Sensorimotor Representation Evidence for Motor Theory?

Sources of Evidence for Sensorimotor interaction

- Active use of sensory information in speech production:
  - Imitation and vocal learning (Meltzoff & Moore, 1977; 1997)
  - Adaptive responses to perturbed auditory feedback in speech production (e.g., Houde & Jordan, 1998)
  - Synchronous speech (e.g., Cummins, 2002)
  - Articulatory convergence (e.g., Lee et al, 2018)

Motor Engagement in Speech Perception

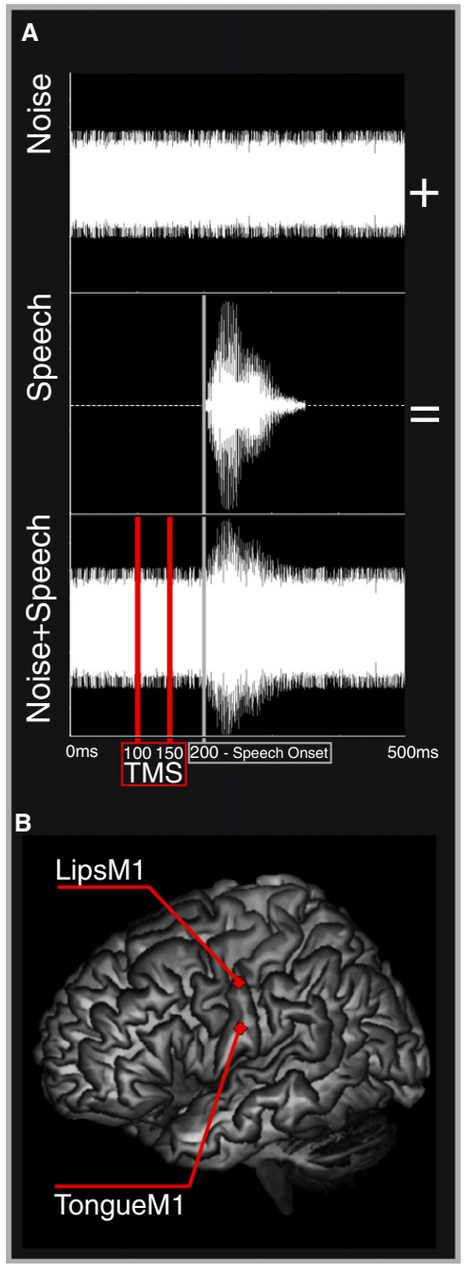
The Motor Somatotopy of Speech Perception

Alessandro D'Ausilio,[1] Friedemann Pulvermüller,[2] Paola Salmas,[3] Ilaria Bufalari,[1] Chiara Begliomini,[1] and Luciano Fadiga[1,3,*]

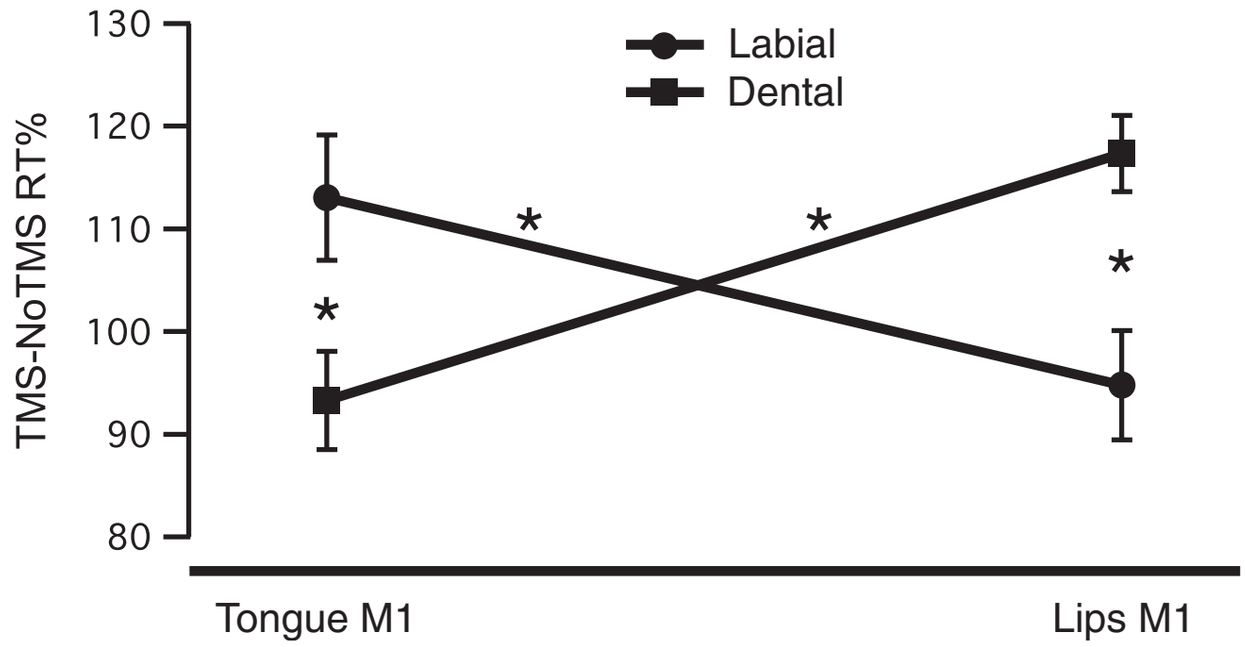
Current Biology *19*, 381–385, March 10, 2009 DOI 10.1016/j.cub.2009.01.017

- Hypothesis: If speech perception engages neural circuitry specific to production of distinct speech gestures, then pre-activation of the motor area that is compatible with particular percept (response on a perception task) should enhance its response and inhibit other responses.

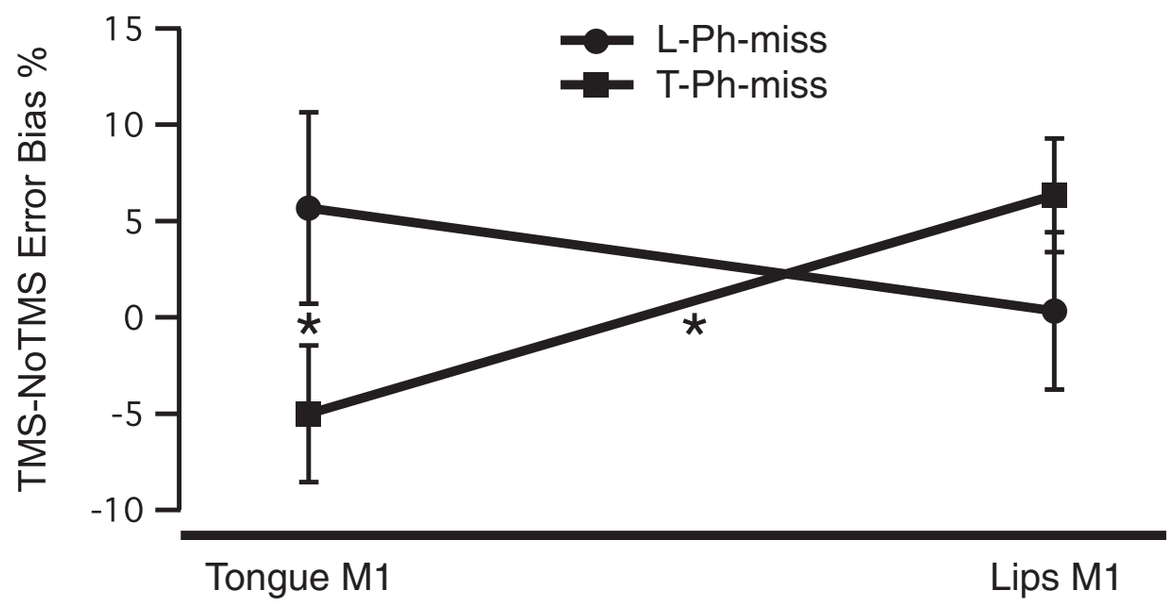
- Present /bæ/ /pæ/ /dæ/ /tæ/
- Noise
- TMS vs No-TMS



Reaction Time (RT)



