Substantive Bias in Phonotactic Learning: Positional Extension of Place and Voicing Contrasts

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1. Background: Synchronic Learning Biases in Phonological Learning

- To what extent is the phonological typology shaped by synchronic 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)
- 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 that are supported by the English lexicon (Hayes & White 2013)
  - 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 a Major Place Contrast

2.1 The Phonotactic Implicational

- If a language has major place contrasts post-vocalically/in codas (e.g. /ap/ vs. /at/ vs. /ak/), it should also have major place contrasts pre-vocalically/in onsets (e.g. /pa/ vs. /ta/ vs. /ka/), but not necessarily vice versa
- Phonetic motivation:
  - Differences in place of articulation more perceptually similar (i.e. harder to distinguish) post-vocalically than pre-vocalically (Steriade 1994, 2001)
  - If place contrast exists post-vocalically, where it is harder to perceive, it should exist pre-vocalically, where it is easier to perceive
- Typological evidence for preference for maintaining major place contrasts pre-vocalically:
  - Coda Cs more likely to be targets of place assimilation than onset Cs (Jun 1995)
  - Many languages exhibit neutralization to an unmarked place in coda position (Lombardi 2001)

2.2 Method

- Expose subjects to a three-way place contrast in word-initial (pre-vocalic) or word-final (post-vocalic) position and test whether they extend the contrast to the other position
- Two training conditions: WordInitialContrast (WIC) and WordFinalContrast (WFC)

Table 1: Experiment 1 Training Conditions

	#P	#T	#K	P#	T#	K#
WordInitialContrast	✓	✓	✓	✗	✓	✗
WordFinalContrast	✗	✓	✗	✓	✓	✓

Table 2: Sample Training Items in WordInitialContrast Condition

#P	#T	#K	P#	T#	K#
pínir **b**ilún …	**t**ínir **d**irúl …	**k**ínir **g**urúl …		jáwi**t** rujú**d** …	

- Properties of items (training and test)
  - $C_1VC_2VC_3$ shape
  - C_1 or C_3 a stop drawn from [p t k b d g]
  - Other two Cs sonorants drawn from [n l r j w] (no final [j]s or [w]s)
  - Vs drawn from [i a u]
  - Voiced and voiceless stops equally represented
  - Labial, coronal, and velar stops equally represented in position with contrast
  - Half of items belong to minimal triplets
  - Half iambs, half trochees (stress not correlated with position featuring the place 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 40 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: #P, #T, #K, P#, T#, and K# items (same for all conditions)
  - No images
- Three types of test items:
  - *Familiar Conforming*: place of articulation and position conform to trained pattern, and item heard in training
  - *Novel Conforming*: place and position conform to trained pattern, but item not heard in training
  - *Novel Nonconforming*: place and position combination not heard in training

Table 3: Sample Test Items for Each Training Condition

	Familiar Conforming	**Novel Conforming**	**Novel Nonconforming**
WordInitialContrast	**p**ínir	**p**anúl	nálu**p**
WordFinalContrast	rujá**p**	nálu**p**	**p**anúl

2.3 Participants

- 25 subjects in WIC and 25 subjects in WFC
- Native English speakers recruited through UCLA Psychology Subject Pool

2.4 Predictions

- Subjects' acceptance rates of Novel Nonconforming items (relative to Novel Conforming items) indicate whether they have extended the place contrast to a new position in a given condition
- Recall the phonotactic implicational: P/T/K# → #P/T/K, but not vice versa
- If learners biased toward phonetically natural phonotactic systems, subjects exposed to place contrast word-finally (WFC) should more readily accept Novel Nonconforming items than subjects exposed to place contrast word-initially (WIC) (i.e. asymmetric extension)
- If learners not biased toward phonetically natural phonotactic systems, subjects should accept Novel Nonconforming items at similar rates in both conditions since two training patterns are of equal formal complexity

