UNIVERSAL BIASES IN PHONOLOGICAL LEARNING

ACTL SUMMER SCHOOL, DAY 3

JAMIE WHITE (UCL)
RESULTS (GENERALIZATION PHASE)

Potentially Saltatory condition

Input:

\[ p \rightarrow v \]

Results:

\[ p \rightarrow b \rightarrow v \]

\[ f \rightarrow v \]

Control condition

Input:

\[ b \rightarrow v \]

Results:

\[ p \rightarrow b \rightarrow v \]

\[ f \rightarrow v \]

White (2014), Cognition
Author's personal copy

The untrained intermediate sounds were changed more often in the Potentially Saltatory condition than in the Control condition, for both untrained stops (70.0% vs. 20.8%) and untrained fricatives (45.0% vs. 15.8%). Within the Potentially Saltatory condition, participants also showed a tendency to change untrained stops more often than untrained fricatives (70.0% vs. 45.0%).

To evaluate these differences, a mixed logit model was fitted, predicting log odds of having a changing response for words ending in untrained target sounds. The final model included fixed effects for Condition (Potentially Saltatory vs. Control), Sound Type (stops vs. fricatives), and a Condition x Sound Type interaction. Random intercepts for subjects and by-subject random slopes for Sound Type were also included. By-subject random slopes were included because they significantly improved model fit according to a likelihood ratio test, $\chi^2(3) = 75.62, p < .001$.

Random intercepts for individual words were not included in the final model because they did not significantly improve model fit, $\chi^2(1) = .12, p = .72$.

The fixed effects for the final model are provided in Table 2. The significant negative intercept indicates that untrained fricatives in the Control condition (coded as the baseline in this model) were changed infrequently. The non-significant main effect of Sound Type follows from the fact that untrained stops were also changed infrequently in the Control condition. Condition was a significant predictor in the model, indicating that participants chose the changing option for words in the Potentially Saltatory condition (i.e., those with final intermediate sounds) significantly more often than for words in the Control condition. These results are consistent with the main prediction: participants changed untrained sounds more often when they were intermediate between a potentially saltatory alternation. There was also a significant interaction, indicating that untrained stops were changed more frequently than untrained fricatives, but only in the Potentially Saltatory condition.

### 2.2.3. Effect of amount of exposure

Due to the experimental design, participants received variable amounts of training, either completing one or two cycles of the exposure phase. This design choice was made because of the implicational nature of the hypothesis: given that a participant has learned a potentially saltatory alternation, how does the participant treat untrained, intermediate sounds? To answer this question, it was more critical to ensure that participants had actually learned the potentially saltatory alternations (or the comparable non-saltatory alternations in the Control condition) before being tested on new cases, as opposed to ensuring that all participants received the same amount of exposure. On average, participants in the Potentially Saltatory condition completed 1.40 cycles of the exposure phase whereas participants in the Control condition completed 1.75 cycles. Thus, it is possible that the amount of exposure, rather than the intermediate status of the untrained sounds, can explain the differences observed between the Potentially Saltatory condition and the Control condition.

![Graph showing individual results by Condition and Sound Type.](image-url)

**Table 2** Summary of the fixed effects for untrained sounds in Experiment 1.

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Estimate</th>
<th>Standard Error</th>
<th>Wald</th>
<th>p-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>2.80</td>
<td>0.57</td>
<td>4.87</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Condition = Potentially Saltatory</td>
<td>2.35</td>
<td>0.78</td>
<td>3.02</td>
<td>.002</td>
</tr>
<tr>
<td>Sound Type = Untrained stops</td>
<td>0.33</td>
<td>0.72</td>
<td>0.46</td>
<td>.65</td>
</tr>
<tr>
<td>Interaction = Potentially Saltatory &amp; Untrained stops</td>
<td>2.80</td>
<td>0.97</td>
<td>2.89</td>
<td>.004</td>
</tr>
</tbody>
</table>

In principle, it was possible to have three cycles, but no participant who completed Experiment 1 within the allotted hour had more than two cycles of the exposure phase.
Explicitly Saltatory condition

Input:

\[ \begin{align*}
\text{p} & \quad \rightarrow \quad \text{v} \\
\text{b} & \quad \rightarrow \quad \text{v}
\end{align*} \]

