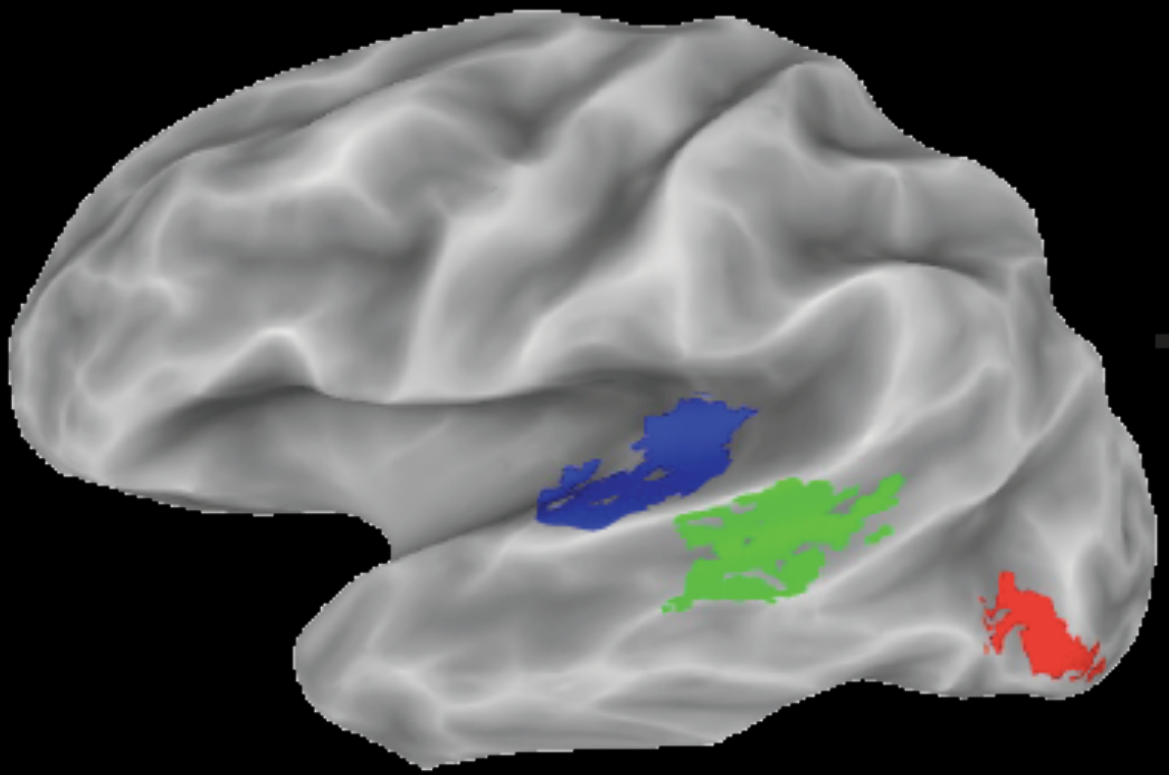


Hypothesis

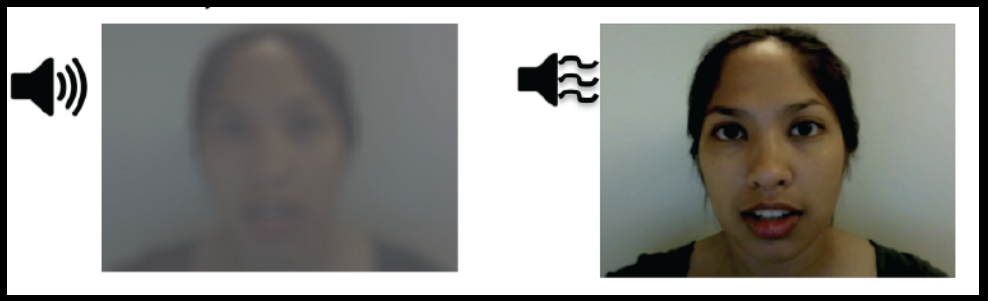
- Functional connectivity reflects stimulus reliability



