Complexity Bias and Substantive Bias in Phonotactic Learning
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1. Background: Synchronic Learning Biases in Phonological Learning

- To what extent is the phonological typology shaped by synchronous learning biases?
- Synchronic (analytic) bias: Learners biased toward acquiring certain phonological systems over others
  - Complexity bias: bias against formally complex patterns
  - Substantive/naturalness bias: bias against phonetically unnatural patterns
- Research question: Does phonetic naturalness bias phonotactic learning?
- Approach: Test whether learners reproduce attested and phonetically-motivated phonotactic implicationals in artificial grammar learning (AGL) experiments

1.1 Past Research on Synchronic Biases

- A number of studies have uncovered evidence for complexity bias: learners acquire featurally simpler phonological patterns better (e.g. Moreton 2008; Hayes et al. 2009; Skoruppa & Peperkamp 2011; Moreton 2012)
- Other studies have found evidence for substantive bias: learners prefer to acquire phonetically natural patterns and underlearn phonetically unnatural patterns (e.g. Wilson 2006; Becker, Ketrez & Nevins 2011; Becker, Nevins & Levine 2012; Finley 2012; Hayes & White 2013; White 2013)
  - However, some studies that purport to find a naturalness bias could be reinterpreted as having found a complexity bias instead (Becker, Ketrez & Nevins 2011; Hayes & White 2013)
  - Others have a pattern of results that is not fully consistent with a naturalness bias account (Wilson 2006)
- Most of these studies have used an AGL paradigm
- Moreton & Pater’s (2012a,b) review of work in this area concluded that there is fairly robust evidence for complexity bias but scant evidence for substantive bias

1.2 Synchronic Biases in Phonotactic Learning

- Investigations of substantive bias have focused mostly on alternations
- A few studies have tested naturalness bias in phonotactic learning:
  - Support for substantive bias:
    - Underlearning of unnatural phonotactic generalizations supported by the English lexicon (Hayes & White 2013)—however, unnatural generalizations were also more complex
  - Lack of support for substantive bias:
    - Equal learning of natural and unnatural phonotactics (Skoruppa & Peperkamp 2011; Myers & Padgett 2014; Greenwood 2016—casual speech condition)
    - Unnatural phonotactic generalization learned better than a natural phonotactic generalization (Greenwood 2016—careful speech condition)
- My approach investigates not just phonotactic restrictions but phonotactic implicationals about the existence of contrasts in different positions
  - Implicitly asking learners to compare existence of contrasts across positions may cause a bias to emerge when simply testing learnability of a specific phonotactic constraint doesn’t
2. Experiment 1: Positional Extension of an Obstruent Voicing Contrast

2.1 The Phonotactic Implicational

- If a language contrasts voicing in obstruents word-finally (e.g. /ap/ vs. /ab/), it will contrast voicing in obstruents word-initially (e.g. /pa/ vs. /ba/), but not necessarily vice versa
- Phonetic motivation: cues to obstruent voicing more abundant word-initially than word-finally; in particular, VOT available word-initially but not word-finally (Steriade 1997)
  - Voiced and voiceless obstruents should be more perceptually similar (i.e. harder to distinguish) at the end of a word than at the beginning of a word
  - If voicing contrast exists word-finally, where it is harder to perceive, it should exist word-initially, where it is easier to perceive (T/D# → #T/D)
- Implicational supported by the typology (Steriade 1997, Lombardi 1999)

2.2 Method

- Expose subjects to an obstruent voicing contrast in word-initial or word-final position and test whether they extend the contrast to the other position
- In addition to manipulating position of contrast, manipulated what value voicing “neutralizes” to
- Four training conditions defined on two dimensions: Trained Contrast Position and Trained Neutralization Value

