



Sensorimotor coding for native and non native phoneme perception: An fMRI study

Tzuyi Tseng

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 **Cognitive-neurolinguistics, Cross-linguistic comparison,
Speech processing, Language learning, fMRI, MVPA**

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2026

2025



2021



2020



Sensorimotor coding for native and non-native phoneme perception: An fMRI study

| Talk at LingLunch, Université Paris Cité | 25.09.2025 |

Tzuyi Tseng, Ph.D.

Collaborators:

Tzuyi Tseng¹, Simon Thibault², Jennifer Krzonowski¹, Mélanie Canault¹³,
Alice C. Roy^{1*}, Claudio Brozzoli^{4*}, Véronique Boulenger^{1*}. (In preparation).

Decoding articulatory phonetic features: somatotopic and sensorimotor representations
in native and non-native phoneme perception.

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* equal contribution

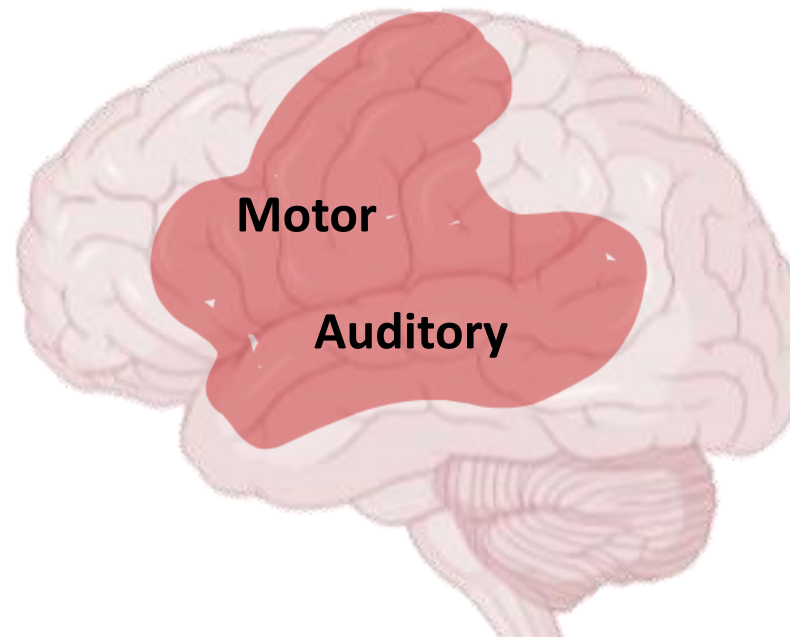
Sensorimotor foundation in speech perception

Embodied Theory of Cognition

(Barsalou 2008;
Fischer & Zwaan 2008)



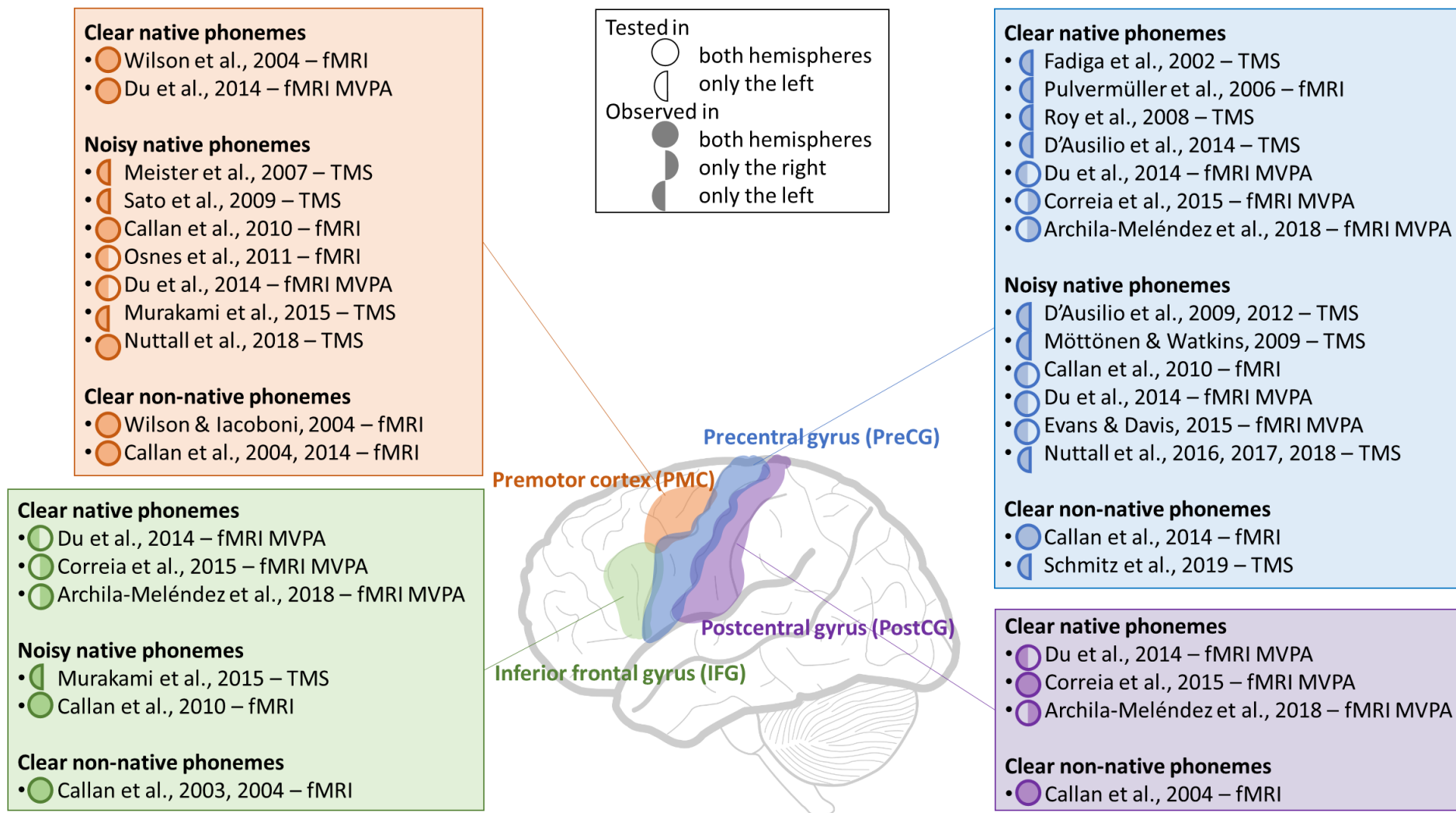
Sensorimotor regions



Sensorimotor processing

(Pulvermüller & Fadiga, 2010;
Rauschecker & Scott, 2009;
Schomers & Pulvermüller, 2016
Schwartz et al., 2008, 2012)

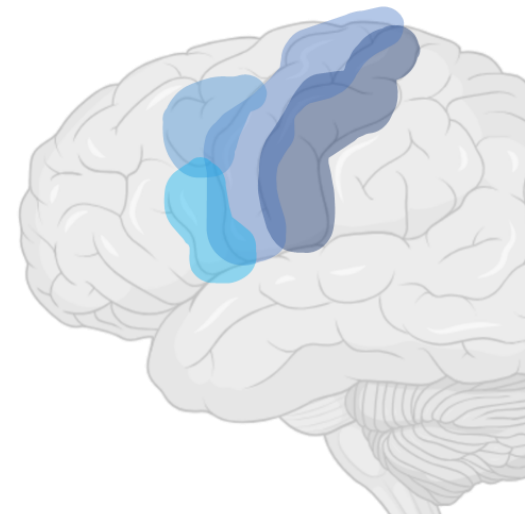
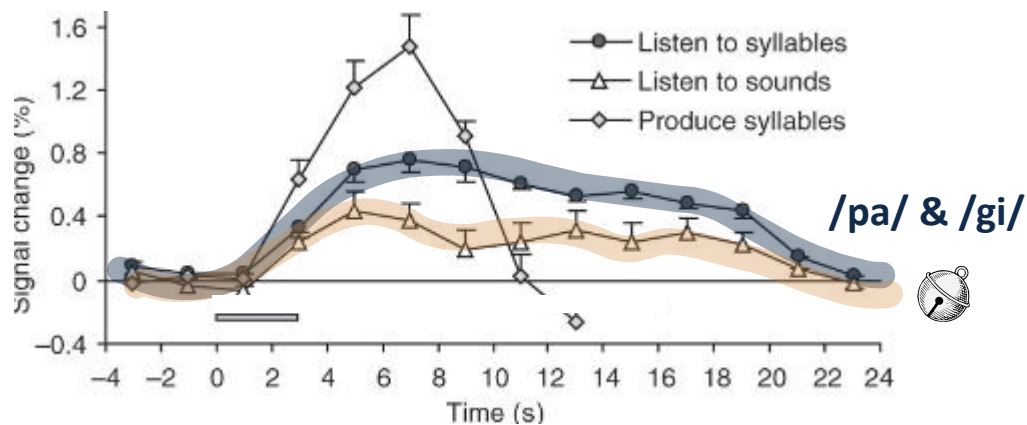
The role of the motor system in phoneme perception



(adapted from Tseng et al. under review. *Neurobiology of Language*.)

Motor activity during intact native phoneme perception

- Speech vs non-speech



fMRI
• Wilson et al., 2004
• Du et al., 2014

PMC

fMRI
• Du et al., 2014
• Correia et al., 2015
• Archila-Meléndez et al., 2018

IFG

TMS
• Fadiga et al., 2002
• Roy et al., 2008
• Möttönen & Watkins, 2009
• D'Ausilio et al., 2014

PreCG

fMRI
• Pulvermüller et al., 2006
• Du et al., 2014
• Correia et al., 2015
• Archila-Meléndez et al., 2018

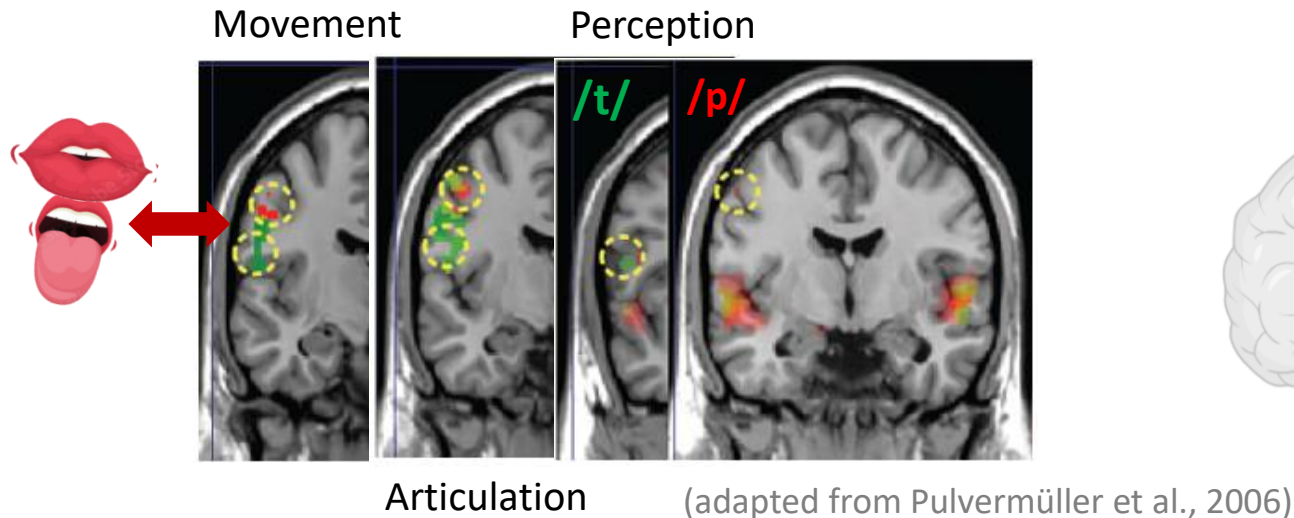
fMRI
• Du et al., 2014
• Correia et al., 2015
• Archila-Meléndez et al., 2018

