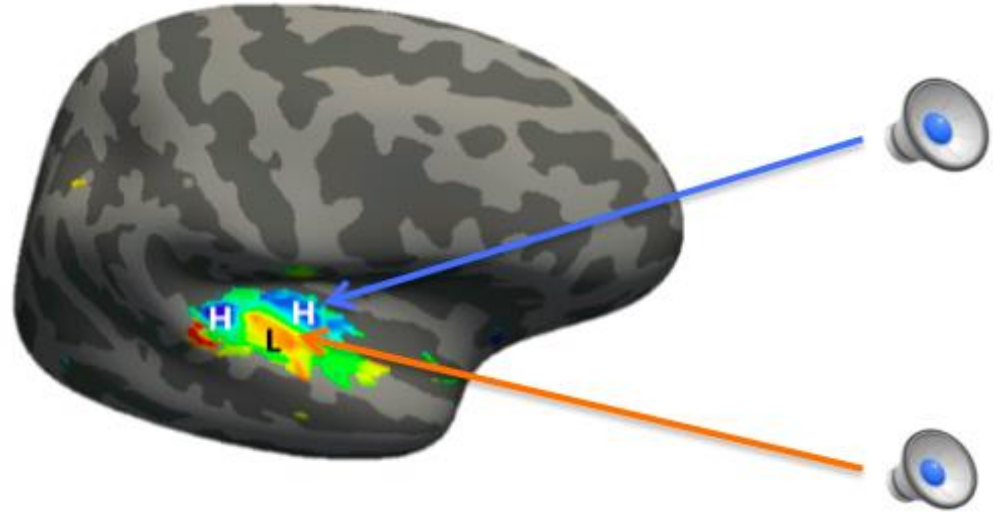
What do we know about Auditory Cortex?

Map of Frequency



Less consensus:

- ***Pitch***
- ***"What vs. where" ???***
- ***"Voice regions" ???***
- ***"Speech regions" ???***
- ***"Music activations" ???***
- ***Spectrotemporal modulation ???***

Why not more progress?

What is the Structure of Human Auditory Cortex?

Images removed due to copyright restrictions. Please see the video.

A data-driven approach……

1. **Collect several hundred 2-second natural sounds,**
2. **Get ratings**
3. **Chose 165 most recognizable and frequently-heard sounds**

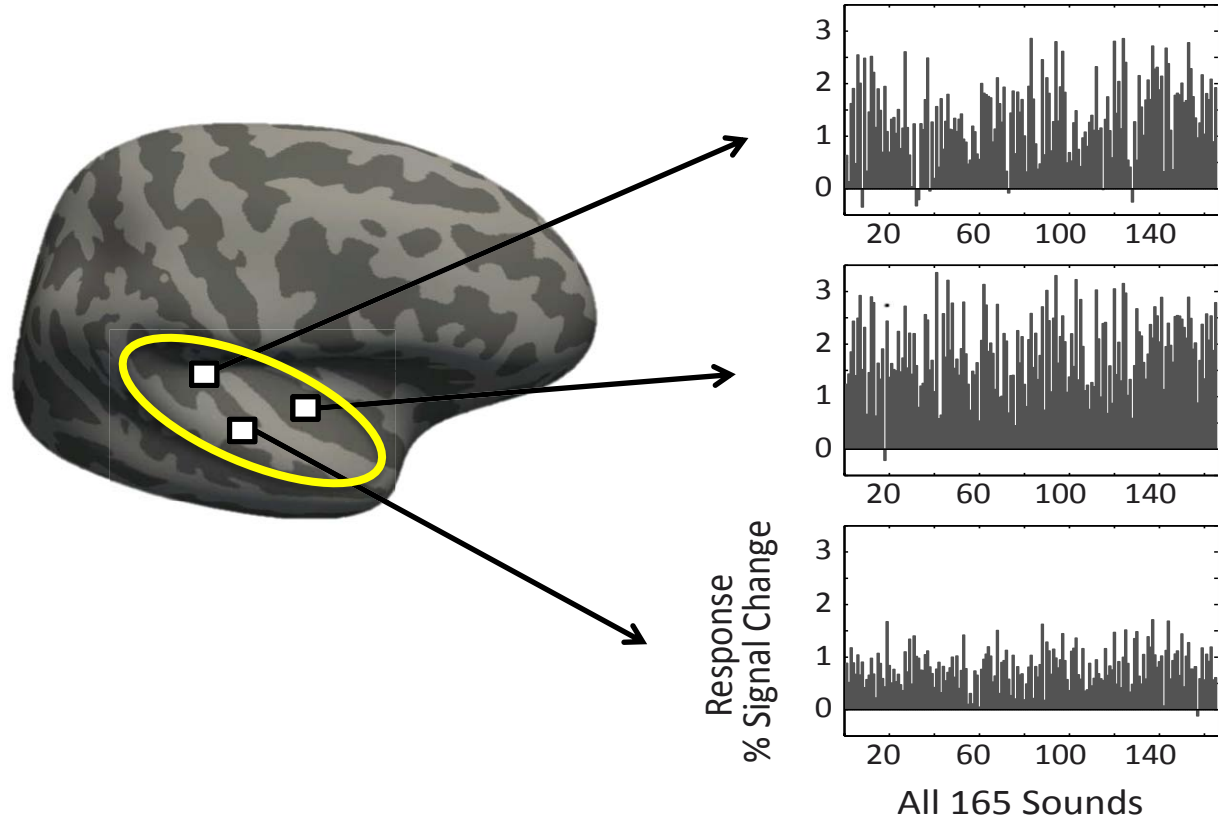
50 of the 165 Sounds in Experiment (each 2-seconds)