Results:

\[ \begin{align*}
\text{f} & \quad \rightarrow \quad \text{v} \\
& \quad \rightarrow \quad \text{v}
\end{align*} \]

\[ \begin{align*}
\text{p} & \quad \rightarrow \quad \text{b} \\
& \quad \rightarrow \quad \text{b}
\end{align*} \]

\[ \begin{align*}
\text{f} & \quad \rightarrow \quad \text{v} \\
& \quad \rightarrow \quad \text{v}
\end{align*} \]

Control condition

Input:

\[ \begin{align*}
\text{p} & \quad \rightarrow \quad \text{b} \\
\text{b} & \quad \rightarrow \quad \text{v}
\end{align*} \]

Results:

\[ \begin{align*}
\text{f} & \quad \rightarrow \quad \text{v} \\
& \quad \rightarrow \quad \text{v}
\end{align*} \]

\[ \begin{align*}
\text{p} & \quad \rightarrow \quad \text{b} \\
& \quad \rightarrow \quad \text{b}
\end{align*} \]

\[ \begin{align*}
\text{f} & \quad \rightarrow \quad \text{v} \\
& \quad \rightarrow \quad \text{v}
\end{align*} \]

White (2014), *Cognition*
INFANTS?

12-month-old infants exhibit the same bias in an artificial language learning task!

• See: White & Sundara 2014, Cognition

What about in L1 learning?
In American English, /t/ and /d/ are neutralized to [ɾ] between vowels if the second is unstressed:

\[ pat \ [pæt] \]
\[ pad \ [pæd] \rightarrow [pærɪŋ] \]

Excellent test case:
- [t ~ ɾ] more frequent in the input.
  → Frequency predicts [t ~ ɾ] learned first.
- [d] and [ɾ] more phonetically similar than [t] and [ɾ].
  → Similarity predicts [d ~ ɾ] learned first.

Sundara, Kim, White, & Chong, under review
CORPUS ANALYSIS

9 infant-mother dyads (infant ages 0;9–2;2) chosen from the Brent Corpus (Brent & Siskind 2001)

Extracted all words ending in –ting/–ding.

**Conclusion:** infants hear far more –ting than –ding.

- Same disparity in other tap contexts (-al, -er, word-finally…)

Sundara, Kim, White, & Chong, under review
EXPERIMENT 1

Do 12-month-olds map [ɾ] to /t/?

Participants

• Monolingual English-learning 12-month-olds (n=24).
• Tested at UCLA.

Used Headturn Preference Procedure (HPP)
HEADTURN PREFERENCE PROCEDURE
**DESIGN**

**Familiarization phase**

- 2 alternating passages (45 s each)
  - E.g. *Patting* animals always relaxes me. My dog gets very angry when he sees me *patting* cats. …
  - *Shooting* an arrow is hard when it’s windy. *Shooting* a movie is my favorite activity. …
- Target words appeared 6 times per passage.

**Counterbalanced design**

- Half heard *patting/shooting* passages.
- Half heard *cutting/meeting* passages.
Test phase (4 trials x 2 blocks)

- Same for all infants.
- 2 familiar and 2 novel word lists without –ing:
  - pat...pat...pat...pat...
  - shoot...shoot...shoot...shoot...
  - cut...cut...cut...cut...
  - meet...meet...meet...meet...

**Prediction:** Infants will listen longer to familiar trials if:

- they can segment the root from the –ing form,
- and they can map [ɾ] to /t/. 
RESULTS: $[\mathcal{r}] \rightarrow /t/$

Either 12mo’s can’t segment –ing, or they can’t map $[\mathcal{r}]$ to $/t/$.
EXPERIMENT 2

Do 12-month-olds map [ɾ] to /d/?

Participants:

- 24 new monolingual English-learning 12-month-olds.

Familiarization phase:

- Identical to Exp. 1 (same recordings).

Test phase:

- Identical to Exp. 1, except ‘words’ ended in /d/:
  - pad...pad...pad...pad...
  - shood...shood...shood...shood...
  - cud...cud...cud...cud...
  - meed...meed...meed...meed...
RESULTS: \([\dot{r}] \rightarrow /d/\)

→ 12mo’s succeed at segmenting –ing and mapping \([\dot{r}]\) to /d/. 
EXPERIMENT 3 – DISCRIMINATION EXP.

Do 12-month-olds fail to discriminate [d] and [ɾ]?

Participants:

• 18 monolingual English-learning 12-month-olds who participated in Exp. 2.

Visual fixation procedure
EXPERIMENT 3 – DISCRIMINATION EXP.

