Role of attention mechanisms in listening, Part II

Barbara Shinn-Cunningham
Director, Neuroscience Institute

Carnegie Mellon University

A talk* based on
A talk by BU
Research Professor
Abigail Noyce

*In Keynote, not Powerpoint

Part IIa

The big theme:

There are specialized cortical networks,

differing in what information content is being processed,

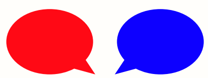
which is related to what sensory modality conveys the information

Brain networks interact in a complex, coordinated "dance" to enable cognitive processing of sound

Watch the brain as it prepares to attend

-1000 Cue — Visual cue indicates attend to pitch, attend to location

-700 ● — Visual fixation point

0  — Pair of competing digits: left / right and high / low

1000 ○ — Response period

Time (ms)

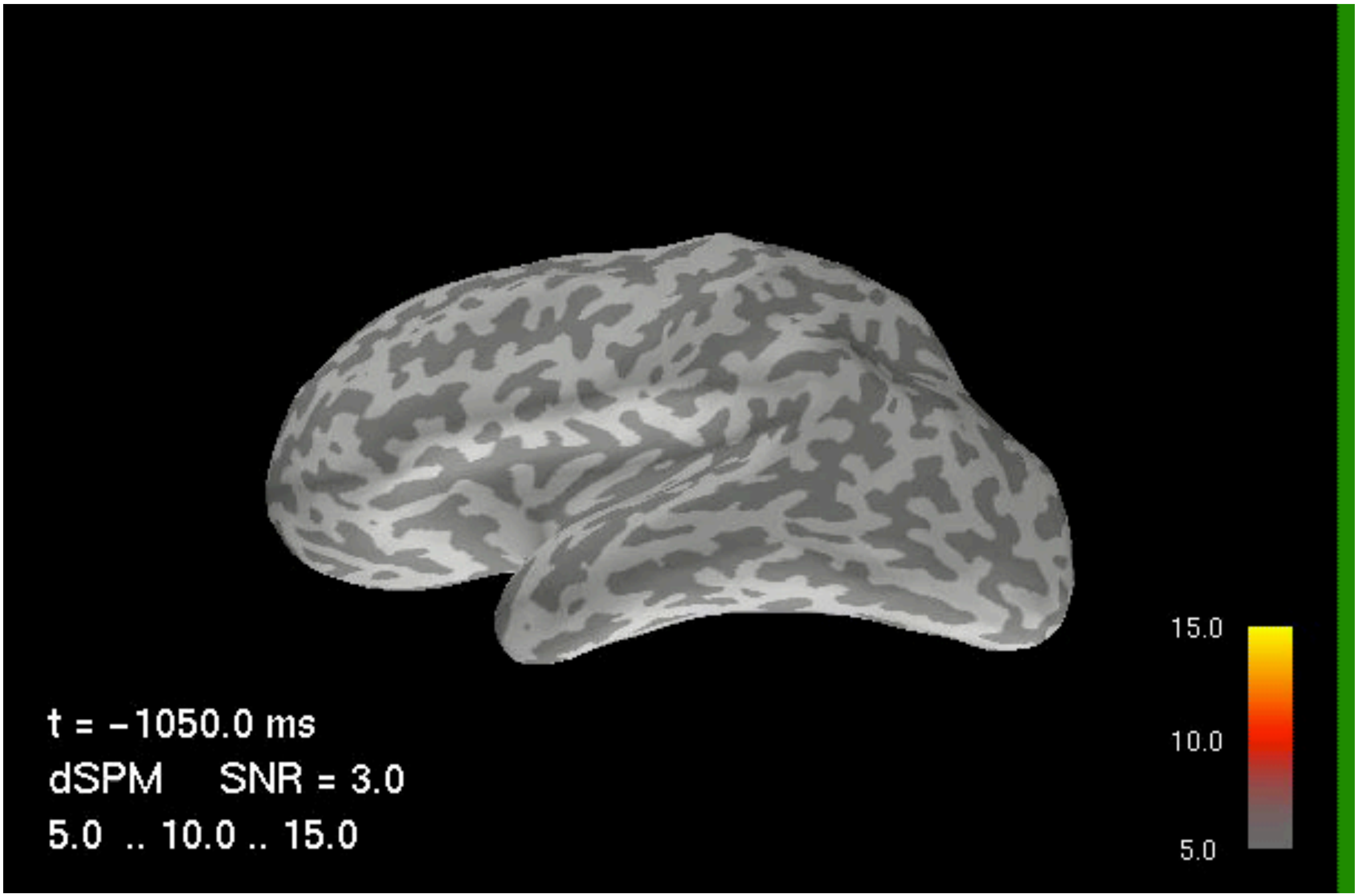
Cue:

Space (left / right)

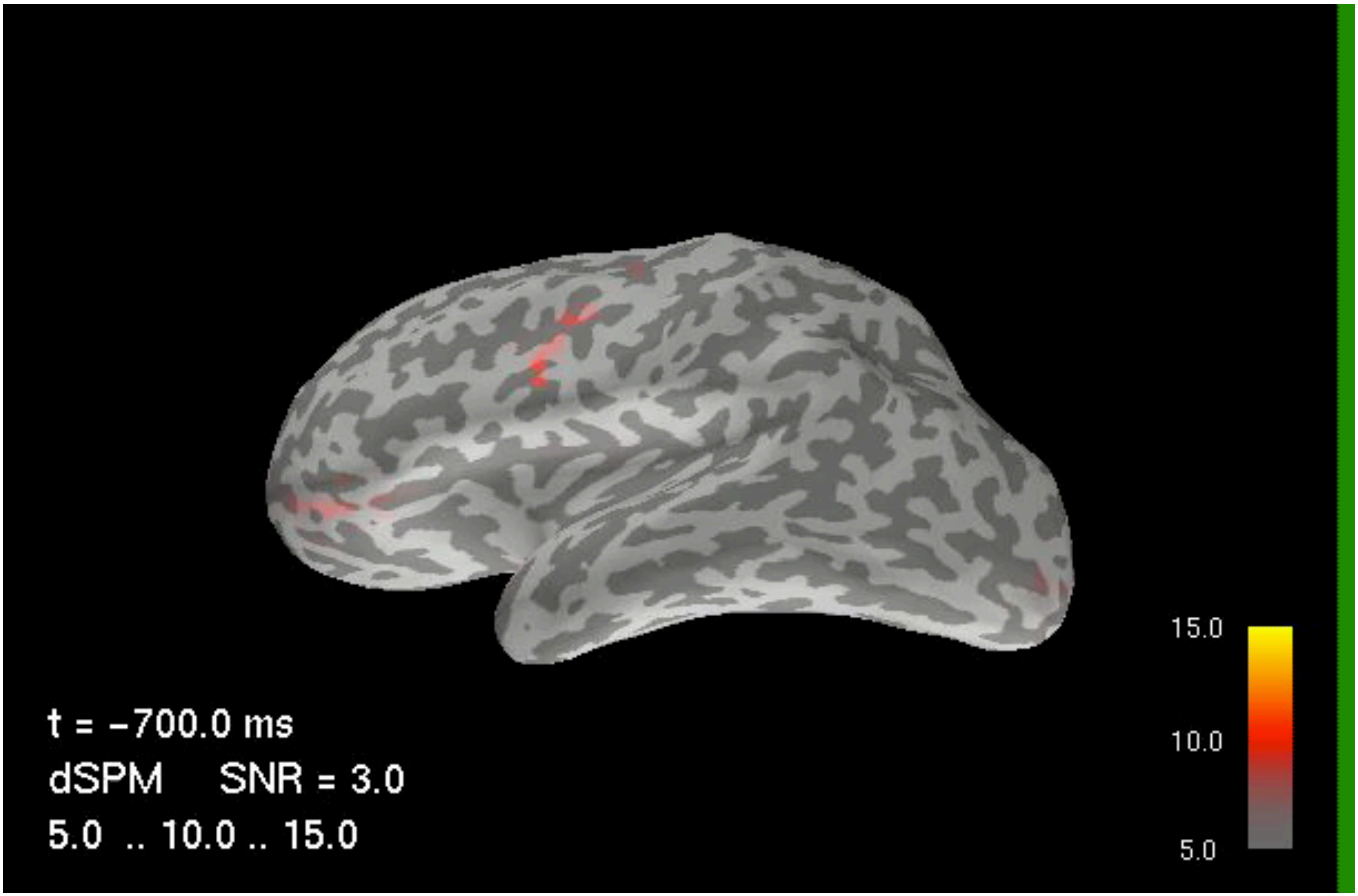
Pitch (high / low)

Lee et al., 2013

The visual cue tells you where you will have to attend in an upcoming sound mixture

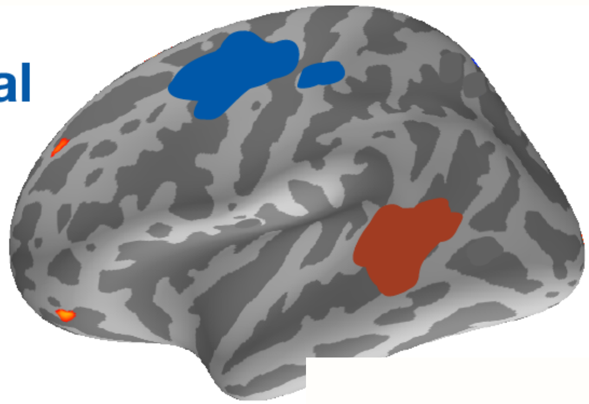


The brain prepares to filter things out *before* the sound starts

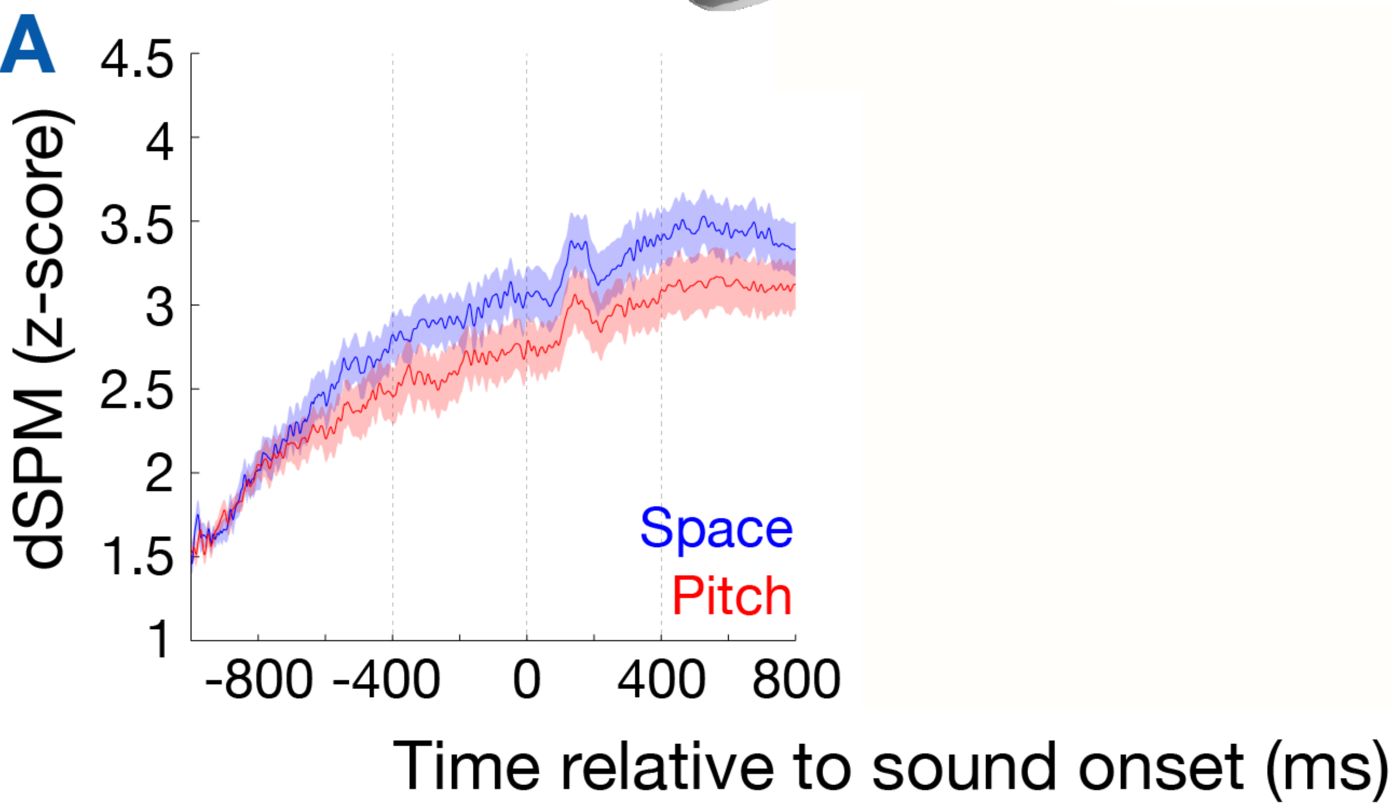


Preparatory activity depends on the feature being attended

A. Frontal eye field



Spatial attention: Visuo-spatial area



Lee et al., Frontiers, 2013

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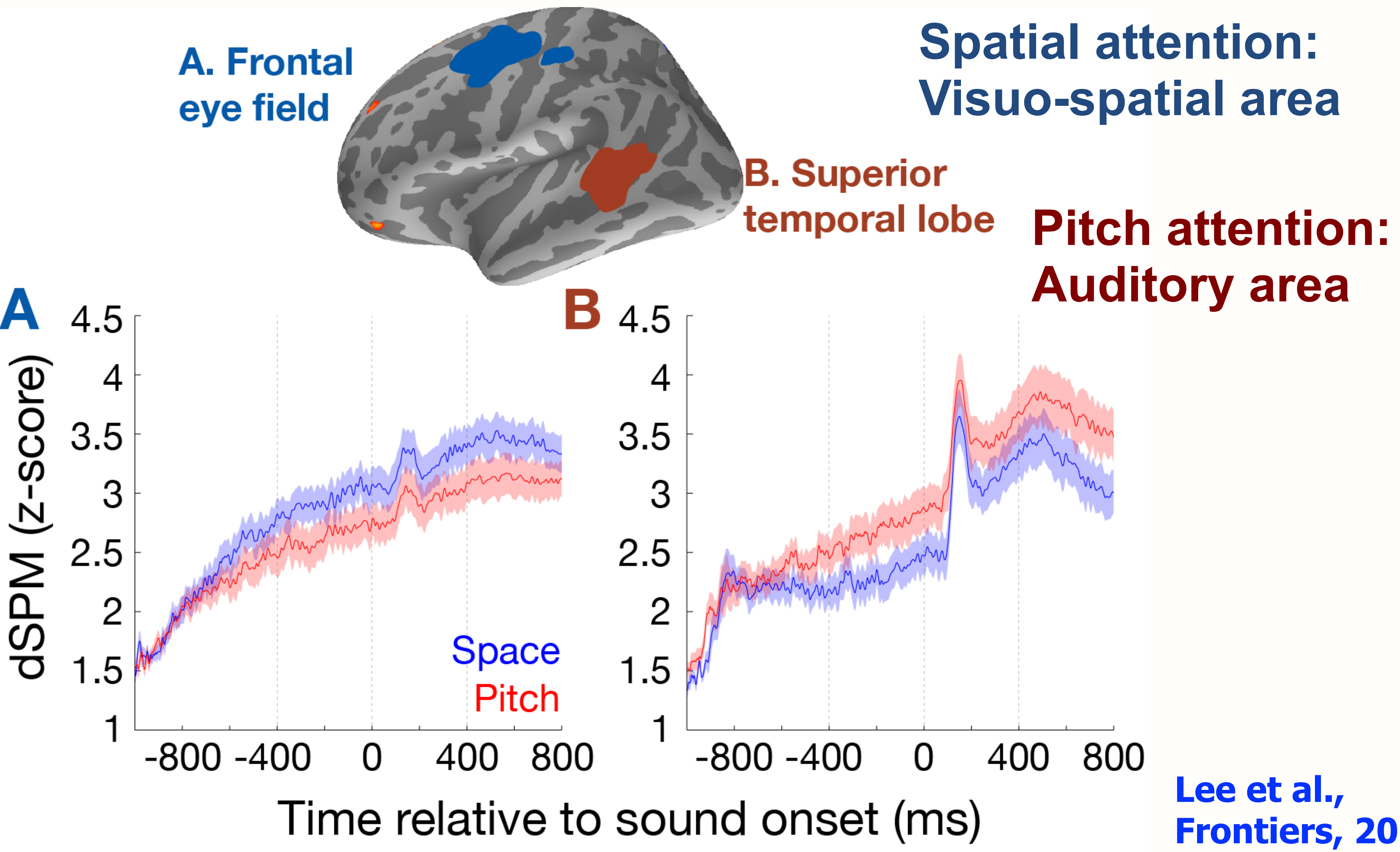
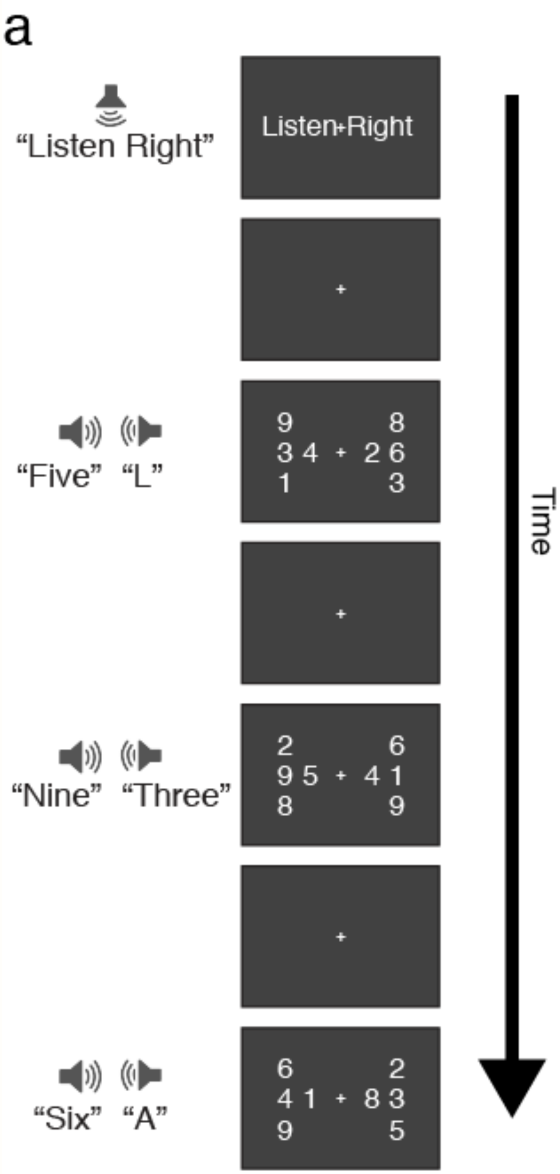


Lee et al., Frontiers, 2013

Auditory and visual selective attention differentially engage brain networks

Sam Michalka (Olin College), David Somers (BU)