PostCG

Motor activity during intact native phoneme perception

- Speech vs non-speech
- Articulatory phonetic features
 - Fadiga et al. (2002): Italian trill /r/
 - Pulvermüller et al. (2006): dental alveolar /t/ & bilabials /p/

Somatotopy

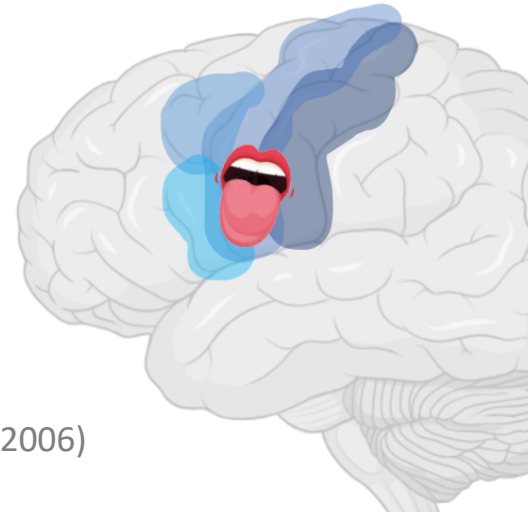


fMRI PMC
• Wilson et al., 2004
• Du et al., 2014

fMRI IFG
• Du et al., 2014
• Correia et al., 2015
• Archila-Meléndez et al., 2018

TMS PreCG
• Fadiga et al., 2002
• Roy et al., 2008
• Möttönen & Watkins, 2009
• D'Ausilio et al., 2014
fMRI
• Pulvermüller et al., 2006
• Du et al., 2014
• Correia et al., 2015
• Archila-Meléndez et al., 2018

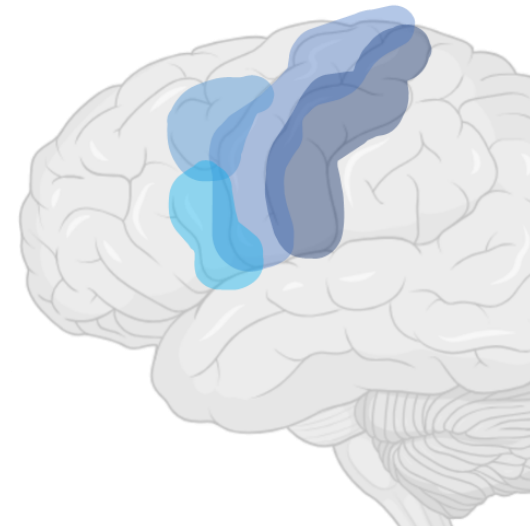
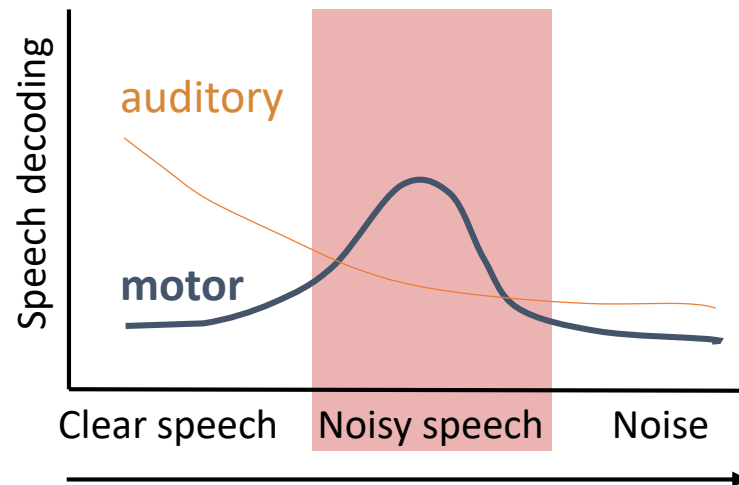
fMRI PostCG
• Du et al., 2014
• Correia et al., 2015
• Archila-Meléndez et al., 2018



Motor activity during noisy native phoneme perception

- Decoding speech in **noisy** condition

- D'Ausilio et al. (2009): dental alveolar /t/ & bilabials /p/ **Somatotopy**
- Degraded but identifiable speech (Du et al., 2014; Osnes et al., 2011)



TMS **PMC**

- Meister et al., 2007
- Sato et al., 2009
- Murakami et al., 2015

fMRI

- Callan et al., 2010
- Osnes et al., 2011
- Du et al., 2014

TMS **IFG**

- Murakami et al., 2015

fMRI

- Callan et al., 2010

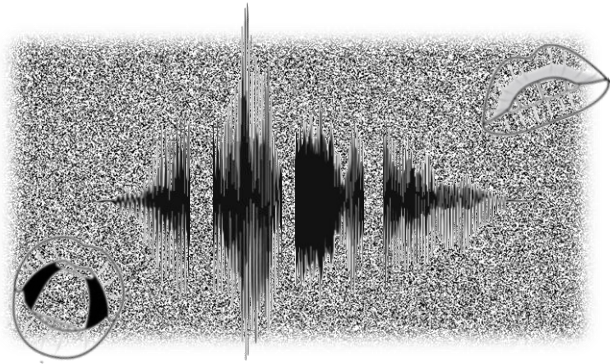
TMS **PreCG**

- D'Ausilio et al., 2009, 2012
- Nuttal et al., 2016, 2017

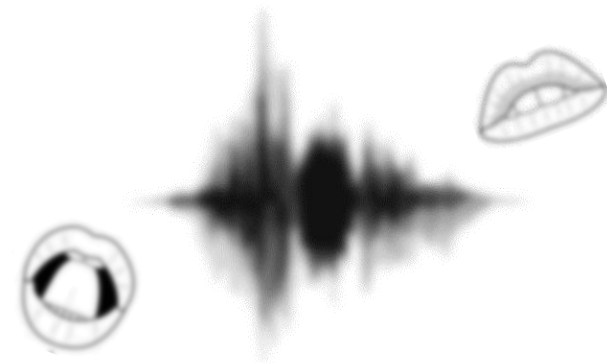
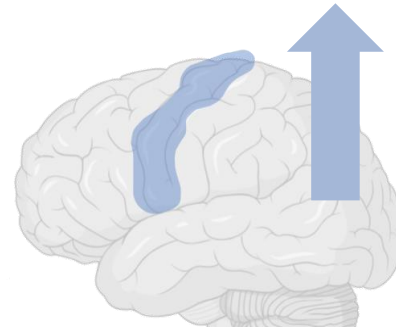
fMRI

- Callan et al., 2010
- Du et al., 2014
- Evans & Davis, 2015

Degraded native phonemes & Non-native phonemes



Incomplete auditory signals



Less defined articulatory features

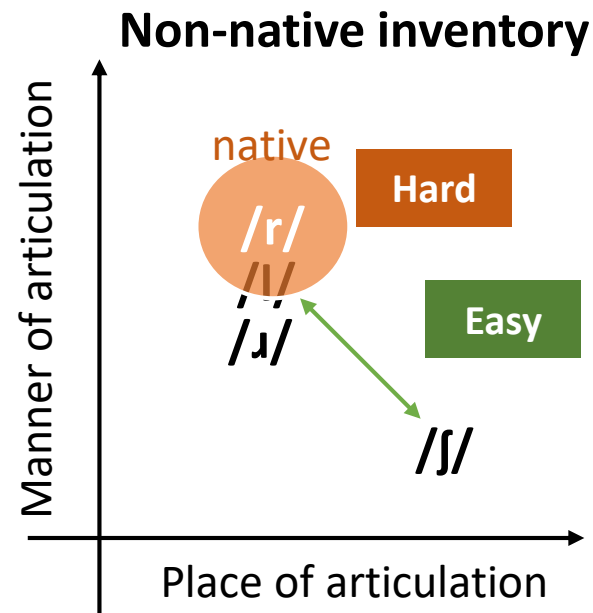
Would listening to non-native phonemes induce similar motor activity?

Non-native phoneme perception

Theoretical model:

- The Speech Learning Model (SLM; Flege, 1995)
- The Perceptual Assimilation Model (PAM; Best, 1994; Best et al., 2001)

Non-native phonemes can be assimilated into a native phoneme category.



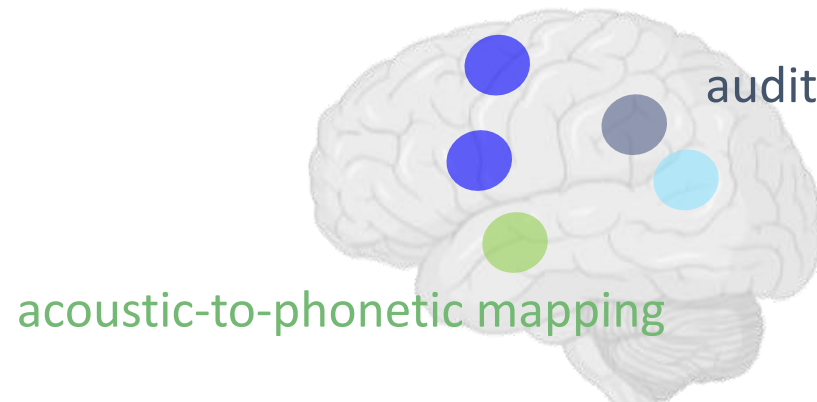
Non-native phoneme perception

Neurolinguistic model:

- The forward and inverse internal models by Callan et al. (2004):
non-native phoneme identification

Auditory signals vs. Predicted articulatory representations

motor planning regions



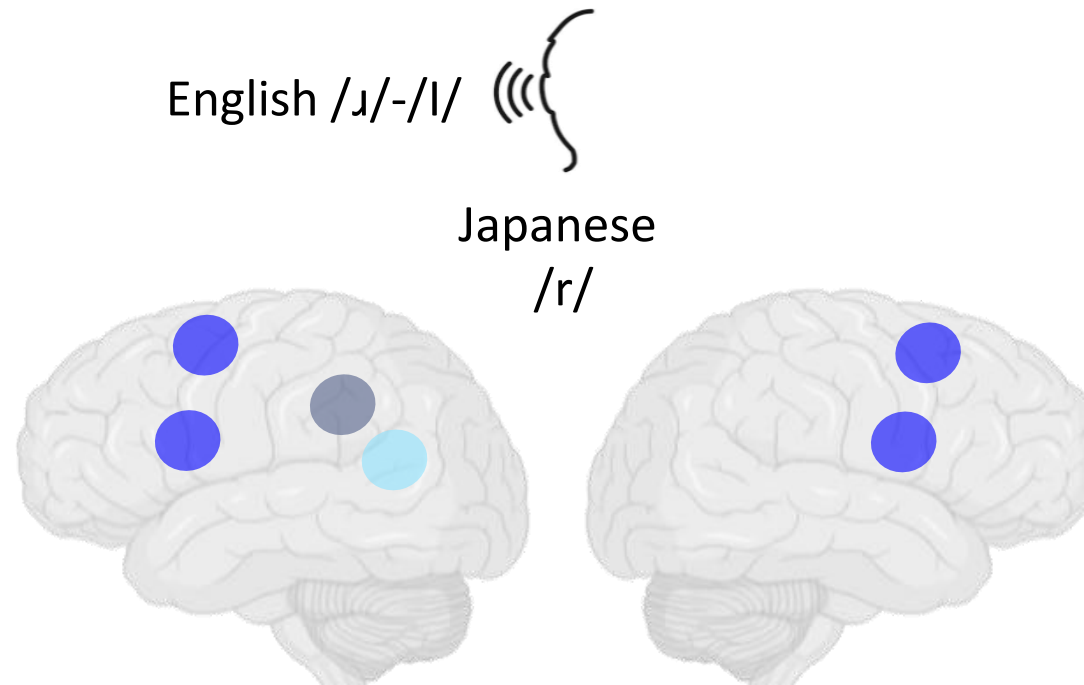
auditory-to-articulatory gestures

- Anterior STG/S
- Posterior STG/Spt (Sylvian parietal temporal)
- SMG (Supramarginal Gyrus)
- IFG/PMC/Anterior Insula

