The cognitive basis for restrictions on vowel harmony

Sara Finley
finley@cogcsci.jhu.edu
William Badecker
Johns Hopkins University
Goal of This Talk:

Learning Involves:

• Abstract Phonological Representations
  – Features

• Constrained by universal grammatical principles
  – Reflected in typological frequency

• Artificial grammar learning experiments can tap into adult phonological representations
Traditional View of Features

- Abstract Learning: Features
- Abstract features traditionally assumed in theoretical phonology
  - SPE feature bundles
  - Autosegmental tree structures, etc.
  - Vowel harmony in SPE

\[ V \Rightarrow [\alpha\text{Back}] \] / \[ V \] [\alpha\text{Back}]
Challenges to Abstract Features

• **Exemplar-models** (Johnson 2006; Port & Leary 2006, etc)
• No need for abstract features
• Store
  – lexical items
  – fine-grained phonetic details
  – statistics
• Compute similarity
• Vowel harmony in exemplar models: statistics over co-occurrence
  – agreeing front vowels, high percentage [i e], [e i]
  – agreeing back, high percentage [u o] [o u], etc.
  – disagreeing vowels, low percentage, * [i u]
Finding Evidence for Features

• Artificial Grammar Learning: Poverty of the Stimulus (Wilson 2006)
  – Test generalization to novel segments/structures
  – Not testing for nativism

• Train Participants on Novel Mini language
  • Brief auditory exposure to language
  • Limited exposure to inventory of possible segments to undergo rule

• Test
  • Old Items (identical to training)
  • New Items (novel words, same segments as training)
  • New Segments (include ‘hold-out’ vowels)
    – generalization to novel segments = feature-based learning
Poverty of the Stimulus and Vowel Harmony (Wilson 2006)

• Vowel Harmony:
  – Process whereby vowels agree for some feature [Back], [Round], etc.
  – Induces morphophonological alternations
    • nek/nak (Hungarian)
  – Not in English (use monolingual English-speaking participants)
  – Learnable process (Pycha et al 2003, Wilson 2003 (nasal assimilation))
Poverty of the Stimulus and Vowel Harmony (Wilson 2006)

-Artificial Back Harmony:
  - 6 vowel inventory
  - Training Includes 4 vowels
  - Test Includes all 6 vowels

<table>
<thead>
<tr>
<th>Front</th>
<th>Back</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>i</td>
<td>u</td>
<td>Training/Test</td>
</tr>
<tr>
<td>e</td>
<td>o</td>
<td>TEST ONLY</td>
</tr>
<tr>
<td>æ</td>
<td>a</td>
<td>Training/Test</td>
</tr>
</tbody>
</table>
Experiment 1: Back Harmony

• Will adult learners of an artificial back harmony language generalize to novel segments?
• Is there a difference in generalization based on vowel height?
Experiment 1: Back Harmony

• Stems trigger alternation in suffix vowel
  – Stems: CVCV
    • consonants [p, t, k, b, d, g, m, n]
    • 6 Vowels Total:
      – front [i, e, æ]
      – back [u, o, a]
  – Suffix alternates between
    [-mi] (front)/ [-mu] (back)

• Front vowels trigger [-mi]
  – [bige] ⇒ [bigemi]

• Back vowels trigger [-mu]
  – [bugo] ⇒ [bugomu]
Experiment 1: Stimuli

• Naturally produced stimuli
  – Adult male
    • Native English Speaker
  – English Vowels
• Intensity Scaled to 70 db
• Stimuli rated by 1st author and 2 native English speakers
Experiment 1: Hold-Out Conditions

- 4 Vowels in training
- 2 Hold-Out Conditions
- Low Hold-Out: [i, e, u, o]
- Mid Hold-Out: [i, u, æ, a]
4 Learning Hypotheses

- Segment-Based Learning: Learners learn rule based on individual segments
  - no generalization to novel segments
- Formally Restricted Feature-Based Learning: Abstract learning but to the smallest possible natural class
  - generalization to mid but not low vowels
- General Feature-Based Learning: Learners learn a general, abstract rule
  - generalization to mid and low vowels
- Substantively Biased Feature-Based Learning: Abstract learning, constrained by universal grammatical tendencies
  - generalization to mid and low vowels
# Predictions: Experiment 1

<table>
<thead>
<tr>
<th>Hypothesis</th>
<th>Mid Vowel</th>
<th>Low Vowel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Segment</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Formally-Restrictive</td>
<td>√</td>
<td>X</td>
</tr>
<tr>
<td>General</td>
<td>√</td>
<td>√</td>
</tr>
<tr>
<td>Substantivity - Biased</td>
<td>√</td>
<td>√</td>
</tr>
</tbody>
</table>
Participants (all experiments)

- Adult native English speakers
- Johns Hopkins Undergraduate Students (for extra credit)
- 12 participants in each training condition
Experiment 1: Training