Errors



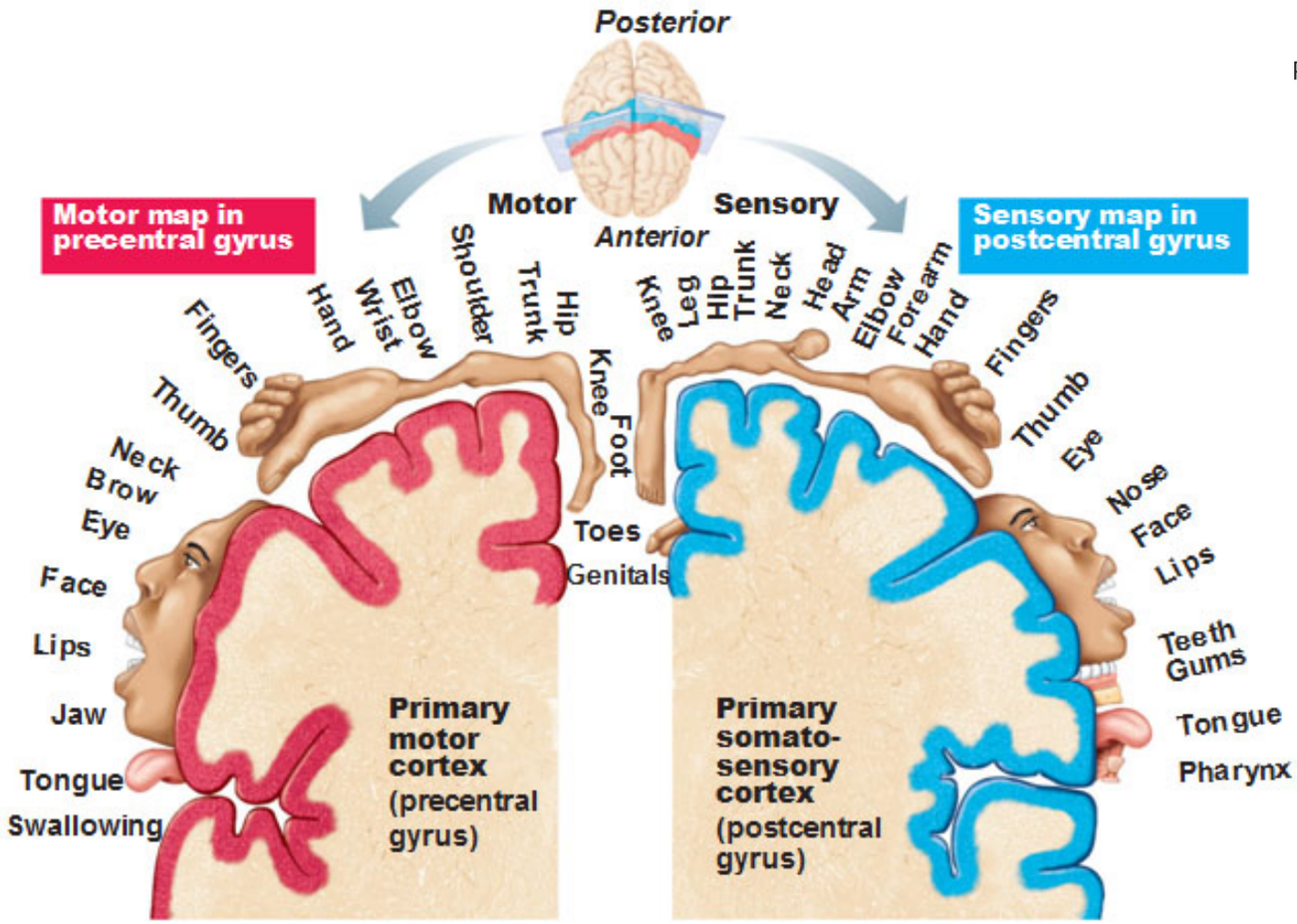
Activation in motor cortex during listening

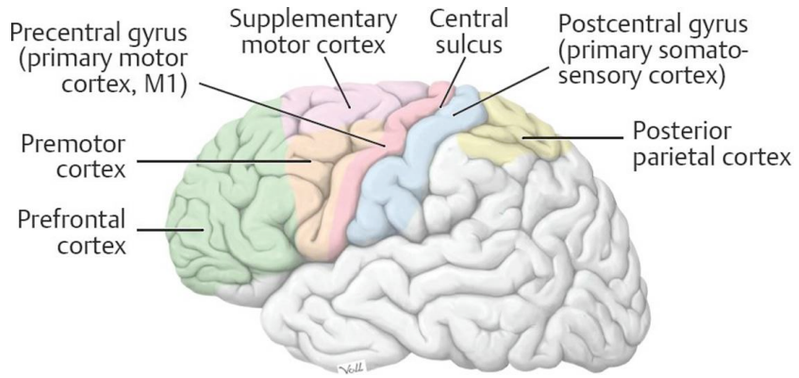
- Evidence for activation in the motor cortex during listening to speech (e.g., Wilson et al, 2004)
- Compare the structure of:
  - auditory cortex representations during listening
  - motor cortex representations during speaking
  - motor cortex representations during listening

Sensorimotor "homunculus"

Homunculus of Sensorimotor Cortex

Note that each hemisphere receives info from the opposite side of the body

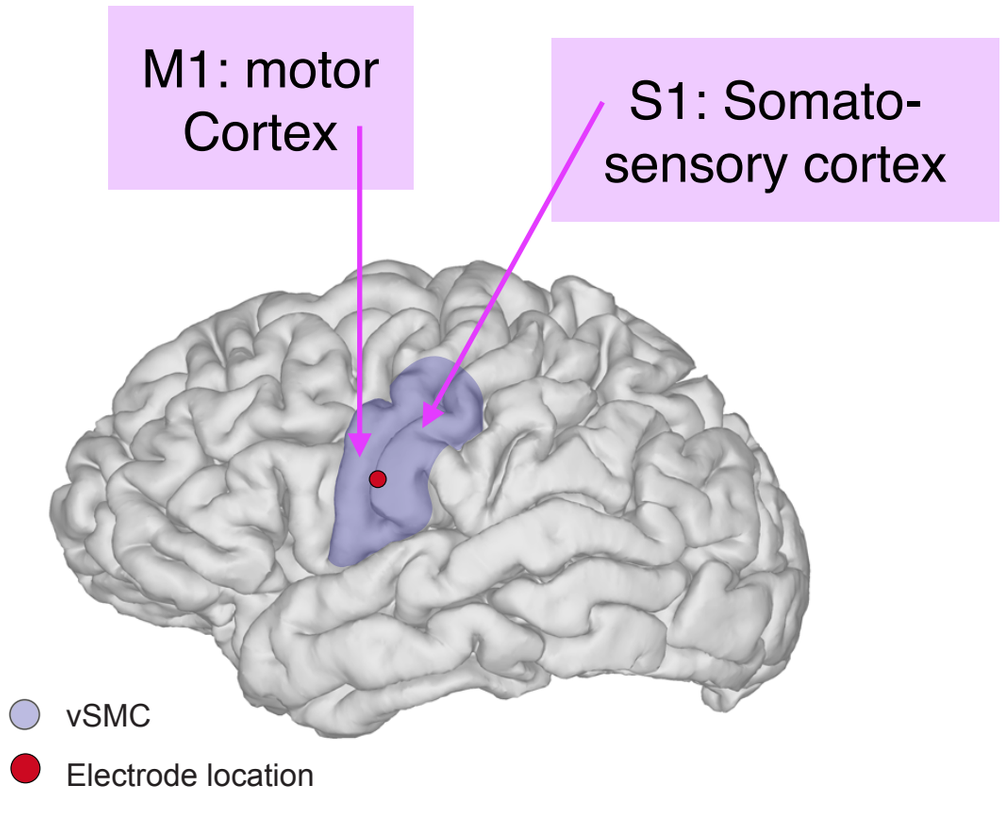




Size of region is proportional to the resolution (fineness) of control or sensory discrimination of the organ

Activation in vSMC during speaking

- Electrocorticography (ECoG) application of a mesh of tiny electrodes directly on the surface of the brain of a patient who is being prepared for brain surgery.
- Allows recording from very small populations of neurons.
- Examine multiple sites in vSMC *while patient is speaking*.
- 460 read sentences (MOCHA-TIMIT)
- 130 electrode sites (across 5 participants)
- Test which descriptions of speech best predict patterns of activation in particular electrode locations (phoneme id, formants, constriction formation, individual articulators).

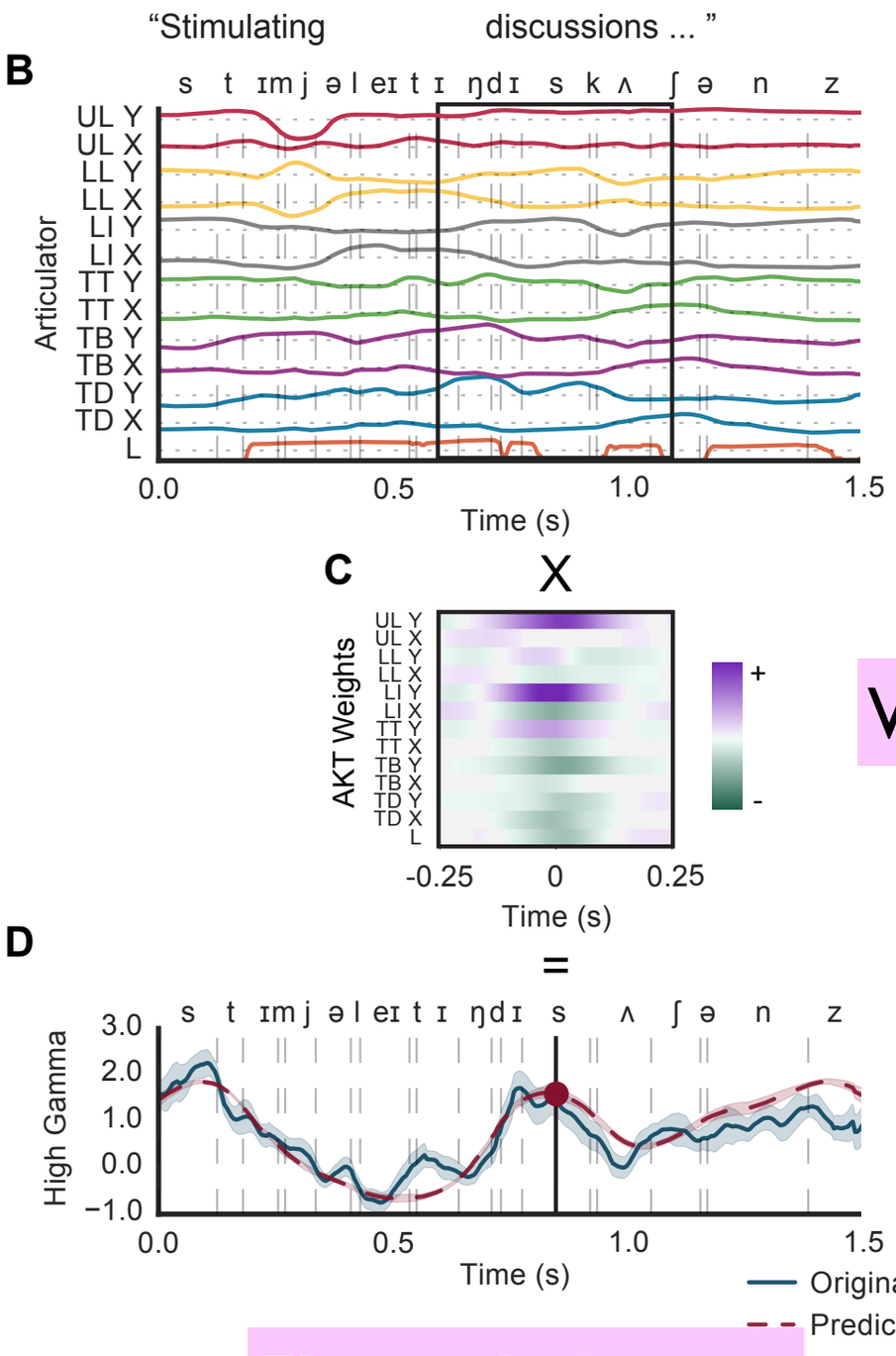


Because only acoustics are recorded, authors trained a model to infer time functions of EMA markers on Lips, Tongue, and Jaw audio (overall correlation of original and inferred EMA = ~.65 for untrained speaker).

