# Decision Strategies during Mandarin Tone Category Learning Relate to Different Networks of Emerging Representations

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## Introduction

### Non-native speech category learning + representations

- Learning to categorize speech sounds is critical for speech perception and communication.
- Speech category representations are robust in superior temporal gyrus (Chang et al., 2010; Mesgarani et al, 2014) and can emerge even in a single session of learning (Feng et al., 2019).
- Little is known about the nature of emerging neural representations during novel category learning.

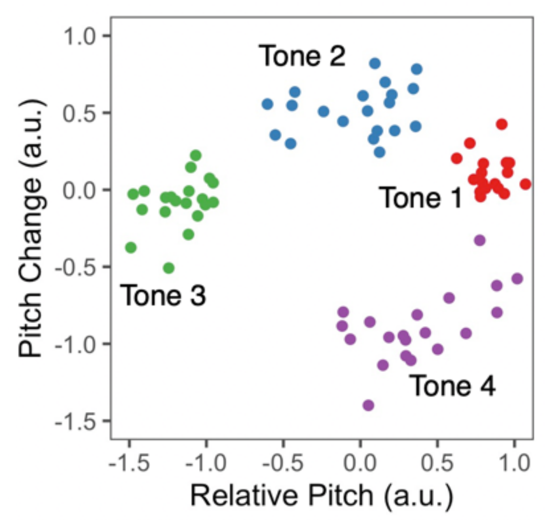
### Large individual differences in strategies and accuracy

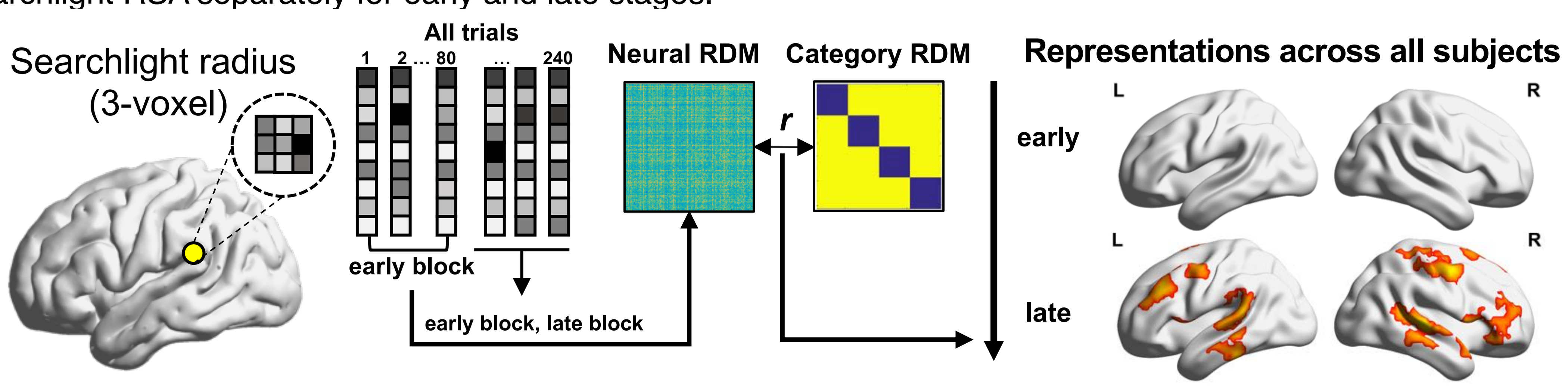
- Learners differ in category learning outcomes and the decision strategies they use during learning.
- Different decision strategies are linked to distinct cortico-striatal learning mechanisms that support learning (Ashby et al., 1998).

We compare how individuals learning the same non-native speech categories may recruit distinct representational networks based on the strategies they use.

## Methods

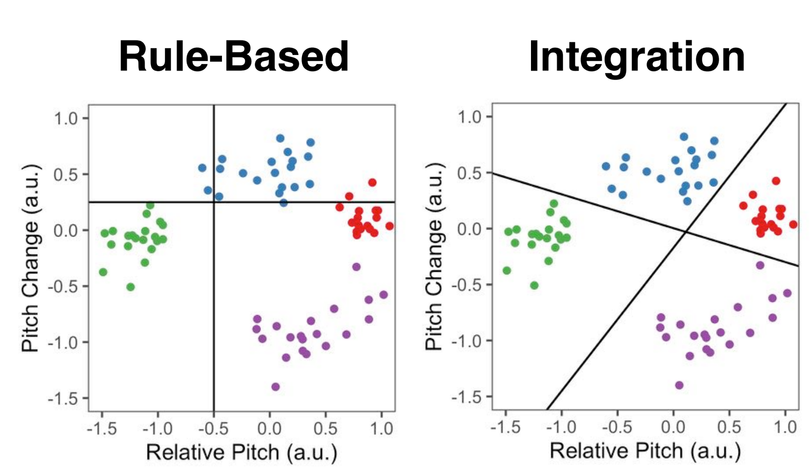
- 53 native English listeners from prior fMRI studies (Feng et al., 2019; Yi et al., 2016).
- Four Mandarin tone categories. 240 trials with feedback. Early stage: Trials 1-120, Late stage: Trials 121-240.
- 3T fMRI, T2*-weighted whole brain BOLD images during categorization. Preprocessed (SPM12) to correct for head movement, coregistered to the subject's anatomic T1 image, and standardized to MNI template using segmentation.
- Representational similarity analyses (RSA, Kriegeskorte et al., 2008): constructed representational dissimilarity matrix (RDM) for tone category and conducted whole-brain searchlight RSA separately for early and late stages.



