

Bias in the Learning of Sound Patterns: An Experimental Investigation

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Today's Talk

- Two phonological experiments testing for learning bias
- Experiment 1: bias against phonetically unnatural patterns
 - Preference for phonetically unnatural patterns
 - Why?
 - Complexity bias: preference for simpler patterns
- Experiment 2: follow-up

Asymmetries in the Phonological Typology

- Final devoicing is common (Polish, German, Catalan, Turkish...) ^{1,2}
 - Polish: /klub/ → [klup] ‘club’ (cf. [klub-i] ‘club-PL’) ³
- Final voicing is virtually non-existent ^{1,4}
 - No cases like: /klup/ → [klub] (cf. [klup-i])
- The distribution of sound patterns in the world’s languages is asymmetric
- Why?

¹Lombardi 1991, ²Brockhaus 1995, ³Kenstowicz & Kisseberth 1979, ⁴Blevins 2004

Asymmetries in the Phonological Typology

- One hypothesis: learning bias
 - Sound patterns people don't like to learn will not develop or will not be acquired by next generation
 - Naturalness bias: against phonetically unnatural patterns

Asymmetries in the Phonological Typology

- How might naturalness bias explain asymmetry in (de)voicing patterns?
- Final devoicing (common): **D** → **T** / __#
 - /klub/ → [klup]
- Final voicing (non-existent): **T** → **D** / __#
 - /klup/ → [klub]

Articulatory Naturalness Bias

- **Voiced stops** harder to produce at word edges than **voiceless stops**¹
 - Necessary pressure differential harder to maintain at word edges
- Final devoicing = natural: make all final stops **voiceless** (easy)
- Final voicing = unnatural: make all final stops **voiced** (hard)
- Naturalness bias could explain why final devoicing common and final voicing non-existent
- In this case, naturalness bias **articulatory**

¹Westbury & Keating 1986

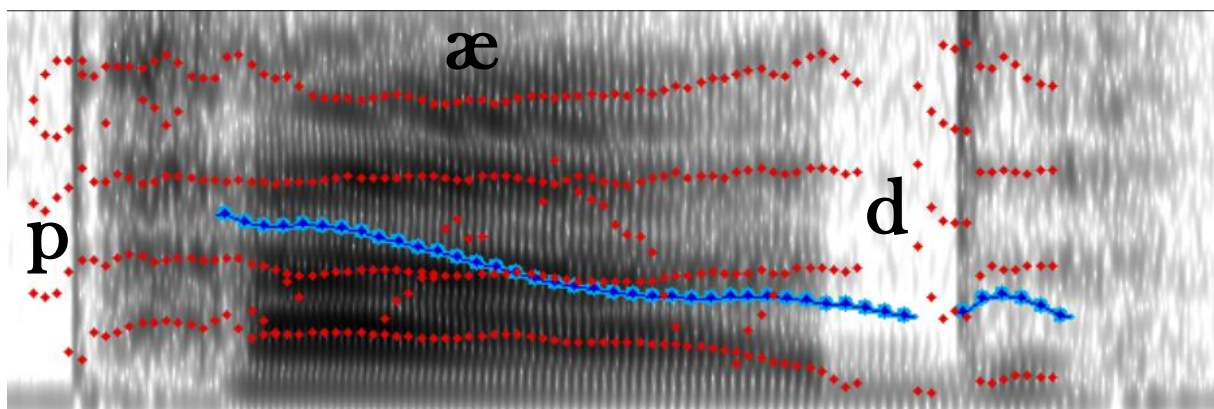
Asymmetries in the Phonological Typology

- More asymmetries exist
- If a stop voicing contrast in only one word-edge position, always #__ (initial), never __# (final)^{1, 2, 3}
- Final devoicing (common):
 - pan, ban, nap, ~~nab~~
- Initial devoicing (non-existent):
 - pan, ~~ban~~, nap, nab
- If voiced stops harder to produce at word edges than voiceless stops, why no initial devoicing languages?

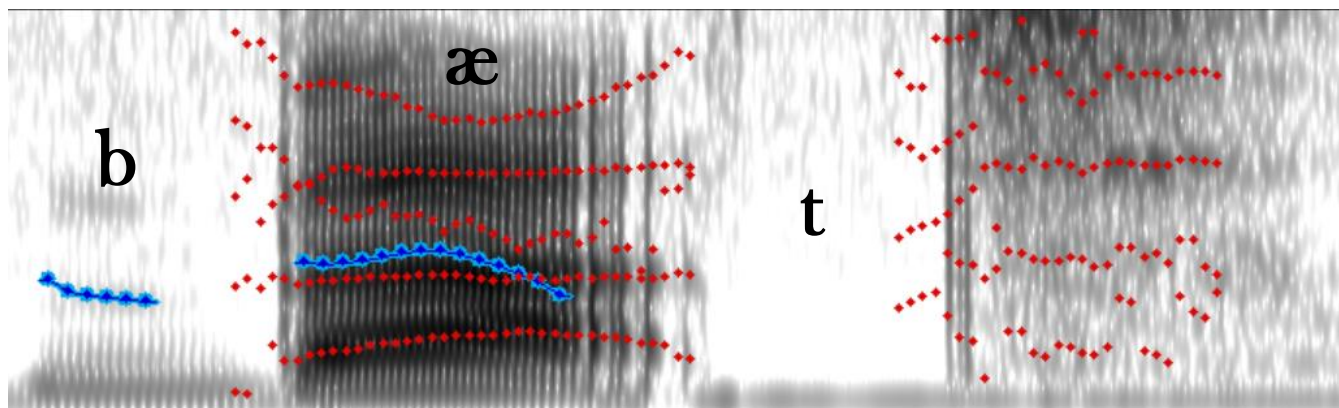
¹Steriade 1997, ²Lombardi 1999, ³Blevins 2004

Perceptual Naturalness Bias

- Acoustic cues to stop voicing better word-initially than word-finally¹



pad



bat

¹Steriade 1997

Perceptual Naturalness Bias

- Voiced and voiceless stops more perceptually similar in ___# (**ap** vs. **ab**) than in #___ (**pa** vs. **ba**)
- If voicing contrast exists where harder to perceive (**ap** vs. **ab**), should also exist where easier to perceive (**pa** vs. **ba**)

Perceptual Naturalness Bias

- Final devoicing = natural: contrast only where easier to hear (# __)
 - **pan, ban**, nap, ~~nab~~
- Initial devoicing = unnatural: contrast only where harder to hear (__ #)
 - pan, ~~ban~~, **nap, nab**
- Naturalness bias could explain why final devoicing languages common and initial devoicing languages non-existent
- In this case, naturalness bias **perceptual**

Naturalness Bias

- Devoicing more natural than voicing (at word edges)
 - **Articulatorily** motivated
- Voicing contrast only word-initially more natural than voicing contrast only word-finally
 - **Perceptually** motivated

Are learners biased against word-edge voicing and having a voicing contrast only word-finally?

Testing for Learning Biases

- Artificial Grammar Learning (AGL) experiments
 - Teach participants mini made-up languages
 - Can carefully control mini languages
 - Compare how well they're learned
 - Differences in learning → evidence for learning bias

Testing for Learning Biases

- Typological asymmetries in voicing restated:
 1. If a language has a stop voicing contrast word-finally (**ap** vs. **ab**), then it also has a contrast word-initially (**pa** vs. **ba**)
 2. If a language has voiced stops (/b d g/) in a given word-edge position, then it also has voiceless stops (/p t k/) in that position

Testing for Learning Biases

- If people prefer to learn phonetically natural phonological patterns:
 1. If a language has a stop voicing contrast word-finally (**ap** vs. **ab**), then it also has a contrast word-initially (**pa** vs. **ba**)
 - Exposed to a word-final stop voicing contrast (**ap** vs. **ab**) → assume a word-initial stop voicing contrast too (**pa** vs. **ba**)
 2. If a language has voiced stops (/b d g/) in a given word-edge position, then it also has voiceless stops (/p t k/) in that position
 - Exposed to /b d g/ in a word-edge position → assume /p t k/ there too

Experiment 1

- An AGL experiment testing for naturalness bias in the learning of the distribution of voiced and voiceless stops
 - Expose subjects to stop voicing contrast in #__ (pa vs. ba) or __# (ap vs. ab) and test if they **extend** contrast to other position
 - In position with no contrast, expose subjects to voiceless stops (/p t k/) or voiced stops (/b d g/) and test if they **extend** to the other

Experiment 1: Design

Table 1: Training Conditions

	#T	#D	T#	D#
Final Contrast-Initial Voiced	X	✓	✓	✓
<i>Final Contrast-Initial Voiceless</i>	✓	X	✓	✓
Initial Contrast-Final Voiced	✓	✓	X	✓
<i>Initial Contrast-Final Voiceless</i>	✓	✓	✓	X

Experiment 1: Design

Table 1: Training Conditions

	#T	#D	T#	D#
<i>D...T/D</i>	X	✓	✓	✓
<i>T...T/D</i>	✓	X	✓	✓
<i>T/D...D</i>	✓	✓	X	✓
<i>T/D...T</i>	✓	✓	✓	X

Experiment 1: Design

Table 2: Sample Training Items in
Final Contrast-Initial Voiced (D...T/D)

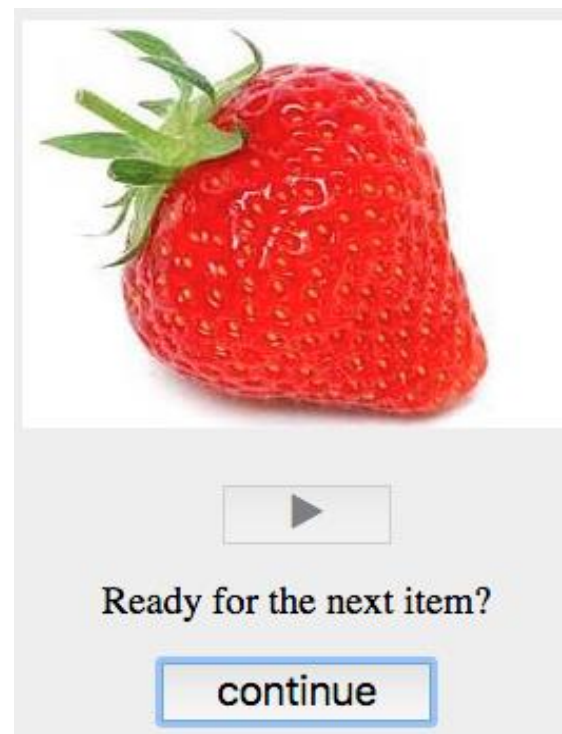
#T	#D	T#	D#
	b ímir d irín g awám ...	míw i p niw í t nuw á k ...	míw i b mir í d nuw á g ...

