Variability and Strength in Gradient Phonotactic Acquisition

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Introduction

• Phonotactics
  – Restrictions over sequences of speech sounds
  – Often gradient
    • Some sequences appear more often than others
  – Part of the speaker’s grammatical knowledge
    • Used in production and perception of novel items
      – E.g. Jusczyk et al. (1993); McQueen (1998); Vitevitch & Luce (1998); Munson (2001)
Gradient phonotactics

syllable-final [s] vs. [z]

[kɪs]  
[mæs]  
[sæs]  
[nus]  
[bʌs]  

[s] appears in more contexts, more frequently, than [z] syllable/word-finally
Gradient phonotactics

What factors play a role in the acquisition of gradient phonotactic constraints?

1. Contextual variability
2. Exemplar strength
Gradient phonotactics

What factors play a role in the acquisition of gradient phonotactic constraints?

1. Contextual variability
   – High contextual variability draws learner’s attention to invariant aspects of input
   – Measured by type frequency

2. Exemplar strength
Gradient phonotactics

What factors play a role in the acquisition of gradient phonotactic constraints?

1. Contextual variability
2. Exemplar strength
Gradient phonotactics

What factors play a role in the acquisition of gradient phonotactic constraints?

1. Contextual variability

2. Exemplar strength
   - Strength of individual items making up pattern affects strength of entire pattern
   - Measured by token frequency
Overview

• 3 artificial language experiments
  – Sources of information correlated in the input
    • Token frequency, type frequency
  – Artificial language experiments allow us to decorrelate contextual variability and exemplar strength
Overview

Three experiments:

Experiment 1  
Correlated

Experiment 2  
Isolated

Experiment 3  
Anti-correlated

32 participants each  
Online (Amazon Mechanical Turk)
BACKGROUND
Contextual variability

• Thought experiment
  – You’re a Martian who has never encountered a “chair” before
  – How do you learn the category CHAIR?
Seat •
Back •
Four legs •
No arms •
Grey •
Metal •
<table>
<thead>
<tr>
<th>Feature</th>
<th>Grey</th>
<th>Metal</th>
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Description:
- Seat: •
- Back: •
- Four legs: •
- No arms: •
- Grey: •
- Metal: •
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- Seat
- Back
- Googly eyes
- Tongue
<table>
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<th>Feature</th>
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<tbody>
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<td>Grey</td>
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<td>Metal</td>
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- Seat
- Back
- Googly eyes
- Tongue
CHAIR!
Contextual variability

• Directs learner’s attention to invariant features of category
  – Learn what is important
    • [Back], [Seat]
  – Also, what’s not important
    • Material, arms

– Classic finding from psychology
  • Estes & Burke (1953); Munsinger & Kessen (1966); Dukes & Bevan (1967); Posner & Keele (1968)
Contextual variability

• Enhances pattern learning
• Correlated with pattern productivity
Contextual variability

• Enhances pattern learning
  • Phonetics (Lively, Logan & Pisoni, 1993)
    – High variability training improves acquisition of non-native phoneme categories
  • Across many linguistic domains (e.g. Rost & McMurray, 2009; Endress & Hauser, 2011; Twomey, Ranson, & Horst, 2014; Gomez, 2002; Richtsmeier, 2011)

• Correlated with pattern productivity
Contextual variability

• Enhances pattern learning

• Correlated with pattern productivity
  – Morphology (Bybee, 1988)
    • High type-frequency morphemes are highly productive
  – Phonotactics (see Pierrehumbert, 2003)
Contextual variability

• Phonotactics
  – What is context for a phonotactic pattern?
    • Other segments in the syllable
  – Variability along relevant dimension
  – **Type frequency = contextual variability**
Contextual variability

*syllable-final [s] vs. [z]*

\[
\begin{aligned}
\text{kīs} & \quad \text{buz} \\
\text{mæs} & \quad \text{kuis} \\
\text{las} & \quad \text{luz} \\
\text{nus} & \quad \text{bʌz}
\end{aligned}
\]

[s] appears in more *variable contexts*
Exemplar strength

• Strength of individual items making up a pattern
  – Facilitatory
  – Not significant
Exemplar strength

• Strength of individual items making up a pattern
  – Facilitatory
    • Facilitatory effects of frequency ubiquitous in language processing
    • If items making up pattern are highly active, entire pattern may be more active/productive
  – Not significant
Exemplar strength

• Strength of individual items making up a pattern
  – Facilitatory
  – Not significant
    • High frequency items are so strong they are exceptional
      – HF morphemes often exceptional (Bybee, 1988)
    • Learners attribute features of HF item as idiosyncratic to that item, not generalizable to other similar items
      – N.B. Can’t be completely irrelevant
Exemplar strength

syllable-final [s] vs. [z]

