Individual differences in phoneme categorization

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19th Mid-Continental Phonetics & Phonology Conference
The problem of lack of invariance

- There is no one-to-one relation between a sound (i.e. formant frequencies) and the perceived phoneme

Hillenbrand, Getty, Clark & Wheeler, 1995
The problem of lack of invariance

• There is no one-to-one relation between a sound (i.e. formant frequencies) and the perceived phoneme

• One solution: *categorical perception*
The problem of lack of invariance

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The problem of lack of invariance

• There is no one-to-one relation between a sound (i.e. formant frequencies) and the perceived phoneme

• One solution: categorical perception
  + Simple solution
  + Fast commitment
Two alternative forced choice (2AFC)

Werker & Tees, 1987; Joanisse et al, 2000; López-Zamora et al, 2010
The problem of lack of invariance

- There is no one-to-one relation between a sound (i.e. formant transitions) and the perceived phoneme
- One solution: **categorical perception**
  + Simple solution
  + Fast commitment
- Alternative: **gradient perception**
The problem of lack of invariance

• There is no one-to-one relation between a sound (i.e. formant transitions) and the perceived phoneme

• One solution: categorical perception
  + Simple solution
  + Fast commitment

• Alternative: gradient perception
  + Flexibility
  + Late commitment
  + Keep useful within-category information
Gradiency in speech perception

• Evidence for gradiency from eye-movements

McMurray, Tanenhaus & Aslin (2002)
Two alternative forced choice (2AFC)

- Is gradiency **good** or **bad** for speech perception?
Gradiency in speech perception

- Measuring gradiency: Visual analog scaling (VAS) task
Gradiency in speech perception

Gradiency in speech perception

Summary and aims

• Summary points:
  • Listeners are capable of gradient categorization of phonemes
  • The VAS task allows for this gradiency to be expressed in participants’ responses
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- Where does gradiency come from? Is it good or bad for speech perception?
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  • Listeners are capable of *gradient* categorization of phonemes
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• Where does gradiency come from? Is it good or bad for speech perception?
  • Establish a way of *quantifying gradiency* via the VAS task
Summary and aims

• Summary points:
  • Listeners are capable of gradient categorization of phonemes
  • The VAS task allows for this gradiency to be expressed in participants’ responses

• Where does gradiency come from? Is it good or bad for speech perception?
  • Establish a way of quantifying gradiency via the VAS task
    1. Investigate possible sources of gradiency (e.g. executive function)
    2. Link gradiency to multiple cue use
    3. Examine whether gradiency is good or bad for speech perception
Method

• Stimuli:

<table>
<thead>
<tr>
<th></th>
<th>labial</th>
<th>alveolar</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Real words</strong></td>
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• Seven (7) VOT steps (primary cue) and five (5) F0 steps (secondary cue)
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  - Seven (7) VOT steps (primary cue) and five (5) F0 steps (secondary cue)

- Tasks:
  - Visual analog scaling (VAS) task
  - Two alternative forced choice (2AFC)
Method

• Additional tasks:
  • Trail making task (cognitive flexibility)
  • N-Back task (working memory)
  • Flanker task (inhibition)

\[\text{non-speech cognitive processes}\]
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- Participants: 130 undergraduates at the U of Iowa
Results
Results

Sub 8

Sub 7

Sub 9

Sub 68
Results: Quantifying gradiency
Results: Quantifying gradiency

- Extracting gradiency from VAS data
Results: Quantifying gradiency

- Extracting gradiency from VAS data

Steep s slope

Shallow s slope
Results: Quantifying secondary cue use

- Extracting F0 use from 2AFC data
Results
Results: Stimulus and place effects

[Graphs showing VAS and 2AFC responses for different stimuli and place effects.]
Results: Stimulus and place effects

![Graphs showing results for different stimuli and place effects.](image)
Results: Place differences in F0 use

$F(1, 250) = 27.8, p < 0.001$
Results

1. Do individual differences in gradiency derive from differences in general cognitive function?
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- EF measures did not account for a statistically significant amount of variance in VAS slope, $F(3,108)=1.75$, $p=.162$, or F0 use, $F<0$. 

\[\text{gradient} \quad \text{Working memory by gradient} \]

\[\text{gradient} \quad \text{Executive function by gradient} \]

\[\text{gradient} \quad \text{Inhibition by gradient} \]
Results

1. Do individual differences in gradiency derive from differences in general cognitive function?

   - EF measures did not account for a statistically significant amount of variance in VAS slope, $F(3,108)=1.75$, $p=.162$, or F0 use, $F<0$

   - Speech perception processes may be played out on a different level of processing than higher cognitive processes, such as working memory
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1. Do individual differences in gradiency derive from differences in general cognitive function?

2. Are individual differences in gradiency linked to multiple cue use?
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2. Are individual differences in gradiency linked to multiple cue use?

   - **Positive relationship**: Better encoding of fine-grained detail (more gradiency) enables access to multiple cues

   - **Negative relationship**: Listeners who use more cues have more accurate, sharper boundaries
Results

\[ \beta = -0.305, \ t = -3.4, \ p < 0.01 \]
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1. Do individual differences in gradiency derive from differences in general cognitive function?

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3. In what way are these differences important for speech perception?
Results

- Gradiency and perception of speech-in-noise

\[ r = .164, \ p = .068 \]
Results

- Gradiency and perception of *speech-in-noise*

\[ r = .164, p = .068 \]

\[ r = .243, p = .007 \]
Results

- Gradiency and perception of *speech-in-noise*

1) Gradiency -> Speech-in-noise

2) Gradiency -> Working Memory
   Working Memory -> Speech-in-noise
Results

- Gradiency and perception of **speech-in-noise**

\[ R^2 = 0.019 \]

\[ \beta = -0.14, t = -1.48, p = .143 \]
Results

• Gradiency and perception of **speech-in-noise**
Results

1. Do individual differences in gradiency derive from differences in general cognitive function?

2. Are individual differences in gradiency linked to multiple cue use?

3. In what way are these differences important for speech perception?
   - More gradient listeners tend to better perceive speech in noise
Summary and conclusions

1. Do individual differences in gradiency derive from differences in general cognitive function?
   • Probably not.
   • Maybe speech perception operates on a different level than higher cognitive processes.
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2. Are individual differences in gradiency linked to multiple cue use?
   - Yes, more gradient listeners tend to rely more on the secondary cue (F0).
   - Better encoding of fine-grained detail (more gradiency) enables access to multiple cues.
   - And/or more gradient listeners commit later to a category.
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   - Better encoding of fine-grained detail (more gradiency) enables access to multiple cues.
   - And/or more gradient listeners commit later to a category.

3. In what way are these differences important for speech perception?
   - More gradient listeners do a bit better (marginally) in perceiving speech in noise.
   - Gradiency is not all that bad - maybe good for some things.
Take home messages

1. Gradiency indicates more accurate, true-to-the-signal perception.
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2. Some listeners are more gradient than others in categorizing phonemes.
Take home messages

1. Gradiency indicates more accurate, true-to-the-signal perception.
2. Some listeners are more gradient than others in categorizing phonemes.
3. This gradiency may be a good thing.
Thank you!