Josh Chartier, Gopala K. Anumanchipalli, Keith Johnson, Edward F. Chang (2019). Encoding of articulatory kinematic trajectories in human speech sensorimotor cortex. *Neuron*.

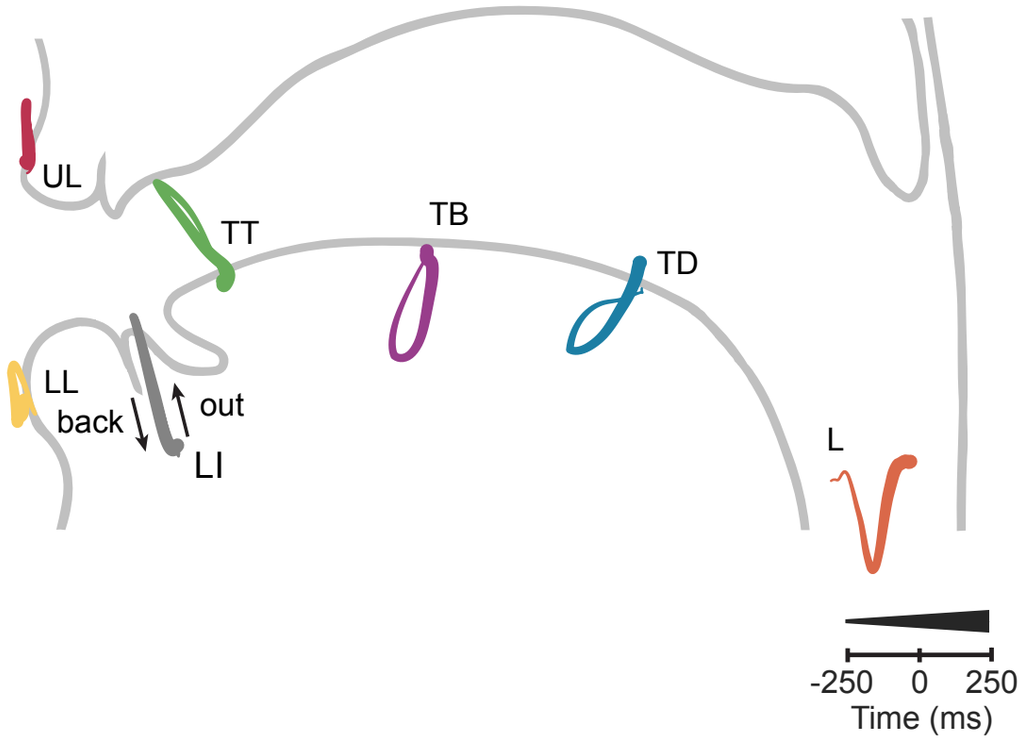
Example results

Inferred EMA



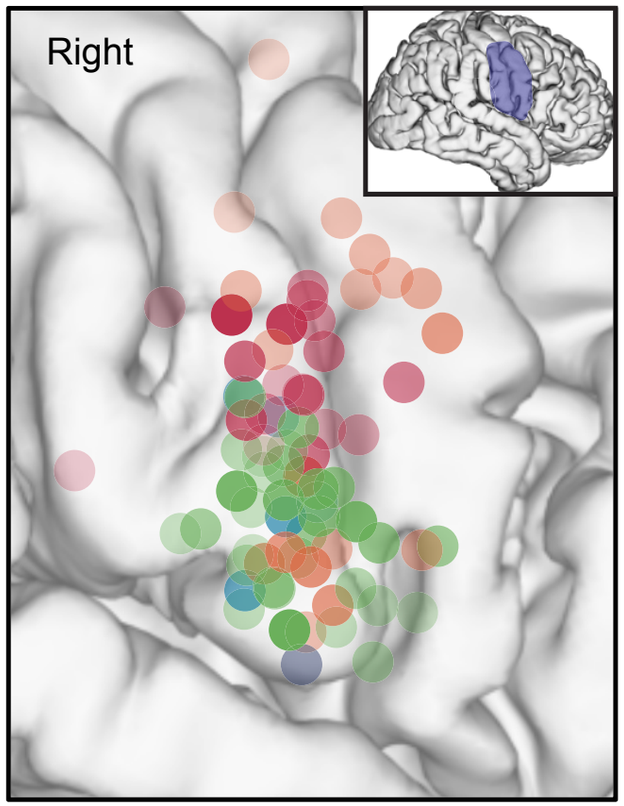
Weights

Electrode Activity



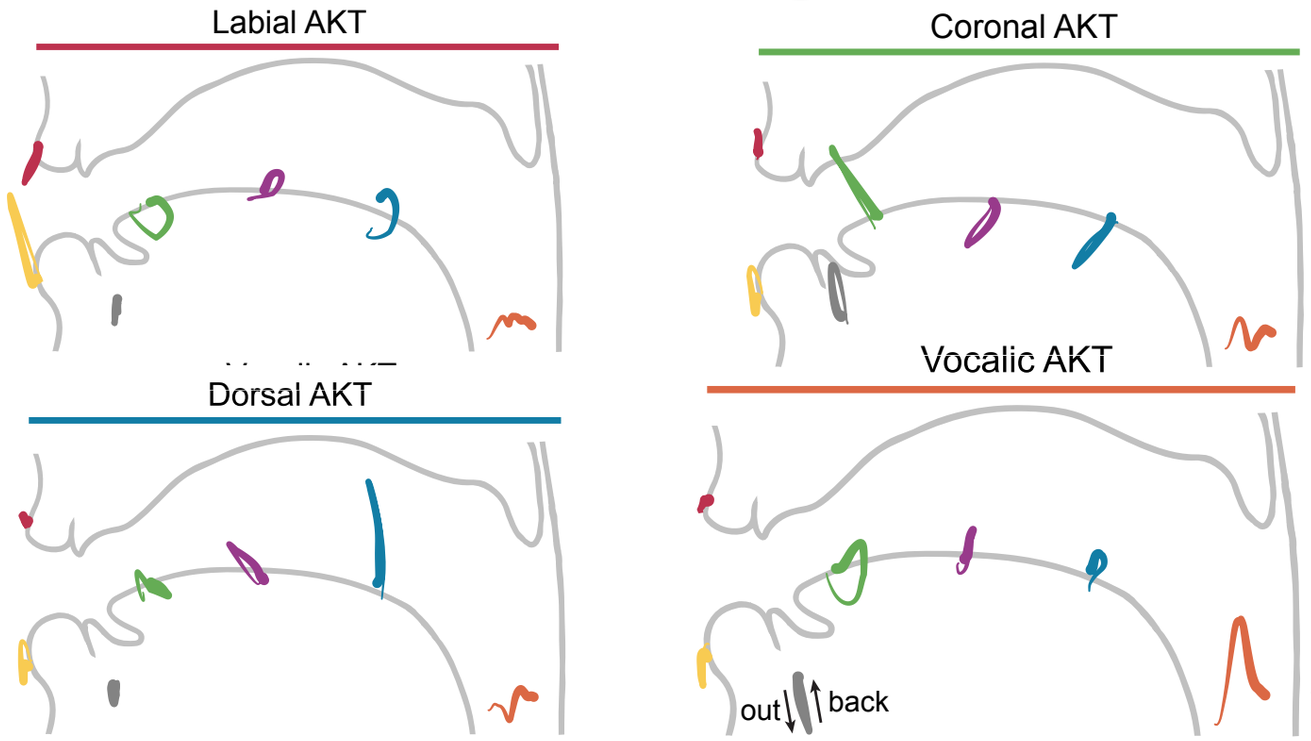
Weight pattern corresponds to coordinated articulator motion that produces and releases a coronal constriction.

