Coarticulation of Tone and CV segment in citation and sentence forms

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ABSTRACT

Traditional and modified locus equations (LE) were used to examine the interaction of tone on the coarticulation of C+V of a tone bearing syllable as a function of tone (Mid and High) and speech style (citation and sentence). Traditional LE slope found no significant coarticulatory differences for Mid-tone relative to Low-tone condition, but showed higher slopes for sentence relative to citation forms. Systematic tone effects were observed by modified locus equations (MLE) parameter. 3D plots of F0, F1 & F2 also found tone and style effects.

Keywords: Coarticulation, tone, speech style locus equations, modified locus equations

1. INTRODUCTION

Studies of the interaction of obstruents with the F0 of an upcoming vowel within a tone bearing syllabic unit has often implicated the phonetic and phonology of a language. For tonal languages the research interest is mostly on co-occurrence patterns e.g., voiced obstruents tend to occur with low tone and voiceless with high tone [1]; on the interaction of tone across a medial consonant in a VCV sequence [2, 3], on the perturbation of tone or the surface variation of tone [4]. With reference to intonational languages, F0 shows up acoustically as a prosodic feature that discernably affects the extent and degree of CV coarticulation. Thus, CV and V to CV bonding are affected by emphatic stress [5, 17], by speech tempo, and pattern of perturbation [6]. While there has been serious interests in accounting for the mechanics of consonant-tone articulation [7]; the status and behavior of tone in the degree of C+V bonding has received less attention in spite of the independence of tone and segments suggested by the autosegmental theory [8].

The study reported in this paper asks: Does the tonal identity of a syllable affect the bonding of its constituent units? To explore this question, Yoruba VCV units produced in citation form and in carrier sentence were acoustically studied. The degree of coarticulation was determined using locus equations [9]. Modified locus equations [10] were also used to explore and quantify the effects of tone separate from contextual vowel variations. The suitability of LE and MLE for these purposes has been sufficiently established by diverse studies that have shown LE to provide acoustic relational invariance, and quantify the effect of a vowel on a preceding consonant under different speech perturbations [15, 18]. LEs are linear regression fits to scatterplots of coordinates representing, separately for each consonantal category, all F2 transition onsets, plotted on the y-axis, in relation to mid-vowel frequencies plotted on the x-axis [10]. Often, the plotted data cluster tightly around the regression line. LE slope values range from 0 to 1 indicating minimum to maximum CV coarticulation [11, 13, 16]. Both slope and y-intercept are seen as effective predictors of stop place of articulation [9, 11].

2 METHODOLOGY

2.1 Speech sample and elicitation of data

The data for this study came from Yoruba language of Nigeria. It has seven vowels /i, e, ɛ, ɑ, o, ɔ, ʊ/ four voiced stops; /b, d, g, gb (labial-velar stop)/, and three level tones: Mid, Low and High. The test items paired meaningful Yoruba words that differed in tone. It compared V_1CV_2 (Mid tone) to $\grave{V}_1C\grave{V}_2$ (Low tone). Studied vowels were /i, e, ɛ, ɑ, o, ɔ/. V_1 & V_2 were identical. The medial consonants were /b,d,g/. The following pair exemplify the test word for each stop place: ***aba**raméjì vs. **àbà**rápméjì*, *ò**dodo** vs. **òdò**dó*, and ***igi**rere vs. **ìgì**ripa*,

The bolded VCV items were the focus of the investigation. The subjects were three adult male native Yoruba speakers. They read the list of words directly into a Dell laptop using Praat. Each subject produced 72 tokens: (6Vs*3Cs*2-tones*2styles). The recorded signals were sampled at 22 kHz, digitized, and filtered with Praat [12]. All acoustic measurements were performed from wide band spectrograms using Praat. F1 & F2 values were obtained for V_1mid, V_2mid, V_1offset, and V_2onset following established procedure [9, 11]. ProsodyPro [14] was used to obtain pitch [F0] and duration. Tokens with wrongly realized tones were deleted.