Test auditory vs. visual spatial attention for same AV stimuli



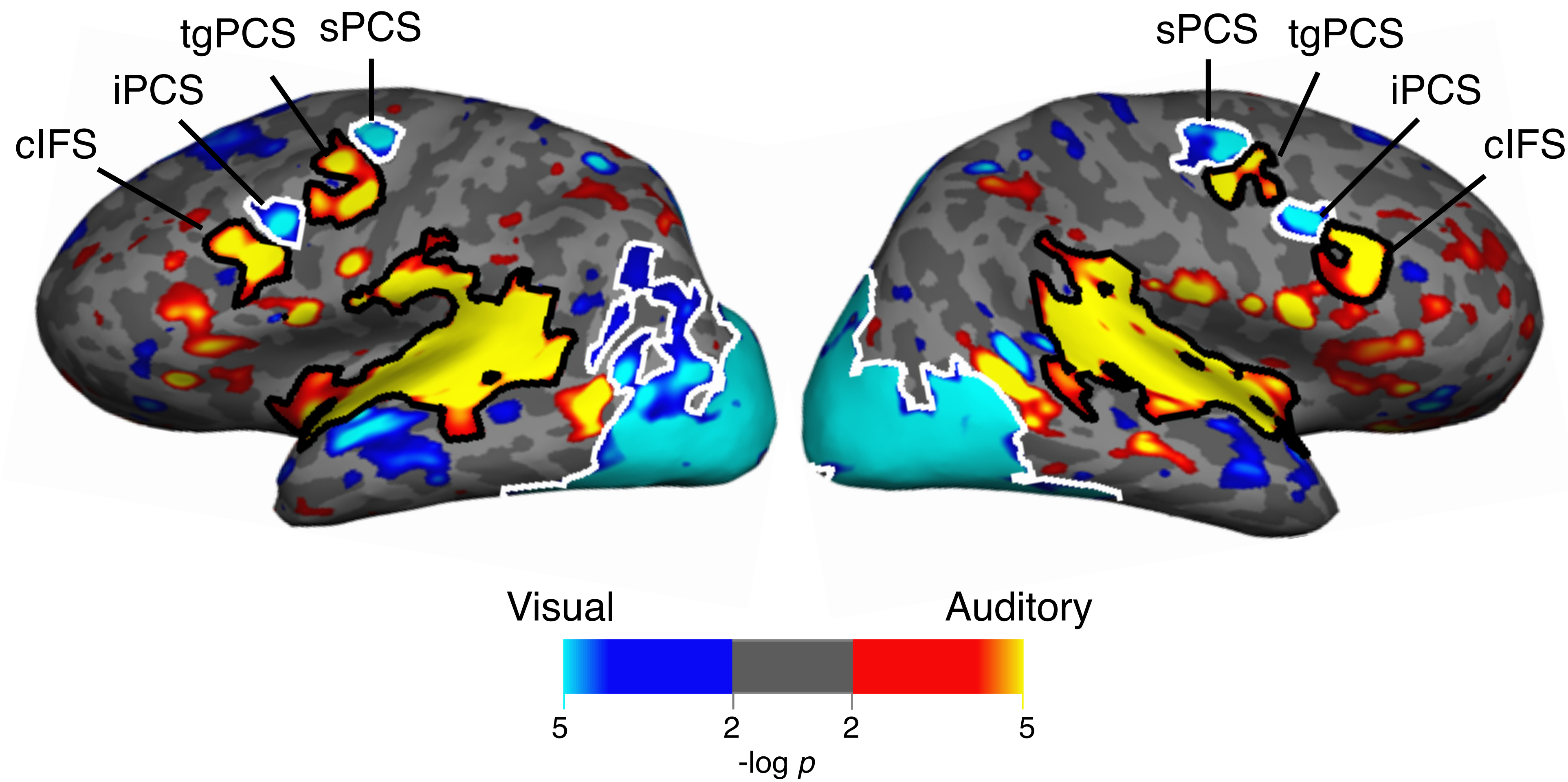
Direct attention to stream that is

left or right

auditory or visual

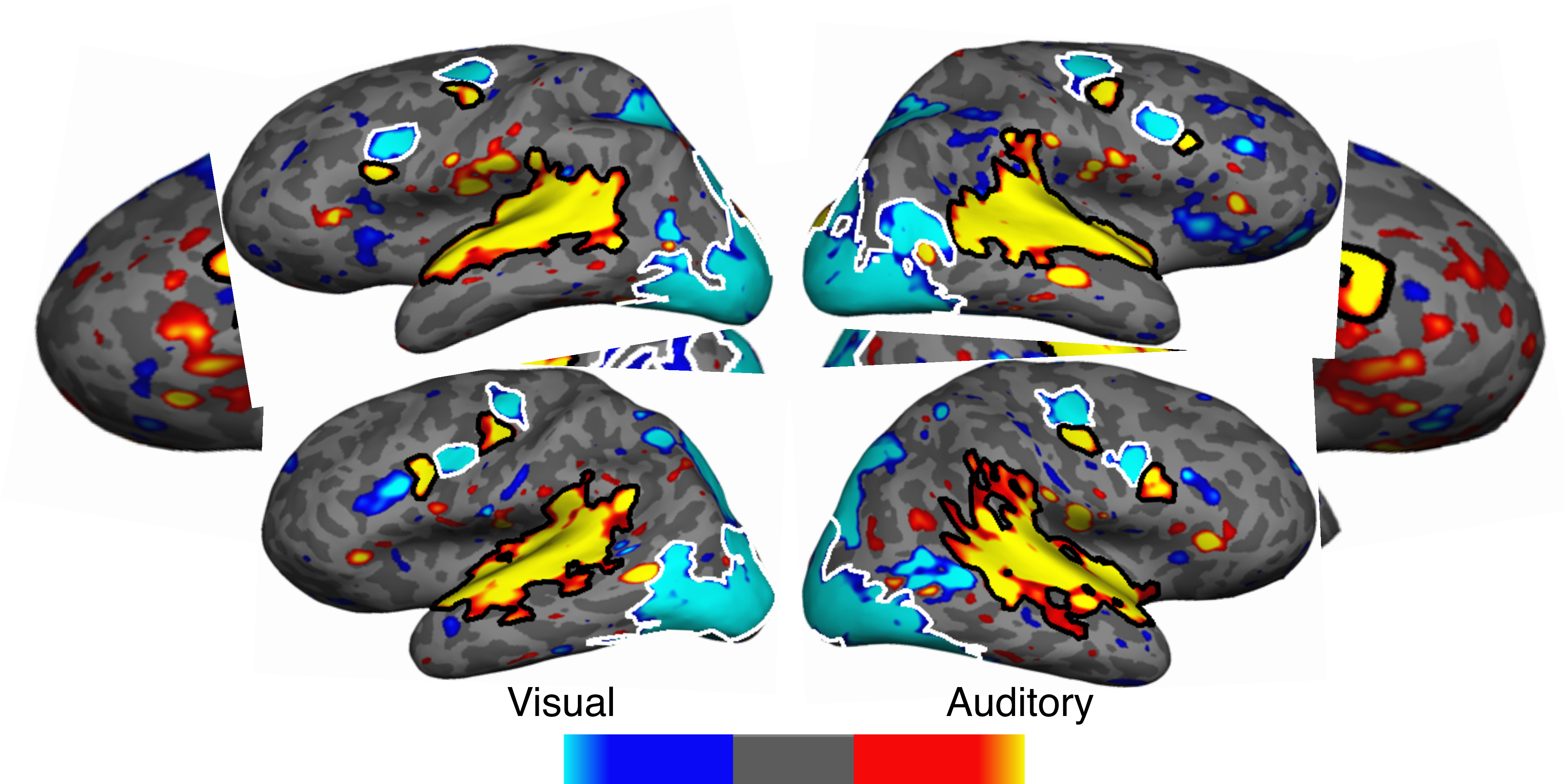
Michalka et al., Neuron, 2015

Lateral frontal cortex has inter-digitated sensory-biased structures (contrasting attention tasks' activity)



Michalka, Kong, Rosen, Shinn-Cunningham, & Somers (2015) *Neuron*
Noyce, Cestero, Michalka, Shinn-Cunningham, & Somers (2017) *J. Neuroscience*

This pattern is found reliably in nearly all subjects



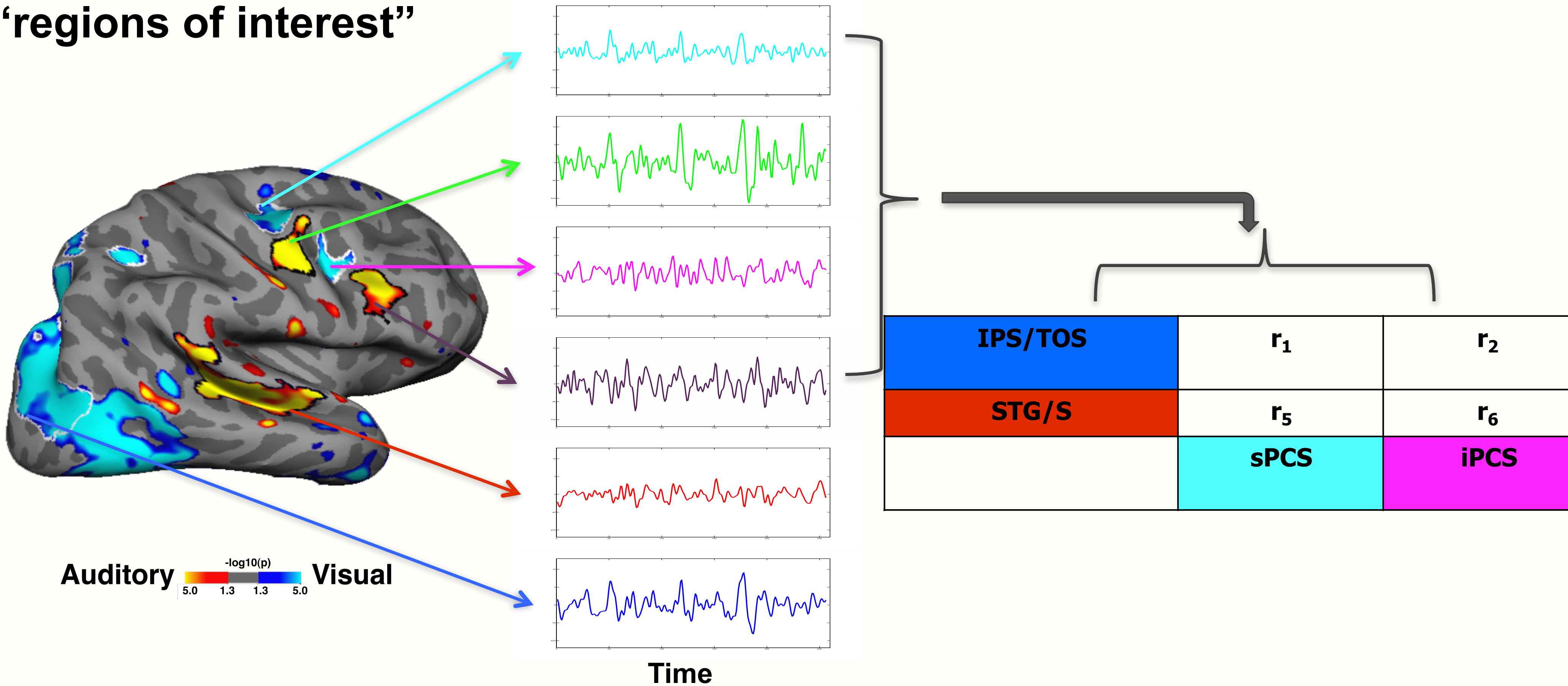
Noyce et al. (2017) *J. Neuroscience*
Michalka et al. (2015) *Neuron*

Resting state: what brain areas are naturally co-active?

1. Use task data to define user-specific "regions of interest"

2. Extract ROIs' time courses

3. Calculate correlations between ROI pairs



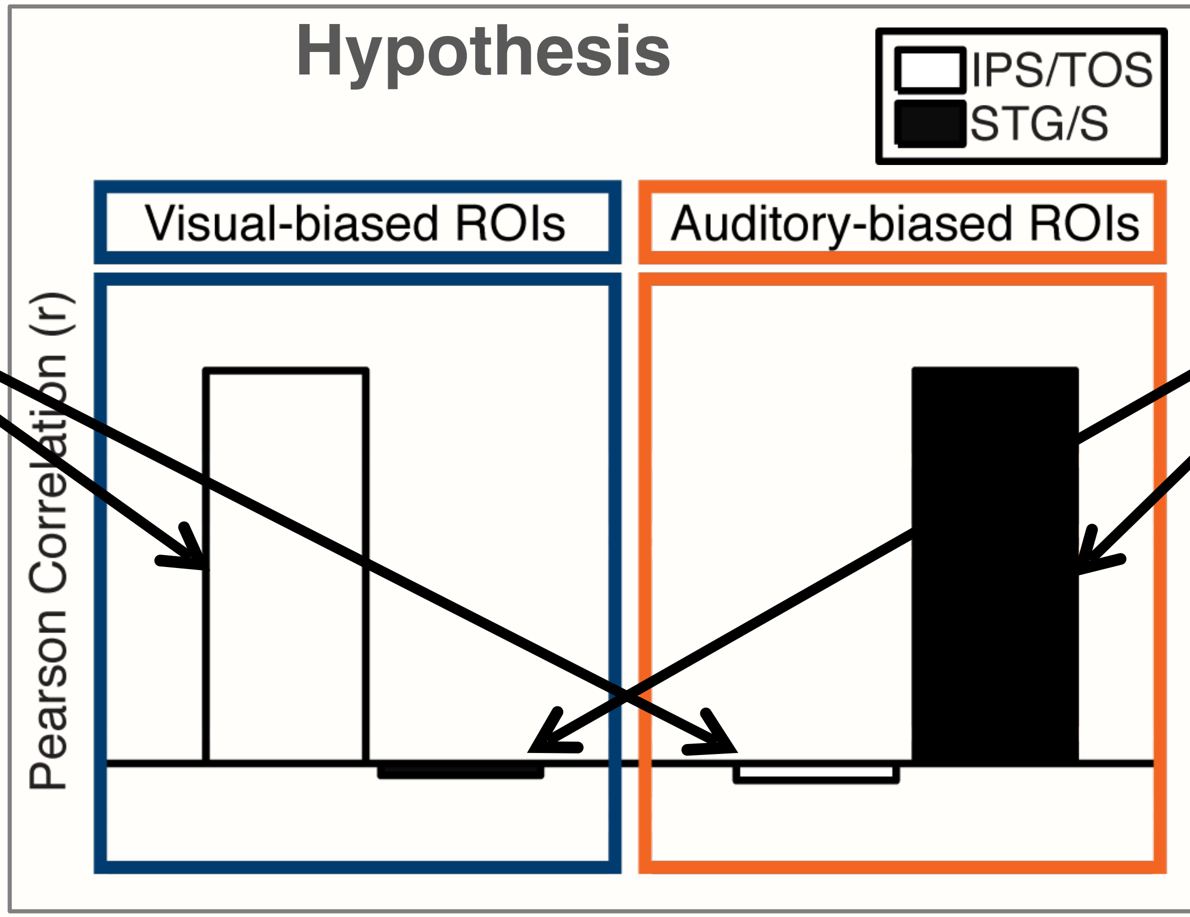
Auditory vs. Visual Sustained Attention

Rest / No Task

Michalka et al., Neuron, 2015

Hypothesize that sensory inputs connect to different networks

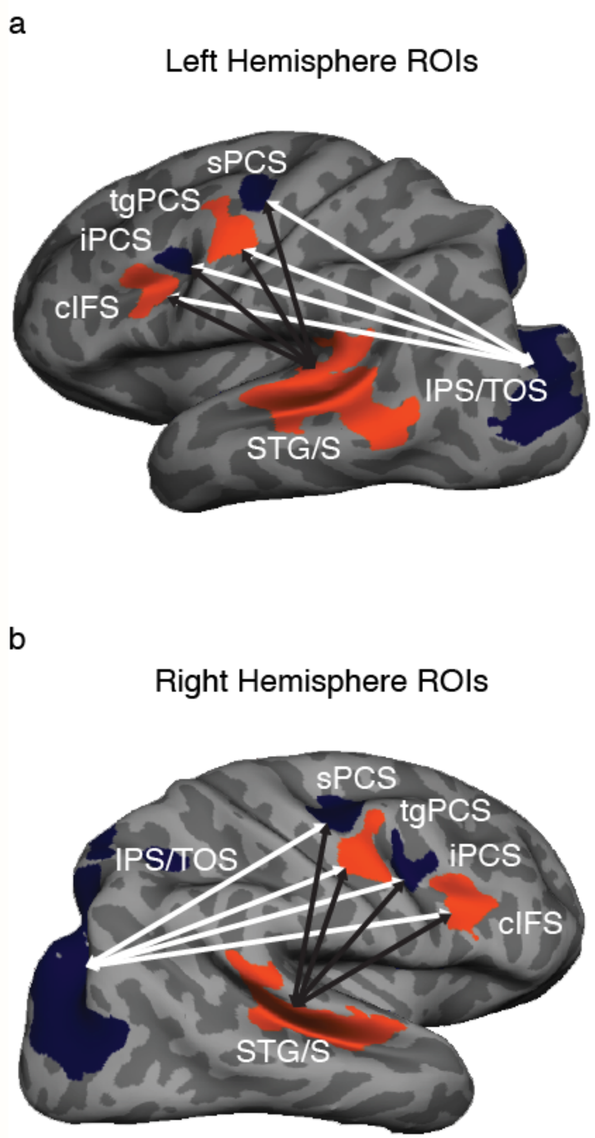
visual sensory regions

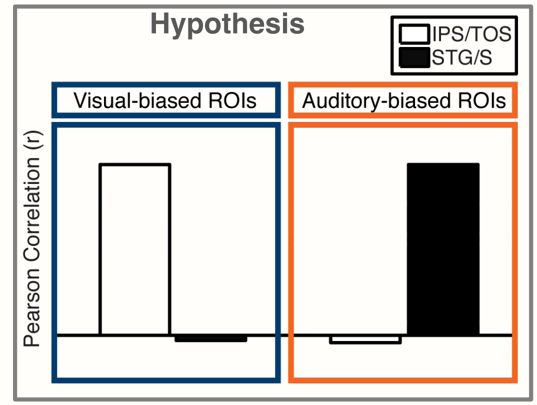


auditory sensory regions

Michalka et al., Neuron, 2015

Resting state connectivity confirms sensory-biased regions





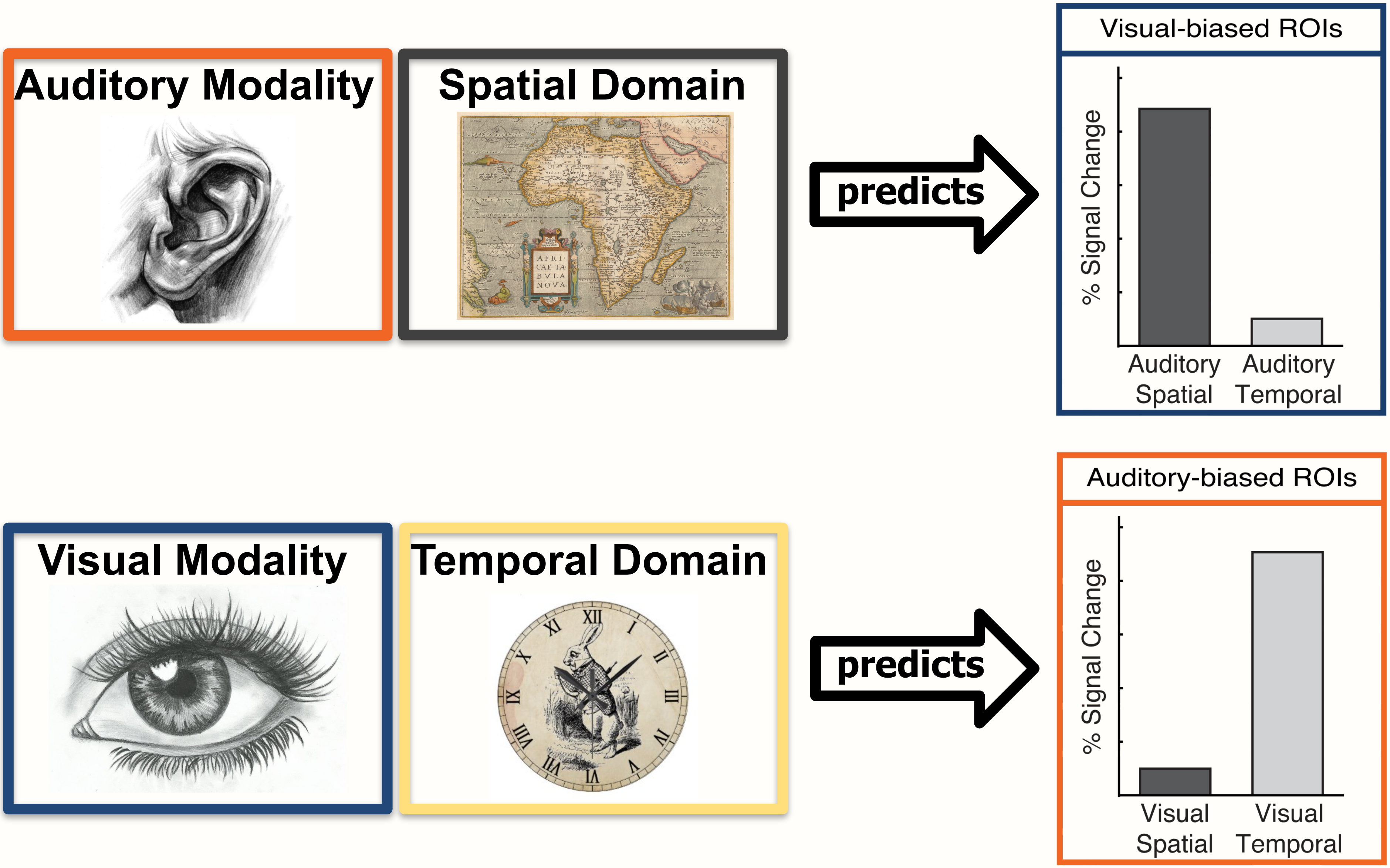
Visual sensory areas correlate with vision-biased lateral prefrontal regions

Auditory and visual attention differentially engage brain networks

… but task demands change network recruitment

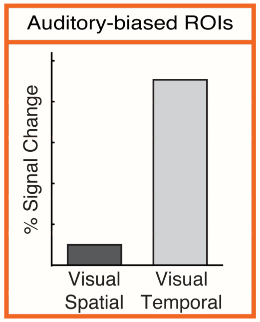
Sam Michalka (Olin College), David Somers (BU)

“Domain recruitment” hypothesis



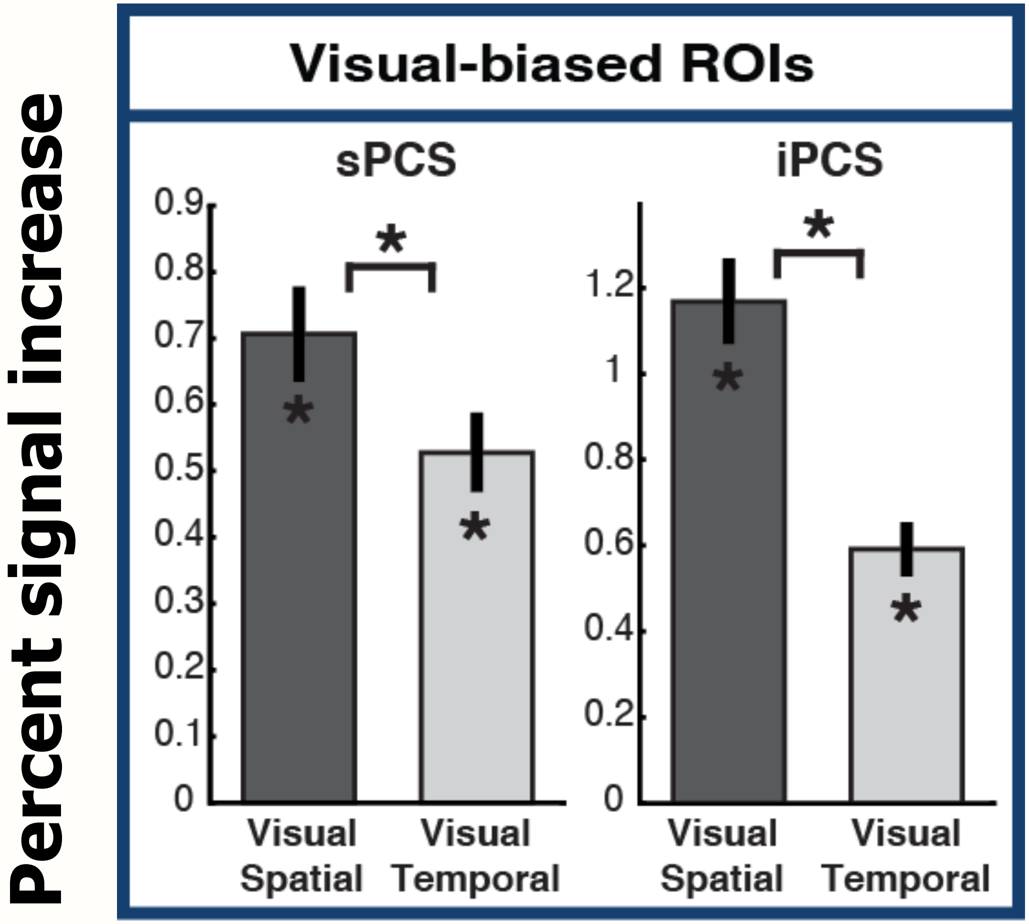
Visual tasks recruit “visual” prefrontal ROIs