Experiment 1: Procedure

- Training phase
 - Subjects listened to words of a new language
 - 2 blocks of the same 36 training items
 - Each item paired with an image

Experiment 1: Procedure

- Training phase

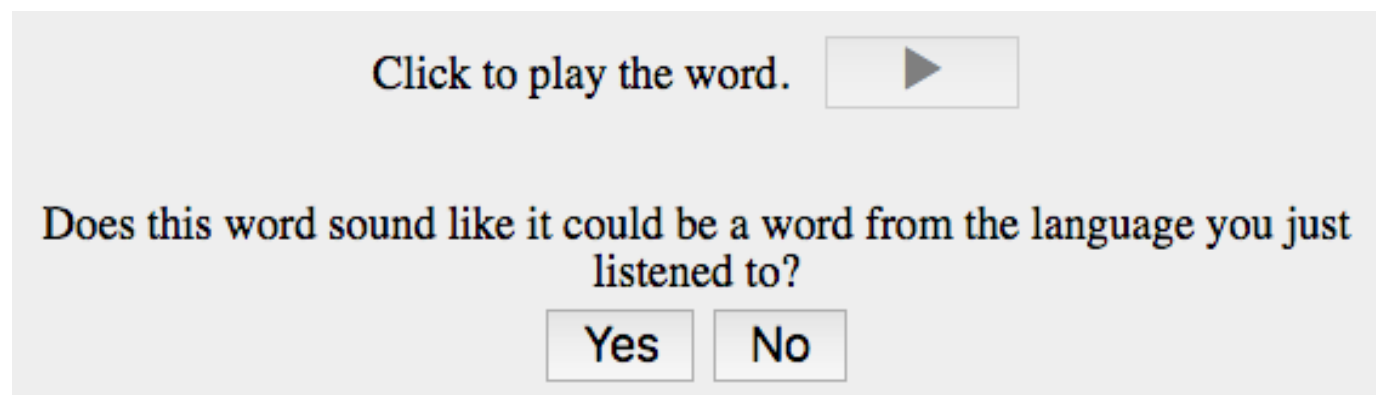
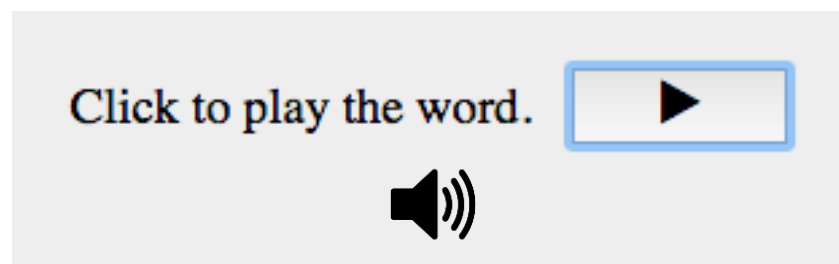


Experiment 1: Procedure

- Test phase
 - Subjects listened to additional words
 - Had to say if they could be words of the language they had been listening to or not
 - 1 block of 48 test items: #T, #D, T#, D# (same for all conditions)
 - No images

Experiment 1: Procedure

- Test phase



Experiment 1: Design

- Three types of test items
 - *Familiar Conforming*: repeated training items
 - *Novel Conforming*: new items that fit the training pattern
 - *Novel Nonconforming*: new items that do not fit the training pattern

Experiment 1: Design

Table 3: Sample Test Items for Each Training Condition

	Familiar Conforming	Novel Conforming	Novel Nonconforming
Final Contrast-Initial Voiced	nimáp	rínup	pírum
<i>Final Contrast-Initial Voiceless</i>	nimáp	rínup	bírum
Initial Contrast-Final Voiced	kawám	kámir	múlik
<i>Initial Contrast-Final Voiceless</i>	kawám	kámir	múlig

Experiment 1: Predictions

- Accepting Novel Nonconforming items = **EXTENSION**
 - **Extending** stop voicing contrast to new position
 - **Extending** from stops with one voicing value to stops with other voicing value

Experiment 1: Predictions

- Extending stop voicing contrast to new position

Final Contrast-Initial Voiced (D...T/D) Condition

#T	#D	T#	D#
	bímir dirín gawám ...	míwip niwít nuwák ...	míwib miríd nuwág ...

Experiment 1: Predictions

- Extending stop voicing contrast to new position

Final Contrast-Initial Voiced (D...T/D) Condition

#T	#D	T#	D#
páwin ✓	bímir	míwip	míwib
tijún ✓	dirín	niwít	miríd
kuníl ✓	gawám	nuwák	nuwág
...

Experiment 1: Predictions

- Extending stop voicing contrast to new position

Final Contrast-Initial Voiced (D...T/D) Condition

#T	#D	T#	D#
páwin X	bímir	míwip	míwib
tijún X	dirín	niwít	miríd
kuníl X	gawám	nuwák	nuwág
...

Experiment 1: Predictions

- Extending from one stop type to the other

Final Contrast-Initial Voiced (D...T/D) Condition

#T	#D	T#	D#
	bímir dirín gawám ...	míwip niwít nuwák ...	míwib miríd nuwág ...

Experiment 1: Predictions

- Extending from one stop type to the other

Final Contrast-Initial Voiced (D...T/D) Condition

#T	#D	T#	D#
páwin ✓	bímir	míwip	míwib
tijún ✓	dirín	niwít	miríd
kuníl ✓	gawám	nuwák	nuwág
...

Experiment 1: Predictions

- Extending from one stop type to the other

Final Contrast-Initial Voiced (D...T/D) Condition

#T	#D	T#	D#
páwin X	bímir	míwip	míwib
tijún X	dirín	niwít	miríd
kuníl X	gawám	nuwák	nuwág
...

Experiment 1: Predictions

- Rejecting Novel Nonconforming items = accurate learning
- **Extending** to Novel Nonconforming items reveals what subjects assume about voicing in their training language

Experiment 1: Predictions

- Perceptual, position-based naturalness bias
 - Final voicing contrast only = unnatural
 - Initial voicing contrast only = natural

Experiment 1: Predictions

- Perceptual, position-based naturalness bias

Final Contrast → Initial Contrast

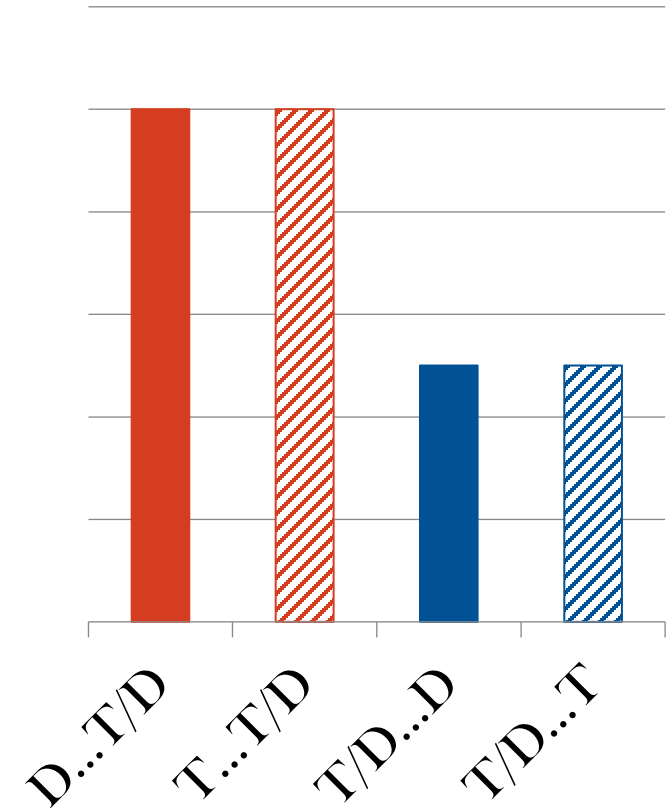
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Initial Contrast → Final Contrast

More
extension



Acceptance Rate of Novel
Nonconforming Items



Experiment 1: Predictions

- Articulatory, voicing-based naturalness bias
 - Voiced stops only = unnatural
 - Voiceless stops only = natural

Experiment 1: Predictions

- Articulatory, voicing-based naturalness bias

Voiced /b d g/ → **Voiceless** /p t k/

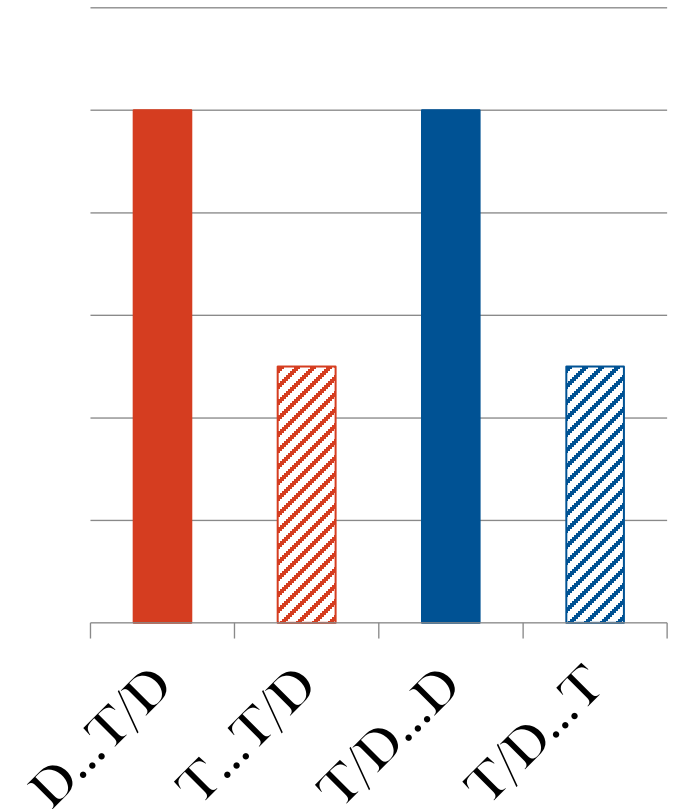
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Voiceless /p t k/ → *Voiced* /b d g/

More
extension



Acceptance Rate of Novel
Nonconforming Items



Experiment 1: Results

- Tested 149 native English-speaking subjects
- Acceptance rates of Familiar Conforming items around 80%
- Acceptance rates of Novel Conforming items around 60%

Experiment 1: Results

- Perceptual, position-based naturalness bias

Final Contrast → Initial Contrast

>

Initial Contrast → Final Contrast?