Non-native phoneme perception

Neurolinguistic model:

- The forward and inverse internal models by Callan et al. (2004)



Non-native > Native

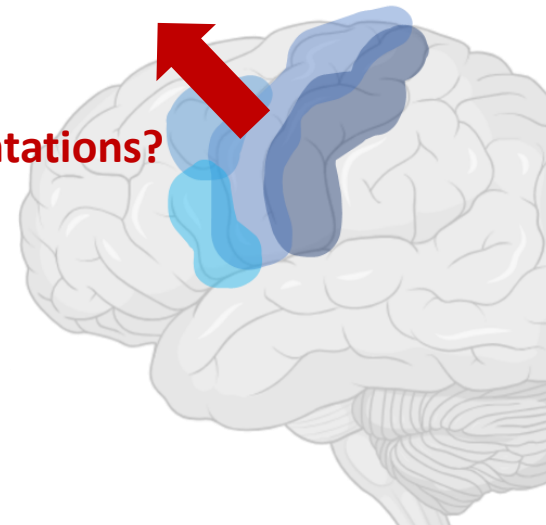
Inconclusive & insufficient findings in phoneme perception

- **Absent motor activity** (e.g. Arsenault & Buchsbaum, 2015 Szenkovits et al., 2012)
- **Observed activity only in degraded condition**
(e.g. D'Ausilio et al., 2012; Osnes et al., 2011)
- **Equal activation for different places of articulation**
(e.g. Arsenault & Buchsbaum, 2016; Cheung et al., 2016)
- **Limited studies (no somatotopy) for non-native phonemes**

~~Necessity~~

~~Somatotopy~~

embodied representations?



fMRI PMC
• Wilson & Iacoboni, 2004
• Callan et al., 2004, 2014

fMRI IFG
• Callan et al., 2003, 2004

TMS PreCG
• Schmitz et al., 2019
fMRI
• Callan et al., 2014

fMRI PostCG
• Callan et al., 2004

Research Aims & Questions

Aims

Sensorimotor representations for native and non-native phoneme perception under both intact and degraded perceptual conditions


Questions

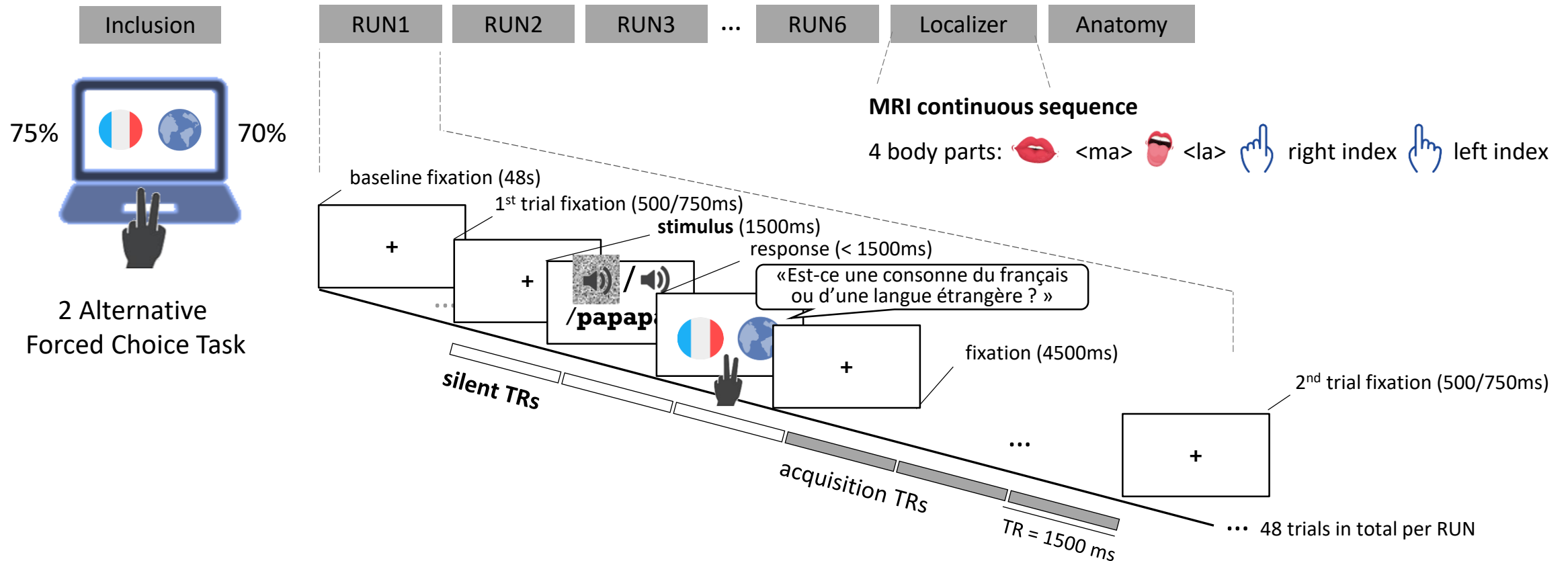
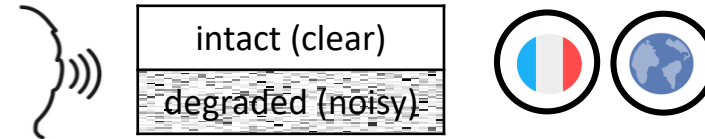
- 1. Are the phonetic features specifically encoded in the sensorimotor regions?**
- 2. Are perceived phonemes somatotopically represented in the motor cortex?**

Methods

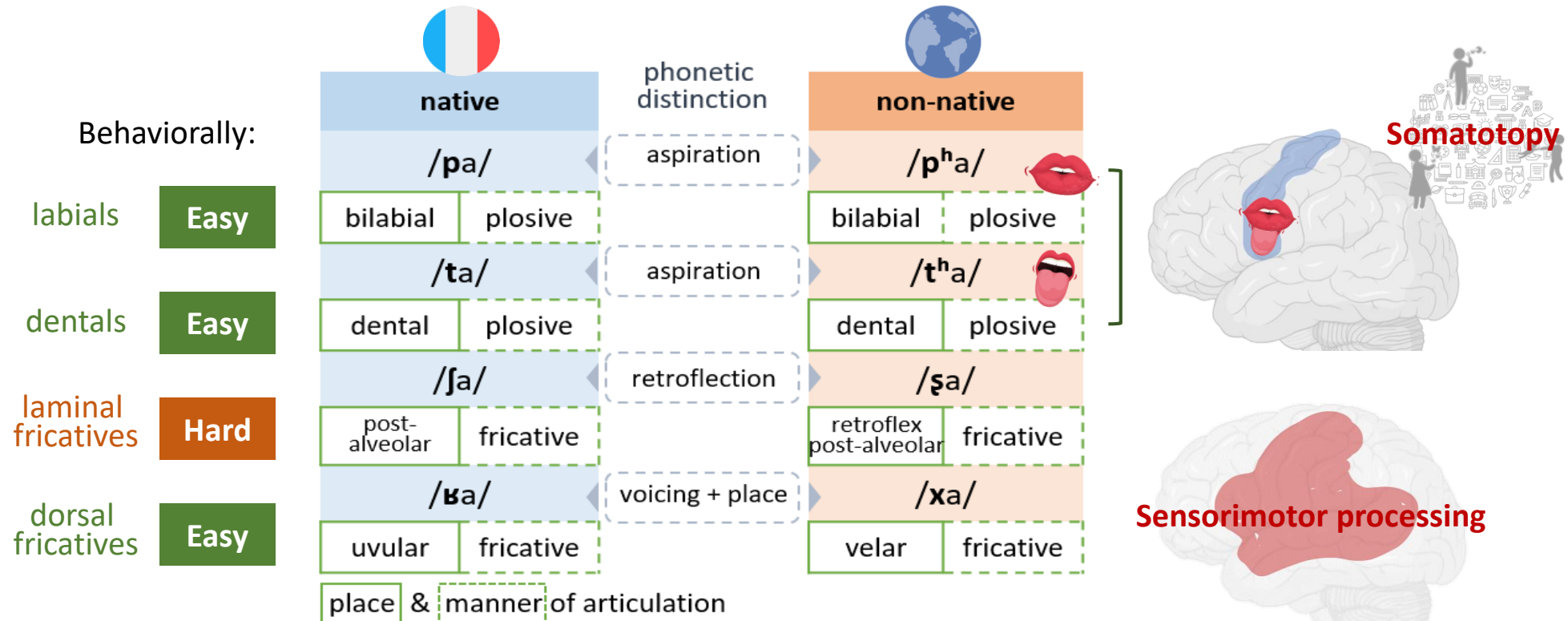
- Univariate regression analysis: brain activation X behavioral phoneme categorization**
- Multivariate pattern analyses (MVPA):**
 - 1. Representational similarity analysis (RSA): encoding of phonetic features**
 - 2. Cross-modal classification: decoding of articulatory phonetic features**

Methodology: Participants, Task & Procedure

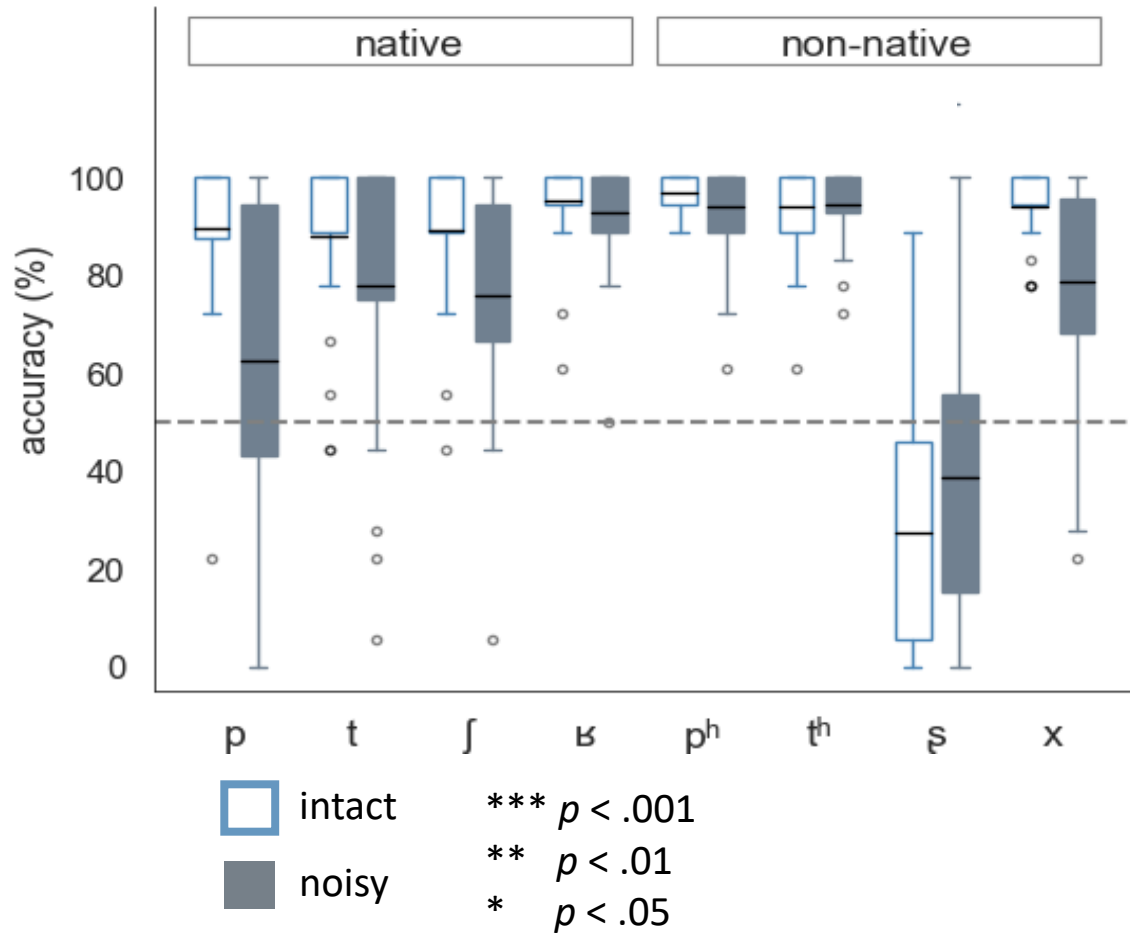
- A behavioral + fMRI study
- **24**  (17 females; age = 24.45 ± 3.12 yrs)
Healthy right-handed monolingual French native adult speakers