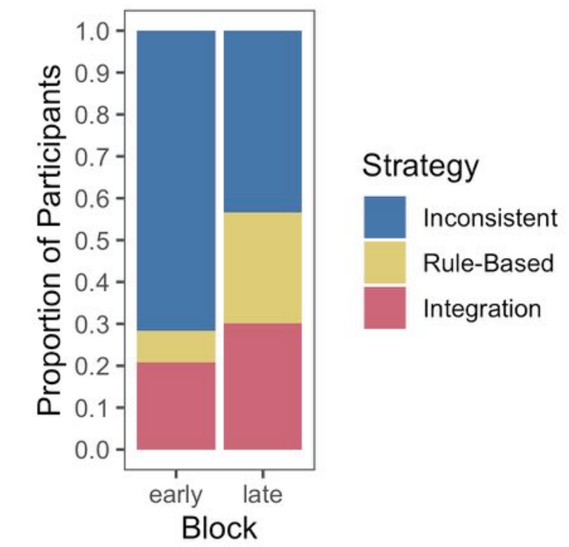

## Decision bound computational modeling

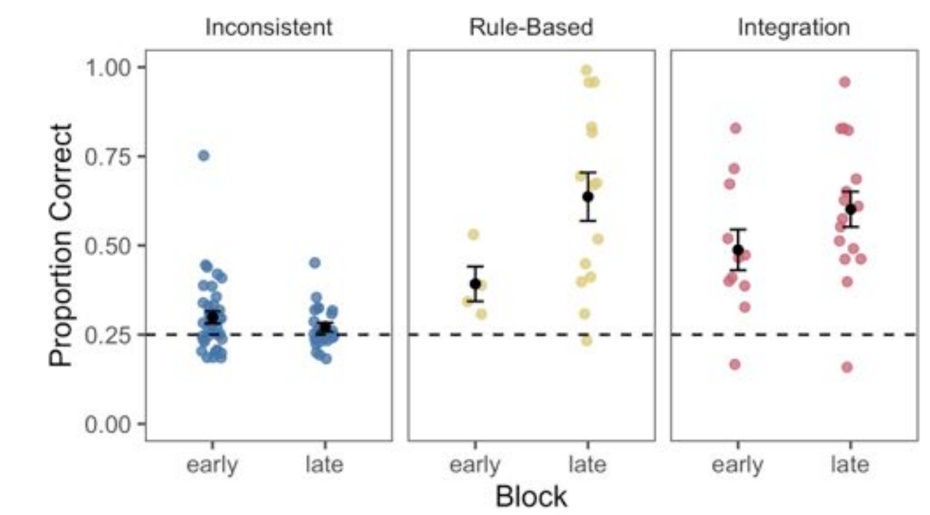
- Different decision strategies (Ashby, 1992; Maddox & Ashby, 1993) are linked to distinct cortico-striatal learning mechanisms:
  - **Rule-based strategies** rely on hypothesis testing and selective attention to dimensions and involves the head of the caudate in the striatum, frontal, and parietal regions. Boundaries are orthogonal to dimensions.
  - **Integration strategies** rely on procedural learning mechanisms and involves body and tail of the caudate in the striatum and the putamen. Thought to be optimal for learning Mandarin tone categories. Boundaries are not orthogonal to dimensions.
  - **Inconsistent strategies** reflect situations where participants may have been randomly guessing or inconsistently applying multiple strategy types.




## Decision strategies

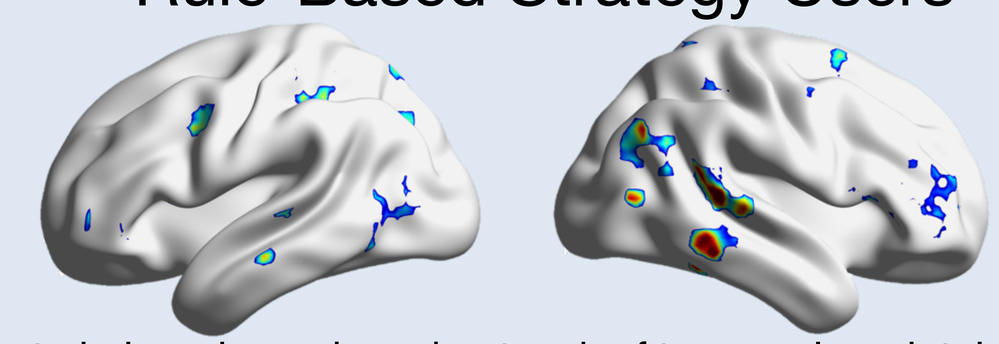
- Participants used a variety of strategies during learning and accuracy varied greatly across individuals.
- Rule-Based and Integration strategies were similarly effective in terms of accuracy (early: $t(10.7) = 1.27$, $p = 0.23$; late: $t(24.5) = 0.42$, $p = 0.68$).