- 4 Vowels in training: 2 Hold-Out Conditions
  - Low Hold-Out: [i, e, u, o]
  - Mid Hold-Out: [i, u, æ, a]
- 24 items, each played 5 times
  - Stem followed by Stem + Suffix
    - bige, bigemi  budo, budomu
- Controls
  - 48 stems, 24 harmonic stems, 24 disharmonic stems
Experiment 1: Test

- Forced choice
  - Heard 2 suffixed forms
  - Pick Form ‘Most likely to be in language’
    » bidimi bidimu

- 36 test items

- 3 test conditions:
  - Old Items (Identical to training)
  - New Items (Identical segments)
  - New Vowels (mid vowels/low vowels)
The Role of Generalization

- High Performance on Old Items:
  - form-by-form learning
- High Performance on New Items:
  - abstract rule
- High Performance on New Vowels:
  - feature-based rule
Experiment 1: Results

Figure 1: Proportion of Harmonic Responses for All Conditions

• Controls at chance
• Mid Hold-Out generalized to Mid vowels, but did numerically worse on new items (low vowels)
• Low Hold-Out generalized to new items, but not low vowels
Exp 1 Results Summary

• Generalization to Mid Vowels
  – Supports Feature-Based Accounts

• No Generalization to Low Vowels

• Round Confound
  – suffix [mi]/[mu] alternates in backness AND rounding
  – Low vowels unround
    • may have lead to poor generalization
    • Low Vowels do not participate in round harmony
      – supports substantive-biased hypothesis
# Predictions: Experiment 1

<table>
<thead>
<tr>
<th>Hypothesis</th>
<th>Mid Vowel</th>
<th>Low Vowel</th>
<th>Overall</th>
</tr>
</thead>
<tbody>
<tr>
<td>Segment</td>
<td>☹️</td>
<td>✓</td>
<td>☹️</td>
</tr>
<tr>
<td>Formally-Restrictive</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>General</td>
<td>✓</td>
<td>☹️</td>
<td>☹️</td>
</tr>
<tr>
<td>Substantively-Biased</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>
Experiment 2

• Are differences in generalization in Experiment 1 based on cross-linguistic tendencies or general dispreference for low vowels?

• Goals of Exp 2
  – Make front/back distinction unambiguous
  – Test Generalization for mid vs. high vowels
  – Test Perception of low vowels
Experiment 2: Low Vowel Suffix

• Front vowels trigger: [-mæk]
• Back Vowels Trigger: [-mak]
• Hold-Out Conditions:
  – Hold Out Mid Vowels
    • [i, æ], [u, a]
  – High Hold-Out
    • [e, æ], [o, a]
Exp 2: Substantively Biased

• If generalization based on typological frequencies
  – Generalization to Mid Vowels
  – Less robust generalization to High Vowels
    • particularly less generalization to High Front Vowels
      – Cross-linguistic tendency for non-participation of high front vowels (e.g., Finnish)
# Predictions: Experiment 2

<table>
<thead>
<tr>
<th>Hypothesis</th>
<th>Mid Vowel</th>
<th>High Vowel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Segment</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Formally-Restrictive</td>
<td>√</td>
<td>X</td>
</tr>
<tr>
<td>General</td>
<td>√</td>
<td>√</td>
</tr>
<tr>
<td>Substantively-Biased</td>
<td>√</td>
<td>√ /X</td>
</tr>
</tbody>
</table>
Experiment 2: Perception Task

- To test whether participants perceive the difference between front/back pairs, especially in the low vowels
- AXB paradigm
  - Participants asked to judge whether X is the same as A or B
    - teteto $X = A$
    - tetoto $X = B$
  - If difference is perceived, then performance should be very high, if no difference is perceived, performance should be low.
- Used as screening (all participants under 70% correct dropped; this occurred for less than 10% participants)
Experiment 2: Results

- Generalization in Both Training Conditions
  - more robust in Mid Hold-Out
Experiment 2: Results

• Generalization more robust to mid vowels than high vowels
  – greater generalization to back high vowels
    • 57% high front harmonic
    • 68% high back harmonic
  – Cross-linguistic tendency for non-participation of high front vowels (e.g., Finnish)

• Perception results at ceiling
# Predictions: Experiments 1 & 2

<table>
<thead>
<tr>
<th>Hypothesis</th>
<th>Exp 1</th>
<th>Mid Vowel</th>
<th>High Vowel</th>
<th>Overall</th>
</tr>
</thead>
<tbody>
<tr>
<td>Segment</td>
<td>😞</td>
<td>😞</td>
<td>😞</td>
<td>😞</td>
</tr>
<tr>
<td>Formally-Restrictive</td>
<td>✓</td>
<td>✓</td>
<td>😞</td>
<td>😞</td>
</tr>
<tr>
<td>General</td>
<td>😞</td>
<td>✓</td>
<td>✓</td>
<td>😞</td>
</tr>
<tr>
<td>Substantively-Biased</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>
Experiment 3: Height Harmony

• When do learners postulate parasitic (restrictive) harmony rules?
  – Further distinguish between different feature-based approaches

• Substantively-Biased Hypothesis:
  – Parallels with Cross-linguistic Typologies

