Absolute Pitch: Behavioral and MEG Experiments

Center for Language, Music, and Emotion
October 11, 2023
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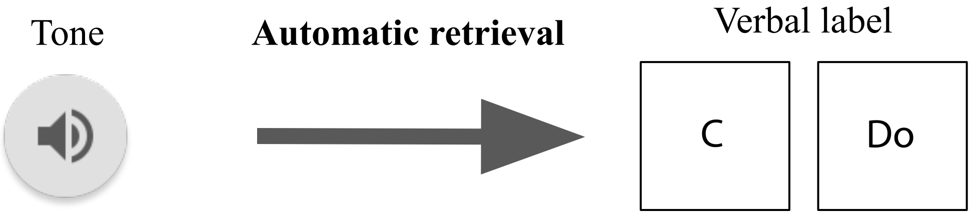
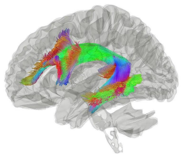
Introduction

Absolute pitch (AP) is a rare ability to identify and label categories of tones





Estimated to occur in less than 1% of the population

We design a set of behavioral and MEG experiments to validate the hypothesis of automatic labeling

AP Test

G	D	A
Sol	Re	La
391 Hz	**349 Hz**	**220 Hz**

Development of Absolute Pitch

Model for interaction between genes and environment (Zatorre, 2003; Levitin and Rogers, 2005)

Identical twins show higher concordance rate than non-identical twins (Theusch and Glitscher, 2011)

Training on ‘fixed-do’ system, Suzuki method, and tone language hypothesis (Baharloo, 1998)

1. Specify the computation, specify the training data
2. Make inferences about architecture sufficient to implement the computation
3. Developmental models of learning (overfitting to early training)

Neuroimaging for Absolute Pitch

Activity in dorsolateral prefrontal cortex (dlPFC) was found to be specifically engaged in the pitch label retrieval process (Leipold et al., 2019; Bermudez and Zatorre, 2005)

Long-range lateral connections in the left arcuate fasciculus facilitating automatic retrieval of phonetic representation accessed in anterior regions (Rogenmoser et al., 2021; Loui, 2011)

Increased phase synchronization in the left hemisphere during rest in AP (Elmer et al., 2015)

Upside: Long history of neuroimaging studies for musicians with AP

Downside: Results are strikingly unclear and sometimes conflicting

Opportunity: More accurately identify individuals with AP (specify the computation)

Hypotheses for Behavioral and MEG Studies

Hypothesis 1: Stroop Interference (Behavioral)

AP individuals will show increased RT on mismatch as compared to match trials in an audiovisual Stroop task

Hypothesis 2: ERP Difference (MEG)

This audiovisual interference in AP will be reflected in differences in ERP profiles across conditions

Conclusion: Automatic Identification and Retrieval of Verbal Labels

Measuring interference, we can more accurately identify individuals with AP

Can then build better models of the phenotype (learned associative mappings)

Hypothesis of Stroop Interference

Activation of a linguistic label (ie. C or *Do*) when hearing tones only in individuals with AP

Leads to audiovisual interference in mismatch trials of Stroop task only in AP individuals

Reflected in delayed RT for mismatch trials as compared to match trials

Measure of Interference: $log(\mu_{mismatch}) - log(\mu_{match})$

In AP individuals, there will be a difference.

In Non-AP individuals, there will be no difference.

Participant Recruitment

26 participants recruited and screened for musical training

NYU Sona System, Music and Audio Research Laboratory (MARL), Screen Scoring

Mean Age: 23.5

Year Started (Instrument): 9.3

Primary Instrument: Piano (14), Guitar (4), Violin (2)

Choice of Note Name: Letter (18) and Solfége (8)

AP Test

Task: Match the tone to the visual letter as fast and accurately as possible

Participants are presented with two conditions:

Match **Mismatch**

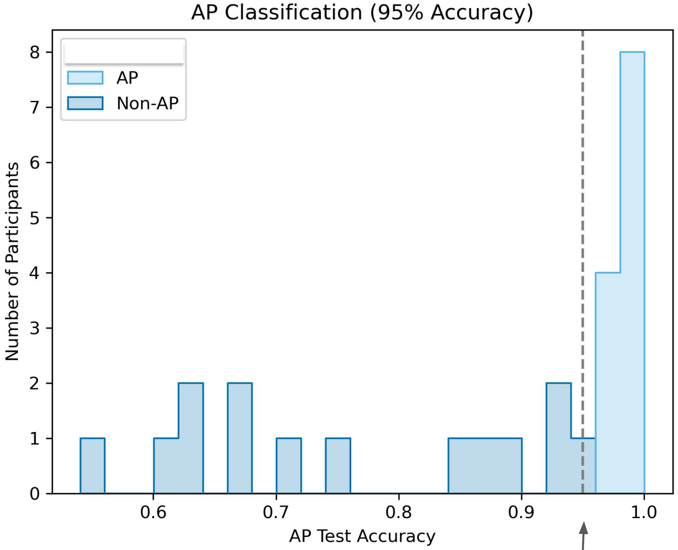
220 Hz 220 Hz

200 trials

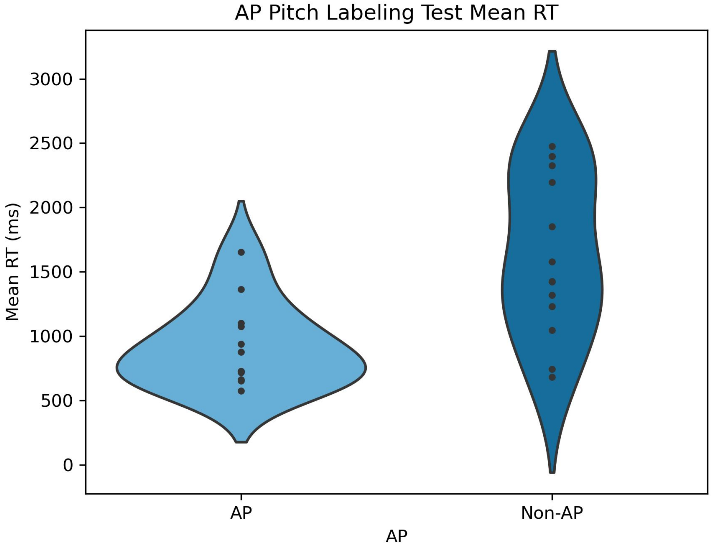
3000 ms presentation, 1600 - 2000 randomized ITI

Accuracy (% Correct) and Speed (RT) of pitch labeling response

AP Test Results



95% Accuracy Threshold



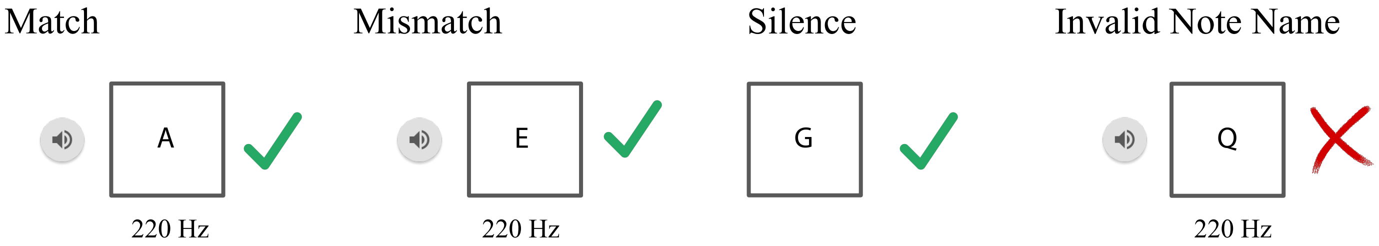
N = 12
920 ms

N = 14
1650 ms

Main Behavioral Task (Stroop)