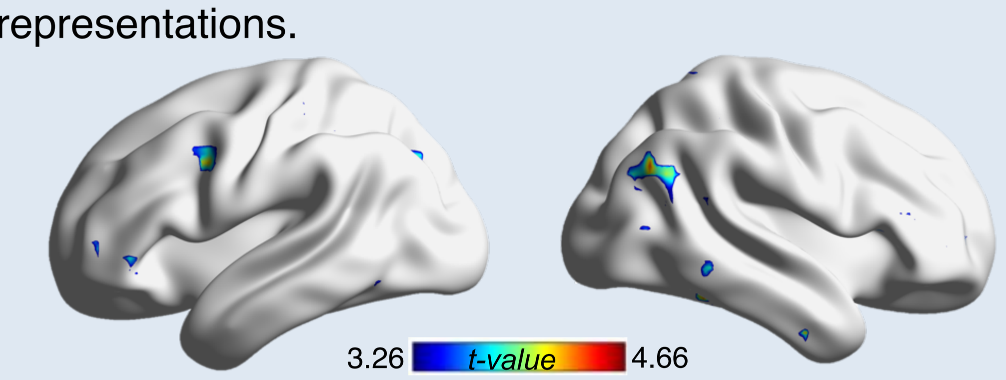




## Representational networks: preliminary evidence

### Rule-Based Strategy Users

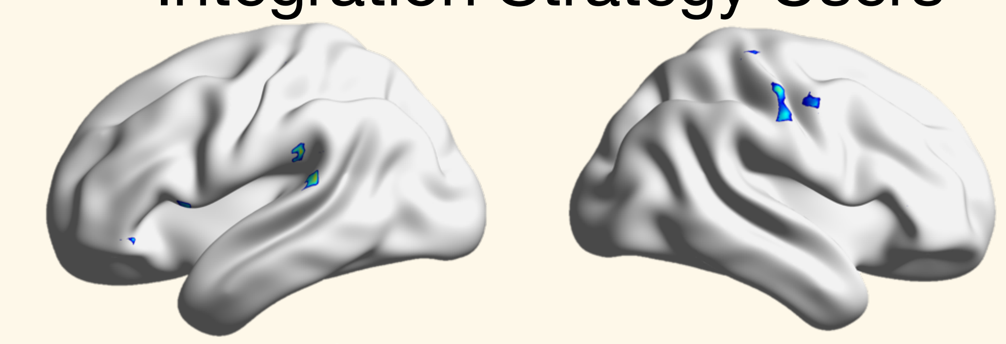


- Late in learning, a broad network of temporal, parietal, and frontal regions contributed to emerging tone category representations.

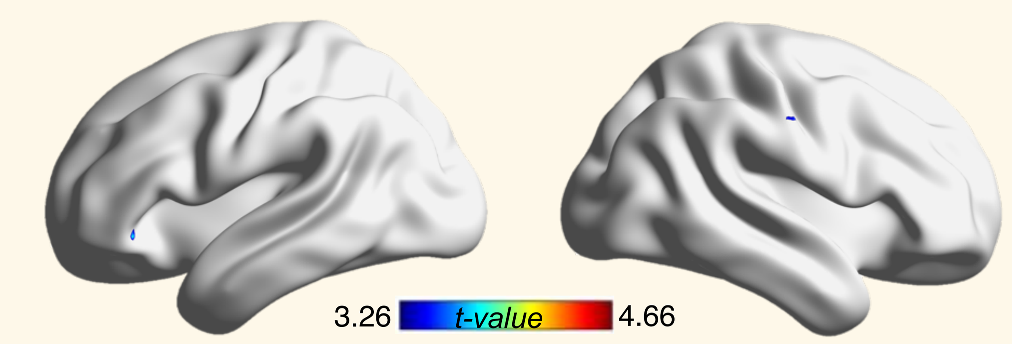



- Relative to Inconsistent strategy users, this rule-based network included angular gyrus, inferior frontal gyrus, precuneus, cingulate gyrus, and superior temporal gyrus.

### Integration Strategy Users



- Late in learning, focal representations in auditory-motor regions contributed to emerging representations.




- Relative to Inconsistent strategy users, this network was limited to left medial frontal gyrus.

- One-way ANOVAs comparing tone category RSA maps for learners using Rule-Based, Integration, and Inconsistent strategies, with individual comparisons between each strategy type and each strategy vs. chance, uncorrected, thresholded at $p < 0.001$.

## Conclusions

- Neural representations of novel speech categories emerged in distinct networks depending on the strategy participants used to distinguish the categories in the last half of learning.
- Results provide insights on the potential sources of emerging neural representation during speech category learning.

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