3 Results

3.1 Locus equations and CV Coarticulation

Locus equations plots were obtained for the subjects across the three stop place consonants. Table 3.1 presents the summary results of LE coefficients for bdg for the Mid tone (MT), Low tone (LT) and for citation (c) and sentence (s) conditions.

Table 3.1: Summary of LE slopes, intercepts and R^2 for 3 subjects and stop place categories /b, d, g/, for Mid tone, Low tone, citation and sentence conditions.

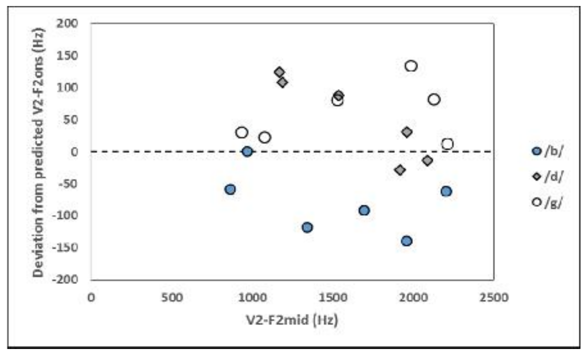
Mid Tone: *Citation*	Mid Tone: *Sentence*
Slope, intercept, R2	**Slope, intercept, R2**
/b/ y = 0.88x + 83.13: R^2 = 0.97	**/b/** y = 0.88x + 60.21: R^2 = 0.97
/d/ y = 0.73x + 510.4: R^2 = 0.92	**/d/** y = 0.81x + 324.6: R^2 = 0.90
/g/ y = 0.98x + 115.6: R^2 = 0.95	**/g/** y = 1.09x - 122.03: R^2 = 0.97
Low Tone: *Citation*	**Low Tone: *Sentence***
/b/ y = 0.91x + 40.82: R^2 = 0.96	**/b/** y = 0.99x + 14.44: R^2 = 0.93
/d/ y = 0.70x + 590.91: R^2 = 0.92	**/d/** y = 1.01x - 68.57: R^2 = 0.85
/g/ y = 1.03x + 27.98: R^2 = 0.93	**/g/** y = 1.05x - 100.54: R^2 = 0.99

Table 3.1 presents the summary of locus equation parameters. A closer look at the slopes for citation condition revealed slightly higher slope values for /b,g/ of LT than MT. For the sentence condition, LT slopes were significantly higher than MT slopes for /b,d/. Between tone conditions, MTs slopes were higher than MTc slopes while LTs slopes were higher than LTc slopes. Overall, the table shows distinctive slopes and intercepts values for /b,d,g/. The slopes were ordered in accordance with previous LE studies, i.e., g > b > d (except LTc). LE parameters provided a non-overlapping categorical sorting for stop place categories. The R^2 values ranging between 0.85 and 0.97 show that the data points clustered close to the regression line and that about 90% of the variations in F2onset were explained by V_2-F2mid.

Given that traditional locus equations only showed noticeably and varying differences in the degree of coarticulation as a function of tone condition and speech style; the modified locus equations were used to more closely assess the differences observed in the LE parameters. The use of modified locus equations involved two steps. Step 1: Multiple regressions were conducted to explore the relationship between CV_2onset and 3 predictor variables: V_1F2; V_2F0 & V_2F2 for each tone condition so as to obtain a baseline regression and slope coefficients (b, c) using the equation: F2onset (V_2) = a + b*F2mid(V_2) + c*F2mid(V_1) + d*F0(V_2). The results showed an overall significant effect of the regression for each tone condition [< 0.000]. For MTc & LTc V_1 and of V_2 were significant [< 0.000] and F0 [0.499 for MTc]. MTs & LTs V_2 was significant [<0.000], V_1, V_2F0 [0.39 & 0.36 for LTs].

