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]

[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
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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*

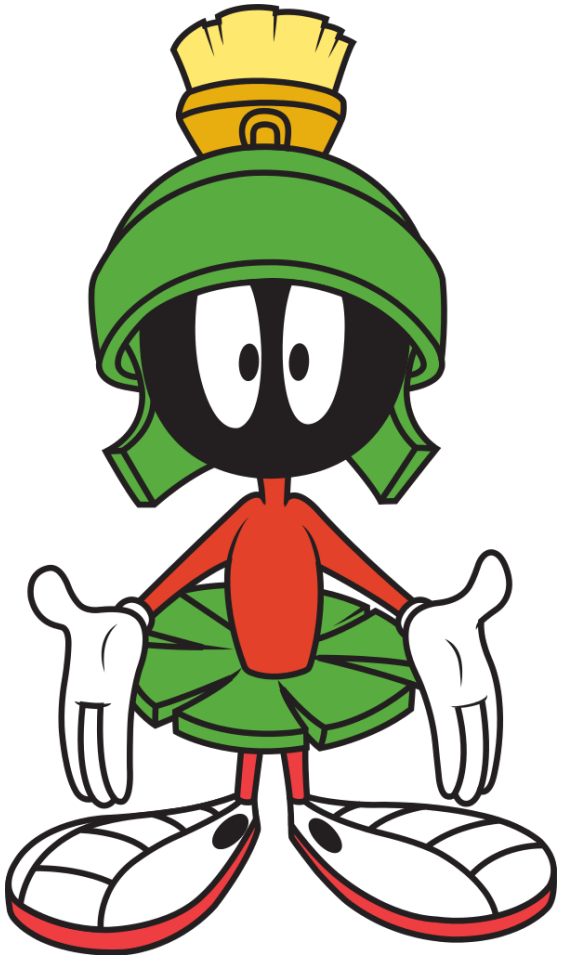
Experiment 3 *Anti-correlated*

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	•

Seat	•	•
Back	•	•
Four legs	•	•
No arms	•	•
Grey	•	
Metal	•	

Seat	•	•	•
Back	•	•	•
Four legs	•	•	•
No arms	•	•	
Grey	•		
Metal	•		

Seat	•	•	•	•
Back	•	•	•	•
Four legs	•	•	•	
No arms	•	•		
Grey	•			
Metal	•			

Seat	• • • •
Back	• • • •
Four legs	• • •
No arms	• •
Grey	•
Metal	•

Seat	• • • •
Back	• • • •
Four legs	• • •
No arms	• •
Grey	•
Metal	•

- Seat
- Back
- Googly eyes
- Tongue

Seat	• • • •
Back	• • • •
Four legs	• • •
No arms	• •
Grey	•
Metal	•

- **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]

kɪs

buz

kɹis

mæs

luz

las

bʌz

bʌs

nus

[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

	Variability	Strength
Advantaged pattern	{fef, sif, buf, saf}	{fef, fef, fef, fef} x **4**
Disadvantaged pattern	{fes, fes, fes, fes}	{fes, fes, fes, fes}
Generalization	faf, nuf, fis, bas	

	Variability	Strength
Advantaged pattern	{fef, sif, buf, saf}	{fef, fef, fef, fef} x **4**
Disadvantaged pattern	{fes, fes, fes, fes}	{fes, fes, fes, fes}
Generalization	faf, nuf, fis, bas	

– 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**

Example set

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

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

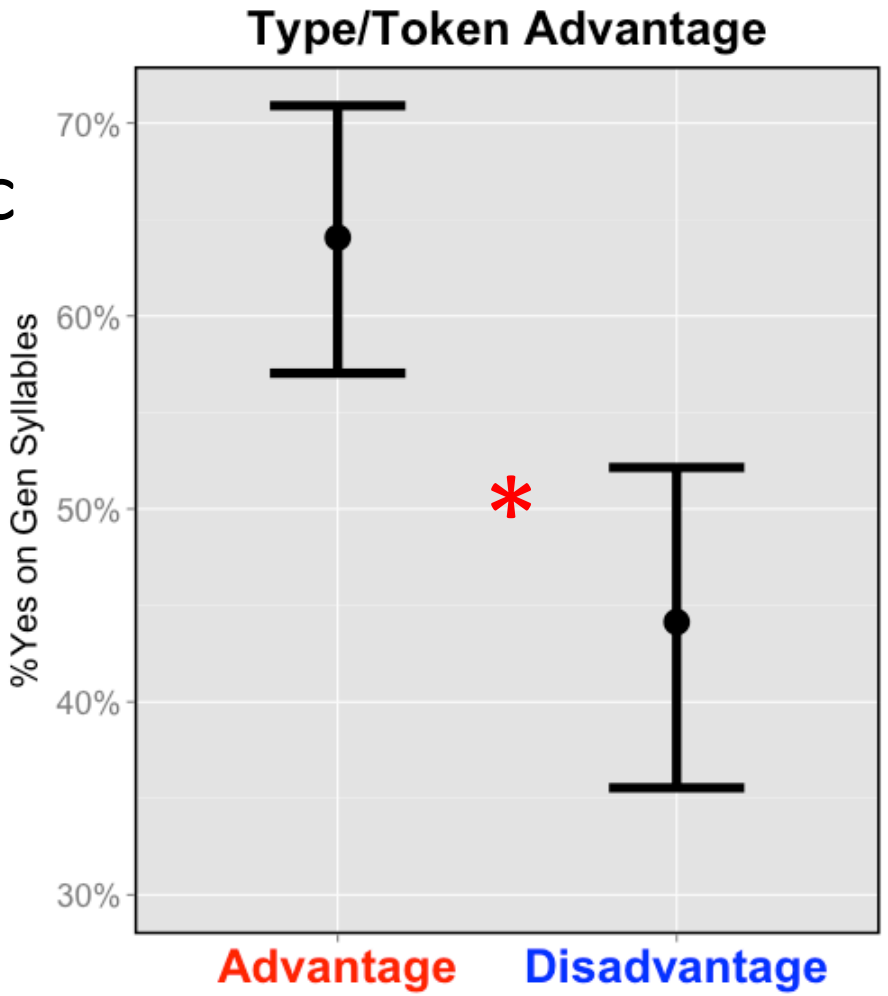
vs.