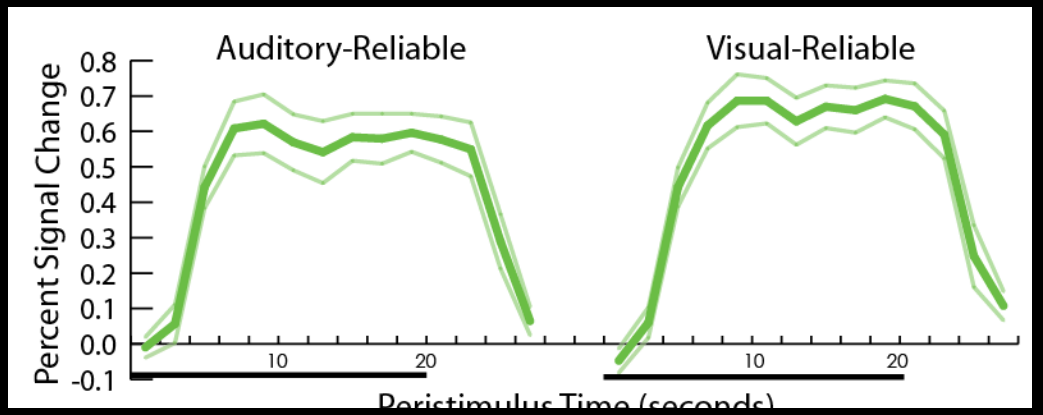
Methods I: Functional Localizers



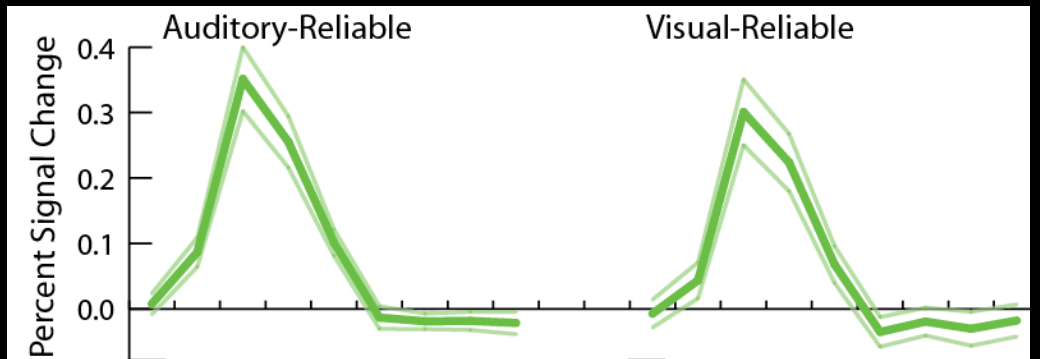
STS responses



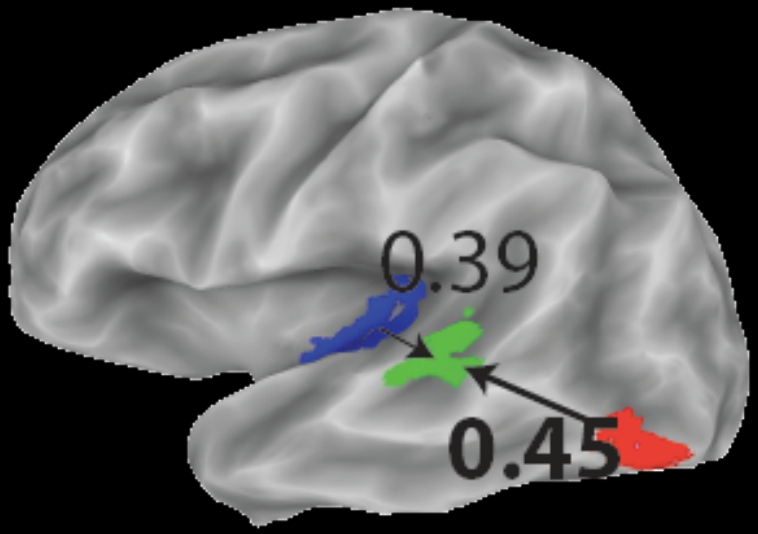
Expt 1

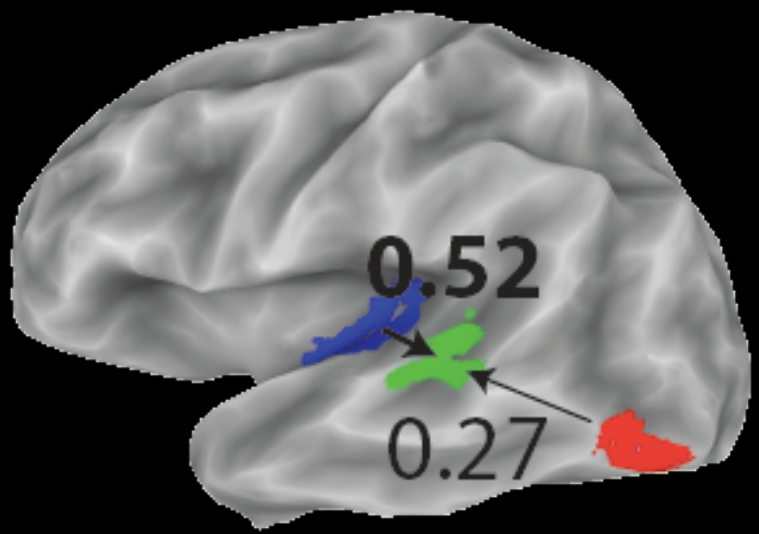


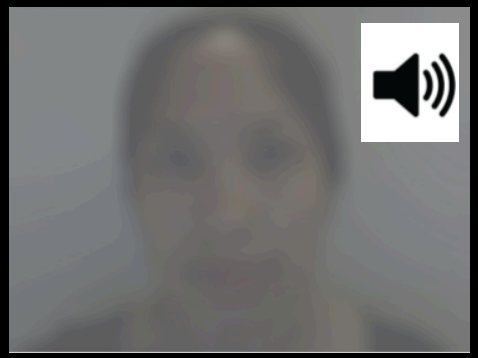
Expt 2



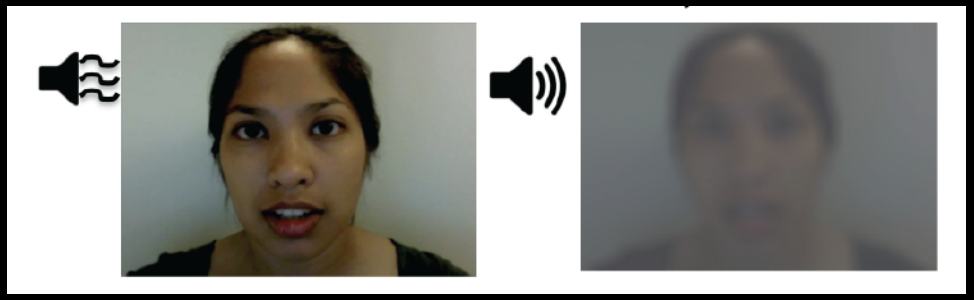
Results: Experiment 1, one subject

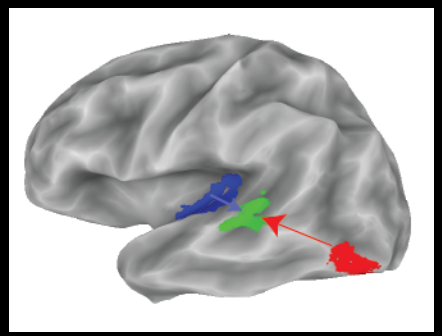


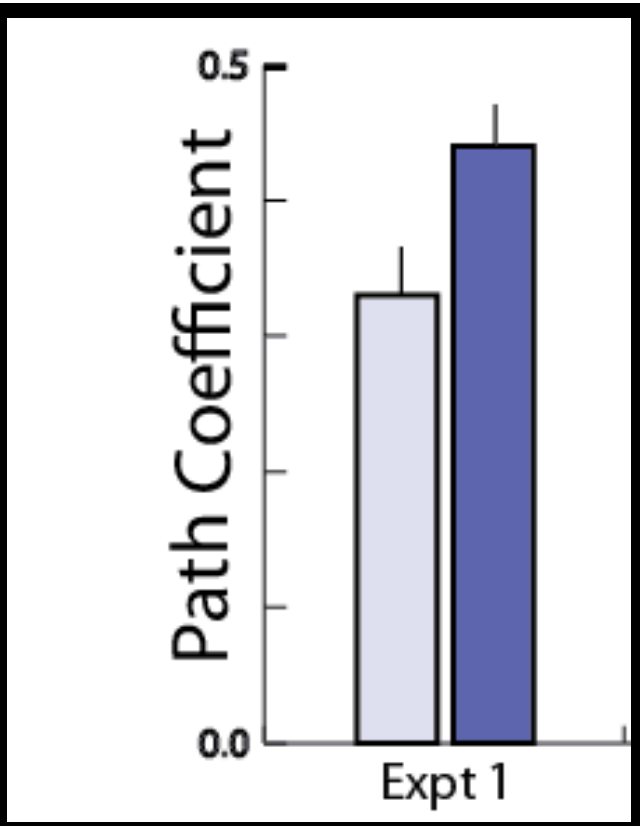




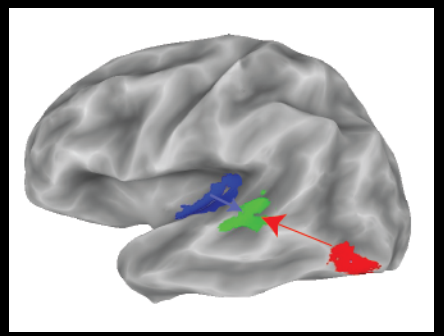
Auditory Cortex to STS

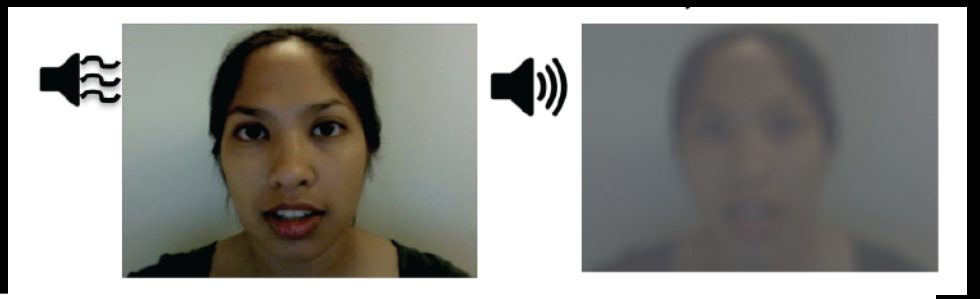


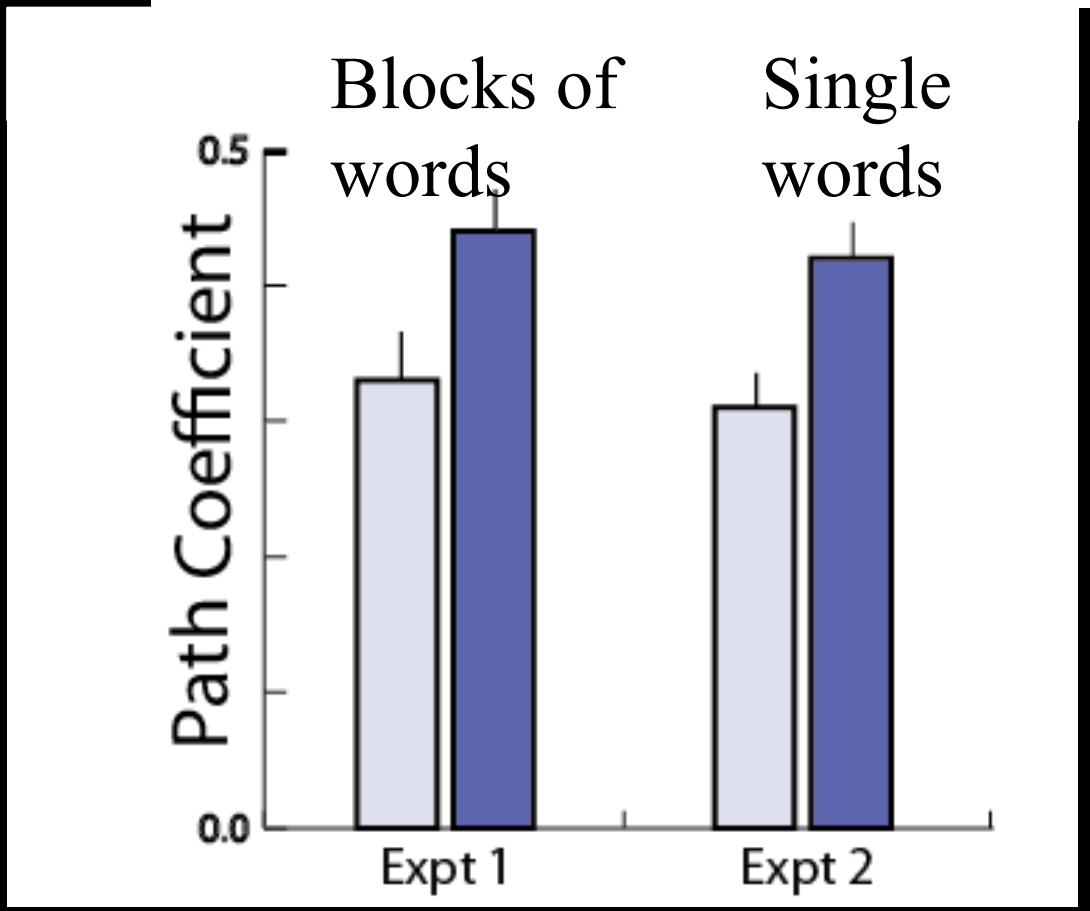




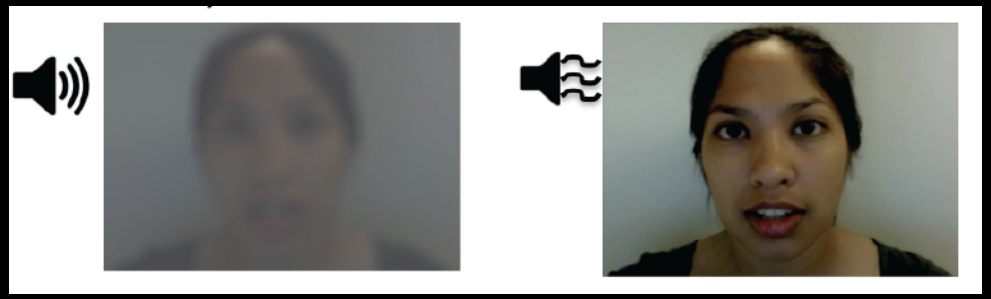
Auditory Cortex to STS

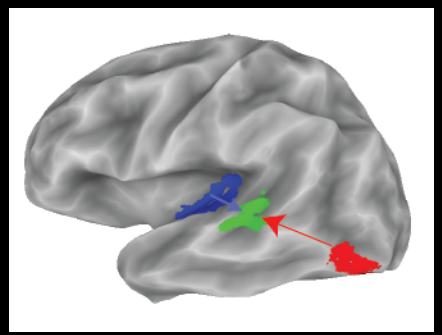


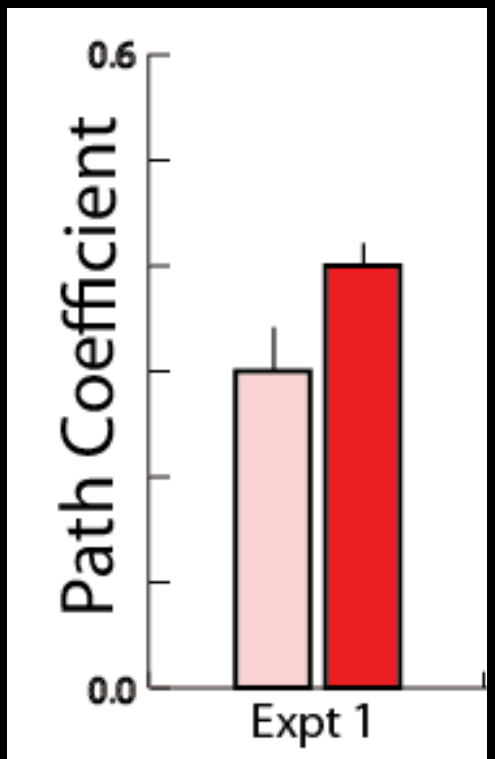




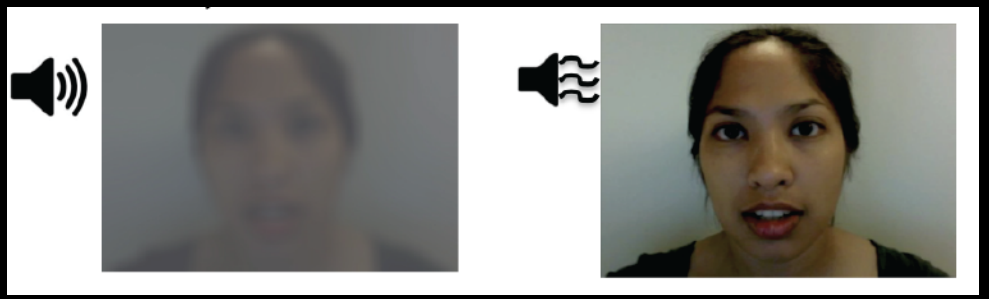
Visual Cortex to STS

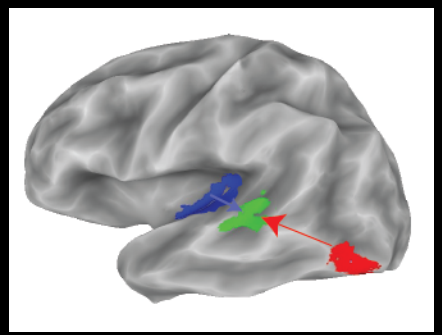


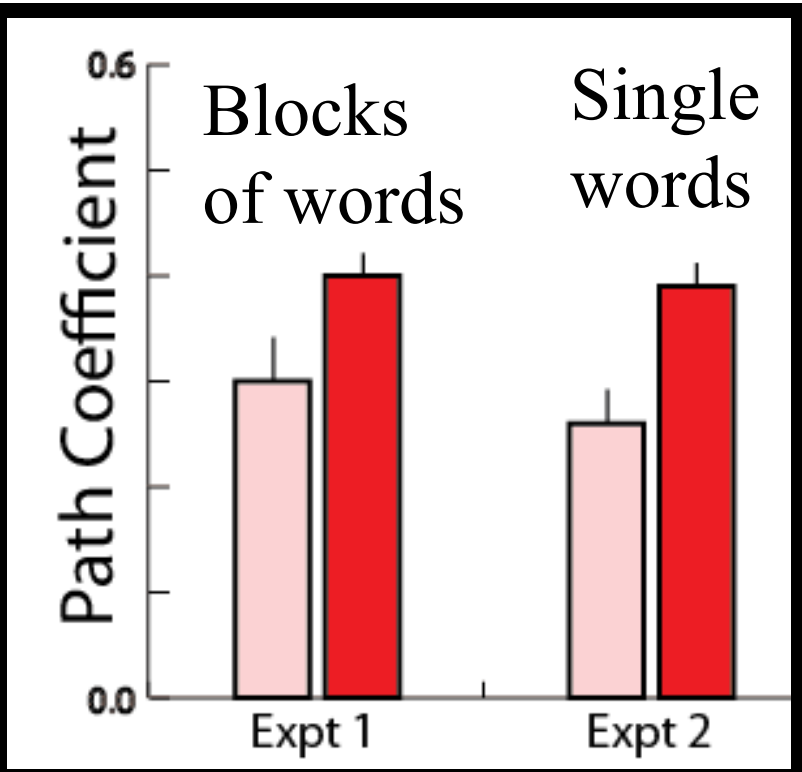




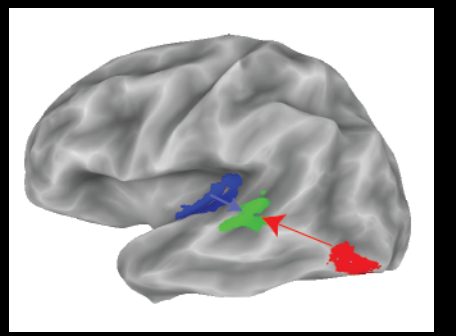
Visual Cortex to STS

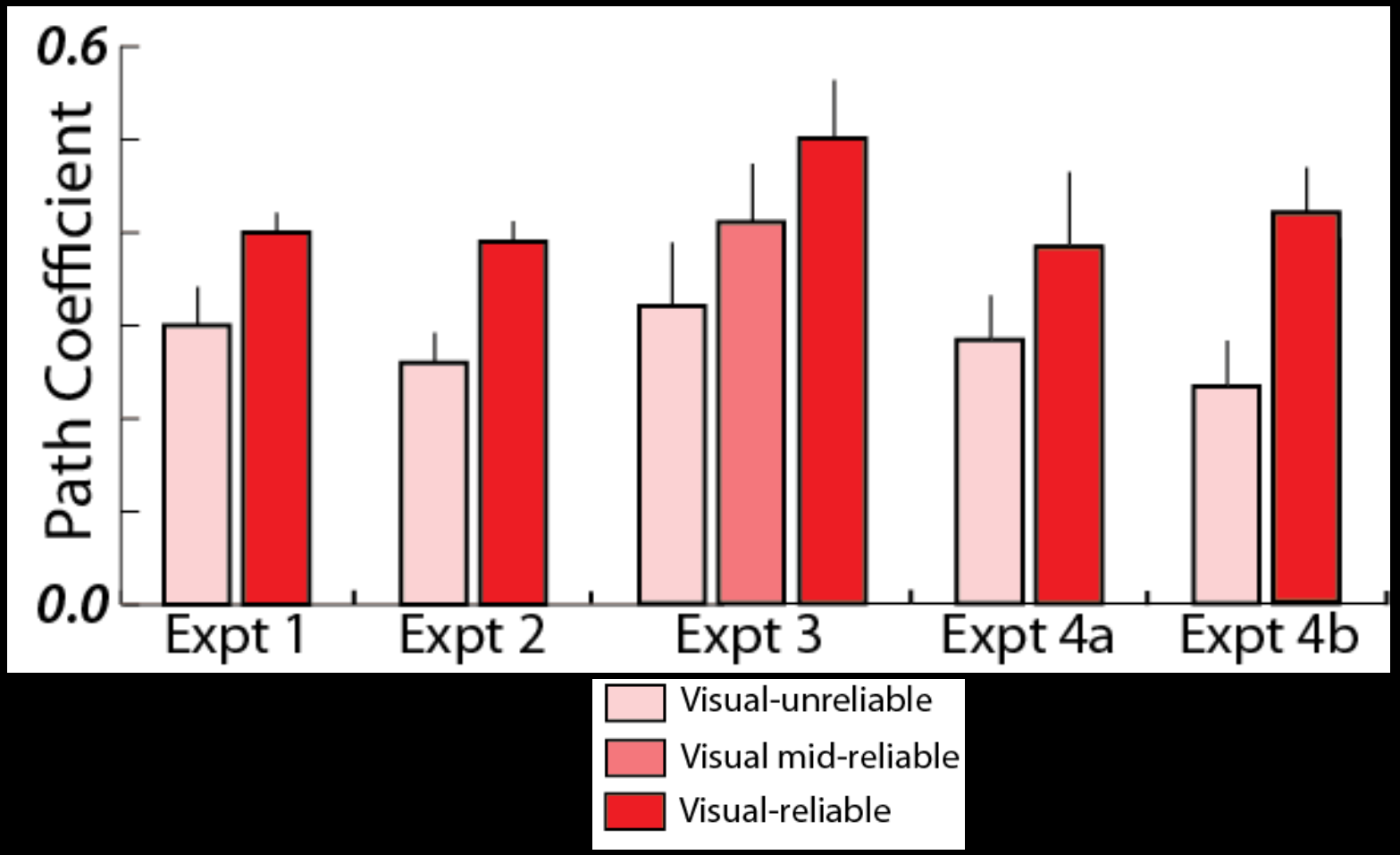






Visual Cortex to STS





Part 4: Summary

- Behaviorally, multisensory integration is optimal: humans perform similarly to ideal observers, weighting each sensory modality by its reliability
