Morphologically-conditioned tonotactics in multilevel Maximum Entropy grammar

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## 1 INTRODUCTION

- This talk presents a case of lexically-conditioned tonotactics variation from Mende (Mande, Sierra Leone).

(1) Top trisyllabic surface tone patterns in the Mende lexicon

- Part of speech-sensitive patterns =
  - different lexical classes can exhibit different phonological patterns.
  - noted cross-linguistically: e.g., English noun versus verb stress patterns
  - applications in e.g., comprehension, parsing

- Two hypotheses about how lexical class-conditioned sensitivity could work:
  
  A. Lexical class differences are limited by the grammar/UG.
     - differences only in faithfulness, not markedness (e.g., Ito & Mester 1995; Alderete 2001; Smith 2011)
     - preferential classes, e.g., nouns // verbs will show a subset of noun patterns (Smith 2011)
  
  B. Lexical classes can each have their own completely independent phonological profiles (e.g., Ito & Mester 1995; Inkelas & Zoll 2007; Anttila 2002; Pater 2009).
     - We argue for this latter hypothesis here.
This talk:
- quantitatively models space of lexically-conditioned variation and frequency of variation across the corpus,
- This approach directly addresses the overarching problem in morphophonology of how to quantify the heterogeneity that morphological conditioning can engender in a phonological system.

2 Mende Tonotactics

2.1 History, early generative accounts

- Early generative accounts of Mende noticed common tone patterns recurrent in the language, particularly in nouns (Leben 1978) → ‘tone melodies’ (see also Hyman 1987 for similar tone melodies in Kukuya).
- In Autosegmental Phonology, these surface tone patterns were modeled using
  - geometric association conventions of Autosegmental Phonology
  - 5 underlying tone melodies (H, L, HL, LH, LHL) as source of all surface patterns.

(2) ndāvulā ‘sling’ \[L \rightarrow R, L \leftrightarrow L\] association, then spread.

L H

- But, subsequent work pointed out many surface patterns that deviate from the supposed five melodies or their “universal” autosegmental association principles (Dwyer 1978; Conteh et al. 1983; Zoll 2003; Zhang 2007).

(3) a. lēlēmā ‘praying mantis’ violates association principles

L H

b. gbāgbēmā ‘sensitive plant’ cannot arise from one of the 5 tone melodies; violates association principles

H LH L

2.2 Data

- Mende dictionary: \(n=5,412\) (Innes 1969)
- 1 to 3-syllable words: \(n=4,989\)
  - Morpheme breaks are not indicated in Innes, but a primary source of morphological complexity (in nouns, at least) appears to be total reduplication in 4-syllable words, which we’re not looking at here.
- Parts of speech
  - Nouns 2,494
  - Neutrals 1,442 (verbs, adjectives)
  - Ideophones 762
  - Other 291 (pronouns, conjunctions, interjections, adverbs, etc.)

2.3 A fresh look at tone: the theoretical underpinnings

- Agreement by Correspondence Theory (ABC; Hansson 2001; Rose & Walker 2004; Bennett 2013; a.o.)
  - grounded in basic principles of similarity and proximity attraction, modeling instability in syntagmatic phonological relationships (Wayment 2009; Inkelas & Shih 2013).
  - Elements that are sufficiently similar/proximal interact in e.g., assimilation/dissimilation.
  - For simplicity in this talk, constraints are reformulated into more familiar phonotactic markedness format (but it’s still ABC under the hood; cf. Hansson 2014).
- Q Theory (e.g., Shih & Inkelas 2014)
  - decomposes segments into strings of (2 or 3) smaller, temporally-sequenced, featurally-uniform subsegments, which bear tone features.
(4)  a.  \( Q \rightarrow (q^1 q^2) \)  
    b.  \( \tilde{a} \rightarrow (\tilde{a} \tilde{a}) \)  
    c.  \( \tilde{LH} \rightarrow (L H) \)  

- provides a more fine-grained point of reference for the grammar: crucial for e.g., contour tones.
- divorces issue of what are the minimal units that carry tone features versus what are the units that participate in tonal alternations/phenomena.