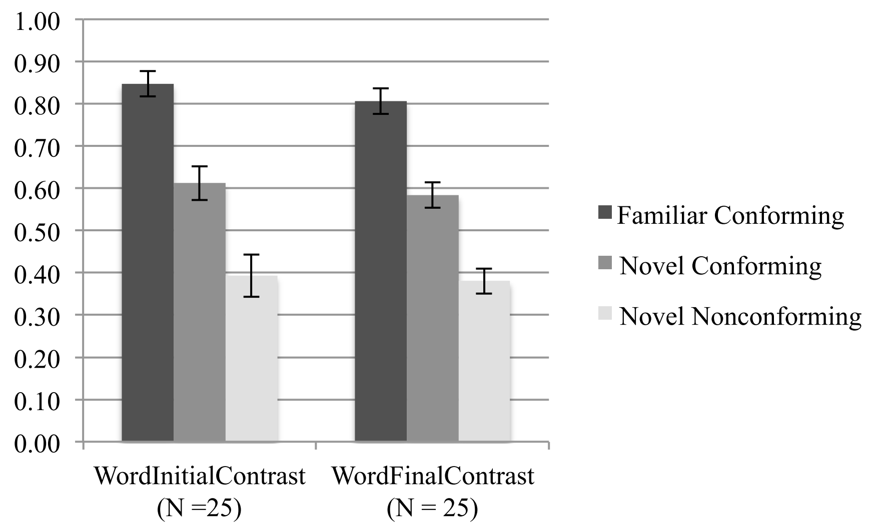
2.5 Results

- Figure 1 (p. 4) shows the acceptance rates of the three types of test items in both conditions
- **Familiar** Conforming items more likely to be accepted than **Novel** Conforming items
- Novel **Conforming** items more likely to be accepted than Novel **Nonconforming** items[1]
- Acceptance rates of Novel Conforming items significantly above chance in both conditions: subjects correctly generalized to new words in their language
- Acceptance rates of Novel Nonconforming items significantly below chance in both conditions: subjects correctly rejected words not in their language

[1] See Appendix for regression models.

- No interactions → natural and unnatural training patterns learned to an equal degree

Fig. 1: Acceptance of Test Items by Condition



2.6 Discussion

- Phonotactic implicational not reproduced: subjects did not extend the place contrast more from word-final to word-initial position than from word-initial to word-final position
- Exp. 1 did not yield support for substantive bias
- Was learning too explicit (i.e. the pattern too easy to identify)?
  - Most subjects (17/25 (68%) in WIC; 19/25 (76%) in WFC) reported seeking a rule to distinguish words in their language from those not in their language
  - Of these, a few (2 in WIC; 4 in WFC) found the correct rule (mentioned labials and/or velars and position)
  - Remaining subjects reported a more intuitive strategy
- Making the task harder (fostering more implicit learning) might cause substantive bias to emerge

3. Experiment 2: Modified Place Contrast Experiment

3.1 Method

- As in Exp. 1, with key differences:
  - 20 all-sonorant fillers (e.g. *lanir*) added to training phase, yielding 60 training items
  - Training blocks increased from 2 to 3
  - Familiar Conforming items removed from test phase

3.2 Participants

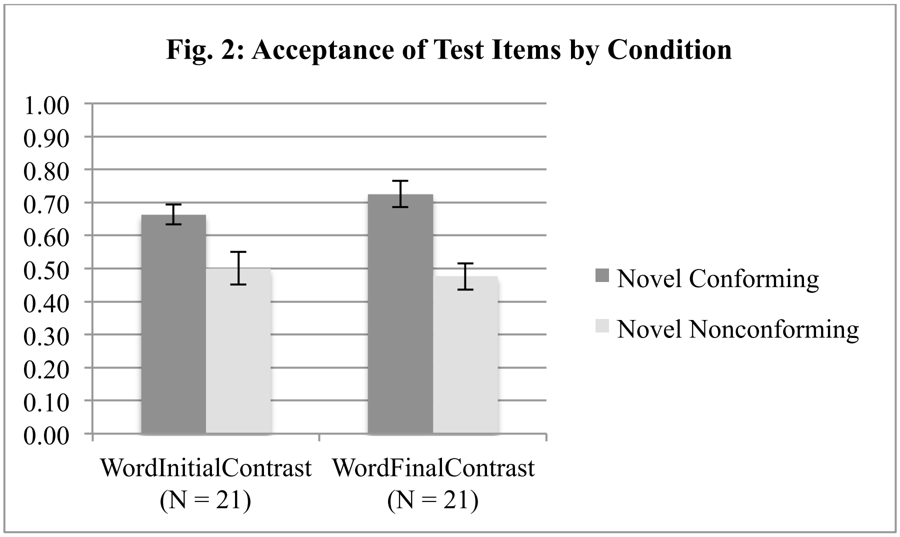
- 21 subjects each in WIC and WFC; from same population as in Exp. 1