- Optimal mutisensory perception is an emergent property of cortical networks: functional connections between sensory areas and multisensory areas are weighted by the reliability of each modality
- Changes in functional connectivity within the network are a strong candidate mechanism for behavioral reliability-weighting

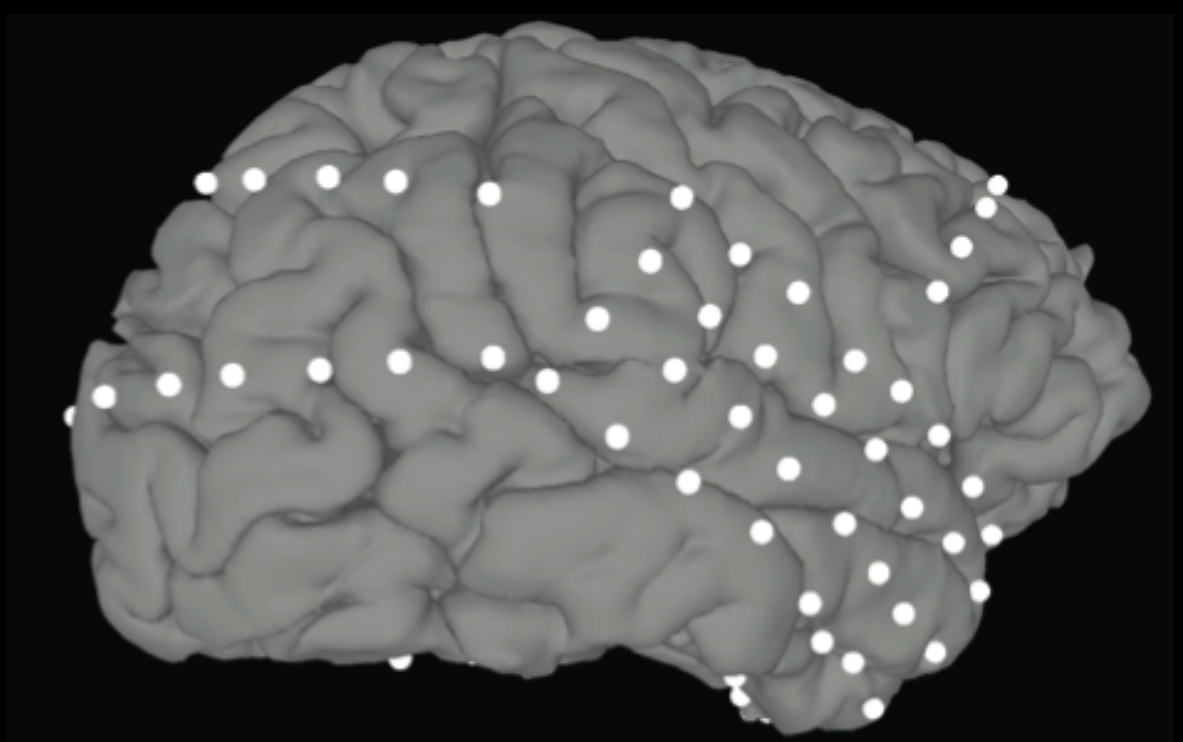
How we've tackled these problems

- What do the blobs mean?
  - Is activity in the area linked to behavior or perception?
  - Is activity in an area truly required for a cognitive function?
- Poor match between analysis (simple) and data (complex)
  - How do areas operate as a network?
- Slow temporal resolution
  - Neuronal responses are on a ~ms time scale, fMRI operates on a ~sec time scale

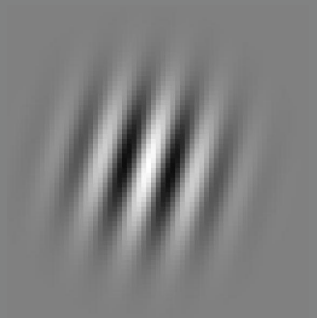
- Multisensory integration, esp. speech perception
- Temporary and permanent lesions of the STS
- Link between STS activity and perception of multisensory speech
- Connectivity of the STS during speech perception
- Electrocorticography with ms time resolution (TPJ)

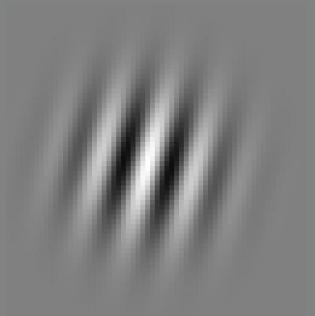
Part 5: Conscious Perception of Visual Stimuli

eCoG and eStim

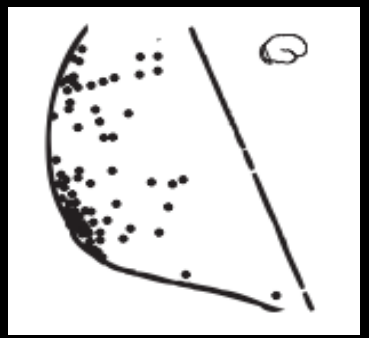


Methods

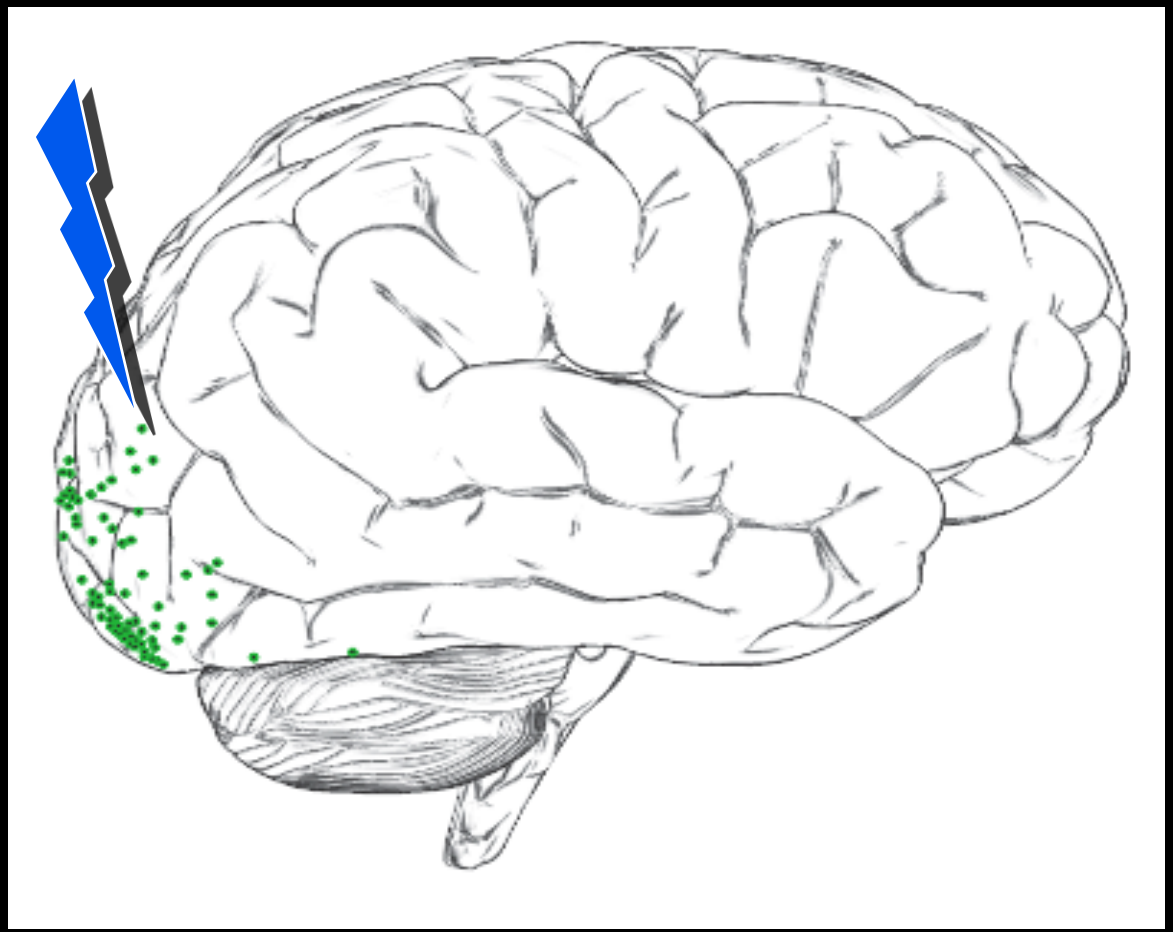




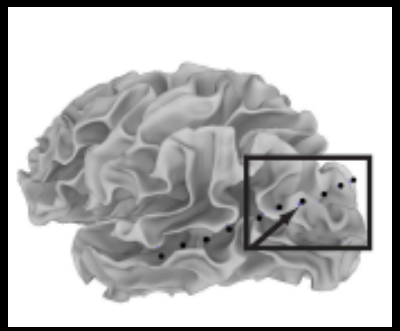
eStim: stimulating the occipital lobe produces phosphenes.