Task: Indicate whether the visual note name is valid or invalid as fast and accurately as possible

Participants are presented with four conditions:



1000 trials (4 blocks)

3000 ms presentation, 1000 - 1600 randomized ITI

Stroop Interference: Difference between mismatch and match (no explicit task instruction to listen to tones)

Main Task Visual Stimuli

Valid Letter Names

A	B	C	D	F	E	G

Invalid Letter Names

V	X	Q	R	M	U	I

Main Task Visual Stimuli

Valid Syllable Names ✓

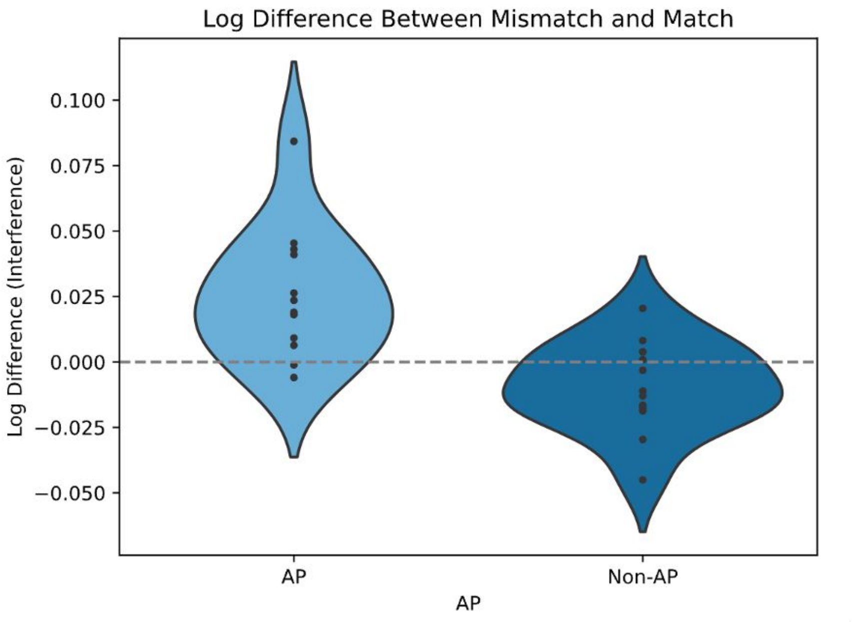
Do	Re	Mi	Fa	Sol	La	Si

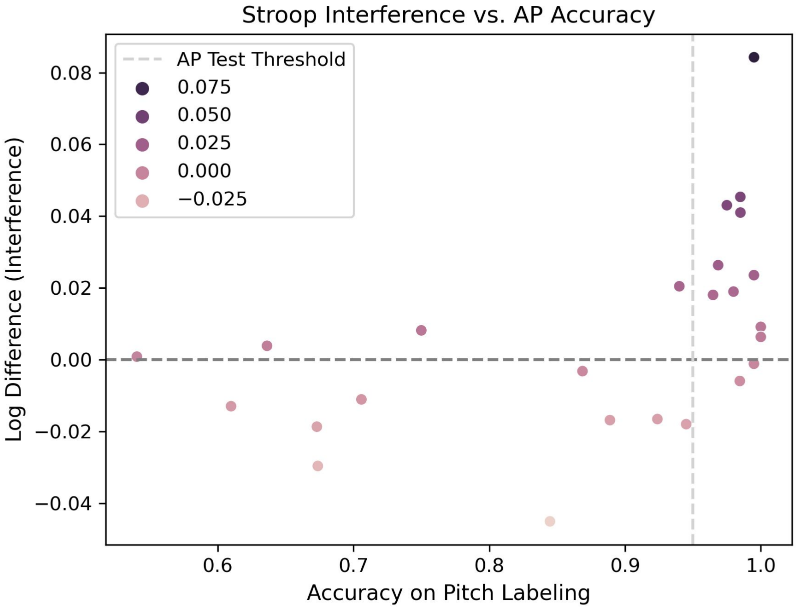
Invalid Syllable Names ✗

Ni	Pi	Ga	Pol	Vo	Ka	Je

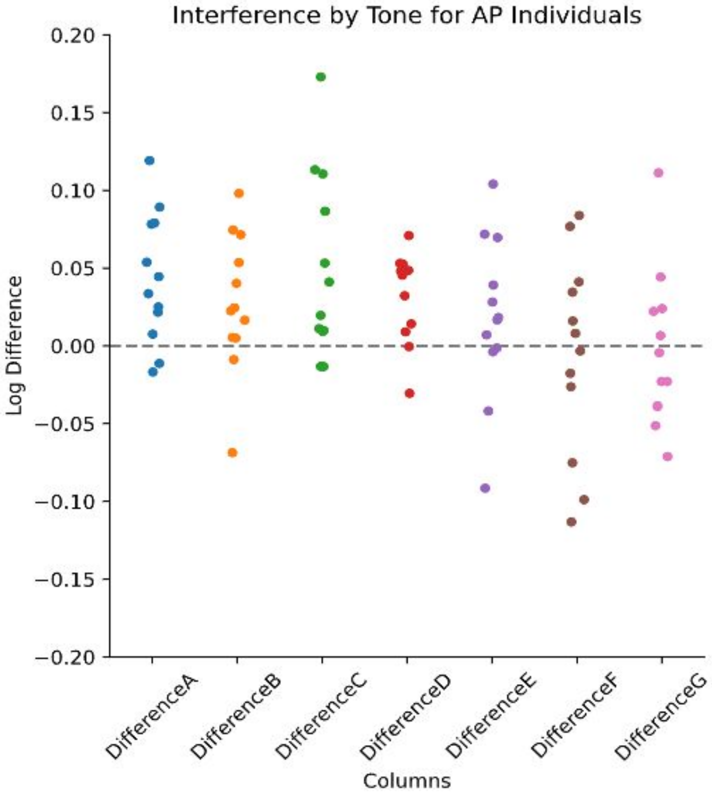
Stroop Interference

Measure of Interference: $log(\mu_{mismatch}) - log(\mu_{match})$





Stroop Interference for Each Tone



MEG Task Design

12 participants

Starting Age for Instrument: 8.70 years

Primary Instrument: Piano (10)