Methodology: Stimuli



Behavioral results



Mixed-effects ANOVA

Language (native vs. non-native)

Noise (intact vs. noisy)

Consonant (labials, dentals, laminal fricatives vs. dorsal fricatives)

Main effect

- **Native > Non-native** → Language***
- **Intact > Noisy** → Noise**
- **Laminal Fricative /ʂ/** → Consonant***

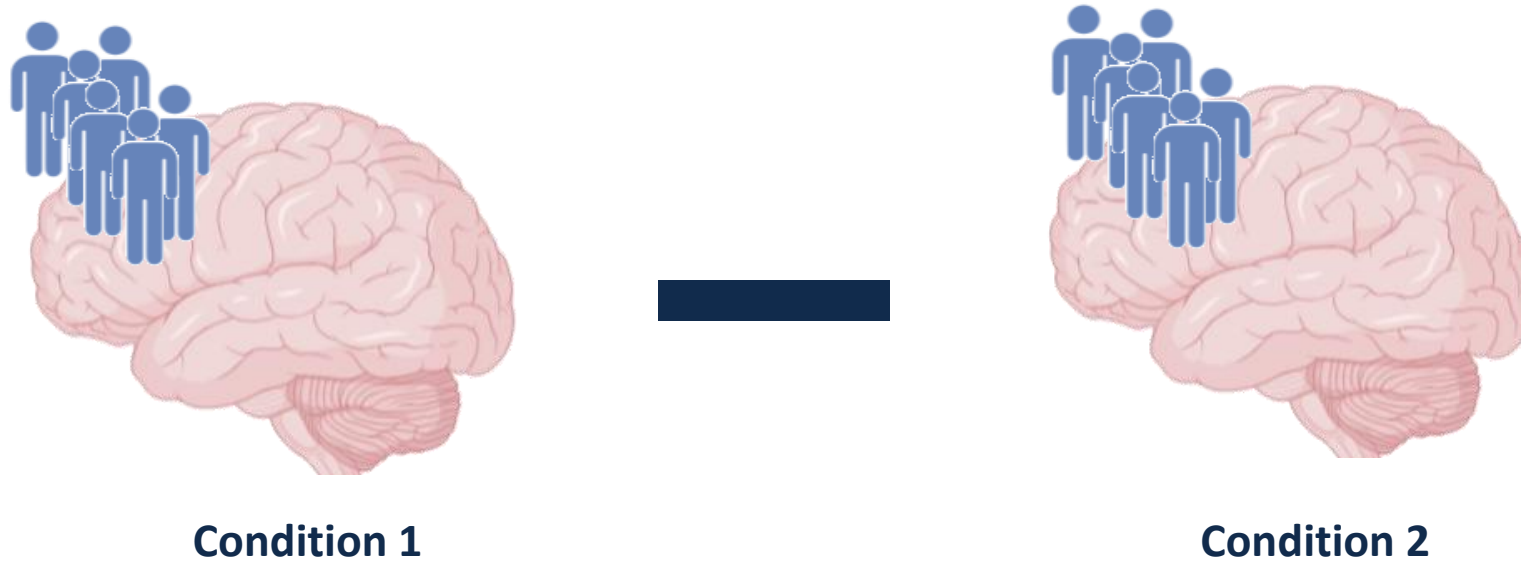
Interactions

- **/ʂ/ > /ʃ/** → Language x Consonant **
- **/p/** → Consonant x Noise**
- **/pʰ/ > /p/** → Language x Consonant x Noise***



- **Fricatives /ʃ/-/ʂ/:** PAM (Best 1994; Best et al. 2001)
- **Plosive /p/:** shorter voice-onset-time (VOT)

fMRI univariate analysis

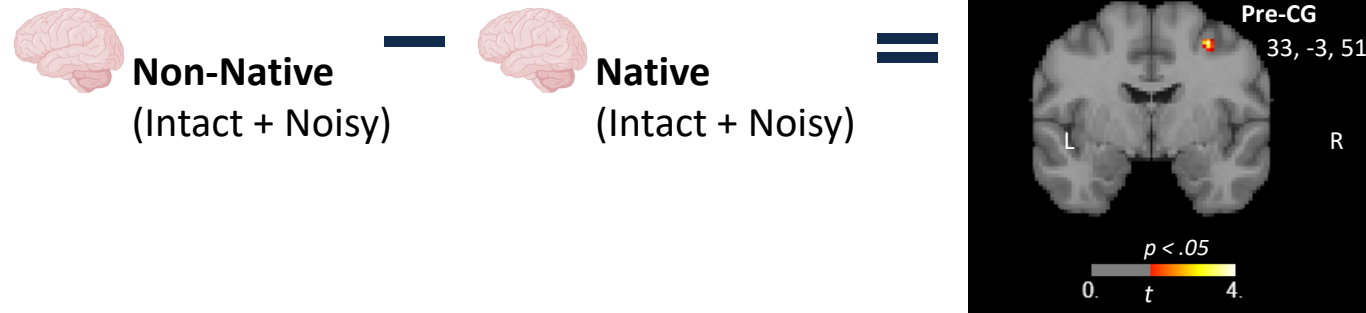


Language	Native
	Non-native
Noise	Intact
	Noisy

fMRI univariate results

Language or Noise effect?

- Main effect of Language: **Non-native** in the **right Pre-CG**

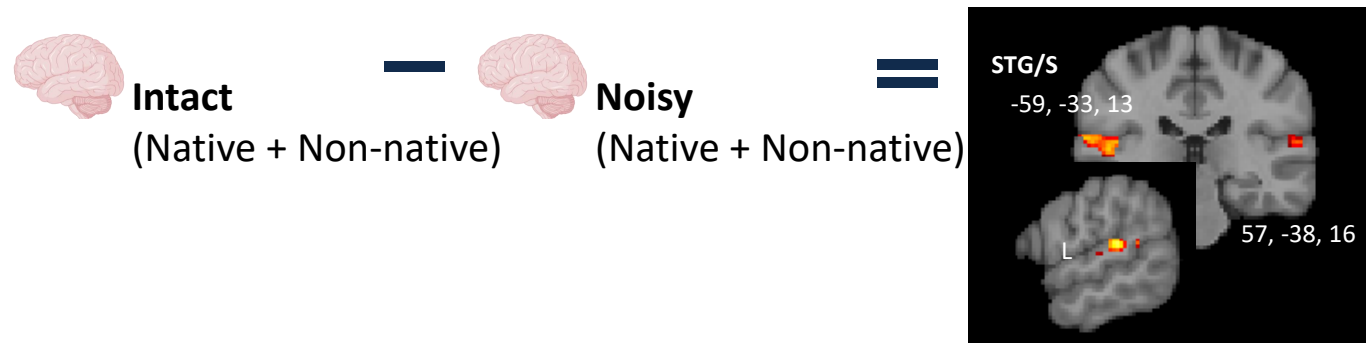


Both auditory and motor activity
are engaged in phoneme categorization

Motor → Language

Auditory → Noise

- Main effect of Noise: **Intact** in the **bilateral STG/S**



Consistent with previous studies:
Callan et al., 2010; Du et al., 2014;
Evans & Davis, 2015; Wilson &
Iacoboni, 2006

fMRI univariate regression analyses

The functional role of sensorimotor regions in phoneme categorization?

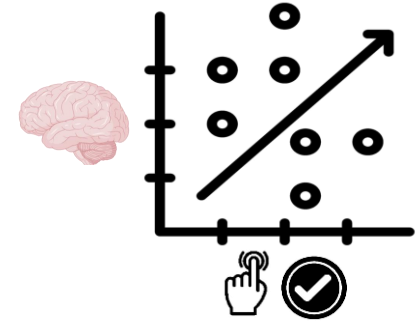
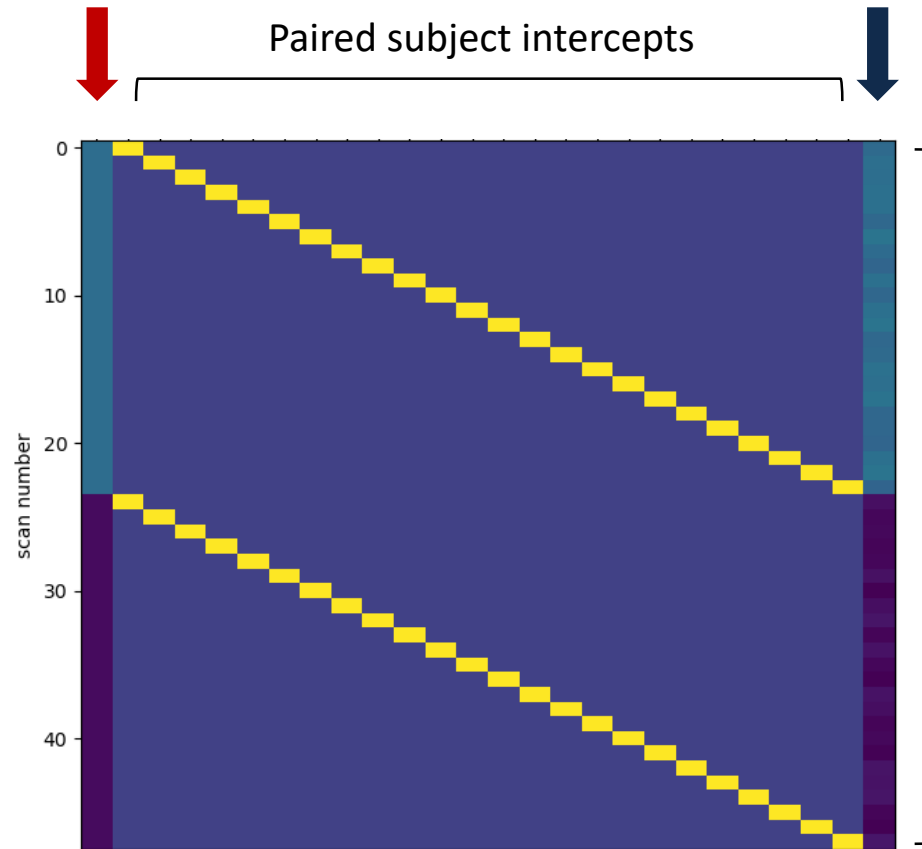


Native vs. baseline
(Intact + Noisy)

Non-Native
(Intact + Noisy)