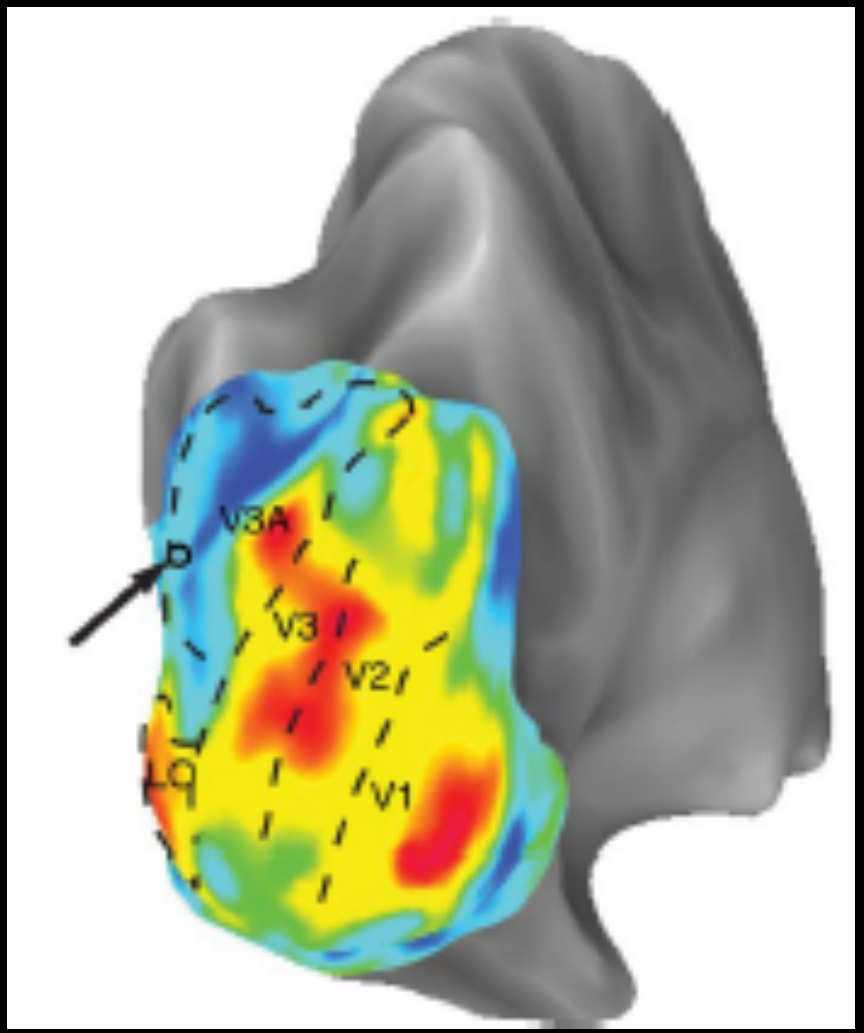


Penfield



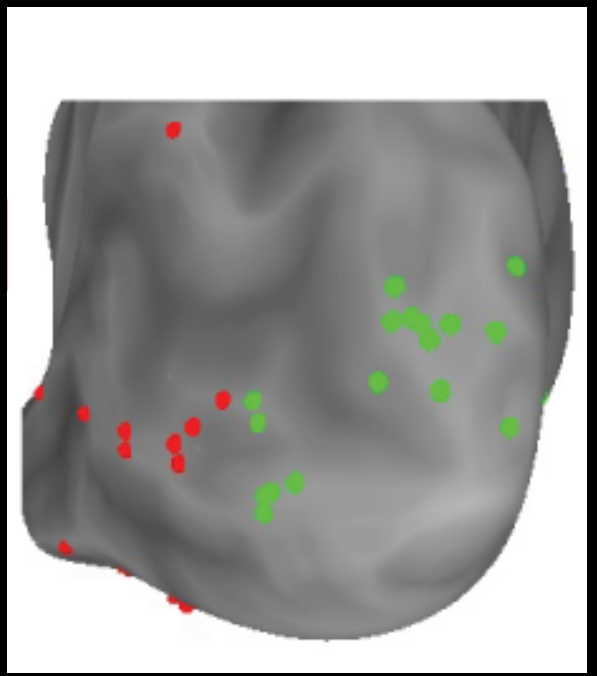
Retinotopic maps with BOLD fMRI combined with electrical stimulation

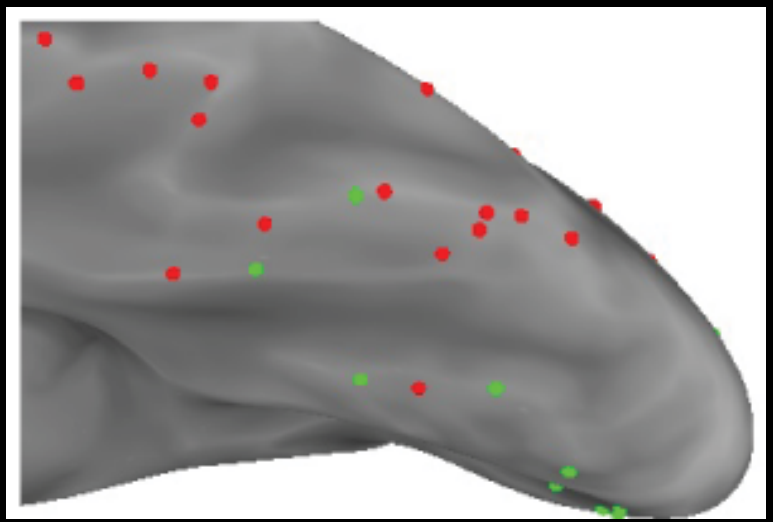


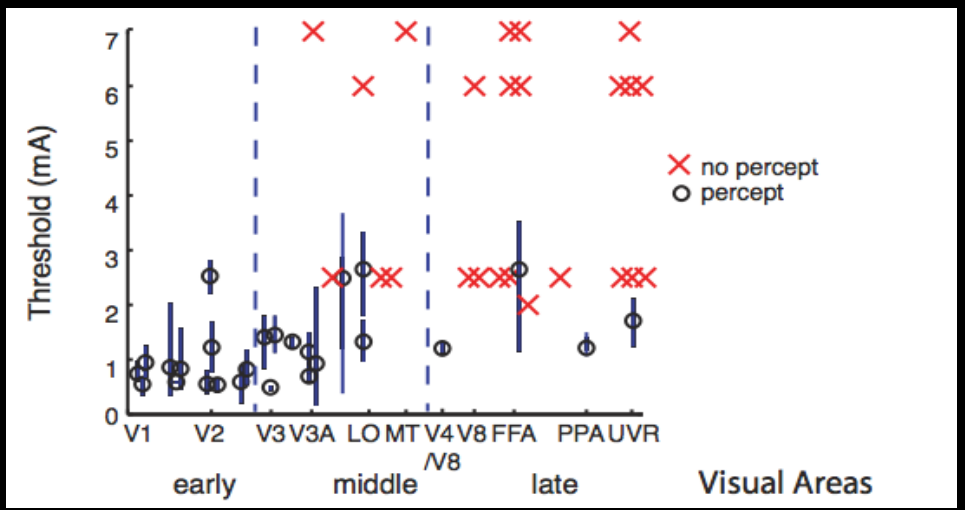


Murphey, Maunsell, Beauchamp, Yoshor, *PNAS* (2009)

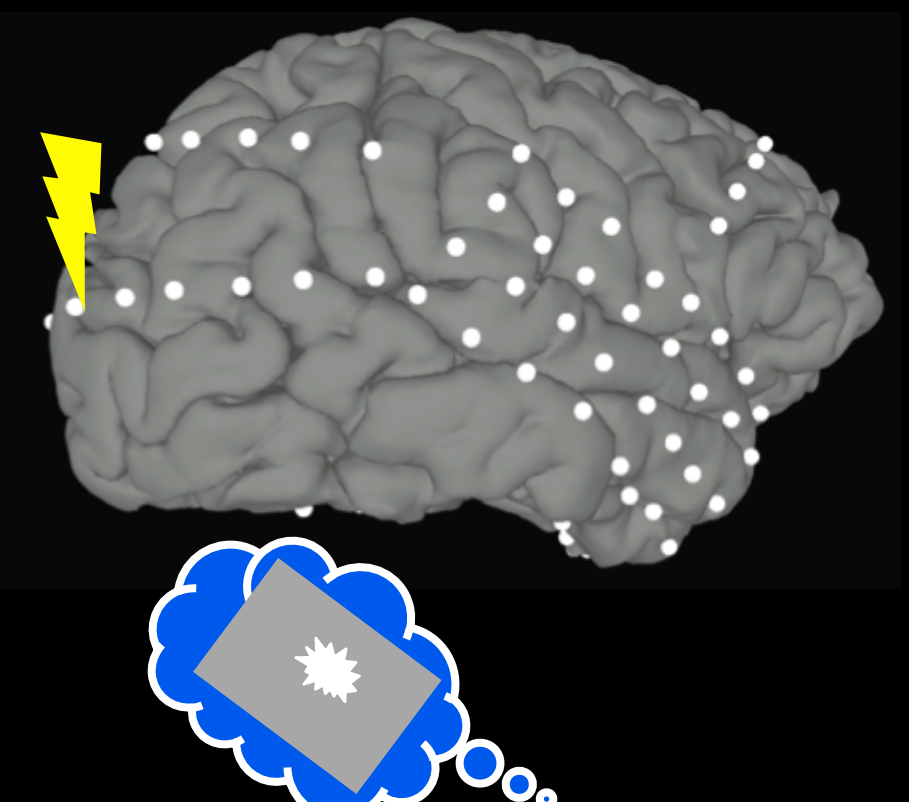
Electrical stimulation of some identified areas produces phosphenes.