3.3 Predictions

- Same as in Exp. 1

3.4 Results

- Figure 2 shows the acceptance rates of the two types of test items in both conditions:



- Novel Conforming items more likely to be accepted than Novel Nonconforming items[2]
- Still no interaction → natural and unnatural patterns still learned equally well

3.5 Discussion

- *Was* learning less explicit in Exp. 2?
  - 10/21 (48%) in WIC and 11/21 (53%) in WFC sought a rule
  - Of these, only 1 in each condition found the correct rule
  - Suggests somewhat more implicit learning in Exp. 2 as compared to Exp. 1
- But this did not lead to a difference between the two conditions → still no evidence for substantive bias

4. Experiment 3: Positional Extension of a Voicing Contrast

4.1 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)

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[2] See Appendix for regression model.

4.2 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 (cf. place contrast experiments where place always neutralized to coronal)
- Four training conditions defined on two dimensions: *Trained Contrast Position* and *Trained Neutralization Value*

Table 4: Experiment 3 Training Conditions

	#T	#D	T#	D#
#D…{T, D}# (*#T)	✗	✓	✓	✓
#T…{T, D}# (*#D)	✓	✗	✓	✓
#{T, D}…D# (*T#)	✓	✓	✗	✓
*#{T, D}…T# (*D#)*	✓	✓	✓	✗

Table 5: Sample Training Items in *#{T, D}…T# (*D#)* **Condition**

#T	#D	T#	D#
pímir **t**ilár **k**awám …	**b**ímir **d**irín **g**awám …	míwi**p** laní**t** nuwá**k** …	

- Properties of items (training and test)
    - $C_1VC_2VC_3$ shape
    - C_1 or C_3 a stop drawn from [p t k b d g]
    - Other two Cs sonorants drawn from [m n l r j w] (no final [j]s or [w]s)
    - Vs drawn from [i a u]
    - 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 an obstruent)
- Design and Task
    - Analogous to Exp. 1
    - Training phase: 2 blocks of the same 36 training items, with images
    - Test phase: 1 block of 48 test items, without images: #T, #D, T#, and D# items (same for all conditions)
    - Three types of test items: Familiar Conforming, Novel Conforming, Novel Nonconforming

Table 6: Sample Test Items for Each Training Condition

	Familiar Conforming	Novel Conforming	Novel Nonconforming
#D…{T, D}# (*#T)	nimá**p**	rínu**p**	**p**írum
#T…{T, D}# (*#D)	nimá**p**	rínu**p**	**b**írum
#{T, D}…D# (*T#)	**k**awám	**k**ámir	múli**k**
*#{T, D}…T# (*D#)*	**k**awám	**k**ámir	múli**g**

4.3 Participants

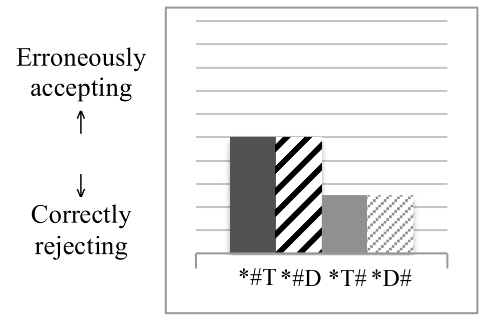
- 149 subjects divided among 4 conditions (subjects per condition ranged from 33 to 41)
- From same population as in Exps. 1 and 2

4.4 Predictions

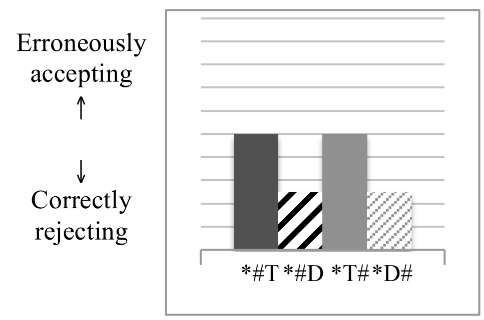
- Subjects' acceptance rates of Novel Nonconforming items (relative to Novel Conforming items) indicate whether they have extended the obstruent voicing contrast to a new position in a given condition

