Bias in the Learning of Sound Patterns: An Experimental Investigation

Eleanor Glewwe
UCLA
Carleton College
May 15, 2019
Loanword adaptation

<table>
<thead>
<tr>
<th>English</th>
<th>Word IPA</th>
<th>Word Characters</th>
<th>Syllable</th>
<th>Syllable Pinyin</th>
<th>Tone</th>
</tr>
</thead>
<tbody>
<tr>
<td>snooker</td>
<td>ˈsnuː.kər*</td>
<td>斯诺克</td>
<td>Si1</td>
<td></td>
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<tr>
<td>marathon</td>
<td>ˈmæ.rəθən</td>
<td>马拉松</td>
<td>song1</td>
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<td>可的松</td>
<td>song1</td>
<td></td>
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<tr>
<td>bassoon</td>
<td>bəˈsuːn</td>
<td>巴松</td>
<td>song1</td>
<td></td>
<td>1</td>
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</tbody>
</table>

Phonetic variation

<table>
<thead>
<tr>
<th>Speaker</th>
<th>Word</th>
<th>Category</th>
<th>Stressed</th>
<th>VDur</th>
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</thead>
<tbody>
<tr>
<td>s01</td>
<td>different</td>
<td>AH</td>
<td>No</td>
<td>0.12273</td>
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<td>s01</td>
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<tr>
<td>s01</td>
<td>state</td>
<td>EY</td>
<td>Yes</td>
<td>0.06848</td>
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<tr>
<td>s01</td>
<td>get</td>
<td>EH</td>
<td>Yes</td>
<td>0.0556</td>
</tr>
</tbody>
</table>

Documenting and analyzing understudied languages

kutṣa kotṣa  ‘sunrise’

vutṣe ̀za ‘it’s dawning’

vitoṛga  sunris[e  ‘it dawned’

vutṣe  ‘good morning’
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
A Phonology Problem: Polish\textsuperscript{1}

<table>
<thead>
<tr>
<th>Singular</th>
<th>Plural</th>
<th>Gloss</th>
</tr>
</thead>
<tbody>
<tr>
<td>klup</td>
<td>klub-i</td>
<td>‘club’</td>
</tr>
<tr>
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<td>trud-i</td>
<td>‘labor’</td>
</tr>
<tr>
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<td>wug-i</td>
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\textsuperscript{1}Kenstowicz & Kisseberth 1979
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/klup/

Intervocalic voicing: voiceless stops → voiced stops / V__V

<table>
<thead>
<tr>
<th>Underlying form</th>
<th>/klup-i/ ‘club-PL’</th>
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</thead>
<tbody>
<tr>
<td>Intervocalic voicing</td>
<td>klub-i</td>
</tr>
<tr>
<td>Surface form</td>
<td>[klub-i] ✓</td>
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Final devoicing: voiced stops → voiceless stops / ___#

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Final devoicing: **voiced stops → voiceless stops** / ___#

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Final devoicing: voiced stops → voiceless stops / __#
Asymmetries in the Phonological Typology

• Final devoicing is common (Polish, German, Catalan, Turkish...)\textsuperscript{1,2}
  ➢ /klub/ → [klup] ‘club’ (cf. [klub-i] ‘club-PL’)

• Final voicing is virtually non-existent\textsuperscript{1,3}
  ➢ No cases like: /klup/ → [klub] (cf. [klup-i])

• The distribution of sound patterns in the world’s languages is asymmetric

• Why?

\textsuperscript{1}Lombardi 1991, \textsuperscript{2}Brockhaus 1995, \textsuperscript{3}Blevins 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): \(D \rightarrow T / \_\_\_#\)
  ➢/klub/ → [klup]

• Final voicing (non-existent): \(T \rightarrow D / \_\_\_#\)
  ➢/klup/ → [klub]
Articulatory Naturalness Bias

• **Voiced stops** harder to produce at word edges than **voiceless stops**
  ➢ 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**

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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):
  \(\text{pan, ban, nap, nab}\)

• Initial devoicing (non-existent):
  \(\text{pan, ban, nap, nab}\)

• If voiced stops harder to produce at word edges than voiceless stops, why no initial devoicing languages?