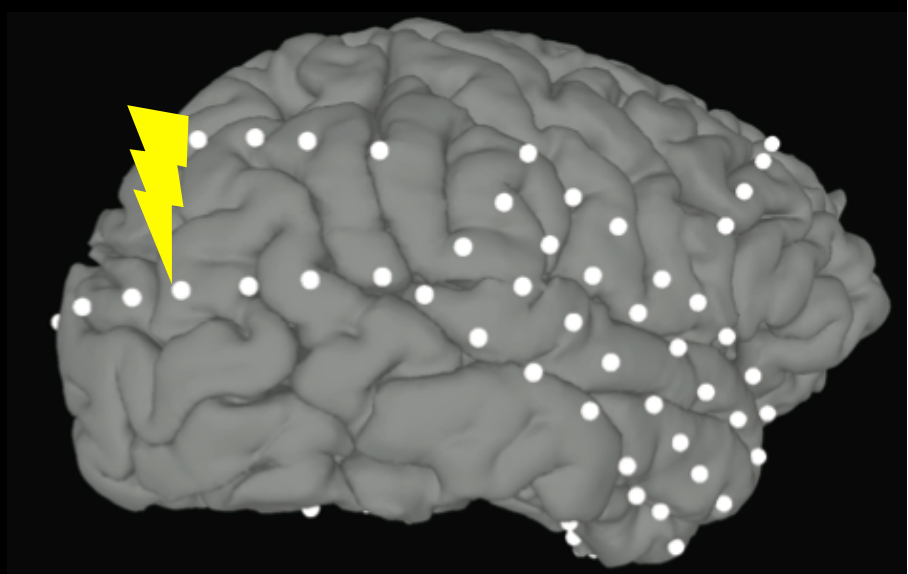




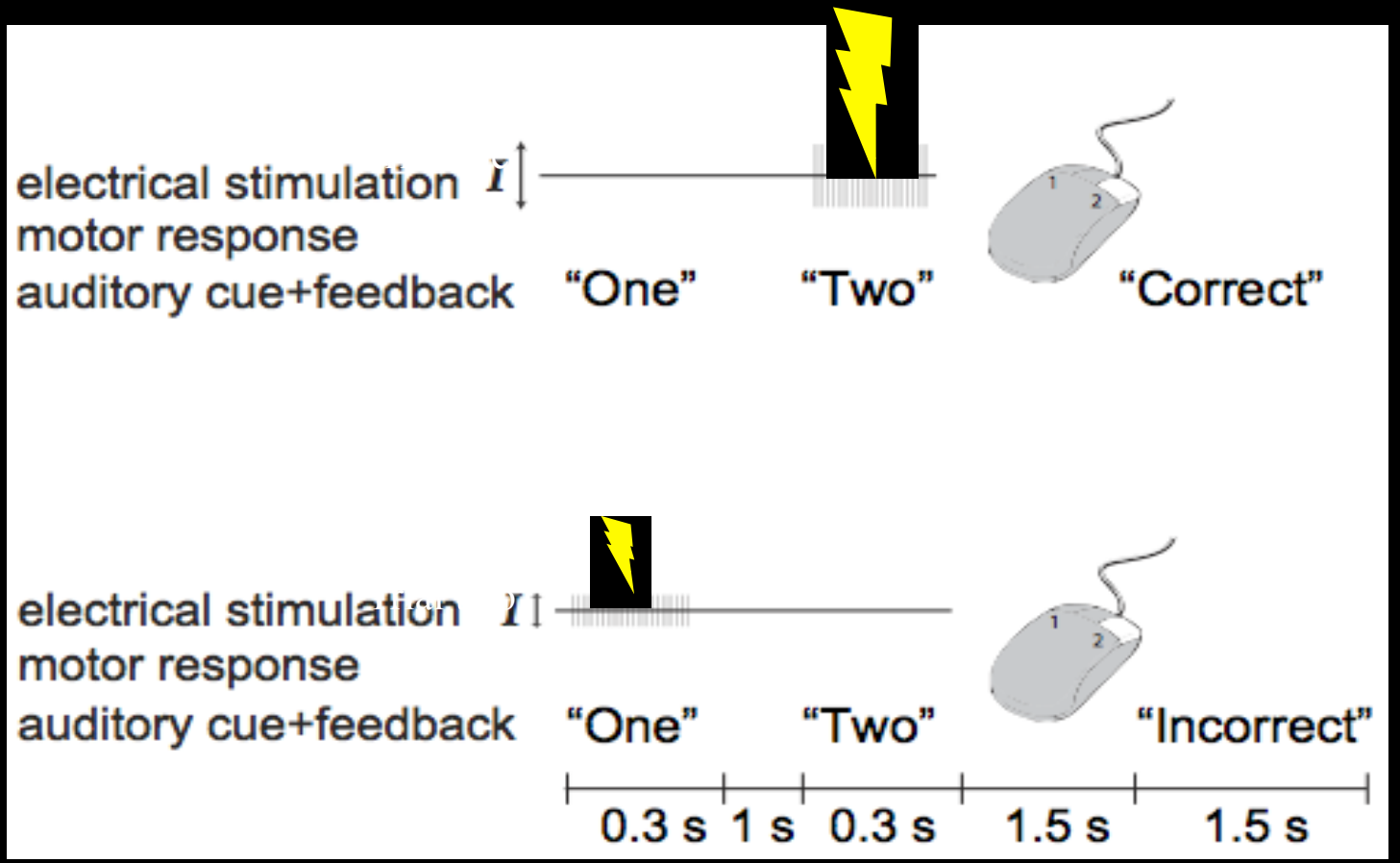


Electrical stimulation of only some brain areas produces phosphenes.





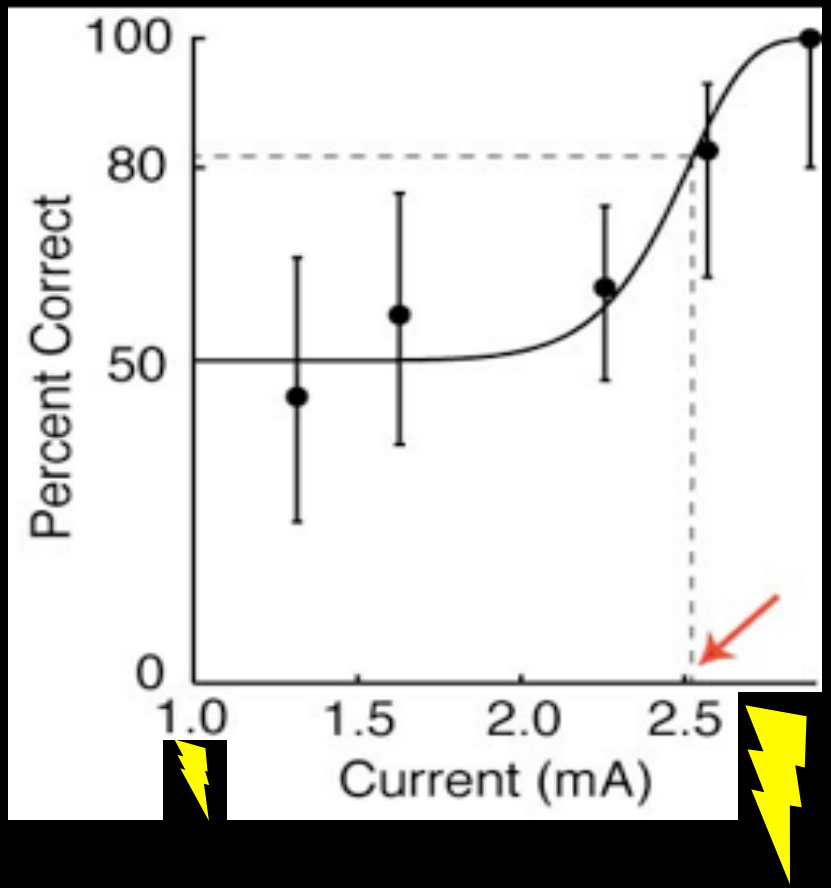
Quantifying detectability of electrical stimulation trial by trial



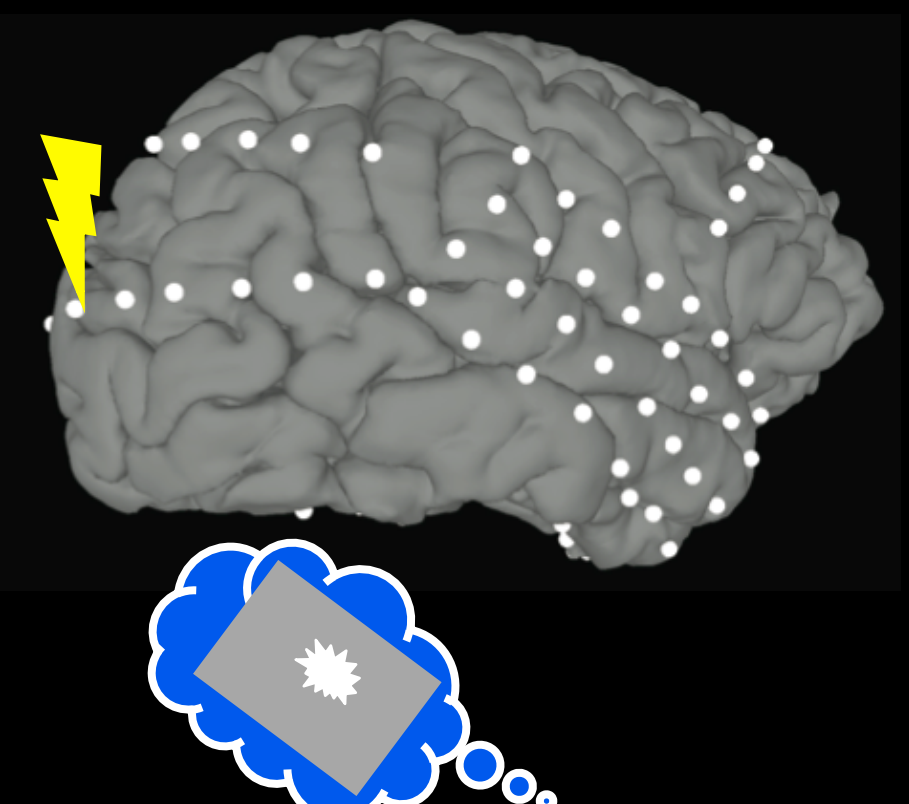
Murphey, Maunsell, Beauchamp, Yoshor, *PNAS* (2009)

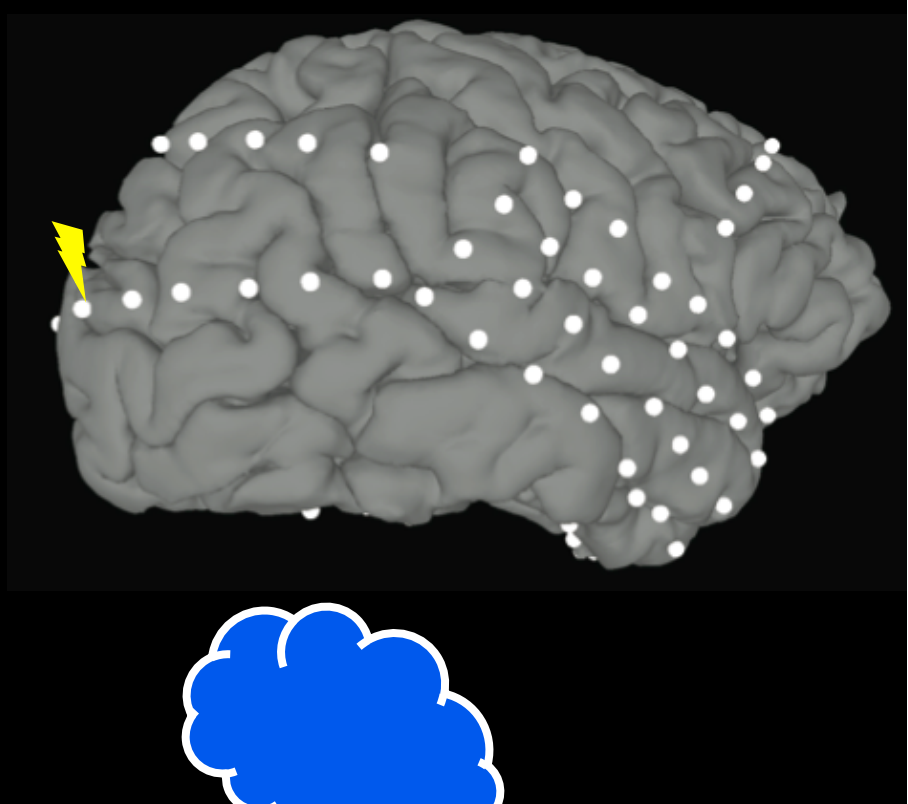
Performance at different currents for one electrode