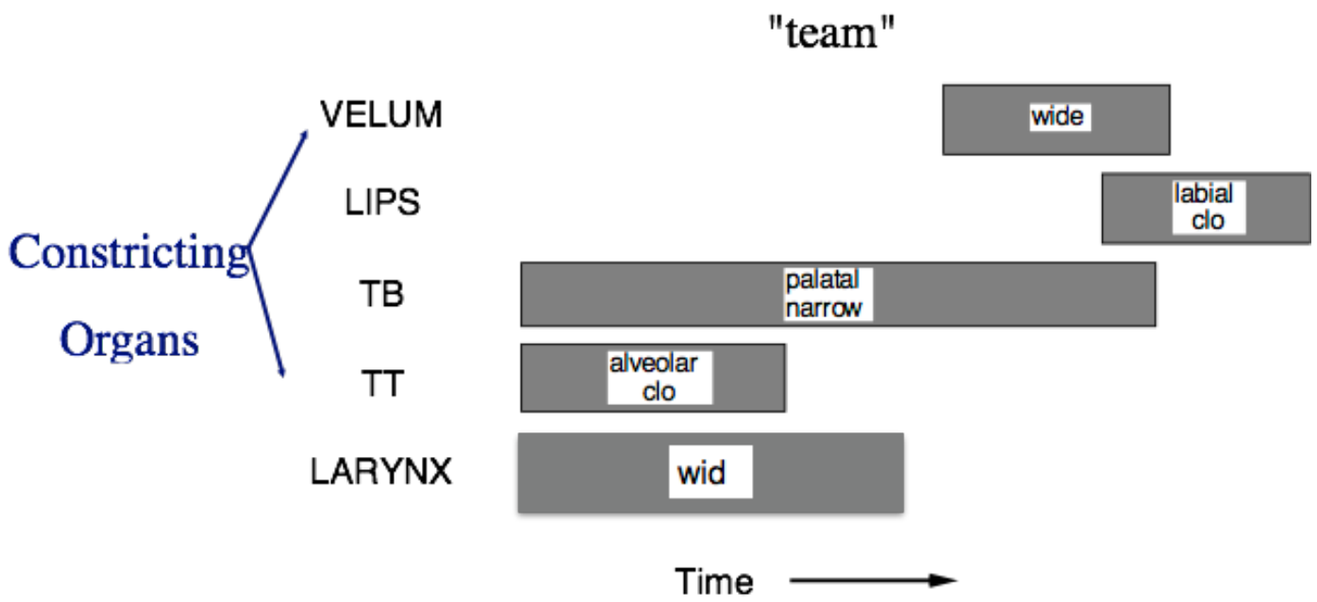
Sites code distinct constriction gestures



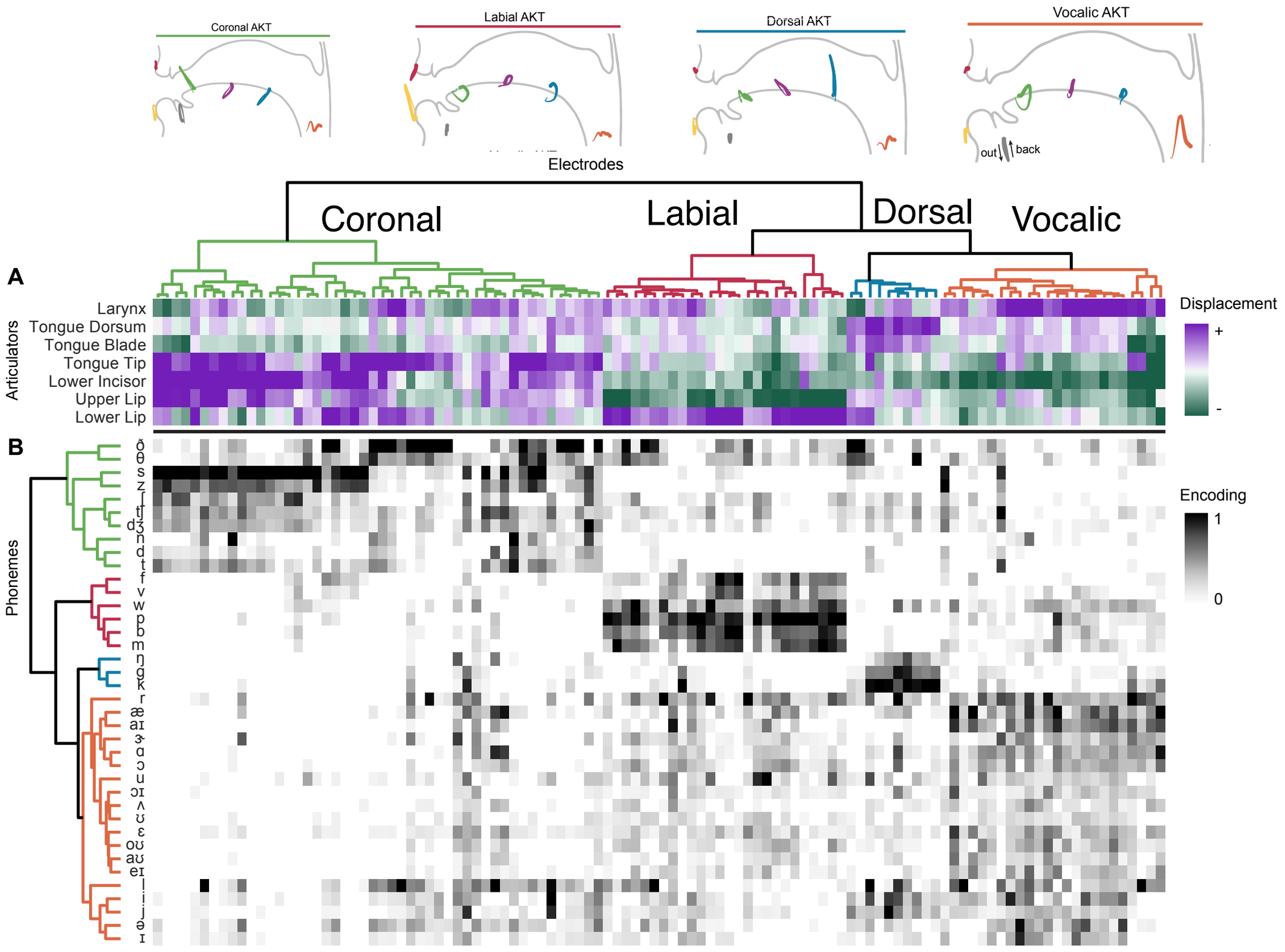
AKT Cluster
- Coronal
- Labial
- Dorsal
- Vocalic

pearson r 0.4 0.0





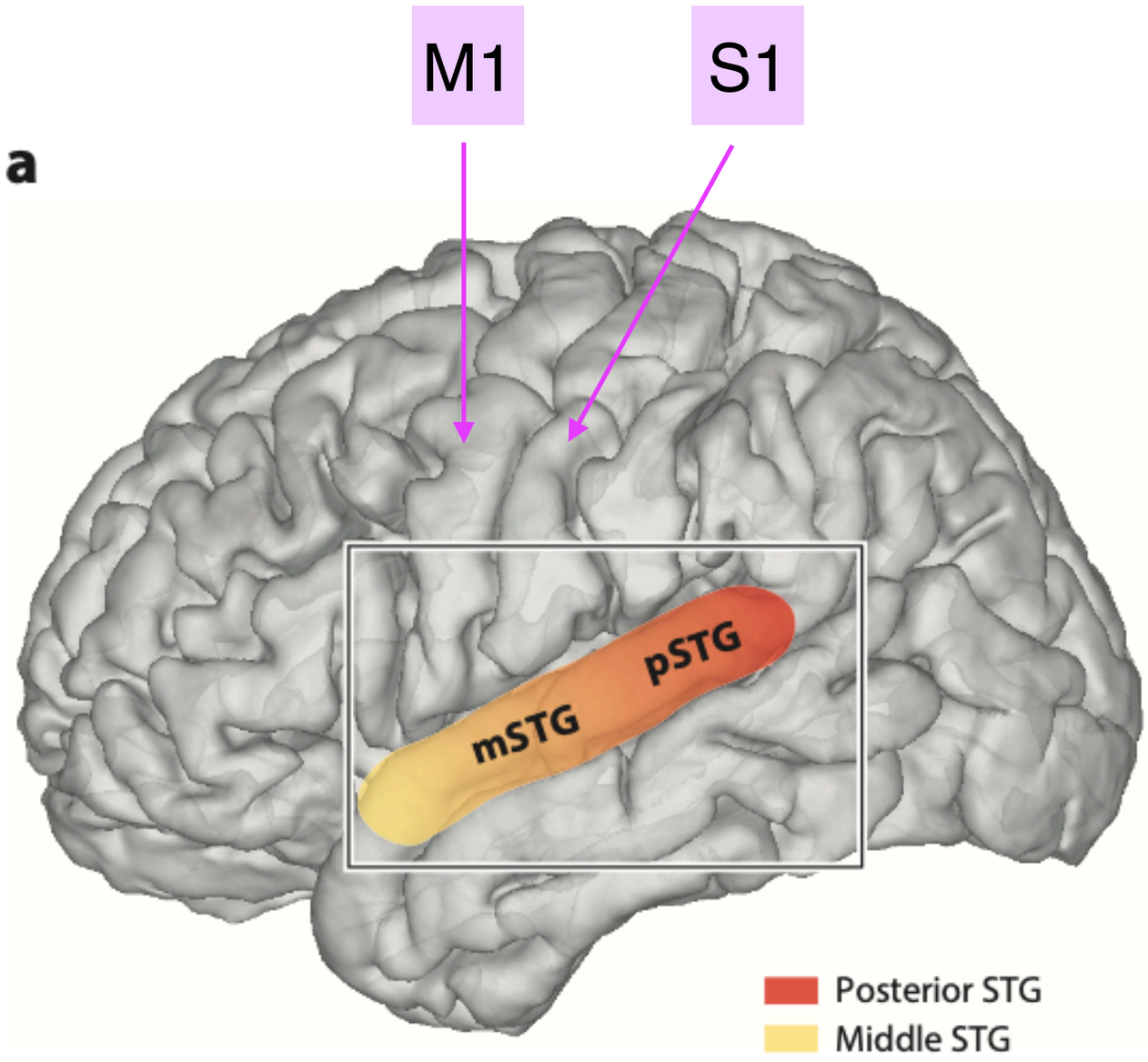
- Best predictor of electrode activity was kinematic articulatory pattern associated with a gesture: coordinated articulator activity that produces and releases a constriction.
- Organized by constriction organ ("place of articulation").