Intact
(Native + Non-native)

Noisy
(Native + Non-native)



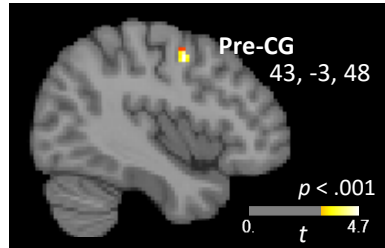
Individual averaged
behavioral accuracy

fMRI univariate results: whole-brain regression analyses

- Better **native** phoneme categorization, higher **right PreCG** activation



Native
(Intact + Noisy)

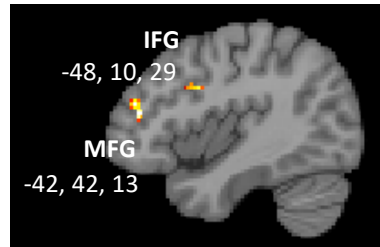


PreCG → Native
IFG → Degraded native/Non-native

- Better **non-native** phoneme categorization, higher **left IFG** activation



Non-Native
(Intact + Noisy)

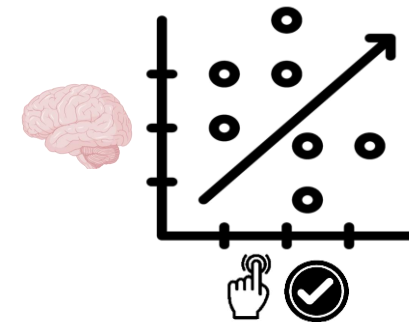
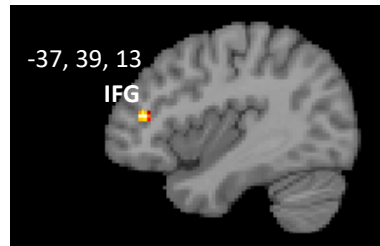


Consistent with previous studies:
Callan et al. 2010; Du et al. 2017

- Better **degraded** phoneme categorization, higher **left IFG** activation



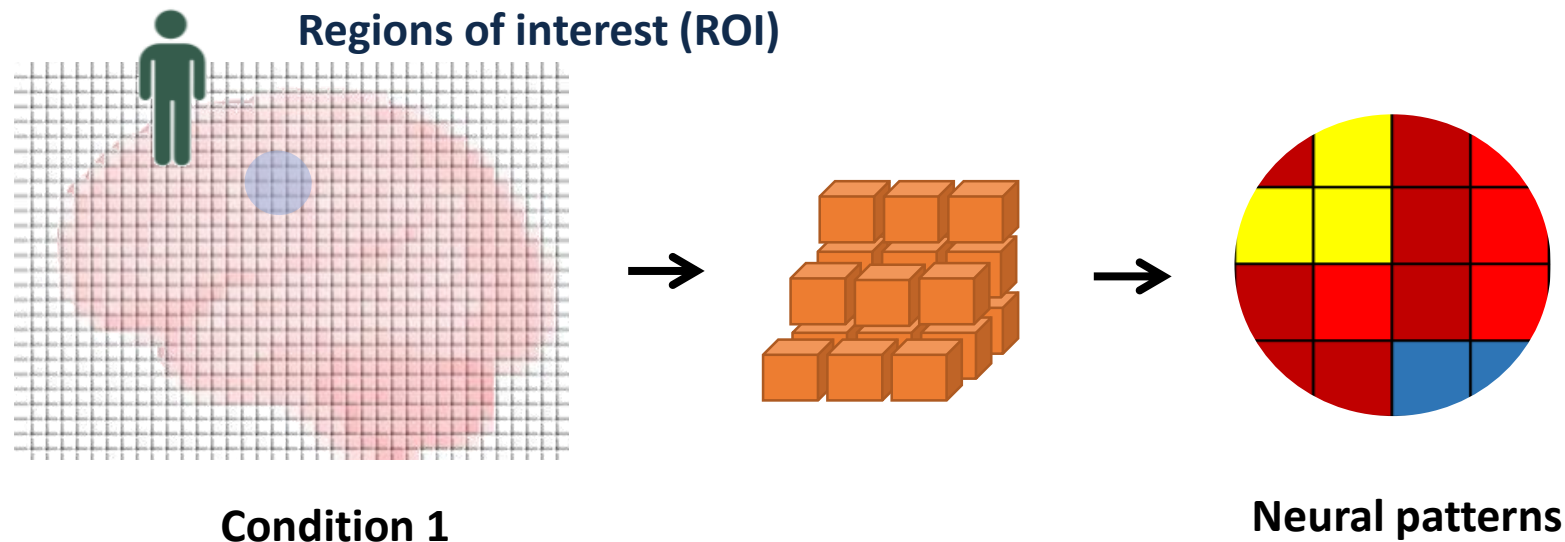
Noisy
(Native + Non-native)



fMRI multivariate pattern analysis (MVPA)

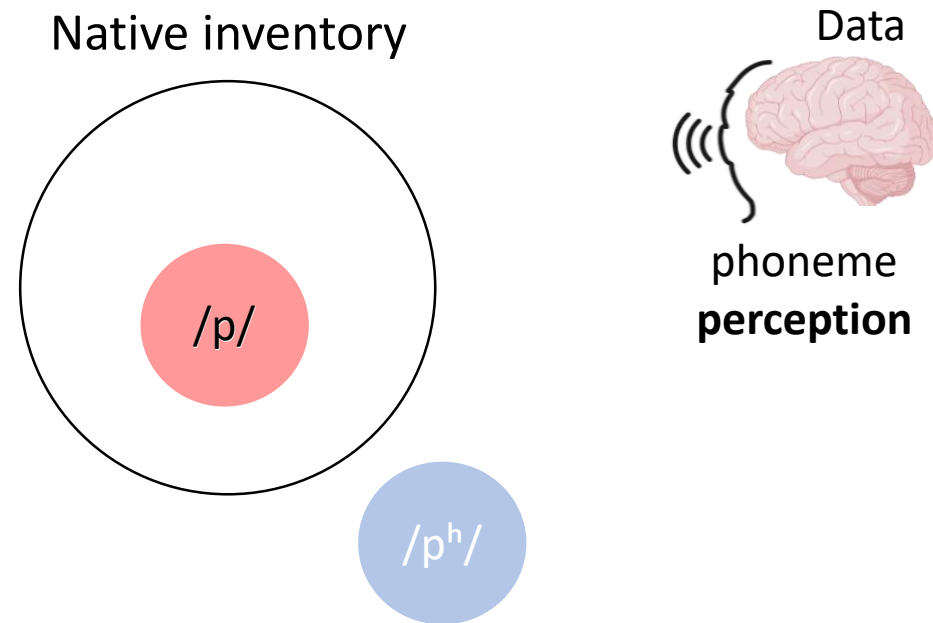
Questions

1. Are the phonetic features specifically encoded in the sensorimotor regions?
2. Are perceived phonemes somatotopically represented in the motor cortex?



MVPA Question – Searchlight Representational Similarity Analyses (RSA)