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

{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

vs.

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

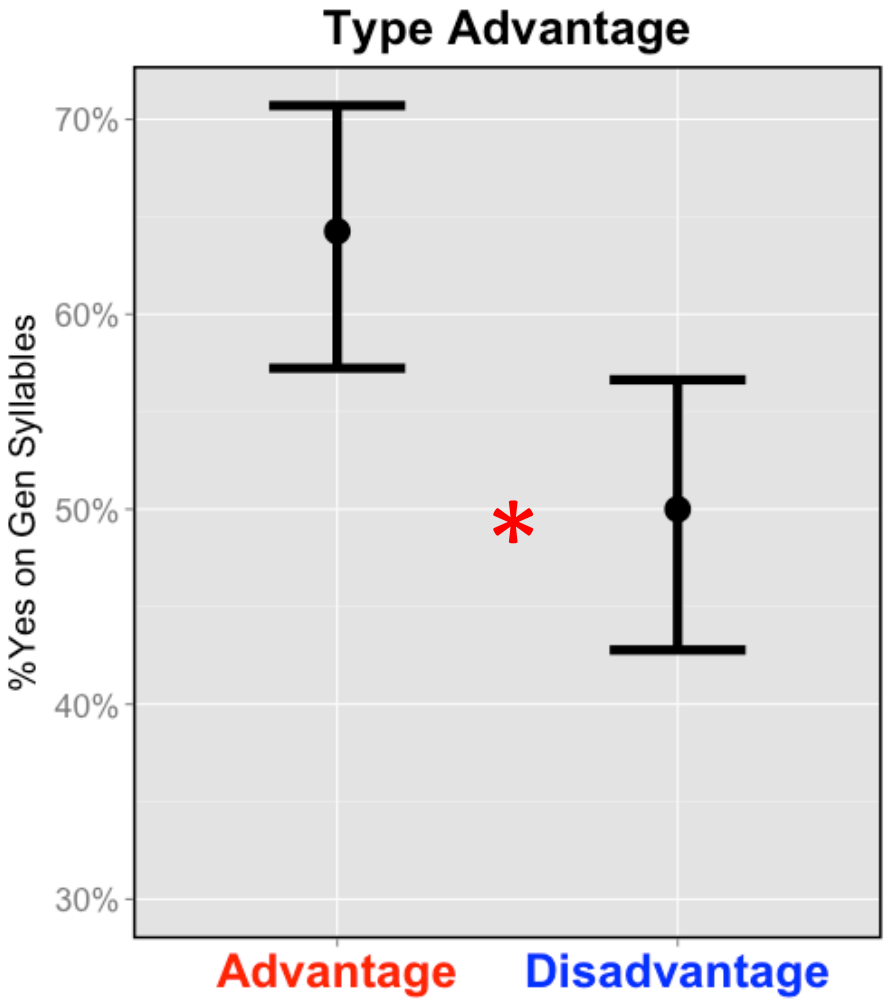
Example set

{baf, ban, buf, bun,
fef, fen, fuf, fun,
naf, nan, nif, nin,
sef, sen, sif, sin}
x 2 or 3 reps