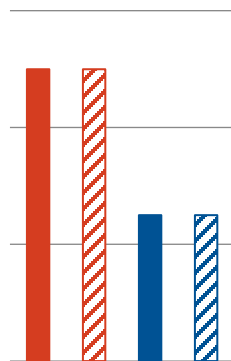
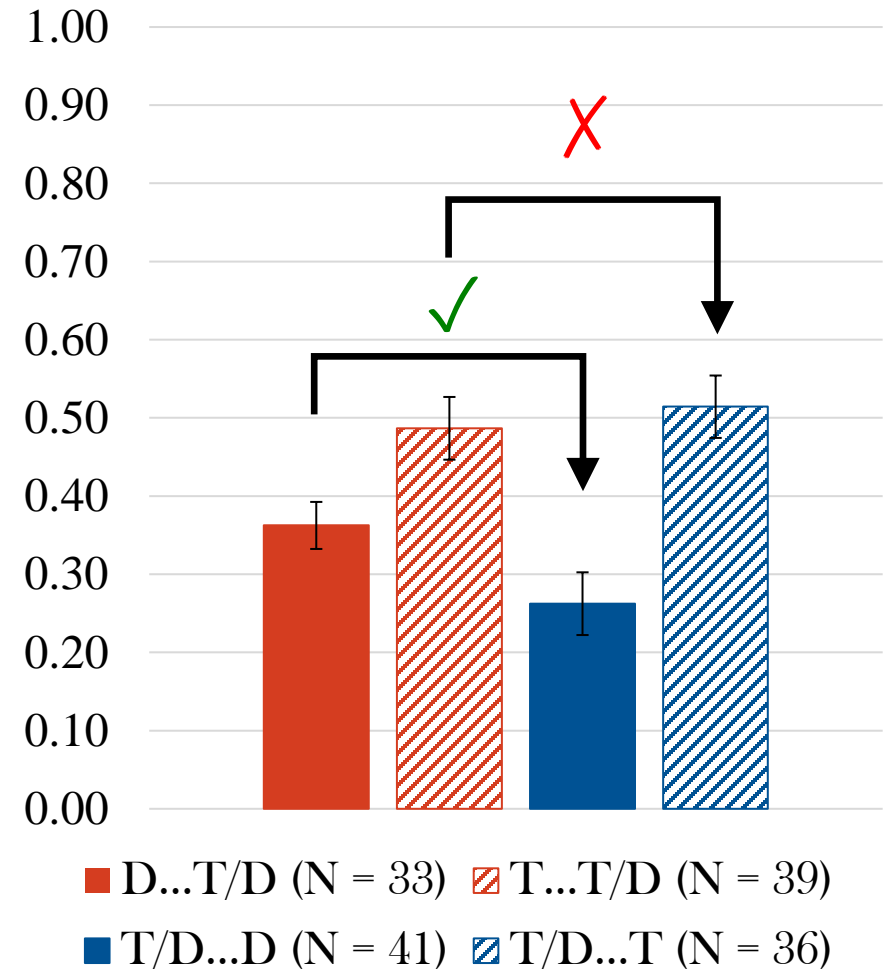


Figure 1: Acceptance Rate of Novel Nonconforming Items by Condition



Experiment 1: Results

- Perceptual, position-based naturalness bias
- Greater extension of voicing contrast from **Final** to **Initial** than vice versa?
 - No, not consistently

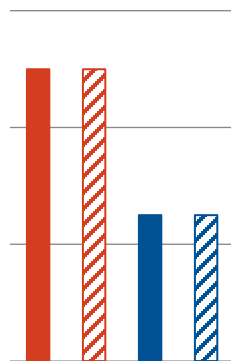
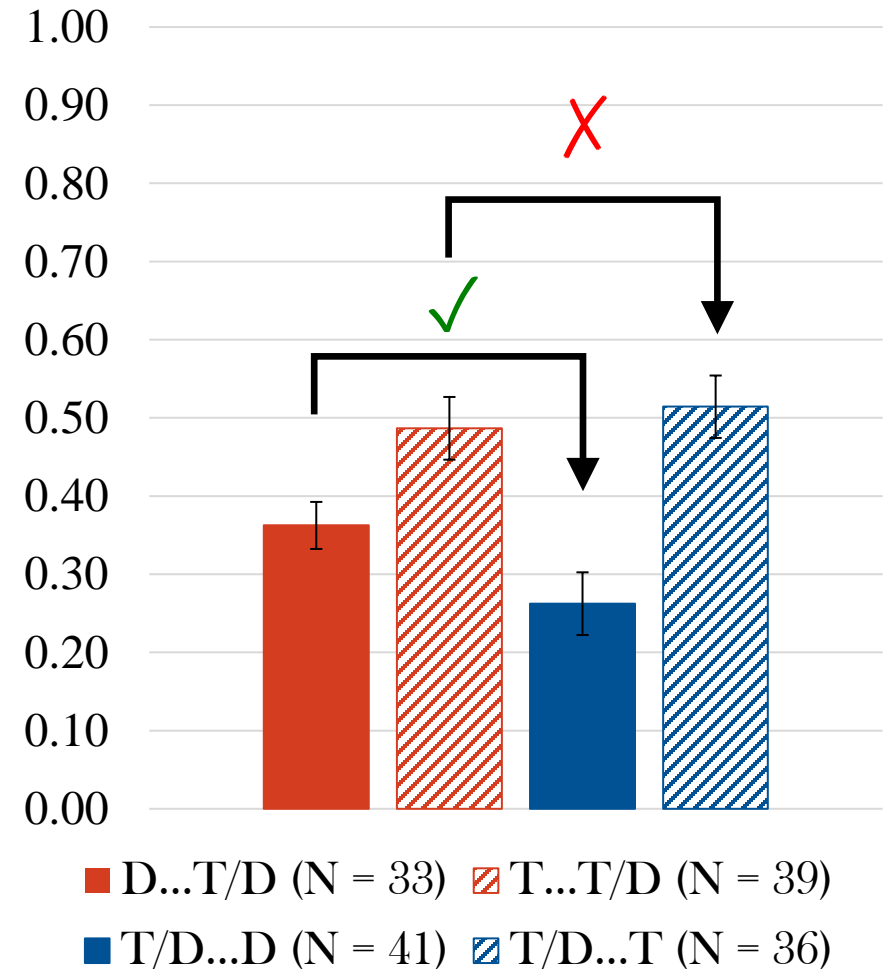


Figure 1: Acceptance Rate of Novel Nonconforming Items by Condition



Experiment 1: Results

- Articulatory, voicing-based naturalness bias

Voiced /b d g/ → **Voiceless** /p t k/
>

Voiceless /p t k/ → *Voiced* /b d g/?

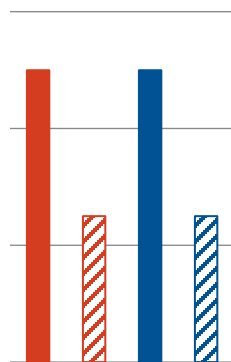
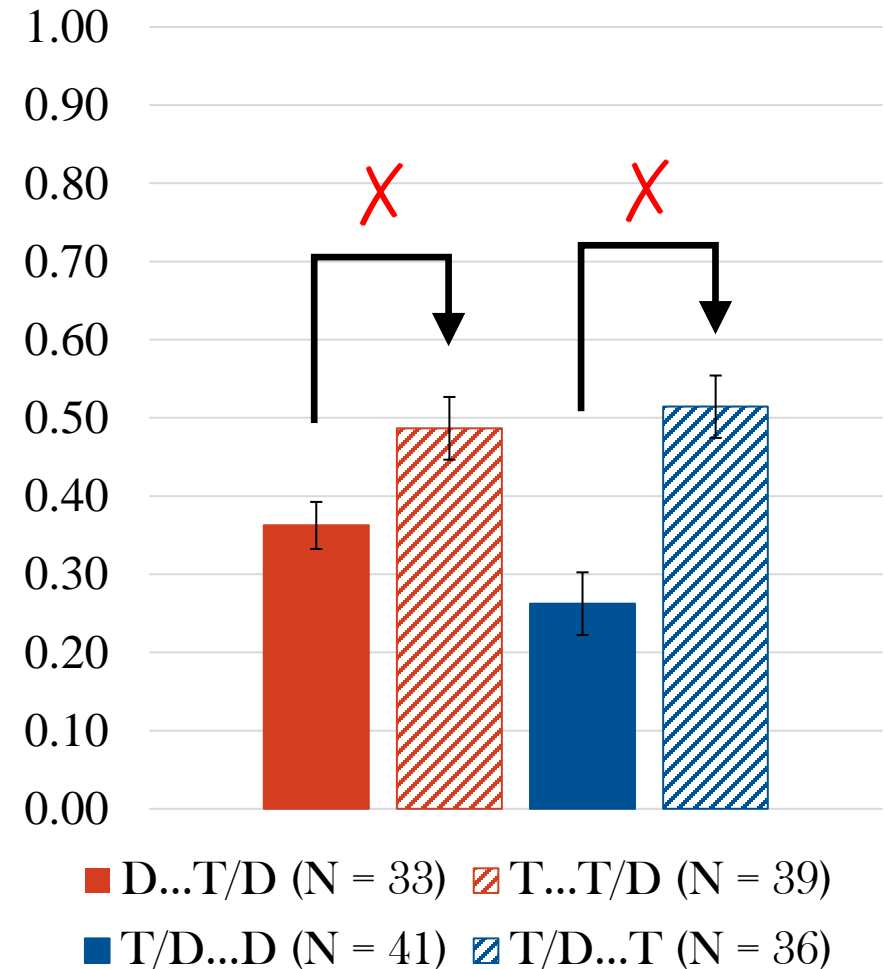


Figure 1: Acceptance Rate of Novel Nonconforming Items by Condition



Experiment 1: Results

- Articulatory, voicing-based naturalness bias
- Greater extension from **Voiced** to *Voiceless* than vice versa?
 - No, the opposite!