V1 - subject 1SG4

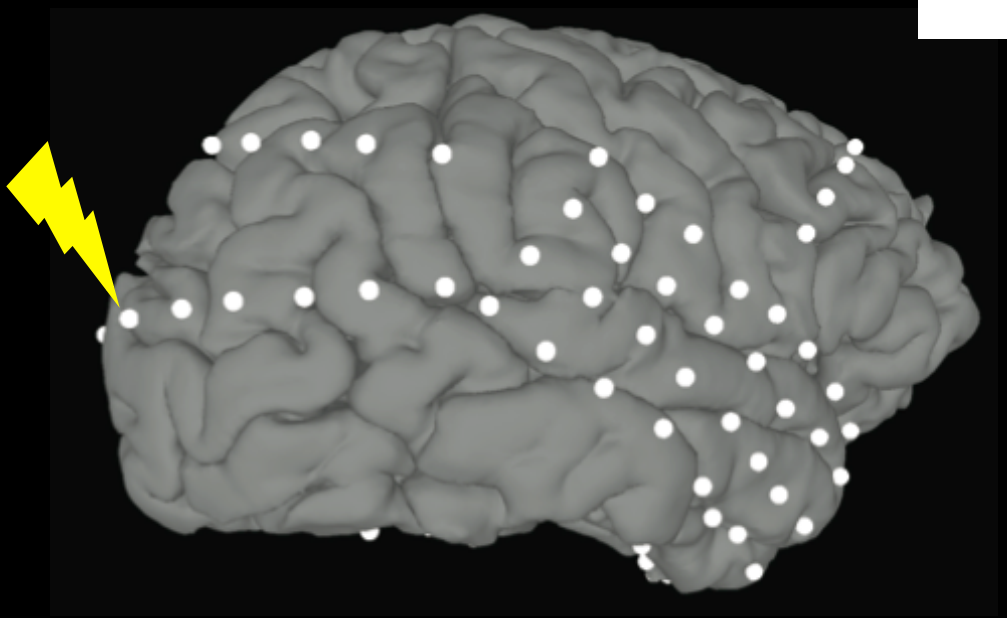


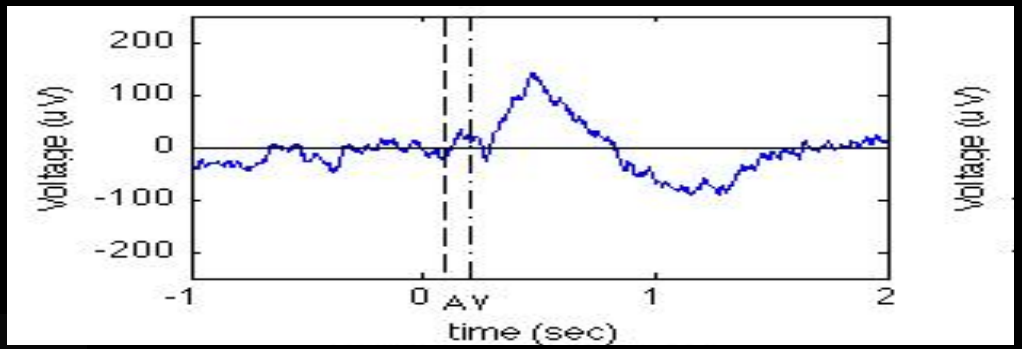
There is a current threshold for phosphene production