{bas, fub, nis, seb}
x 10 reps

Experiment 2a

- Participants **generalize** pattern with **high contextual variability** alone



Experiment 2b

- **Exemplar strength** alone

Example set

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

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

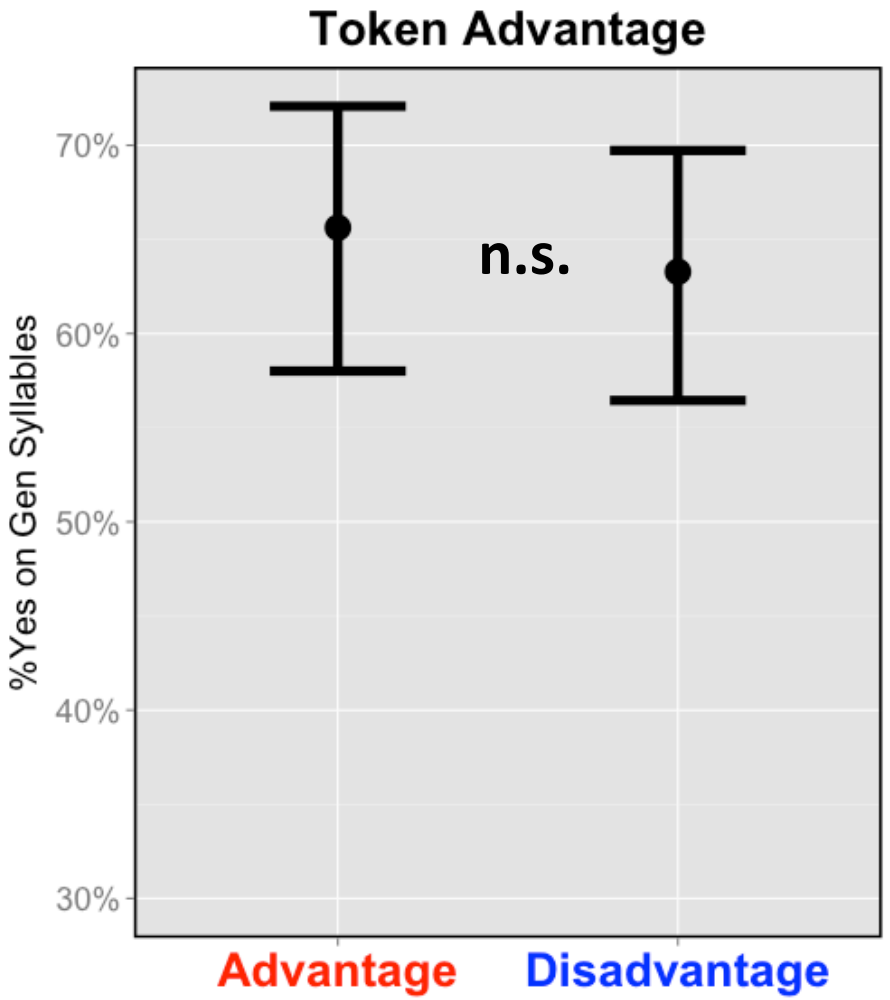
vs.

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

{bas, fub, nis, seb…} 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**

Example set

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

{baf, ban, buf, bun,
fef, fen, fuf, fun,
naf, nan, nif, nin,
sef, sen, sif, sin}
x 1 rep

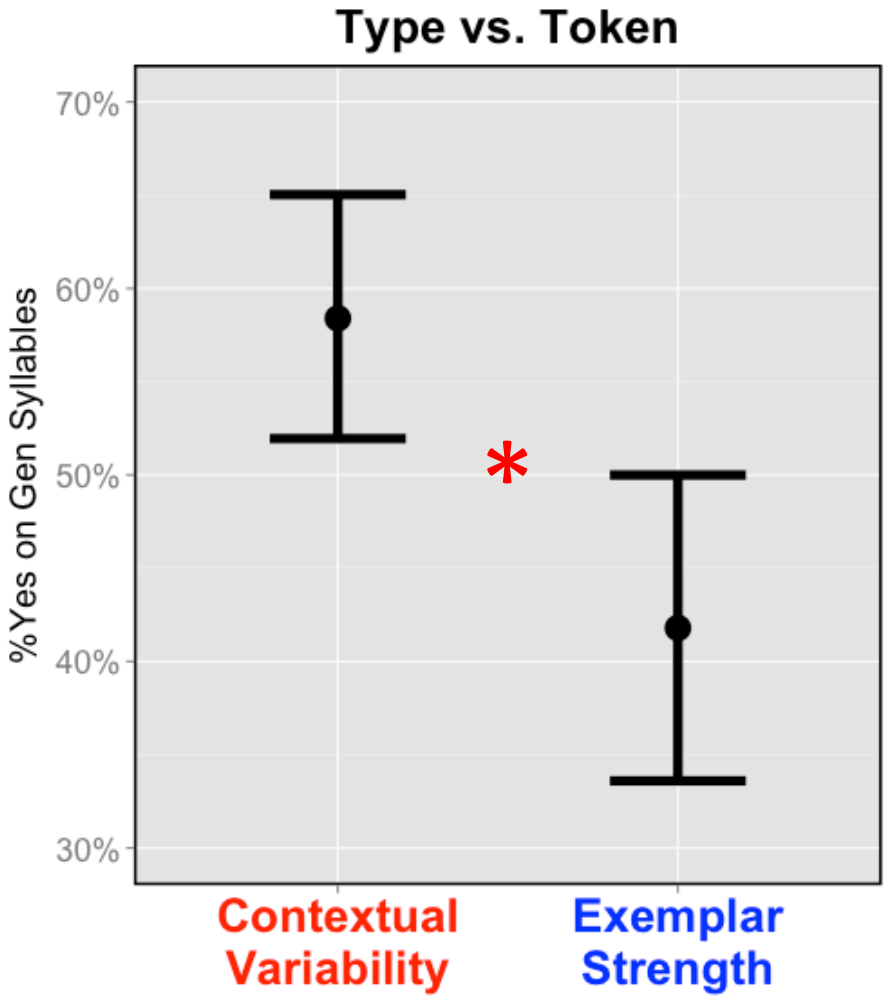
vs.