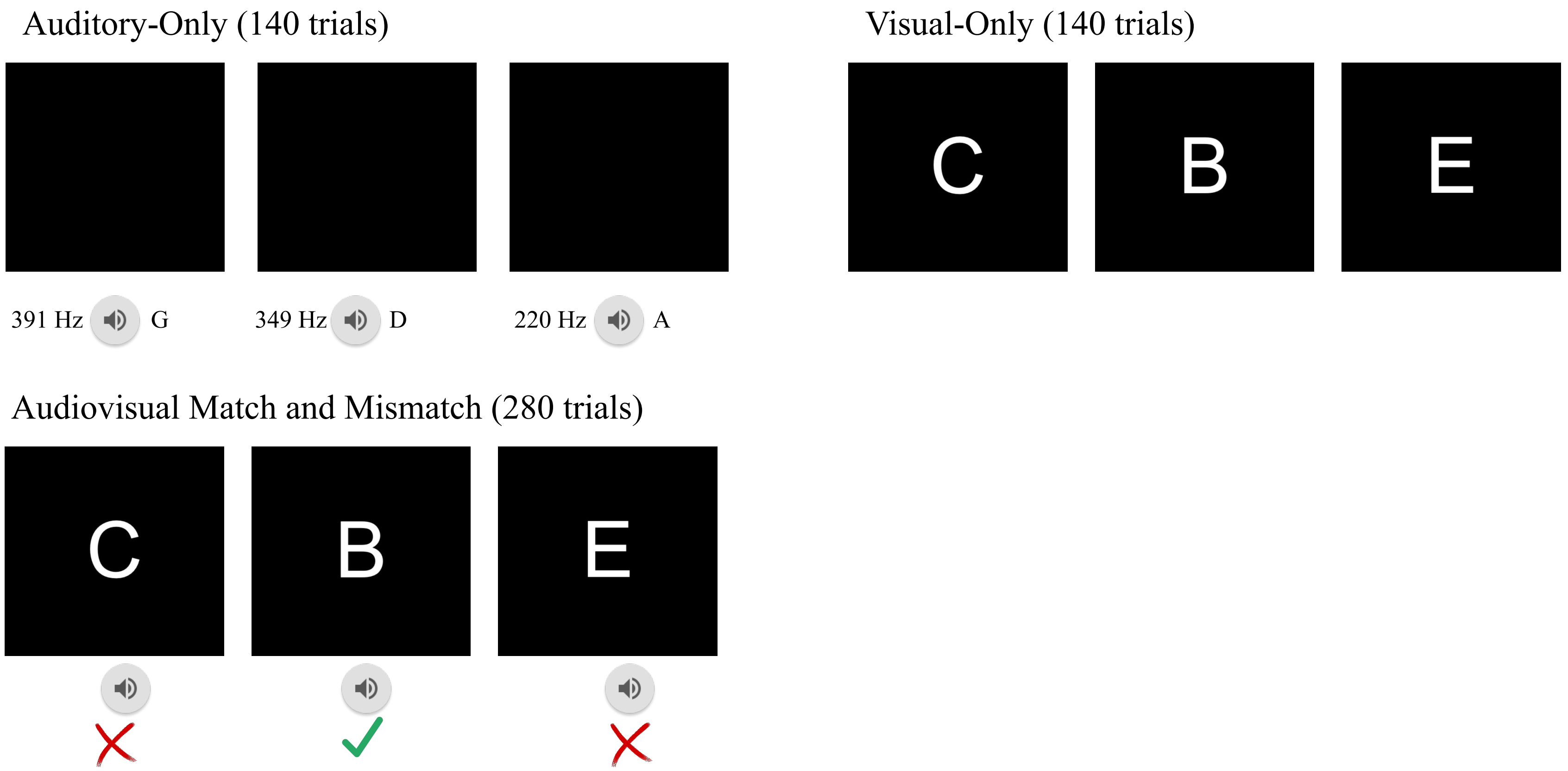
Choice of Note Names: Letters (6) and Solfége (6)

Three Blocks: Auditory-Only (140 trials), Visual-Only (140 trials), Audiovisual Mismatch and Match (280 trials)

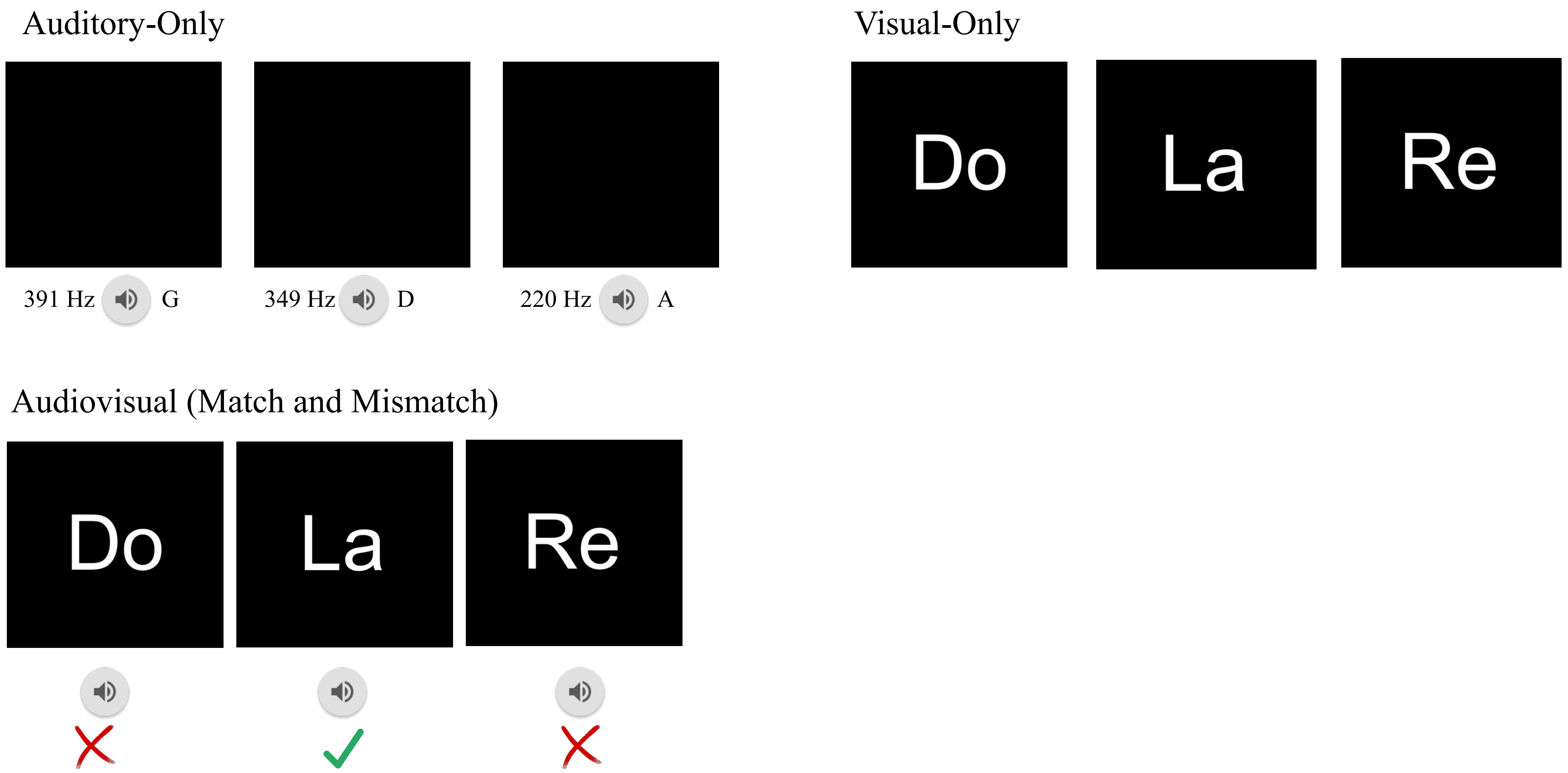
Stimulus presentation for 3000 ms and randomized ITIs from 0 to 400 ms drawn from random uniform distribution

