Variability and Strength in Gradient Phonotactic Generalization

Thomas Denby and Matt Goldrick

NORTHWESTERN UNIVERSITY

BACKGROUND

Gradient phonotactics

Gradient phonotactics are gradient restrictions over sequences and positions of speech sounds

- Segment sequences can appear in more contexts (unique words/syllables) and more frequently (more instances)

syllable-final [s] > [z]

ki[s] crea[s] ma[s] sa[s] noo[s] bu[s]

fi[z] bree[z] tea[z]

What factors play a role in the acquisition of gradient phonotactics?

Contextual Variability

- Variability of contexts surrounding a pattern
- High contextual variability draws learner's attention to invariant aspects of the input
- Measured by # of unique lexical/syllabic contexts in which phonotactic constraint appears

Exemplar Strength

- Strength/activation of individual items making up pattern affects strength of pattern as a whole
  - ➢ Frequency effects ubiquitous in language processing
- Measured by # of instances in which phonotactic constraint appears

How does this further our understanding of phonotactic learning?

- Contextual variability and exemplar strength are highly correlated in natural language phonotactics[1]
  - ➢ Most models of phonotactic learning do not differentiate between the two[2,3]
- By using artificial language experiments, we can decorrelate and deconfound the influence of these factors

EXPERIMENT DETAILS

- 32 participants/experiment
- All participants recruited through Amazon Mechanical Turk
- Significance measured using logistic mixed-effects regression models and χ^2 model comparisons
  - All error bars are 95% bootstrapped CIs

3 Experiments

Input statistics per block

Experiment	# of Unique Syllables			# of Instances		
	Pattern A	*Pattern B*	*Ratio*	*Pattern A*	*Pattern B*	*Ratio*
Experiment 1 Correlated	16	4	4:1	64	16	4:1
Experiment 2A Variability	16	4	4:1	40	40	1:1
Experiment 2B Strength	16	16	1:1	64	16	4:1
Experiment 3 Anti-correlated	16	4	4:1	16	64	1:4

METHODS

Continuous recognition memory task[4]

- Stimuli presented auditorily, one at a time
- Prompt after each stimulus: **"Have you heard this syllable before?"**
- Participants respond **YES** or **NO**

Materials

- 64 total CVC nonsense syllables
- Syllables divided into two patterns based on arbitrary phonotactic constraint
  - ➢ **Coda pattern:** /n,f/ vs. /s,b/

Design

- Familiarization phase
  - ➢ 2 repetitions of set of *familiarization* syllables
- Generalization phase
  - ➢ 4 additional repetitions of *familiarization* set
  - ➢ Intermixed with novel *generalization* syllables (½ follow each coda pattern)

Measure

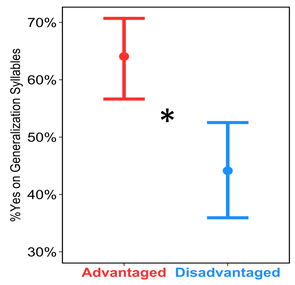
- How often participants **incorrectly respond yes** on **novel generalization syllables**
  - ➢ Measures pattern generalization

By manipulating the variability and strength of each pattern, we can compare their effects on learning

RESULTS

Experiment 1

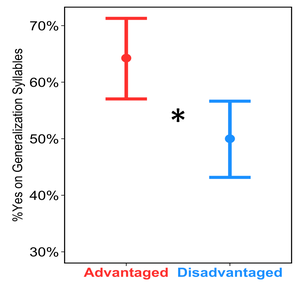
Participants generalize pattern with high variability and high strength



- Participants **generalize** pattern that appears in **more contexts, instances** to novel items (simulates phonotactic constraints in natural language)
- $\beta = 1.07$, s.e. $\beta = 0.19$, $\chi^2(1) = 23.8$, $p < .05$

Experiment 2A

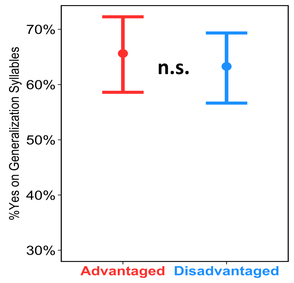
Participants generalize pattern with high contextual variability alone



- Participants **generalize** pattern that appears in **more contexts, but same # of instances**
- $\beta = 0.75$, s.e. $\beta = 0.15$, $\chi^2(1) = 21.9$, $p < .05$

Experiment 2B

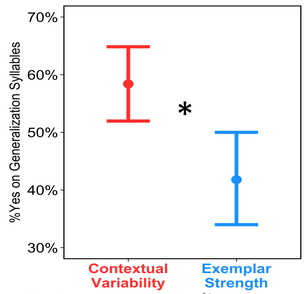
Participants do not generalize pattern with high exemplar strength alone