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

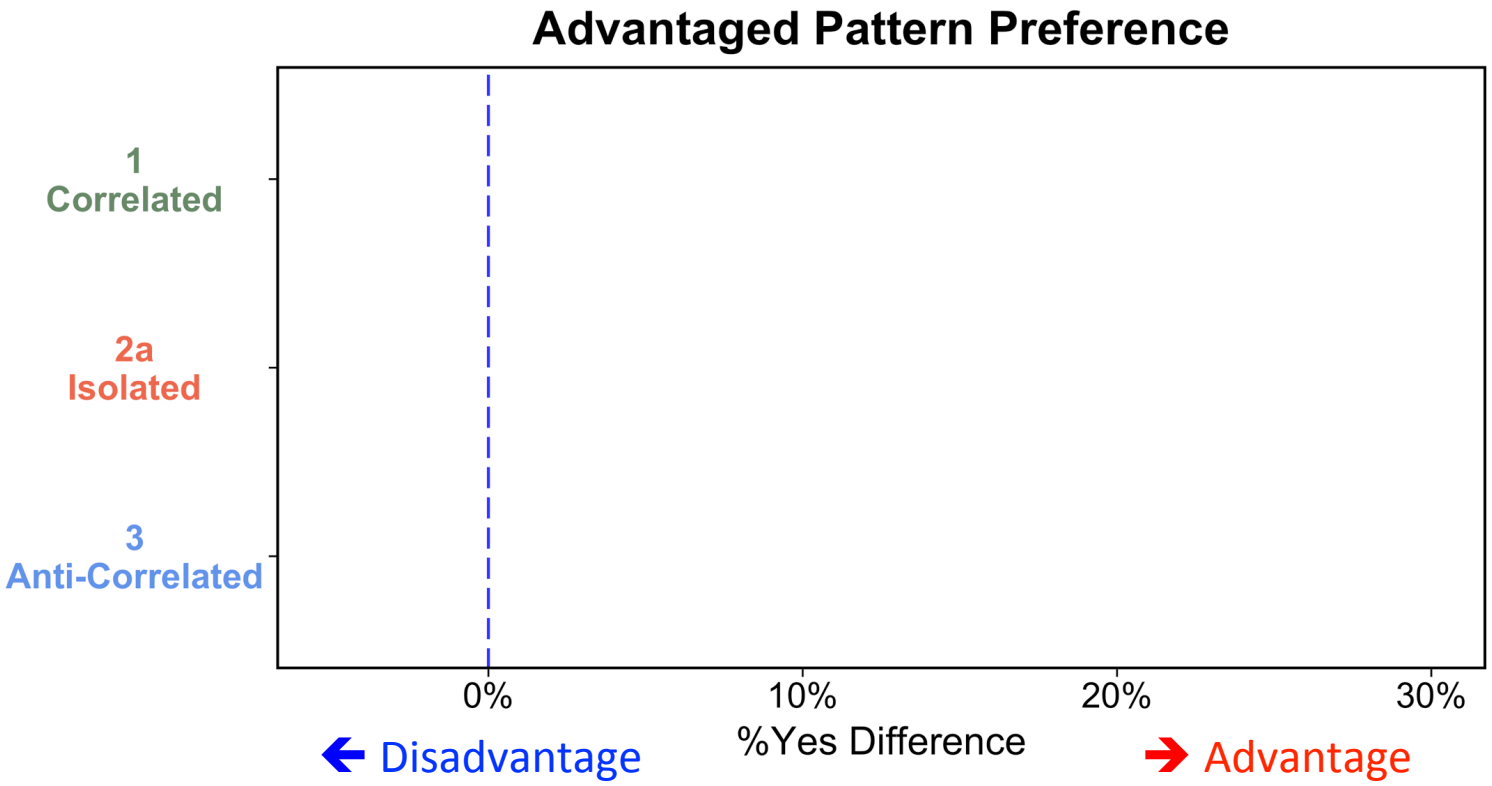
{bas, fub, nis, seb}
x 16 reps

Experiment 3

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

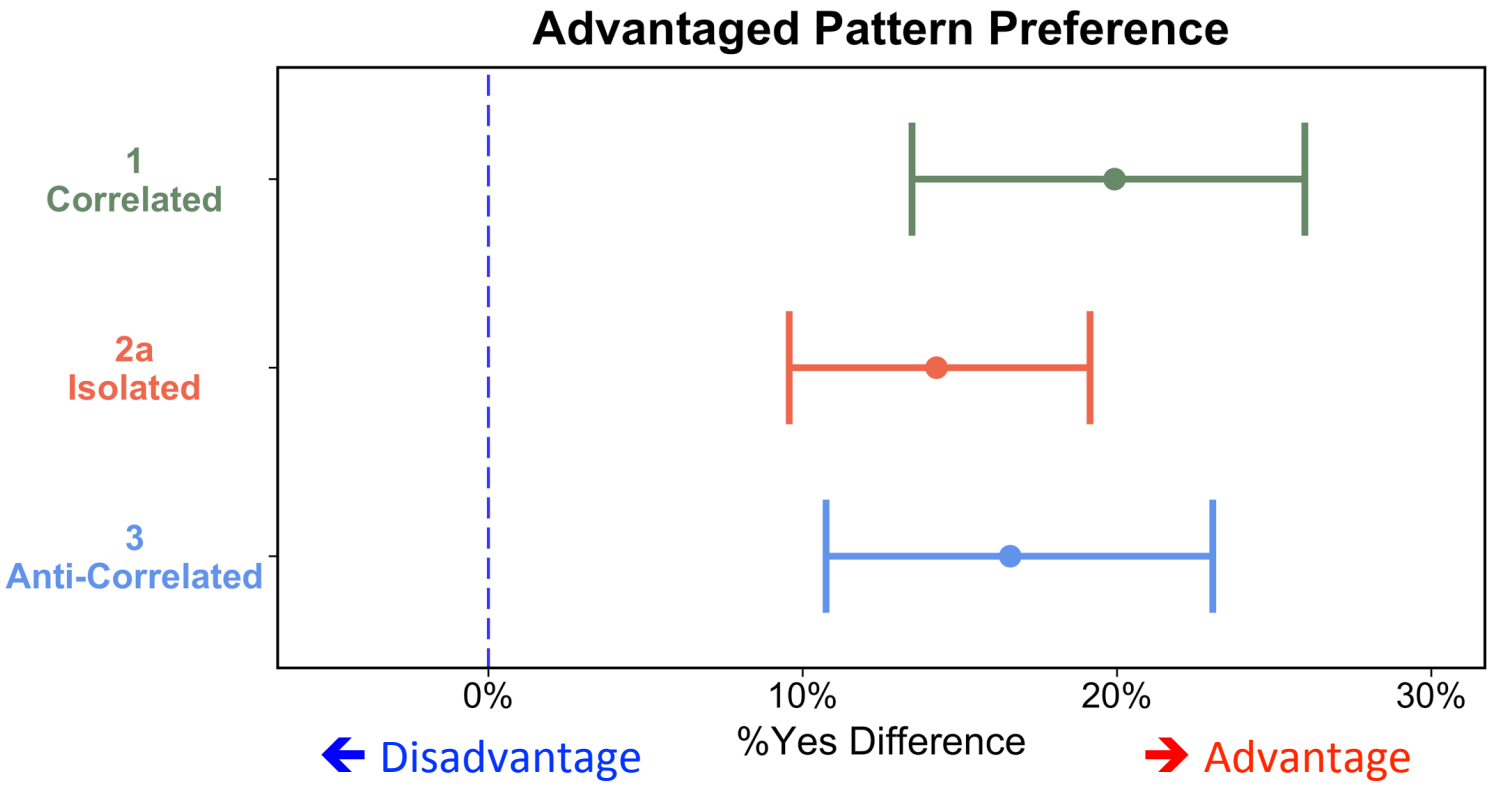