1. Man speaking
2. Flushing toilet
3. Pouring liquid
4. Tooth-brushing
5. Woman speaking
6. Car accelerating
7. Biting and chewing
8. Laughing
9. Typing
10. Car engine starting
11. Running water
12. Breathing
13. Keys jangling
14. Dishes clanking
15. Ringtone
16. Microwave
17. Dog barking
18. Walking (hard surface)
19. Road traffic
20. Zipper
21. Cellphone vibrating
22. Water dripping
23. Scratching
24. Car windows
25. Telephone ringing
26. Chopping food
27. Telephone dialing
28. Girl speaking
29. Car horn
30. Writing
31. Computer startup sound
32. Background speech
33. Songbird
34. Pouring water
35. Pop song
36. Water boiling
37. Guitar
38. Coughing
39. Crumpling paper
40. Siren
41. Splashing water
42. Computer speech
43. Alarm clock
44. Walking with heels
45. Vacuum
46. Wind
47. Boy speaking
48. Chair rolling
49. Rock song
50. Door knocking

Fairly comprehensive: Most sounds you would think of are on the list

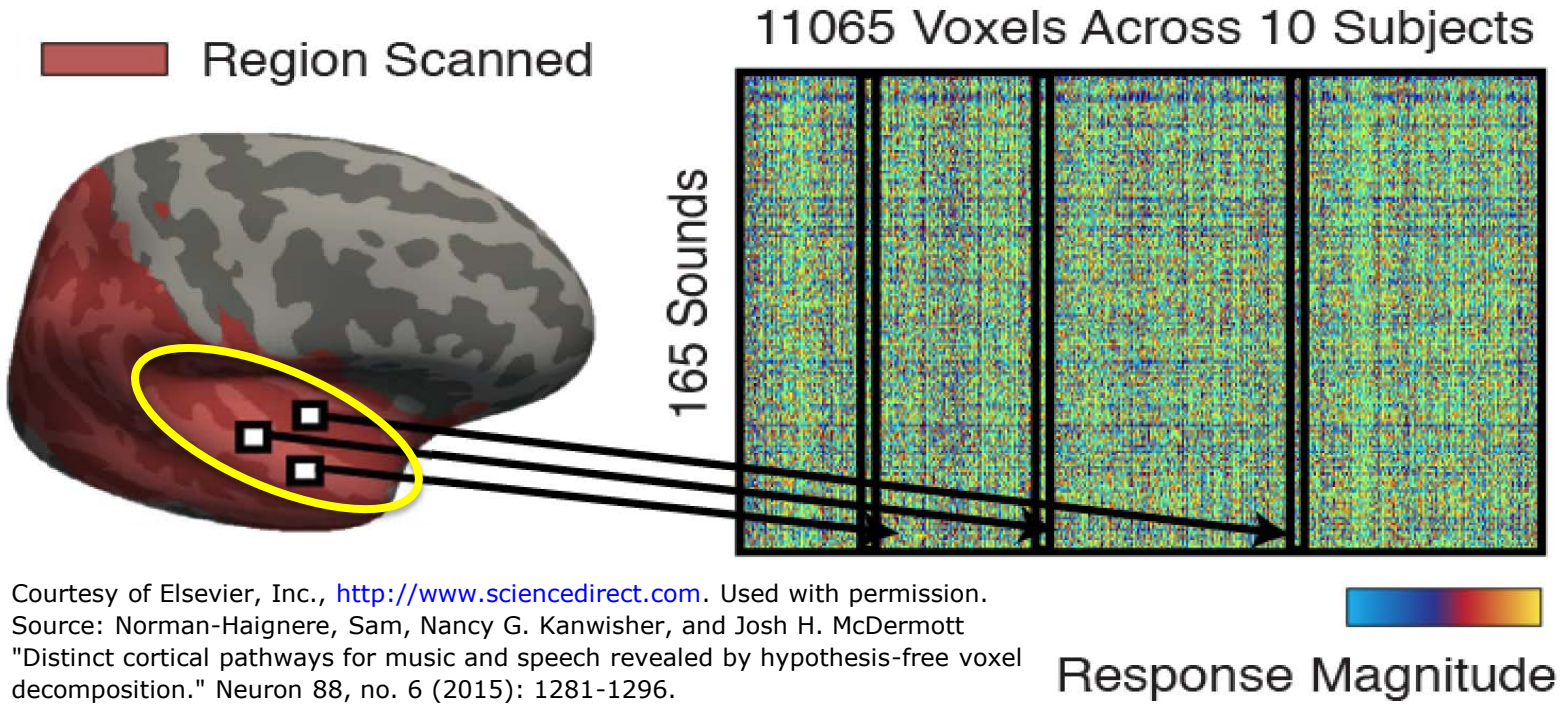
Voxel Responses

- For each voxel, we measure it's response magnitude to each sound



Do this for each voxel in auditory cortex for each of 10 subjects:11,065 voxels

Data Matrix



Courtesy of Elsevier, Inc., http://www.sciencedirect.com. Used with permission.
Source: Norman-Haignere, Sam, Nancy G. Kanwisher, and Josh H. McDermott "Distinct cortical pathways for music and speech revealed by hypothesis-free voxel decomposition." Neuron 88, no. 6 (2015): 1281-1296.

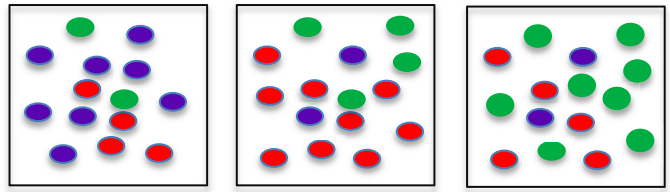
How can we discover structure from this matrix?