Hypothesis

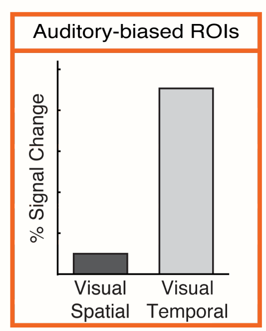


Michalka et al., Neuron, 2015

Visual tasks recruit “visual” prefrontal ROIs

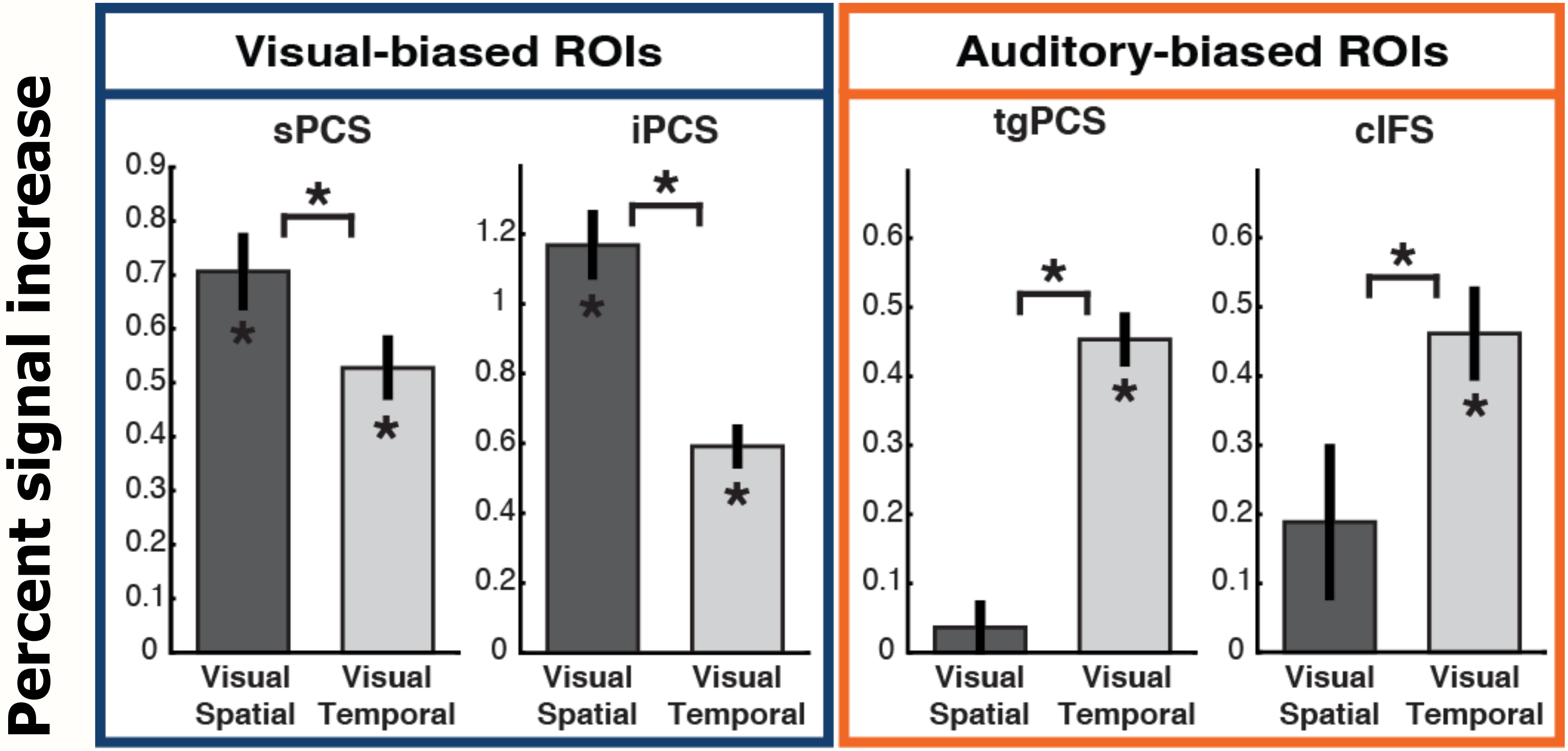


Hypothesis

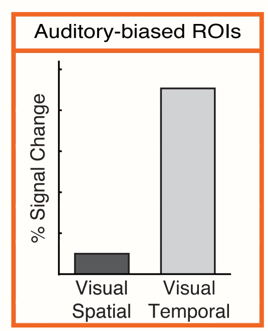


Michalka et al., Neuron, 2015

Visual temporal task recruits “auditory” prefrontal ROIs

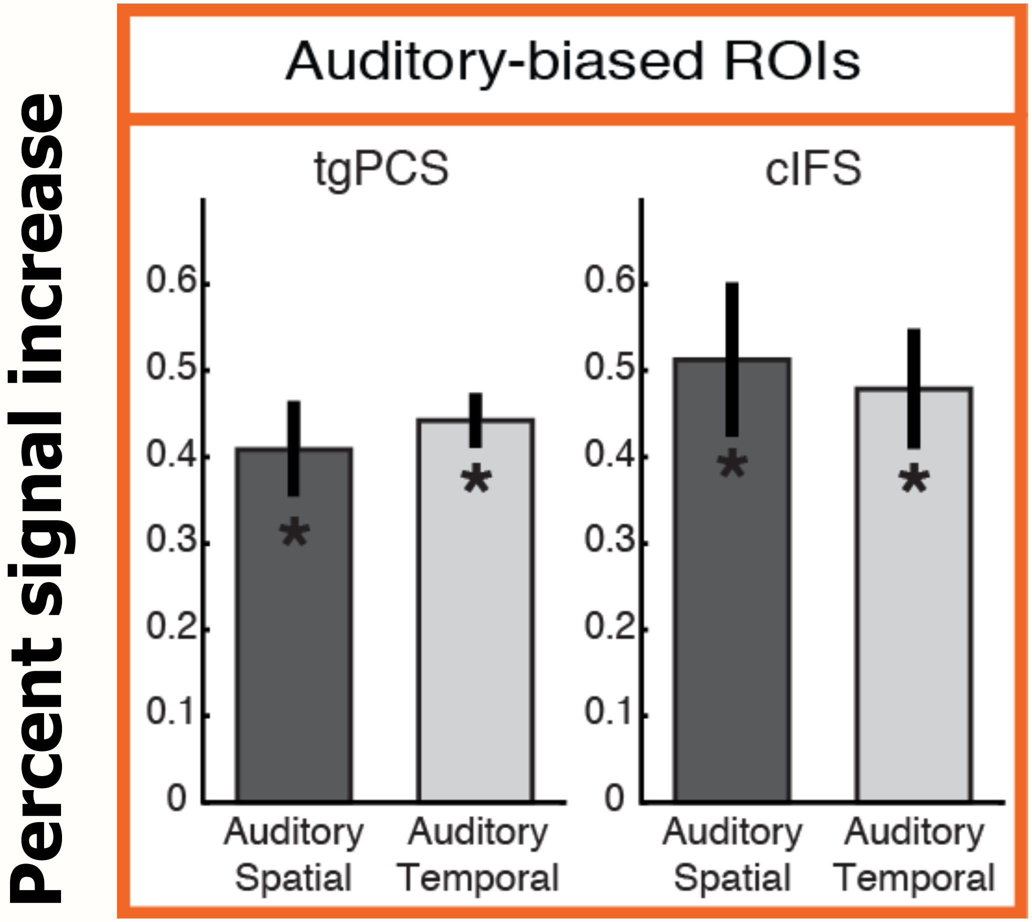


Hypothesis



Michalka et al., Neuron, 2015

Auditory task recruits “auditory” prefrontal ROIs



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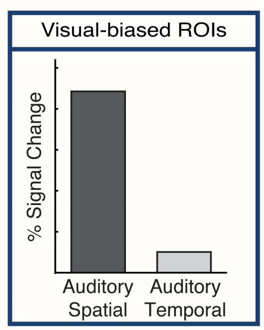
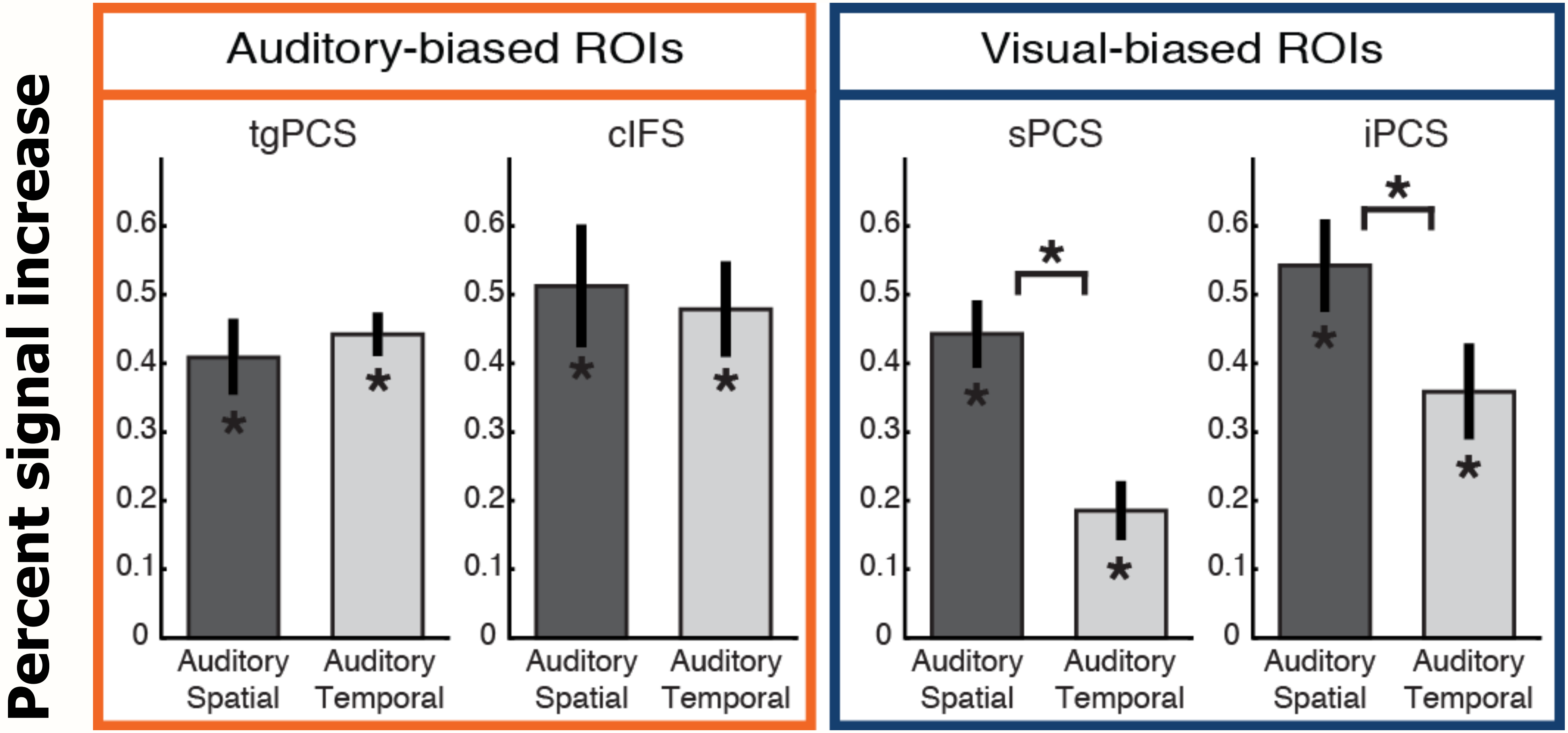
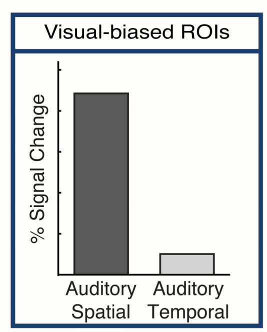


Michalka et al., Neuron, 2015

Auditory spatial task recruits “visual” ROIs more strongly



Hypothesis

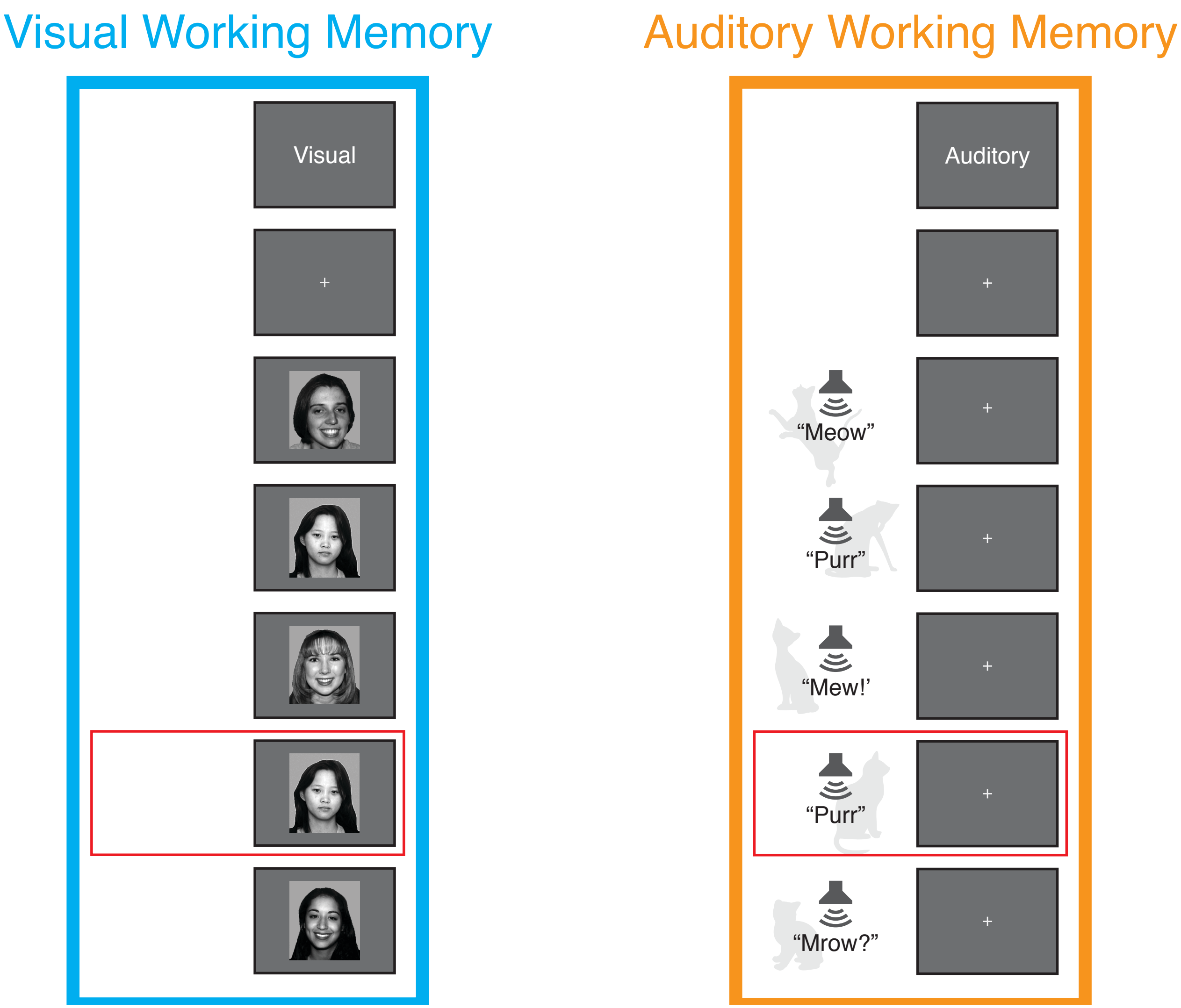


Michalka et al., Neuron, 2015

Working memory and attention recruit the same sensory-biased regions

Abby Noyce
(BU)

Re-examine prefrontal areas' task activation in visual and auditory 2-back working memory



3T Siemens Tim Trio

TR = 2000 ms
TE = 30 ms

SOA 1.25 s
32 stimuli/block
8 runs

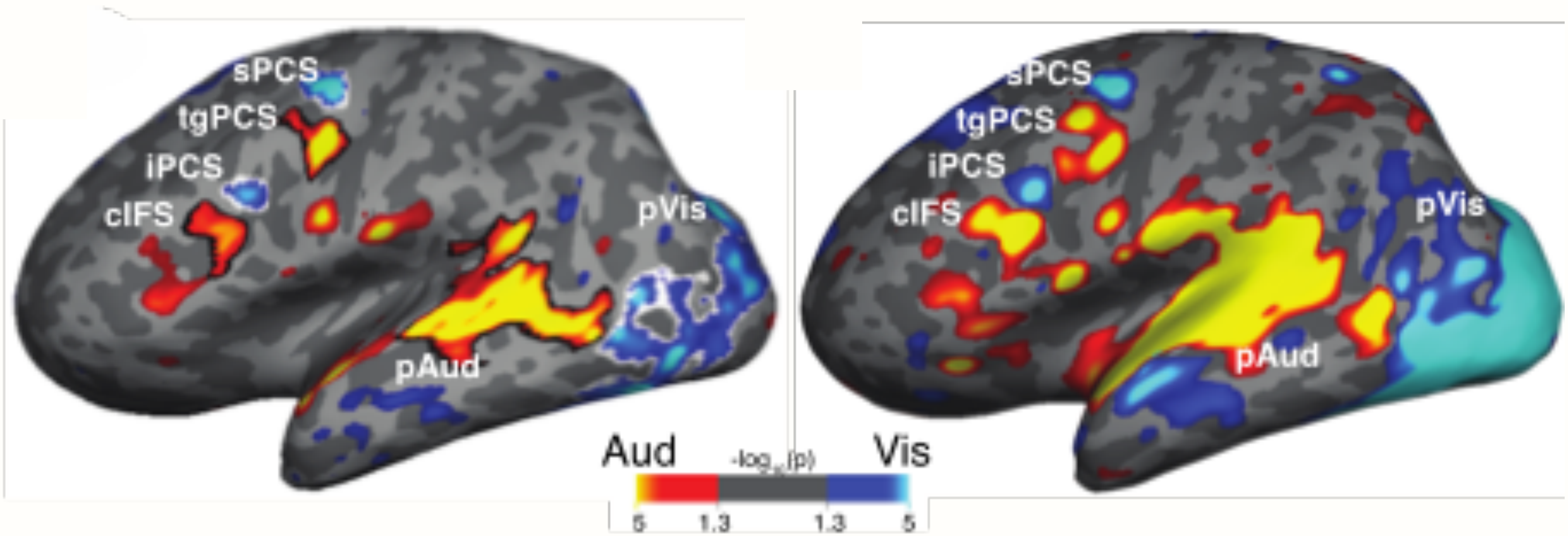
Visual

Auditory

Working (auditory or visual) memory recruits the same control networks as selective attention

Selective attention: auditory vs. visual

Working memory: auditory vs. visual



Same subject, new data, same regions

Michalka et al., Neuron, 2015

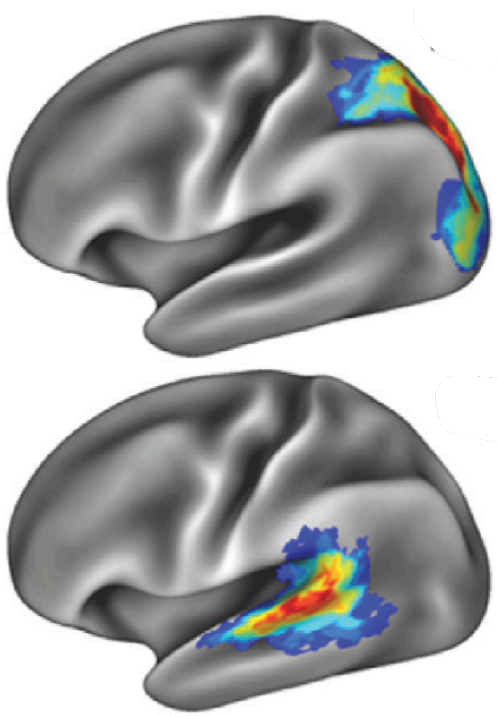
Noyce et al., J Neurosci, 2017

Large-scale connectivity analysis reveals additional candidate sensory-biased frontal regions

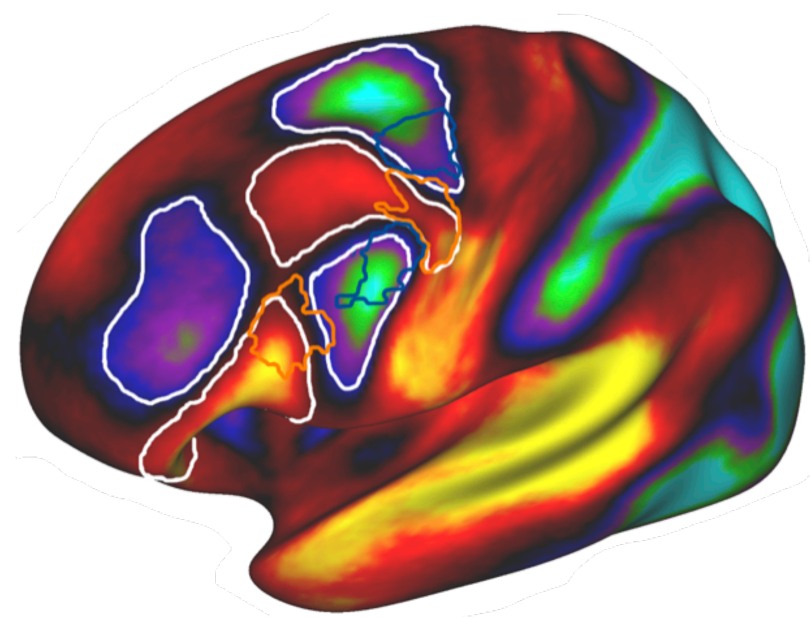
David Somers and co.
(BU)