Experiment comparison



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

Example set

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

{*baf*, **ban**, buf, bun…}
X 2 or 3 reps

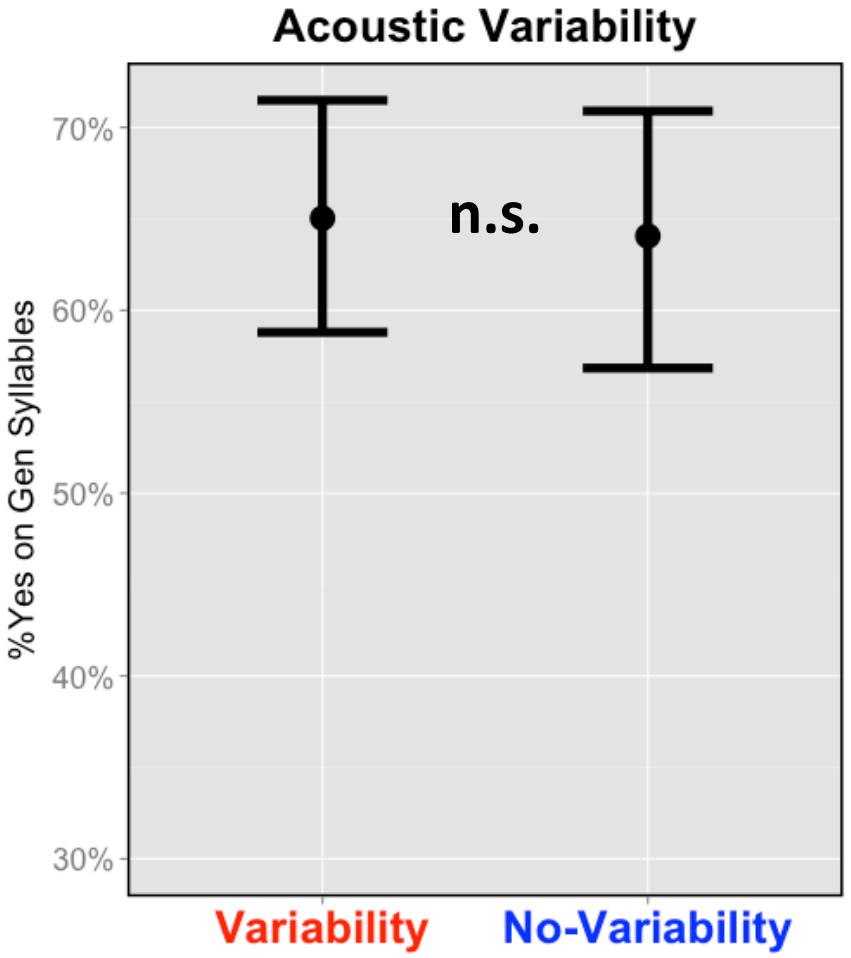
vs.