Habituation phase:

- [ˈədə]…[ˈədə]…[ˈədə]… (or [ˈərə]…[ˈərə]…[ˈərə]…)
  - Multiple tokens of each.
  - Vowel duration and F0 equalized.
  - Terminated when infant listening time reduced by 50%.

Test phase (2 trials):

- ‘Same’ trial
- ‘Switch’ trial

Prediction: If infants can discriminate, increased listening time to Switch trials vs. Same trials.
SAMPLE DISCRIM EXPERIMENT
12mo’s can discriminate [d] and [ɾ].
LOOKING FOR BIASES IN NATURAL L1 LEARNING: CORPUS + EXPERIMENT APPROACH
BASIC IDEA

Two general approaches:

1. Find statistical regularities in a language, using corpora and a statistical model. Then, probe native speaker knowledge to see how well these patterns have been learned.
   • Underlearned or not learned at all $\rightarrow$ bias against the pattern.
   • Overlearned $\rightarrow$ pattern bolstered by UG bias.

2. Find crucial cases that happen to be missing in a language. Test speakers on the missing cases.
   • Like a natural ‘poverty of the stimulus’ experiment.
   • E.g., see Zuraw 2007, Berent et al. 2007.
DUTCH VOICING ALTERNATIONS

Dutch voicing alternations

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>a. verwijden</td>
<td>[vɛʁvɛidən]</td>
<td>‘widen-INF’</td>
</tr>
<tr>
<td></td>
<td>verwijten</td>
<td>[vɛʁvɛitən]</td>
</tr>
<tr>
<td>b. verwijd bijna</td>
<td>[vɛʁvɛid ˈbɛinaː]</td>
<td>‘widen almost’</td>
</tr>
<tr>
<td></td>
<td>verwijt bijna</td>
<td>[vɛʁvɛit ˈbɛinaː]</td>
</tr>
<tr>
<td>c. verwijd niet</td>
<td>[vɛʁvɛit nɪt]</td>
<td>‘widen not’</td>
</tr>
<tr>
<td></td>
<td>verwijt niet</td>
<td>[vɛʁvɛit nɪt]</td>
</tr>
<tr>
<td>d. verwijd</td>
<td>[vɛʁvɛit]</td>
<td>‘widen’</td>
</tr>
<tr>
<td></td>
<td>verwijt</td>
<td>[vɛʁvɛit]</td>
</tr>
</tbody>
</table>

Typical analysis

- Underlying [voice] contrast in obstruents.
- Neutralized to [–voice] word-finally.
- Neutralized to [+voice] before voiced stops (through assimilation).

Ernestus & Baayen 2003, *Language*
What if we forced speakers to go the other way?
- E.g. give them a nonce word [kyf] and asked them to guess the infinitive, [kyfən] or [kyvən].
- N.B.: [kyf] could correspond to either.
- Ernestus & Baayen did such a task.

Task
- Hear phrase containing novel verb in present: [ɪk tɪf] ‘I tief…’
- Write down past tense of novel verb: <tiefte> or <tiefde>
- 192 monosyllabic nonce verbs; 28 participants.

Ernestus & Baayen 2003, *Language*
SOME POSSIBLE RESULTS

Speakers might...

1. Assume that there are no alternations $\rightarrow$ only choose voiceless past tense allomorph.
2. Respond randomly $\rightarrow$ choose voiceless and voiced at roughly chance level.
3. Respond stochastically (broad) $\rightarrow$ match the overall rate of alternation vs. non-alternation in the full lexicon.
4. Respond stochastically (narrow) $\rightarrow$ match rate of alternation in the lexicon according to specific phonological factors (e.g. identity of final obstruent).
5. Binary responding $\rightarrow$ figure out the most likely outcome in the lexicon, and always choose that option.

Ernestus & Baayen 2003, Language
RESULTS

Results in the Dutch lexicon

Results from wug test

Ernestus & Baayen 2003, *Language*
SIMILAR BEHAVIOR IN TAGALOG

Tagalog nasal substitution

- E.g.: [bigaj] ‘give’ → [mamigaj] ‘to distribute’ (from /maŋ + bigaj/)

In the lexicon

Wug test with nonce forms

Zuraw 2000, dissertation; Zuraw 2010, NLLT
This type of behavior is called frequency matching.

- Presumably domain-general. It occurs in other learning domains and in animals.

**Law of Frequency Matching (from Hayes et al. 2009):**

- “Speakers of languages with variable lexical patterns respond stochastically when tested on such patterns. Their responses aggregately match the lexical frequencies.”