Basic relevant differences between Autosegmentalism (e.g., Leben 1973) and ABC+Q for this talk:
- Constraints grounded in principles of similarity- and proximity-based interaction.
- No reliance on geometric, autosegmental ‘line’ representations
- No reliance on operations that reference autosegmental ‘lines’: i.e., tone association rules.¹

2.4  Observed patterns for Mende surface tones

- Primary observations taken from Inkelas & Shih 2015.

2.4.1  Contour toned syllables (and tone transitions in general—except at syllable boundaries) are avoided.

(5)  ▪ Significantly fewer contour syllables than expected, if syllable tone patterns could be HH, LL, LH, and HL. \( \chi^2=6705.270, p<0.0001. \)

(6)  *[αT]::[βT]  (*CHANGE)  
    Penalise every sequence of adjacent \( q \)’s that are tonally non-identical.

(7)  | \( \sigma,\sigma \) | \( freq \) | *CHANGE \( *[αT]::[βT] \) |
    |---|---|---|
    | a. LL.HH | 701 | 1 |
    | b. LL.HL | 389 | W2 |

2.4.2  If necessary, contour tones are tolerated at the right edge.

(8)  ▪ The significant majority of contour syllables occur at the right edge of words.
    ▪ versus equal probability across all syllables: \( \chi^2=353.407, p<0.0001. \)

¹ This possibility was hinted at by Zoll (2003), but not fully explored.
Penalise every adjacent $q$ sequence of non-identical tones within a weak (i.e., non-final) syllable. (cf. COINCIDE-CONTOUR; Zoll 2003)

<table>
<thead>
<tr>
<th>$\sigma.\sigma$</th>
<th>$freq$</th>
<th>*WeakCONTOUR</th>
<th>*CHANGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>LL.HL</td>
<td>389</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>L.H.LL</td>
<td>77</td>
<td>W1</td>
<td>2</td>
</tr>
</tbody>
</table>

2.4.3 Tone changes align with syllable boundaries

- Syllable boundaries coincide significantly with tone changes (in polysyllabic words that have non-level surface patterns): $\chi^2=1428.074, p<0.0001$

Resulting prediction: tone melody complexity should correlate with the number of syllables in a word. More syllables $\rightarrow$ more non-level tone patterns (Inkelas & Shih 2015).

- As # of syllables in a word increases, so does the percentage of more complex melodies. Conversely, less complex, all-level melodies decrease.

Penalise every adjacent, tonally-identical $q$ sequence that is separated by a syllable boundary ($\$$. (cf. xx-Edge constraints; Bennett 2013)

<table>
<thead>
<tr>
<th>$\sigma.\sigma.\sigma$</th>
<th>$freq$</th>
<th>CHANGE@$$</th>
<th>*WeakCONTOUR</th>
<th>*CHANGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>LL.HH.LL</td>
<td>233</td>
<td>W1</td>
<td>L1</td>
<td></td>
</tr>
<tr>
<td>LL.HH.HH</td>
<td>218</td>
<td>W1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LL.LL.LL</td>
<td>112</td>
<td>W2</td>
<td>L</td>
<td></td>
</tr>
<tr>
<td>LL.LL.HH</td>
<td>78</td>
<td>W1</td>
<td>L1</td>
<td></td>
</tr>
<tr>
<td>L.H.HH.LH</td>
<td>64</td>
<td>W1</td>
<td>W3</td>
<td></td>
</tr>
<tr>
<td>L.H.HH.HH</td>
<td>7</td>
<td>W1</td>
<td>W1</td>
<td>2</td>
</tr>
</tbody>
</table>
2.4.4 HLH troughs are avoided

- Troughs are underrepresented, but their presence increases as the number of syllables in words increases.

2.4.5 Words preferably have at least one H tone

- Level H tone patterns (e.g., HH, HH, HH) are more common than Level L tone patterns (e.g., LL, LL, LL).