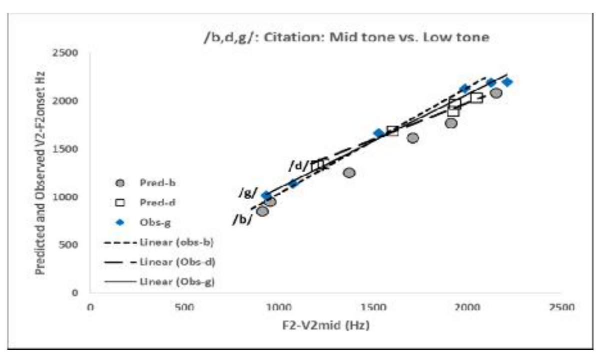
(a) Between Tones: The second involved the derivation of a new LE equations using the baseline intercept (a) and slopes (b, c) obtained for LT condition but with V_1-F2, V_2-F2 and F0-V_2 values from MT condition. A comparison of the resultant predicted relative to observed F2onset would reveal if there was another factor at play separate from contextual vowel variations. The result is presented in Figure 3.1 & 3.2 below.

Figure 3.1: Deviation of observed F2 onset from expected F2 onsets derived for all subjects and for b, d, g: Low tone citation by Mid tone citation.



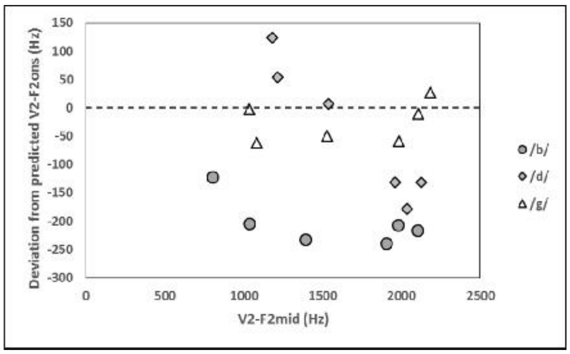
For the top /b/, all predicted vowel values fell below the line of identity except for /a/, for the stop /d/, only /i, e/ fell below the line of identity; values ranged from -28 to 123Hz, and for /g/, all vowels were above their observed counterparts.

Figure 3.2: Plot of predicted and observed onsets. Diamond = /g/, circle = /b/ and square = /d/ data points. The difference between the linear line fit to data points for analogous observed data points, removed for clarity, and predicted show the degree of coarticulation attributable to tone differences.



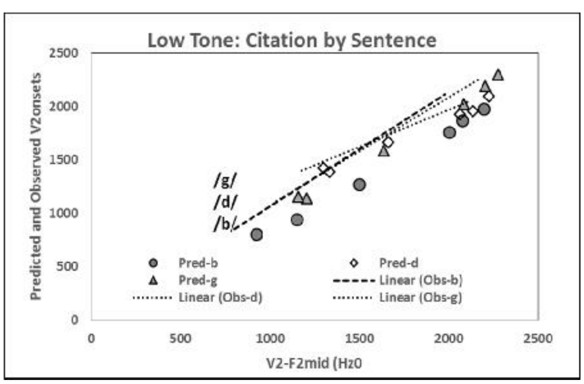
(b) Between style: Using the approach described above, a 2nd regression was obtained using the baseline intercept (a) and slope (b, c) obtained for LTc but with V_1F2, V_2F2 and F0-V_2 values from LTs. A new sets of predicted F2onset values obtained were compared to observed values. The logic been that any deviations between the two would be *unaccounted for* variables due to speech style effects [10]. Figures 3.3 to 3.4 are resulting plots showing how the predicted and observed V_2onsets differed for each of the six vowels and the three stop consonants.

Figure 3.3: Deviation of observed F2 onset from expected F2 onsets derived for all subjects and for b, d, g: Low tone citation by Low tone sentence.



For /b/, all the predicted vowels fell below the line of identity, the difference range from -121 to -239 Hz. For /d/ only /a/ fell close to the line of identity and for /g/, it is /e, ε /. Others are higher or lower than their observed values.

Figure 3.4: Plot of predicted and observed onsets of LTs and LTc. Diamond = /g/, circle = /b/ and square = /d/ data points. The difference between the linear line fit to data points for analogous Observed data points (removed for clarity) and Predicted data points indicate the degree of coarticulation attributable to speech style differences. Note that the linear lines (for observed) are not good fit to the predicted data points.