<table>
<thead>
<tr>
<th>Table 1: Training Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>#T</td>
</tr>
<tr>
<td>-----------------------------</td>
</tr>
<tr>
<td>#D…{T, D}# (*#T)</td>
</tr>
<tr>
<td>#T…{T, D}# (*#D)</td>
</tr>
<tr>
<td>#{T, D}…D# (*T#)</td>
</tr>
<tr>
<td>#{T, D}…T# (*D#)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 2: Sample Training Items in the #{T, D}…T# (*#D) Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>#T</td>
</tr>
<tr>
<td>-----------------------------</td>
</tr>
<tr>
<td>pímir</td>
</tr>
<tr>
<td>tilár</td>
</tr>
<tr>
<td>kawám</td>
</tr>
</tbody>
</table>

- Properties of items (training and test)
  - C₁VC₂VC₃ shape
  - C₁ or C₃ a stop drawn from [p t k b d g]
  - Other two Cs sonorants drawn from [m n l j w] (no final [j]s or [w]s, no [ji]s or [wu]s)
  - Vs drawn from [i u a]
  - Bilabial, alveolar, and velar stops equally represented
  - Half of items belong to minimal pairs
  - Half iambs, half trochees (stress not correlated with position featuring the voicing contrast or position containing a stop)
• Experiment conducted online using Experigen (Becker & Levine 2013)

• Training Phase
  ➢ Subjects told they would be listening to some words of a new language
  ➢ 2 blocks of the same 36 training items
  ➢ Each training item paired with an image

• Test Phase
  ➢ Subjects heard additional words and had to say whether the word could be a word of the language they had been listening to or not (Yes/No)
  ➢ 1 block of 48 test items: #T, #D, T#, and D# items (same for all conditions)
  ➢ No images

• Three types of test items:
  ➢ *Familiar Conforming*: voicing and position conform to trained pattern, and item heard in training
  ➢ *Novel Conforming*: voicing and position conform to trained pattern, but item not heard in training
  ➢ *Novel Nonconforming*: voicing and position combination not heard in training

Table 3: Sample Test Items for Each Training Condition

<table>
<thead>
<tr>
<th>Familiar Conforming</th>
<th>Novel Conforming</th>
<th>Novel Nonconforming</th>
</tr>
</thead>
<tbody>
<tr>
<td>#D…{T, D}# (*#T)</td>
<td>nimáp</td>
<td>rínum</td>
</tr>
<tr>
<td>#T…{T, D}# (*#D)</td>
<td>nimáp</td>
<td>rínum</td>
</tr>
<tr>
<td>#{T, D}…D# (*T#)</td>
<td>kawám</td>
<td>kámir</td>
</tr>
<tr>
<td>#{T, D}…T# (*D#)</td>
<td>kawám</td>
<td>kámir</td>
</tr>
</tbody>
</table>

2.3 Participants

• Native English speakers recruited through UCLA Psychology Subject Pool
• Excluded if: non-native English speaker; more than one linguistics class; history of speech or hearing impairments; incorrect response on either of the two test words preceding the experiment; accepted all test items
• After exclusions (72 out of 221), 149 subjects, divided among 4 conditions (subjects per condition ranged from 33 to 41)

2.4 Predictions

• Subjects’ acceptance rates of Novel Nonconforming items (relative to Novel Conforming items) indicate whether they have extended the obstruent voicing contrast to a new position in a given condition

Hypothesis

#1 Substantive bias hypothesis
(position—Trained Contrast Position):
• Recall the phonotactic implicational: T/D# → #T/D, but not vice versa
• Behavior consistent with implicational would be asymmetric extension: subjects exposed to contrast word-finally should extend it to word-initial position more than subjects exposed to contrast word-initially extend it to word-final position

Predicted Relative Acceptance Rates of Novel Nonconforming Items by Condition

![Bar chart showing predicted relative acceptance rates of Novel Nonconforming Items by Condition.