Run ICA on this matrix

- **hypothesis neutral:**
  - **doesn't know location of voxels**
  - **doesn't know meaning of each sound**

Modeling Assumptions

1. Voxel responses reflect the mixture of neural populations:

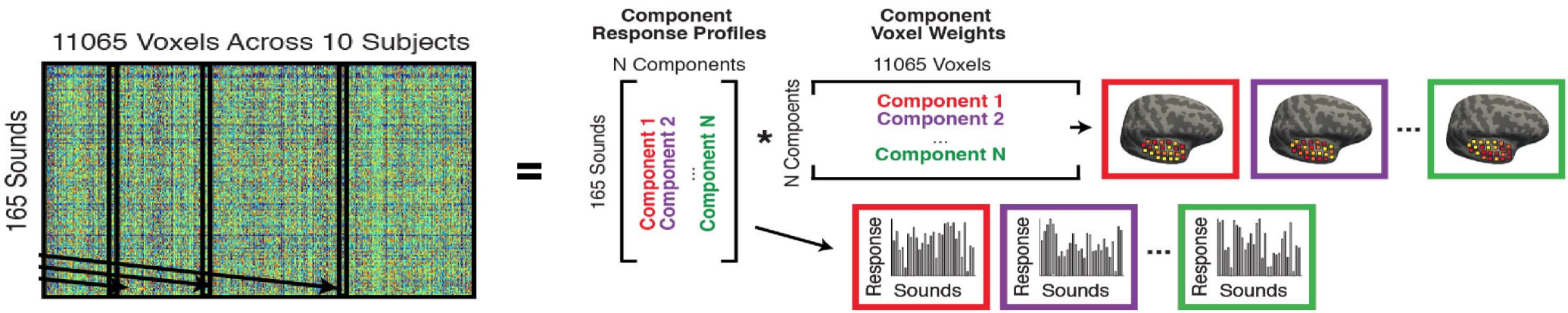


2. Each population has a canonical response profile across the 165 sounds

3. Voxel responses are the sum of the neural populations in each voxel

Goal: discover these canonical response profiles ("components")

Matrix Decomposition & ICA



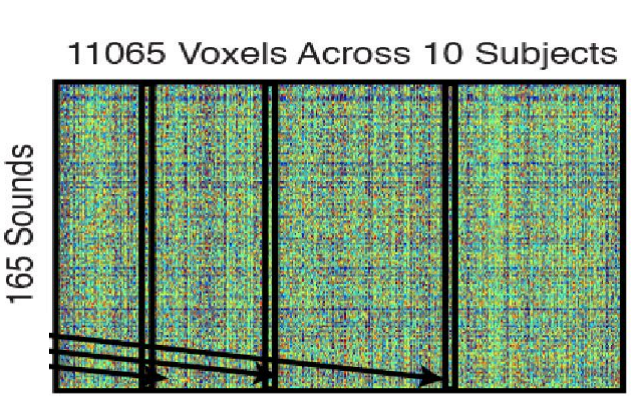
Factor response matrix into set of N components, each with:

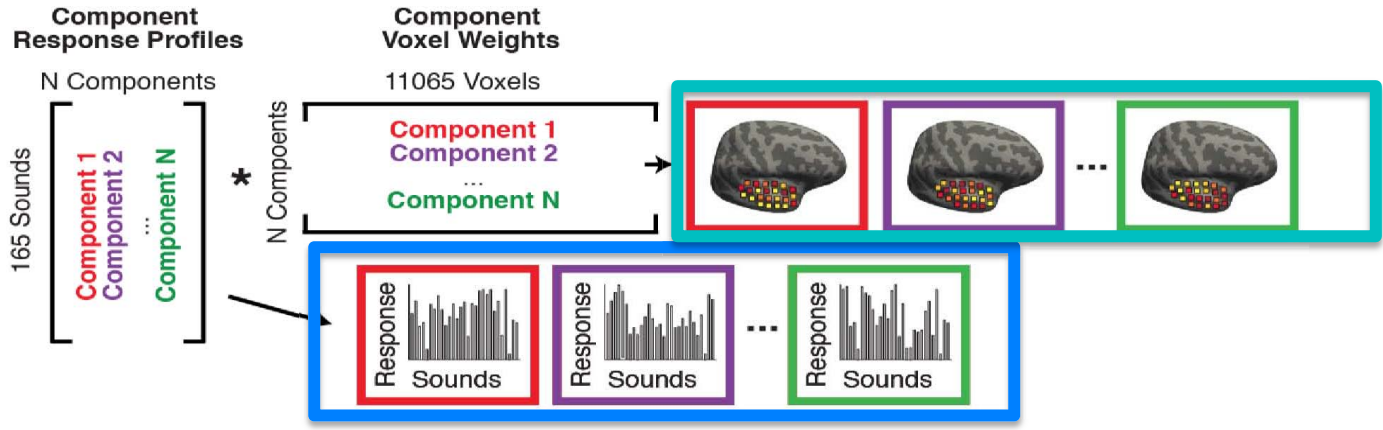
- Response profile across the165 sounds
- Voxel weights specifying the contribution of each component to each voxel

Use ICA to search for components w/ independent voxel weights

- No information about sounds or anatomy used in decomposition
- Hypothesis space is huge and unconstrained ($> 2^{165}$)
- This method should discover *the main dimensions that account for variance in the response across voxels in this stimulus set*

Matrix Decomposition ICA





What do we find?

- 5 components capture all the replicable variance in the matrix
- Today: Describe 2 of the 5 components

1. What response profiles?

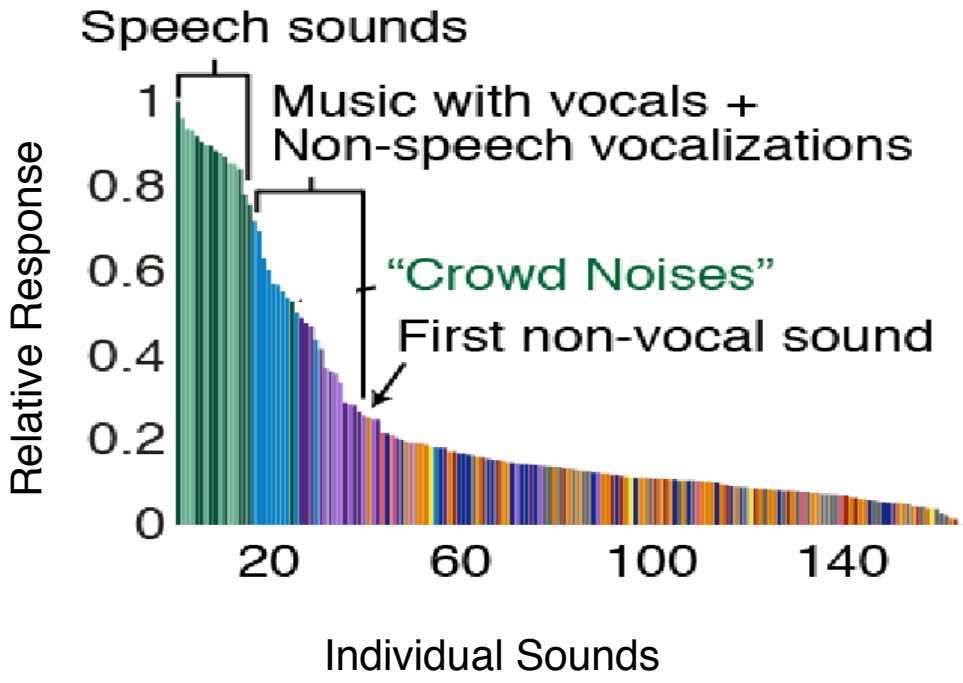
Could be *anything* from huge space
Category-selective responses? Which?
Acoustic features? Which?