Hypothesis	**Predicted Relative Acceptance Rates of <u>Novel Nonconforming</u> Items by Condition**

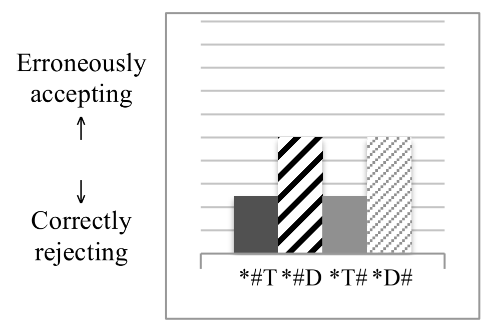
#1 Substantive bias hypothesis (position—Trained Contrast Position):
- Recall the phonotactic implicational: T/D# → #T/D, but not vice versa
- Behavior consistent with implicational would be asymmetric extension: subjects exposed to contrast word-finally should extend it to word-initial position **more**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



#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 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



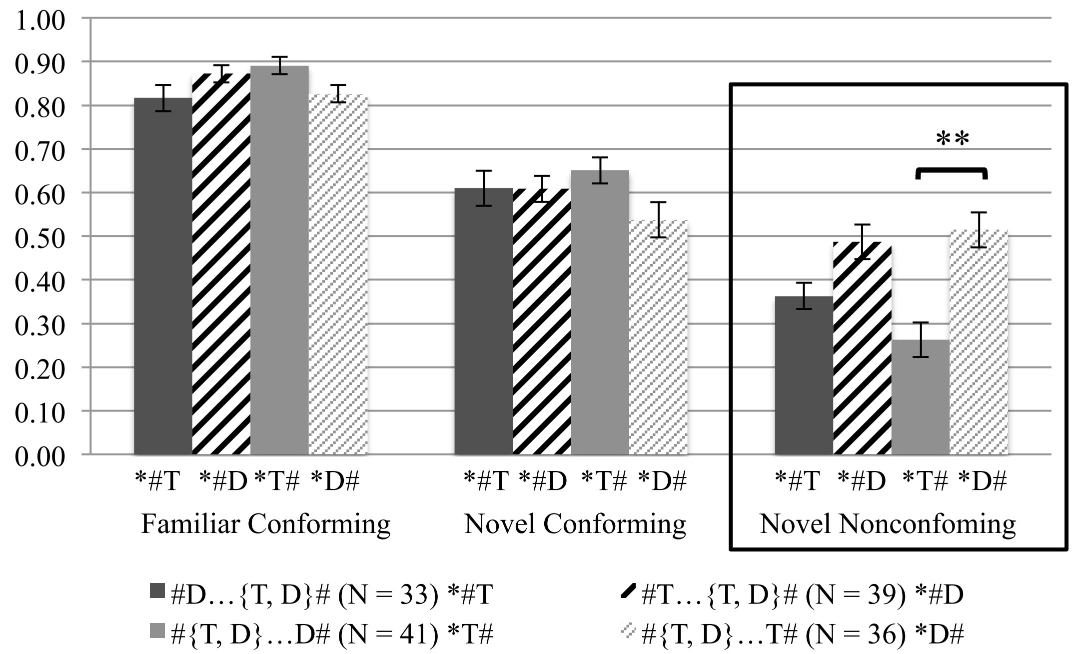
> ➢ #{T, D}…D# (*T#): kawá**m** ✓ míwi**b** ✓ míwi**p** ✗ → *[-voice]#
> ➢ *#{T, D}…T# (*D#)*: kawá**m** ✓ míwi**b** ✗ míwi**p** ✓ → *[-son, +voice]#

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

4.5 Results

- Figure 4 shows the acceptance rates of the three types of test items across conditions:

Fig. 4: Acceptance Rate of Test Items by Condition



- 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 effect: Condition
  - Random intercepts for subject and item
- Conducted post-hoc pairwise comparisons of acceptances rates of Novel Nonconforming items (Tukey method)