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

{bas, fub, nis, seb…}
X 2 or 3 reps

Experiment 4

- Logistic regression and subsequent χ^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**

Example set

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

{baf, ban, buf, bun,
fef, fen, fuf, fun,
naf, nan, nif, nin,
sef, sen, sif, sin}
x 1 rep

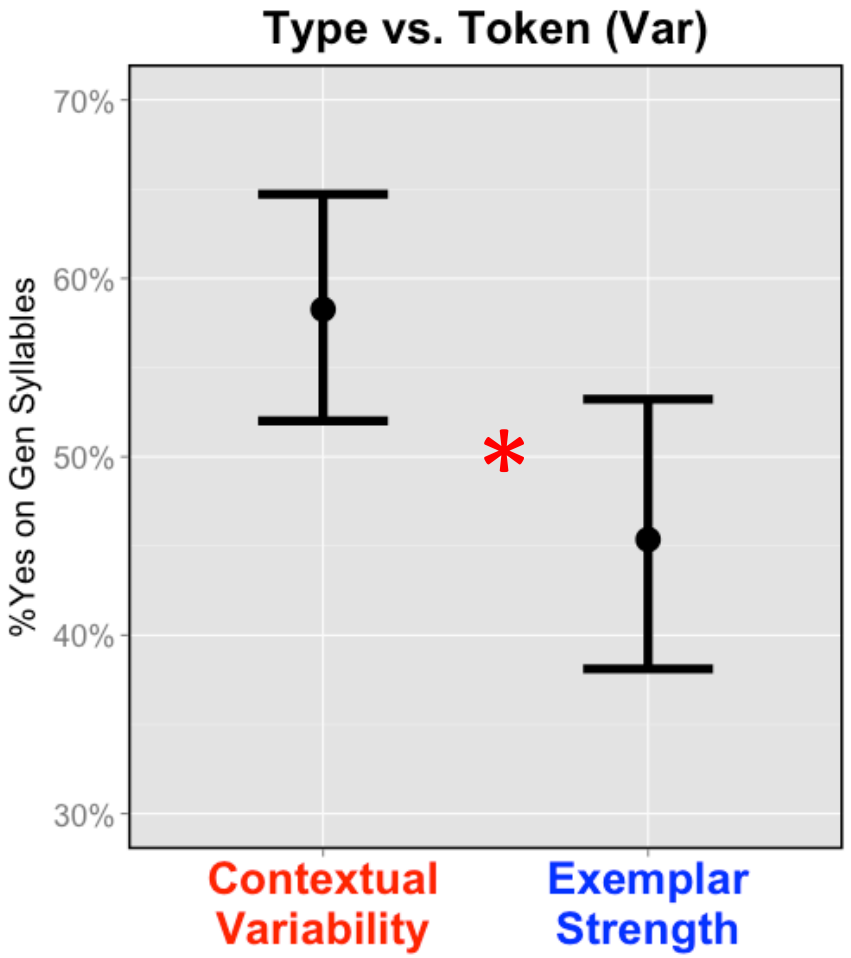
vs.

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

{bas, fub, nis, seb}
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**

Example set

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

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

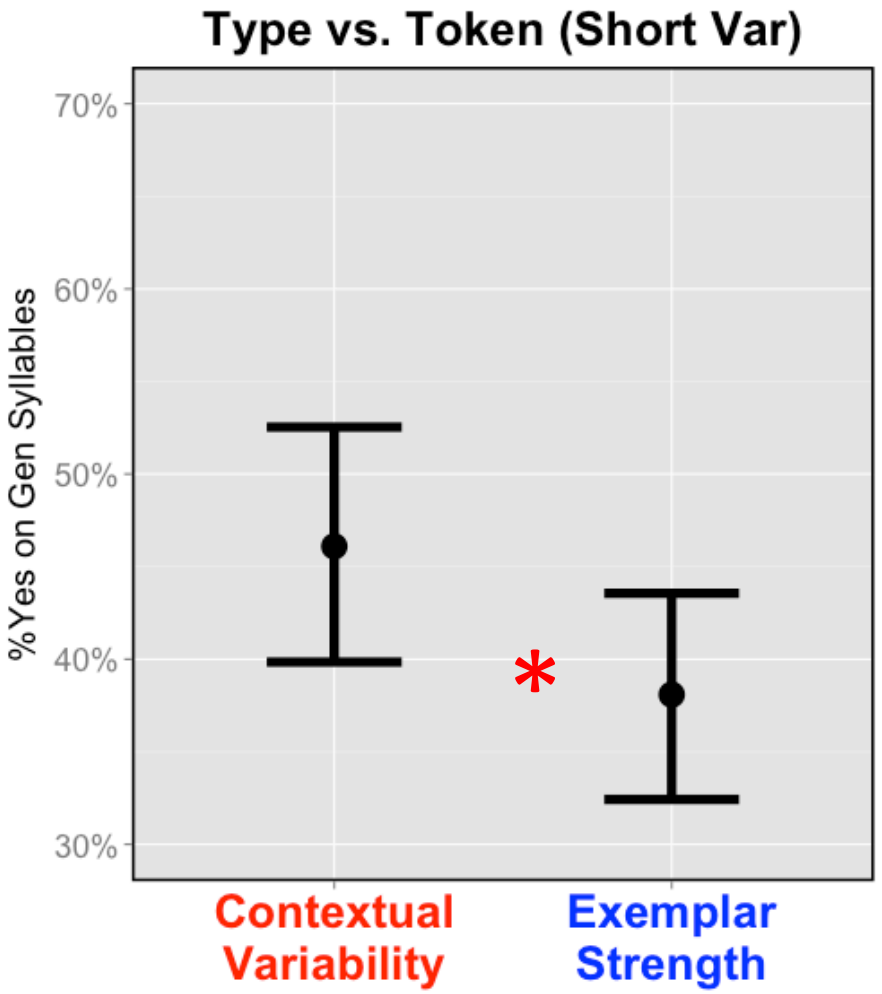
vs.