Epochs spanning from 0 ms to 800 ms after stimulus onset

MEG Task Design

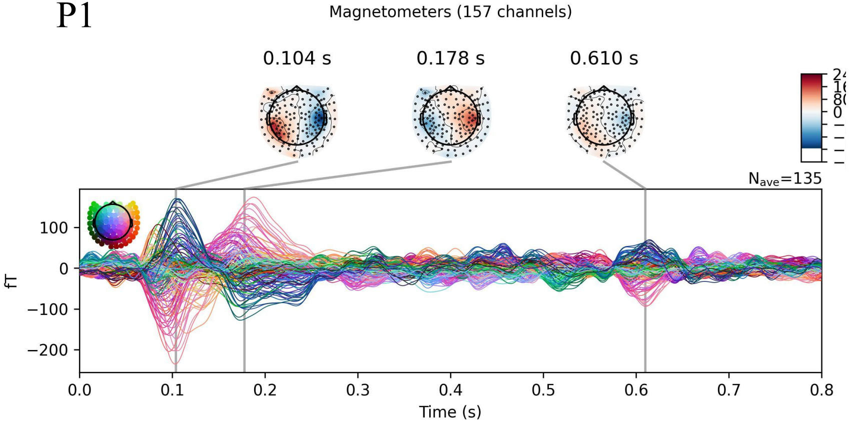


MEG Task Design

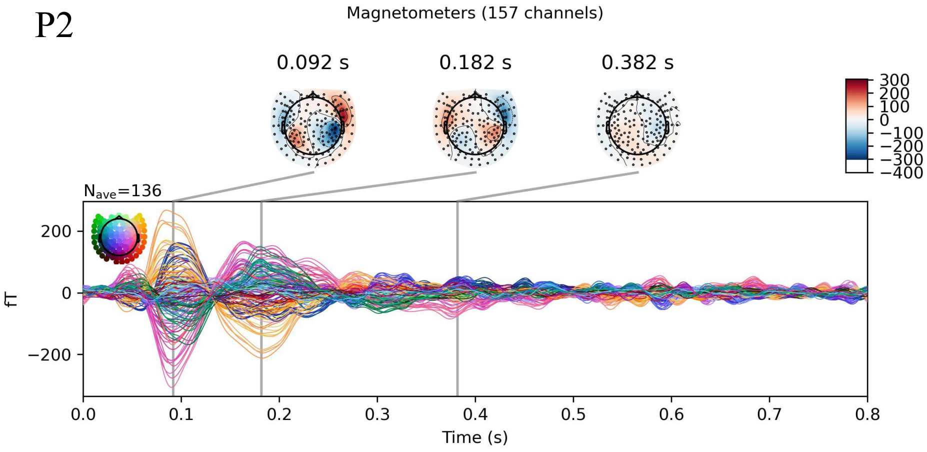


Auditory Evoked Potentials

P1



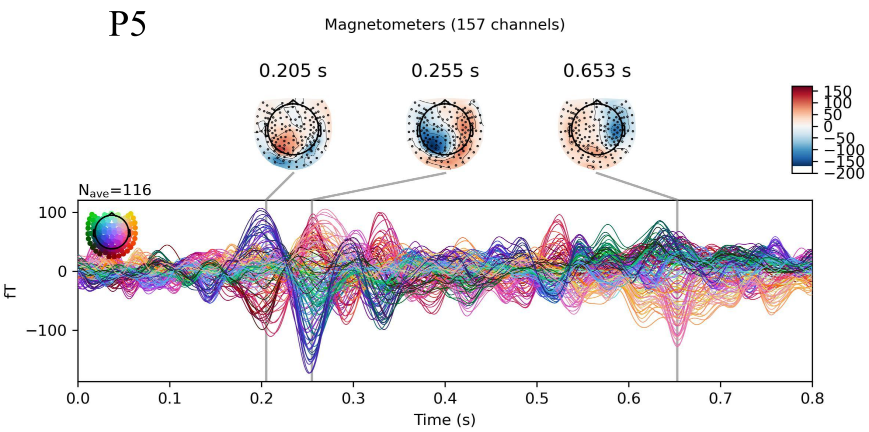
P2

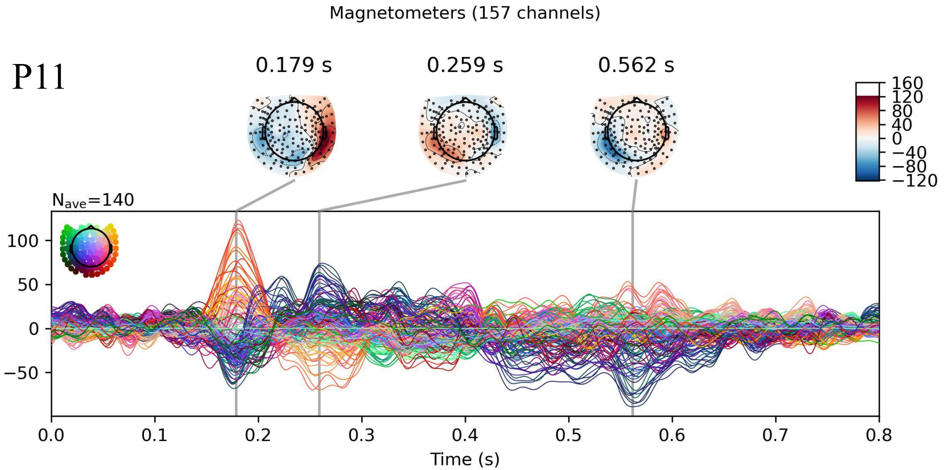


Typical auditory-evoked response profiles (~ 80 ms after stimulus onset)

140 tone categories (20 for each tone)

Visual Evoked Potentials





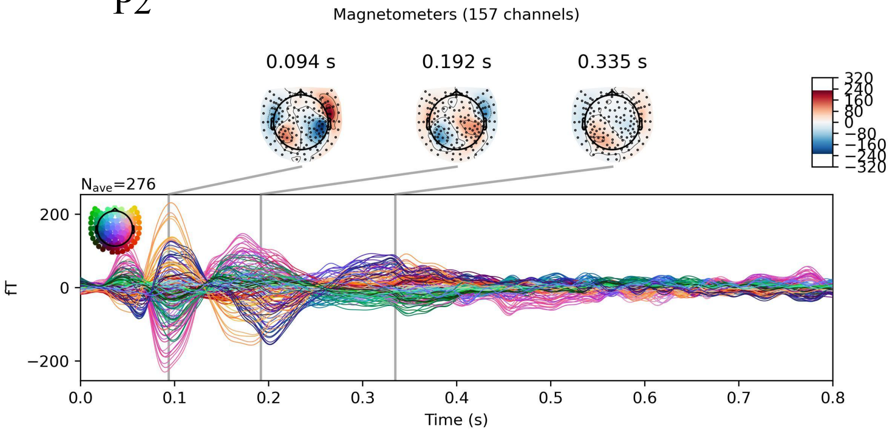
Typical visual-evoked response profiles (~ 180 ms after stimulus onset)

140 tone categories (20 for each tone)

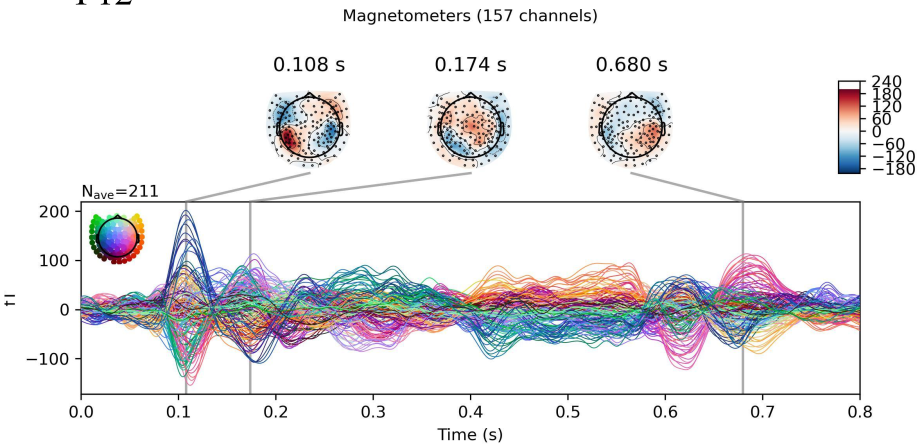
100 ms delay between auditory-evoked and visual-evoked to study interaction (AP McGurk)