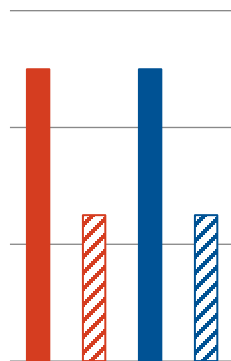
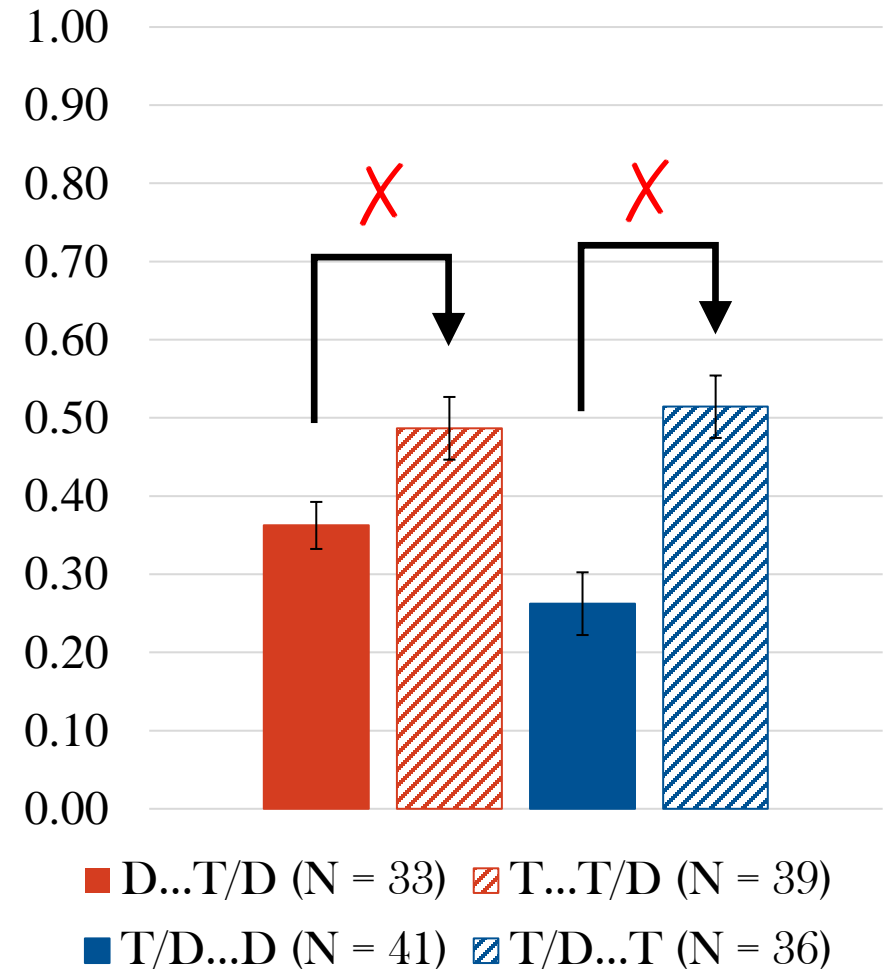


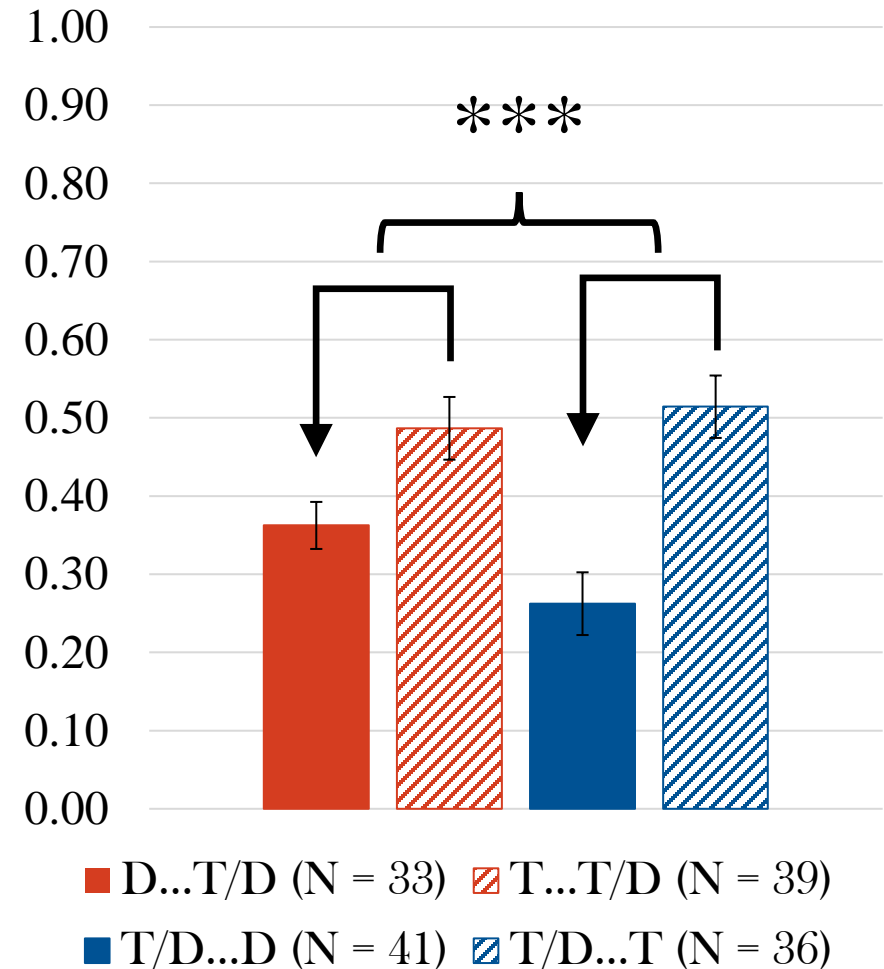
Figure 1: Acceptance Rate of Novel Nonconforming Items by Condition



Experiment 1: Results

- Instead, greater extension from *Voiceless* (easier to produce) to *Voiced* (harder to produce)
- Articulatorily unnatural

Figure 1: Acceptance Rate of Novel Nonconforming Items by Condition



Experiment 1: Discussion

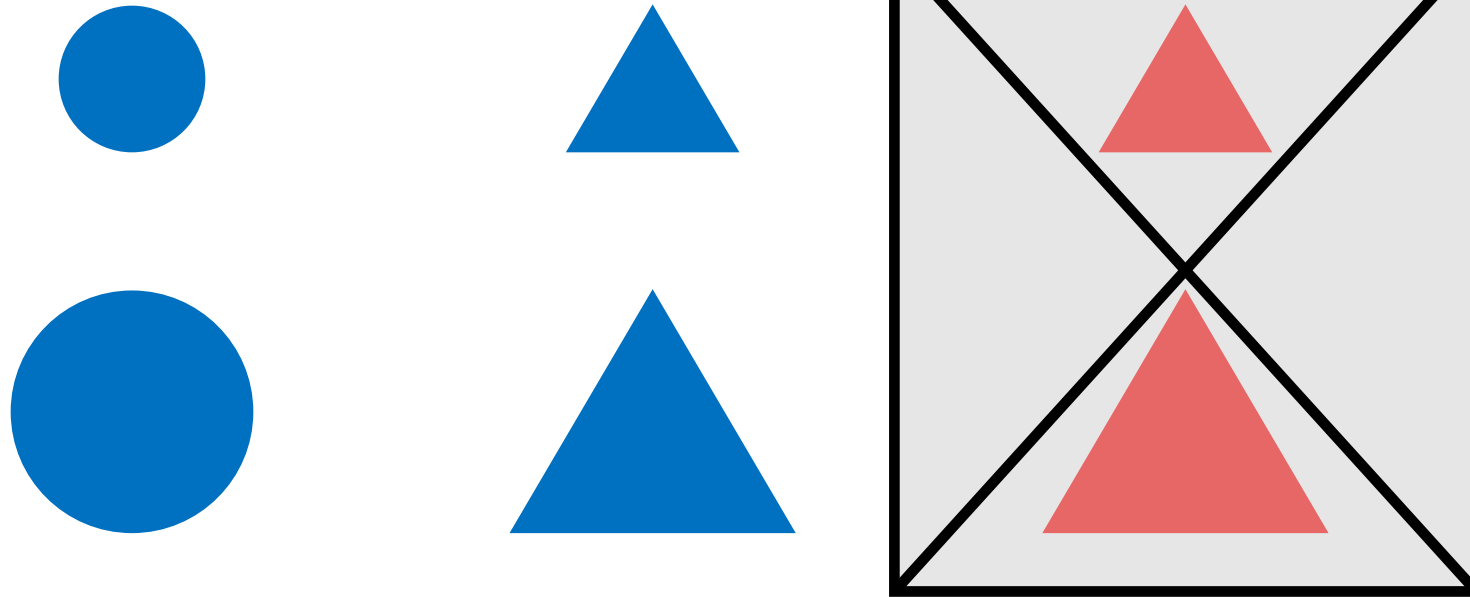
- Why did subjects extend more from voiceless stops /p t k/ to voiced stops /b d g/ than vice versa?
- Complexity bias!