Organization can be identified from connectivity alone

Posterior visual & auditory seeds



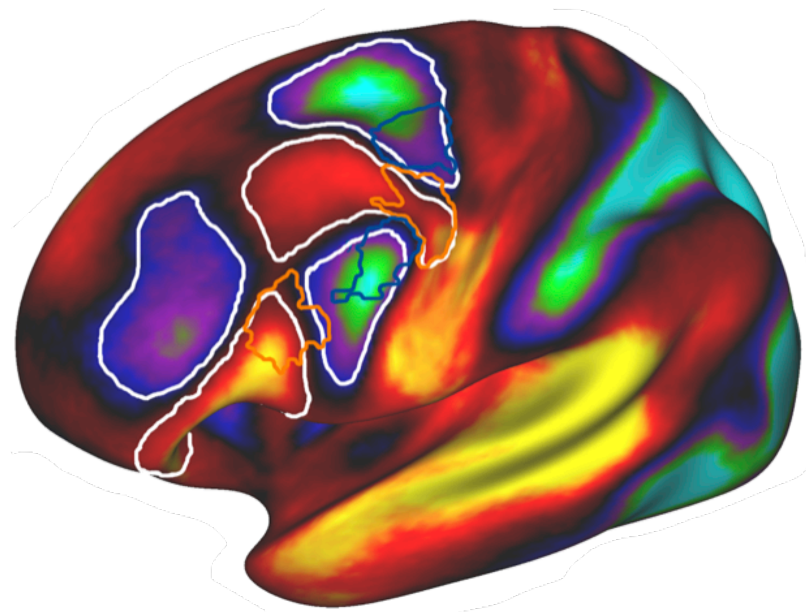
Map of differential connectivity



n=469

Tobyne, Osher, Michalka, & Somers (2017) *NeuroImage*

Large-scale connectivity analysis reveals additional candidate areas for sensory-biased regions



Tobyne et al. (2017) *NeuroImage*

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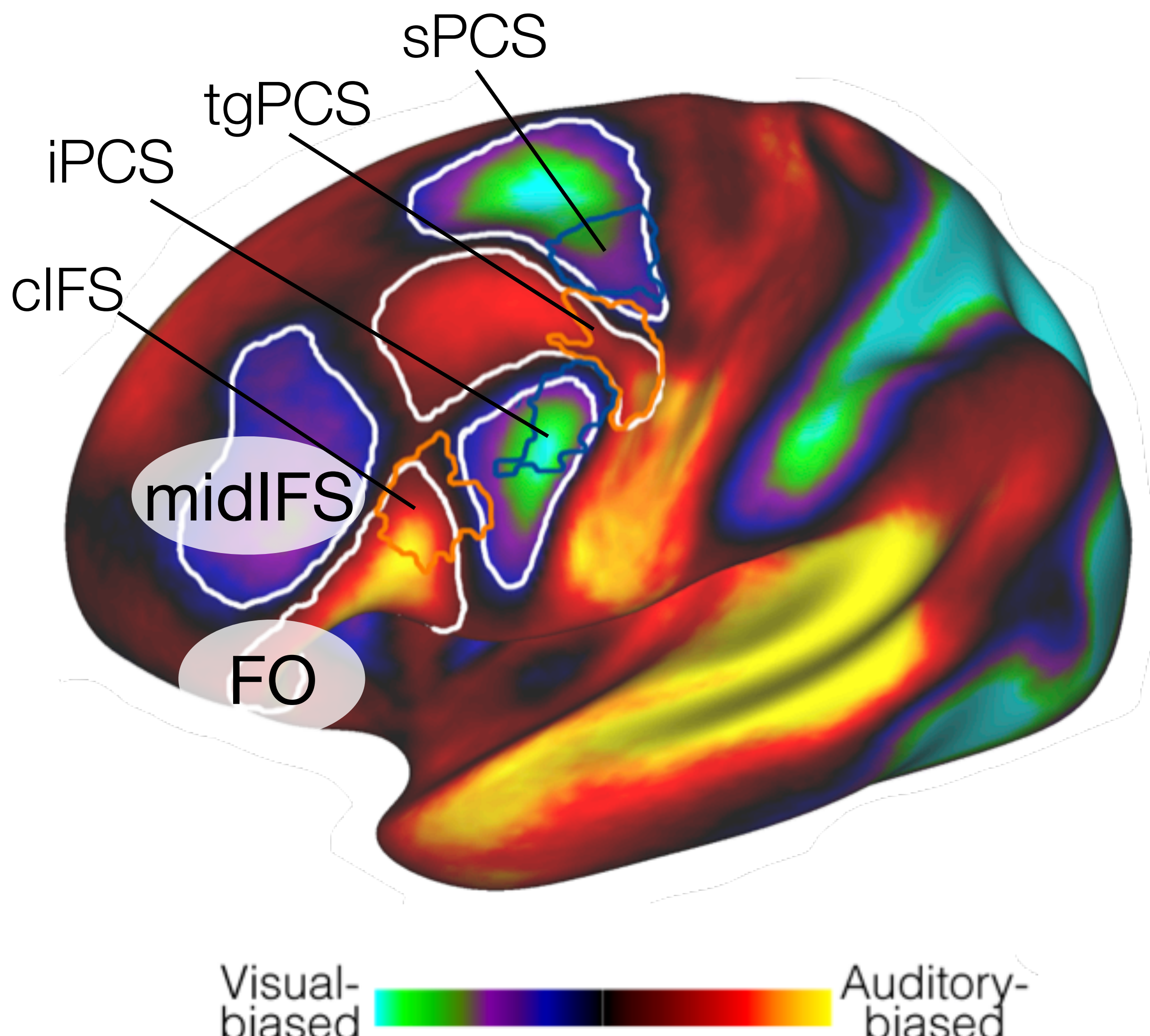
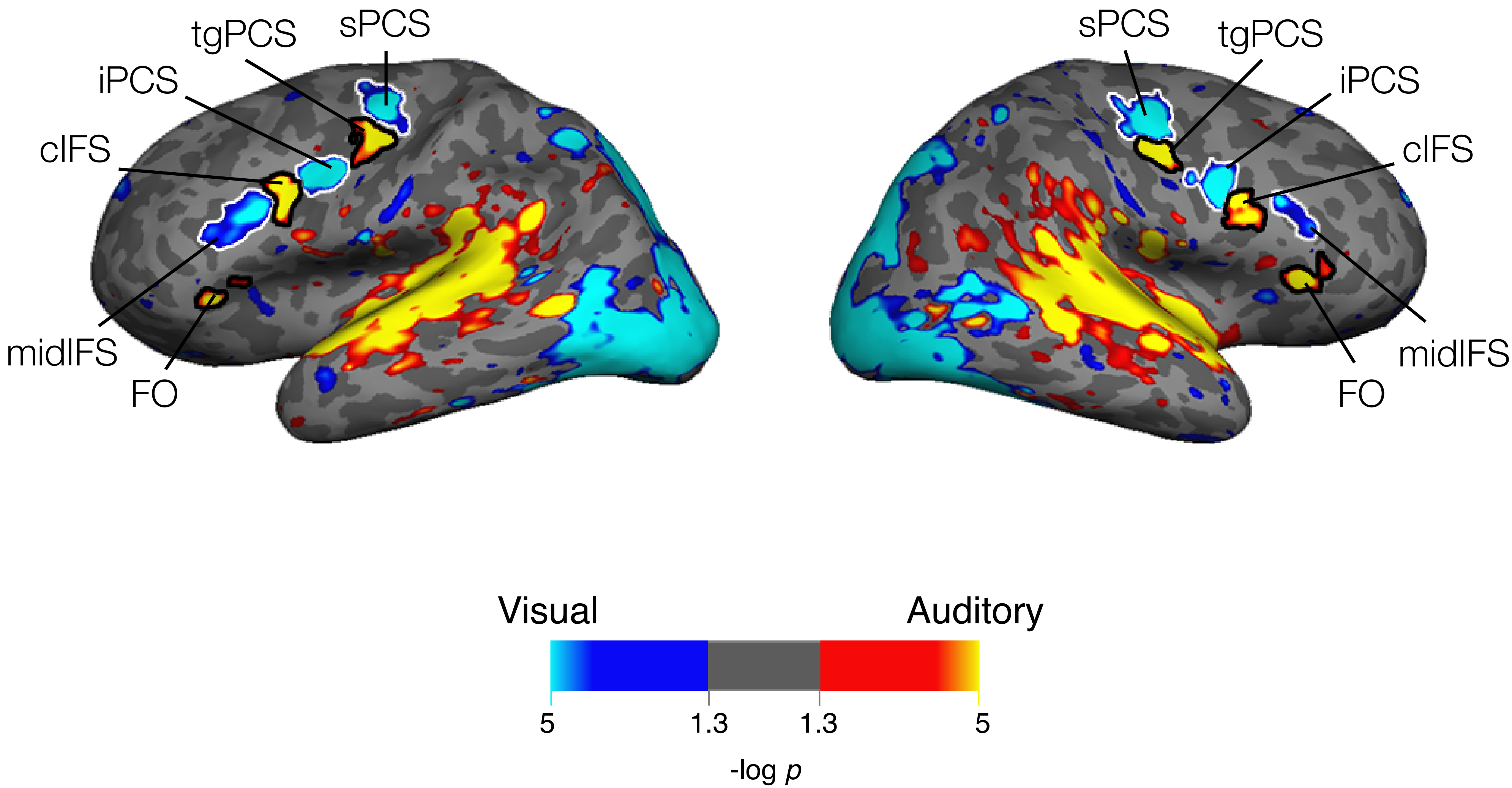


Tobyne et al. (2017) *NeuroImage*

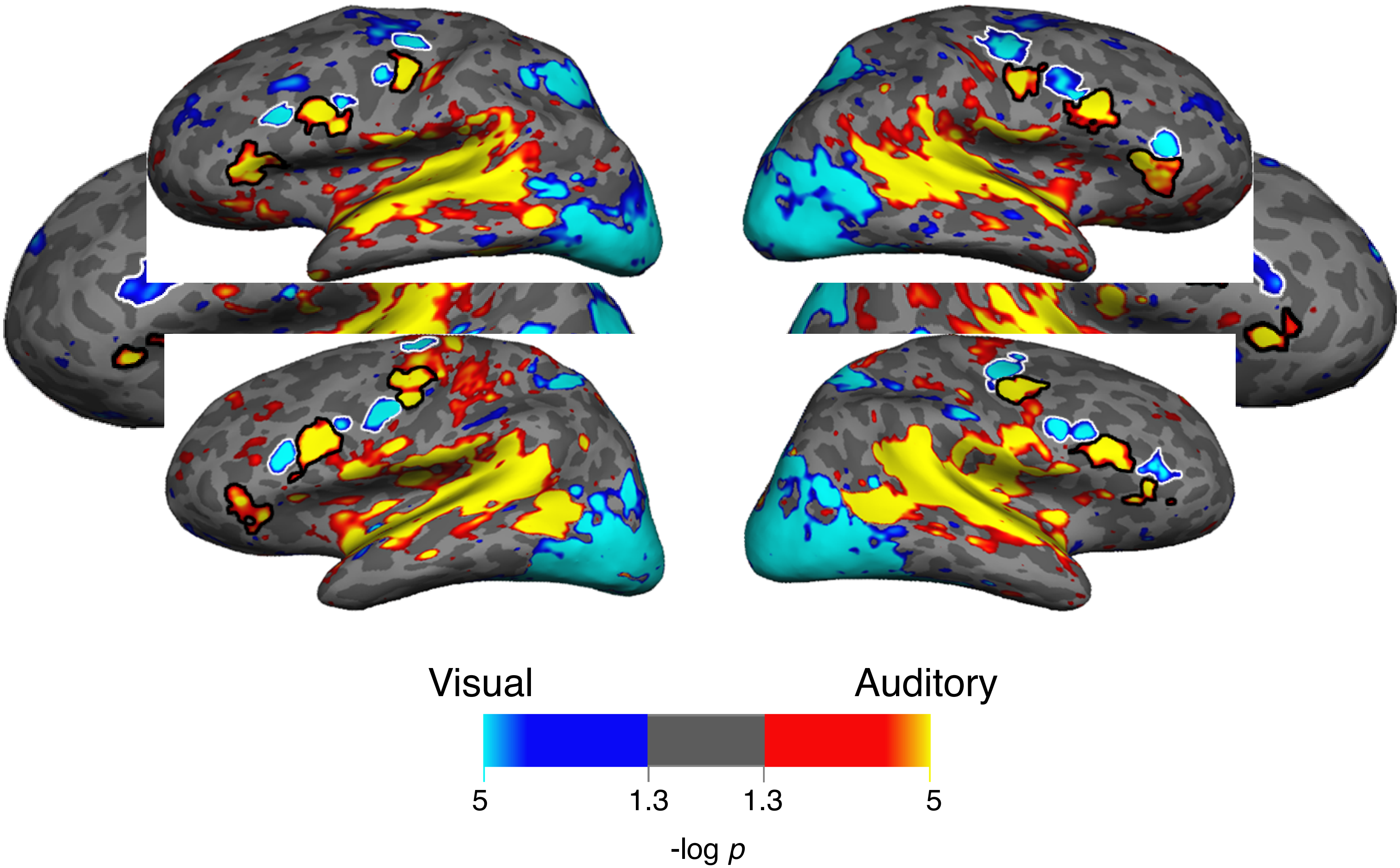
Sensory-biased networks replicate **and extend** using working memory tasks

Abby Noyce
(BU)

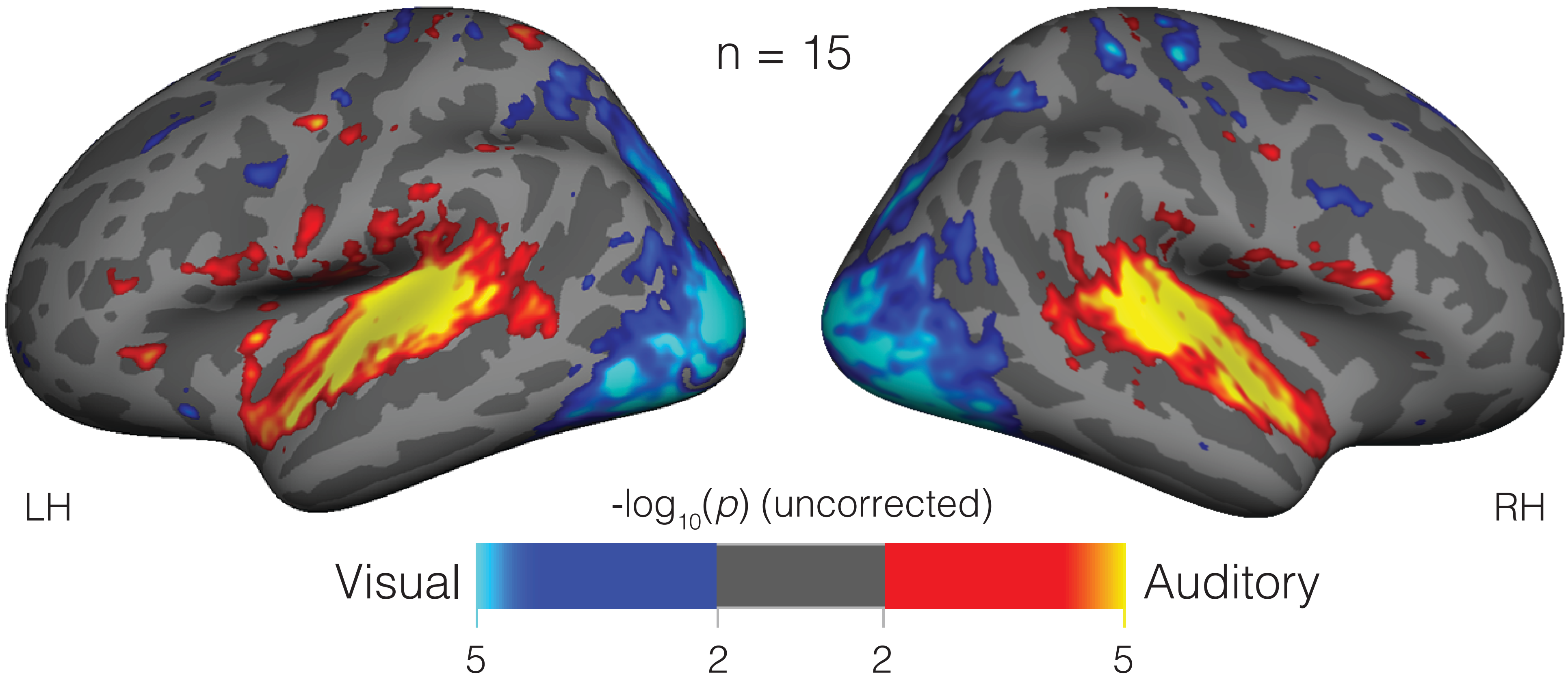
Additional areas identified by connectome large-scale data set are there in the working memory results



This pattern is found reliably in nearly all subjects

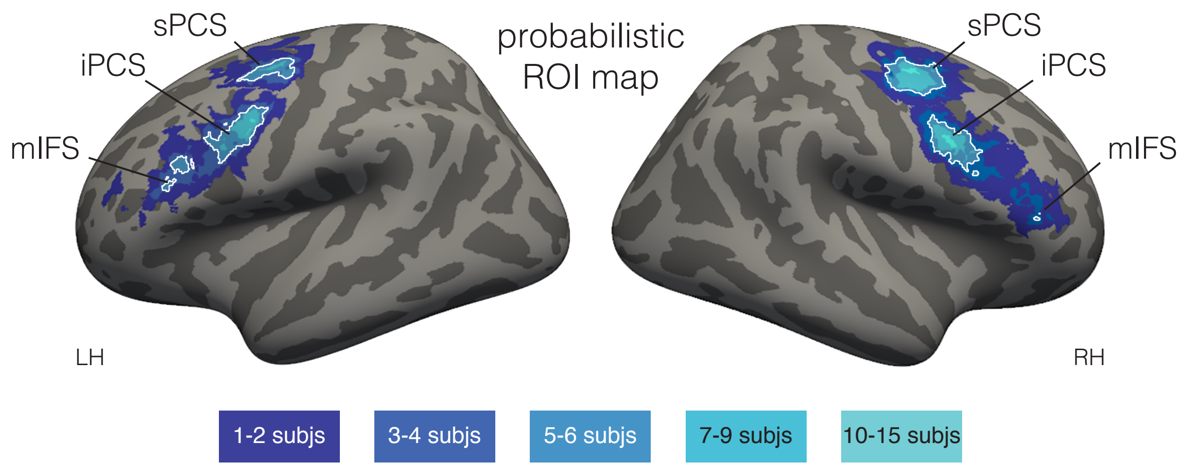


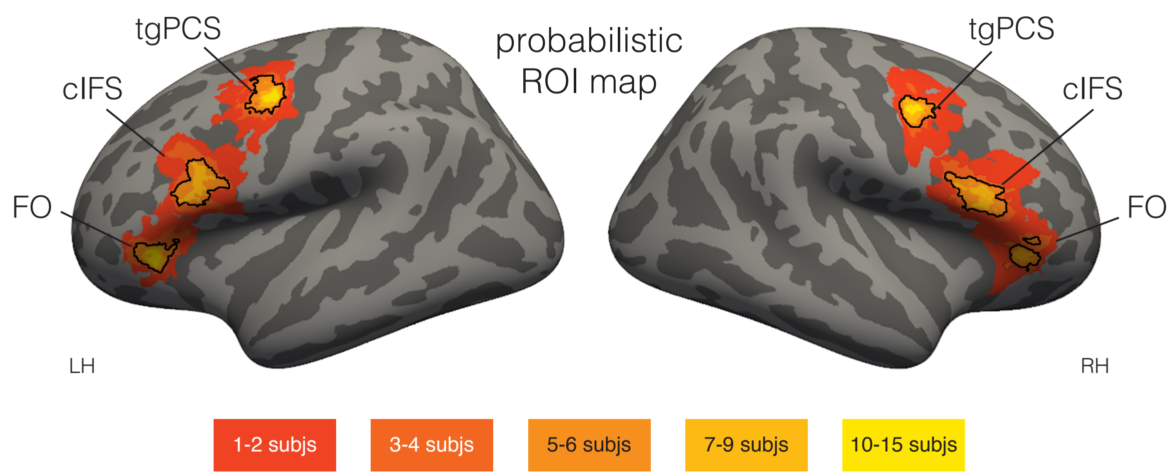
Sensory specialization is **minimally visible in group-average analyses**.



Identification of fine-grained cortical organization requires individual subject analysis.