Table 7: Selected Pairwise Differences in Acceptance Rate of Novel Nonconforming Items

		Predicted Difference	**Prediction borne out?**	***p***
Substantive bias (position) predicts 2 differences:	**1**	**#D…{T, D}# (*#T)** > #{T, D}…D# (*T#)	no	0.528
	2	***#T…{T, D}# (*#D)*** > *#{T, D}…T# (*D#)*	no	0.975
Complexity bias predicts 2 differences:	**3**	***#T…{T, D}# (*#D)*** > **#D…{T, D}# (*#T)**	no	0.408
	4	*#{T, D}…T# (*D#)* > #{T, D}…D# (*T#)	yes	0.004 **

4.6 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 seemed to extend 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
- Support for complexity bias only partial:
  - In word-final position, subjects learn *[-voice] better than *[-son, +voice]
  - In word-initial position, trend is there but difference not significant
  - Why should difference in learnability between simple and complex constraint emerge only in word-final position and not in word-initial position?

5. General Discussion

- **Two phonotactic implicationals** about position of contrasts (place and voicing) tested and **neither reproduced** in AGL experiments
- Exps. 1 and 2 showed that a language with major place contrasts only word-initially and a language with major place contrasts only word-finally were equally learnable → **no evidence for substantive bias**
- Exp. 3 showed that languages with an obstruent voicing contrast only word-finally were as learnable as languages with an obstruent voicing contrast only word-initially → **no evidence for substantive bias**
  - However, Exp. 3 did show that a neutralizing-to-D language was learned better than a neutralizing-to-T language → **some evidence for complexity bias**
- What is the outlook for substantive bias?
  - Results of my experiments in line with Moreton & Pater's (2012a,b) conclusion that there is compelling evidence for complexity bias but little for substantive bias
  - Studies continue to fail to find evidence for substantive bias
  - In fact, some studies that purport to find a naturalness bias can be reinterpreted as having found a complexity bias instead (Becker, Ketrez & Nevins 2011; Hayes & White 2013)
- Asymmetries in the phonological typology (like those that underpin phonotactic implicationals tested here) remain and must be accounted for
  - If synchronic bias is limited to complexity bias, what explains the phonological typology?
  - 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
- As substantive bias continues to prove elusive, channel bias account grows more appealing

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Appendix: Mixed Effects Logistic Regression Models

Experiment 1: Conforming Items

Dependent variable: response (accept or reject)
Fixed effects: Familiarity, Condition, and their interaction
Random effects: intercepts for subject and item

	Coefficient	***p***
Intercept	0.549	0.01*
Familiarity = familiar (vs. unfamiliar)	1.437	<0.001***
Condition = WordFinalContrast (vs. WordInitialContrast)	-0.168	0.53
Familiarity × Condition	-0.147	0.614

Experiment 1: Novel Items

Dependent variable: response (accept or reject)
Fixed effects: Conformity, Condition, and their interaction
Random effects: intercepts for subject and item

	Coefficient	***p***
Intercept	-0.493	0.013*
Conformity = conforming (vs. nonconforming)	1.061	<0.001***
Condition = WordFinalContrast (vs. WordInitialContrast)	-0.065	0.814
Conformity × Condition	-0.106	0.727

Experiment 2

Dependent variable: response (accept or reject)
Fixed effects: Conformity, Condition, and their interaction
Random effects: intercepts for subject and item

	Coefficient	***p***
Intercept	-0.013	0.95
Conformity = conforming (vs. nonconforming)	0.735	0.001**
Condition = WordFinalContrast (vs. WordInitialContrast)	-0.059	0.839
Conformity × Condition	0.337	0.343

Experiment 3

Dependent variable: response (accept or reject)
Fixed effects: Condition
Random effects: intercepts for subject and item

	Coefficient	***p***
Intercept	-0.758	0.016*
Condition = ***#T…{T, D}# (*#D)*** (vs. **#D…{T, D}# (*#T)**)	0.673	0.121
Condition = #{T, D}…D# (*T#) (vs. **#D…{T, D}# (*#T)**)	-0.590	0.176
Condition = *#{T, D}…T# (*D#)* (vs. **#D…{T, D}# (*#T)**)	0.853	0.052

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