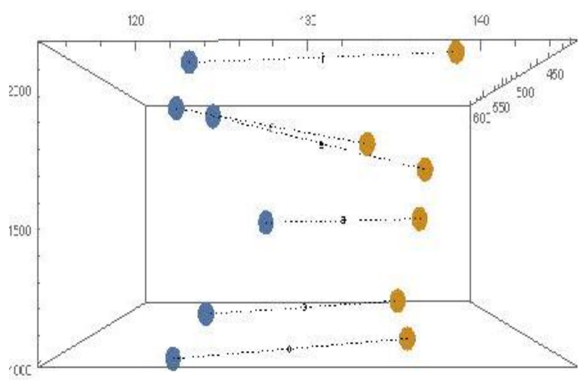
Summary coefficients of slope and intercept are presented in Table 3.2. Except for /d/ all observed slopes were consistently higher than predicted slopes.

Table 3.2: Slopes and intercepts coefficients for predicted and observed locus equations tone and style conditions

	Mid tone: Citation by Sentence				
	Slope	Intercept		Slope	Intercept
Obs-b	1.11	-72	Pred-b	0.99	54
Obs-d	0.77	452	Pred-d	0.93	147
Obs-g	0.98	122	Pred-g	0.96	108
	Low tone: Citation by Sentence				
Obs-b	1.07	-11	Pred-b	0.95	139
Obs-d	0.70	577	Pred-d	0.98	152
Obs-g	1.00	79	Pred-g	0.98	146
	Mid tone Sentence by Low tone Citation:				
Obs-b	1.15	-75	Pred-b	0.99	170
Obs-d	0.84	282	Pred-d	0.99	169
Obs-g	1.10	132	Pred-g	0.99	-40
	Low tone Sentence by Mid tone Sentence				
Obs-b	0.97	31	Pred-b	0.94	180
Obs-d	1.08	-176	Pred-d	0.92	218
Obs-g	1.06	-113	Pred-g	0.94	181

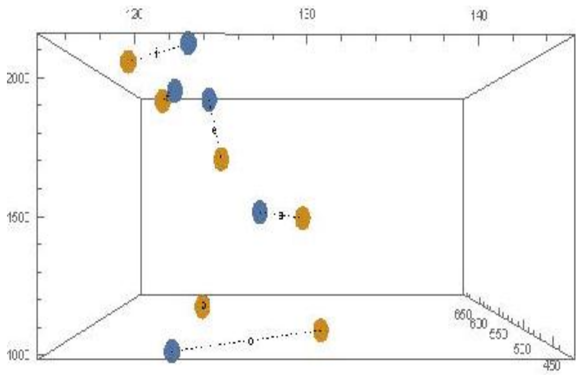
Effect of tone on F1 & F2 dimensions: In order to visualized how F0 interacted with F1 & F2**,** the computer algebraic system of Mathematica was used to display $F0V_2$, $F1V_2$ and $F2V_2$ in 3D comparing LTs to MTs. The result plotted in Figure 3.5 provides a front view of this display. In Fig 3.5 each LT vowel clustered distinctly to the left of the cube separate from their MT counterpart in sentence condition.

Figure 3.5: XYZ plot of $F0V_2$, $F1V_2$ and $F2V_2$ for each test vowel comparing LS (blue) to MS (gold).



Style effect: In order to observe the effects of changing from sentence to citation form, 3D plot was obtained showing the interaction of $F0V_2$ with $F1V_2$ and $F2V_2$. The result is shown in Figure 3.6.

Figure 3.6: XYZ plot of $F0V_2$, $F1V_2$ and $F2V_2$ for each test vowel comparing LS (blue) to LC (gold).



In Fig. 3.6 the front vowels /i,e,ɛ/ of LTs are higher and removed to the right of the cube relative to their LTc counterparts. In opposition, the low and back vowels /a, o/ of LTc are separated to the right of the cube relative to their LTs counterparts. The /ɔ/s were overlapped. Plots reveal separate effects of speech style on tone + segments interaction along the front and back dimensions of the vocal tract.