Clustering of electrodes (by articulator patterns)
Clustering of segments (by electrode patterns)

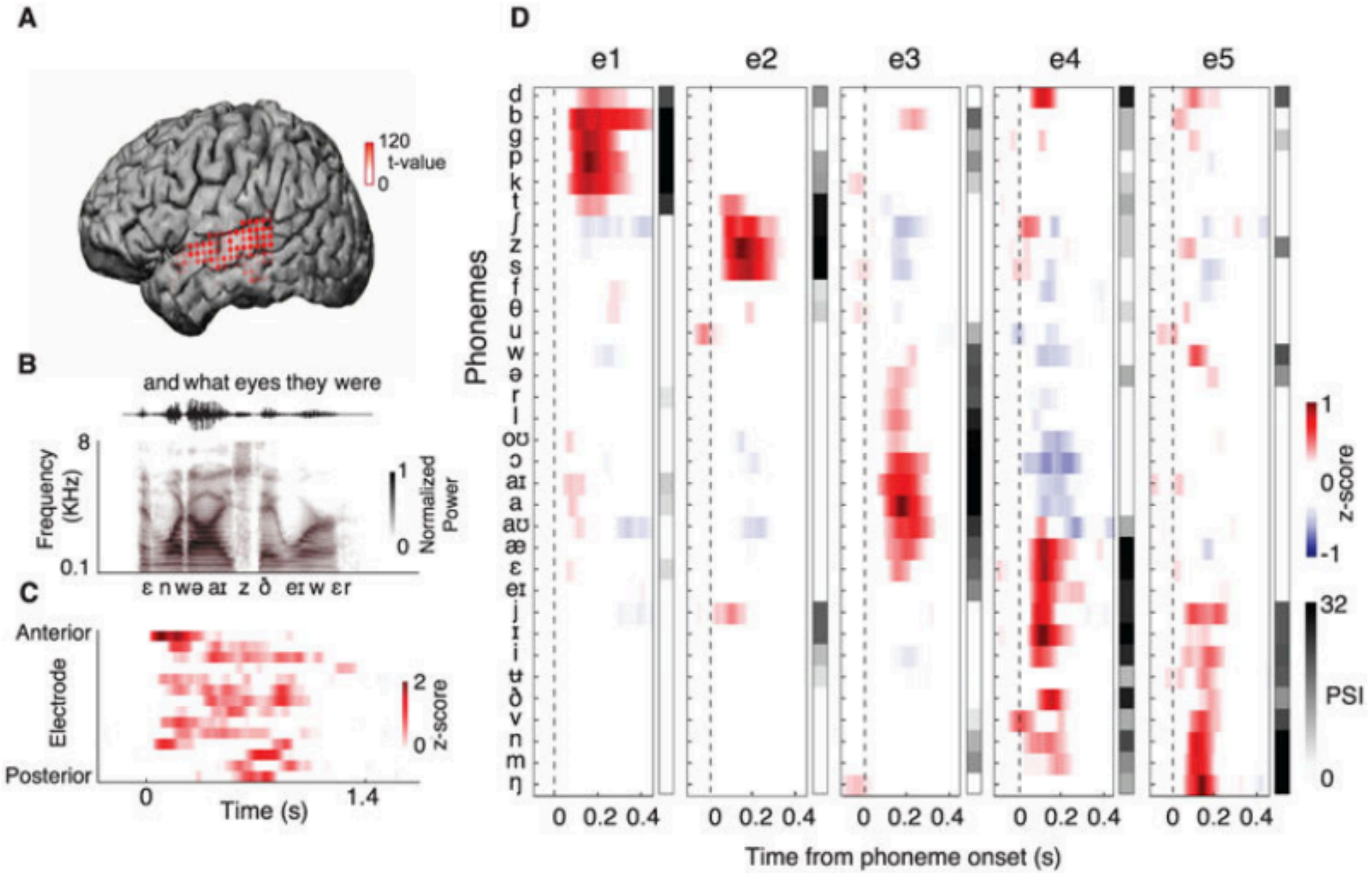
Activation in STG during listening

- Superior Temporal Gyrus:
- site of complex auditory computations
- Similar method as used to investigate motor cortex (vSMC) during speaking.
- 6 participants
- Listened to 500 sentences (TIMIT)
- 256 total electrodes
- How do segments cluster in their patterns of electrodes activation?
- What acoustic patterns are encoded?



Phonetic Feature Encoding in Human Superior Temporal Gyrus
Nima Mesgarani *et al.*
Science **343**, 1006 (2014);

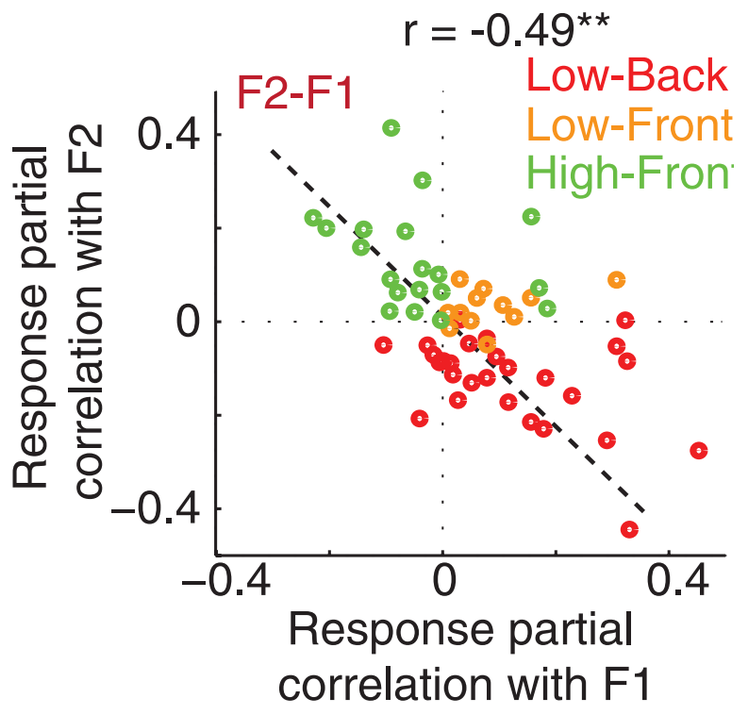
Activation in STG during listening



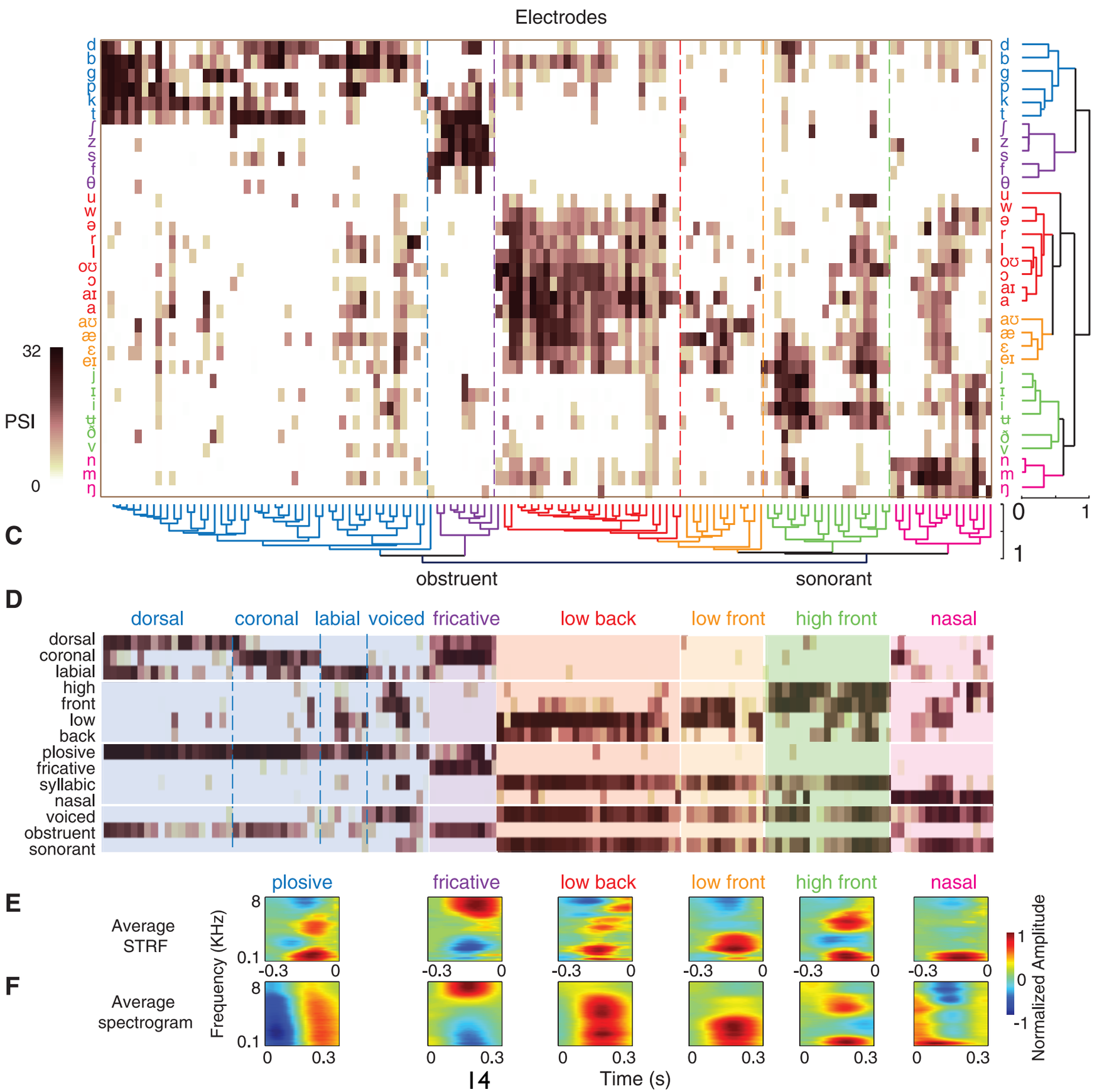
Phonetic Feature Encoding in Human Superior Temporal Gyrus
Nima Mesgarani *et al.*
Science **343**, 1006 (2014);