But organization is nonetheless relatively consistent considering overlap of subjects



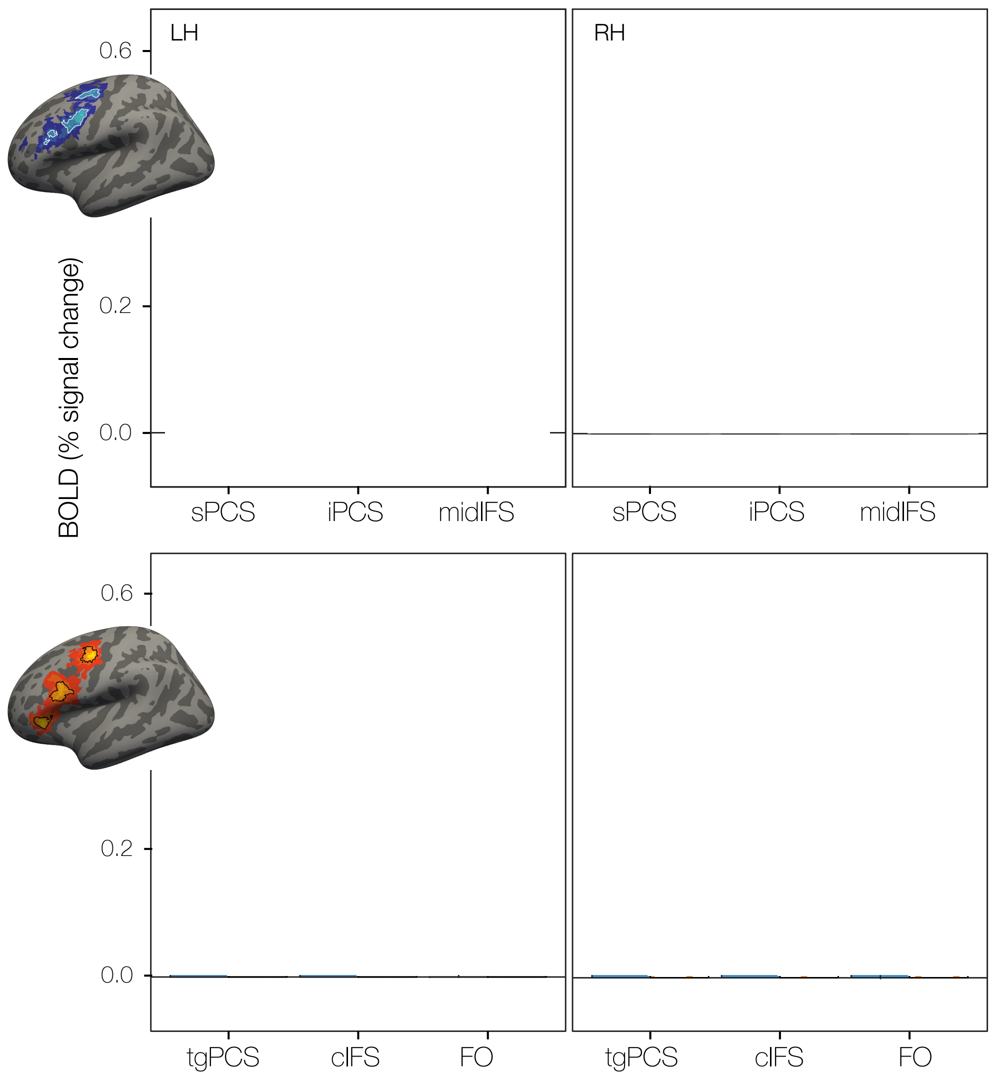


Sensory-biased networks replicate and extend using working memory tasks

…with a consistent asymmetry

Abby Noyce
(BU)

Cross-modal (nonspatial) WM task activation is asymmetric for visual / auditory regions



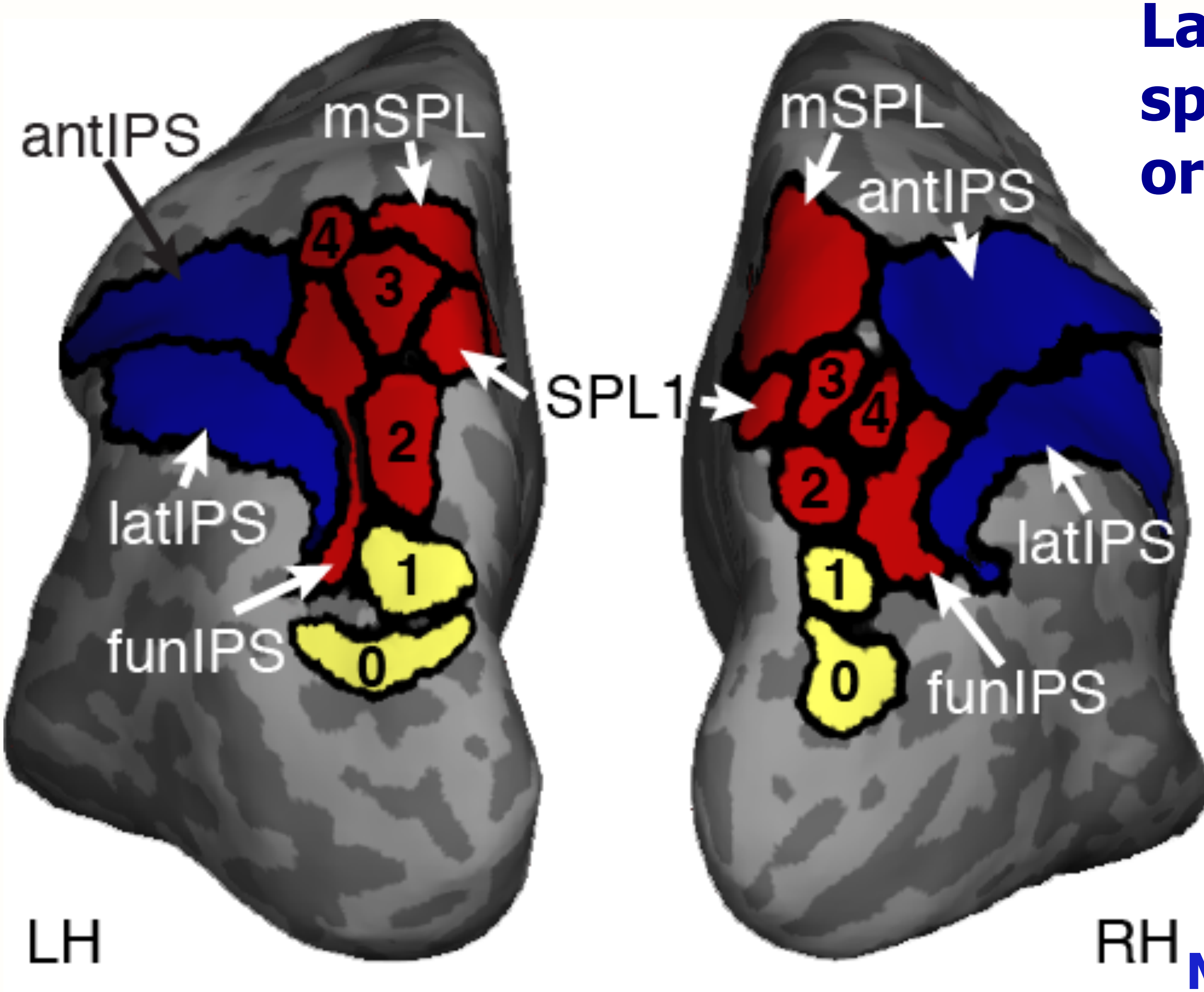
Visual-biased structures are also significantly activated in auditory WM

Auditory-biased structures are not significantly active in visual WM

Auditory spatial tasks also recruit parietal regions responsive to visual inputs

Sam Michalka (Olin College), David Somers (BU)

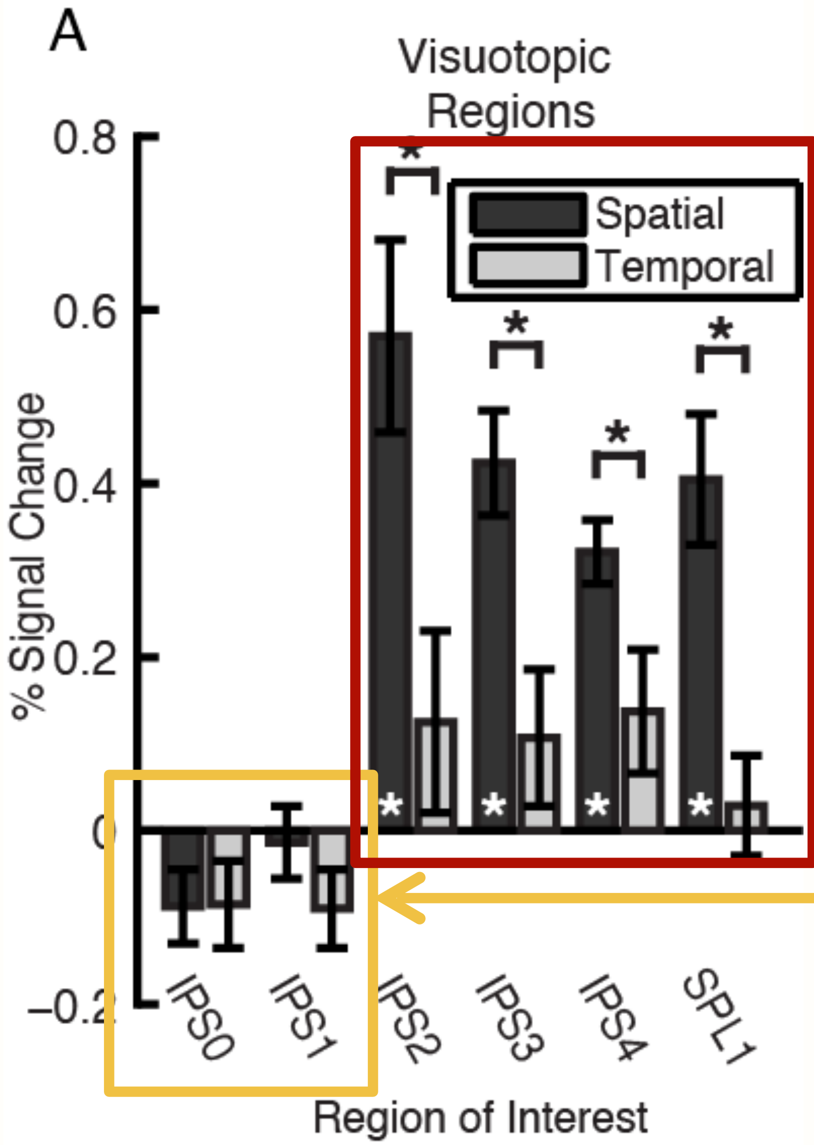
Retinotopic maps exist in parietal cortex, ascending from primary visual regions



Lateral IPS is not spatially organized

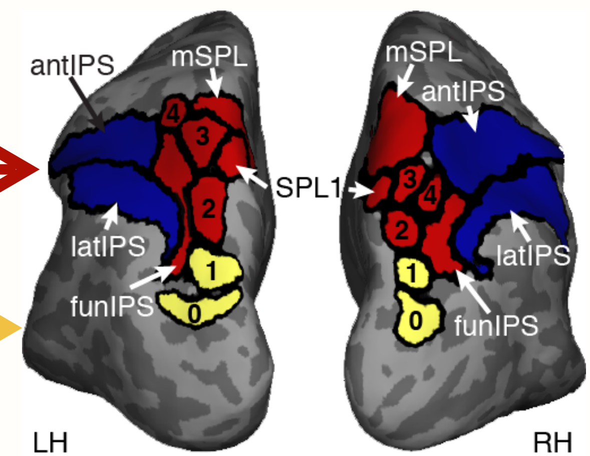
Michalka et al., Cereb Cortex, 2015

Higher visuoparietal areas, but not early areas, are recruited in auditory spatial tasks



IPS2 and up recruited by auditory spatial task

IPS0 and IPS1 appear strictly "visual"



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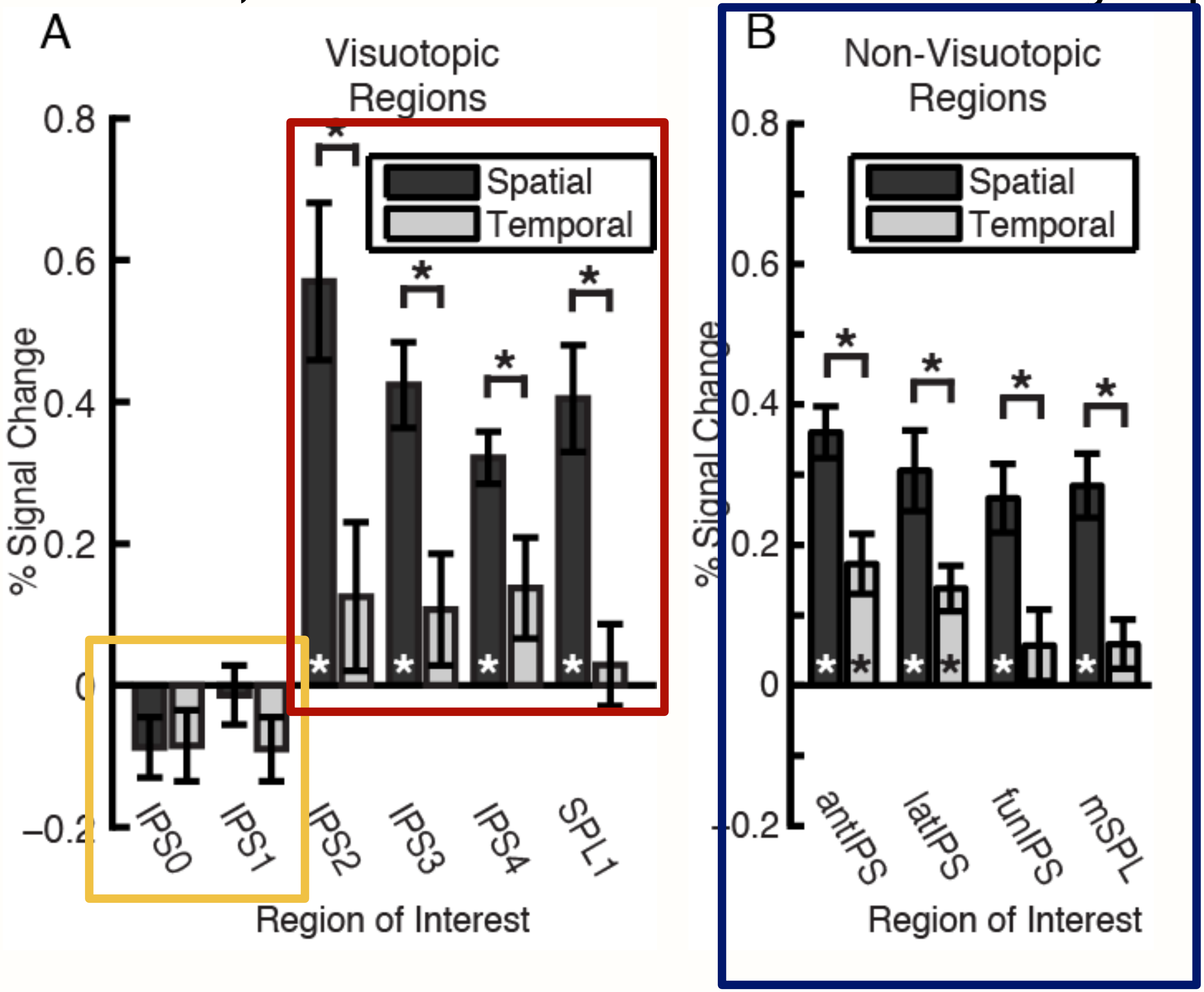
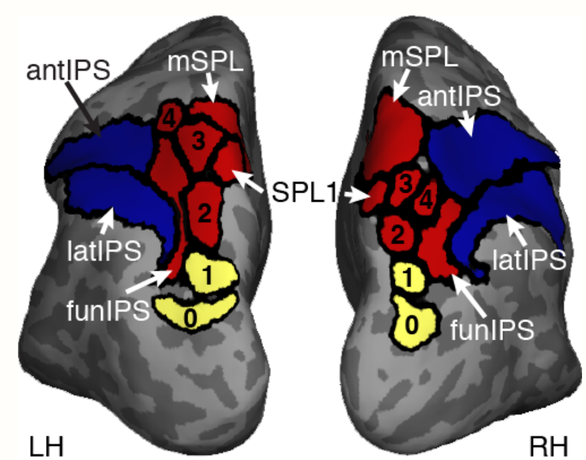
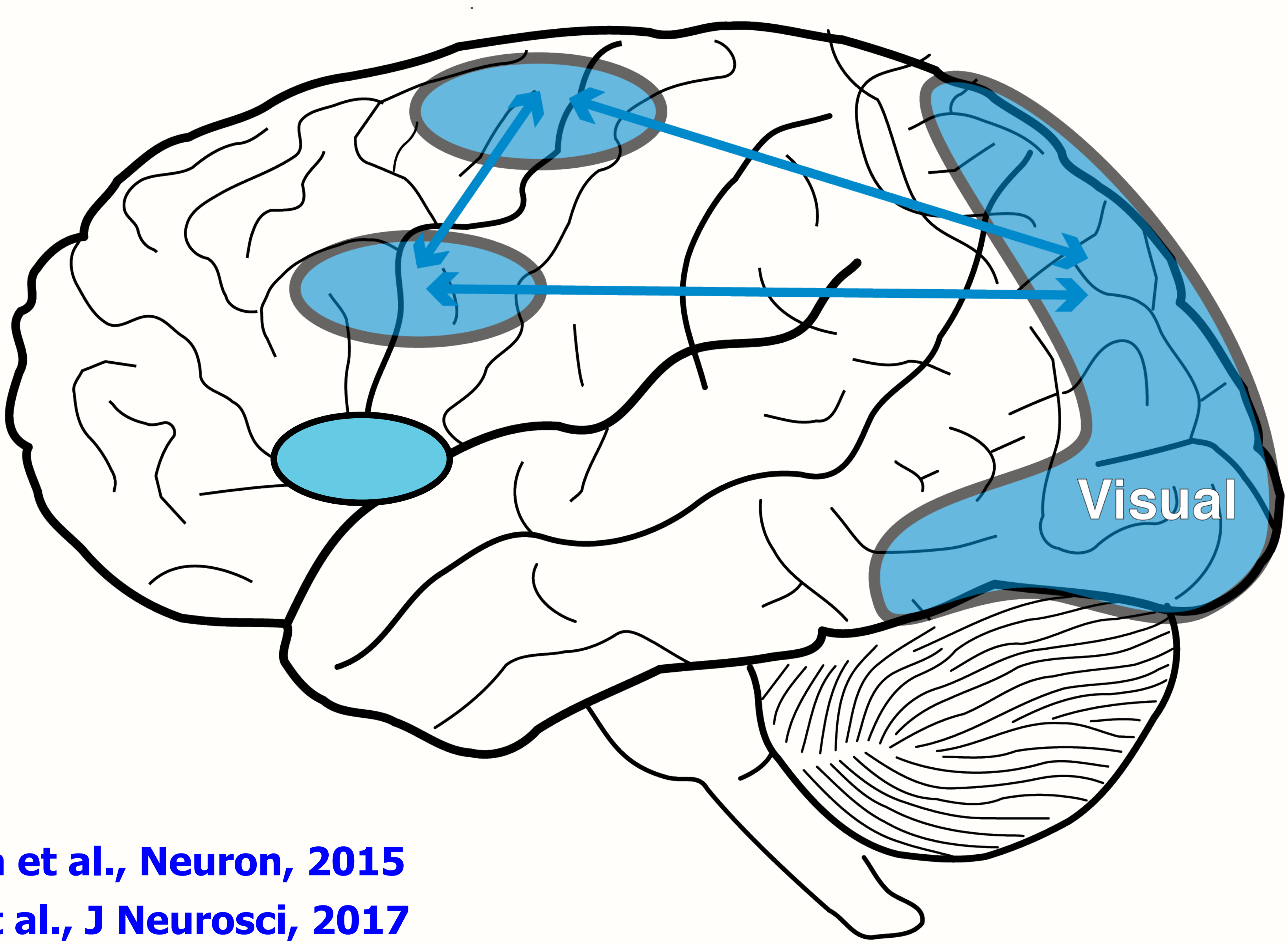