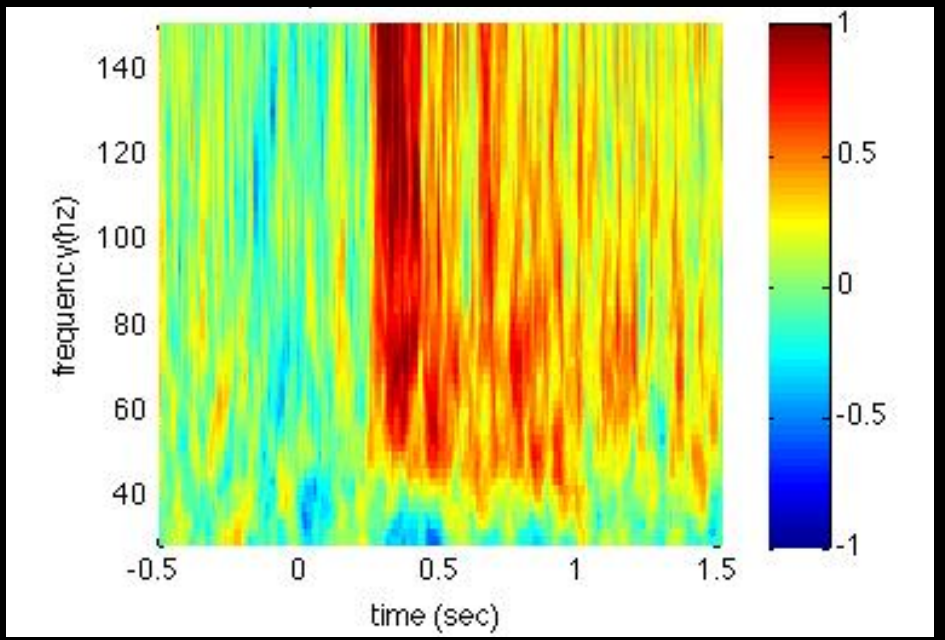


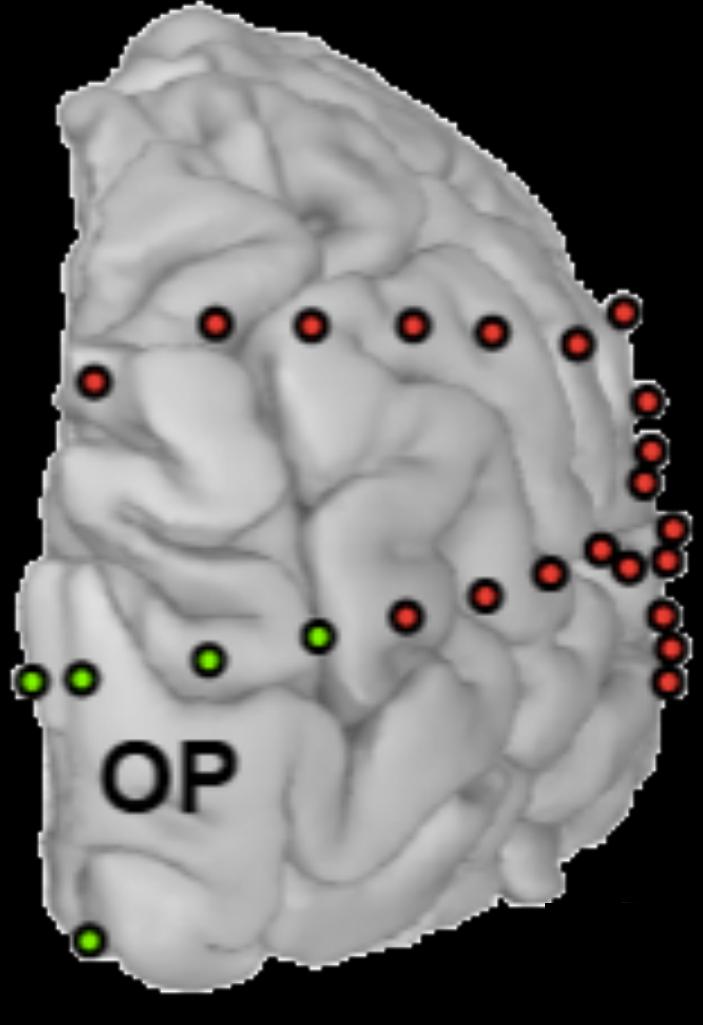


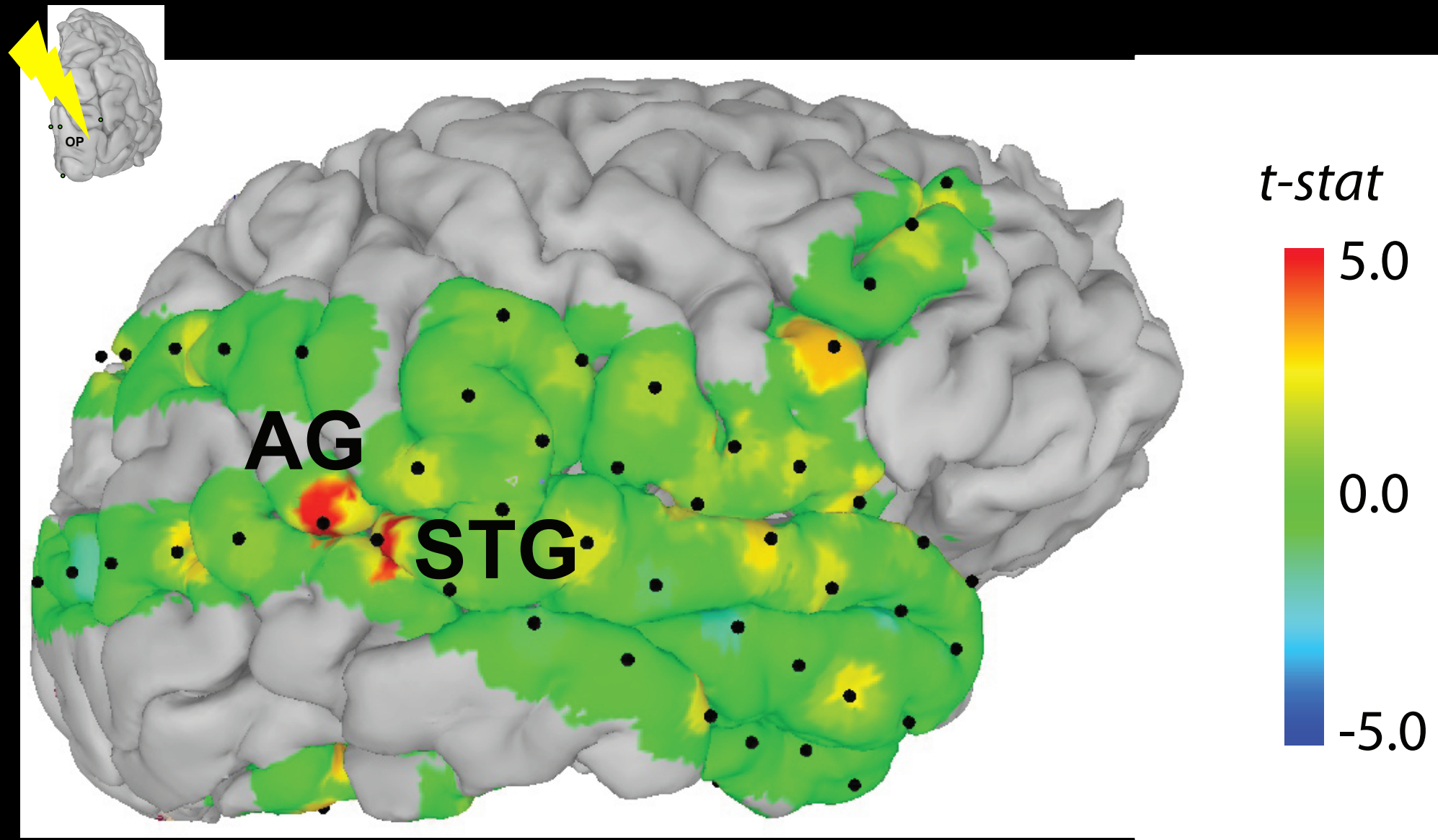
Stimulate AND Record

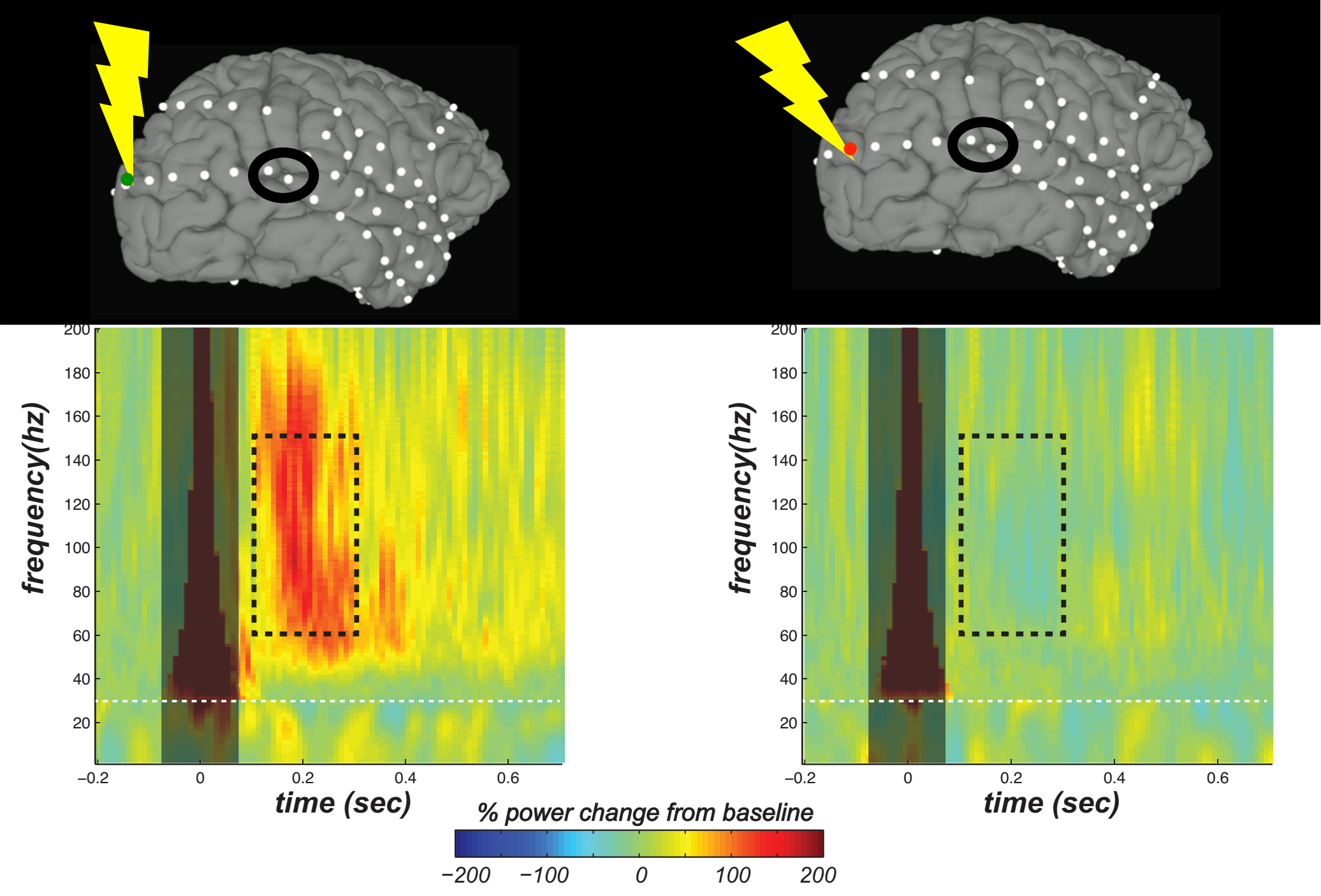


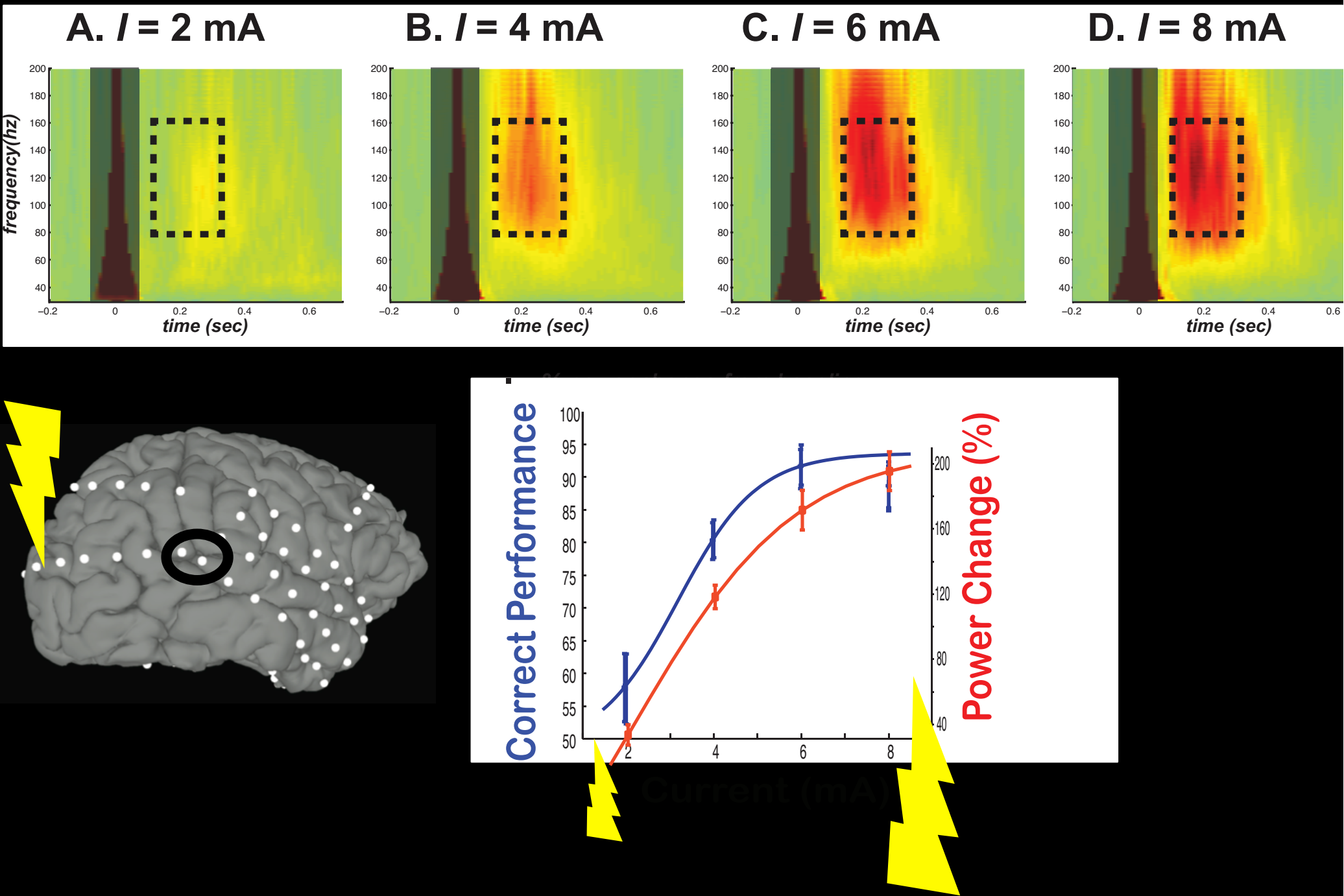




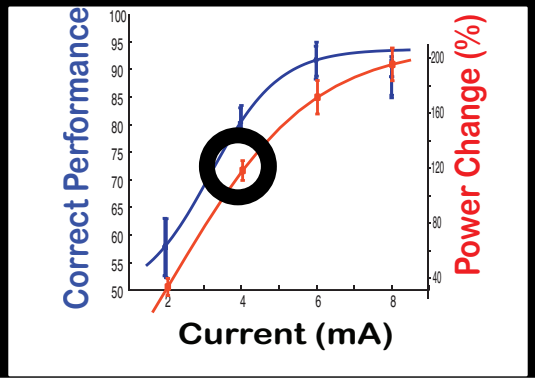

OP


OP
AG
STG
t-stat
5.0
0.0
-5.0

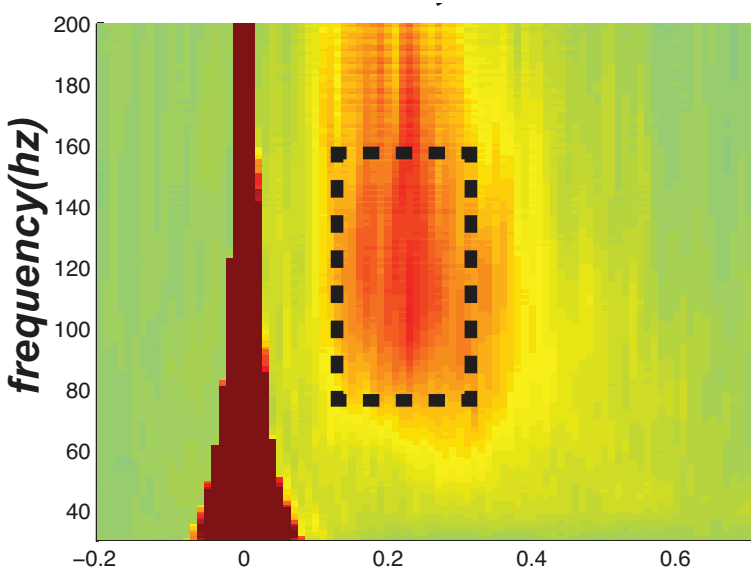

frequency(hz)
200
180
160
140
120
100
80
60
40
20
−0.2
0
0.2
0.4
0.6
time (sec)
% power change from baseline
−200
−100
0
100
200

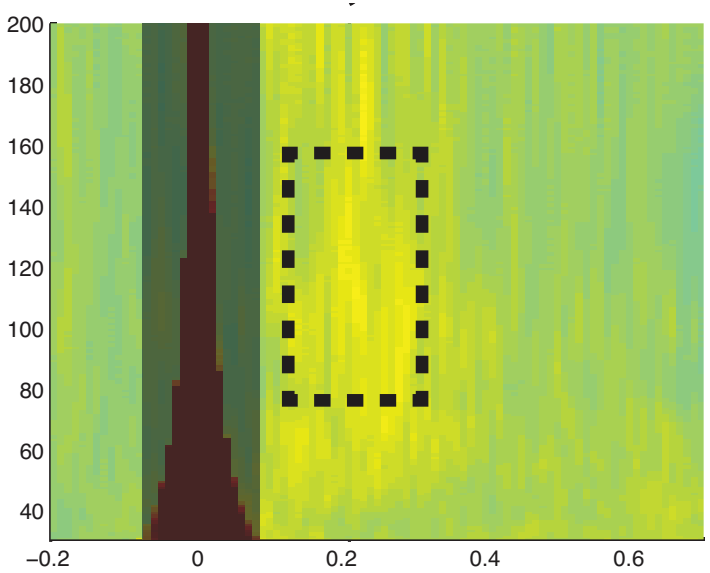

A. I = 2 mA
B. I = 4 mA
C. I = 6 mA
D. I = 8 mA
frequency(hz)
time (sec)
Correct Performance
Power Change (%)
Current (mA)