- Erroroneously accepting
- Correctly rejecting

- #T #D
- *T# *D#
#2 Substantive bias hypothesis

*(voicing—Trained Neutralization Value)*:

- Voiced obstruents more marked than voiceless obstruents → more extension from voiced to voiceless obstruents than from voiceless to voiced obstruents

#3 Substantive bias hypothesis

*(position and voicing)*:

- More extension from word-final to word-initial position AND more extension from voiced to voiceless obstruents

#4 Complexity bias hypothesis:

- Post-hoc, but turned out to provide best account, so presented here for clarity

- Due to presence of sonorant Cs in training items, constraint needed to exclude Novel Nonconforming items in neutralizing-to-T conditions could be more complex than constraint needed in neutralizing-to-D conditions

\[
\begin{align*}
\text{'#{T, D}…D# (*T#): kawám ✓ mìwib ✓ mìwip ✗ → *[-voice]#} \\
\text{'#{T, D}…T# (*D#): kawám ✓ mìwib X mìwip ✓ → *[-son, +voice]#}
\end{align*}
\]

- Predicts more “extension” from voiceless to voiced obstruents than from voiced to voiceless obstruents (opposite of voicing-related Hypothesis #2 above)

2.5 Results

- Figure 1 shows the acceptance rates of the three types of test items across conditions:
• Acceptance rates of Novel Conforming items:
  ➢ Above chance in all conditions (generalization → learning of trained pattern)
  ➢ Not significantly different across conditions
• Mixed-effects logistic regression fit to Novel Nonconforming items:
  ➢ Dependent variable: response (accept or reject)
  ➢ Fixed effects: Trained Contrast Position and Trained Neutralization Value
  ➢ Random intercepts for subject and item
• Predictions:
  ➢ Position-based substantive bias: Main effect of Trained Contrast Position such that Novel Nonconforming acceptance rates higher in word-final contrast conditions than in word-initial contrast conditions
  ➢ Complexity bias: Main effect of Trained Neutralization Value such that Novel Nonconforming acceptance rates higher in neutralizing-to-T conditions than in neutralizing-to-D conditions

Table 4: Fixed Effects of the Novel Nonconforming Items Regression

<table>
<thead>
<tr>
<th></th>
<th>Coefficient</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>-1.161</td>
<td>&lt;0.001***</td>
</tr>
<tr>
<td>Trained Contrast Position = final (vs. initial)</td>
<td>0.197</td>
<td>0.522</td>
</tr>
<tr>
<td>Trained Neutralization Value = T (vs. D)</td>
<td>1.063</td>
<td>&lt;0.001***</td>
</tr>
</tbody>
</table>

• Main effect of Trained Contrast Position not significant → no evidence for substantive bias
• Significant main effect of Trained Neutralization Value supports complexity bias

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1 If the interaction of Trained Contrast Position and Trained Neutralization Value is included as a fixed effect in the model, it is not significant (p = 0.208).
2.6 Discussion

- The phonotactic implicational (T/D# → #T/D) was not reproduced in this experiment
  - No greater extension of voicing contrast from word-final to word-initial position
  - **Substantive bias hypothesis not supported**
- Instead, subjects trained to “neutralize” to T extended to D more than subjects trained to
  “neutralize” to D extended to T
  - Opposite of behavior expected based on relative markedness of T vs. D
  - But given (voiced) sonorant Cs, can be explained by a complexity bias
- #D…{T, D)# (*#T) and #{T, D}…D# (*T#) subjects can learn *#[−voice] and *#[-voice]#
- But #T…{T, D)# (*#D) and #/T, D/…T# (*D#) subjects must learn more complex
  *#[-son, +voice] and *#[-son, +voice]#
- Complexity bias account depends on English sonorants having active [+voice] feature
- Other AGL results consistent with complexity bias story for Exp. 1:
  - Greenwood 2016: Phonotactic learning experiment in which subjects trained on a restriction
    against word-final voiced obstruents (*Z#) or word-final voiceless obstruents (*S#)
    - Crucially, training stimuli included items ending in (voiced) sonorants
    - Thus in *S# condition, subjects could learn *#[-voice] while in *Z# condition they had
to learn *#[-son, +voice]#
    - In careful speech condition, *S# language learned better than *Z# language
  - Glewwe et al. 2018: Alternation learning experiment in which subjects trained on final
devoicing (mulɛ́b-i → mulɛ́p) or final voicing (tuláp-i → tuláb)
    - In both final devoicing and final voicing conditions, there were sonorant-final stems that
did not alternate (komášl-i → komášl)
    - Thus to drive final voicing subjects could learn *#[-voice] while to drive final devoicing
they had to learn *#[-son, +voice]#
    - Final voicing was learned better than final devoicing