[s] appears more frequently overall, *regardless of context*
EXPERIMENTS
Methodology

• Continuous recognition memory task (Bernard, 2015)
  – Stimuli presented auditorily
  – Prompt: “Have you heard this syllable before?”
  – After stimulus plays: respond “YES” or “NO”
Methodology

• **Familiarization phase**
  – Two repetitions of set of *familiarization* syllables
    • Syllables divided into two patterns
    • Arbitrary phonotactic constraint
      – **Coda pattern**: /n,f/ vs. /s,b/
    • Monosyllabic nonce words

• **Generalization phase**
  – Four additional repetitions of set, intermixed with single presentation of novel *generalization* syllables
    • ½ follow each coda pattern
<table>
<thead>
<tr>
<th></th>
<th>Variability</th>
<th>Strength</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Advantaged pattern</strong></td>
<td>{fef, sif, buf, saf}</td>
<td>{fef, fef, fef, fef} x 4</td>
</tr>
<tr>
<td><strong>Disadvantaged pattern</strong></td>
<td>{fes, fes, fes, fes}</td>
<td>{fes, fes, fes, fes}</td>
</tr>
<tr>
<td><strong>Generalization</strong></td>
<td></td>
<td>faf, nuv, fis, bas</td>
</tr>
</tbody>
</table>
Rate of participants *incorrectly responding yes on novel generalization syllables* a measure of generalizing pattern

- Compare false alarm rates for generalization syllables reflecting each pattern
Experiment 1

• Variability/strength correlated

• **Advantaged** pattern: 16 syllables x 4 reps
  – 64 tokens/block

• **Disadvantaged** pattern: 4 syllables x 4 reps
  – 16 tokens/block

Example set

{baf, ban, buf, bun, fef, fen, fuf, fun, naf, nan, nif, nin, sef, sen, sif, sin} x 4 reps

{bas, fub, nis, seb} x 4 reps
Experiment 1

- Participants acquire gradient phonotactic
- Participants generalize pattern with high contextual variability, high exemplar strength
- Reality check!
Experiment 2

• Isolate individual factors
  – Experiment 2a
    • Contextual variability
  – Experiment 2b
    • Exemplar strength
Experiment 2a

• Contextual variability alone

  • **Advantaged** pattern: 16 syllables x 2 or 3 reps
    – 40 tokens/block

  • **Disadvantaged** pattern: 4 syllables x 10 reps
    – 40 tokens/block

Example set

{ba\text{f}, ba\text{n}, bu\text{f}, bu\text{n}, fe\text{f}, fe\text{n}, fu\text{f}, fu\text{n}, naf, nan, nif, nin, se\text{f}, se\text{n}, sif, sin}\n
\text{vs.}\n
{bas, fub, nis, seb}\n
x 10 reps
Experiment 2a

- Participants generalize pattern with high contextual variability alone
Experiment 2b

• **Exemplar strength** alone

  • **Advantaged** pattern: 16 syllables x 4 reps
    – 64 tokens/block

  • **Disadvantaged** pattern: 16 syllables x 1 rep
    – 16 tokens/block

  Example set

  \{baf, ban, buf, bun, fef, fen, fuf, fun, naf, nan, nif, nin, sef, sen, sif, sin\}

  vs.

  \{bas, fub, nis, seb...\}

  x 4 reps

  x 1 rep
Experiment 2b

- Exemplar strength effect on generalization not significant
Experiment 3

• Exemplar strength
  – Not powerful enough on its own to induce generalization
  – Can still modulate generalization?

• Experiment 3
Experiment 3

• Exemplar strength

• Experiment 3
  – Contextual variability, exemplar strength anti-correlated
  – Not found in natural language
Experiment 3

• Variability/strength **anti-correlated**

  • **Var-advantaged** pattern:
    16 syllables x 1 rep
    – 16 tokens/block

  • **Strength-advantaged** pattern:
    4 syllables x 16 reps
    – 64 tokens/block

Example set

\{baf, ban, buf, bun, fef, fen, fuf, fun, naf, nan, nif, nin, sef, sen, sif, sin\} 

vs.

\{bas, fub, nis, seb\} 

x 1 rep

x 16 reps
Experiment 3

- Participants generalize pattern with **high contextual variability**, not high exemplar strength
Experiment comparison

Is effect of contextual variability modulated by exemplar strength?
Experiment comparison

No significant difference whether contextual variability is correlated, isolated, or anti-correlated.
CONCLUSION
Conclusion

• Other experiments
  – Acoustic variability
  – Input statistics

• Future directions
Conclusion

• Other experiments

• Future directions
  – Lexical items
    • Instead of nonce words
  – Consolidation
    • How long do these effects last?
    • How do patterns change after consolidation?
Conclusion

• Contextual variability
  – Enhances phonotactic learning
  – Learners home in on invariant features of input
  – Consistent with evidence from other domains

• Exemplar strength
Conclusion

• Contextual variability

• Exemplar strength
  – Not significant for phonotactic learning?
  – Beyond some minimum threshold, strength of members of pattern doesn’t modulate strength of pattern as a whole
Thank you!