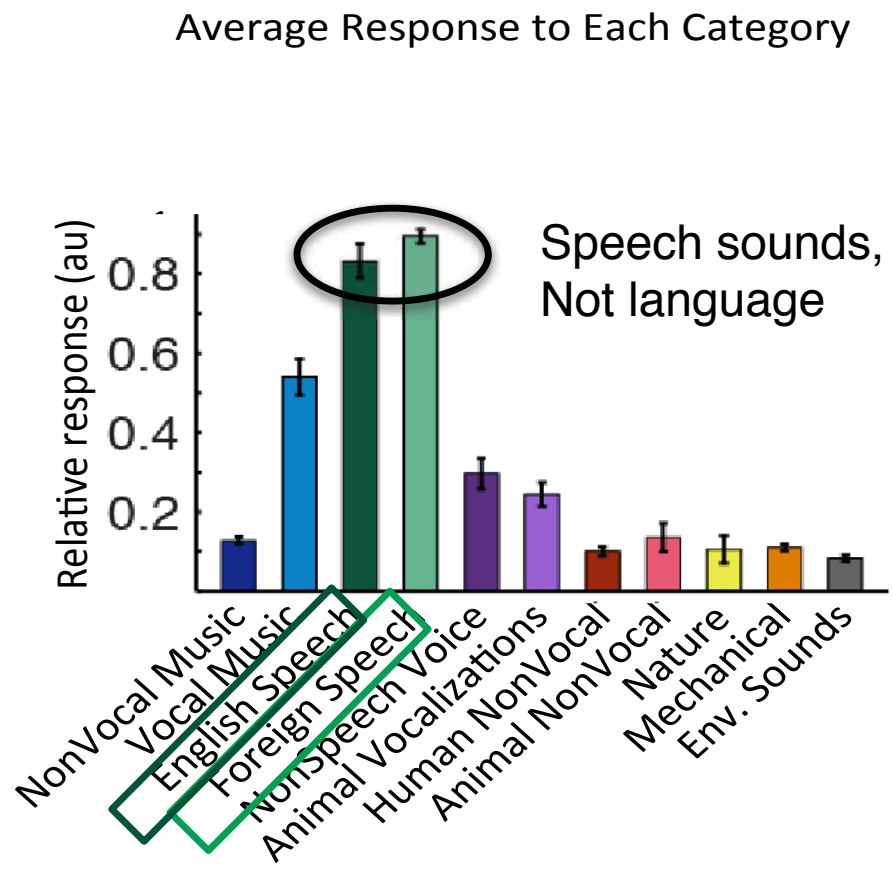
2. Where does this component live in the brain?