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

{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

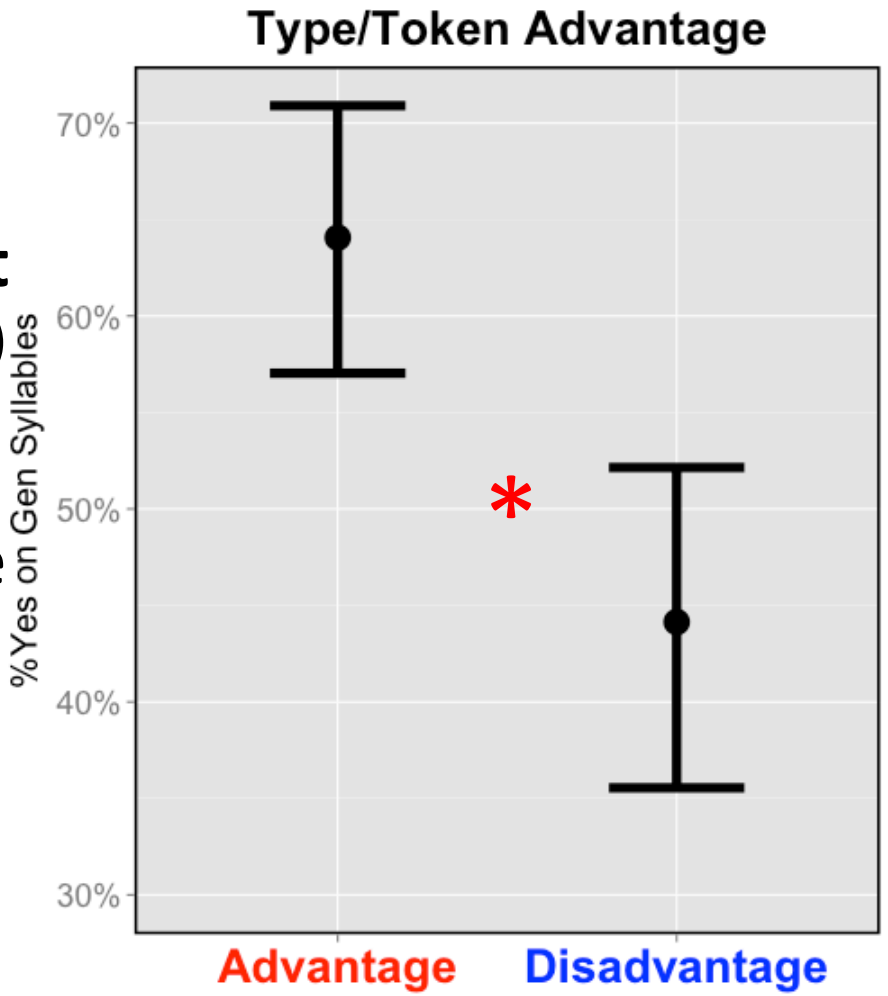


Appendix

Detailed results

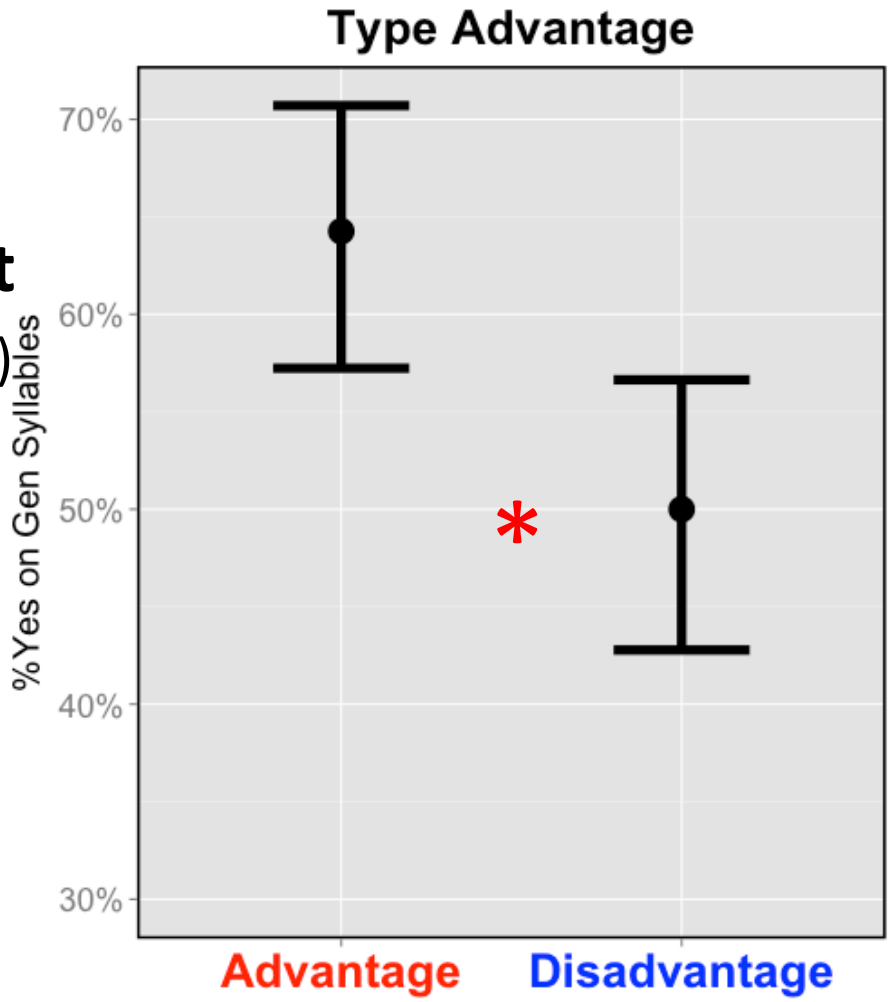
Experiment 1

- Logistic regression and subsequent χ^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