1. Are the phonetic features specifically encoded in the sensorimotor regions?

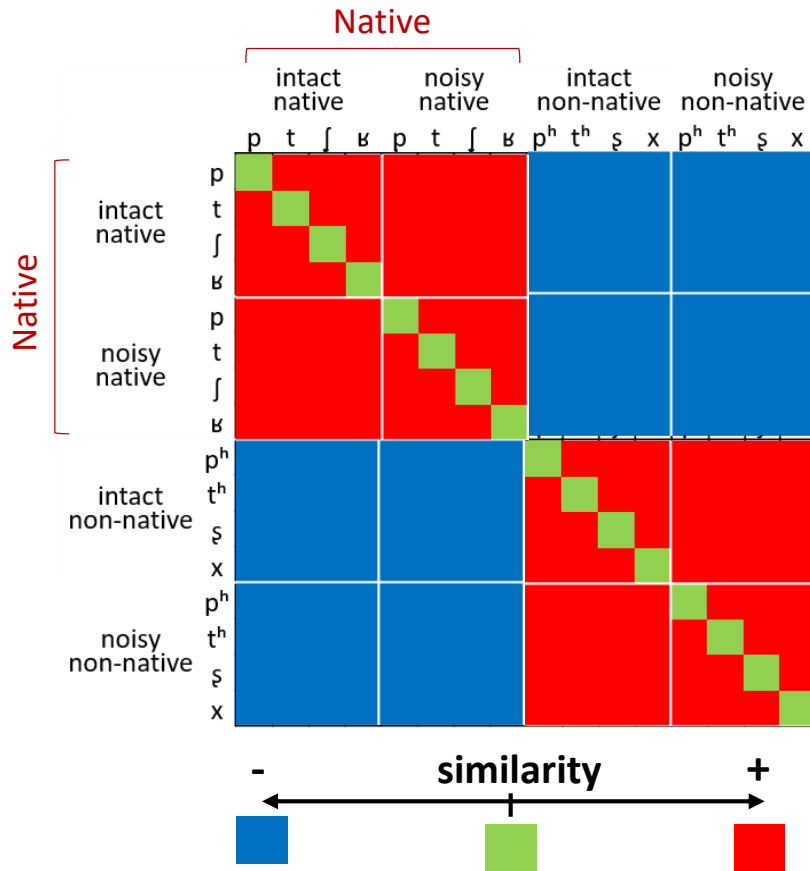


Searchlight RSA Methods

1. Are the phonetic features specifically encoded in the sensorimotor regions?

Predicted model: language

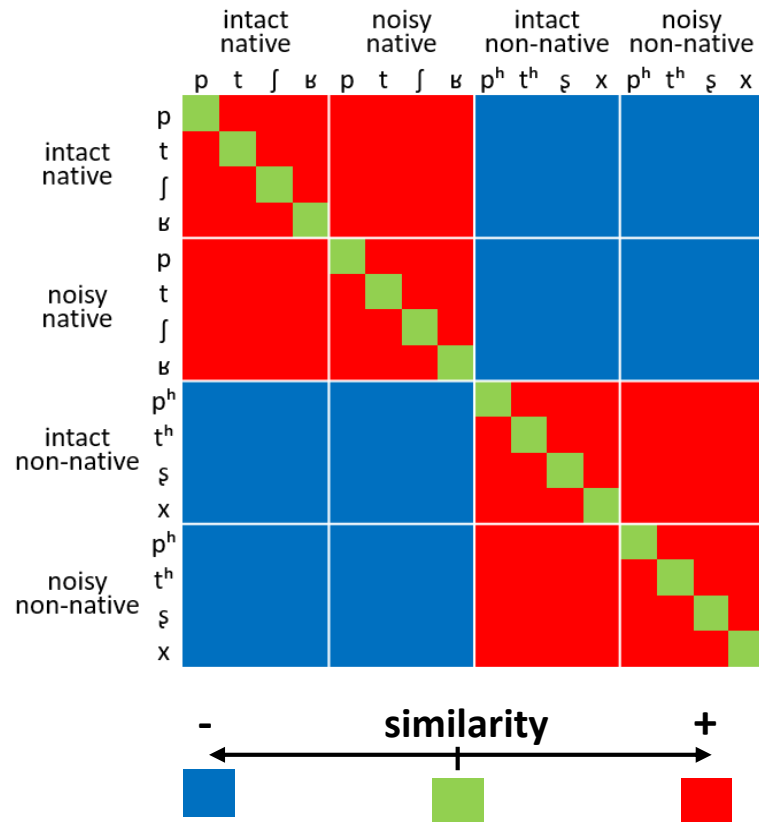
Observed matrix



Searchlight RSA Methods

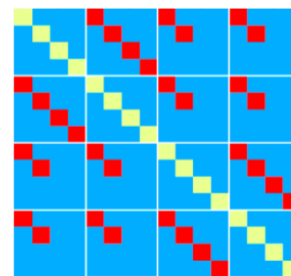
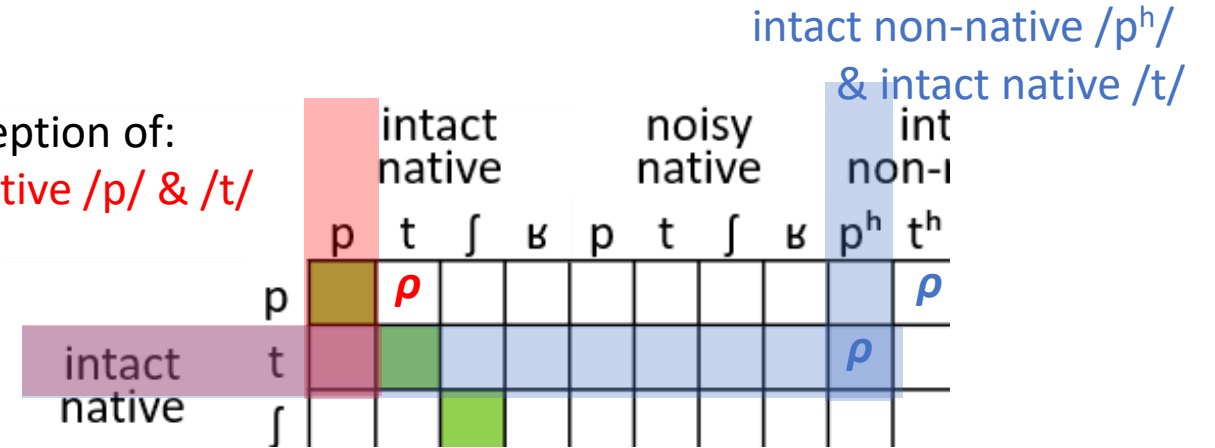
1. Are the phonetic features specifically encoded in the sensorimotor regions?

Predicted model: language



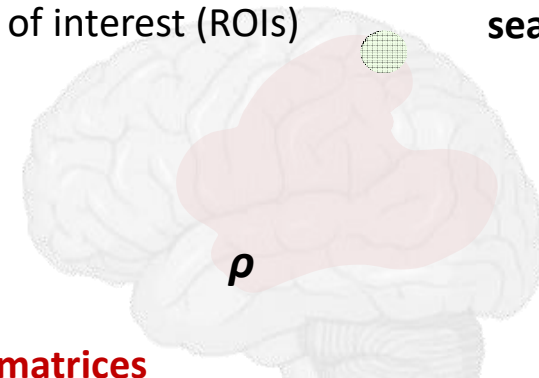
Observed matrix : correlated neural patterns of each condition

The perception of:
intact native /p/ & /t/



Regions of interest (ROIs)

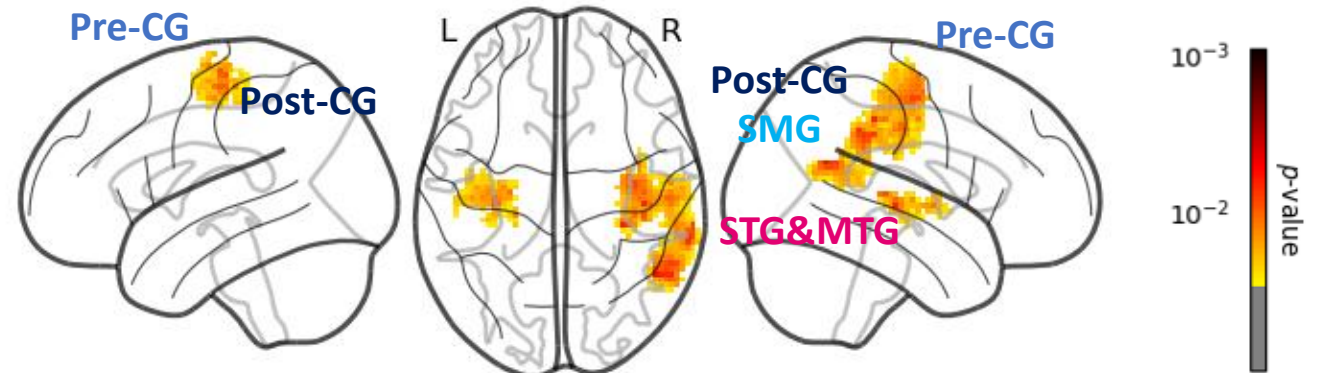
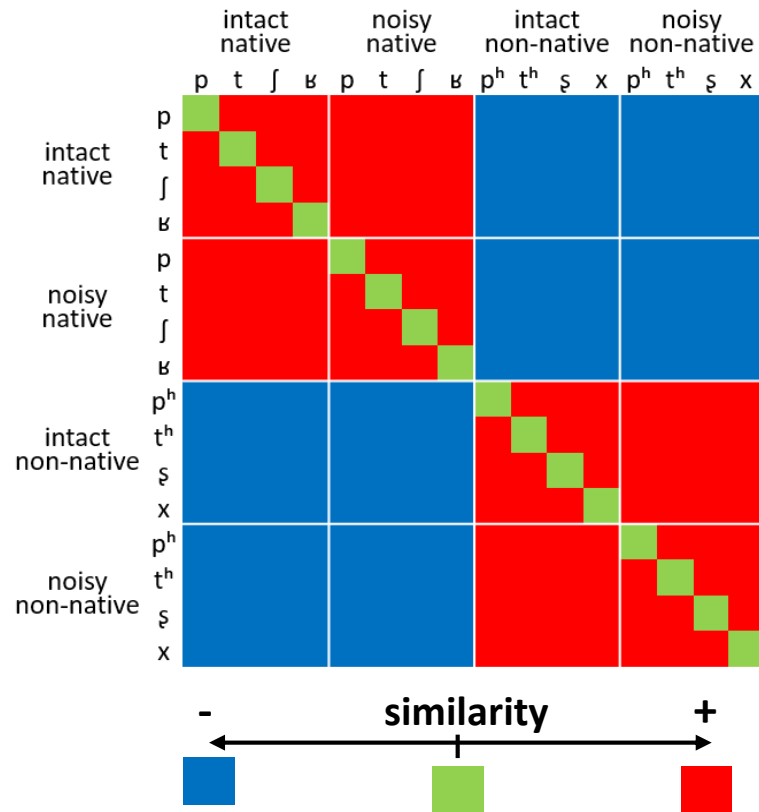
searchlight



Better fit of the observed to predicted matrices
→ neural patterns encode the phonetic feature of interest

Searchlight RSA Results

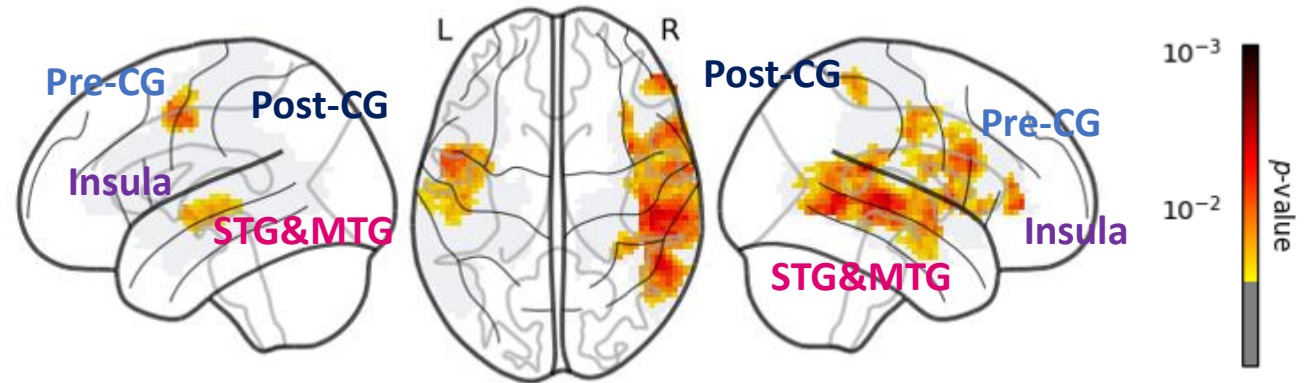
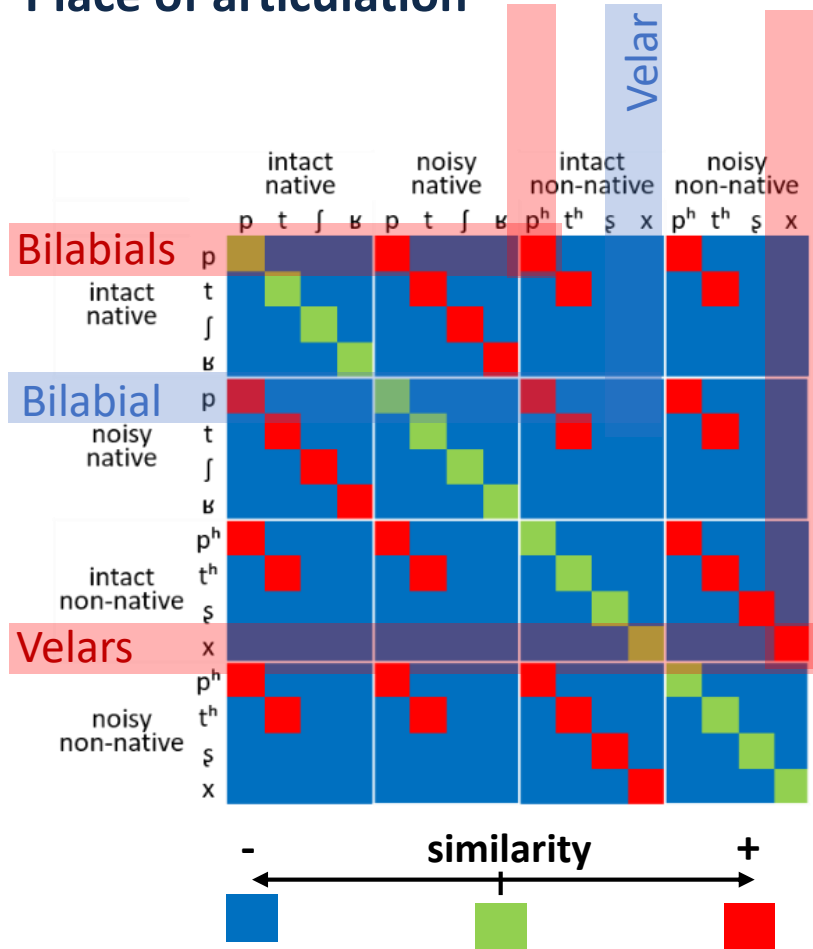
Language



These regions encode phonemes from the same language similarly.