2.5 Constraint summary

<table>
<thead>
<tr>
<th>Constraint</th>
<th>Nickname</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>*[αT]:[βT]</td>
<td>*CHANGE</td>
<td>Penalise every sequence of adjacent q’s that are tonally non-identical.</td>
</tr>
<tr>
<td>*(αT):[(βT)ₜₚ]</td>
<td>*WeakCONTOUR</td>
<td>Penalise every adjacent q sequence of non-identical tones within a weak (i.e., non-final) syllable.</td>
</tr>
<tr>
<td>*[αT]:[αT]</td>
<td>CHANGE@$</td>
<td>Penalise every adjacent, identical q sequence that is separated by a syllable boundary.</td>
</tr>
<tr>
<td>*TROUGH</td>
<td>*TROUGH</td>
<td>Penalise any two H tones separated by any number of consecutive L tones.</td>
</tr>
<tr>
<td>HAVEH</td>
<td>HAVEH</td>
<td>Penalise any word with no H tone.</td>
</tr>
</tbody>
</table>

- Note that no matter the OT analysis, the goal in this paper is to examine and model the variance of part-of-speech-specific tonotactics. (Almost) any constraint set would be fine for this, and the fact that there’s lexically-conditioned differences (see (1)) doesn’t change.
3 ANALYSIS

3.1 Maximum Entropy Harmonic Grammar

  - ranks probabilities (i.e., comparative grammaticality) of outcome candidates in variable data.
- Output = probability distribution over all possible surface tone pattern combinations of LL, HH, LH, HL syllables (LHL, HLH are found on monosyllables only)

3.2 Cophonologies/Indexed Constraints as Varying Slopes

- Varying slopes = additive weight adjustment for constraints in the Base Grammar, per each lexical class.
  - Such an approach has been hinted at before: e.g., Albright 2008; Coetzee & Pater 2011.

\[ w_1 c_1 + w_2 (c_1 \times \text{NOUN}) + w_3 (c_1 \times \text{NEUT}) + w_4 (c_1 \times \text{Id}) + \cdots + w_k c_{iN} \]  
  (cf. fn 2)

- Base Grammar predicts overall tonotactics for the language, and lexical class-specific tonotactics are predicted by the additive combination of weights of Base Grammar constraints and class-specific weights.
- Cophonologies ≅ bundles of Indexed Constraints.
  - because there is a finite set of lexical classes, varying slopes are formally executed here as interaction terms.³
    - for other previous uses of interaction terms in MaxEnt HG, usually as weighted constraint conjunction: see e.g., Hayes et al. 2012; Pater & Moreton 2012; Green & Davis 2014; Shih, to appear.

3.3 What is the base grammar?

- Trained a base grammar on bootstrapped samples \((n=2500 / \text{sample})\) of possible tone melodies in Mende, drawn from the existing distribution.
  - mirrors a Mende speaker knowing word tone patterns but not (yet) part of speech.
  - did not want to \textit{a priori} assume one lexical class as “default.”
  - across base grammar samples, the results are stable; a representative result is reported here.

- A grammar trained without any data for base grammar provides very similar results (not reported here).
- Another baseline: grammar on a totally random tone patterns \((n=5000)\), generated from random combinations of HH, LL, LH, and HL syllables for 1–3 syllable words is also provided here for comparison.

² \( H_{\text{armony}}(x, i) = \sum_{k=1}^{N} w_k c_i(x) = w_k \cdot c_i \), where \( x \) = candidate for input \( i \), \( w_k \) = weight of constraint \( c_i \), \( c_i(x) \) = number of violations of \( c_i \) that \( x \) incurs, and \( N \) = vector of constraints \((c_{i1} \ldots c_{iN})\).