Audiovisual Event Related Potentials

P2



P12

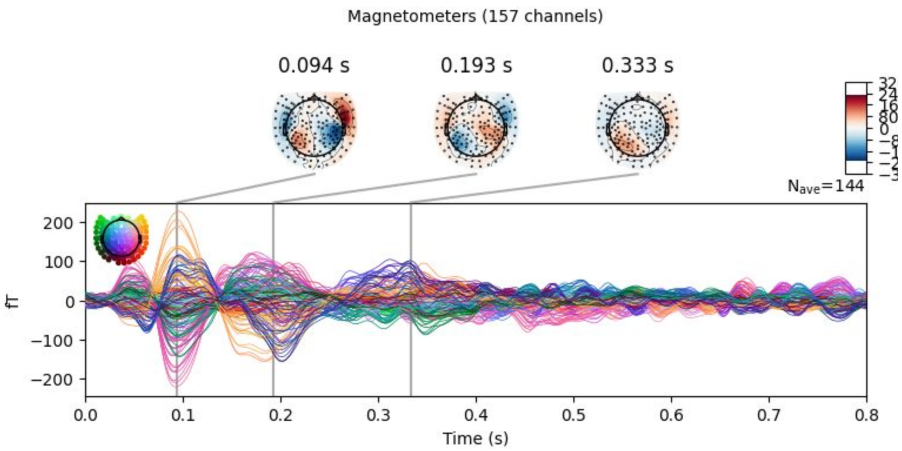


Typical audiovisual ERPs (both match and mismatch trials)

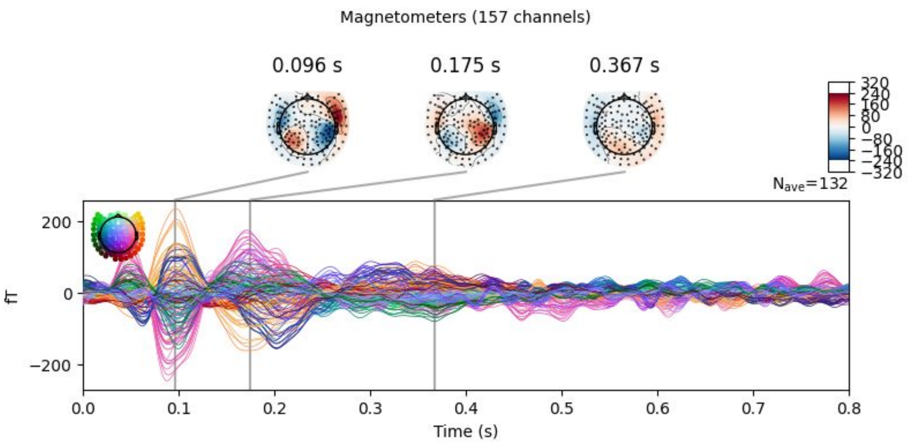
280 trials total (140 match + 140 mismatch)

Match and Mismatch Trials (Non-AP)

Match (P2)

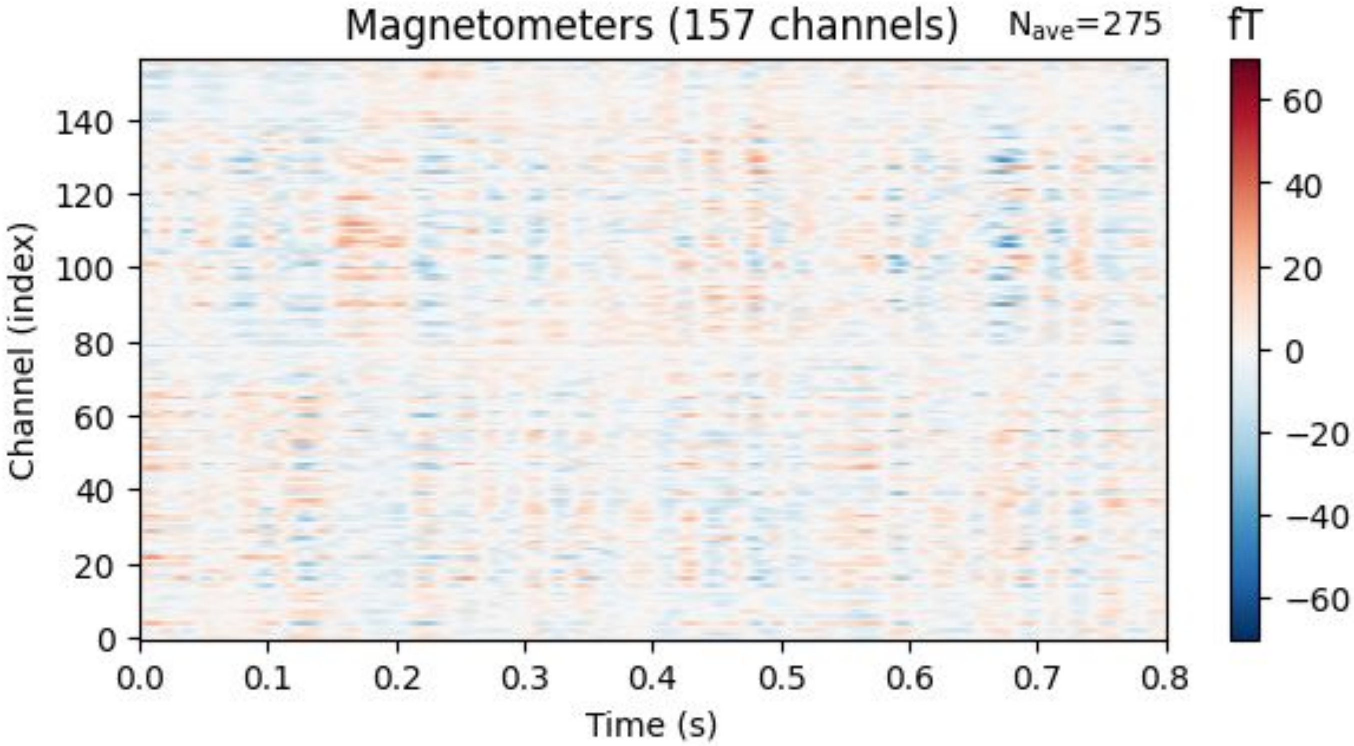


Mismatch (P2)