Anterior-lateral ROIs respond *more* in spatial than temporal auditory tasks



Michalka et al., Cereb Cortex, 2015

Sensory control brain networks



Michalka et al., Neuron, 2015

Noyce et al., J Neurosci, 2017

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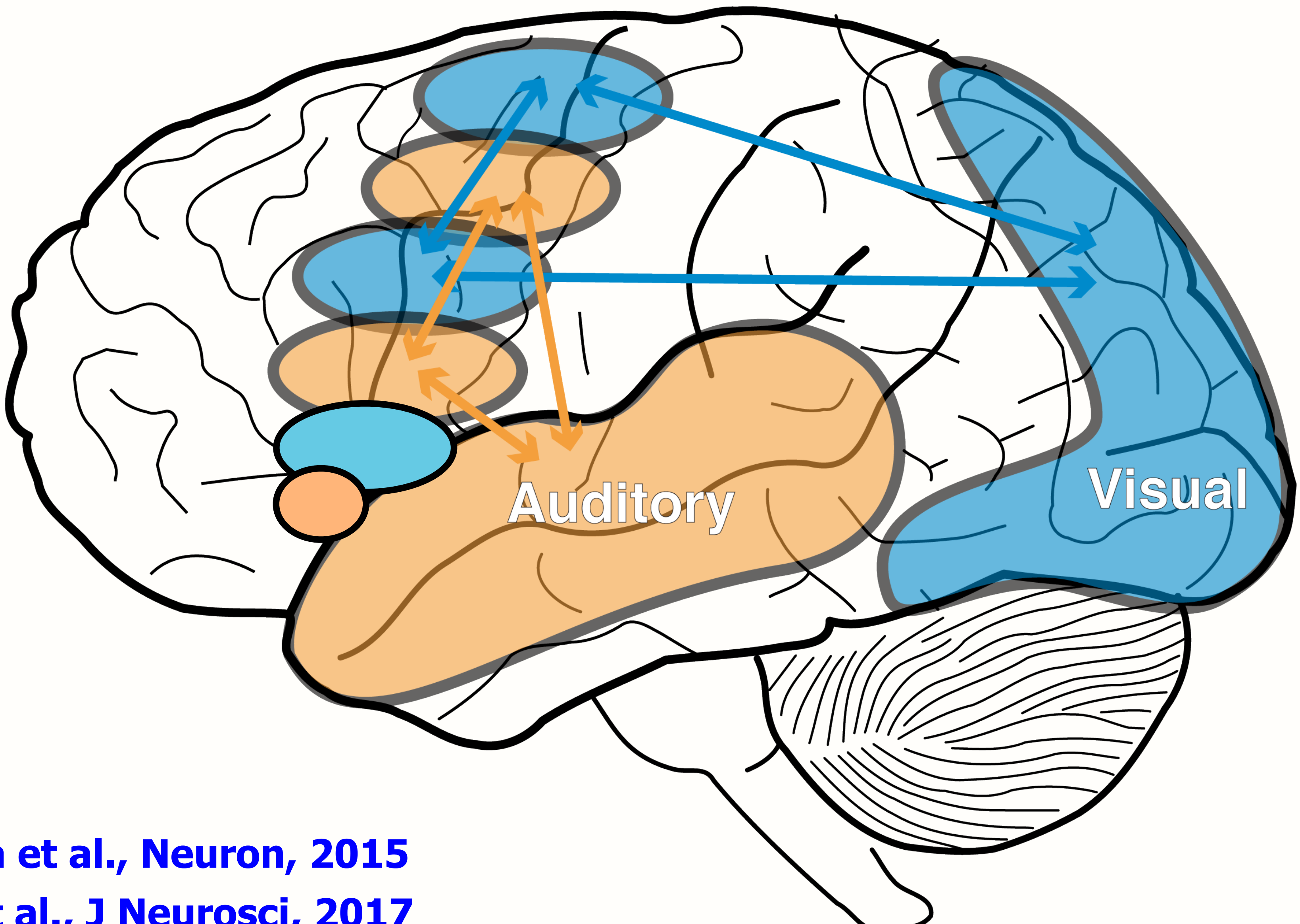
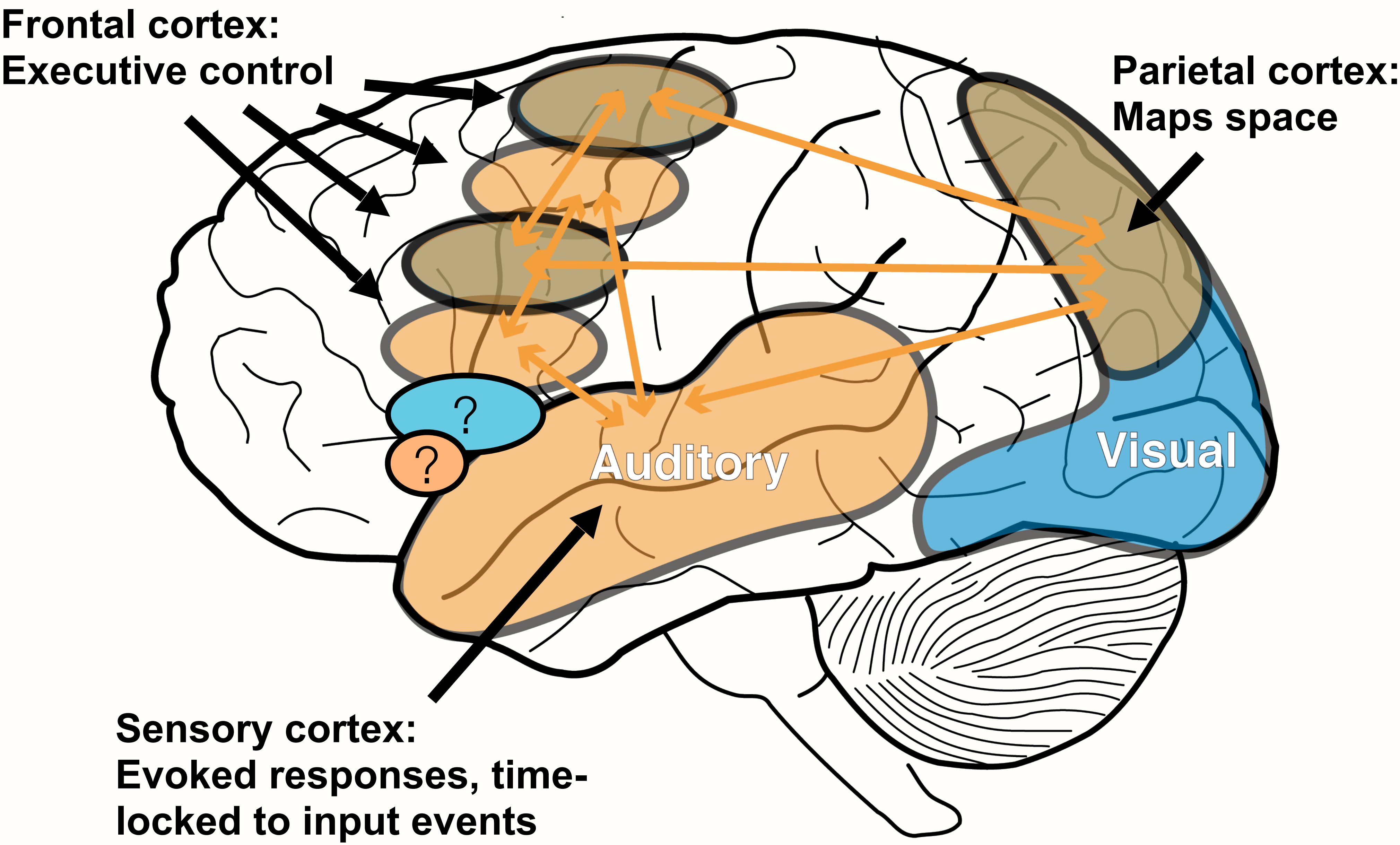


Michalka et al., Neuron, 2015
Noyce et al., J Neurosci, 2017

Spatial auditory tasks recruit “visual” (spatial) network



Part IIa summary

Selective auditory attention leads to coordinated activity across different brain networks, even before sound plays, that fundamental alters information represented in cortex

This activity engages sensory biased visual and auditory networks that include inter-digitated frontal regions

Parietal regions in the “visual” network are also engaged by auditory spatial tasks

There is an asymmetry across modalities— auditory tasks recruit visually biased regions more strongly and consistently than visual tasks recruit auditory-biased regions (so far!)

Part IIa mysteries

What are multiple frontal regions doing? How do they differ?

Is the ubiquity of the visual network activity because every sensation has *some* spatial attribute?

Where are *language* areas relative to the auditory network?

Part IIb

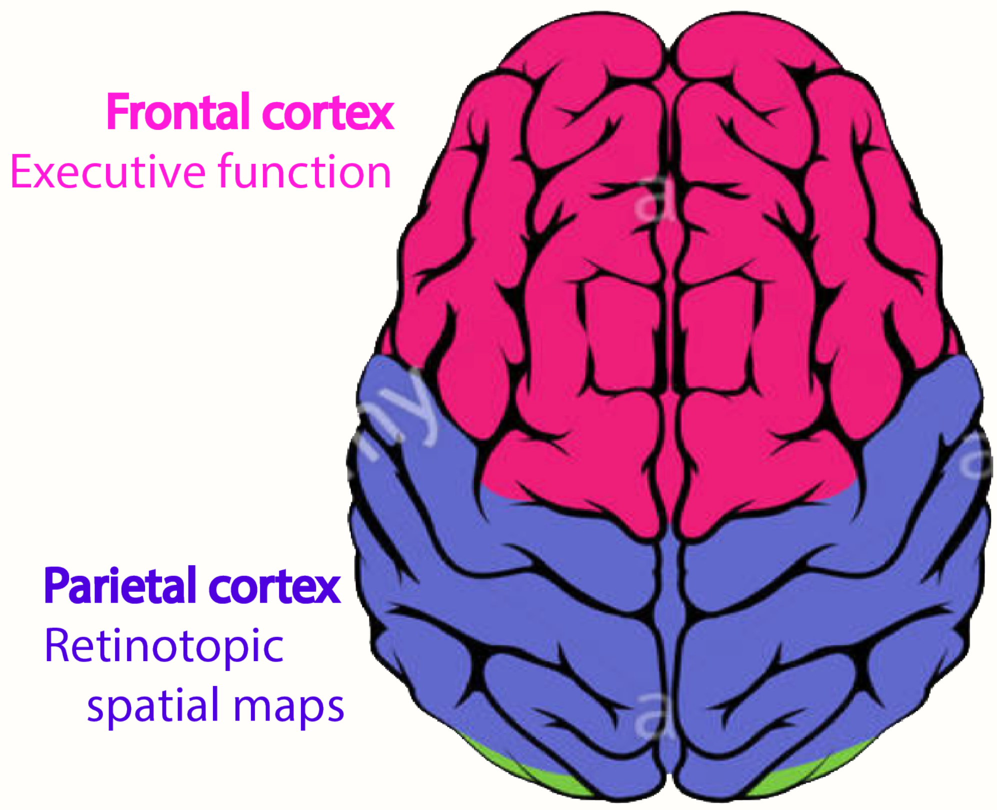
The big theme:

Different brain networks work in an intricate, tightly choreographed dance to effect attention,

which fundamentally changes the representation of information in cortex,

but this process can fail when attention is disrupted by external salient events or when spatial auditory processing is compromised

Parietal maps represent contralateral space, asymmetrically



Huang et al., Neuroimage, 2014

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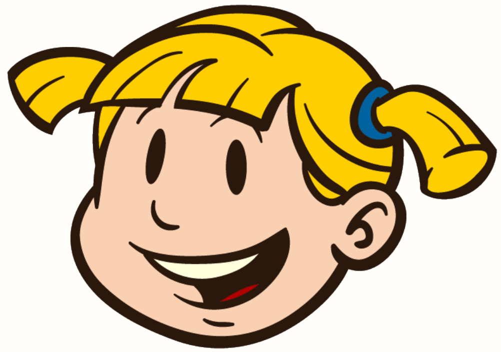

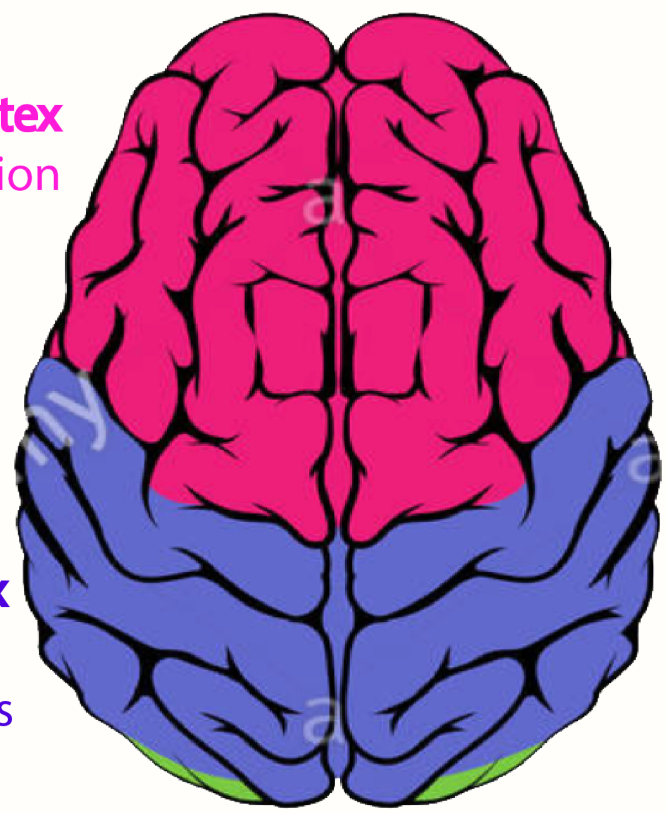

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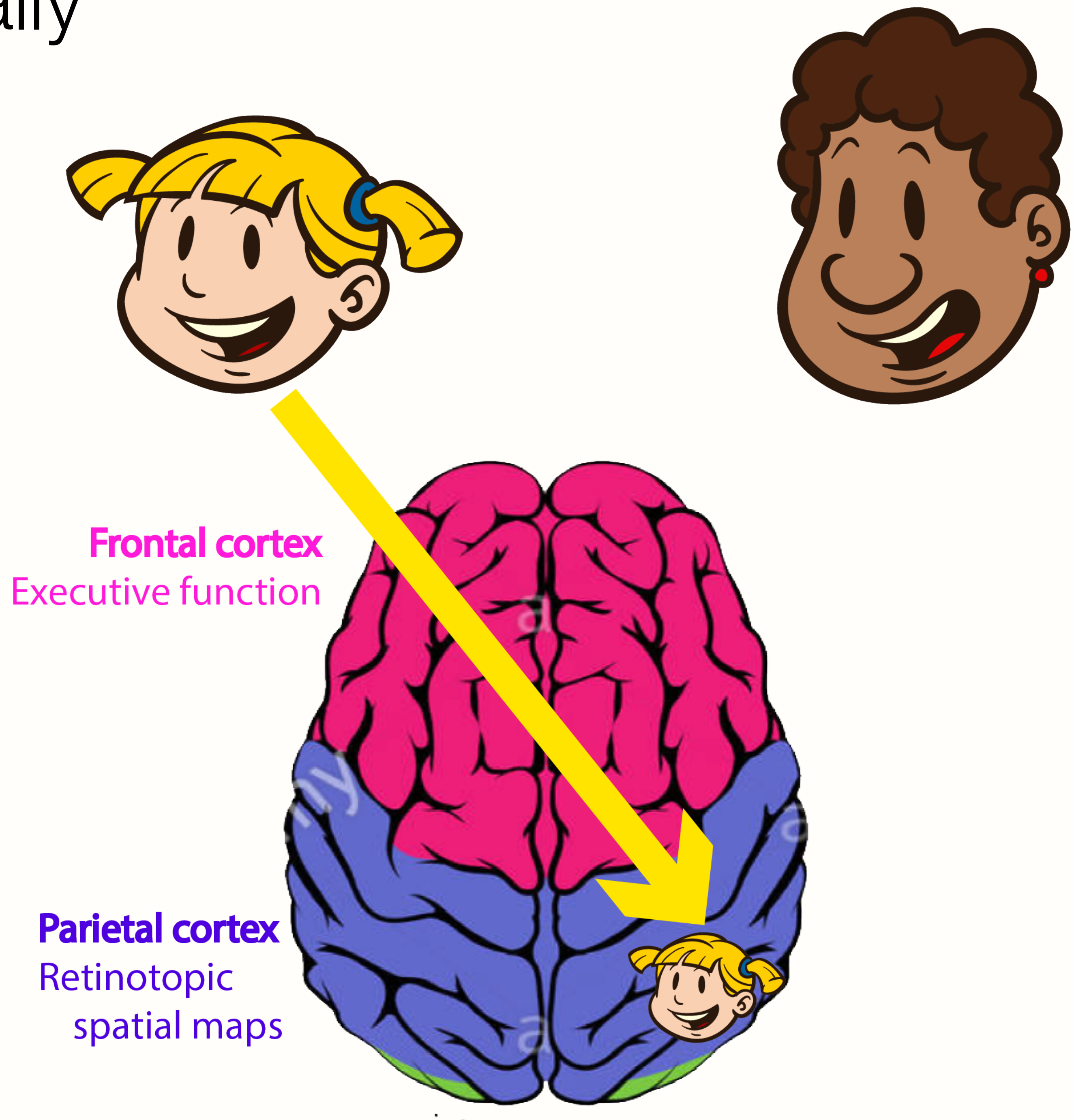

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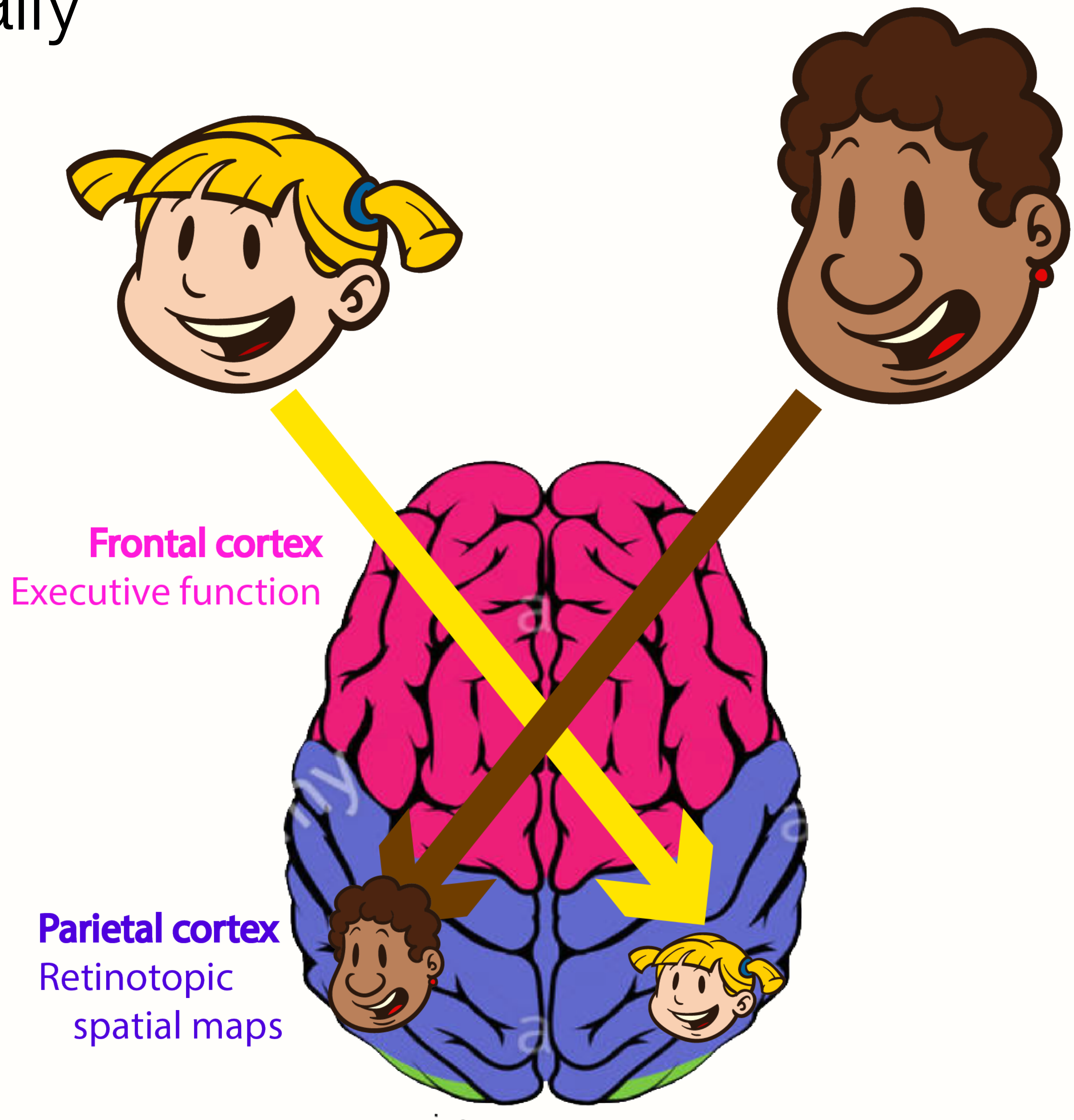

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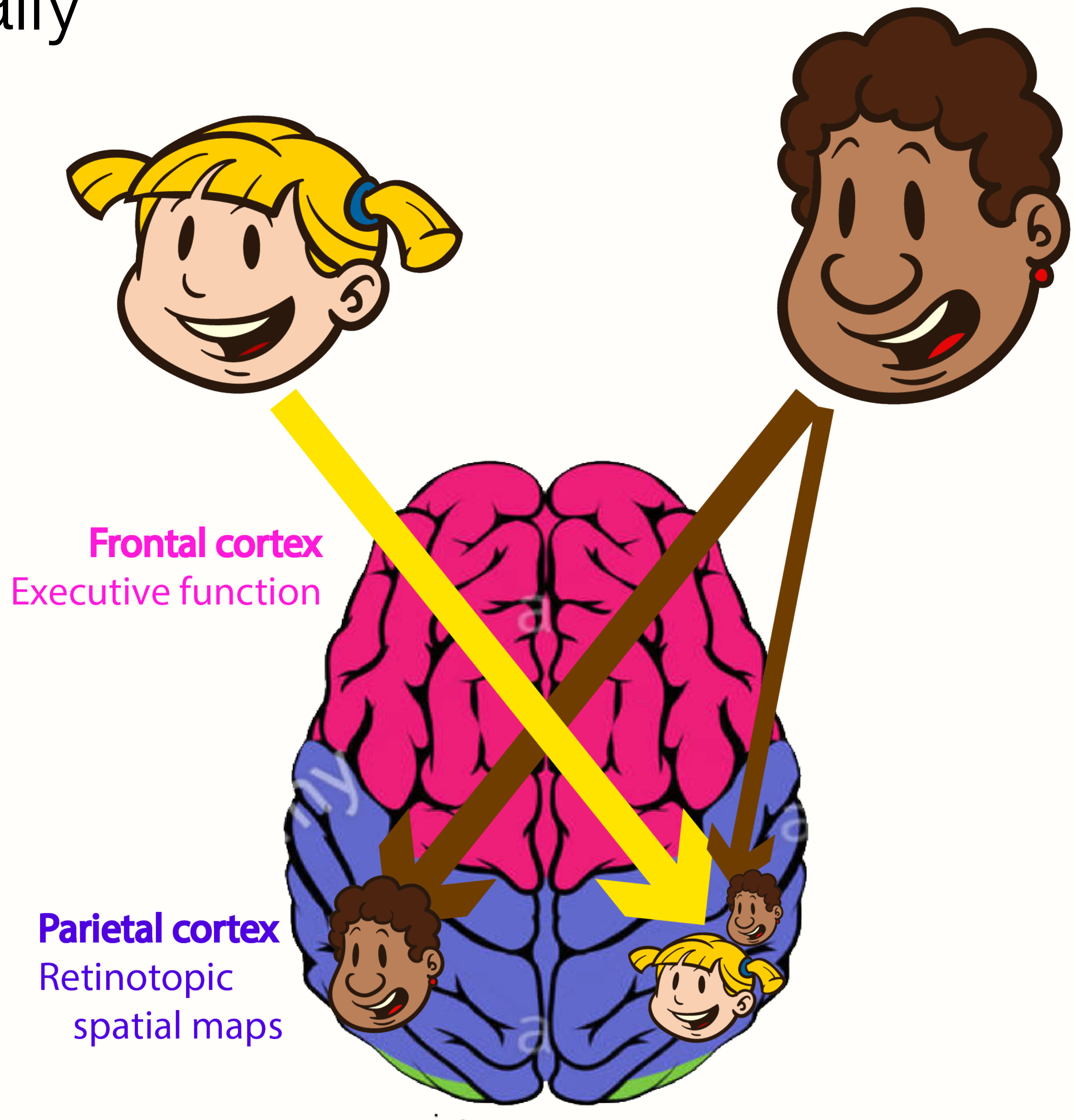
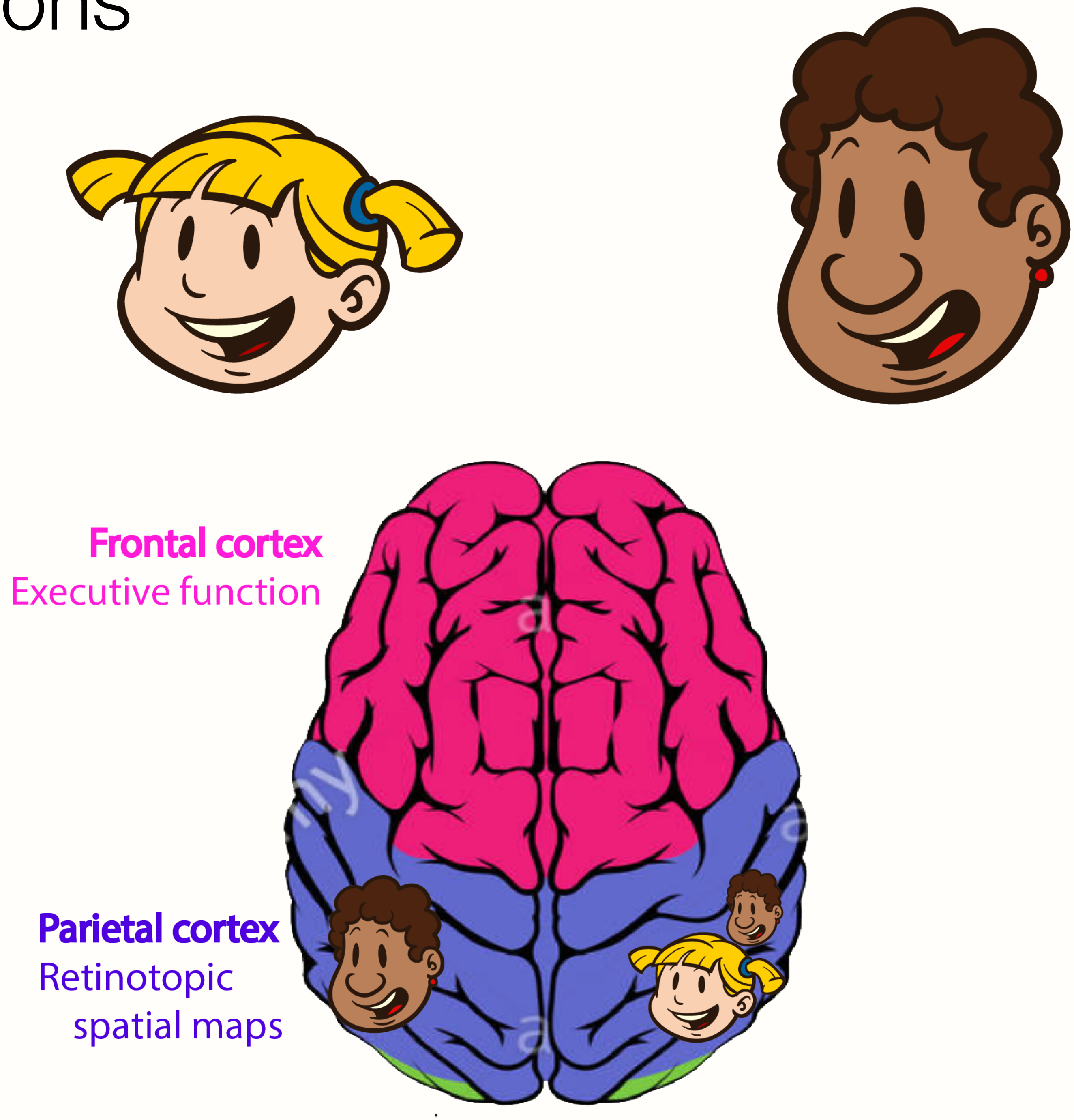