³ For justification on the equivalency of interaction terms and random slopes in this situation, see e.g., Gelman & Hill 2007.
4 RESULTS

(21) Adjusted MaxEnt weights, in graphical form

(adjusted $w_{C_i} = \text{base } w_{C_i} + \text{indexed } w_{C_i}$)

(22) Adjusted MaxEnt weights, in numbers

<table>
<thead>
<tr>
<th></th>
<th>Base</th>
<th>Adjusted Grammars</th>
<th>Ideophones</th>
<th>Other</th>
<th>Random</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1.356</td>
<td>1.356</td>
<td>1.356</td>
<td>2.537</td>
<td>1.734</td>
</tr>
<tr>
<td>*CHANGE</td>
<td>1.220</td>
<td>1.220</td>
<td>1.391</td>
<td>1.220</td>
<td>1.220</td>
</tr>
<tr>
<td>*WeakCONTOUR</td>
<td>0.426</td>
<td>1.612</td>
<td>0.426</td>
<td>1.409</td>
<td>0.691</td>
</tr>
<tr>
<td>*TROUGH</td>
<td>0.017</td>
<td>0.411</td>
<td>1.361</td>
<td>0.017</td>
<td>0.232</td>
</tr>
<tr>
<td>HAVE H</td>
<td>0.017</td>
<td>0.175</td>
<td>0.543</td>
<td>0</td>
<td>0.099</td>
</tr>
<tr>
<td>CHANGE@$</td>
<td>0</td>
<td>0.175</td>
<td>0.543</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

(23) Constraint weights by lexical class (top→bottom: highest weight→lowest weight)

<table>
<thead>
<tr>
<th></th>
<th>Base</th>
<th>Cophonology Indexed Grammars</th>
<th>Ideophones</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>*CHANGE</td>
<td>*TROUGH</td>
<td>*WeakCONTOUR</td>
<td>*CHANGE</td>
</tr>
<tr>
<td>*WeakCONTOUR</td>
<td>*CHANGE</td>
<td>HAVE H</td>
<td>*TROUGH</td>
<td>*WeakCONTOUR</td>
</tr>
<tr>
<td>*TROUGH</td>
<td>*WeakCONTOUR</td>
<td>*CHANGE</td>
<td>*WeakCONTOUR</td>
<td>*TROUGH</td>
</tr>
<tr>
<td>HAVE H</td>
<td>HAVE H</td>
<td>CHANGE@$</td>
<td>CHANGE@$</td>
<td>HAVE H</td>
</tr>
<tr>
<td>CHANGE@$</td>
<td>CHANGE@$</td>
<td>*TROUGH</td>
<td>HAVE H</td>
<td>CHANGE@$</td>
</tr>
</tbody>
</table>

4.1 Results and observations

4.1.1 Sanity check

- A MaxEnt grammar on completely random data yields constraint weights pretty close to 0.

4.1.2 Base grammar

- Reveals importance of general contour tone avoidance and R-edge contour tone alignment.
  - *CHANGE = 1.356
  - *WeakCONTOUR = 1.220
  - cf. “Random” model results, where weights are much lower, nearly at 0.
- These two constraints remain highly weighted across all lexical classes.
  - weight of *WeakCONTOUR stays stable across the lexicon, suggesting that it’s a very general principle.
- Reflects universal dispreferences for (nonfinal) contour tones (e.g., Gordon 2001; Zhang 2004).
### 4.1.3 Syllable edge – Tone change alignment

- Only nouns and neutrals show an effect of syllable edge-tone transition alignment. → see adjusted weights for \( \text{CHANGE}[@:] \):
  - \( \text{CHANGE}[@:] \times \text{NOUN} = 0.175 \)
  - \( \text{CHANGE}[@:] \times \text{NEUT} = 0.543 \)
  - versus \( \text{CHANGE}[@:] \times \text{ID} = 0 \)

- Shows that ideophones often involve much simpler surface tone patterns than the other lexical classes.
  - e.g., ṭəvələ̀ ‘creaking’
  - In addition, ideophones significantly increase the weight of \( *\text{CHANGE} \)