3. Experiment 2: Modified Voicing Contrast Experiment

3.1 Motivation

- Complexity bias account of Exp. 1: Subjects accepted Novel Nonconforming items less (i.e.
learned their language better) when they could use a simpler constraint to master their language
- Which conditions could be learned with simpler constraints depended crucially on features of
non-critical Cs of the stimuli, i.e. the voiced sonorants
- To test validity of complexity bias account of Exp. 1, I conducted Exp. 2, which was designed to
reverse predictions of complexity bias
- Exp. 2 identical to Exp. 1, except **non-critical Cs converted from voiced sonorants to voiceless fricatives**
  - Now it should be easier to learn to reject voiced stops (*D) than to reject voiceless stops (*T)

3.2 Method

- Identical to Exp. 1: Same four training conditions shown in Table 1
- Properties of items (training and test)
  - Identical to Exp. 1, except non-critical Cs (other two Cs in each CVCVC item) drawn from [f θ sʃ h] ([h] only word-initial)
  - Stimuli for Exp. 2 created from Exp. 1 stimuli by converting sonorants to voiceless fricatives
    - [m n ɹ l] changed to [f θ sʃ], respectively
• Word-initial [j]s changed to [h]s; word-initial [w]s changed to [f], [s], or [h]; word-medial [j]s and [w]s changed to [f], [s], or [ʃ]
• No glides changed to [θ] because [θ] infrequent in English

Table 5: Sample Training Items in the #{T, D}…T# Condition

<table>
<thead>
<tr>
<th>#T</th>
<th>#D</th>
<th>T#</th>
<th>D#</th>
</tr>
</thead>
<tbody>
<tr>
<td>pífis</td>
<td>bífis</td>
<td>físip</td>
<td></td>
</tr>
<tr>
<td>tífás</td>
<td>disíθ</td>
<td>jáθít</td>
<td></td>
</tr>
<tr>
<td>káfáf</td>
<td>gaʃáf</td>
<td>0uʃák</td>
<td></td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
<td></td>
</tr>
</tbody>
</table>

• Procedure identical to that of Exp. 1

3.3 Participants

• Same population and same exclusion criteria as in Exp. 1
• After exclusions (99 out of 243), 144 subjects, divided among 4 conditions (subjects per condition ranged from 35 to 37)

3.4 Predictions

• Like Exp. 1, Exp. 2 still tests for substantive bias, but complexity bias predictions have changed

Hypothesis  Predicted Relative Acceptance Rates of Novel Nonconforming Items by Condition

#1 Substantive bias hypothesis
(position—Trained Contrast Position):
• Phonotactic implicational: T/D# → #T/D, but not vice versa
• Subjects exposed to contrast word-finally should extend it to word-initial position more than subjects exposed to contrast word-initially extend it to word-final position

#2 Substantive bias hypothesis
(voicing—Trained Neutralization Value)
• Voiced stops more marked than voiceless stops → more extension from voiced to voiceless stops than from voiceless to voiced stops
#3 Complexity bias hypothesis:

- Due to presence of voiceless fricatives in training items, constraint needed to exclude Novel Nonconforming items in neutralizing-to-D conditions could be more complex than constraint needed in neutralizing-to-T conditions

\[
\begin{align*}
\text{'T, D'} & \cdots D (\ast T\#) \quad \uparrow \downarrow \quad \text{túsif} \checkmark \quad \text{físib} \checkmark \quad \text{físip} \times \quad \rightarrow \quad \ast[-\text{cont}, -\text{voice}]# \\
\text{'T, D'} & \cdots T (\ast D\#) \quad \uparrow \downarrow \quad \text{túsif} \checkmark \quad \text{físib} \checkmark \quad \text{físip} \checkmark \quad \rightarrow \quad \ast[+\text{voice}]#
\end{align*}
\]