Complexity Bias

- General bias, not specific to sound patterns
- Restrictions that are more complex (= require more features to state) are harder to learn

Complexity Bias¹

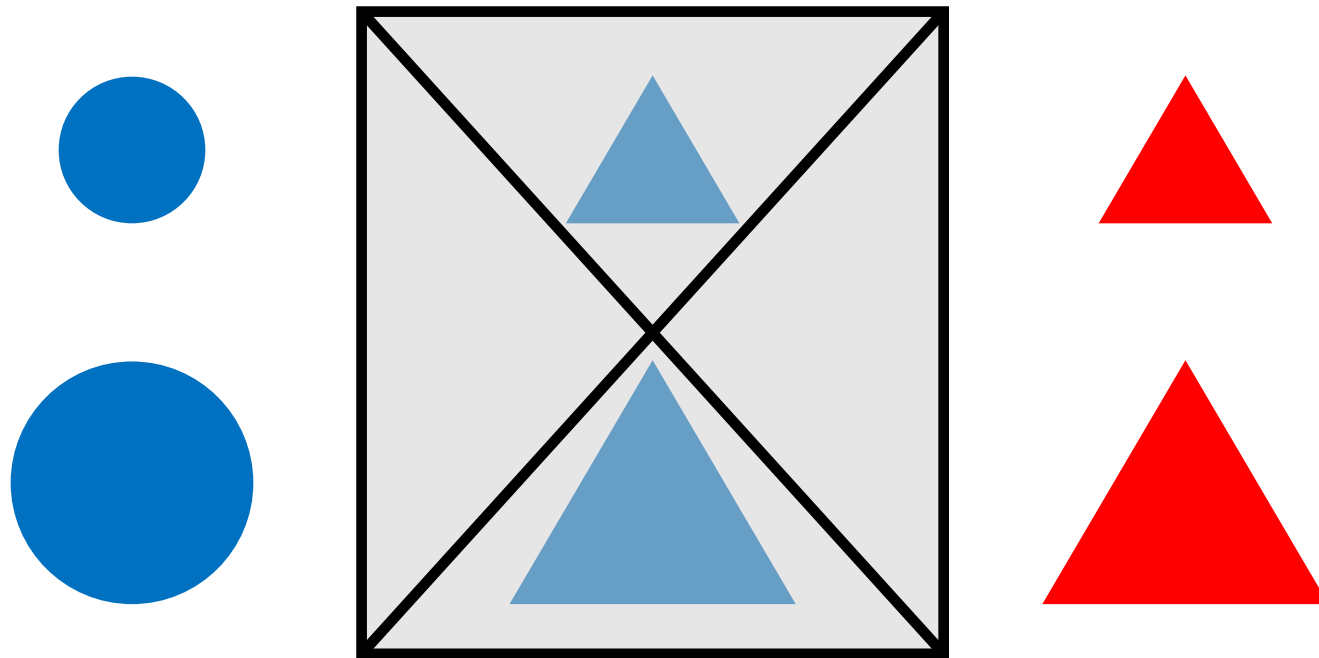
- Include: blue circles, blue triangles; exclude: red triangles
- Restriction: *[+red]



¹Cf. Moreton & Pater 2012a, Shepard, Hovland, & Jenkins 1961

Complexity Bias¹

- Include: blue circles, red triangles; exclude: blue triangles
- Restriction: *[+triangle, +blue]



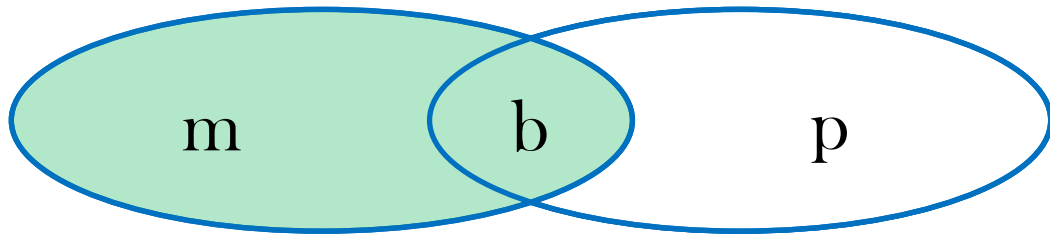
¹Cf. Moreton & Pater 2012a, Shepard, Hovland, & Jenkins 1961

Experiment 1: Discussion

- Why did subjects extend more from voiceless stops /p t k/ to voiced stops /b d g/ than vice versa?
- Complexity bias!
- Restriction needed to reject Novel Nonconforming items in *Voiceless* conditions more complex than restriction needed in **Voiced** conditions

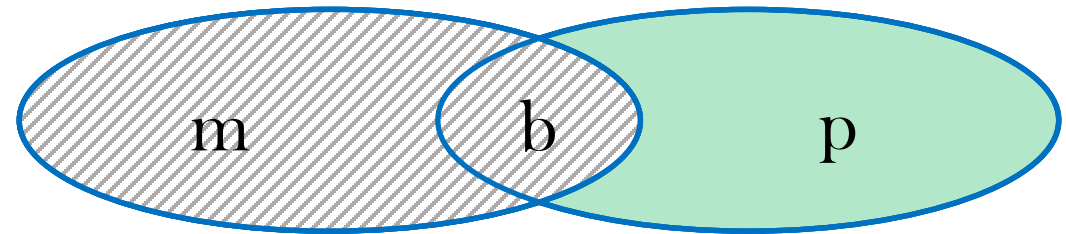
Experiment 1: Discussion

- **Initial Contrast-Final Voiced:**



kawám ✓ míwib ✓ míwip ✗
*[-voice]#

- ***Initial Contrast-Final Voiceless:***



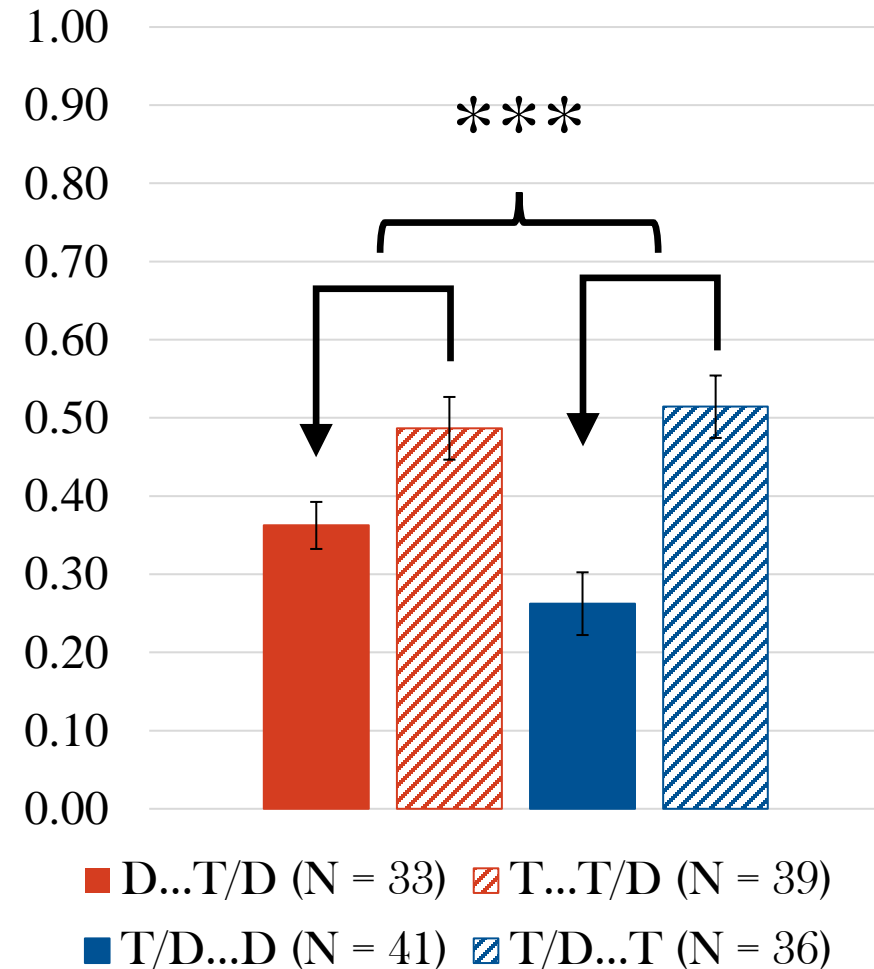
kawám ✓ míwib ✗ míwip ✓
*[+voice]#

- Harder to reject Novel Nonconforming items in *Voiceless* conditions
→ more extension in *Voiceless* conditions

Experiment 1: Discussion

- Perceptual, position-based naturalness bias ✗
- Articulatory, voicing-based naturalness bias ✗
- Complexity bias ✓

Figure 1: Acceptance Rate of Novel Nonconforming Items by Condition



Experiment 1: Discussion

- How to confirm complexity bias account correct?
- Complexity bias story for Experiment 1 depends on non-stop consonants (i.e. sonorants) being [+voice]
- If non-stop consonants [–voice], complexity bias prediction reverses

Experiment 2: Design

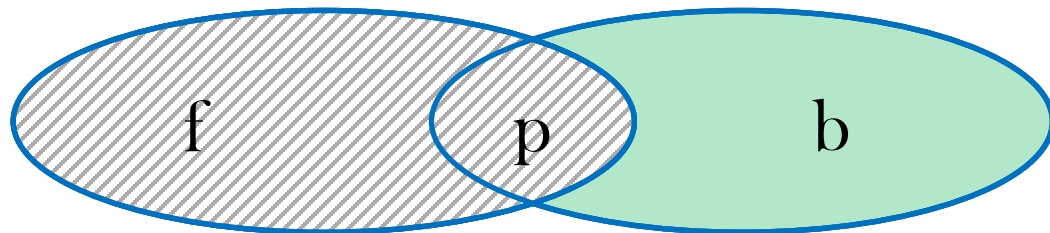
- Redo Experiment 1, but convert voiced sonorants to voiceless fricatives

Table 3: Sample Training Items in
Final Contrast-Initial Voiced (D...T/D)

#T	#D	T#	D#
	bífis disíθ gafáf ...	físip ʃaθít θuʃák ...	físib fisíd θuʃág ...