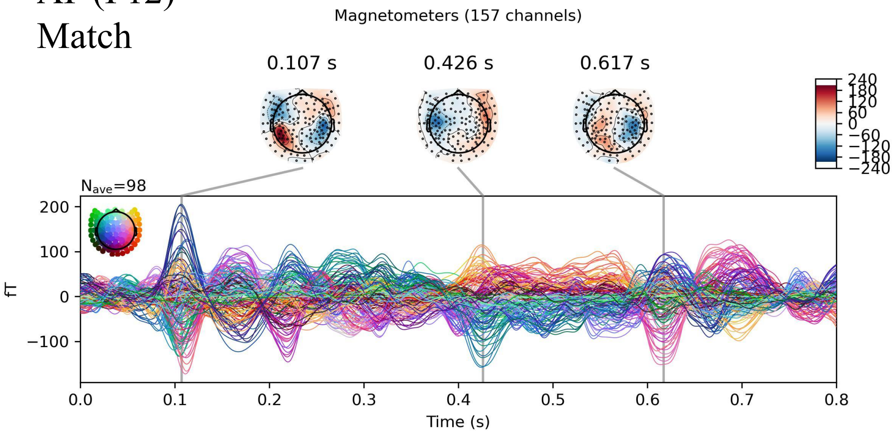
Subtract the difference in amplitude between mismatch and match ERPs

Difference Between Mismatch and Match (Non-AP)

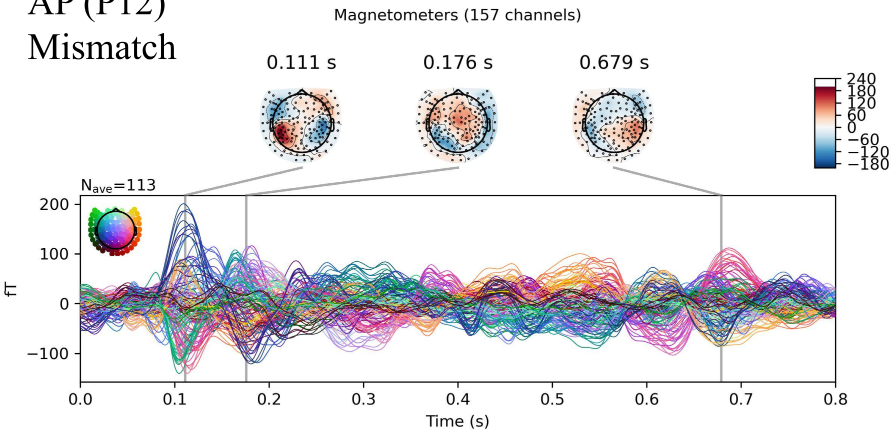


Match and Mismatch Trials (AP)

AP (P12)
Match

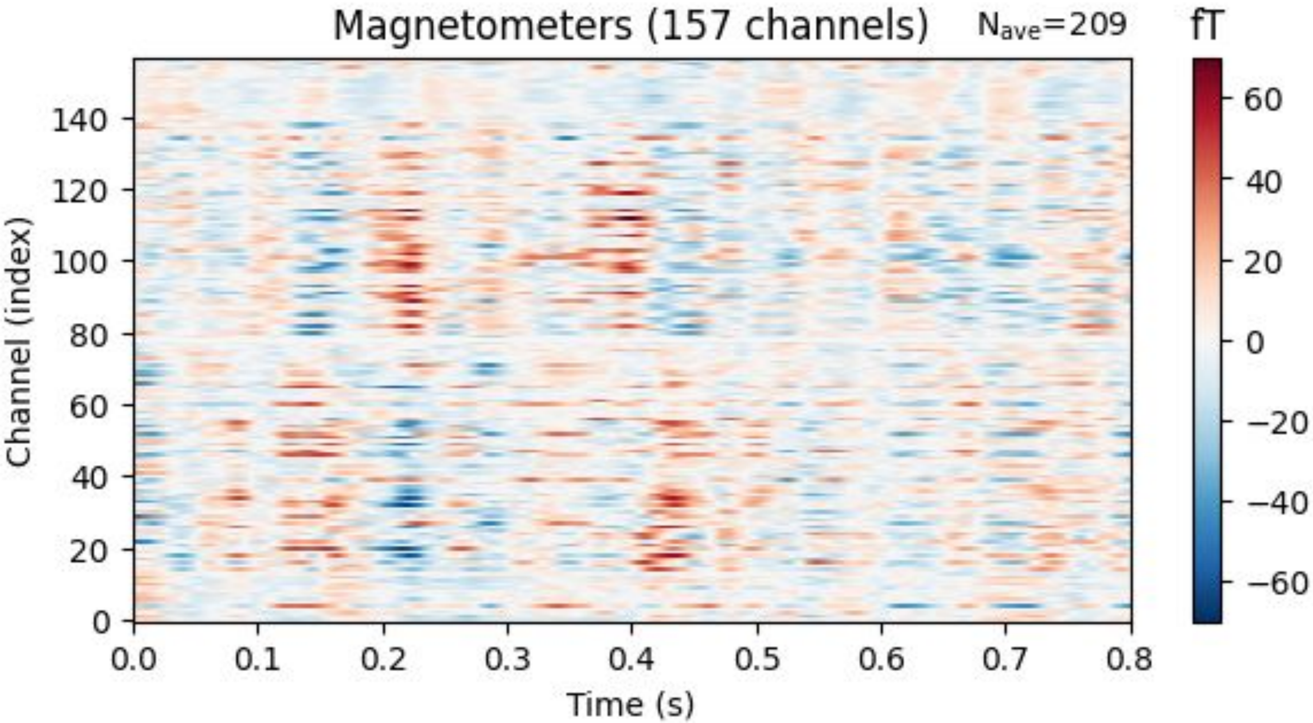


AP (P12)
Mismatch



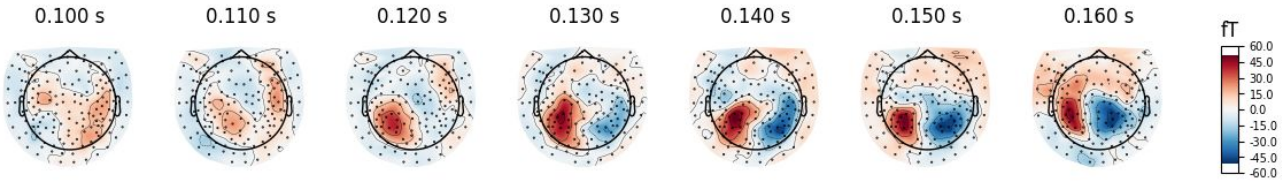
Subtract the difference in amplitude between mismatch and match ERPs

Difference Between Mismatch and Match

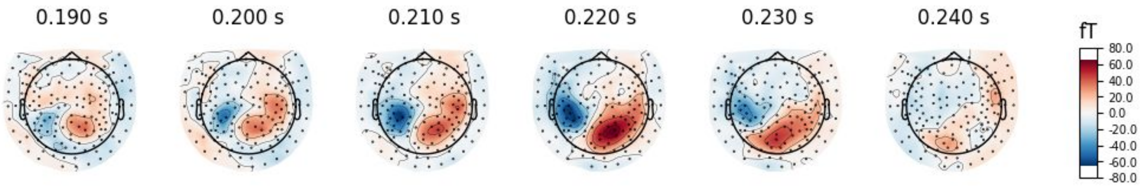


Time course and topography of interference

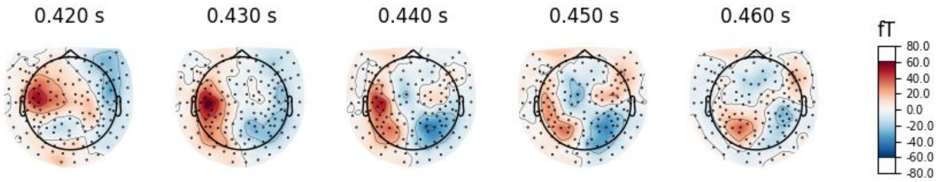
Difference in Auditory Window (100 ms - 160 ms)