Could be *anything*: * blobs w/ overlap speckly mess

*spatially independent

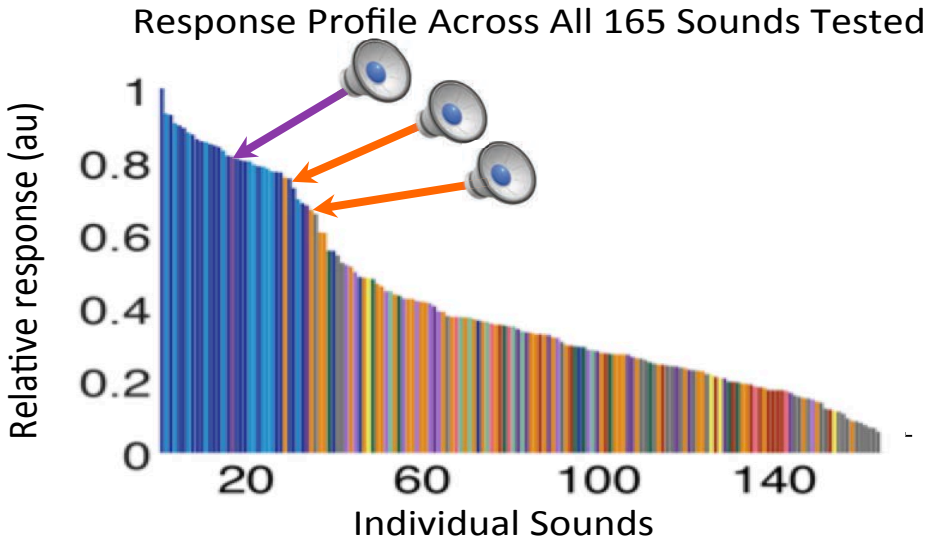
ICA Component Response Profile 4
Speech

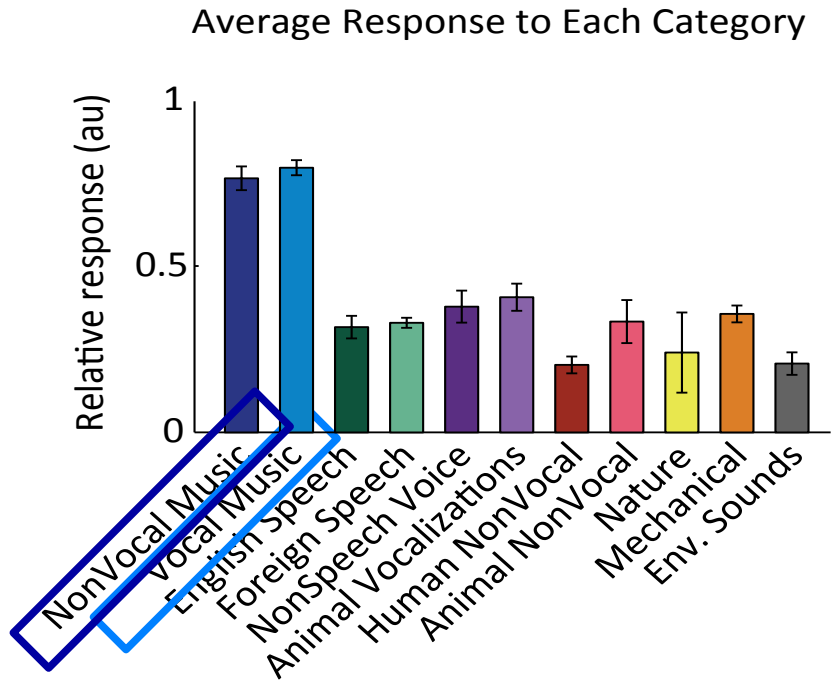




Source: Norman-Haignere, Sam, Nancy G. Kanwisher, and Josh H. McDermott. "Distinct cortical pathways for music and speech revealed by hypothesis-free voxel decomposition." *Neuron* 88, no. 6 (2015): 1281-1296.

ICA Component Response Profile 5
Music





Source: Norman-Haignere, Sam, Nancy G. Kanwisher, and Josh H. McDermott. "Distinct cortical pathways for music and speech revealed by hypothesis-free voxel decomposition." *Neuron* 88, no. 6 (2015): 1281-1296.

Note subjects are not trained musicians.
Music is universally and exclusively human, but
no one even knows what music is *for*.
Yet we apparently have a specialized brain system for music?
Really?

Controlling for Acoustic Features

Do these two components really reflect speech and music? **Yes**

Or, can acoustic features account for them? **Apparently not**

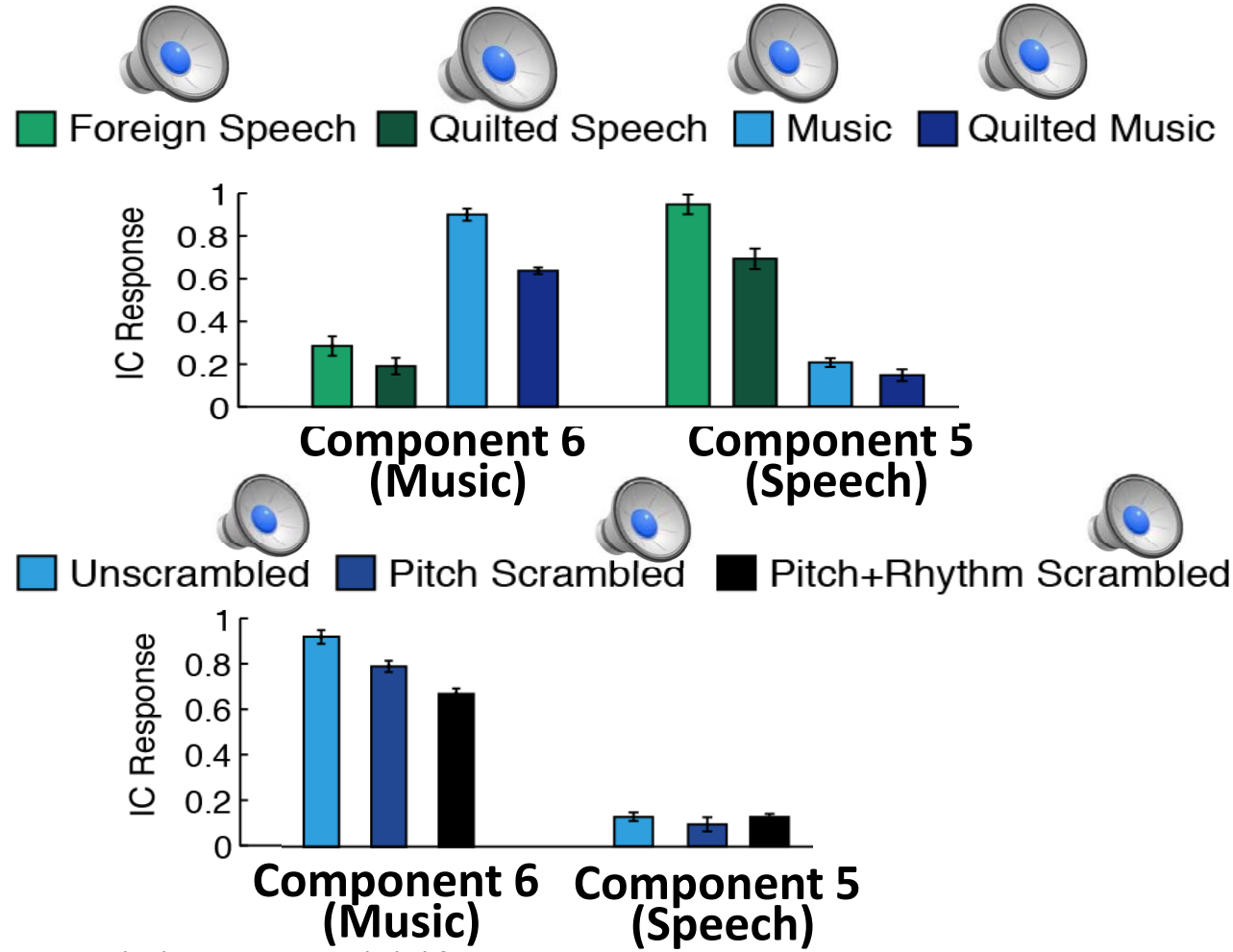
Control Experiment 1:

Quilting=

A scrambling procedure

Invented by Josh

McDermott & Dan Ellis

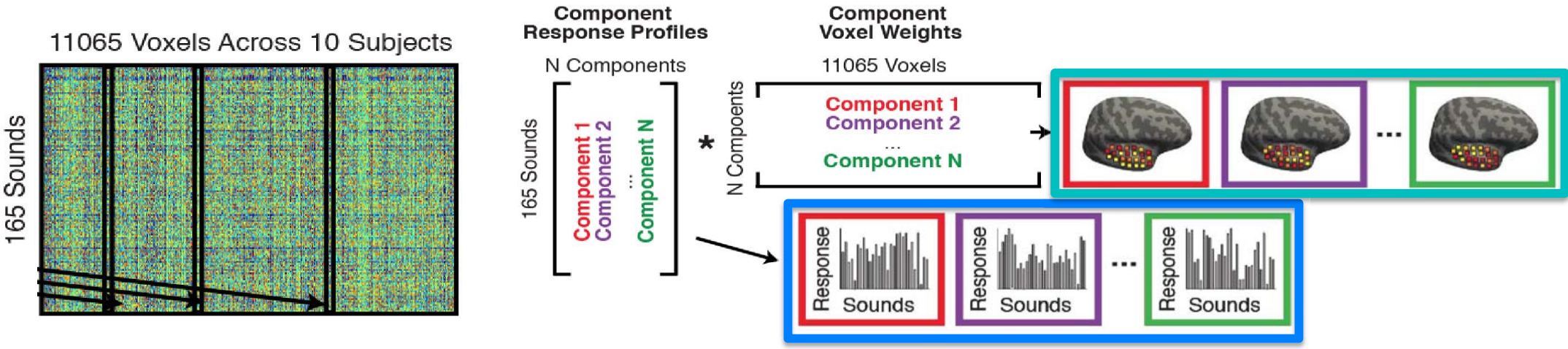


Control Experiment 2:

MIDI scrambling

Source: Norman-Haignere, Sam, Nancy G. Kanwisher, and Josh H. McDermott. "Distinct cortical pathways for music and speech revealed by hypothesis-free voxel decomposition." Neuron 88, no. 6 (2015): 1281-1296.

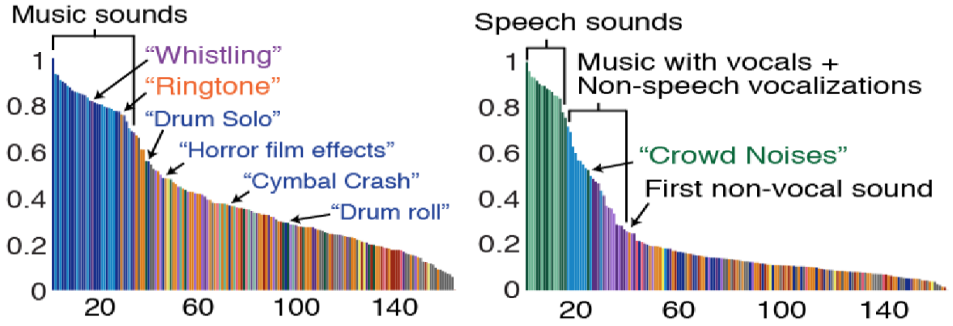
Matrix Decomposition ICA



Describe 2 of the 5 components

1. Plot response profiles

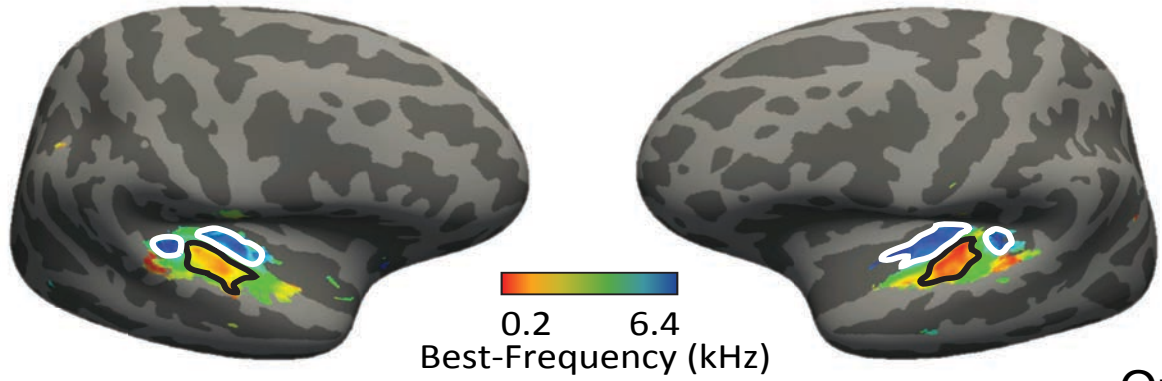
Two category-selective components



2. Where do these things live in the brain?

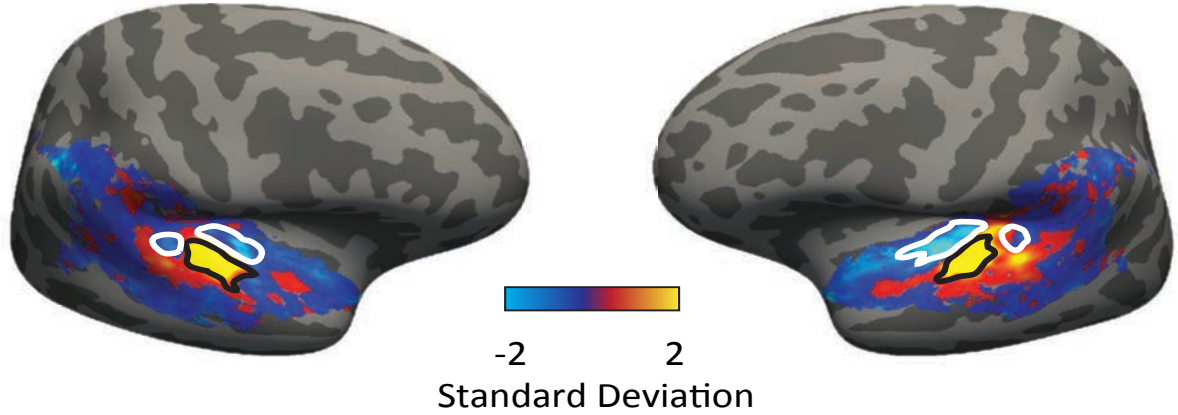
Project voxel weights back into the brain….
First, some landmarks….