This observation sets the stage for looking for learning biases:

- **Null hypothesis:** speakers learn statistical patterns in their input and will frequency match when tested.
- Cases where people do NOT frequency match → learning bias
TURKISH LARYNGEAL ALTERNATIONS

Basic pattern:

• Contrast between voiced stops and voiceless aspirated stops neutralized in coda position:

<table>
<thead>
<tr>
<th>bare stem</th>
<th>possessive</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. (\text{at\textsuperscript{f}})</td>
<td>(\text{at\textsuperscript{f}})-i</td>
</tr>
<tr>
<td>b. (\text{anat\textsuperscript{f}})</td>
<td>(\text{anat\textsuperscript{f}})-i</td>
</tr>
<tr>
<td>c. (\text{gyt\textsuperscript{f}})</td>
<td>(\text{gyt})-y</td>
</tr>
<tr>
<td>d. (\text{amat\textsuperscript{f}})</td>
<td>(\text{amat})-i</td>
</tr>
</tbody>
</table>

Traditional analysis (like Dutch final devoicing):

• Underlying contrast.
• Contrast neutralized in coda position, through devoicing and aspiration of the stops.

Becker, Ketrez, & Nevins 2011, *Language*
CORPUS ANALYSIS

Factors affecting the likelihood that a stem alternates in the lexicon (based on Turkish Electronic Living Lexicon):

1. Place: 
   COR < PAL < LAB, DOR

2. Size: 
   Mono < Poly; 
   CVC < CVCC

3. Prec V height: 
   Nonhigh < high

4. Prec V backness: 
   front < back

Becker, Ketrez, & Nevins 2011, *Language*
NATURALNESS OF THE PATTERNS

Natural:

• Size
  • Faithfulness (lack of alternation) in a prominent position, i.e. the initial syllable. This has typological support (Beckman 1998).

• Place
  • Also has typological support – different places often act differently w.r.t. laryngeal features.

Unnatural:

• Prec V height
• Prec V backness
  • Uncommon for features of V to determine features of following C.

Becker, Ketrez, & Nevins 2011, Language
WUG TEST

Participants
- 24 Turkish speakers.

Task
- Self-paced forced-choice task.
- See nonce noun in orthography, e.g. <fet>.
- Hear Ali’nin ___ (‘Ali’s ____’) followed by 2 genitive options:
  - E.g. feṭḥi ... feḍi (order counterbalanced)
- Choose which is the correct genitive form (button press).
- 72 target items + 36 filler items.

Becker, Ketrez, & Nevins 2011, Language
<table>
<thead>
<tr>
<th>Best model of the corpus</th>
<th>Best model of the experimental results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Significant factors:</td>
<td>Significant factors:</td>
</tr>
<tr>
<td>Place</td>
<td>Place</td>
</tr>
<tr>
<td>Size</td>
<td>Size</td>
</tr>
<tr>
<td>Prec V height</td>
<td></td>
</tr>
<tr>
<td>Prec V backness</td>
<td></td>
</tr>
<tr>
<td>Place * Size</td>
<td>Place * Size</td>
</tr>
<tr>
<td>Place * Prec V height</td>
<td></td>
</tr>
<tr>
<td>Place * Prec V backness</td>
<td></td>
</tr>
</tbody>
</table>
The authors refer to this as a ‘surfeit of the stimulus’ effect.

- Turkish speakers fail to pick up on some statistical patterns in the Turkish lexicon, even though these patterns have ample support.
- The existence of these patterns is likely due to historical factors, but they have no status in the synchronic grammar.

What type of bias?

- The authors suggest a hard bias approach – the patterns are unlearnable.
- I.e., learners cannot access the constraints that would be necessary to encode such patterns in their grammar.
  - Constraints not part of UG, or are otherwise impossible to induce.
“The proposal advanced here is that the results are best understood in light of a theory of universally possible phonological interactions, as encoded in a set of universal constraints. Only factors that can be expressed in terms of constraint interaction can be identified by language learners, with other lexical generalizations going unnoticed.”

(See also Becker, Nevins, & Levine 2012, Language, for a case in English.)
ANOTHER EXAMPLE: HUNGARIAN

Hungarian has a highly productive pattern of backness harmony in vowels.