Difference in Visual Window (190 ms - 240 ms)



Late Component Difference (420 ms - 460 ms)



Conclusion

1. Significant behavioral difference between AP and Non-AP in Stroop task interference
2. Audiovisual interference reflected in MEG signal without task instruction
3. Evidence for hypothesis of automatic retrieval of verbal labels in AP individuals hearing tones

Well-defined computational account of AP (automaticity of pitch labeling response)

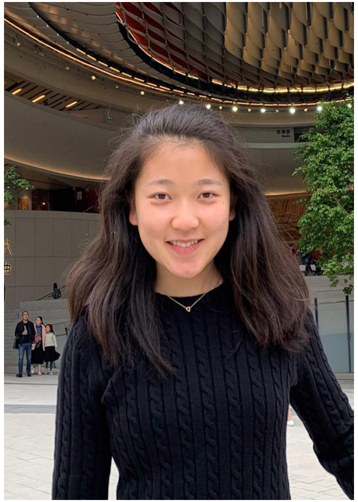
Stronger definition of phenotype may lead to higher replicability of results

Implications for neuroimaging studies and developmental models of learning

Team

Claire Pelofi

Emma Ning



David Poeppel

Jeff Walker

MEG Data Preprocessing

FastICA to isolate sources of non-neural activity (blinks, saccades, heartbeats)

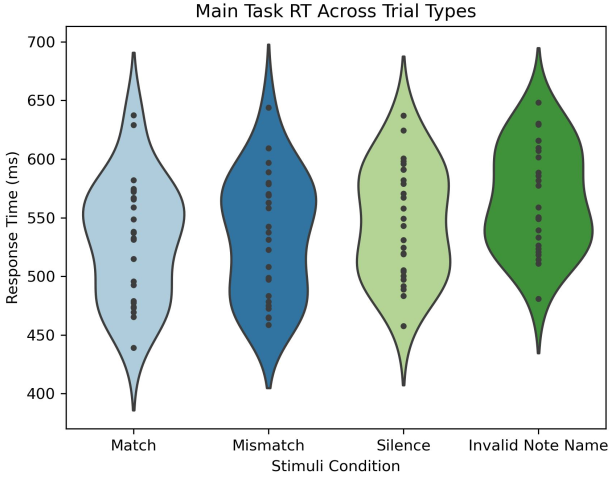
Epochs spanning from 0 ms to 800 ms after stimulus onset

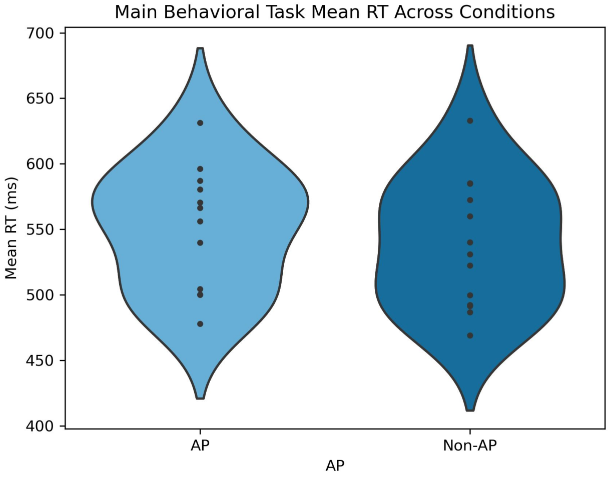
Stimulus presentation for 3000 ms and randomized ITIs from 0 to 400 ms drawn from random uniform distribution

Before preprocessing, we have 140 auditory, 140 visual, and 280 audiovisual trials

Averaged evoked responses give us matrices of 160 MEG channels x 801 timepoints

Main Task Results

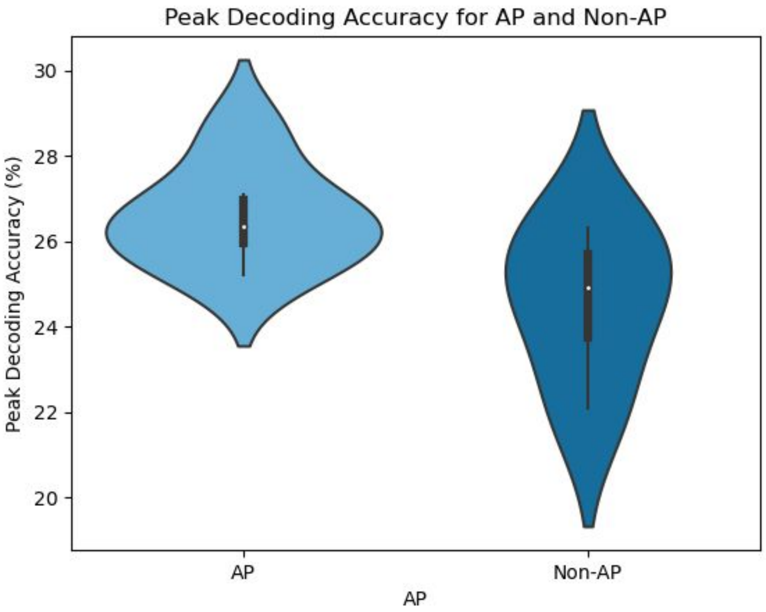




Main Task	AP	Non-AP	t-statistic	p-value
All Conditions	0.551	0.54	0.60	0.55
Match	0.535	0.53	0.26	0.7942
Mismatch	0.549	0.524	1.22	0.2355
Silence	0.551	0.543	0.39	0.6967
Invalid Name	0.571	0.562	0.47	0.63939

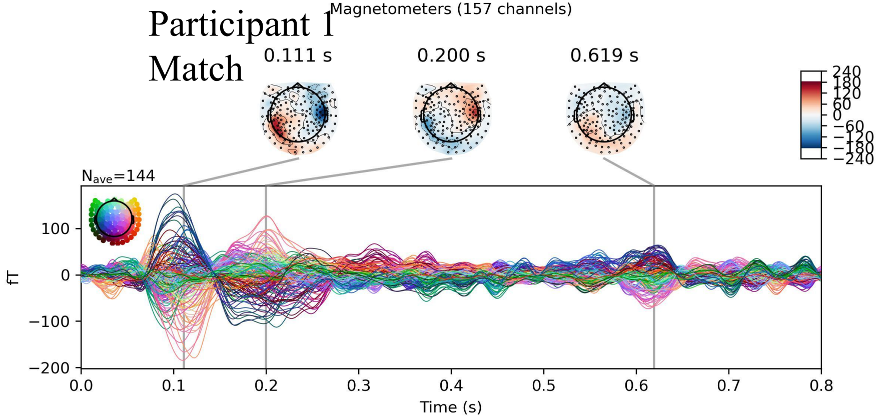
Auditory Decoding Accuracy

Participant	**AP**	**Peak Decoding Accuracy**
P02	Non-AP	22.1%
P04	**AP**	**27.1%**
P05	Non-AP	26.3%
P06	**AP**	**28.6%**
P07	Non-AP	24.3%
P08	**AP**	**25.9%**
P09	Non-AP	25.5%
P10	**AP**	**25.2%**
P11	**AP**	**26.6%**
P12	**AP**	**26.1%**