• Formally-Restrictive Hypothesis
  – Always form restricted, parasitic-type rule

• General Feature-Based Learning Hypothesis
  – Never form restrictive, parasitic rule
Experiment 3: Height Harmony

- Height Harmony
  - Parasitic on Tenseness
  - But not Backness
- Substantively Biased Hypothesis
  - Learners exposed to tense vowels undergoing vowel harmony will form parasitic rule
    - not generalize to lax vowels
  - Learners exposed to front vowels undergoing height harmony will form general rule
    - generalize to back vowels
# Predictions: Experiment 3

<table>
<thead>
<tr>
<th>Hypothesis</th>
<th>Lax Vowel</th>
<th>Back Vowel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Segment</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Formally-Restrictive</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>General</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Substantively-Biased</td>
<td>X</td>
<td>✓</td>
</tr>
</tbody>
</table>
Experiment 3: Materials

- Suffix: [-mi], [-me]
- Three training conditions:
  - Control
  - Lax Hold-Out [i, u, e, o]
  - Back Hold-Out: [i, ɪ, e, ɛ]

[+HIGH] i u
   ɪ

[–HIGH] e o
   ε
Experiment 3: Results

- Learning in both Conditions
- Generalization to Back Vowels
- No Generalization to Lax Vowels
## Predictions: Experiments 1-3

<table>
<thead>
<tr>
<th>Hypothesis</th>
<th>Exp 1</th>
<th>Exp 2</th>
<th>Lax Vowel</th>
<th>Back Vowel</th>
<th>Overall</th>
</tr>
</thead>
<tbody>
<tr>
<td>Segment</td>
<td>😞</td>
<td>😞</td>
<td>✓</td>
<td>😞</td>
<td>😞</td>
</tr>
<tr>
<td>Formally-Restrictive</td>
<td>✓</td>
<td>😞</td>
<td>✓</td>
<td>😞</td>
<td>😞</td>
</tr>
<tr>
<td>General</td>
<td>😞</td>
<td>✓</td>
<td>😞</td>
<td>✓</td>
<td>😞</td>
</tr>
<tr>
<td>Subst-Biased</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>
The Substantively-Biased Learner

• Generalization to Back but not Lax vowels
  Supports the Substantively-Biased Learning Hypothesis

• Substantively-Biased Learning:
  – abstract, feature-based representations
  – rules posited in line with typological frequencies
Experiment 4 Novel Suffixes

• Feature-based Generalization to novel vowels
  – How abstract is the rule formed?
  – Just memorized association to suffix?

• Can learners generalize to novel suffixes?
  – Evidence for more abstract rule
Experiment 4-Novel Suffixes

• Round Harmony Rule
• 4 vowel inventory [i, u, e, o] (all conditions)
• 3 conditions
  – Control
  – Generalize to Mid-Vowel Suffixes
    • train on high-vowel suffix
  – Generalize to High-Vowel Suffixes
    • train on mid vowel suffix
• CVCV stems
• High suffix
  • either [-mi]/[-mu], [-gi]/[-gu]
• Mid Suffix
  • Either [-me]/[-mo], [-ge]/[-go]
Experiment 4: Test

• 3 Conditions, 36 items
• Old
  • Stem and suffix exactly same as training
• New Stem
  • suffix identical to training
  • Novel Stem
• New Suffix
  • Stem identical to training
  • Novel suffix vowel
  • Different Consonant
    – if training suffix [-mi]/[-mu], novel suffix [-ge]/[-go]
Exp 4: Results

- All Groups Learned
- Generalization to Novel Suffixes
Exp 4: Summary

- Generalization to novel suffix vowel
- Both for Mid and High Vowels
- Supports feature-based learning
- Rule more abstract than memorized stem + Suffix association
Substantively-Biased Learning

- Abstract, feature-based representations
- Generalize to multiple alternations
- Rules posited in line with cross-linguistic typology
Alternative, Phonetic Interpretations

- Exemplar Learning: Match statistical co-occurrence of segments to exemplars heard in training
  - Exemplar-based version of the segment-based hypothesis
  - Learning outside training space (Marcus 1999) goes against it

- Acoustic Distance to Suffix: If new segments are too far from the suffix, won’t generalize
  - Exp. 3- Lax vowels closest to suffix vowels [i]/[e], but no generalization

- Acoustic Distance of Novel Segments: If novel segments are too close acoustically, won’t be able to match to suffix
  - Exp. 2: predicts best generalization to high vowels [i]/[u] since are furthest apart, but generalization here was less robust
Conclusions

• Abstract features used in learning
• Universal grammatical principles constrain learning
  – What are they, exactly?
• Artificial grammar experiments can be used to test phonological theories
  – More research, more refined paradigms, needed
THANK YOU!

• Acknowledgements:
  – Ari Goldberg, Becky Piorkowski, Paul Smolensky, Rebecca Morley, Colin Wilson, Luigi Burzio, Audience at the 2007 LSA Annual Meeting, and the JHU Psycholinguistics Lab