A Stochastic OT Analysis of Production and Perception in Yucatec Maya

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This paper uses the Gradual Learning Algorithm (GLA, Boersma and Hayes 2001) to develop a stochastic OT analysis (Boersma 1997, 2006, 2007) of pitch and glottalization in Yucatec Maya. Acoustic data taken from a production study involving 12 native speakers form the input to the GLA. The resulting ranking demonstrates how discrete surface forms are mapped onto gradient phonetic outputs in production, and Boersma's model predicts that this same ranking is also used in perception. This prediction is tested by a perception experiment involving 14 native speakers, and the results of this experiment can be accurately analyzed with the same ranking that resulted from the GLA.

The GLA models how a language learner, who starts with a set of constraints of equal ranking, adjusts the ranking of these constraints to fit the linguistic input that the learner receives. In stochastic OT, a ranking is represented by a number which is the mean ranking of a constraint; at any point of evaluation the actual ranking of a constraint is randomly selected from a normal distribution with said mean. Thus, the relative order of constraints may differ at each point of evaluation, and variation is accounted for. The current analysis looks at the relationship between a *surface form* (the output of the phonology) and a *phonetic form* (the output of the phonetics – what the speaker actually says). Because there is naturally a high degree of variation in phonetic productions, stochastic OT is advantageous in that it can account for variation whereas strict dominance of constraints cannot. According to Boersma (2006), cue constraints, similar to faithfulness constraints, compare surface forms to phonetic forms and assign violation marks as applicable. E.g., a cue constraint that says "/i/ is not produced with an F1 of 500 Hz" would be violated by any candidate with an F1 of 500 Hz given an input of /i/. Articulatory constraints, like markedness constraints, assign violation marks to offending candidates regardless of the input (e.g. "do not produce an F1 of 500 Hz"). One of the major insights of the cue constraints is that they work in both production and perception (Boersma 2006).

Yucatec Maya uses a four-way suprasegmental contrast (Bricker et al. 1998); two of these contrasts are of interest here. "High tone" vowels are long with initial high pitch. "Glottalized" vowels are also long with initial high pitch but begin with modal voice that is interrupted by either creaky voice or a glottal stop. According to the results of the production study, as shown in Fig. 1 and Table 1, these two vowel types significantly differ both by pitch and by glottalization.

Though the productions differ by both initial pitch and glottalization, the constraint ranking that results from the GLA predicts glottalization to be the most important cue in perception. Various acoustic parameters were taken directly from the production study and input into the GLA using OTSoft (Hayes et al. 2003). Pitch measurements were relativized to each speaker's 'baseline' (which was the average of the middle pitch point produced for each low tone vowel) with the formula log(pitch/baseline). Cue constraints penalized the pairing of each acoustic parameter with each of the possible surface forms. Articulatory constraints penalized likely costly productions, such as high pitch and creaky voice. Fig. 2 shows the rankings (that the GLA predicts the learner to develop given this set of linguistic input) of the cue constraints that penalize various relativized values for initial pitch and various types of glottalization when produced for the high tone and glottalized vowels. E.g., the cue constraint that says "a high tone vowel is not produced with a relativized initial pitch of -.08" has a ranking of 101.8. Dips in the graphs denote low constraint rankings and hence preferred acoustic values. For initial pitch, the rankings are very similar for both high tone and glottalized vowels, but there are striking differences for glottalization.

Because the ranking of cue constraints is also used in perception, this ranking predicts that glottalization type plays an important role in perceiving the contrast between high tone and glottalized vowels, while initial pitch does not. The perception experiment confirms this result. Participants heard stimuli that varied in terms of initial pitch and glottalization and were forced to choose between two words – one with a high tone vowel and one with a glottalized vowel. The results (Table 2) confirm that glottalization and not initial pitch is used as a cue to differentiate these two vowel types.

This paper thus shows that stochastic OT is well-suited to account for significant amounts of variation at the phonetic level. Furthermore, the GLA can handle real acoustic data, which is the input the learner receives, to create a ranking that accurately defines both production and perception, as demonstrated by this study of pitch and glottalization in Yucatec Maya.

Figure 1: average pitch contours for high tone and the glottalized vowels (males and females averaged together); the initial pitch point and the point at 25% of vowel duration are significantly different between the two vowel types (t = 3.29, p = .0011; t = 3.45, p =.0006, respectively)

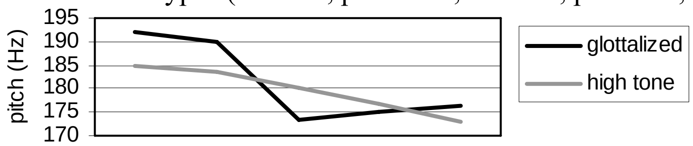

Table 1: production of glottalization in high tone and glottalized vowels ($\chi^2 = 134.3$, $p<.0001$)

	type of glottalization			
	no glottalization	weak glottalization	creaky voice	full glottal stop
high tone	90.9%	6.7%	2.5%	0.0%
glottalized	41.7%	18.4%	37.7%	2.1%

Figure 2: ranking of cue constraints as determined by the GLA

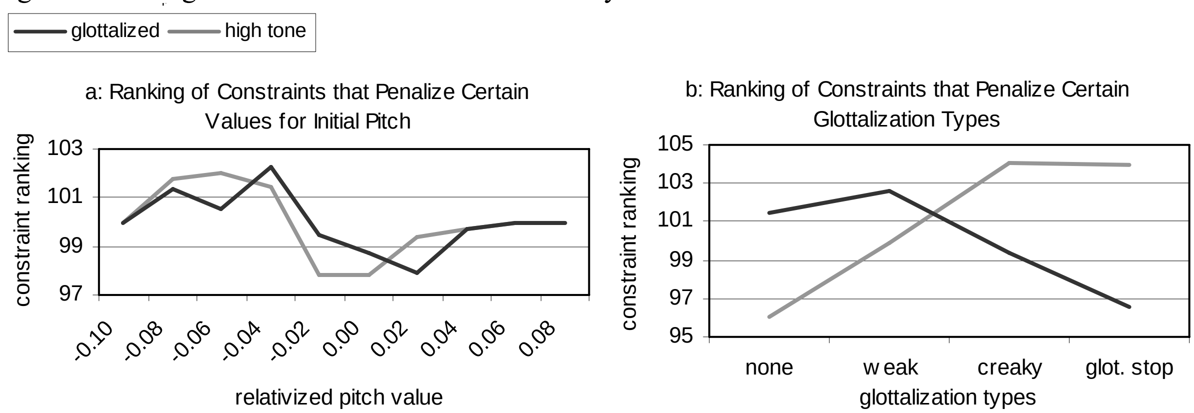

Table 2: percentage of times participants answered "glottalized vowel" for each stimulus type; significant main effect of glottalization type (Wald $\chi^2 = 189.2$, $p <.0001$), nonsignificant main effect of pitch (Wald $\chi^2 = 1.7$, $p = .64$), nonsignificant interaction (Wald $\chi^2 = 3.8$, $p = .92$)

	relativized initial pitch			
glottalization type	-.018	.031	.075	.116
none	27%	25%	23%	29%
weak	44%	44%	41%	37%
creaky	61%	63%	62%	69%
glottal stop	79%	85%	77%	83%

↓ *significant effect of glottalization*

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