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Appendix

Acoustic variability
Relevance

• All variability not created equal
  – Only relevant variability facilitates learning
    • Gomez (2002); Rost & McMurray (2009)
    • Irrelevant variability: whether chair is displayed on computer screen, piece of paper, or projected

  – What constitutes relevant variability for phonotactics?
Acoustic variability

• If phonotactic representations...
  
  – Contain **phonetically fine-grained** information
    • Acoustic variability relevant, enhances generalization
  
  – Represented at more **abstract** level
    • Acoustic variability irrelevant, no generalization

  – Duration variability
    • Stimuli manipulated from 70% - 130% of baseline duration
Experiment 4

• **Acoustic variability** alone

  • **Advantaged** pattern: 16 syllables x 2 or 3 reps
    – Duration variability
    – 40 tokens/block

  • **Disadvantaged** pattern: 16 syllables x 2 or 3 reps
    – No duration variability
    – 40 tokens/block

Example set:

\{baf, ban, \underline{buf}, bun\ldots\} X 2 or 3 reps

vs.

\{bas, fub, nis, seb\ldots\} X 2 or 3 reps
Experiment 4

- Logistic regression and subsequent $\chi^2$ model comparison—**not significant**
  - $\beta = 0.14$, s.e. $\beta = 0.15$, $\chi^2(1) = 0.82$, $p > .05$

- Acoustic variability has **no effect** on generalization

- Phonotactics are represented **abstractly**
Experiment 3b

• Acoustic variability (anti-correlated)
  • Confound: contextual variability ➔ acoustic variability
  • Exemplar strength + acoustic variability
    – Stronger effect than exemplar strength alone?
    – More naturalistic

• Add duration variability to both patterns
  – 70% - 130% of baseline stimulus duration
  – Linguistically meaningful/relevant, can enhance L2 word learning (Sommers & Barcroft, 2007)
Experiment 3b

• Var/strength anti-correlated, variability
  
  • Var-advantaged pattern:
    16 syllables x 1 rep
    – 16 tokens/block
  
  • Strength-advantaged pattern:
    4 syllables x 16 reps
    – 64 tokens/block

Example set

{baf, ban, buf, bun, fef, fen, fuf, fun, naf, nan, nif, nin, sef, sen, sif, sin} vs. {bas, fub, nis, seb}

x 1 rep vs. x 16 reps
Experiment 3b

- Participants generalize pattern with **high contextual variability**, not high exemplar strength
- Difference from XP 3 not significant
Appendix

Input statistics
Input statistics

• Narrow slice of parameter space
  – All advantages have been 4:1 ratio

• Experiment 5
  – Cut ratio to 2:1
    • Half as many unique syllables
  – More stringent test of variability advantage
  – N.B. Duration variability added
Experiment 5

• Var/strength anti-correlated, short

  • Var-advantaged pattern:
    8 syllables x 2 rep
    – 16 tokens/block

  vs.

  • Strength-advantaged pattern:
    4 syllables x 8 reps
    – 32 tokens/block

Example set

\{buf, bun, fuf, fun, nif, nin, sif, sin\}
  x 2 reps

\{bas, fub, nis, seb\}
  x 8 reps
Experiment 5

- Participants generalize pattern with high contextual variability, not high exemplar strength.
- No difference from XP 3a, 3b.
Appendix

Detailed results
Experiment 1

- Logistic regression and subsequent $\chi^2$ model comparison—**significant**
  - $\beta = 1.07$, s.e. $\beta = 0.19$, $\chi^2(1) = 23.75$, $p < .05$
- No significant difference vs. in-lab result
Experiment 2a

- Logistic regression and subsequent $\chi^2$ model comparison—**significant**
  - $\beta = 0.75$, s.e. $\beta = 0.15$, $\chi^2(1) = 21.92$, $p < .05$
Experiment 2b

• Logistic regression and subsequent $\chi^2$ model comparison—**not significant**
  
  • $\beta = 0.09$, s.e. $\beta = 0.17$, $\chi^2(1) = 0.3$, $p > .05$
Experiment 3

• Logistic regression and subsequent $\chi^2$ model comparison—**significant**
  • $\beta = 0.65$, s.e. $\beta = 0.18$, $\chi^2(1) = 11.55$, $p < .05$

• No significant difference vs. anti-correlated without acoustic variability