3 categories of vowels:
- **Back (B)** = [u, uː, o, oː, ɔ, aː]
- **Front (F)** = [y, yː, ø, øː]
- **Neutral (N)** = [i, iː, eː, e]

Cases of exceptionless harmony:

(5) Closest vowel back: back suffixes
   BB  [ɔblók-nék]  ‘window-DAT’
   NB  [biːroː-nék]  ‘judge-DAT’
   FB  [glykoːz-nék]  ‘glucose-DAT’

(6) Closest vowel front rounded: front suffixes
   F   [yʃt-nék]  ‘cauldron-DAT’
   NF  [semɔltʃ-nék]  ‘wart-DAT’
   BF  [ʃofʃːr-nék]  ‘chauffeur-DAT’

(7) F + N*: front suffixes
   FN   [fyːser-nék]  ‘spice-DAT’
   FNN  [ʃriziʃt-nék]  ‘custody-DAT’

Hayes, Zuraw, Siptár, & Londe 2009, *Language*
**ZONES OF VARIATION**

Certain types of stems show variation (‘zones of variation’):

- BN, BNN
- All neutrals (N, NN)

Examples of different outcomes within word of the same type falling in the ‘zones of variation’:

<table>
<thead>
<tr>
<th>WORD ([o] + [eː])</th>
<th>GLOSS</th>
<th>GOOGLE HITS (Sept. 2008)</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>doménnak</td>
<td>[domeːn-nək]</td>
<td>‘domain (on Web)-DAT’</td>
<td>5</td>
</tr>
<tr>
<td>doménnek</td>
<td>[domeːn-nɛk]</td>
<td></td>
<td>234</td>
</tr>
<tr>
<td>bohémnak</td>
<td>[boheːm-nək]</td>
<td>‘easy-going-DAT’</td>
<td>433</td>
</tr>
<tr>
<td>bohémnek</td>
<td>[boheːm-nɛk]</td>
<td></td>
<td>1,340</td>
</tr>
<tr>
<td>honvédnak</td>
<td>[honveːd-nək]</td>
<td>‘Hungarian soldier-DAT’</td>
<td>8,820</td>
</tr>
<tr>
<td>honvédnek</td>
<td>[honveːd-nɛk]</td>
<td></td>
<td>3,084</td>
</tr>
<tr>
<td>poénak</td>
<td>[poeːn-nək]</td>
<td>‘punch line-DAT’</td>
<td>56,400</td>
</tr>
<tr>
<td>poénnek</td>
<td>[poeːn-nɛk]</td>
<td></td>
<td>36</td>
</tr>
</tbody>
</table>

Table 1. Examples: lexical arbitrariness of harmony within the zones of variation.

Hayes, Zuraw, Siptár, & Londe 2009, *Language*
The corpus was collected by way of Google searches.

- (See Hayes & Londe 2006, *Phonology*)
- Searched for the [–nɔk] and [–nɛk] forms of several thousand noun stems.
- Heavily cleaned the corpus, removing potentially problematic cases (e.g. compounds).
- The resulting corpus had 8,915 stems.

Hayes, Zuraw, Siptár, & Londe 2009, *Language*
LEXICAL PATTERNS IN THE ‘ZONES OF VARIATION’

Two effects deemed natural: height and locality

Hayes, Zuraw, Siptár, & Londe 2009, Language
FOUR UNNATURAL STATISTICAL EFFECTS IN THE LEXICON

1. If stem-final C is a labial non-continuant → Front suffix

2. If stem-final C is a sibilant → Front suffix

3. If stem-final C is a coronal non-sonorant → Front suffix

4. If stem ends in CC → Front suffix

(All significant in the corpus.)

Hayes, Zuraw, Siptár, & Londe 2009, *Language*
WUG TEST

Participants:

- 131 Hungarian speakers (online)

Hálupem

Choose the best answer to fill in the blank:

Hálupem was a goddess worshipped by the early pagan Hungarians. It is believed that Hálupem was the goddess of weaving. Not just the Hungarians but also neighboring peoples celebrated __________ (dat.)’s divine powers.

○ Hálupemnak
○ Hálupemnek

Please rate each item from 1 to 7:

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hálupemnak</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Hálupemnek</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

This is item 2 (of 13)

1,703 Wug stems tested in total.

Each stem only seen by one participant.

13 stems per participant.

Hayes, Zuraw, Siptár, & Londe 2009, Language
RESULTS (HEIGHT/DISTANCE EFFECTS)

Hayes, Zuraw, Siptár, & Londe 2009, Language
RESULTS FOR THE UNNATURAL PATTERNS

They learn them all.