Searchlight RSA Results

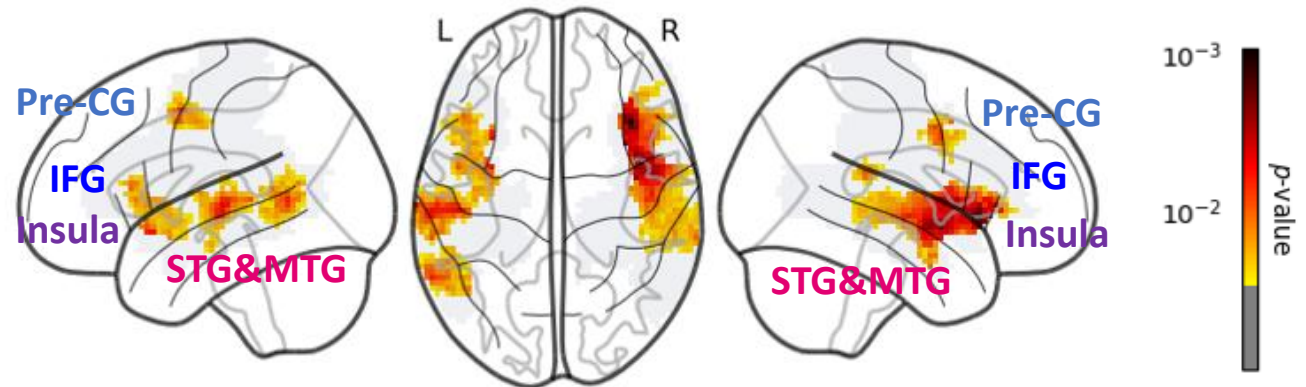
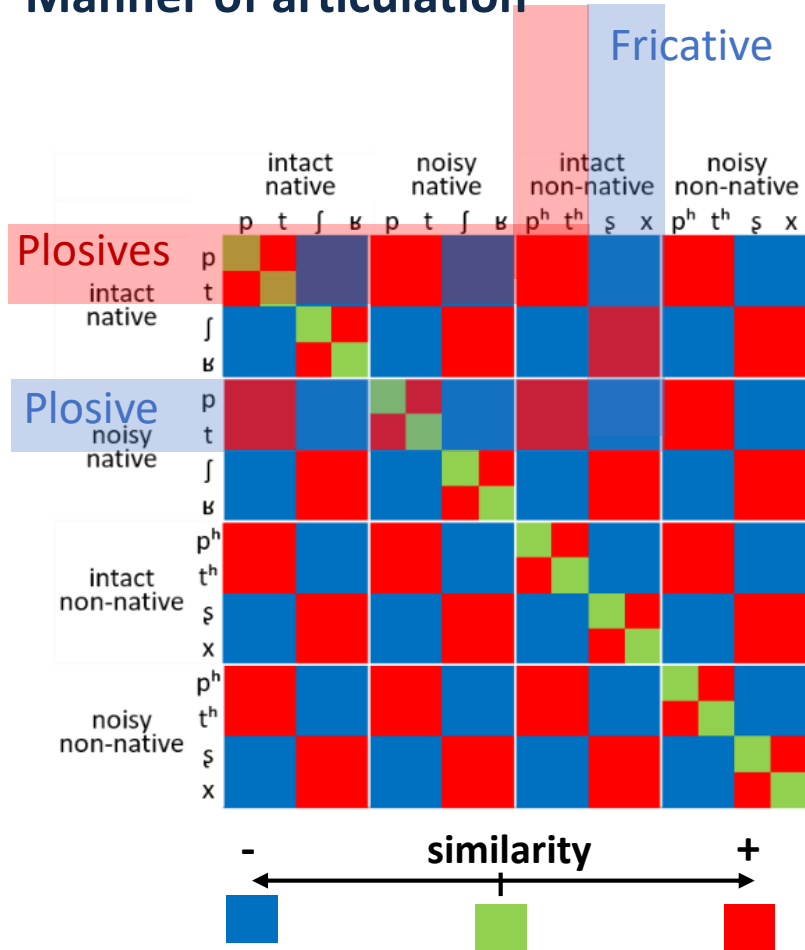
Place of articulation



These regions similarly encode phonemes with the same place of articulation.

Searchlight RSA Results

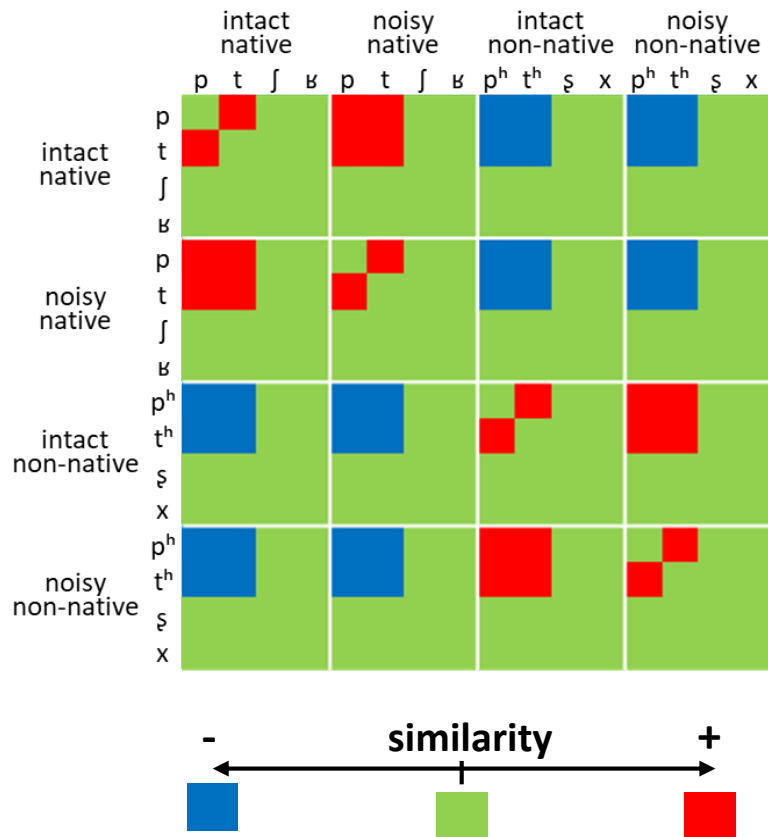
Manner of articulation



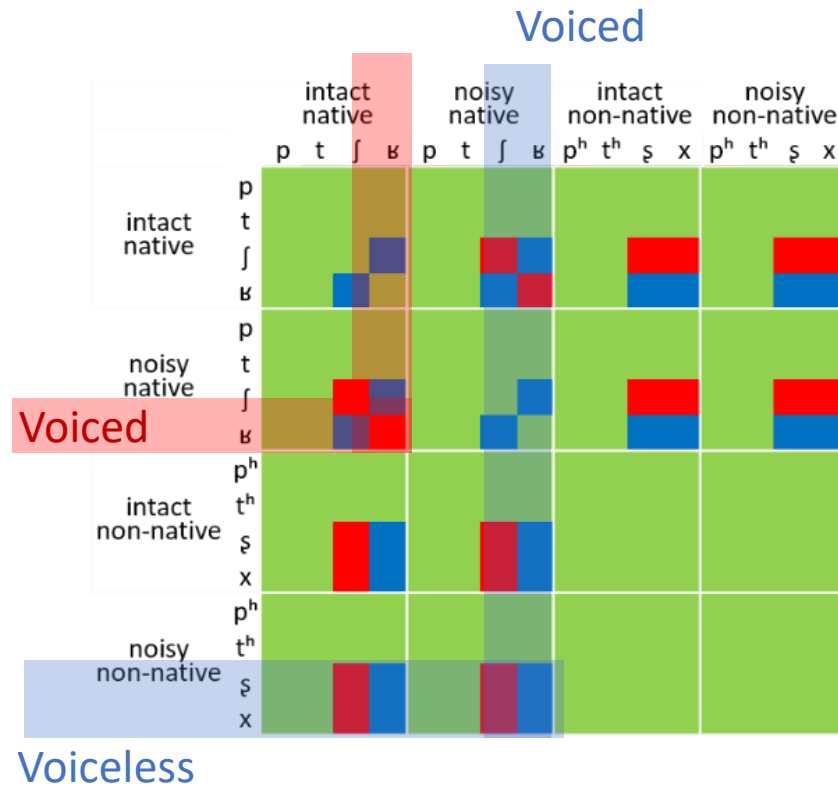
These regions similarly encode phonemes with the same manner of articulation.

Searchlight RSA Results

Aspiration



Voicing

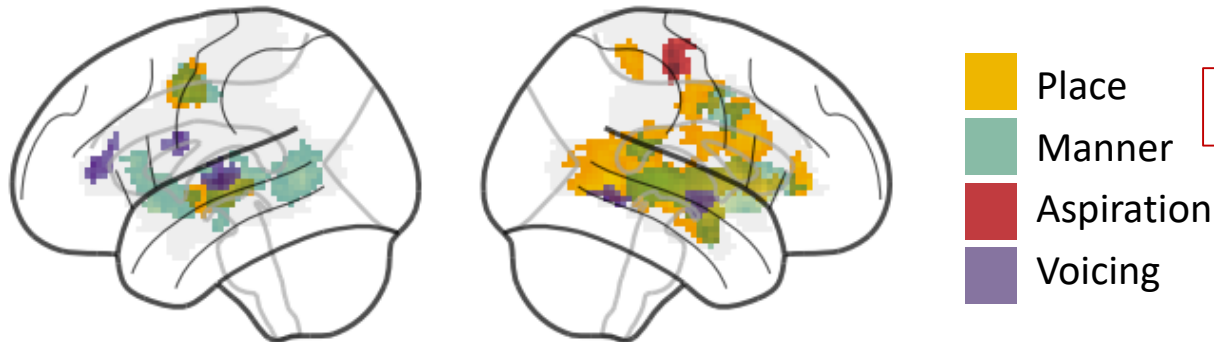


Searchlight RSA Results

1. Are the phonetic features specifically encoded in the sensorimotor regions?



Phoneme categorization relies on phonetic features encoded in the sensorimotor regions, both within and across languages.



complex coordination of the articulators

Voicing

- Arsenault & Buchsbaum 2015
LH: Insula, STG
- Correia et al. 2015
RH: STS

Manner of articulation

- Arsenault & Buchsbaum 2015
RH: IFG, SMG, STG
- Correia et al. 2015
Bilateral postCG
RH: SMG, INS