4. Discussion and conclusion

The degree of coarticulation as statistically captured by LE slopes showed minimal differences between MT and LT. Averaged slopes were: MTc 0.86 vs. LTc 0.88; MTs and LTs: 0.93 v. 1.02. Speech style however produced greater slope (coarticulatory) difference between sentence and citation forms. The averaged slope values for MTc was 0.86 relative to MTs 0.93; and LTc 0.88 relative to LTs 1.02. The non-prosodic nature of Yoruba tone suggests perhaps the lack of greater articulatory efforts for them [14].

Contrarily, MLE parameters showed significant and quantifiable effects of speech style as shown in Figure 3.1 to 3.4 and Table 3.2. Whereas the tone of a CV unit did not significantly impact the influence of vowel on the onset of consonant, F0 remained influential in the overall spatial configuration of F1 & F2 as a function of tone and speech style. The independence of tone from segments as suggested by the autosegmental view to phonology is thus conditional for Yoruba CV + tone since the results of the dissociation of tone from contextual vowel variations effects were varied.

4 REFERENCES

[1] Jean_Marie Hombert (1977) Consonant Types, Vowel Height and Tone in Yoruba" Studies in African Linguistics V.8, Nr.2: 173-190

[2] Gandour, J.T., Potisuk, S., Dechongkit, S. and Suvit, P. 1992, "Tonal coarticulation in Thai disyllabic utterances: a preliminary study", in *Linguistics of the Tibeto-Burman Area*, vol. 15, no. 1:93-110

[3] Gandour, J.T. 1992, "Anticipatory tonal coarticulation in Thai noun compounds", in *Linguistics of the Tibeto-Burman Area*, vol. 15, no. 1, pp. 111-124

[4] Xu, C. X. and Xu, Y. 2003. Effects of Consonant Aspiration on Mandarin Tones. *Journal of the International Phonetic Association* 33: 165-181

[5] Lindblom, B, Agwuele, A., Sussman, H, & Eir Cortes, L 2007. "The effect of Stress on consonant vowel coarticulation. To appear in JASA 121 (6)

[6] Moon S-J & Lindblom, B. 1989. "Formant undershoot in "clear and citation-form speech: a second progress report. STL-QPRS (30) 121-123

[7] Xu, Y. (2004). Understanding tone from the perspective of production and perception. *Language and Linguistics* 5: 757-797.

[8] Goldsmith, H. 1976. "An ovweview of autosegmental phonology. *Linguistics Analysis* 2: 23-68

[9] Sussman, H.M., McCaffrey, H.A., & Matthews, S.A. 1991. "An investigation of locus equations as a source of relational invariance for stop place categorization. JASA. 90, 1309 -1325

[10] Agwuele, A, Sussman H. M & Lindbom B. 2009. "The Effect of Speaking Rate on Consonant Vowel Coarticulation". Phonetica 65: 194-209

[11] Krull, D. 1987. "Second formant locus patterns and consonant-vowel coarticulation in spontaneous speech." PERILUS 5: 43-61.

[12] Boersma, P. & Weenink, D. 2004. Praat [Version5.1.41]. Doing phonetics by computer from http://www.praat.org.

[13] Lindblom, B. 1963. "On vowel reduction." Report No. 29, Speech Transmission Laboratory, The Royal Institute of Technology, Sweden.

[14] Xu, Yi. 2013. ProsodyPro-A tool for large-scale Systematic Prosody Analysis. In Proceedings of Tools and Resources for the Analysis of Speech Prosody (TRASP 2013), Aix-en Provence, France. 7-10.

[15] Sussman, H. M., Fruchter, D., Hilbert, J., and Sirosh, J. 1998. "Linear correlates in the speech signal: The orderly output constraint," Behav. Brain Sci. 21, 241–299

[16] Neary, T. M. & Shammass, S.E. 1987. "Formant transitions as partly distinctive invariant properties in the identification of voiced stops," JASA. 15 (4) 17-24

[17] De Jong K. 1995. "The supraglottal articulation of prominence in English: Linguistic stress as localized hyperarticuation" JASA, 97, 491-504.

[18] Lindblom, B & Sussman H.M. 2012. Dissecting coarticulation: How Locus equations happen. Journal of Phonetics 40: 1–19

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