- Predicts more “extension” from voiced to voiceless stops than from voiceless to voiced stops
  - **Same prediction** as voicing-related Hypothesis #2 above!
  - Exp. 2 cannot disambiguate between voicing-based substantive bias and complexity bias
  - However, Exp. 1 could, and there was no evidence for voicing-based substantive bias
  - Thus I will interpret this pattern of results in Exp. 2 as supporting complexity bias

#4 Substantive bias hypothesis

*Substantive bias hypothesis (position) and Complexity bias hypothesis*

- More extension from word-final to word-initial position AND more extension from voiced to voiceless obstruents
- I will interpret this pattern of results as supporting position-based substantive bias and complexity bias

3.5 Results

- Figure 2 shows the acceptance rates of the three types of test items across conditions
- Acceptance rates of Novel Conforming items:
  - Above chance in all conditions (generalization → learning of trained pattern)
  - Not significantly different across conditions
- Mixed-effects logistic regression fit to Novel Nonconforming items:
  - Dependent variable: response (accept or reject)
  - Fixed effects: Trained Contrast Position and Trained Neutralization Value
  - Random intercepts for subject and item
- Predictions:
  - Position-based substantive bias: Main effect of Trained Contrast Position such that Novel Nonconforming acceptance rates higher in word-final contrast conditions than in word-initial contrast conditions
  - Complexity bias: Main effect of Trained Neutralization Value such that Novel Nonconforming acceptance rates higher in neutralizing-to-D conditions than in neutralizing-to-T conditions
• Significant main effect of Trained Contrast Position supports substantive bias
• Marginally significant main effect of Trained Neutralization Value supports complexity bias

### Table 6: Fixed Effects of the Novel Nonconforming Items Regression

<table>
<thead>
<tr>
<th>Coefficient</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>-1.200</td>
</tr>
<tr>
<td>Trained Contrast Position = final (vs. initial)</td>
<td>0.711</td>
</tr>
<tr>
<td>Trained Neutralization Value = D (vs. T)</td>
<td>0.522</td>
</tr>
</tbody>
</table>

3.6 Discussion

• Subjects did behave in accordance with the phonotactic implicational (T/D# → #T/D)
  ➢ Greater extension of voicing contrast from word-final to word-initial position
  ➢ **Supports substantive bias**
• Also, subjects trained to “neutralize” to D extended to T more than subjects trained to “neutralize” to T extended to D
  ➢ Higher acceptance of Novel Nonconforming items in conditions where subjects had to learn *
  ➢ [−cont, −voice] than in conditions where subjects could learn * [+voice]
  ➢ **Consistent with complexity bias**
• Flipping voicing of non-critical Cs flipped direction of differences in Novel Nonconforming acceptance rates between neutralizing-to-T and neutralizing-to-D languages
  ➢ Subjects always better at rejecting Novel Nonconforming items featuring stops whose voicing is opposite that of non-critical Cs

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2 If the interaction of Trained Contrast Position and Trained Neutralization Value is included as a fixed effect in the model, it is not significant (p = 0.699).
Non-critical Cs crucially affect AGL performance
Subjects infer phonotactic constraints according to experiment-internal distribution of sounds, opting for simplest constraint with which they can master pattern

- Still no evidence for voicing-based substantive bias
  - Voicing-based substantive bias and complexity bias cannot be disambiguated in Exp. 2
  - Novel Nonconforming items featuring Ds might be rejected more because Ds more marked or because Ds can be excluded with simpler constraint (*[+voice])
  - If both biases active, Ds should be rejected even more (accepted even less) than Ts in Exp. 1, which could only be excluded with simpler constraint (*[−voice])
  - But in fact Ds rejected less (accepted more) than Ts in Exp. 1 (see Figure 3) → no combined effect
  - Taken with results of Exp. 1, suggests no effect of voicing-based substantive bias