Experiment 2: Predictions

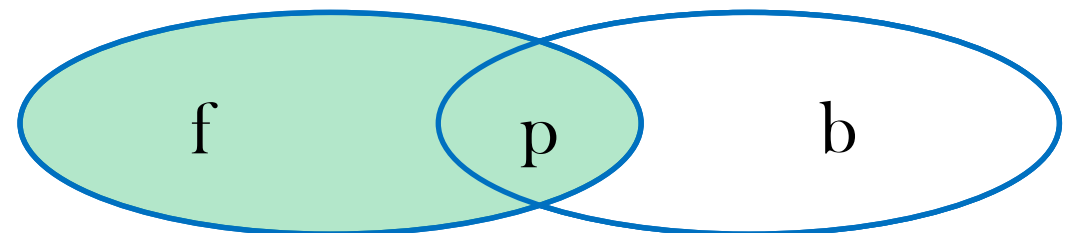
- **Initial Contrast-Final Voiced:**



túsif ✓ físip ✗ físb ✓

*[-voice]#

- *Initial Contrast-Final Voiceless:*



túsif ✓ físip ✓ físb ✗

*[+voice]#

- Harder to reject Novel Nonconforming items in **Voiced** conditions → more extension in **Voiced** conditions

Experiment 2: Predictions

- Complexity bias
 - Harder to reject voiceless stops than voiced stops
 - More extension from voiced stops to voiceless stops than vice versa

Experiment 2: Predictions

- Complexity bias

Voiced /b d g/ → **Voiceless** /p t k/

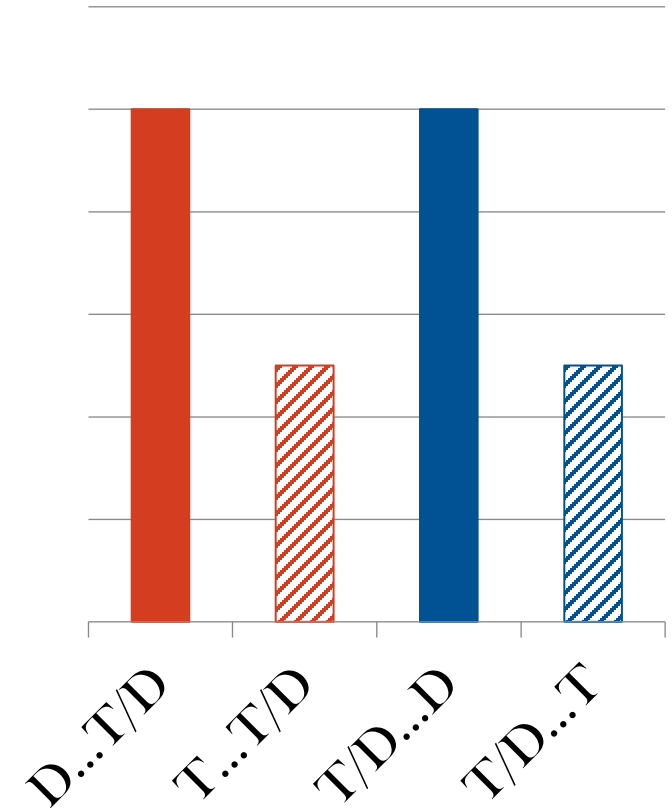
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Voiceless /p t k/ → *Voiced* /b d g/

More
extension



Acceptance Rate of Novel
Nonconforming Items



Experiment 2: Results

- Tested 144 native English-speaking subjects
- Acceptance rates of Familiar Conforming items around 80%
- Acceptance rates of Novel Conforming items around 60%

Experiment 2: Results

- Complexity bias

Voiced /b d g/ → **Voiceless** /p t k/

>

Voiceless /p t k/ → *Voiced* /b d g/?

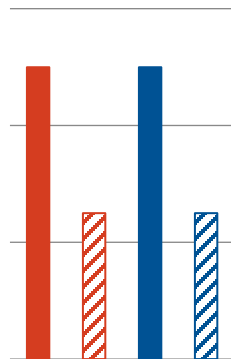
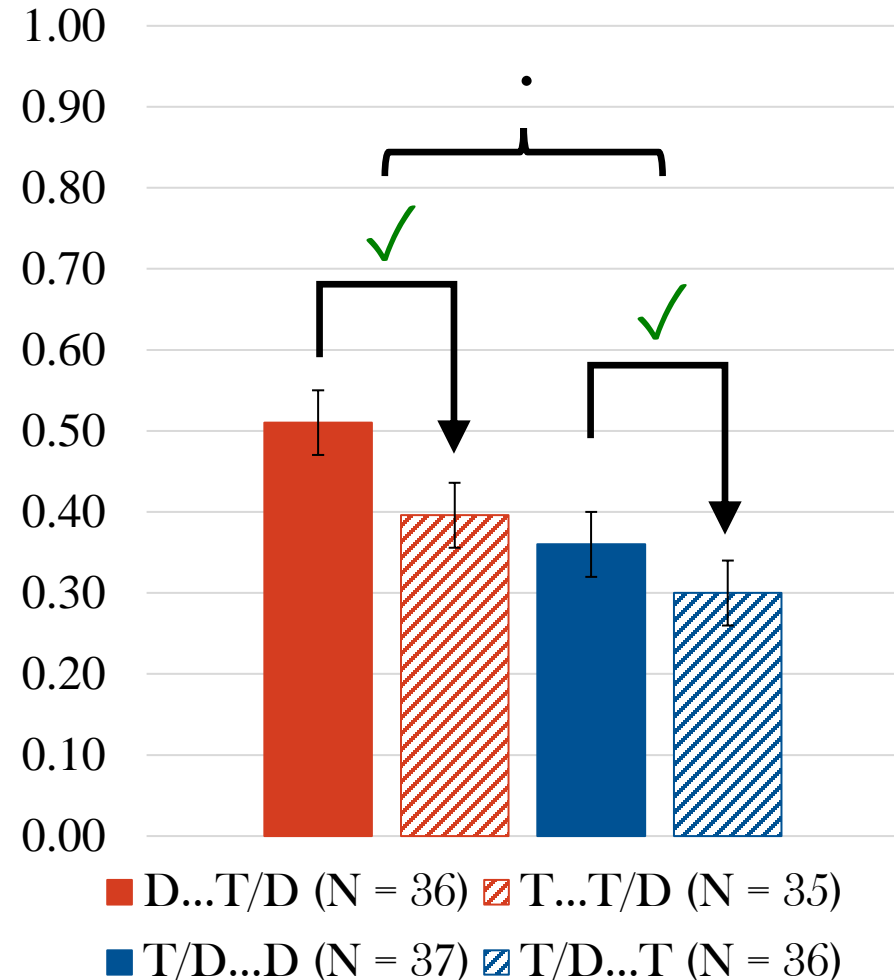


Figure 2: Acceptance Rate of Novel Nonconforming Items by Condition



Experiment 2: Results

- Complexity bias
- Greater extension from **Voiced** to *Voiceless* than vice versa?
 - Yes

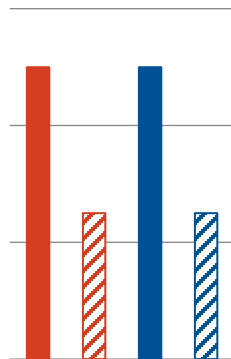
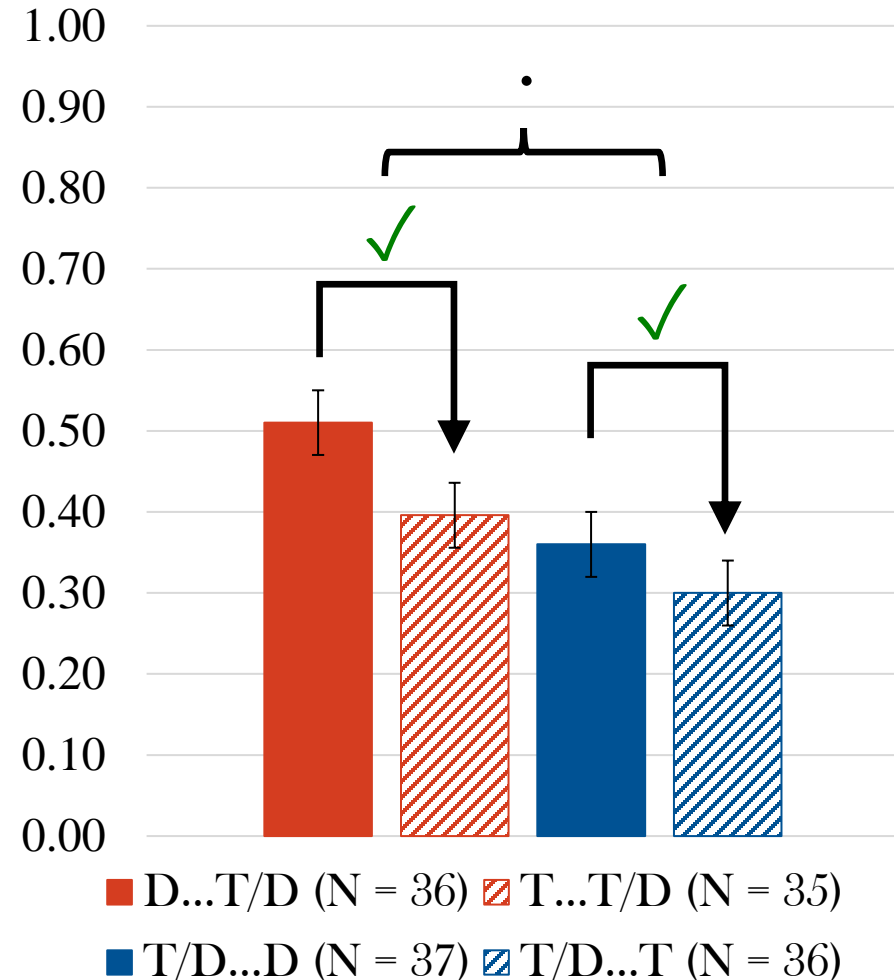


Figure 2: Acceptance Rate of Novel Nonconforming Items by Condition



Experiment 2: Results

- Perceptual, position-based naturalness bias

Final Contrast → Initial Contrast

>

Initial Contrast → Final Contrast?