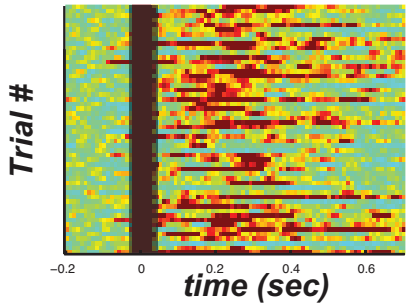
Correct

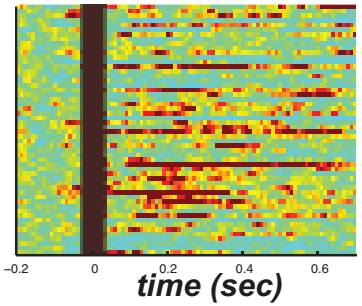


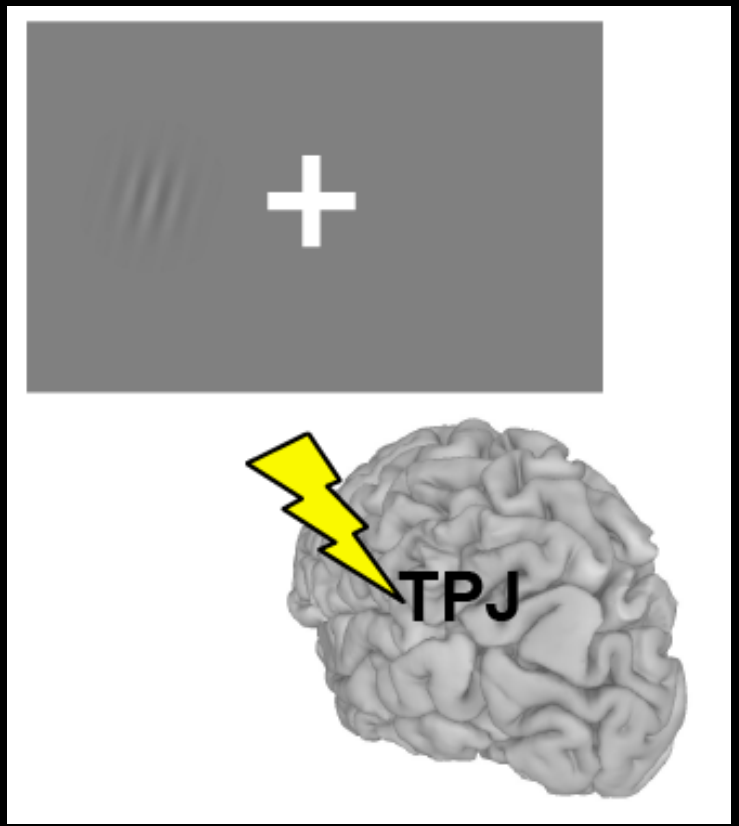
Wrong

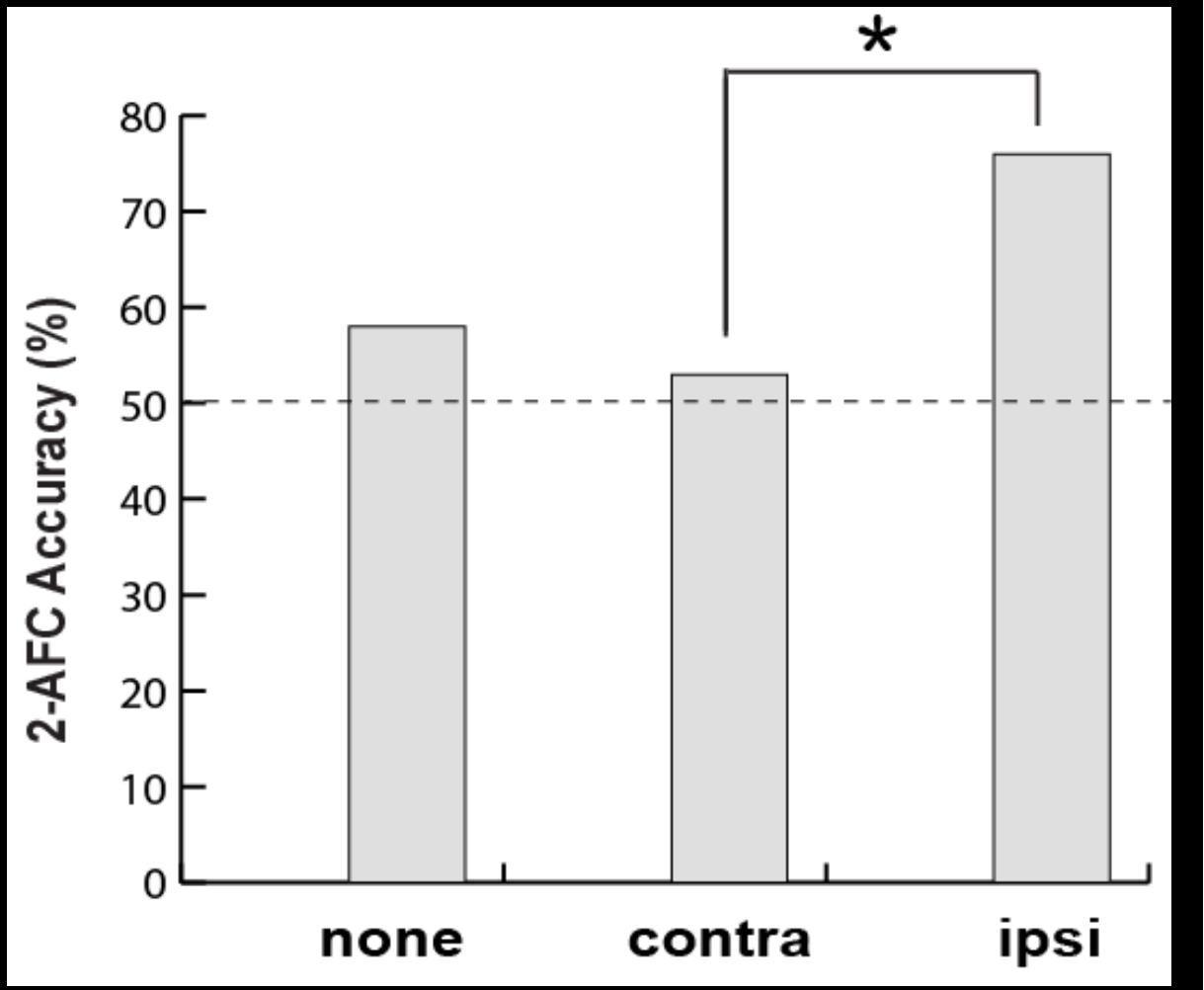




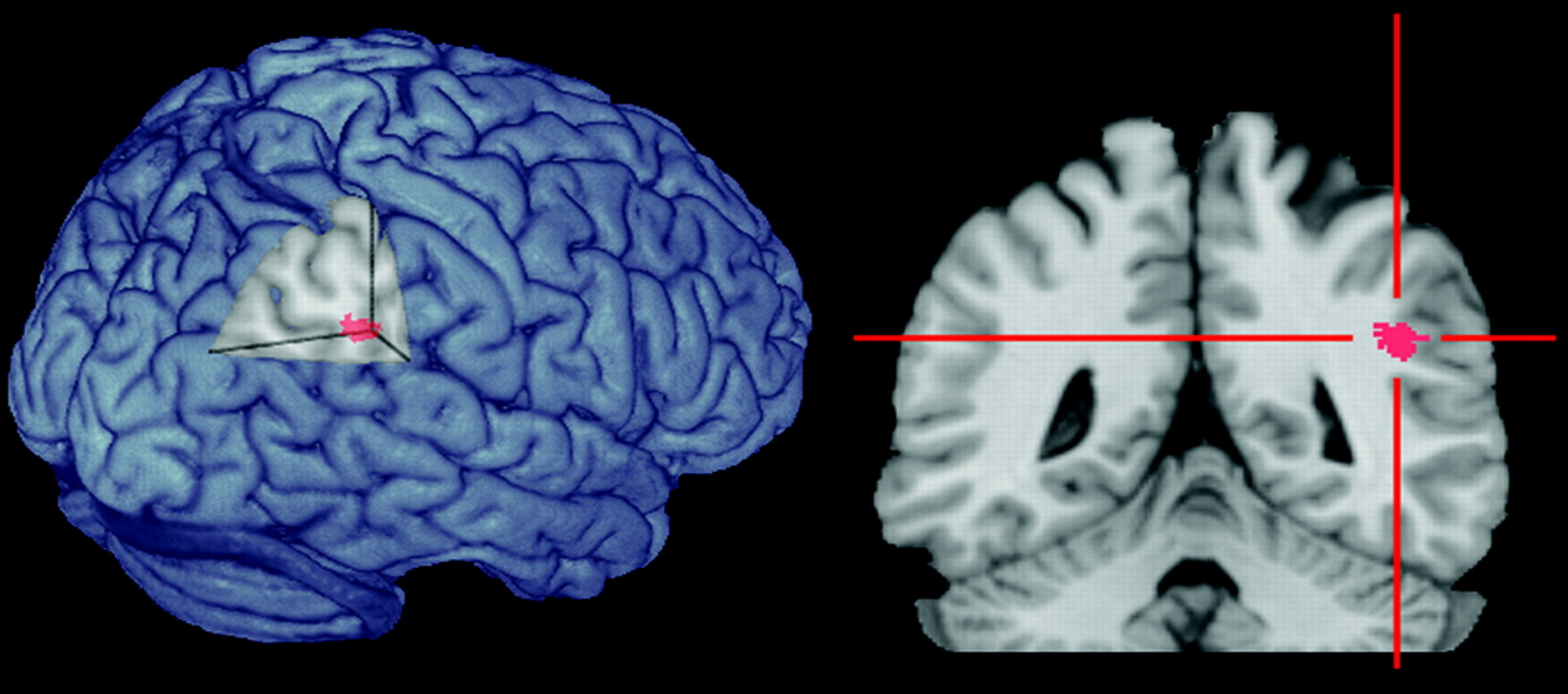





TPJ


*
2-AFC Accuracy (%)
80
70
60
50
40
30
20
10
0
none
contra
ipsi

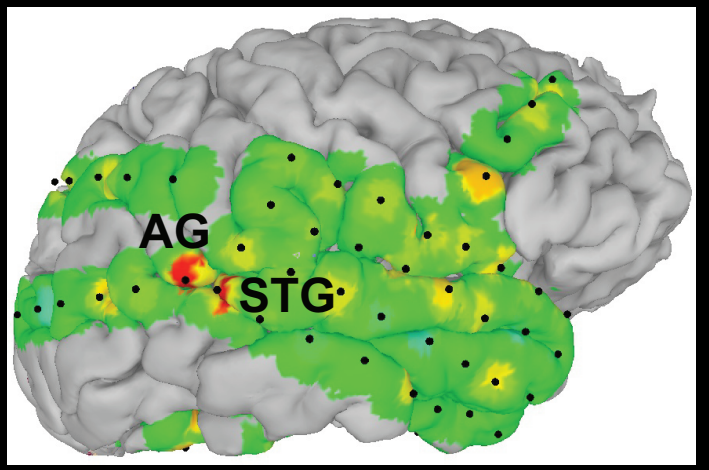
Visual neglect



Mort D J et al. Brain 2003;126:1986-1997

Part 5 Summary: Conscious awareness and the TPJ

- Conscious perception of eStim requires gamma activity in the temporo-parietal junction (TPJ)
- 1) Stimulation of percept-generating sites cause an increase in gamma power in TPJ
- 2) Neurometric-psychometric comparison: similar threshold and slope
- 3) Choice probability: at threshold stimulation, significantly more TPJ gamma in correct trials in 2IFC task



- Neglect, Exogenous orienting: Corbetta & Shulman,2002; Karnath, 2001
- Body perception: Blanke *et al.*, 2002

General principles

- Multisensory integration at the geographic intersection of different modalities
- Patchy organization
- MSI at every tier of the system—last time I gave this talk , someone asked about the superior colliculus….

Overall Summary

- the STS is important for auditory-visual integration in speech perception
- The weight of unisensory inputs to multisensory areas depends on stimulus reliability (fMRI connectivity)
- Gamma band activity in parietal lobe underlie conscious awareness of weak stimuli (eCog, electrocorticography)

Funding and Collaborators

Speech Perception
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Debshila Basu

Autism
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Rich Frye

TMS
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Siavash Pasalar

Intracranial
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Ping Sun

Development/NIRS
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Heather Bortfeld
John Oghalai

DTI & Methods
Tim Ellmore
Robert Cox, Ziad Saad, Dave Akers

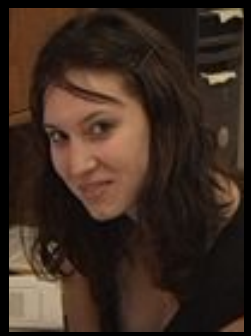
UNITED STATES DEPARTMENT OF VETERANS AFFAIRS

NIDCD National Institute on Deafness and Other Communication Disorders
Improving the lives of people who have communication disorders

National Science Foundation
WHERE DISCOVERIES BEGIN

National Institute of Neurological Disorders and Stroke
National Institutes of Health

Sarah Baum



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Audrey Nath

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