Figure 3: Acceptance Rates of Novel Nonconforming Items—Exps. 1 and 2

- Why were Novel Nonconforming acceptance rates for “simple” conditions higher in Exp. 2 than in Exp. 1 (i.e. why was complexity bias effect weaker in Exp. 2)?
  - English sonorants necessarily voiced, so when subjects perceive sonorants, they know they are voiced
  - English has voiced as well as voiceless fricatives, so subjects could misperceive voiceless fricatives as devoiced voiced fricatives
  - If they do, they can no longer posit *[+voice] in neutralizing-to-T conditions because this would exclude voiced fricatives they mistakenly think are licit
  - They must posit *[−cont, +voice] → constraint and condition no longer simpler

4. General Discussion

- Two experiments tested the phonotactic implicational whereby a word-final obstruent voicing contrast entails a word-initial contrast, but not vice versa
  - Exp. 1: Natural languages with a stop voicing contrast only word-initially not reliably learned better than unnatural languages with a stop voicing contrast only word-finally
  - Exp. 2: Natural languages with a stop voicing contrast only word-initially learned better than unnatural languages with a stop voicing contrast only word-finally
  - Mixed evidence for substantive bias

- What is the outlook for substantive bias?
  - Results of Exps. 1 and 2 in line with Moreton & Pater (2012a,b): substantive bias elusive
I have also tested a phonotactic implicational about the distribution of major place contrasts (Glewwe 2017, 2018)

- Languages with major place contrasts only word-initially and languages with major place contrasts only word-finally always equally learnable → no evidence for substantive bias
- Could place of articulation and voicing be different?

Typological asymmetries rooted in phonetic naturalness must still be accounted for

Substantive bias’s major competitor in this debate: the diachronic explanation/channel bias (Blevins 2004, Moreton 2008)

- Phonetic factors (e.g. articulatory difficulty, perceptibility) drove imperfect transmission of languages over time, yielding the present typology

Substantive bias may be subtle/hard to detect, yet notable AGL results exist (Finley 2012, White 2013)

Perhaps a difference between articulatory substantive bias and perceptual substantive bias?

- In Exps. 1 and 2, position-based substantive bias perceptual while voicing-based substantive bias articulatory, and only position-based substantive bias found any support
- Naturalness arguments in Finley 2012 and White 2013 rooted in perception
- Glewwe et al. 2018: naturalness argument articulatory (final devoicing vs. final voicing) and no evidence for substantive bias

Both experiments also provided evidence for complexity bias

- Subjects accepted Novel Nonconforming items less (i.e. demonstrated superior learning) when pattern could be mastered with a featurally simpler phonotactic constraint
- Effect more consistent and robust across two experiments than substantive bias effect
- Held true whether simpler conditions were neutralizing-to-D conditions (Exp. 1—sonorant non-critical Cs) or neutralizing-to-T conditions (Exp. 2—voiceless fricative non-critical Cs)
- Exps. 1 and 2 highlight decisive role non-critical segments/phone inventory of an artificial language can play
- Interpretations of AGL results must take potential role of non-critical sounds into account

Appendix

Alternate Statistical Analyses of Exps. 1 and 2

1. Experiment 1—Pairwise Comparisons of Novel Nonconforming Acceptance Rates

- Mixed-effects logistic regression fit to Novel Nonconforming items:
  - Dependent variable: response (accept or reject)
  - Fixed effect: Condition
  - Random intercepts for subject and item
- Conducted post-hoc pairwise comparisons of acceptances rates of Novel Nonconforming items (Tukey method)
- Position-based substantive bias predicts subjects trained on obstruent voicing contrast word-finally should accept Novel Nonconforming items more than subjects trained on contrast word-initially