STG representation during listening

- Electrode activity clusters by manner class.
  - stops
  - fricatives
  - nasals
  - back vowels & liquids
  - low front vowels
  - high front vowels

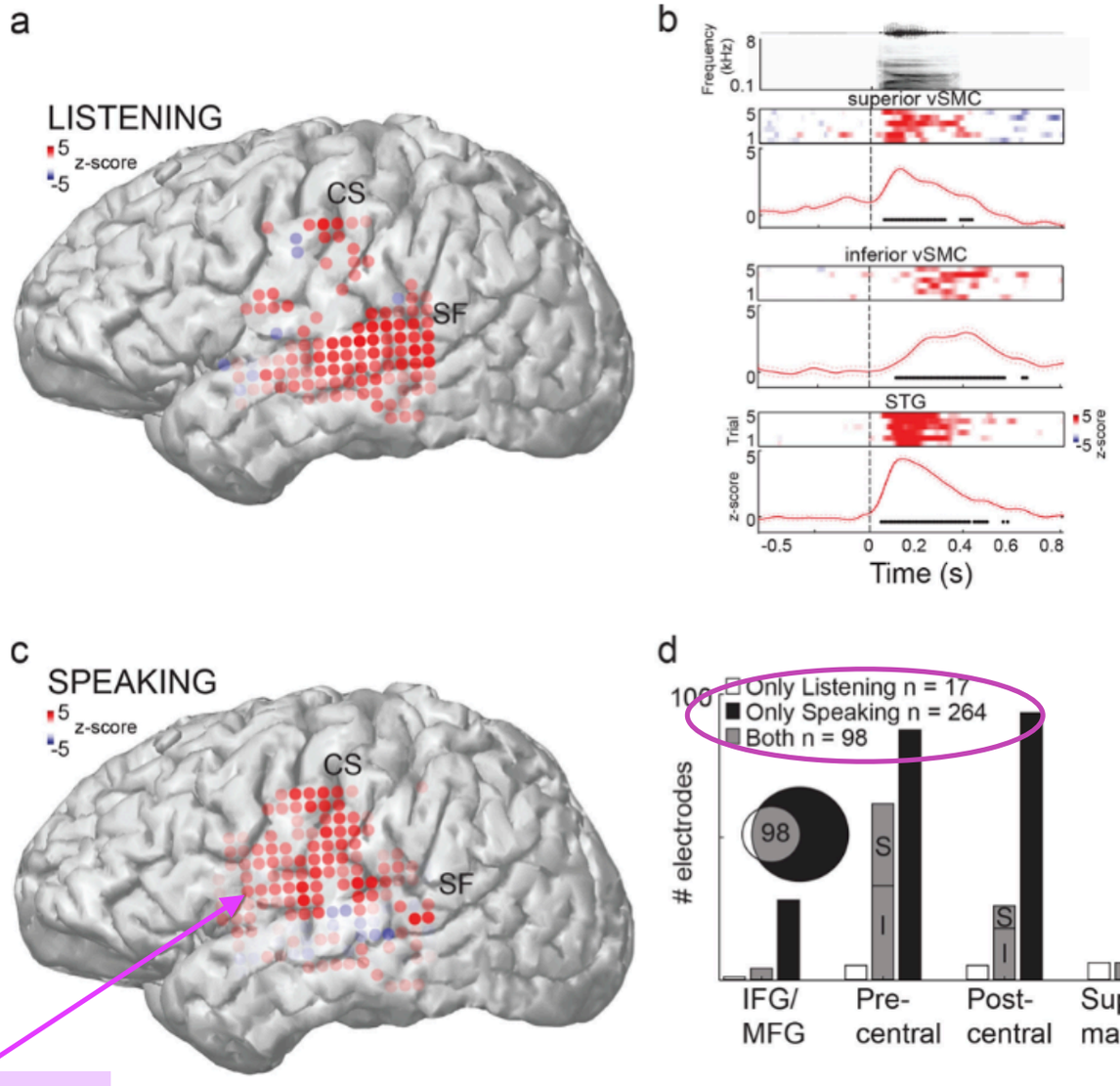


- Classes differ in gross acoustic patterns
- More fine grained representation of vowel formants.
  - Electrodes tuned to relation of F1 and F2.


Electrodes
32
PSI
0
C
obstruent
sonorant
D
dorsal
coronal
labial
high
front
low
back
plosive
fricative
syllabic
nasal
voiced
obstruent
sonorant
E
F
Average
STRF
Average
spectrogram
Frequency (KHz)
8
0.1
-0.3
0
0.3
Time (s)
Normalized Amplitude
1
0
-1

Neural activation in motor areas (vSMC) during listening

- Several studies have revealed activity in motor cortex during passive listening.
- Has been used as evidence for motor engagement during perception.
- Little is known about the structure of the neural activation during listening.
- Cheung et al (2016) measure electrode activity in both STG and vSMC during listening and speaking
- Stimuli:
  /pa ba ta da ka ga sa ʃa/
- Nine participants



IFG: inferior frontal Gyrus

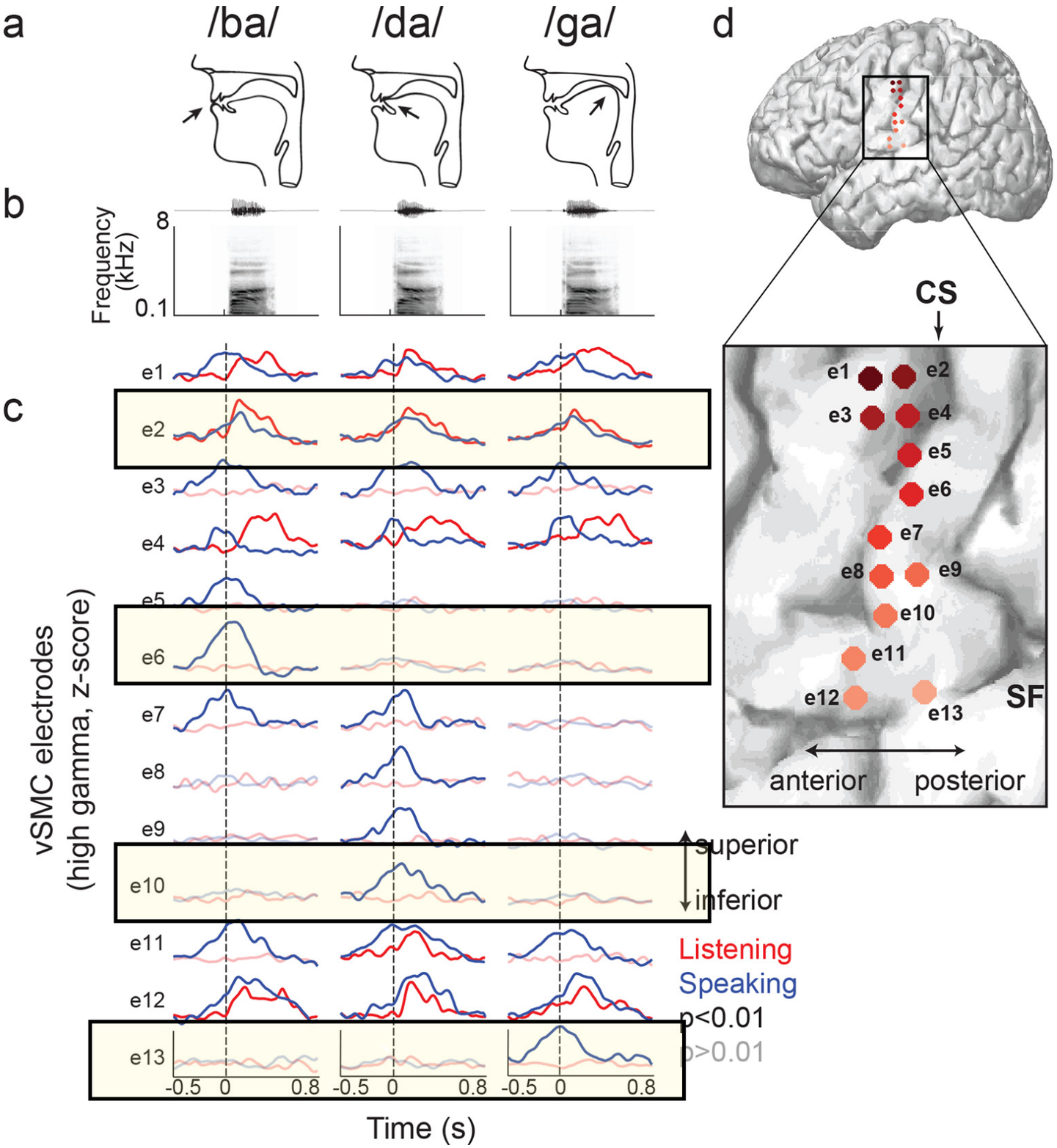
The auditory representation of speech sounds in human motor cortex

Connie Cheung[1,2,3,4†], Liberty S Hamilton[2,3,4†], Keith Johnson[5], Edward F Chang[1,2,3,4*]

Cheung *et al*. eLife 2016;5:e12577. DOI: 10.7554/eLife.12577

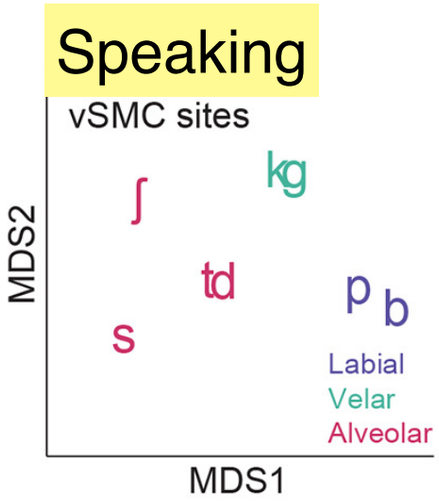
Selectivity of vSMC electrodes during speaking and listening

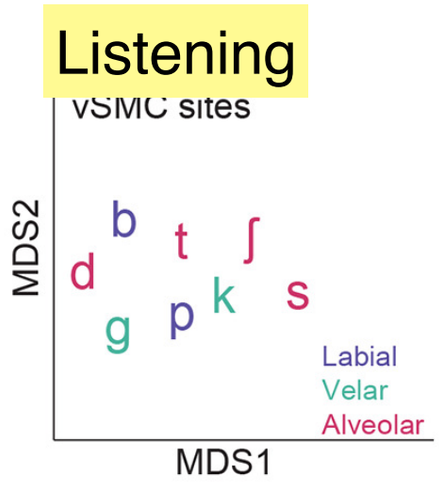
- Electrodes found that respond differentially to /b,d,g/ are typically those that are active only during speaking.
- Electrodes that are active during both listening and speaking do not exhibit clear selectivity as a function of constriction effector (labial, coronal, dorsal).