<table>
<thead>
<tr>
<th>σ.σ.σ, ID</th>
<th>freq</th>
<th>( \text{CHANGE} \times \text{ID} )</th>
<th>( \text{CHANGE}[@:] \times \text{ID} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. LL.HH.LL</td>
<td>2</td>
<td>( w_{adj} = 2.537 )</td>
<td>( w_{adj} = 0 )</td>
</tr>
<tr>
<td>b. LL.LL.LL</td>
<td>76</td>
<td>1.2</td>
<td>0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>( 24 )</th>
<th>( \alpha )</th>
<th>( \beta )</th>
<th>( \sigma )</th>
<th>( $w_{adj}$ )</th>
<th>( \text{HAVE} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. LL.HH.LL</td>
<td>2</td>
<td>W2</td>
<td>1</td>
<td>5.073</td>
<td></td>
</tr>
<tr>
<td>b. LL.LL.LL</td>
<td>76</td>
<td>1.2</td>
<td>0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### 4.1.4 HAVE H: a verb thing

- Neutrals in particular (but also nouns to a certain extent) show a much greater affinity for a requisite H tone than ideophones.
  - = level L surface patterns much more tolerated for Ideophones > Nouns > Neutrals.

<table>
<thead>
<tr>
<th>σ.σ.σ, NEUT</th>
<th>freq</th>
<th>( \text{HAVE} \times \text{NEUT} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. LL.LL.LL</td>
<td>5</td>
<td>( w_{adj} = 1.360656 )</td>
</tr>
<tr>
<td>b. LL.LL.LL</td>
<td>25</td>
<td>( w_{adj} = 0.410611 )</td>
</tr>
<tr>
<td>c. LL.LL.LL</td>
<td>76</td>
<td>( w_{adj} = 0.016843 )</td>
</tr>
</tbody>
</table>

### 4.1.5 *TROUGH: not a verb thing

- Neutrals also differ from Nouns and Ideophones by showing greater preference for tone transitions that align with syllable boundaries, even if these result in a HLH trough.
  - e.g., ṭùvùndı̀ ‘be mouldy, mildewed’
  - = Greater dispreference of troughs in Nouns and Ideophones.
  - Much lower adjusted weight for \( *\text{TROUGH} \) in Neutrals than other lexical classes:
    - \( *\text{TROUGH} \times \text{NEUT} = 0.426 \)
    - \( *\text{TROUGH} \times \text{NOUN} = 1.612 \)
    - \( *\text{TROUGH} \times \text{ID} = 1.409 \)
Perhaps a contrast maximization issue?

<table>
<thead>
<tr>
<th></th>
<th>freq</th>
<th>*TROUGH×NEUT w_adj=0.426</th>
<th>*TROUGH×NEUT w_adj=0.543</th>
<th>CHANGE@$\alpha T$:*$\alpha T$×NEUT w_adj=0.41</th>
<th>$\chi^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>a.</td>
<td>i. HH.LL.HH</td>
<td>78</td>
<td>1</td>
<td>0.43</td>
<td>0.43</td>
</tr>
<tr>
<td></td>
<td>ii. HH.HH.HH</td>
<td>48</td>
<td>2</td>
<td>1.09</td>
<td>1.09</td>
</tr>
<tr>
<td>b.</td>
<td>i. HH.LL.HH</td>
<td>21</td>
<td>1</td>
<td>1.61</td>
<td>1.61</td>
</tr>
<tr>
<td></td>
<td>ii. HH.HH.HH</td>
<td>101</td>
<td>2</td>
<td>0.35</td>
<td>0.35</td>
</tr>
<tr>
<td>c.</td>
<td>i. HH.LL.HH</td>
<td>2</td>
<td>1</td>
<td>1.41</td>
<td>1.41</td>
</tr>
<tr>
<td></td>
<td>ii. HH.HH.HH</td>
<td>79</td>
<td>2</td>
<td>0.00</td>
<td>0.00</td>
</tr>
</tbody>
</table>

4.2 Importance of lexical conditioning

- Are the cophonology/indexed grammars contributing significantly to improving our base grammar?
- Tested here using Akaike Information Criterion ($AIC_c$) model comparison.4
  - How much information is lost when cophonology/indexed constraints are removed?

\[ \Delta AIC_c \text{ from full model for each cophonology removed} = \text{how much information is lost for each cophonology is in turn removed}.5 \]

- $AIC_c$ comparison results show that lexical class-specific cophonologies/indexed constraints produce a better fit for the data.
- Exception that is expected: the “Other” part of speech class, which is heterogeneous as is.
- Certain lexical classes provide more information on top of the baseline, suggesting ‘distance’ from the full model.
- Neutral-specific cophonology contributes a lot of additional information to the grammar.
- Interestingly, ideophones are not the most extreme lexical class.
- For future work: comparing individual indexed constraints versus entire cophonologies of indexed constraints.