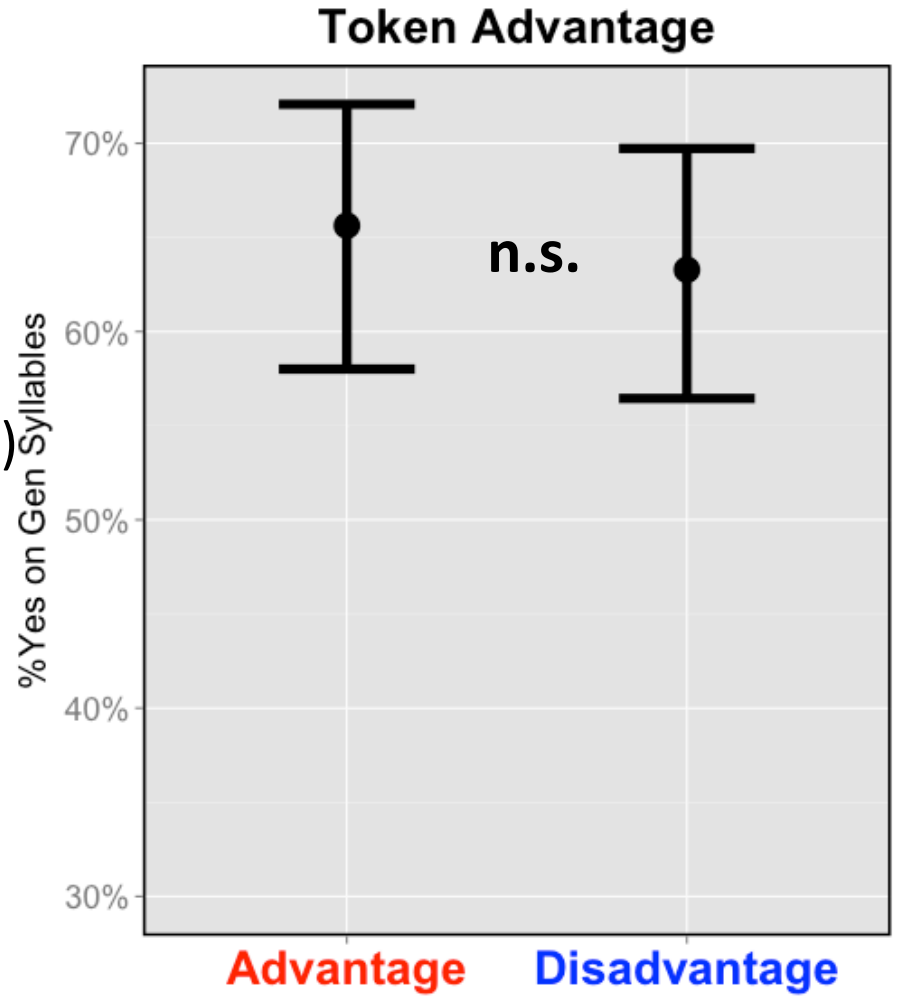
Experiment 2a

- Logistic regression and subsequent χ^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 χ^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 χ^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