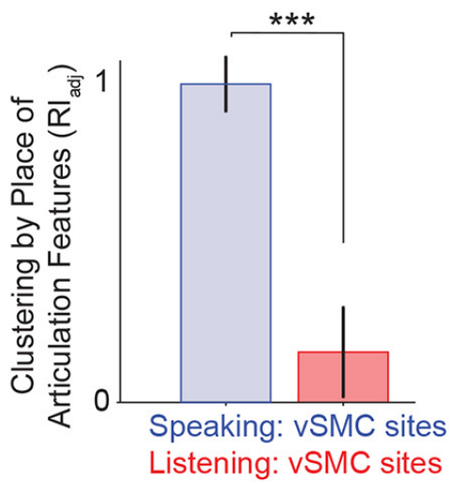


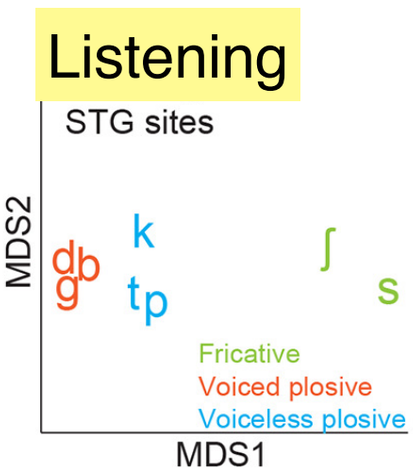
Clustering of electrode activation patterns

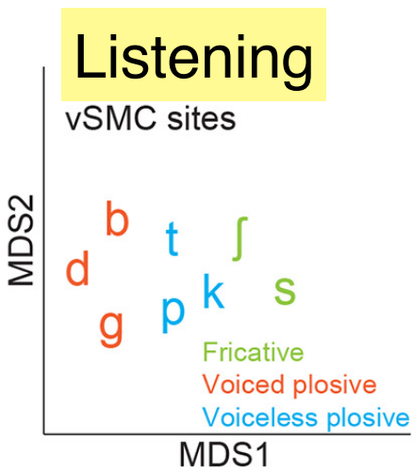
- vSMC
- Clustering by constriction effector is strong during speaking.
- Clustering by effector is weak during listening.
- Clustering by acoustic properties during listening is strong, but a bit weaker than in STG
- Clustering by Manner is stronger than clustering by constriction (place) during listening in vSMC.