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4 Second-order $AIC_c$ is used here, because it adjusts more strictly for differences in the number of constraints between comparison grammars. See e.g., Burnham & Anderson 2002 for justification of $AIC_c$-based model comparison. For use in comparing phonological grammars, see e.g., Shih, to appear (cf. Wilson & Obdeyn 2009).

5 $\Delta AIC_c \geq 10$ is considered large (equivalent to 150:1 that the second best model has essentially no support of being as good as the best model).
5 IMPLICATIONS & CONCLUSION

Lexically-conditioned phonology
- Part-of-speech phonological differences go beyond noun-adjective-verb distinctions (as observed by e.g., Smith 2011).
  - more closely resemble the complexity of morphophonological alternations and variation.
- Lexically-conditioned phonology is not just a matter of differential faithfulness (e.g., FAITH_{NOUN} » FAITH_{VERB}; Smith 2011).
- Overall, indexation of markedness constraints per lexical class gains better fit for the data.
- There are hints of markedness reversals of the kind that ‘Grammar Dependence’ (Alderete 2001) predicts impossible (cf. Pater 2009):
  - E.g., Across nearly all of the grammars (base and lexical class-specific) in Mende, *TROUGH is ranked fairly highly w/r/t the other constraints.
  - In Neutrals, however, *TROUGH is weighted at the bottom.
  - Therefore, a structure (e.g., HLH) that might otherwise be highly marked in the rest of the language is quite good and (comparatively) unmarked for Neutrals.

Quantifying morphological conditioning
- Our approach can quantify how much lexical class-specific phonotactics can differ from the rest of the lexicon.
  - E.g., how different can ideophone phonology be? → long standing issue for e.g., African languages (see Rose 2015 for recent summary).
  - Results show that ideophones operate within fairly conservative parameters of the overall Mende tonotactics grammar—cf., neutrals.
- Because we a priori restrict standard HG/OT grammars to positive weights (i.e., to only penalise rather than reward structures), we’re not really examining the full potential space of variation between cophonologies yet.
- In the future, this ‘varying slopes’ approach could extend to other types of morphology (e.g., affixation; dominant tone melodies): e.g., what are the tone patterns that are grammaticalised in a language as productive morphemes?

For the future
- What is the utility of these phonological differences between groups?
  - There’s evidence from other languages that speakers are capable of learning these lexical statistics (e.g., Coetzee 2014),
  - and that such phonological differences help in e.g., acquisition, processing, information load (e.g., Monaghan et al. 2010).

Acknowledgements
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To save trees, references are available online.
http://cogsci.ucmerced.edu/shih/ShihInkelas_AMP2015handout.pdf
6 References

ALBRIGHT, ADAM. 2008. How many grammars am I holding up? Discovering differences between word classes.


HAYES, BRUCE; COLIN WILSON; and ANNE SHISKO. 2012. Maxent grammars for the metrics of Shakespeare and Milton. Language 88.691–731.


INKELAS, SHARON; and STEPHANIE S SHIH. 2015. Tone melodies in the age of Surface Correspondence. Paper presented at the 51st Annual Meeting of the Chicago Linguistic Society (CLS), University of Chicago.


KULLBACK, SOLOMAN; and RICHARD A. LEIBLER. 1951. On Information and Sufficiency. Annals of Mathematical Studies 2.79–86.


PATER, JOE; and ELLIOT MORETON. 2012. Structurally biased phonology: Complexity in learning and typology. The English and Foreign Languages Journal 3.1–44.


WILSON, COLIN; and MARIEKE OBDEYN. 2009. Simplifying subsidiary theory: statistical evidence from Arabic, Muna, Shona, and Wargamay.