\(^1\)Steriade 1997, \(^2\)Lombardi 1999, \(^3\)Blevins 2004
Perceptual Naturalness Bias

- Acoustic cues to stop voicing better word-initially than word-finally\(^1\)

\(^1\)Steriade 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 ɡ/) 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 ɡ/) in a given word-edge position, then it also has voiceless stops (/p t k/) in that position
    ➢ Exposed to /b d ɡ/ 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 ɡ/) and test if they extend to the other
Table 1: Training Conditions

<table>
<thead>
<tr>
<th></th>
<th>#T</th>
<th>#D</th>
<th>T#</th>
<th>D#</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Final Contrast-Initial Voiced</strong></td>
<td>X</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td><strong>Final Contrast-Initial Voiceless</strong></td>
<td>✓</td>
<td>X</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td><strong>Initial Contrast-Final Voiced</strong></td>
<td>✓</td>
<td>✓</td>
<td>X</td>
<td>✓</td>
</tr>
<tr>
<td><strong>Initial Contrast-Final Voiceless</strong></td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>X</td>
</tr>
</tbody>
</table>
## Experiment 1: Design

### Table 1: Training Conditions

<table>
<thead>
<tr>
<th>Condition</th>
<th>#T</th>
<th>#D</th>
<th>T#</th>
<th>D#</th>
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</thead>
<tbody>
<tr>
<td>D...T/D</td>
<td>X</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>T...T/D</td>
<td>✓</td>
<td>X</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>T/D...D</td>
<td>✓</td>
<td>✓</td>
<td>X</td>
<td>✓</td>
</tr>
<tr>
<td>T/D...T</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>X</td>
</tr>
</tbody>
</table>
## Experiment 1: Design

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

<table>
<thead>
<tr>
<th>#T</th>
<th>#D</th>
<th>T#</th>
<th>D#</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>bímir</td>
<td>míwip</td>
<td>míwib</td>
</tr>
<tr>
<td></td>
<td>dirín</td>
<td>niwit</td>
<td>miríd</td>
</tr>
<tr>
<td></td>
<td>gawám</td>
<td>nuwák</td>
<td>nuwáŋ</td>
</tr>
</tbody>
</table>
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

![Diagram of click to play the word and a question: Does this word sound like it could be a word from the language you just listened to? Yes, No]
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

<table>
<thead>
<tr>
<th>Training Condition</th>
<th>Familiar Conforming</th>
<th>Novel Conforming</th>
<th>Novel Nonconforming</th>
</tr>
</thead>
<tbody>
<tr>
<td>Final Contrast-Initial Voiced</td>
<td>nimáp</td>
<td>rínup</td>
<td>pírum</td>
</tr>
<tr>
<td><strong>Final Contrast-Initial Voiceless</strong></td>
<td>nimáp</td>
<td>rínup</td>
<td>bírum</td>
</tr>
<tr>
<td>Initial Contrast-Final Voiced</td>
<td>kawám</td>
<td>kámir</td>
<td>múlik</td>
</tr>
<tr>
<td><strong>Initial Contrast-Final Voiceless</strong></td>
<td>kawám</td>
<td>kámir</td>
<td>múlìg</td>
</tr>
</tbody>
</table>
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

<table>
<thead>
<tr>
<th>Final Contrast-Initial Voiced (D...T/D) Condition</th>
</tr>
</thead>
<tbody>
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<td>#T</td>
</tr>
<tr>
<td>-----</td>
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</tr>
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Experiment 1: Predictions

- **Extending** stop voicing contrast to new position

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

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<td>kuníl ✓</td>
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- **Extending** stop voicing contrast to new position

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<td>páwin X</td>
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<td>míwip</td>
<td>niwít</td>
<td>nuwák</td>
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Experiment 1: Predictions

- Extending from one stop type to the other

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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

Initial Contrast → Final Contrast
Experiment 1: Predictions

• Articulatory, voicing-based naturalness bias

  ➢ Voiced stops only = unnatural

  ➢ Voiceless stops only = natural
Experiment 1: Predictions

- Articulatory, voicing-based naturalness bias

\[ \text{Voiced} /\text{b} \, \text{d} \, \text{g}/ \rightarrow \text{Voiceless} /\text{p} \, \text{t} \, \text{k}/ \]

\[ \rightarrow \]

\[ \text{Voiceless} /\text{p} \, \text{t} \, \text{k}/ \rightarrow \text{Voiced} /\text{b} \, \text{d} \, \text{g}/ \]

More extension
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

\[ \text{Final Contrast} \rightarrow \text{Initial Contrast} \]

\[ \text{Initial Contrast} \rightarrow \text{Final Contrast} \]?
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/ \(\rightarrow\) Voiceless /p t k/

Voiceless /p t k/ \(\rightarrow\) Voiced /b d g/?
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](image-url)
Experiment 1: Results