Tonotopy Measured with Standard Methods



Our main question:
Where are the speech and music components?

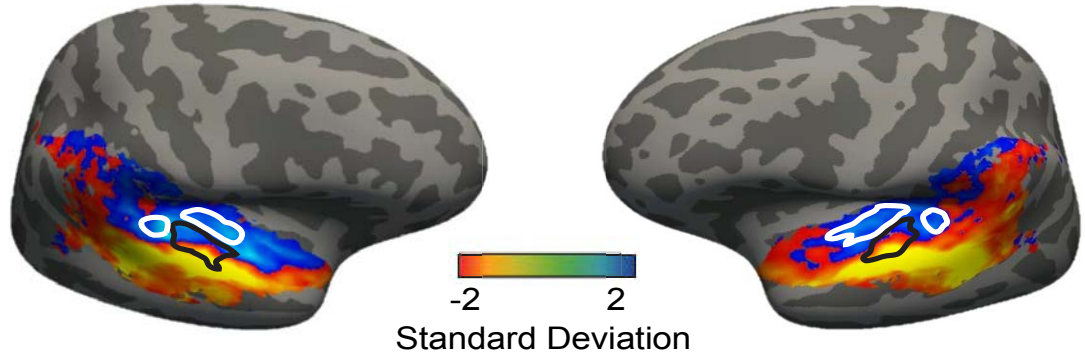
ICA Component 1 voxel weights:



A positive control: ICA can detect tontopy

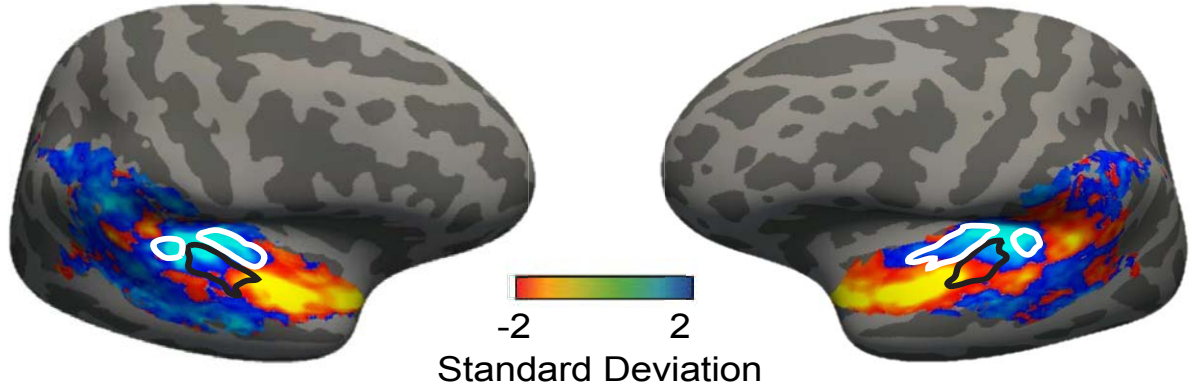
Source: Norman-Haignere, Sam, Nancy G. Kanwisher, and Josh H. McDermott. "Distinct cortical pathways for music and speech revealed by hypothesis-free voxel decomposition." Neuron 88, no. 6 (2015): 1281-1296.

