Towards a Neural Measure of Perceptual Distance

Classification of Electroencephalographic Responses to Synthetic Vowels

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Overview

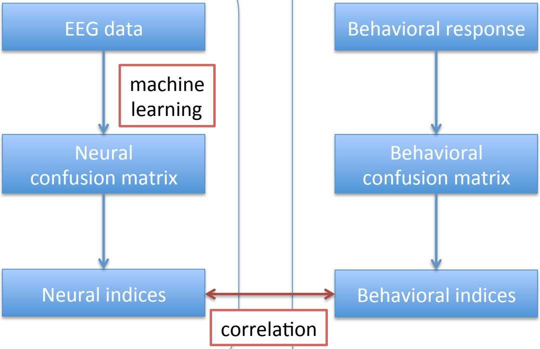
Q: Can we use EEG responses to predict the **perceptual distance** between two vowels?

EEG experiment

Behavioral experiment

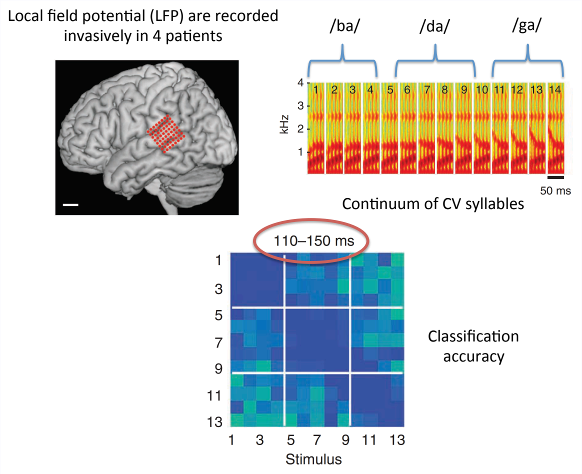
	[ɔ]	[ʌ]	[œ]	[ɛ]
[ɔ]		72	77	86
[ʌ]			66	83
[œ]				76
[ɛ]				

	[ɔ]	[ʌ]	[œ]	[ɛ]
[ɔ]		1.2	1.5	2.3
[ʌ]			0.9	2.0
[œ]				1.5
[ɛ]				



Literature Review: Chang et al. (2010, Nat. Neurosci.)

Timing for consonant discrimination



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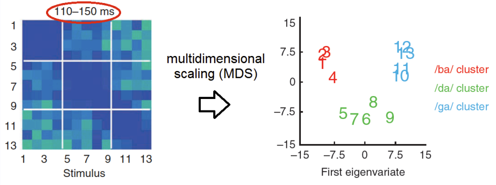
Brain–behavior correspondance

- Multidimensional scaling (MDS) is applied:



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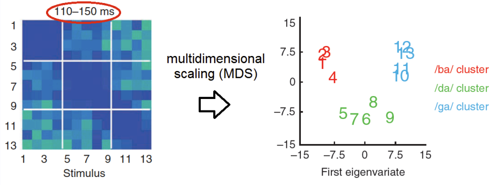
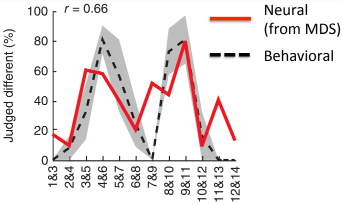


- Distance within the reconstructed MDS space correlates strongly with % of different responses in a same–different judgment task.



The present study

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    - Chang et al. (2010) localize the timing of consonant discrimination to be between 110–150 ms.
    - EEG: Only Wang et al. (2012) have attempted to optimize the parameters for consonant discrimination:
        - Features: DFT phase information between 2-9 Hz.
        - Best analysis window: 0-760 ms.

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2. **[Correlation]** Is the discriminability of EEG responses correlated with behavioral performance?