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

- Articulatorily unnatural
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 Bias\textsuperscript{1}

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

\textsuperscript{1}Cf. 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:**
  - m
  - b
  - p
  - kawá \(\checkmark\)
  - míwib \(\checkmark\)
  - míwip \(\times\)
  - \([-\text{voice}]\)

- **Initial Contrast-Final Voiceless:**
  - m
  - b
  - p
  - kawá \(\checkmark\)
  - míwib \(\times\)
  - míwip \(\checkmark\)
  - \([+\text{voice}]\)

- Harder to reject Novel Nonconforming items in **Voiceless** conditions
  \(\rightarrow\) more extension in **Voiceless** conditions
Experiment 1: Discussion

- Perceptual, position-based naturalness bias $\times$
- Articulatory, voicing-based naturalness bias $\times$
- Complexity bias $\checkmark$

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)

<table>
<thead>
<tr>
<th>#T</th>
<th>#D</th>
<th>T#</th>
<th>D#</th>
</tr>
</thead>
</table>
| bí fis | fisip | fisib |...
| disíθ | saθít | fisíd |...
| gafáf | θuʃák | θuʃág |...
| ... | ... | ... |...
Experiment 2: Predictions

• **Initial Contrast-Final Voiced:**

  \[\begin{array}{c}
  f \\
  p \\
  b \\
  \end{array}\]

  \[\begin{array}{c}
  \text{túsif }\checkmark \\
  \text{físip }\times \\
  \text{físib }\checkmark \\
  \end{array}\]

  *\([-\text{voice}]\)#


• **Initial Contrast-Final Voiceless:**

  \[\begin{array}{c}
  f \\
  p \\
  b \\
  \end{array}\]

  \[\begin{array}{c}
  \text{túsif }\checkmark \\
  \text{físip }\checkmark \\
  \text{físib }\times \\
  \end{array}\]

  *\([+\text{voice}]\)#

• 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/  

Voiceless /p t k/ → Voiced /b d g/
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

\[ \text{Voiced} /b \ d \ g/ \rightarrow \text{Voiceless} /p \ t \ k/ \]
\[ > \]

\[ \text{Voiceless} /p \ t \ k/ \rightarrow \text{Voiced} /b \ d \ g/ \]

![Figure 2: Acceptance Rate of Novel Nonconforming Items by Condition](image-url)
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 $\rightarrow$ Initial Contrast

Initial Contrast $\rightarrow$ Final Contrast?
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 ✓
Experiment 2: Discussion

• Flipping voicing of non-stop consonants reversed complexity bias prediction:
  ➢ Experiment 1:
  Voiceless /p t k/ → Voiced /b d ɡ/
  >
  Voiced /b d ɡ/ → Voiceless /p t k/
  ✓
Experiment 2: Discussion

• Flipping voicing of non-stop consonants reversed complexity bias prediction:
  ➢ Experiment 2:
  Voiced /b d ɡ/ → Voiceless /p t k/
  >
  Voiceless /p t k/ → Voiced /b d ɡ/
  ✓

• Confirms complexity bias account of Experiment 1
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 find\(^1\)
- 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

\(^1\)Moreton & Pater 2012b
The Big Picture: Naturalness Bias

- Positive results:

<table>
<thead>
<tr>
<th>Perceptual</th>
<th>Articulatory</th>
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<tbody>
<tr>
<td>Wilson 2006</td>
<td>Shapp 2012</td>
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<tr>
<td>Carpenter 2006</td>
<td>Baer-Henney 2015</td>
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<tr>
<td>Finley 2012</td>
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<tr>
<td>Finley &amp; Badecker 2012</td>
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<tr>
<td>White 2013</td>
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<td>Kimper 2016</td>
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The Big Picture: Naturalness Bias

• Null results:

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<td></td>
<td>Skoruppa &amp; Peperkamp 2011</td>
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The Big Picture: Naturalness Bias

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The Big Picture: Naturalness Bias

• A novel proposal:

  Only perceptual naturalness biases phonological learning, not articulatory naturalness.
What’s Next?

• An experiment with voiced and voiceless non-stop consonants

• **Initial Contrast-Final Voiced:**
  - kawám ✓ túsif ✓ míwib ✓
  - *[-cont, -voice]#

• **Initial Contrast-Final Voiceless:**
  - kawám ✓ túsif ✓ míwib ✓ mówip ✓
  - *[-son, +voice]#

• Neither voiceless stops nor voiced stops easier to reject → no effect of complexity bias
What’s Next?

• 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!
References


References


References