<table>
<thead>
<tr>
<th>Unnatural constraints</th>
<th>COEFFICIENT</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>USE FRONT / bilabial __</td>
<td>−1.211</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>USE FRONT / [ + cor, + son] __</td>
<td>−0.519</td>
<td>0.0074</td>
</tr>
<tr>
<td>USE FRONT / sibilant __</td>
<td>−0.500</td>
<td>0.0230</td>
</tr>
<tr>
<td>USE FRONT / CC __</td>
<td>−0.762</td>
<td>&lt; 0.0001</td>
</tr>
</tbody>
</table>

BUT – are the constraints underlearned?

Hayes, Zuraw, Siptár, & Londe 2009, *Language*
Basic overview of their method:

- Train a MaxEnt grammar on the real wug test results = G_{WUG}
- Train a MaxEnt grammar on the lexicon (corpus data) = G_{LEX}
- We want to compare these – but we can’t compare them directly because they are trained on different sets (and amounts) of data.

- So instead…
- Assume that each participant used G_{LEX} as the basis of their wug responses.
- Use the probabilities outputted by G_{LEX} to simulate 10,000 random runs of the wug test (all 1703 words). (=Monte Carlo method)
- This gives you a distribution of the 10,000 Pseudo-G_{WUG} weights for each constraint, assuming people rely on G_{LEX}.
- Compare the real weights of each constraint in G_{WUG} to the distribution of the weights.

Hayes, Zuraw, Siptár, & Londe 2009, *Language*
UNDERLEARNING OF UNNATURAL CONSTRAINTS

Hayes, Zuraw, Siptár, & Londe 2009, Language
“We judge that [cases where people learn unnatural rules] indicate an ability in people to locate and internalize phonological generalizations on an inductive basis, without having them prespecified in UG. This does not imply, however, that endogenous factors (i.e. UG, broadly construed) could not play a role in phonological learning, and we judge that some of the experimental work cited…above in fact supports this view. Thus, the theory we ultimately advocate is a mixed, bias-based theory, in which learning can be assisted by UG, but is not limited to a strict UG-specified form.”
NATURAL AND UNNATURAL PHONOTACTIC GENERALIZATIONS

- A MaxEnt model for learning phonotactics from a corpus.
- Induces the phonotactic constraints (in terms of natural classes), using an algorithm that searches through the set of possible constraints and selects them based on search heuristics (simplicity, accuracy, generality).
- Requires few prior assumptions (a key one: a feature set, and we also included syllable structure).
- Resulting grammar of constraints is weighted to maximize the likelihood of the data (MaxEnt learning).
NATURAL AND UNNATURAL CONSTRAINTS IN ENGLISH PHONOTACTICS

Corpus:

- Created a corpus consisting of all words appearing both in the CMU Pronouncing Dictionary and in CELEX with a frequency of at least 1.
- Lots of cleaning.

We let the learner run until it had learned 160 constraints.

- Then, we searched for 10 constraints that we deemed natural, and 10 constraints that we deemed unnatural.

Crucially: the weights of the unnatural constraints were, on average, slightly higher than those of the natural constraints.

- Thus: the unnatural constraints represent lexical patterns that are equally strong (or slightly stronger) than the natural constraints.

Hayes & White 2013, Linguistic Inquiry
NATURAL CONSTRAINTS

<table>
<thead>
<tr>
<th>Constraint</th>
<th>Violating - Control</th>
<th>IPA</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. *[−son] [+son] IN CODA</td>
<td>kipl - kilp</td>
<td>[’kɪpl] - [’kɪlp]</td>
</tr>
<tr>
<td>b. *[+cons] [−cons] IN CODA</td>
<td>canifl - canift</td>
<td>[kə’niʃl] - [kə’niʃt]</td>
</tr>
<tr>
<td>c. *[−cons] [+cons] IN ONSET</td>
<td>tilr - tilse</td>
<td>[’tɪlə] - [’tɪls]</td>
</tr>
<tr>
<td>d. *[−cont] [−cont] IN ONSET</td>
<td>shapenr - shapent</td>
<td>[ʃə’pɛnə] - [ʃə’pɛnt]</td>
</tr>
<tr>
<td>e. *[−cont] [+nasal] IN ONSET</td>
<td>hlup - plup</td>
<td>[’hʌp] - [’plʌp]</td>
</tr>
<tr>
<td>f. *[+labial] [+dorsal] IN CODA</td>
<td>hmit - smit</td>
<td>[’hmit] - [’smit]</td>
</tr>
<tr>
<td>g. *[+dorsal] [+labial] IN CODA</td>
<td>cping - sping</td>
<td>[’kpiŋ] - [’spiŋ]</td>
</tr>
<tr>
<td>h. *[+labial] [+labial] IN ONSET</td>
<td>ctice - stice</td>
<td>[’ktaɪs] - [’staɪs]</td>
</tr>
<tr>
<td>i. *[−son] [−son] [−voice] [+voice]</td>
<td>cnope - clope</td>
<td>[’knəʊp] - [’kləʊp]</td>
</tr>
<tr>
<td>j. *[−syllabic] [+high] IN CODA</td>
<td>pneck - sneck</td>
<td>[’pnɛk] - [’snɛk]</td>
</tr>
</tbody>
</table>