Huang et al., Neuroimage, 2014

Spatial attention modulates parietal representations



Huang et al., Neuroimage, 2014

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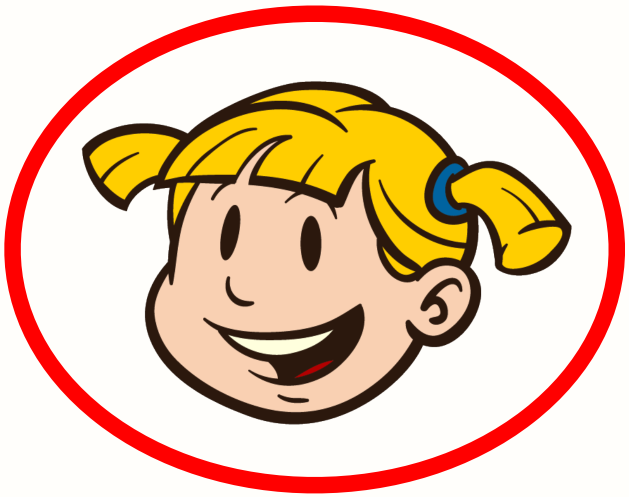

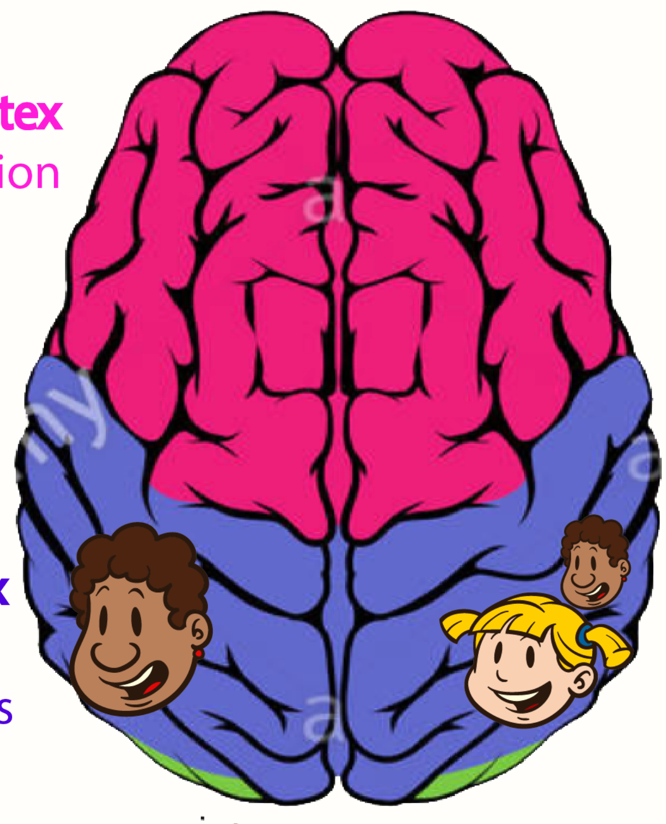

Huang et al., Neuroimage, 2014

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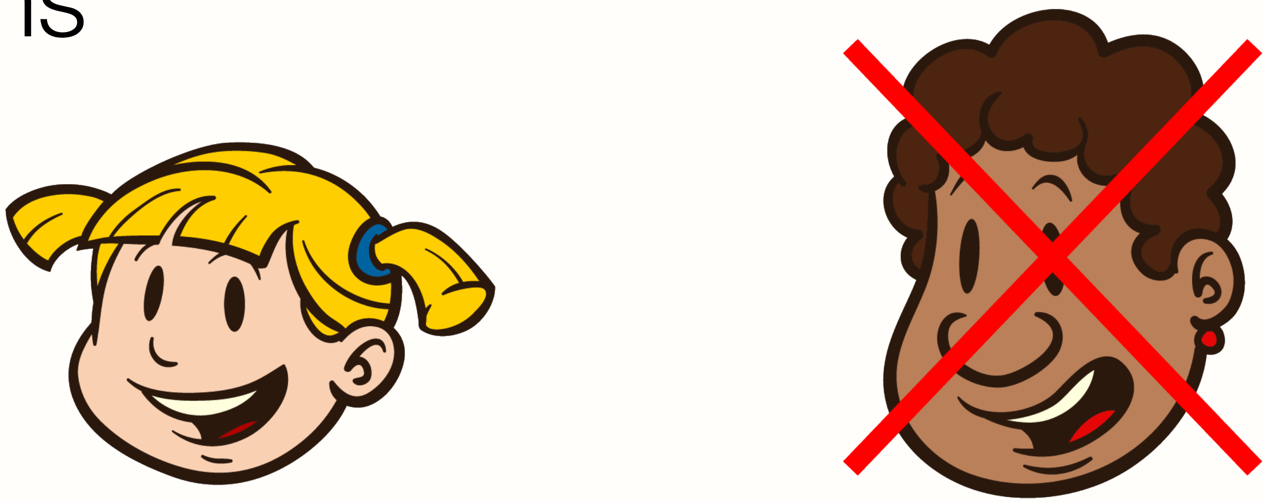

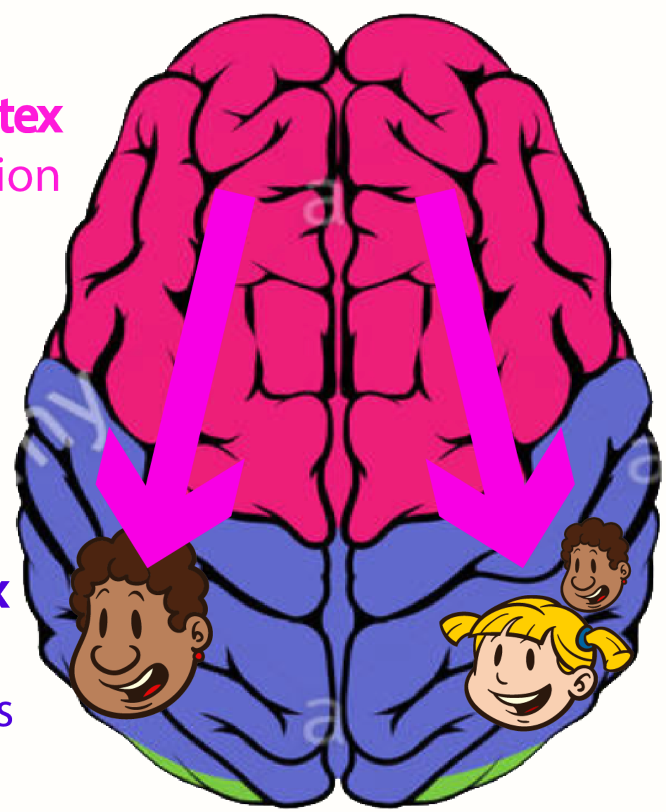

Huang et al., Neuroimage, 2014

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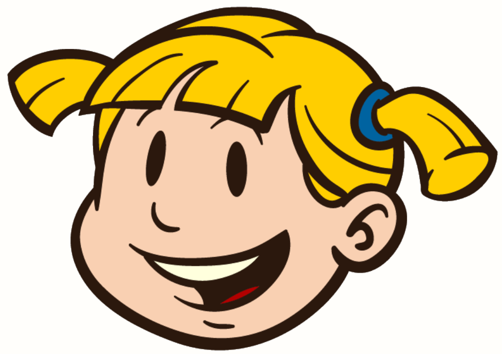

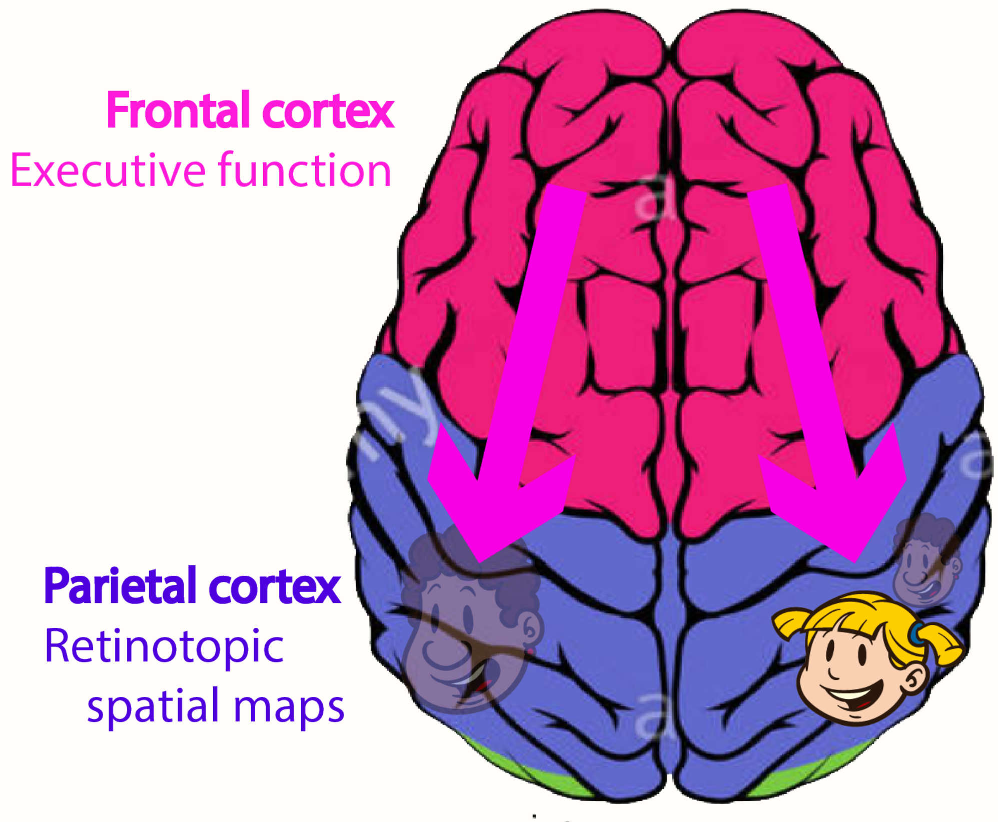

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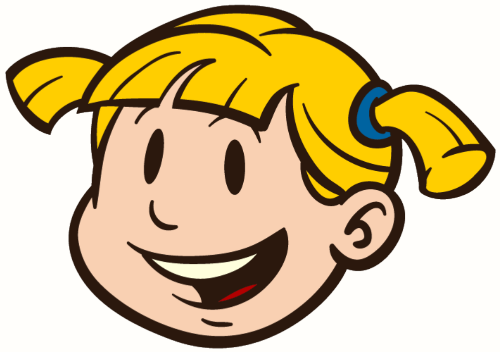
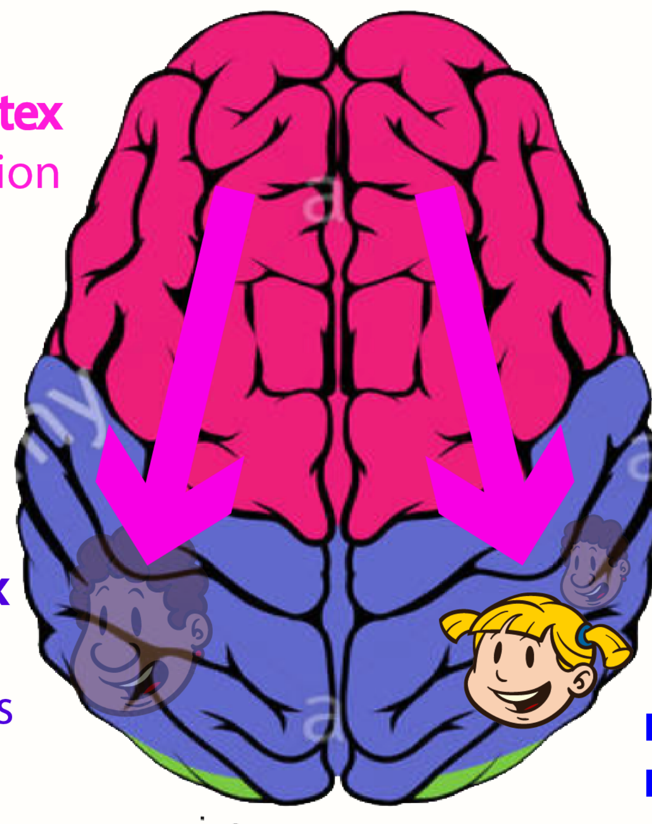


Frontal cortex
Executive function



Alpha oscillations (8-12 Hz)
Signal suppression
Often increases IPSILATERAL to attended object

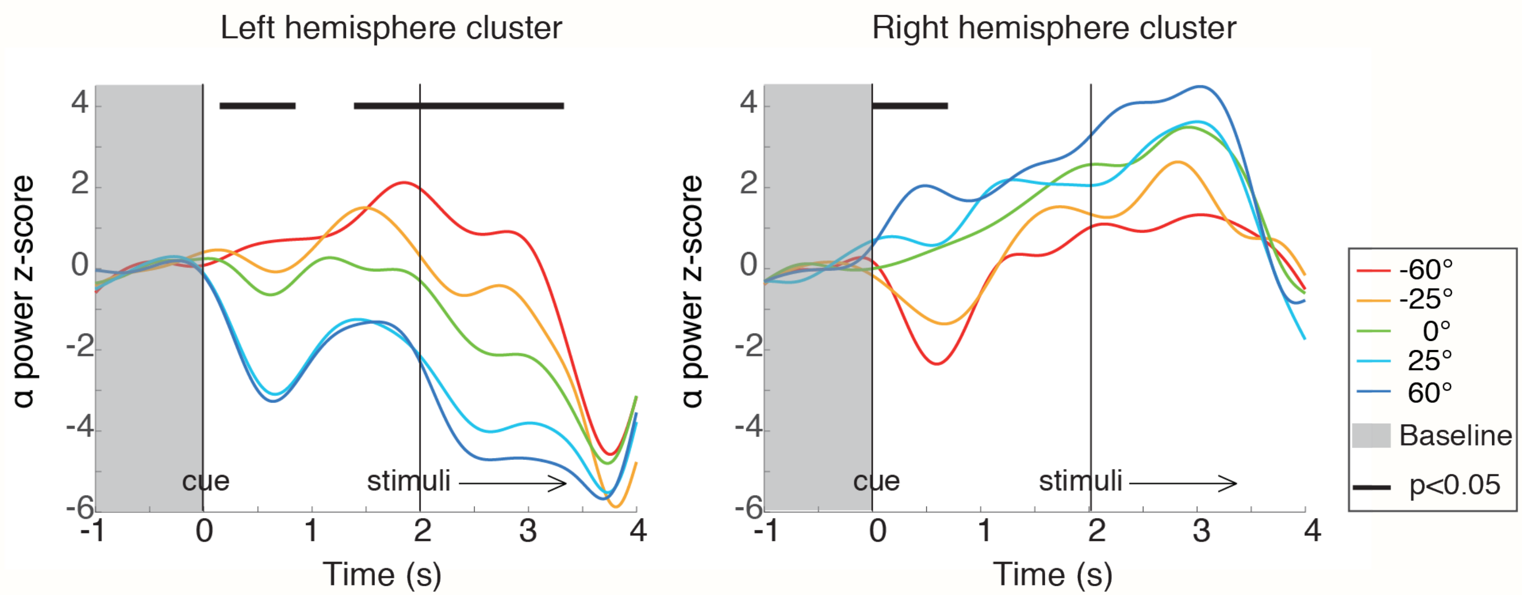
Parietal cortex
Retinotopic spatial maps

Deng et al., in process
Bonnaci et al., in process

Parietal maps show lateralized alpha oscillation power during spatial auditory attention

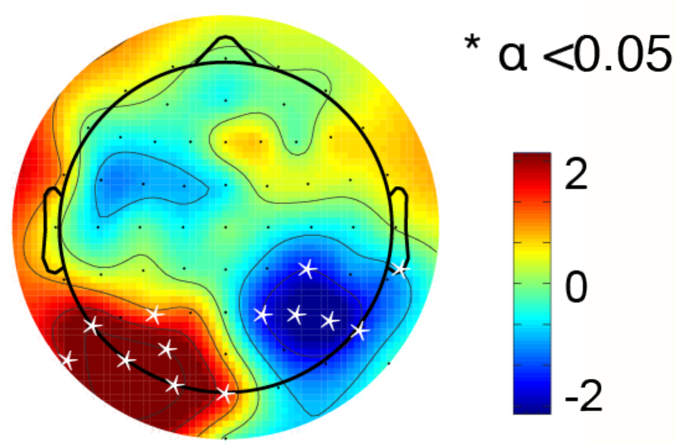
Yuqi Deng
(BU)

Lateralization of alpha power in parietal cortex reflects contralateral suppression



Alpha oscillations (8-12 Hz)
Signal suppression
Often increases IPSILATERA
to attended object