- Participants **do not generalize** pattern that appears in **more instances, but same # of contexts** more than disadvantaged pattern
- $\beta = 0.09$, s.e. $\beta = 0.17$, $\chi^2(1) = 0.3$, $p > .05$

Experiment 3

Participants generalize pattern with high variability over pattern with high strength

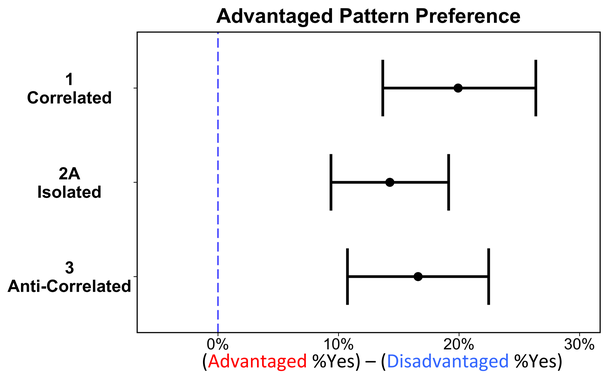


- Participants **generalize** pattern that appears in **more contexts/fewer instances** than the pattern that appears in few contexts/many instances
- $\beta = 0.65$, s.e. $\beta = 0.18$, $\chi^2(1) = 11.6$, $p < .05$

Experiment Comparison

Is the effect of contextual variability modulated by exemplar strength?

- **No significant difference** whether variability is correlated, isolated, anti-correlated with strength
- Pattern robust to manipulations of acoustic variability and relative input statistics in separate experiments (not shown)



Contextual variability enhances generalization

Exemplar strength does not modulate generalization

DISCUSSION

Why does variability enhance generalization?

- Variability in the context surrounding the pattern allows learners to home in on invariant features of the input
- Consistent with evidence from visual pattern learning for adults[5] and toddlers[6], acquisition of non-native phonemes[7], words for infants[8], stress patterns[9], morphemes[10], and syntactic dependencies[11]

Why doesn't strength modulate generalization?

- High strength items may become exceptional
  - ➢ Learners attribute features as idiosyncratic to particular item, not generalizable to novel items
  - ➢ e.g. high token frequency morphemes often exceptional[12] (e.g. *go*/*went*)

ACKNOWLEDGEMENTS

Thanks to our collaborators Sean Arn, Svetlin Dimov, and Jeffrey Schecter. Thanks also to Ann Bradlow, Chun Chan, and the NU Soundlab.

SELECTED REFERENCES

[1] Schecter, J. (2011). Effects of Type and Token Frequency on Phonotactic Learning. Undergraduate Honor's Thesis. Northwestern University. **[2]** Hayes, B., & Wilson, C. (2008). A Maximum Entropy Model of Phonotactics and Phonotactic Learning. *Linguistic Inquiry*, *39*(3) **[3]** Warker, J. a, & Dell, G. S. (2006). Speech errors reflect newly learned phonotactic constraints. *Journal of Experimental Psychology. Learning, Memory, and Cognition*, *32*(2) **[4]** Bernard, A. (2015). An onset is an onset: Evidence from abstraction of newly-learned phonotactic constraints. *Journal of Memory and Language*, *78* **[5]** Posner, M., & Keele, S. (1968). On the genesis of abstract ideas. *Journal of Experimental Psychology*, *77* **[6]** Quinn, P. C., & Bhatt, R. S. (2006). Are some Gestalt principles deployed more readily than others during early development? The case of lightness versus form similarity. *Journal of Experimental Psychology: Human Perception and Performance*, *32*(5) **[7]** Bradlow, A. R., Pisoni, D. B., Akahane-Yamada, R., & Tohkura, Y. I. (1997). Training Japanese listeners to identify English/r/and/l: IV. Some effects of perceptual learning on speech production. *The Journal of the Acoustical Society of America*, *101*(4) **[8]** Twomey, K. E., Ranson, S. L., & Horst, J. S. (2014). That's More Like It: Multiple Exemplars Facilitate Word Learning. *Infant and Child Development* **[9]** Gerken, L., & Bollt, A. (2008). Three Exemplars Allow at Least Some Linguistic Generalizations: Implications for Generalization Mechanisms and Constraints. *Language Learning and Development*, *4*(3) **[10]** Endress, A. D., & Hauser, M. D. (2011). The influence of type and token frequency on the acquisition of affixation patterns: implications for language processing. *Journal of Experimental Psychology. Learning, Memory, and Cognition*, *37*(1) **[11]** Gómez, R. L. (2002). Variability and detection of invariant structure. *Psychological Science : A Journal of the American Psychological Society / APS*, *13*(5) **[12]** Bybee, J. L. (1988). Morphology as Lexical Organization. In *Theoretical Approaches to Morphology*