Twenty-nine UCLA undergraduate students participated in the experiment.
## UNNATURAL CONSTRAINTS

<table>
<thead>
<tr>
<th>Constraint</th>
<th>Violating - Control</th>
<th>IPA</th>
</tr>
</thead>
<tbody>
<tr>
<td>c. * [-back] [+diphthong]</td>
<td>metchter - metchner</td>
<td>['meʃtʃer] - ['meʃnə]</td>
</tr>
<tr>
<td>d. * [+diphthong] [word] [+round] [+high]</td>
<td>pyshon - pyson</td>
<td>['paisən] - ['paisən]</td>
</tr>
<tr>
<td>e. * [+diphthong] [word] [-ant]</td>
<td>foushert - fousert</td>
<td>['fauʃət] - ['fauʃət]</td>
</tr>
<tr>
<td>f. * [+coronal] [+cont] [-son]</td>
<td>hethker - hethler</td>
<td>['heθkə] - ['heθlə]</td>
</tr>
<tr>
<td>h. * [+diphthong] [+round] [-back] [-ant]</td>
<td>potho - pothy</td>
<td>['paθə] - ['paθi]</td>
</tr>
<tr>
<td>i. * [+voice] [+cont] [+stress] [-son] [-ant]</td>
<td>taitho - taithy</td>
<td>['teɪθə] - ['teɪθi]</td>
</tr>
<tr>
<td>No [u, ʊ, w] before [h]</td>
<td>zhep - zhem</td>
<td>['ʒep] - ['ʒem]</td>
</tr>
<tr>
<td>No [j] before [ai, au, əi]</td>
<td>zhod - zhar</td>
<td>['ʒad] - ['ʒar]</td>
</tr>
<tr>
<td>No word-initial [u, ʊ]</td>
<td>ouzie - oussie</td>
<td>['auzi] - ['ausi]</td>
</tr>
</tbody>
</table>
DO LEARNERS SHOW AWARENESS OF THE UNNATURAL CONSTRAINTS?

(TO THE SAME LEVEL AS THE NATURAL CONSTRAINTS?)
MAGNITUDE ESTIMATION TASK

We're going to show you a series of lines on the computer screen. The line given above will be your reference. Some of the lines will be longer than this line and some will be shorter. Your task is to determine how much longer or shorter each line is compared to the reference line.

Click the Next button to continue.

Participants: 29 English speakers
5.2 Results and Discussion

5.2.1 Calibration

Studies using magnitude estimation can be calibrated to assess their validity. We first examine if participants are self-consistent in the training phase described in the previous section: do the lines they draw match up to the numbers they are attempting to match, and vice versa? We can check this by performing a regression analysis, comparing a participant's numerical response to a line of a particular length against the same participant's line length for the same number. This analysis (carried out with log values) yields a strong positive correlation ($r = .96$).

The slope of the regression line is almost exactly one. This showed that, as in previous work, our participants had no trouble performing the basic magnitude estimation task. In addition, as a group, they neither underestimated nor overestimated in either modality.

We also examined how participants' responses to the nonword items compared across the two modalities. Regression analysis for these values indicated nearly perfect correlation ($r = .98$) and a perfect slope of one. This indicates that participants were consistent in their nonword ratings across the two modalities. Therefore, we may assume that these values are valid and reliable (for discussion, see Lodge 1981 and Bard, Robertson, and Sorace 1996).