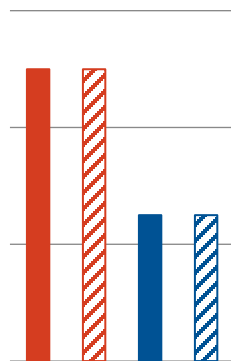
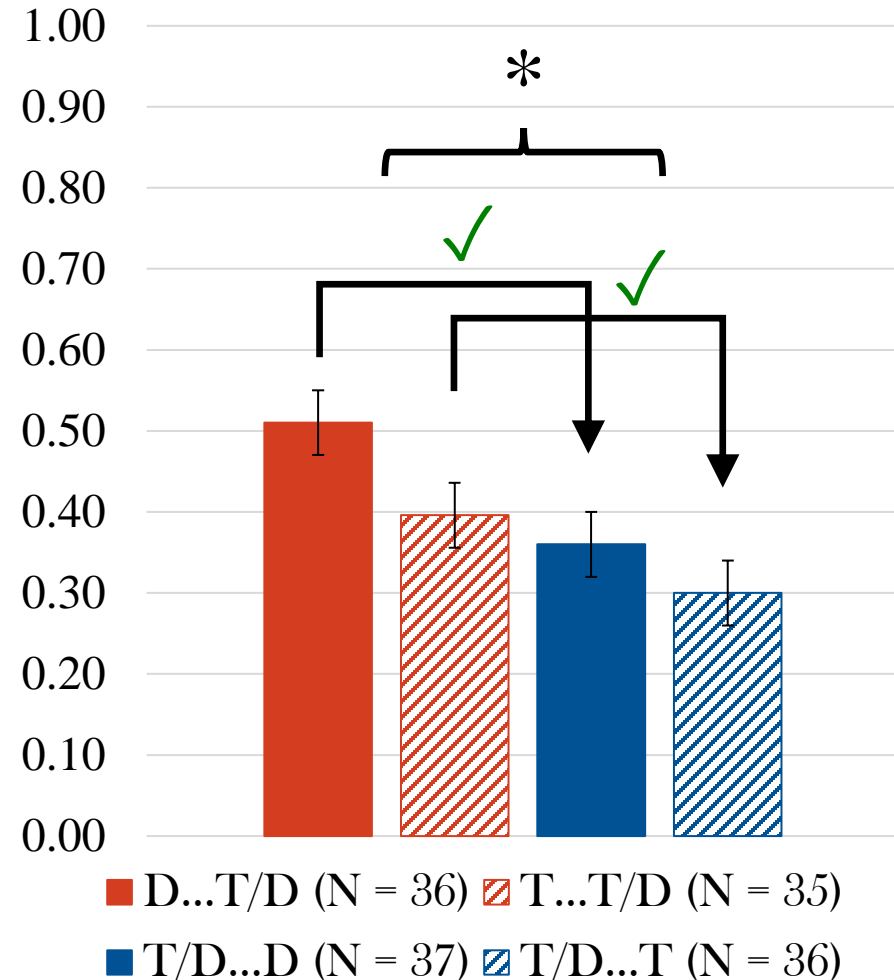


Figure 2: Acceptance Rate of Novel Nonconforming Items by Condition



Experiment 2: Results

- Perceptual, position-based naturalness bias
- Greater extension of voicing contrast from **Final** to **Initial** than vice versa?
 - Yes

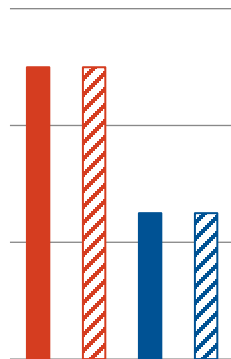
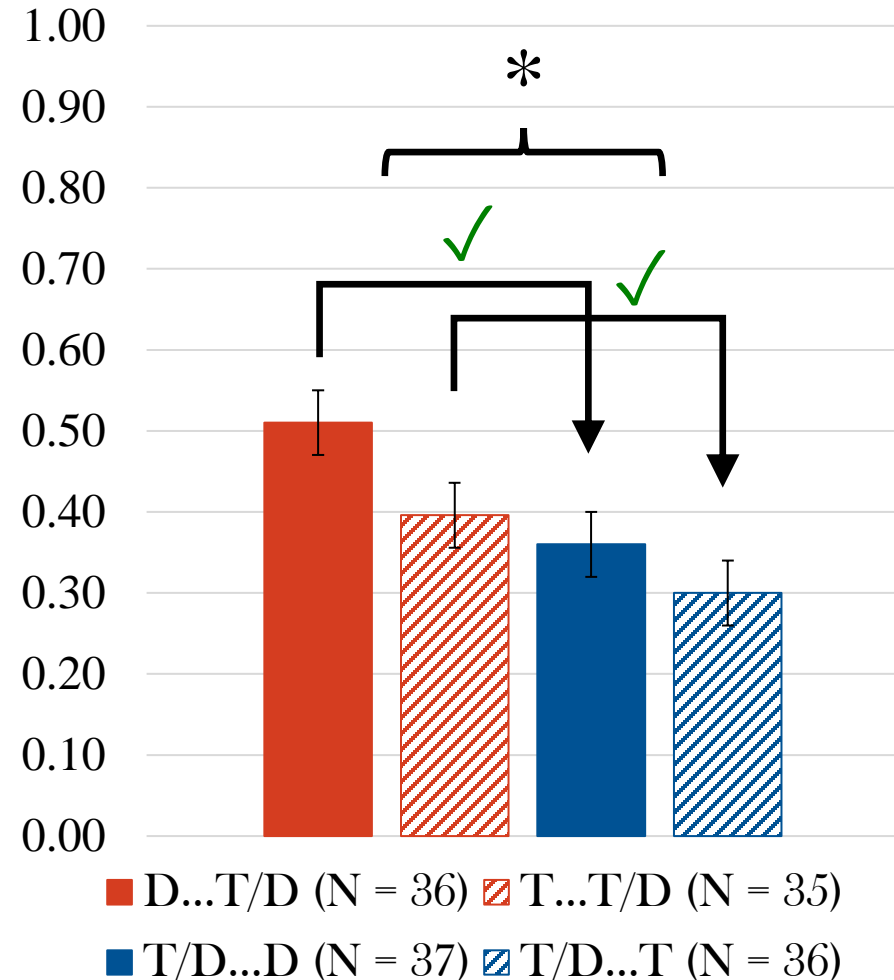


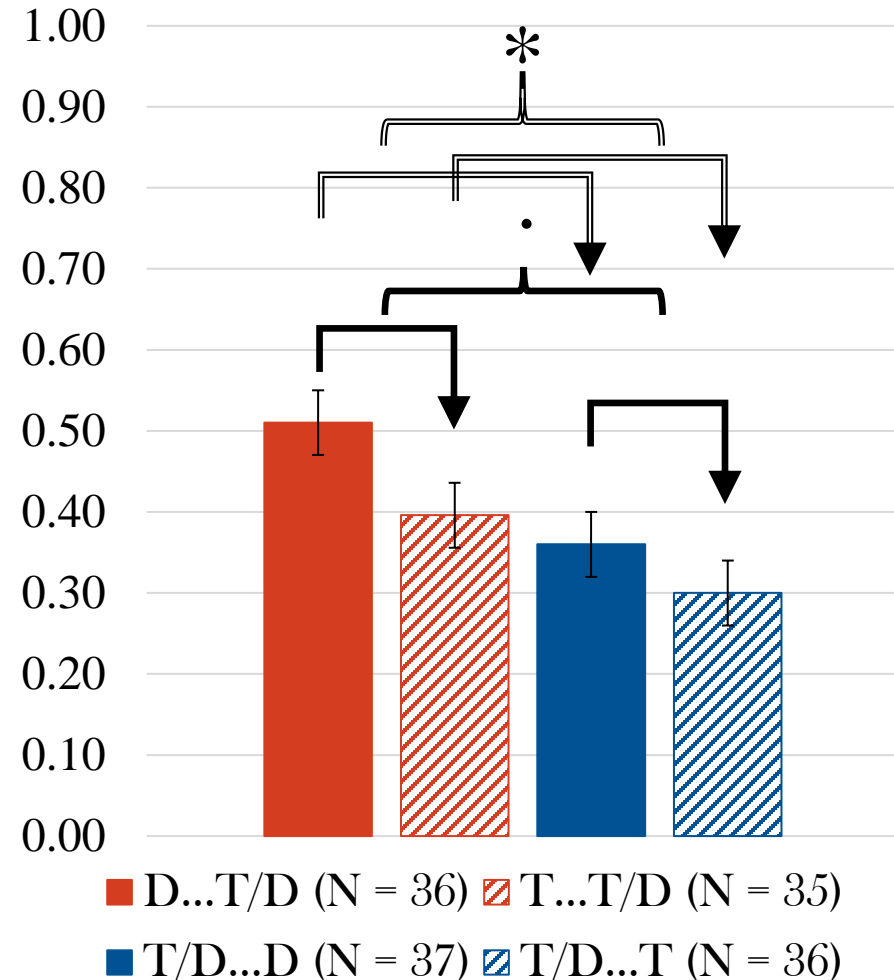
Figure 2: Acceptance Rate of Novel Nonconforming Items by Condition



Experiment 2: Discussion

- Complexity bias ✓
- Perceptual, position-based naturalness bias ✓

Figure 2: Acceptance Rate of Novel Nonconforming Items by Condition



Experiment 2: Discussion

- Flipping voicing of non-stop consonants reversed complexity bias prediction:

➤ Experiment 1:

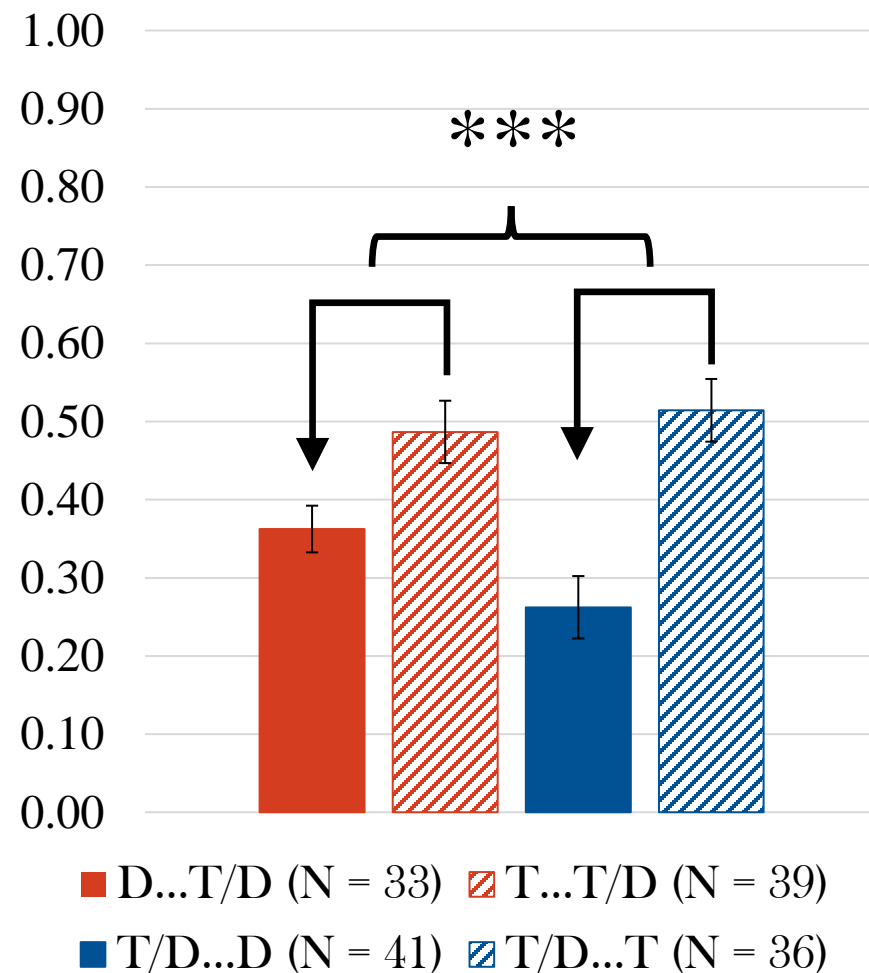
Voiceless /p t k/ → *Voiced* /b d g/

>

Voiced /b d g/ → *Voiceless* /p t k/



Figure 1: Acceptance Rate of Novel Nonconforming Items by Condition



Experiment 2: Discussion

- Flipping voicing of non-stop consonants reversed complexity bias prediction:

➤ Experiment 2:

Voiced /b d g/ → **Voiceless** /p t k/

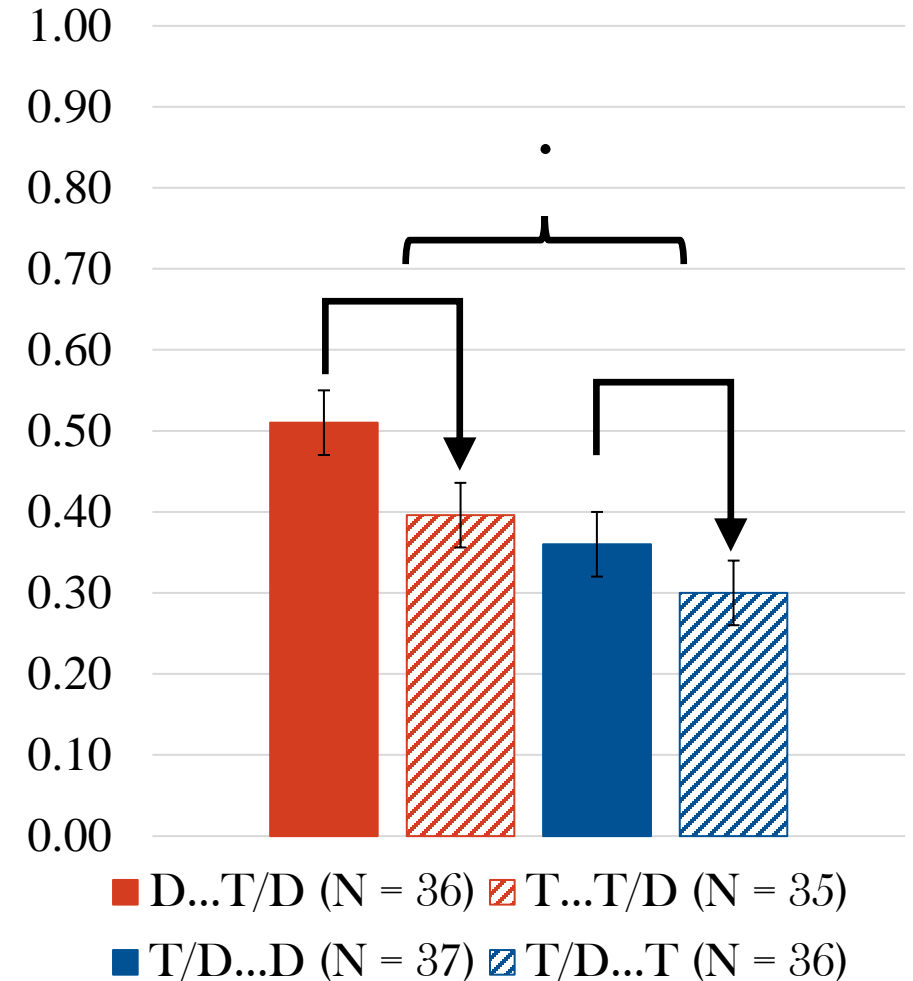
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Voiceless /p t k/ → *Voiced* /b d g/



- Confirms complexity bias account of Experiment 1

Figure 2: Acceptance Rate of Novel Nonconforming Items by Condition



Experiments 1 and 2

- Are learners biased against stop voicing contrast only word-finally?
- Mixed evidence for this perceptual, position-based naturalness bias:
 - Experiment 1: Subjects did not consistently extend voicing contrast more from **Final** position to **Initial** position
 - Experiment 2: Subjects *did* extend voicing contrast more from **Final** position to **Initial** position

Experiments 1 and 2

- Are learners biased against word-edge voicing?
- No evidence for this articulatory, voicing-based naturalness bias:
 - Experiment 2: Articulatory naturalness bias and complexity bias make same predictions
 - Results consistent with both
 - Experiment 1: Articulatory naturalness bias and complexity bias make opposite predictions
 - Results support complexity bias
 - Complexity bias in *both* experiments

The Big Picture: Naturalness Bias

- Evidence for naturalness bias hard to find¹
- Many null results
- Is naturalness bias real?
- Distinguish types of naturalness bias?
 - Experiments 1 and 2: some evidence for perceptual naturalness bias, none for articulatory naturalness bias

¹Moreton & Pater 2012b

The Big Picture: Naturalness Bias

- Positive results:

Perceptual	Articulatory
Wilson 2006 Carpenter 2006 Finley 2012 Finley & Badecker 2012 White 2013 Kimper 2016 Greenwood 2016	Shapp 2012 Baer-Henney 2015

The Big Picture: Naturalness Bias

- Null results:

Perceptual	Articulatory
Carpenter 2006	Pycha et al. 2003
Finley 2008	Saffran & Thiessen 2003
Finley & Badecker 2009	Seidl & Buckley 2005
Greenwood 2016	Peperkamp & Dupoux 2007
	Skoruppa & Peperkamp 2011
	Myers & Padgett 2014
	Greenwood 2016
	Do, Zsiga, & Havenhill 2016
	Glewwe et al. 2018
	Lysvik 2018

The Big Picture: Naturalness Bias

	Perceptual	Articulatory
Positive Results	<p>Wilson 2006 Carpenter 2006 Finley 2012 Finley & Badecker 2012 White 2013 Kimper 2016 Greenwood 2016</p>	<p>Shapp 2012 Baer-Henney 2015</p>
Null Results	<p>Carpenter 2006 Finley 2008 Finley & Badecker 2009 Greenwood 2016</p>	<p>Pycha et al. 2003 Saffran & Thiessen 2003 Seidl & Buckley 2005 Peperkamp & Dupoux 2007 Skoruppa & Peperkamp 2011 Myers & Padgett 2014 Greenwood 2016 Do, Zsiga, & Havenhill 2016 Glewwe et al. 2018 Lysvik 2018</p>

The Big Picture: Naturalness Bias

- A novel proposal:

Only perceptual naturalness biases phonological learning,
not articulatory naturalness.

What's the Latest?

- An experiment with voiced *and* voiceless non-stop consonants

- **Initial Contrast-Final Voiced:**

➤ kawám ✓ túsif ✓ míwib ✓



➤ *[-cont, -voice]#

- **Initial Contrast-Final Voiceless:**

➤ kawám ✓ túsif ✓  míwip ✓

➤ *[-son, +voice]#

- Neither voiceless stops nor voiced stops easier to reject → no effect of complexity bias ✓

What's the Latest?

- An experiment with voiced *and* voiceless non-stop consonants
- Articulatory, voicing-based naturalness bias:
 - Not confounded with complexity bias
 - Need not overcome complexity bias
 - Confirm lack of an effect ✓

Takeaways

- Two experiments yielded some evidence for perceptual naturalness bias and good evidence for complexity bias in phonological learning
- Sound inventory of an artificial language crucially affects subjects' behavior
- Naturalness bias should be broken down into perceptual vs. articulatory
- Evidence suggests only perceptual naturalness bias may exist

Thank you!

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