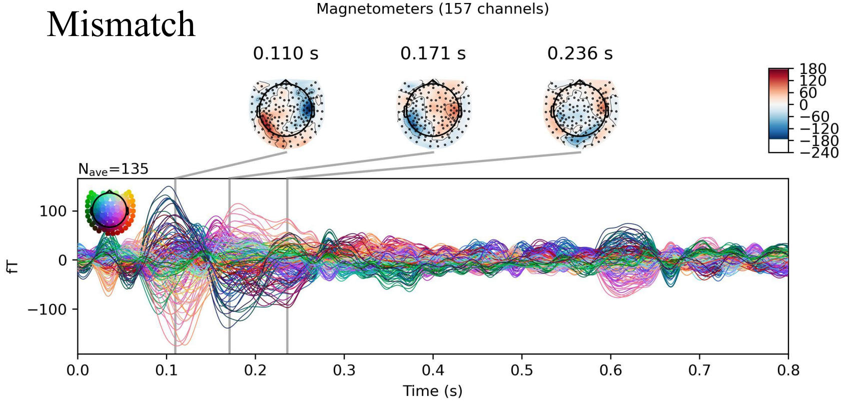


Match and Mismatch Trials

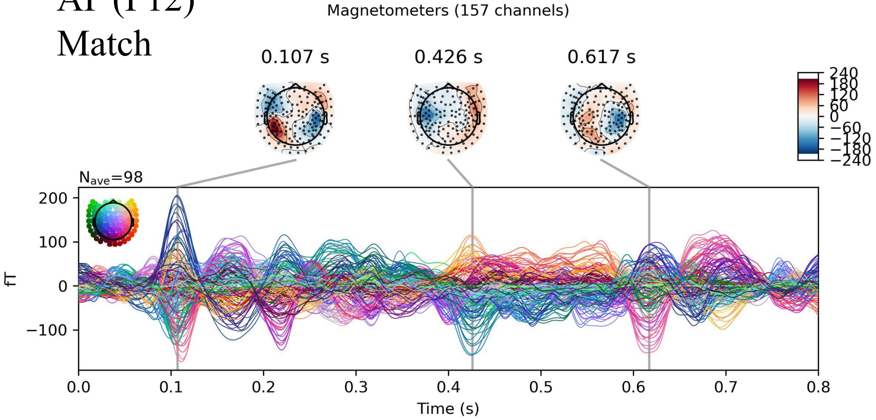
Participant 1
Match



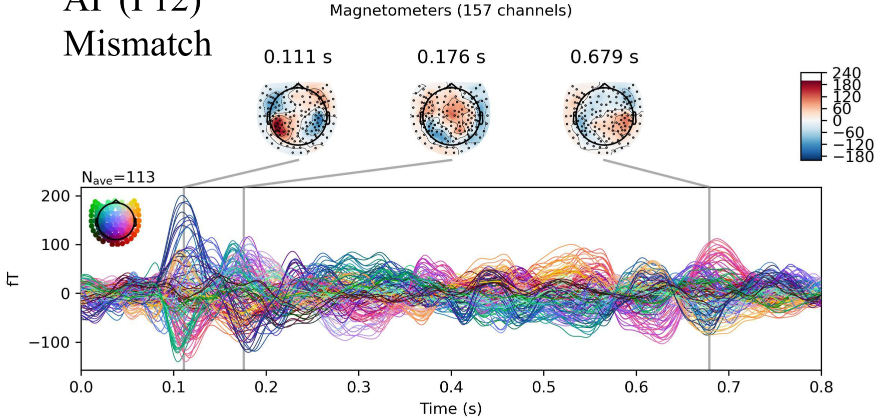
Participant 1
Mismatch



AP (P12)
Match



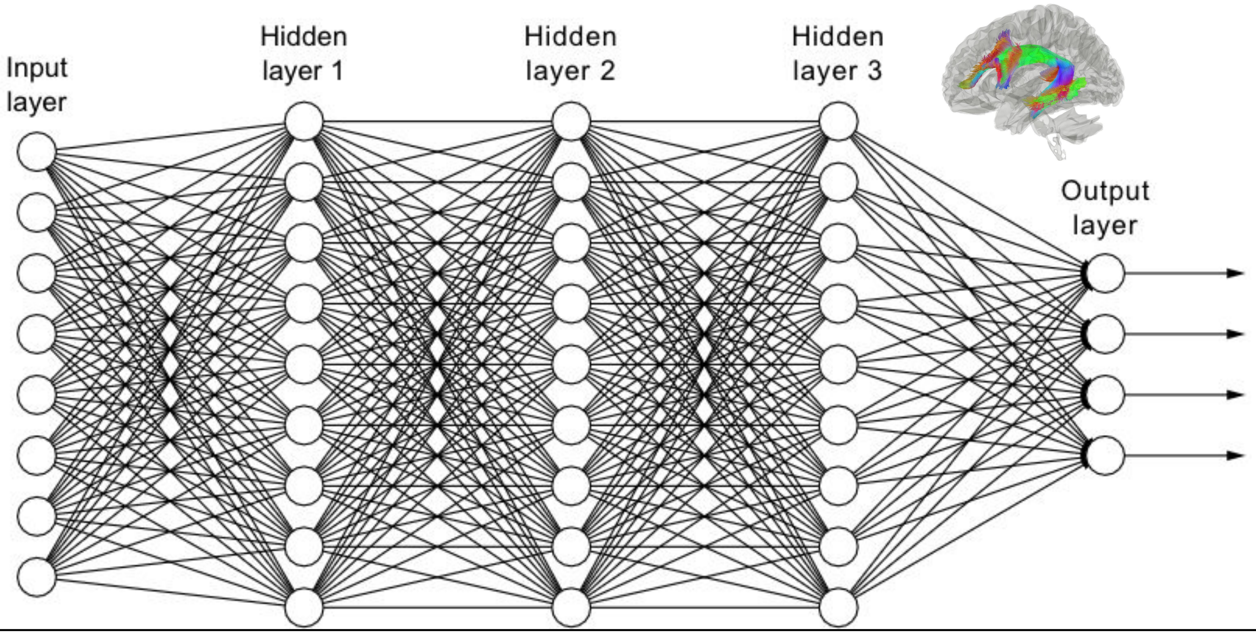
AP (P12)
Mismatch



Task-Optimized Network for Tone Recognition

Frequency Input

C0: 16 .35 Hz
C1: 32.7 Hz
C2: 65.41
C3: 130.81 Hz
C4: 261.63 Hz
C5: 523.25 Hz
C6: 1046.5 Hz
C7: 2093 Hz
C8: 4186 Hz



Label Output

C

Do

AP as a compelling benchmark for measuring manifold capacity for tone classification

Rarity of AP and auditory feature recognition tasks

Instance of overfitting to early training data

Invariant tone recognition has not been explicitly studied in context of AP

Neuroimaging for Absolute Pitch

Upside: Long history of neuroimaging studies involving AP

Downside: Results strikingly unclear and often conflicting

Opportunity 1: Build standardized stimuli, Python scripts, and performance criteria

Opportunity 2: More accurately identify individuals with AP (large-scale studies)

PsychoPy
Now running studies online

MNE
MEG + EEG ANALYSIS & VISUALIZATION

Upside: Long history of neuroimaging studies involving AP

Downside: Results strikingly unclear and often conflicting

Opportunity: More accurately identify individuals with AP (large-scale studies)

Automaticity in Pitch Labeling

Ambiguity about the nature of automaticity in the pitch labeling process (Greber et al., 2021)

To address this gap, we specifically probe the automaticity of response

Stroop Task

Build a computationally precise definition of the phenotype

To more accurately identify individuals with AP and the architecture necessary for this computation