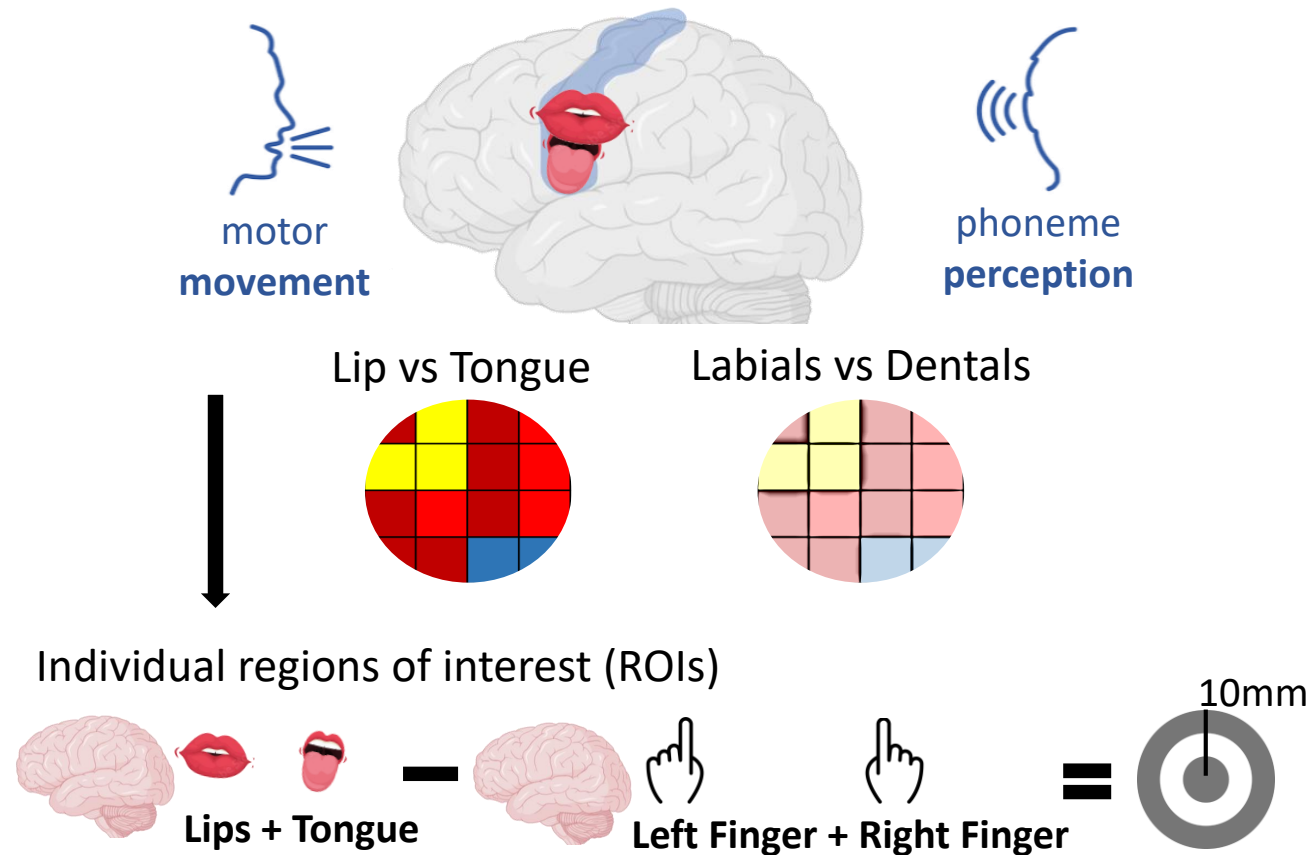
Place of articulation

- Zheng et al. 2025
LH: HG, STG
RH: preCG
- Archila-Meléndez et al. 2018
RH: motor region, insula, frontal areas
- Arsenault & Buchsbaum 2015
Bilateral STG
LH: postCG, IFG
- Correia et al. 2015
Bilateral postCG, STS/G
RH: preCG, IFG, INS

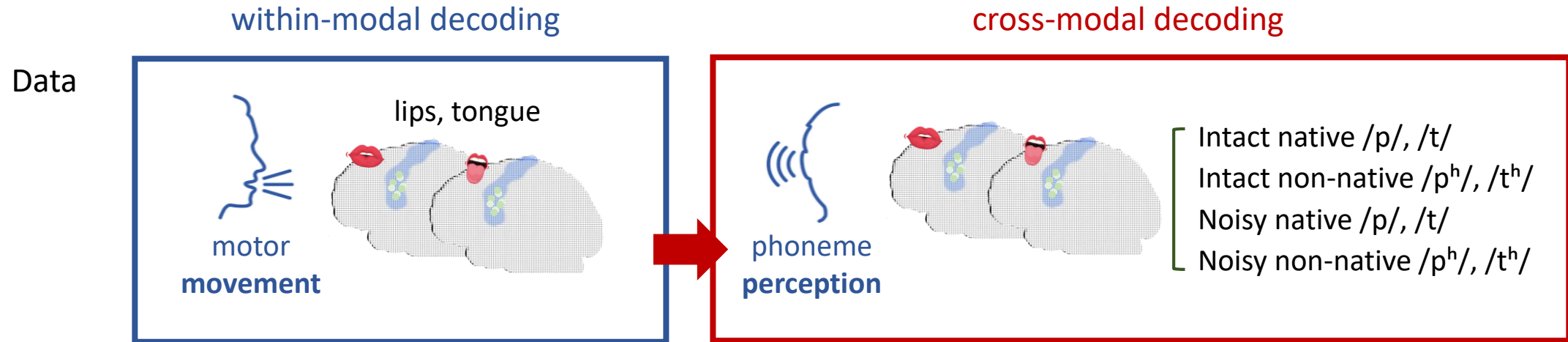
Cross-modal classification analysis

2. Somatotopy during perception in the motor cortex?

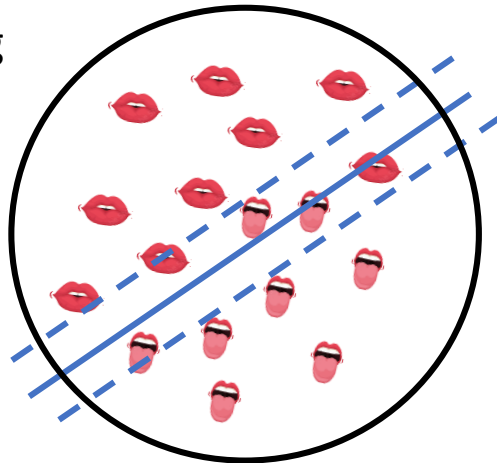
Using neural patterns of articulatory movement to decode those of perception



Cross-modal classification analysis



Training & Testing
Lips vs Tongue



support vector machines

(SVM, Misaki et al., 2010. *NeuroImage*.)

Leave-one-RUN-out cross-validation

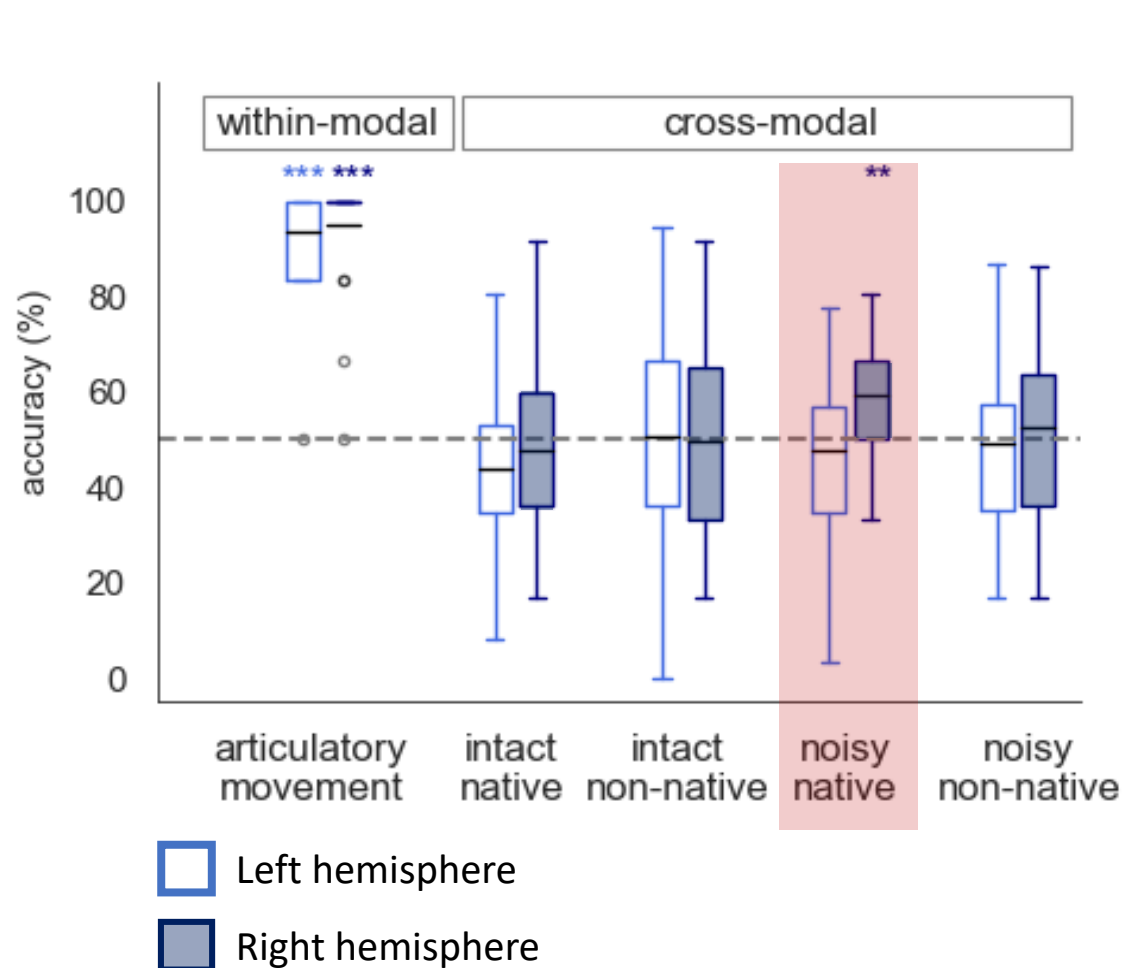
RUN1	RUN2	RUN3	RUN4	RUN5	RUN6
Training					Testing
Training				Testing	
...					
Testing	Training				



one-sample t-test

Cross-modal decoding results

2. Somatotopy during perception in the motor cortex?

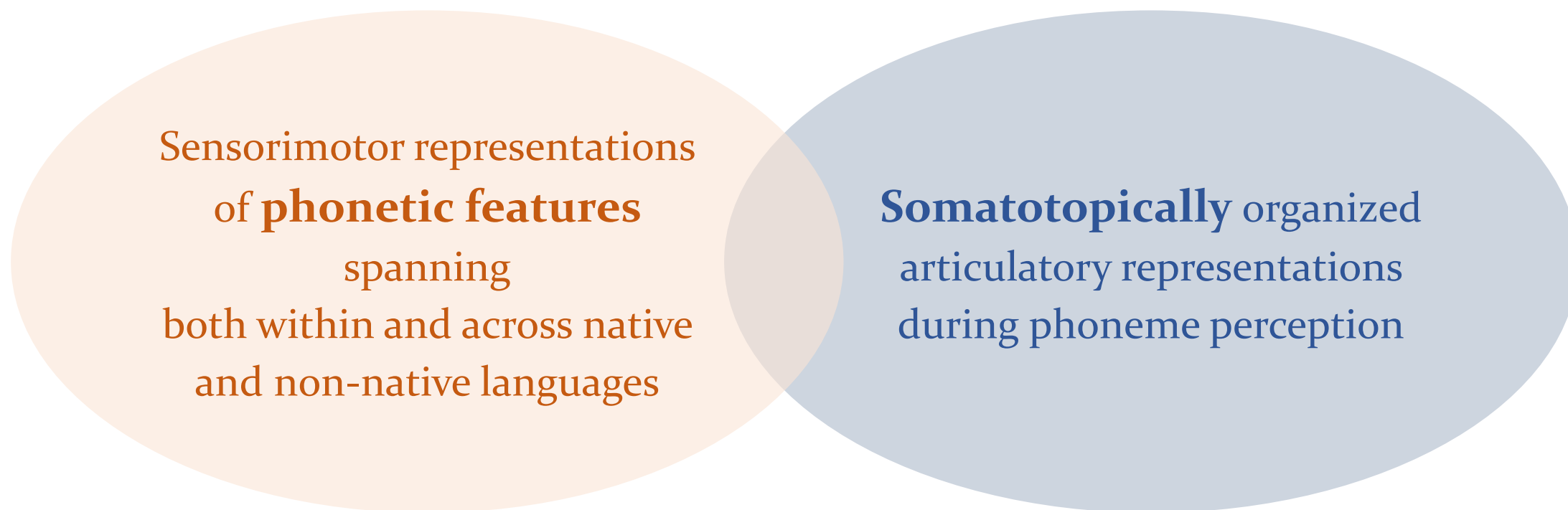


**Somatotopically organized motor patterns
in the right precentral gyrus
when perceiving degraded native phonemes**

- **Embodied articulatory representations in the motor cortex**
(Dmitrieva et al. 2024; Pulvermüller et al. 2006)
- **Enhanced motor activity under challenging perceptual conditions**
(Callan et al. 2010; Du et al. 2014; Evans & Davis 2015; Osnes et al. 2011)

Take-home messages on phonetic coding in sensorimotor regions

1. Are the phonetic features specifically encoded in the sensorimotor regions?
2. Are perceived phonemes somatotopically represented in the motor cortex?



underlying sensorimotor representations in phoneme perception

Thank you very much for your attention!