<table>
<thead>
<tr>
<th>Predicted Difference</th>
<th>Actual Difference</th>
<th>Estimate</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>#D…[T, D]# &gt; # {T, D}…D#</td>
<td>#D…[T, D]# &gt; # {T, D}…D#</td>
<td>0.590</td>
<td>0.528</td>
</tr>
<tr>
<td>#T…[T, D]# &gt; # {T, D}…T#</td>
<td>#T…[T, D]# &lt; # {T, D}…T#</td>
<td>-0.180</td>
<td>0.975</td>
</tr>
</tbody>
</table>
• Neither pairwise difference yields support for position-based substantive bias
• Complexity bias predicts subjects in neutralizing-to-T conditions should accept Novel Nonconforming items more than subjects in neutralizing-to-D conditions

Table 2: Pairwise differences in acceptance rates of Novel Nonconforming items that test the complexity bias hypothesis

<table>
<thead>
<tr>
<th>Predicted Difference</th>
<th>Actual Difference</th>
<th>Estimate</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>#T...{T, D}# &gt; #D...{T, D}#</td>
<td>#T...{T, D}# &gt; #D...{T, D}#</td>
<td>0.673</td>
<td>0.408</td>
</tr>
<tr>
<td>#{T, D}...T# &gt; #{T, D}...D#</td>
<td>#{T, D}...T# &gt; #{T, D}...D#</td>
<td>1.443</td>
<td>0.004 **</td>
</tr>
</tbody>
</table>

• Within the initial contrast conditions, subjects in the neutralizing-to-T condition did accept Novel Nonconforming items more than subjects in the neutralizing-to-D condition, supporting complexity bias

2. Experiment 2—Pairwise Comparisons of Novel Nonconforming Acceptance Rates

• Mixed-effects logistic regression fit to Novel Nonconforming items:
  ➢ Dependent variable: response (accept or reject)
  ➢ Fixed effect: Condition
  ➢ Random intercepts for subject and item
• Conducted post-hoc pairwise comparisons of acceptances rates of Novel Nonconforming items (Tukey method)
• Position-based substantive bias predicts subjects trained on stop voicing contrast word-finally should accept Novel Nonconforming items more than subjects trained on contrast word-initially

Table 3: Pairwise differences in acceptance rates of Novel Nonconforming items that test the position-based substantive bias hypothesis

<table>
<thead>
<tr>
<th>Predicted Difference</th>
<th>Actual Difference</th>
<th>Estimate</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>#D...{T, D}# &gt; #{T, D}...D#</td>
<td>#D...{T, D}# &gt; #{T, D}...D#</td>
<td>0.817</td>
<td>0.164</td>
</tr>
<tr>
<td>#T...{T, D}# &gt; #{T, D}...T#</td>
<td>#T...{T, D}# &gt; #{T, D}...T#</td>
<td>0.599</td>
<td>0.447</td>
</tr>
</tbody>
</table>

• Both differences in direction supporting substantive bias; neither significant, though within the neutralizing-to-D conditions the difference comes close
• Complexity bias predicts subjects in neutralizing-to-D conditions should accept Novel Nonconforming items more than subjects in neutralizing-to-T conditions

Table 4: Pairwise differences in acceptance rates of Novel Nonconforming items that test the complexity bias hypothesis.

<table>
<thead>
<tr>
<th>Predicted Difference</th>
<th>Actual Difference</th>
<th>Estimate</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>#D...{T, D}# &gt; #T...{T, D}#</td>
<td>#D...{T, D}# &gt; #T...{T, D}#</td>
<td>0.631</td>
<td>0.389</td>
</tr>
<tr>
<td>#{T, D}...D# &gt; #{T, D}...T#</td>
<td>#{T, D}...D# &gt; #{T, D}...T#</td>
<td>0.413</td>
<td>0.730</td>
</tr>
</tbody>
</table>

• Both differences in direction supporting complexity bias, though neither significant

Acknowledgments

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References