Attend -60° - Attend 60°



Deng et al., in process

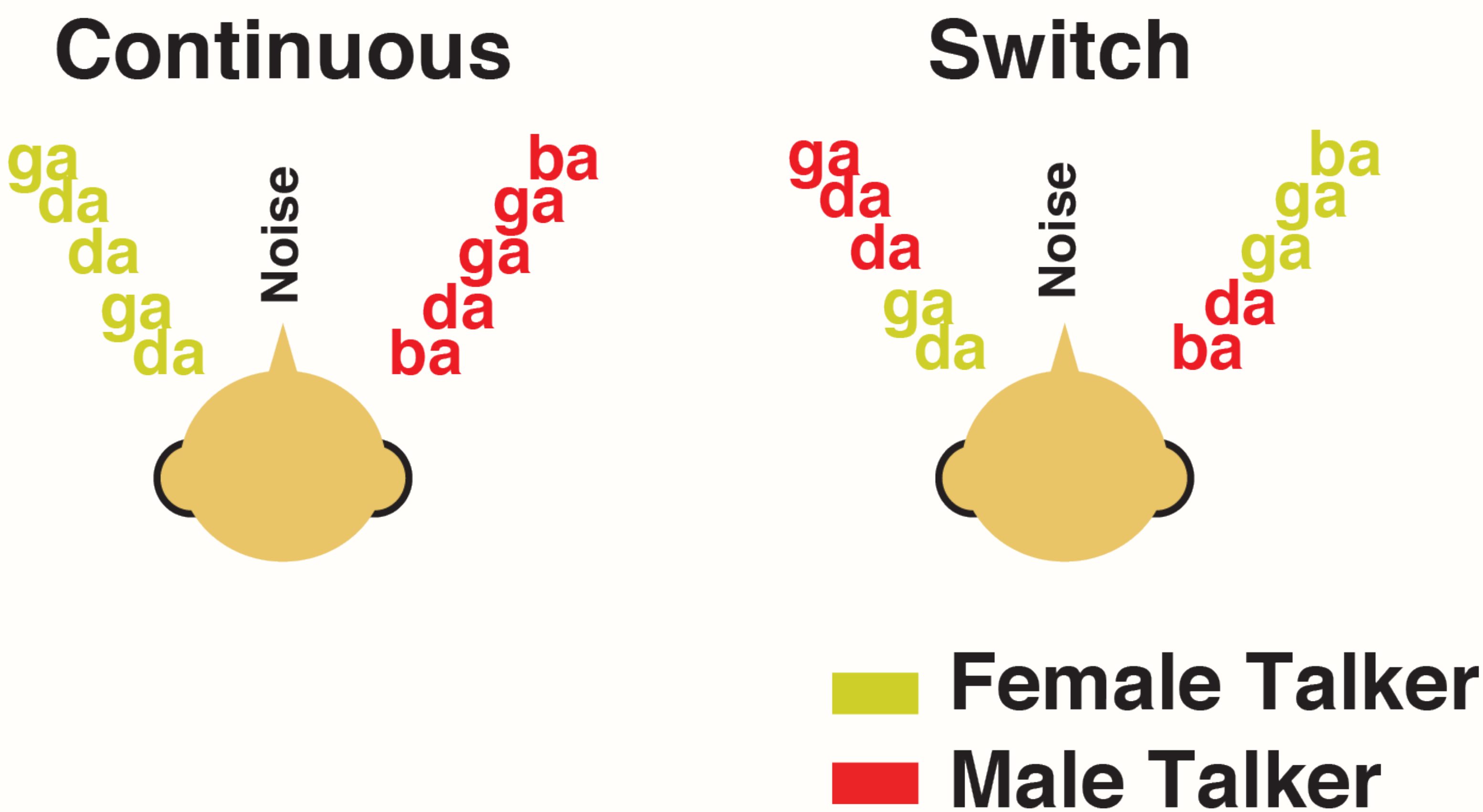
Bottom-up disruptions of a stream interfere with spatial attention and disrupt parietal activity

Goldie Mehraei

(Decibel Therepeutics)

Listen in a direction– where voice may switch

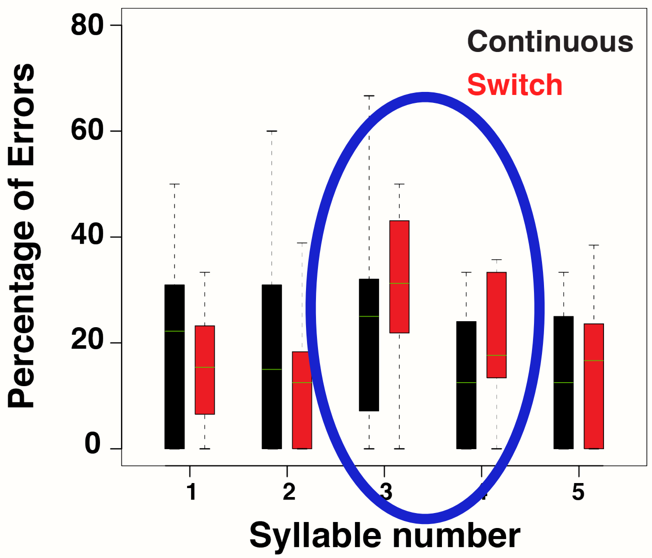
Spatial and voice cues “compete” at switch point

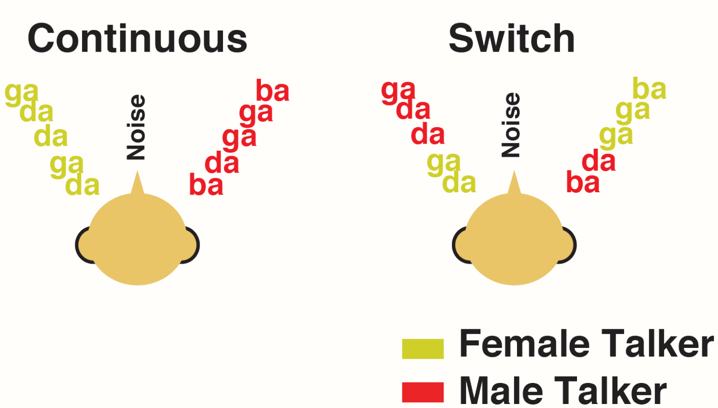


Mehraei et al., Neuroimage, 2018

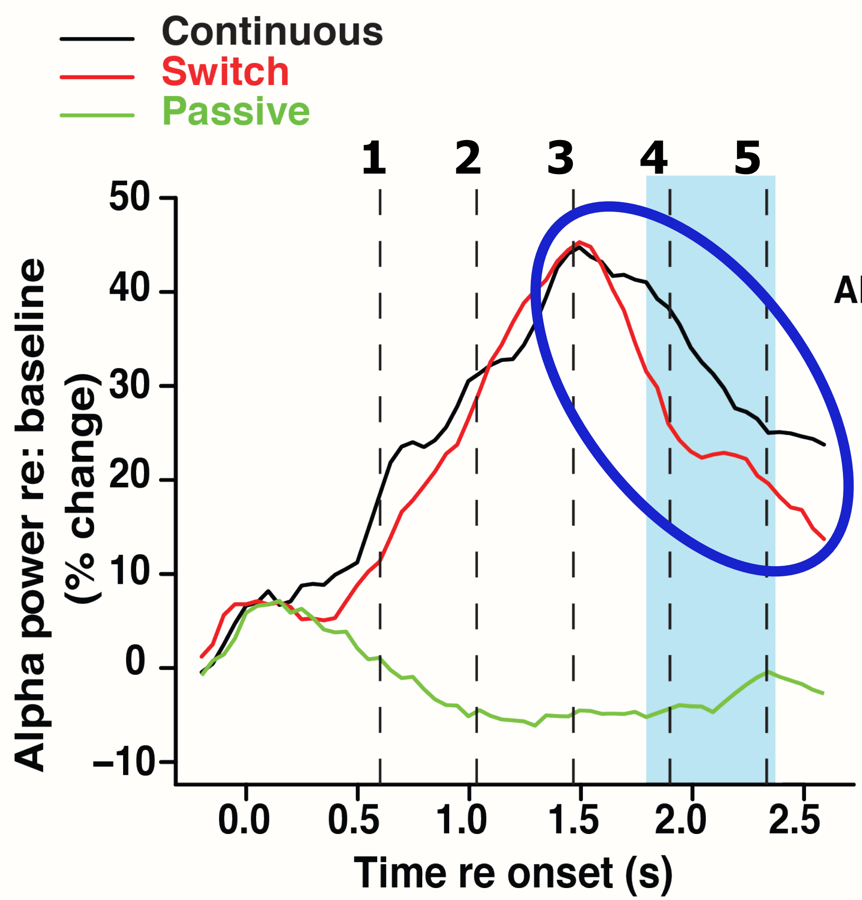
Bottom-up voice discontinuity hurts performance and disrupts alpha

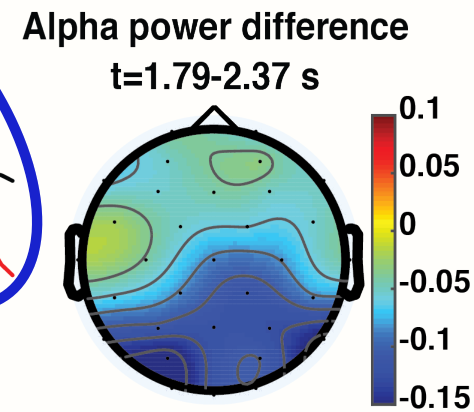
Errors increase at switch point





Alpha power drops at switch point

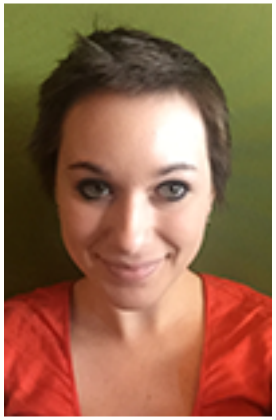




Selective spatial attention fails for many hearing impaired listeners

Lengshi Dai
(Mathworks)

Lia Bonacci
(BU)



Hearing impairment ”blurs” sound features in the acoustic scene

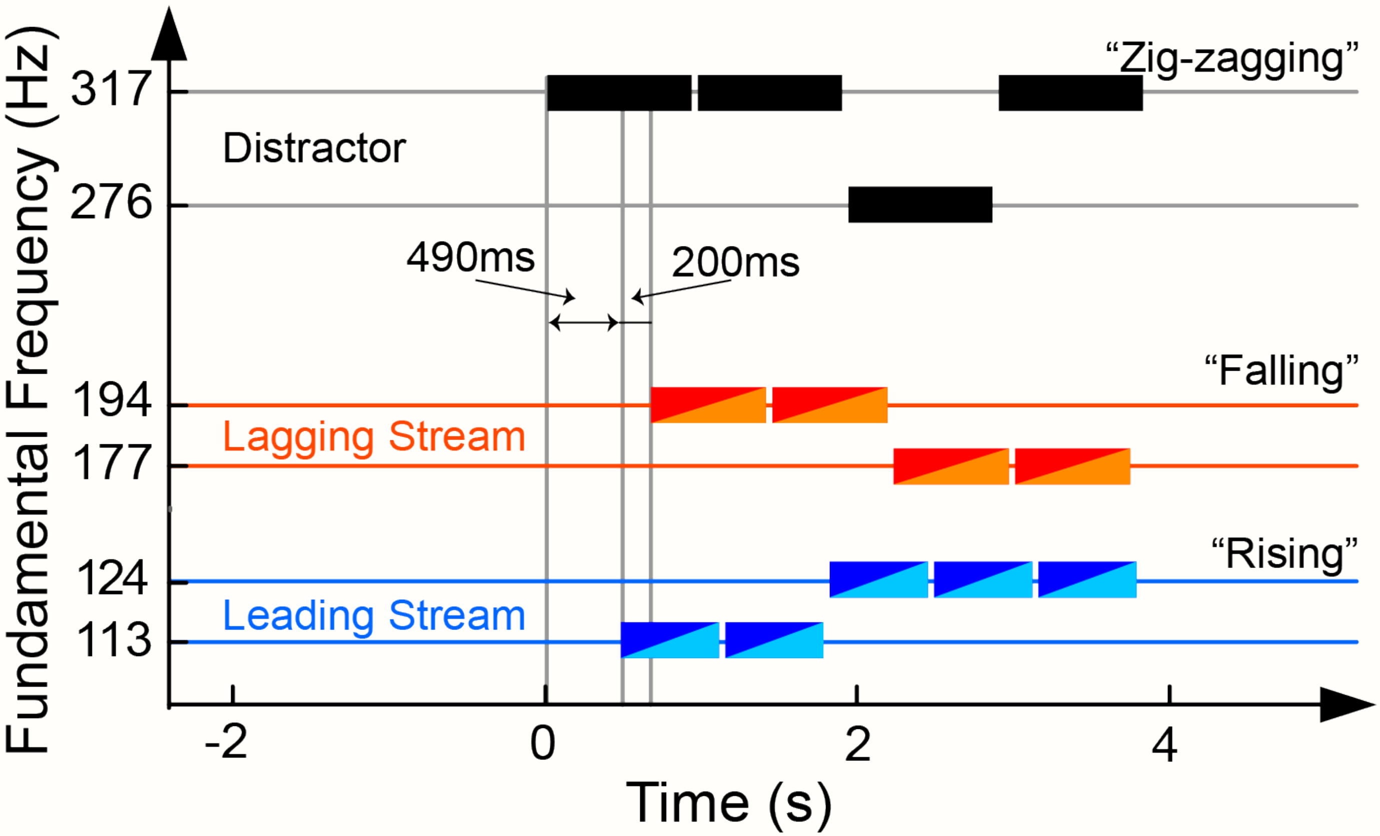
Normal hearing

Hearing impaired

Harder to analyze scene and segregate sources
=> Failure of attention

Shinn-C et al., SHAR, 2017
Shinn-C and Best, Trends Amplif, 2008

Three competing streams



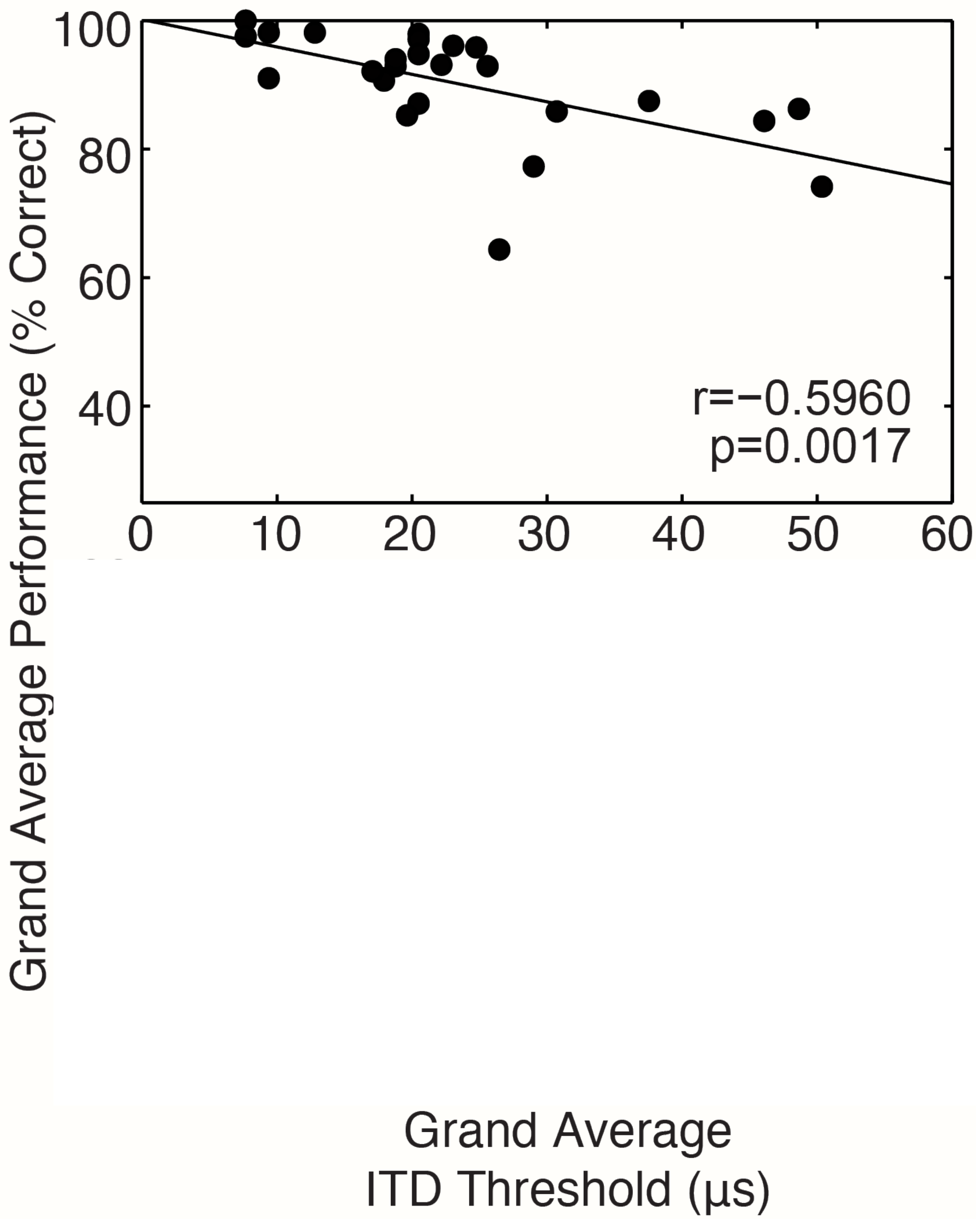
One center
One to each side

Separations either large (easy) or small (hard)

Dai et al., PNAS, 2018

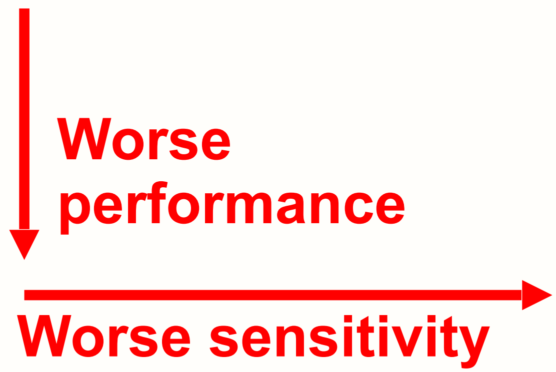
Spatial sensitivity, performance, & neural suppression all correlate

Normal Hearing (N=25)



Hearing Impaired (N=15)

Performance relatively good for normal hearing listeners



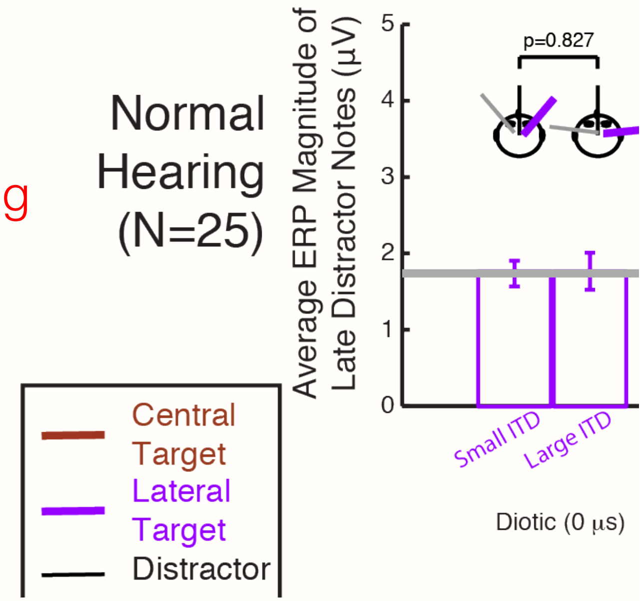
Hearing impaired range from good to chance levels of performance

Dai et al., PNAS, 2018

Hearing impairment hurts neural suppression (esp. when it is hard)

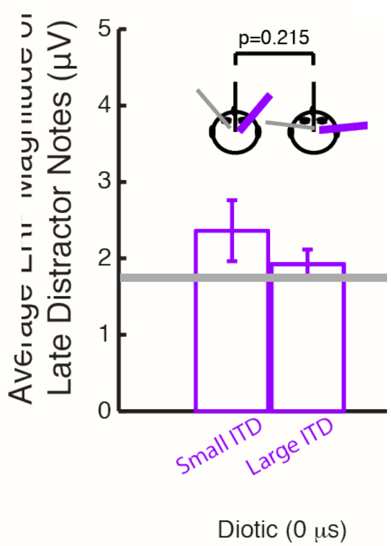
Smaller is better (suppressing distractor)

Normal Hearing (N=25)



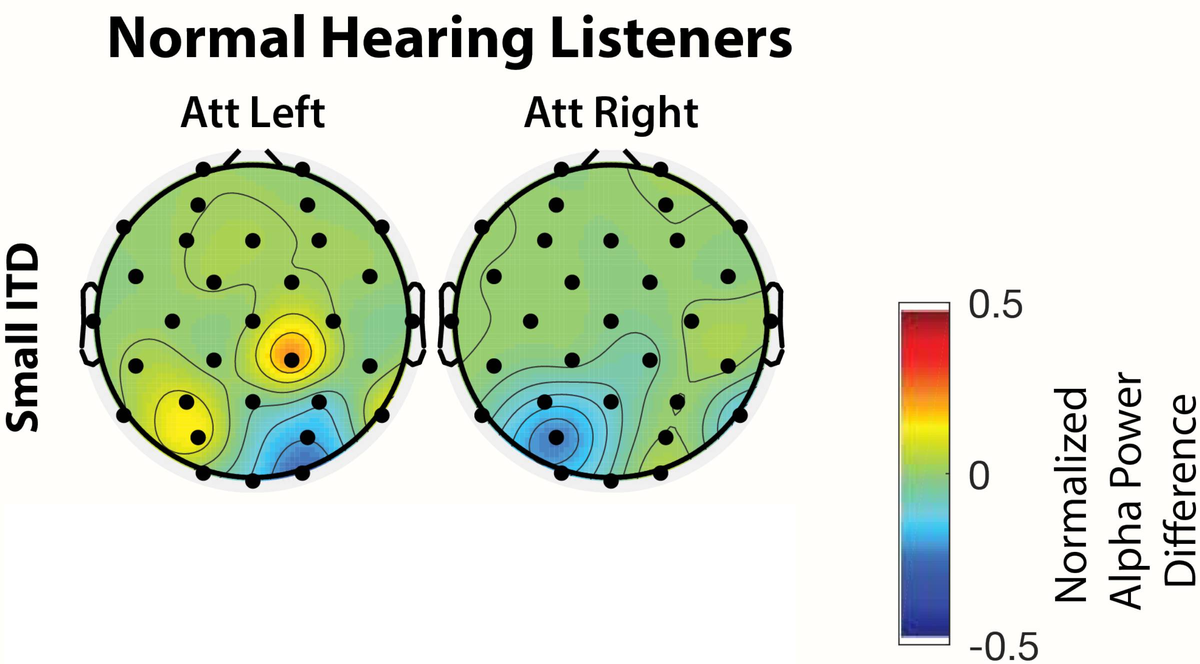
Distractors not well suppressed when flanking the target

Hearing impaired cannot analyze scene using spatial cues



Dai et al., PNAS, 2018

Parietal alpha (spatial suppression) not present in hearing impaired



NH alpha oscillations lateralized
Greater for larger spatial separations

Part IIb summary

The “dance” of network signaling includes activity in parietal (spatial map) brain regions that is controlled volitionally, seen in alpha power and its lateralization

Salient external events can disrupt attention performance, as well as alpha lateralization

Listeners with hearing impairment cannot effectively direct spatial auditory attention

Part IIb mysteries

Even if hearing impairment leads to poor spatial auditory processing, why is preparatory alpha modulation to a visual cue absent?

Will I really convert to Keynote after 20 years of MS pain?

Who is coming to visit CMU / Pittsburgh? (Our Hospitality Suite is available for visitors!)

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Other Communication Disorders (NIDCD)