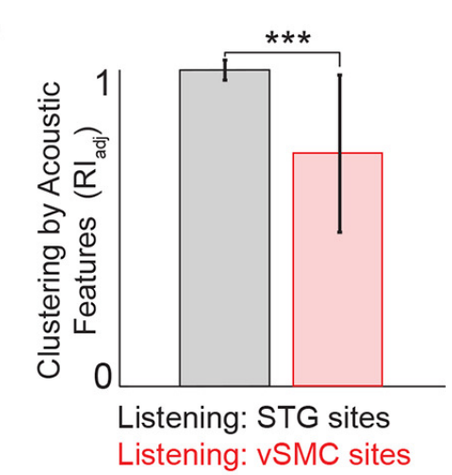


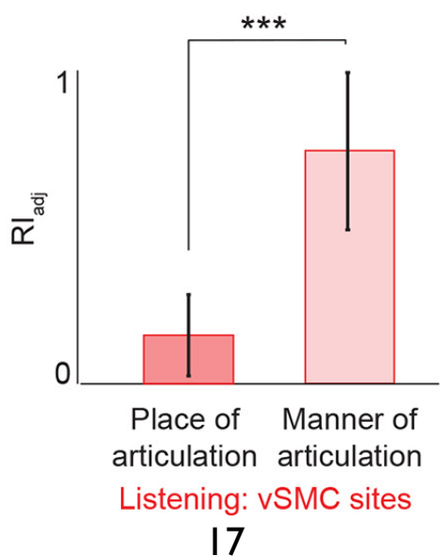






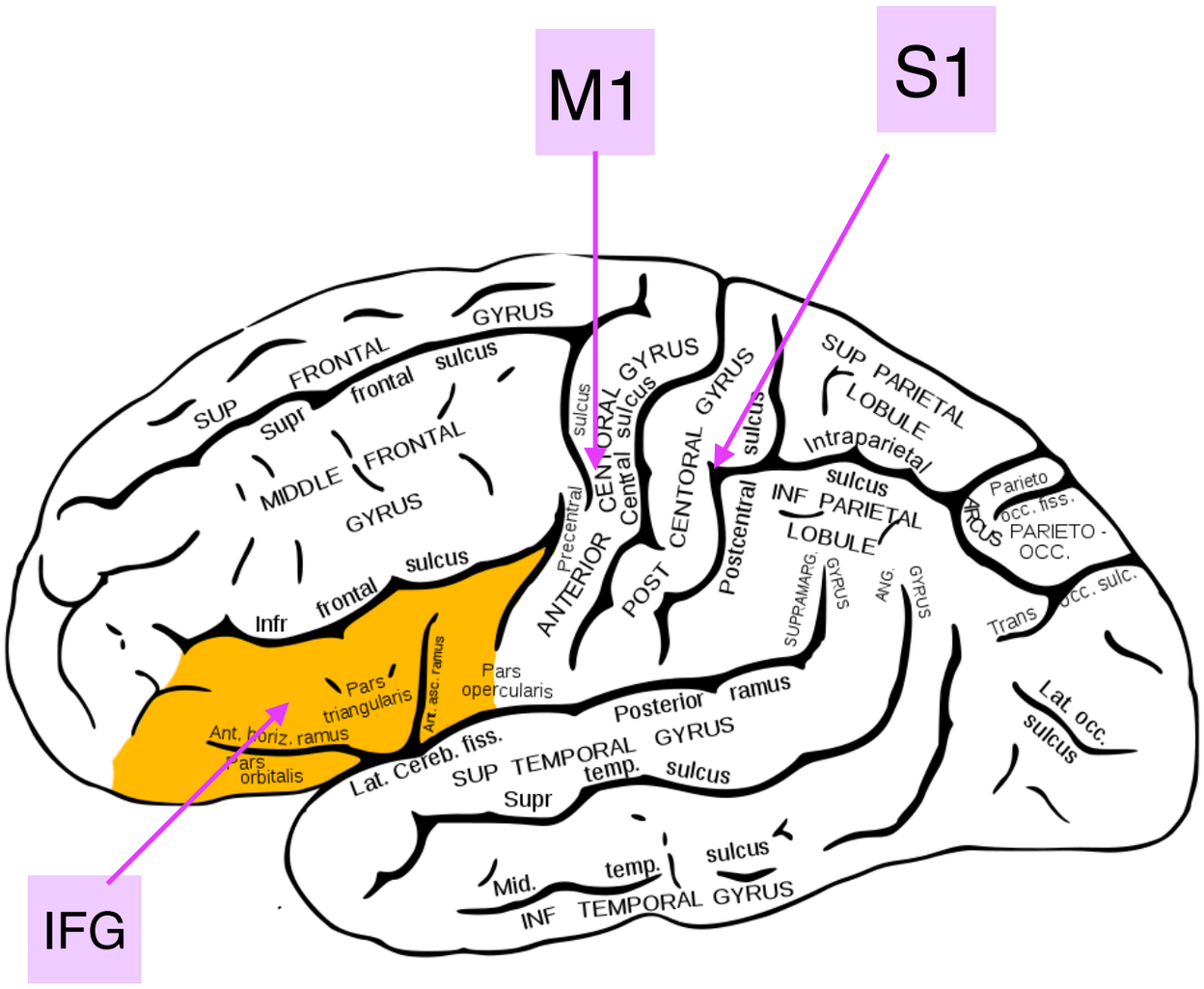




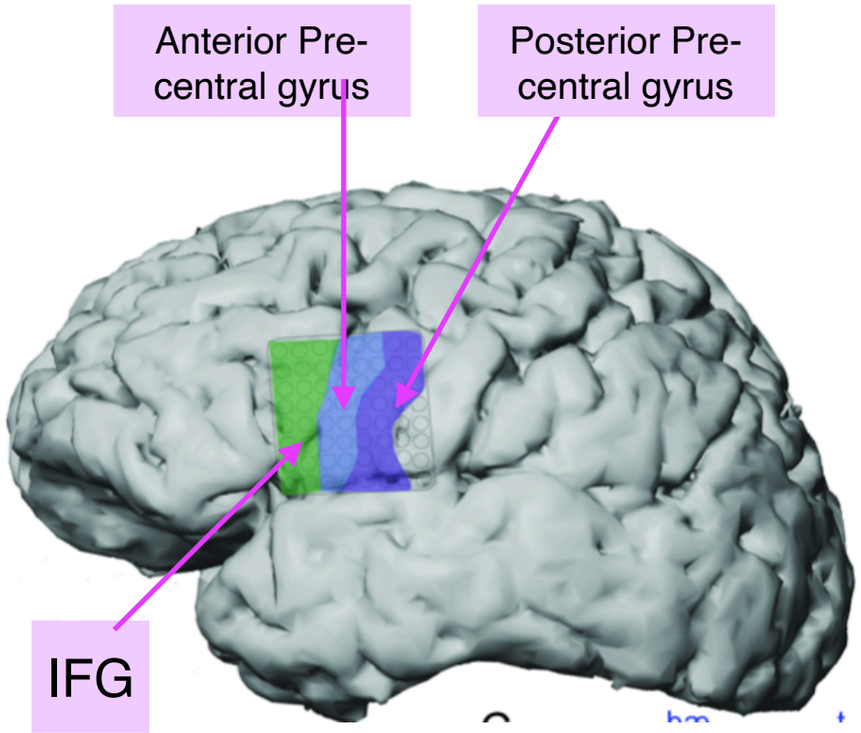


Other brain areas and motor organization of speech

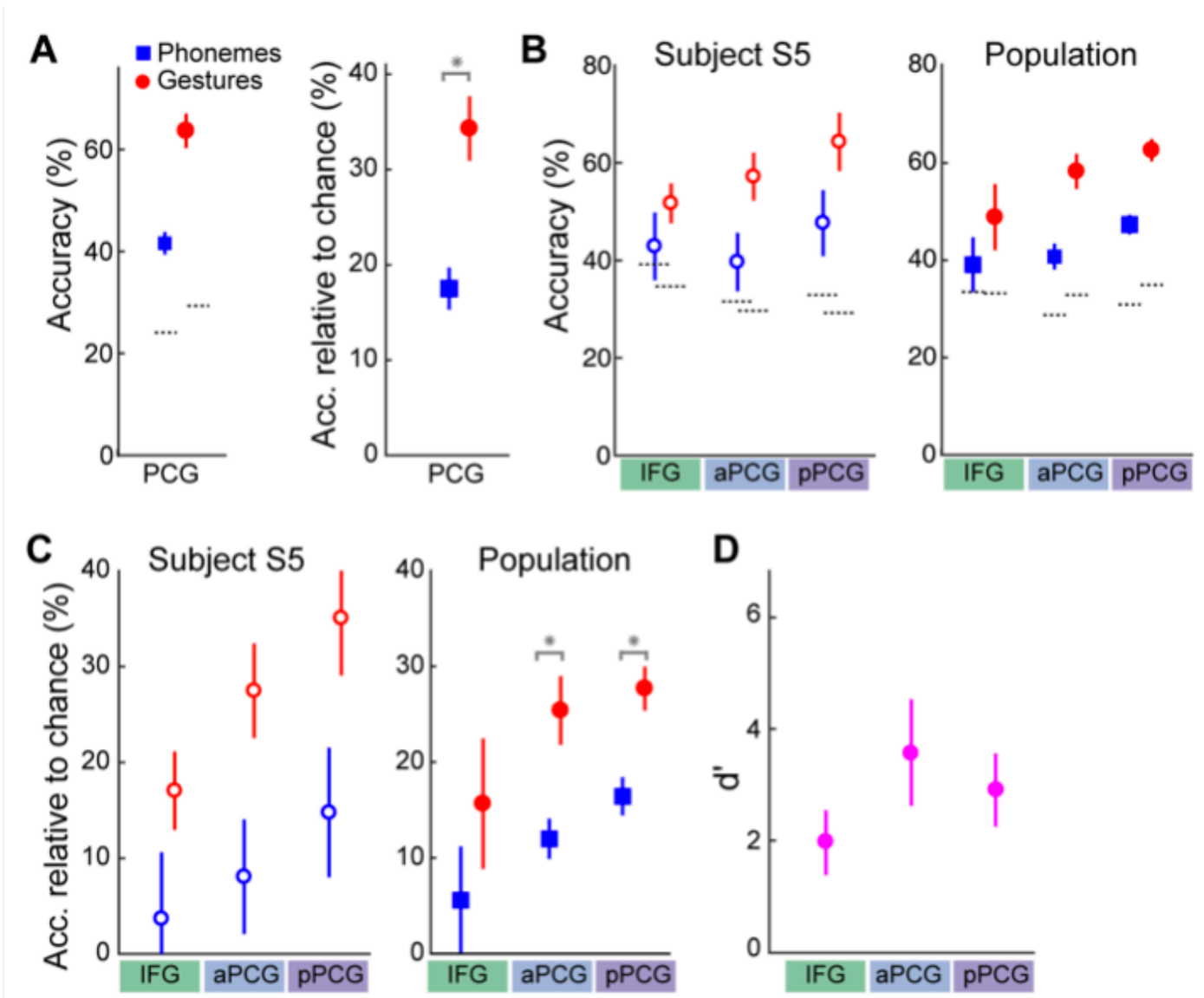
- IFG (Inferior Frontal Gyrus)
- Includes traditional "Broca's area"
- Possibly responsible for planning temporal coordination of speech gestures.



Gesture and phoneme representation in M1 and IFG



- ECoG activity
- Mostly CVC words
- 9 speakers
- Classification of gesture>phonemes
- Difference not significant in IFG

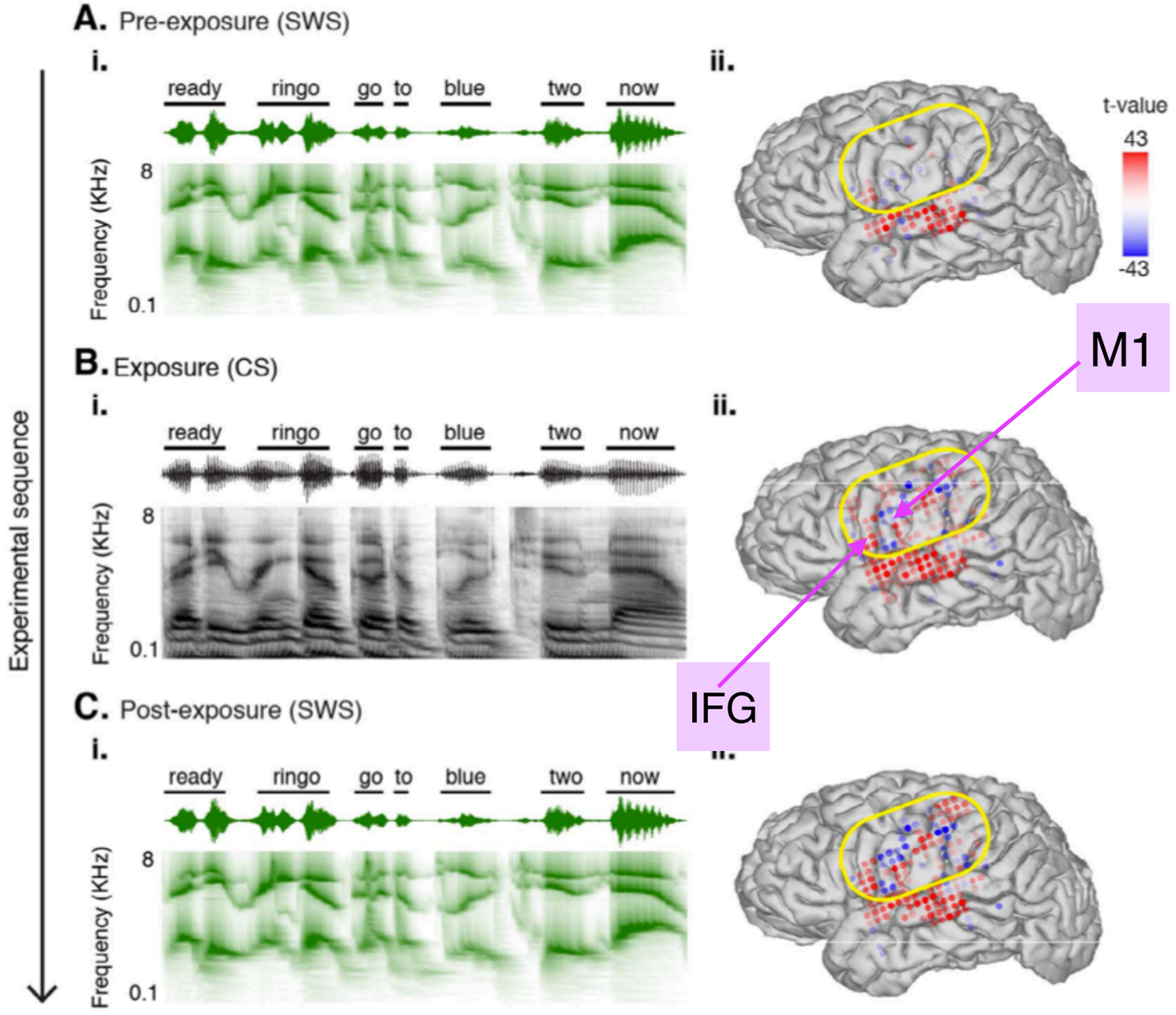


Differential representation of articulatory gestures and phonemes in precentral and inferior frontal gyri

Mugler, E. M., Tate, M. C., Livescu, K., Templer, J. W., Goldrick, M., & Slutzky, M. (2018) Journal of Neuroscience, 26, 1206-1218

Brain Activation Listening to SWS

- Listening to SWS sentence without comprehension leads to activation in STG almost exclusively
- Listening to the original leads to STG, M1,IFG
- Listening to the SWS sentence after the original leads to similar patterns to the original
- Is there gesture-specific activation patterns in IFG during listening and comprehending SWS?



Khoshkhoo S.*, Leonard, M.K.*, Mesgarani, N., & Chang, E.F. (2018). **Neural correlates of sine-wave speech intelligibility in human frontal and temporal cortex.** *Brain and Language*. (*Equally contributing authors.)

https://doi.org/10.1016/j.bandl.2018.01.007

Summary of results