Methodology

Subjects

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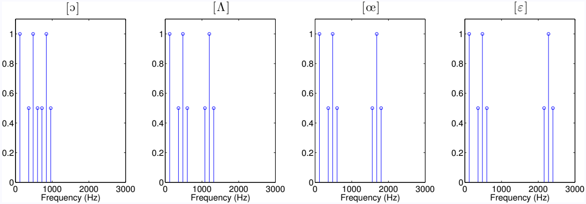
Stimuli

- 4 synthetic mid-vowels differing only in second formant frequency (F2)



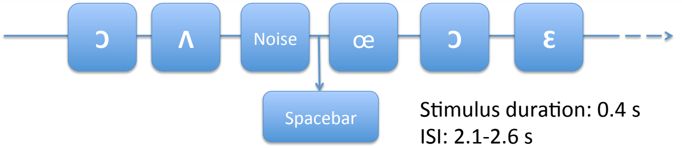
c.f. (Hose et al., 1983; Ohl and Scheich, 1997)

- [ɔ], [œ], [ɛ] present in native Cantonese;
- [ʌ] closest to a vowel in non-native Mandarin.

Methodology

Stimulus presentation procedure

- **Task**: Respond only to the noise stimuli by pressing the space bar on a standard computer keyboard.



- Each subject attends 4 EEG sessions. In each session:
  - Critical stimuli: The 4 vowels (each x 240).
  - Fillers: Noise stimulus (x 120).

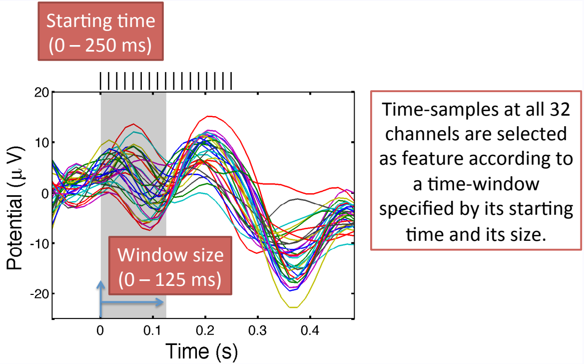
EEG data acquisition

- A 32-channel Biosemi Active 2 EEG system.

Data analysis

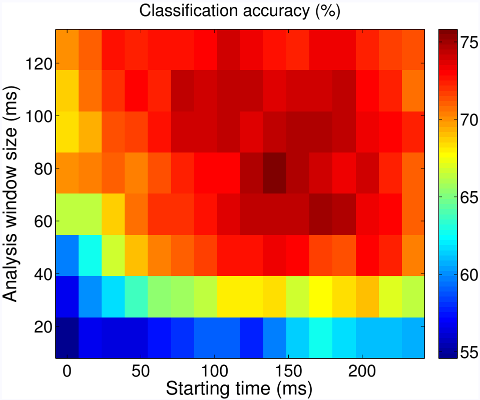
Classification

- Linear discriminant analysis (LDA) is used to classify every vowel-pair.
- Classification accuracy was assessed using test samples formed from 20 successive trials of each class.
- Feature selection:



Results: on the timing issue

Binary classification accuracy



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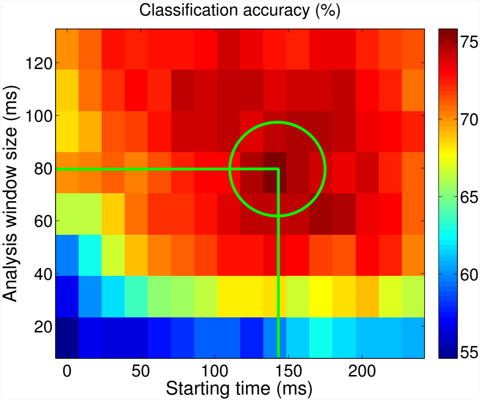

Best analysis window:
140-220 ms

Results: on correlation

Neural discriminability indices

Binary classification rate (%)

	[ɔ]	[ʌ]	[œ]	[ɛ]
[ɔ]		72	77	86
[ʌ]			66	83
[œ]				76
[ɛ]				

Signal detection Theory →

Neural discriminability indices (d' scores)

	[ɔ]	[ʌ]	[œ]	[ɛ]
[ɔ]		1.16	1.54	2.33
[ʌ]			0.87	2.04
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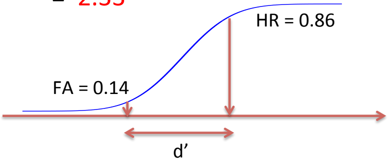
E.g., for [œ]–[ɛ]:

	[œ]	[ɛ]
[œ]	86	14
[ɛ]	14	86

Confusion matrix

d' = z (hit rate) – z (false alarm)
= 2.33



Results: on correlation

Behavioral discriminability indices

Behavioral data

	Natural			
Synthetic	**[ɔ]**	**[ʌ]**	**[œ]**	**[ɛ]**
[ɔ]	99	97	100	99
[ʌ]	99	91	61	98
[œ]	100	59	82	93
[ɛ]	100	97	84	99

(purple) % judged the same

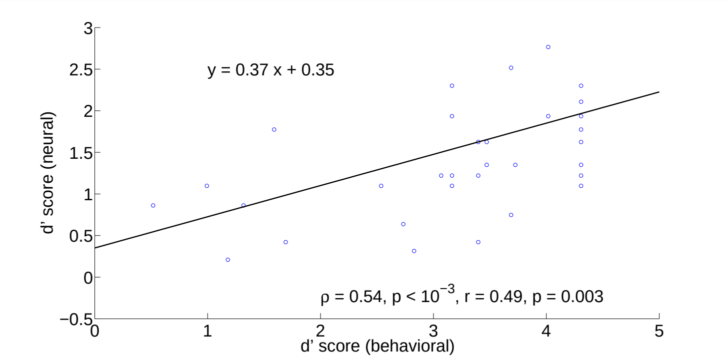
(green) % judged different

Behavioral discriminability indices (d' scores)

	[ɔ]	[ʌ]	[œ]	[ɛ]
[ɔ]		3.61	3.68	4.16
[ʌ]			1.47	3.59
[œ]				3.06
[ɛ]				

Results: on correlation

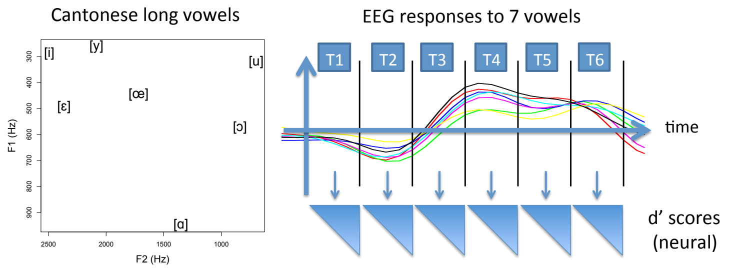
Brain–behavior correspondence



Behavioral performance is significantly correlated with classification performance.

Discussion

What can we achieve with this framework?



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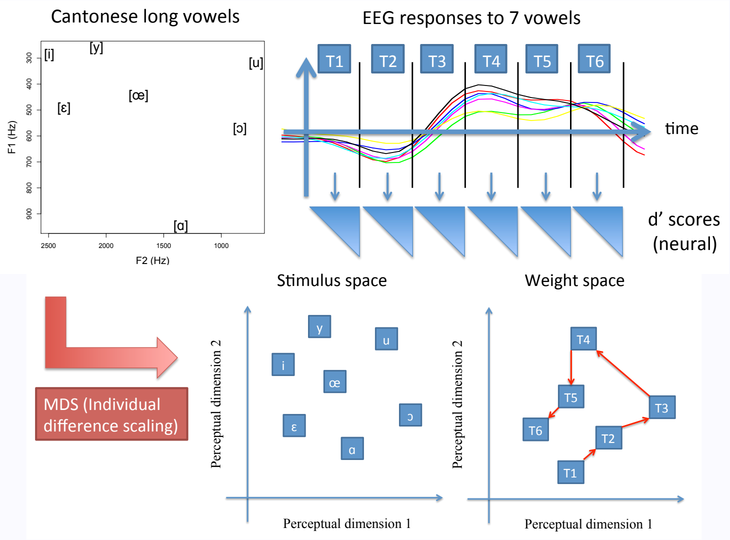

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1. The time window most critical for steady vowel discrimination was determined to be 140-220 ms.
2. Perceptual similarity between vowels can be inferred using EEG features, supporting the intuitive idea that vowels that are behaviorally more distinct evoke brain activities that are more distinct.
3. We are now working on extending this line of research to the full set of 7 Cantonese long vowels. When fully extended, we expect that the work presented here will shed light on the temporal dynamics in processing the different perceptual dimensions important for vowel perception.

References

Chang, Edward F et al. (2010). "Categorical speech representation in human superior temporal gyrus". *Nature neuroscience* 13.11, pp. 1428–1432.

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