5.2.2 Replication of Scholes 1966 and Albright 2009

We found that the mean log ratings of the borrowed fillers correlated strongly with log ratings from Scholes 1966 and Albright 2009 ($r = .90$ and $r = .86$, respectively), indicating that our experiment succeeded in eliciting similar phonotactic well-formedness intuitions.

5.2.3 Main Results

For the following analyses, data from the line-drawing task and the number estimation task, which yielded very similar results, have been collapsed. As a check, we ran all of the analyses on the line data and numerical data separately, and the results showed the same basic pattern as with the combined data.

Figure 1 shows the mean log ratings for nonwords according to the Naturalness of the constraint being tested (Natural or Unnatural) and to the nonwords' status as Control or Violating.

![Bar chart showing mean log ratings for Control and Violating forms across Natural and Unnatural conditions](chart.png)

- Control forms
- Violating forms

Mean log rating:
- Natural: 5.0 (n.s.)
- Unnatural: 4.5 (*)

Hayes & White 2013, *Linguistic Inquiry*
## эффекты индивидуальных ограничений

<table>
<thead>
<tr>
<th>Ограничение</th>
<th>Статус</th>
<th>Пары</th>
<th>Размер эффекта</th>
</tr>
</thead>
<tbody>
<tr>
<td>*[− cont] [− cont] in onset</td>
<td>natural</td>
<td>cping/sping, ctice/stice</td>
<td>1.65</td>
</tr>
<tr>
<td>*[glide] in coda</td>
<td>natural</td>
<td>jouyljout, tighw/tibe</td>
<td>1.56</td>
</tr>
<tr>
<td>*[− cons] [+ cons] in onset</td>
<td>natural</td>
<td>hlup/plup, hmit/smit</td>
<td>1.51</td>
</tr>
<tr>
<td>*[− cont] [− nasal] in onset</td>
<td>natural</td>
<td>cnope/clop, pneck/sneck</td>
<td>1.44</td>
</tr>
<tr>
<td>*[+ labial] [− dorsal] in coda</td>
<td>natural</td>
<td>bik/lbm, sad/kp/sad/k</td>
<td>1.44</td>
</tr>
<tr>
<td>*[− son] [− cons] in coda</td>
<td>natural</td>
<td>shapenr/shapent, tilr/tile</td>
<td>1.34</td>
</tr>
<tr>
<td>*[+ labial] [+ labial] in onset</td>
<td>natural</td>
<td>bewell/brell, pwickon/twic</td>
<td>1.23</td>
</tr>
<tr>
<td>*[− cont] [− nasal] in onset</td>
<td>unnatural</td>
<td>hethker/hethler, muthpy/muspy</td>
<td>1.14</td>
</tr>
<tr>
<td>*[− ant] [− stress] [− round]</td>
<td>unnatural</td>
<td>pothol/pothy, taitho/taithy</td>
<td>1.10</td>
</tr>
<tr>
<td>*[− ant] [+ diphthong]</td>
<td>unnatural</td>
<td>boitcher/boisfer, noiron/nyron</td>
<td>1.10</td>
</tr>
<tr>
<td>*[− ant] [− cont] [− son]</td>
<td>unnatural</td>
<td>foushert/fousert, pyshon/psyon</td>
<td>1.08</td>
</tr>
<tr>
<td>*[− ant] [− high]</td>
<td>unnatural</td>
<td>ooker/locke, utrume/treme</td>
<td>1.03</td>
</tr>
<tr>
<td>*[− ant] [− diphthong]</td>
<td>unnatural</td>
<td>youse/yoss, yout/yut</td>
<td>1.02</td>
</tr>
<tr>
<td>*[− ant] [− voice] [− son] [− round]</td>
<td>unnatural</td>
<td>zhep/zhem, zhod/zhah</td>
<td>1.01</td>
</tr>
<tr>
<td>*[− ant] [− stress] [− son] [− round]</td>
<td>unnatural</td>
<td>ishty/ishmy, metchter/metcher</td>
<td>0.99</td>
</tr>
<tr>
<td>*[− voice] [− son] [− voice]</td>
<td>natural</td>
<td>esger/ezger, trocdal/troctal</td>
<td>0.98</td>
</tr>
<tr>
<td>*[− high] [− son] [− cons]</td>
<td>unnatural</td>
<td>luhallem/laihallem, tuhaim/towhaim</td>
<td>0.97</td>
</tr>
</tbody>
</table>


• Zuraw, Kie. (2007). The role of phonetic knowledge in phonological patterning: Corpus and survey evidence from Tagalog.