Voxel Weights for Speech Component

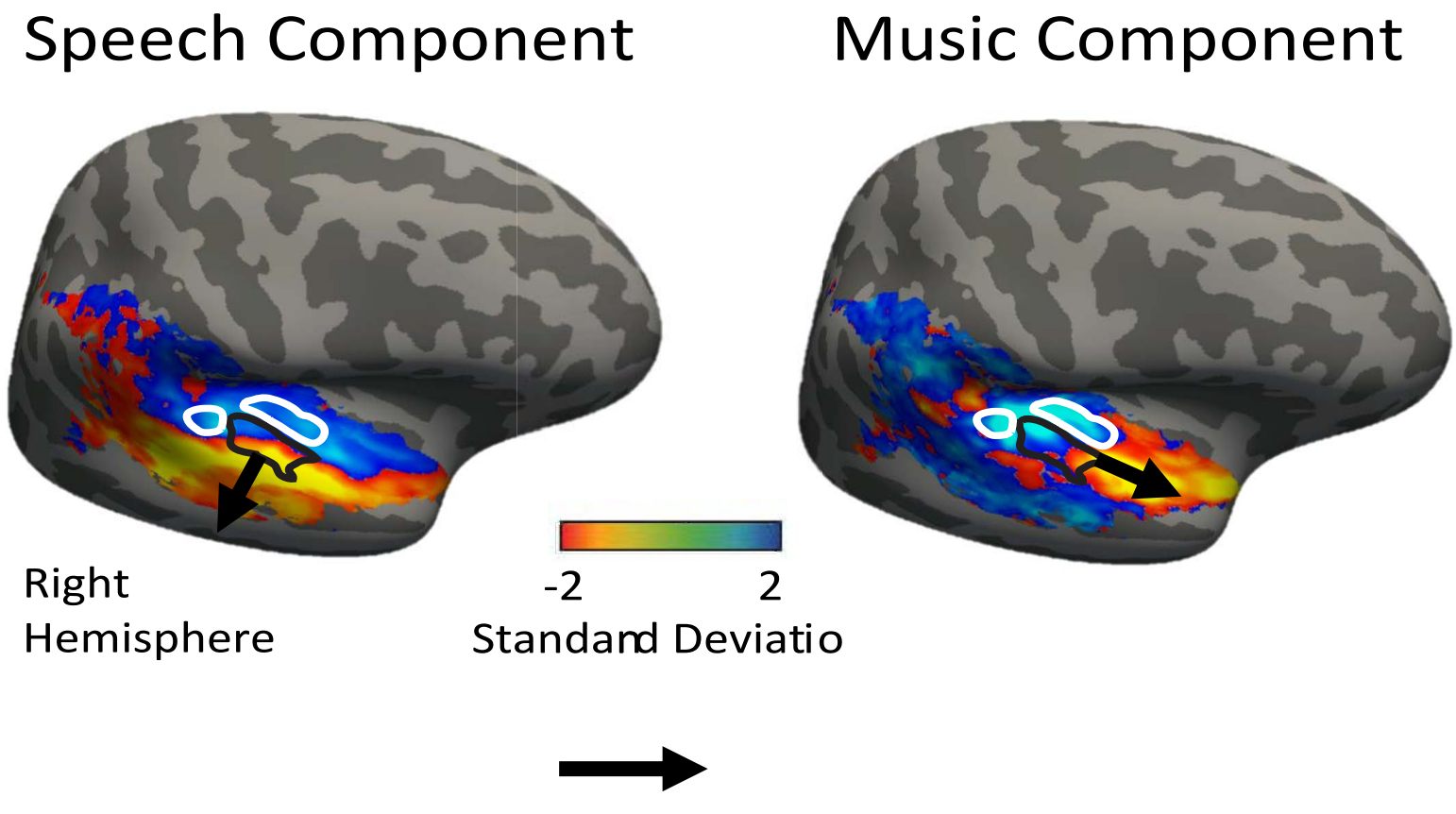


c.f. Binder et al., 2000; Hickok & Poeppel, 2007; Mesgarani & Chang, 2014

Voxel Weights for Music Component

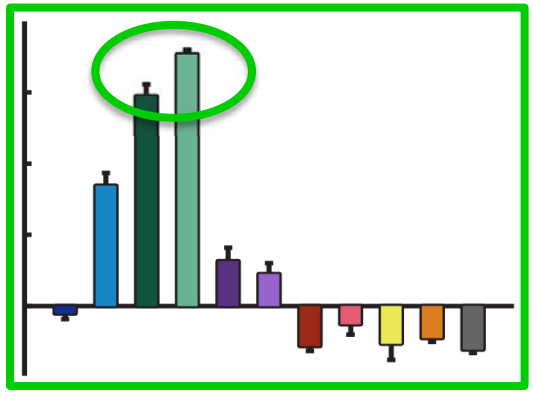


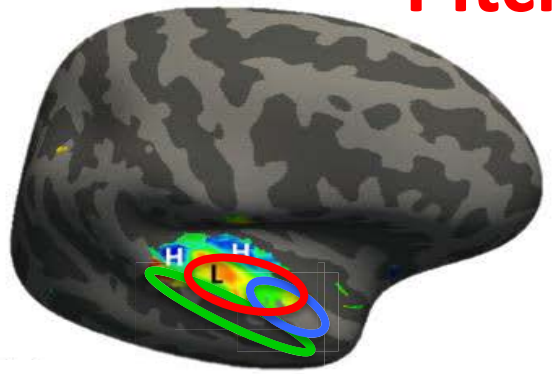
Source: Norman-Haignere, Sam, Nancy G. Kanwisher, and Josh H. McDermott. "Distinct cortical pathways for music and speech revealed by hypothesis-free voxel decomposition." Neuron 88, no. 6 (2015): 1281-1296.

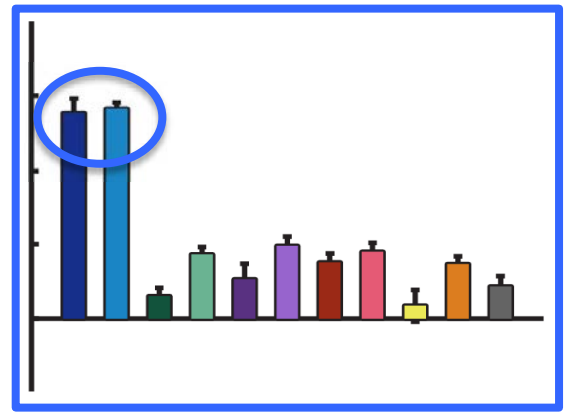


Source: Norman-Haignere, Sam, Nancy G. Kanwisher, and Josh H. McDermott. "Distinct cortical pathways for music and speech revealed by hypothesis-free voxel decomposition." Neuron 88, no. 6 (2015): 1281-1296.

Conclusions

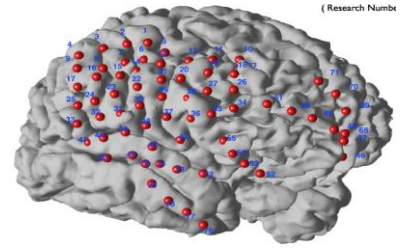


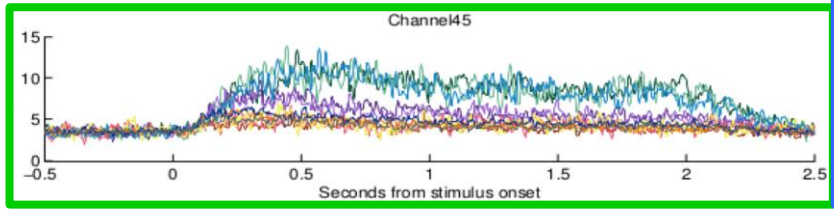


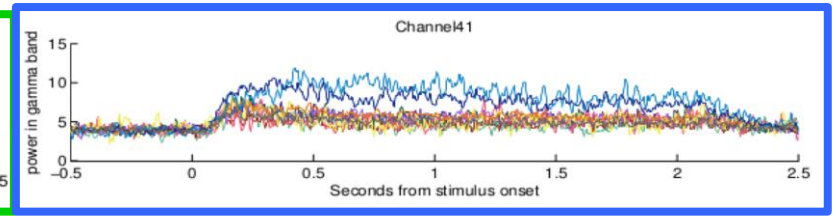


Source: Norman-Haignere, Sam, Nancy G. Kanwisher, and Josh H. McDermott. "Distinct cortical pathways for music and speech revealed by hypothesis-free voxel decomposition." Neuron 88, no. 6 (2015): 1281-1296.

- New finding: Strong neural selectivity for pitch, speech and music
  all three = uniquely human functions?
  >> cannot study in animal models
- Reflects not just the experimenter's pet hypotheses, but actual dominant structure of auditory cortex.
- Converging evidence from ECOG recordings
- Many more questions….







Resource: Brains, Minds and Machines Summer Course
Tomaso Poggio and Gabriel Kreiman