The Effect of Syllable Structure on Bidirectional Coarticulation

Golnaz Modarresi and Harvey Sussman
University of Texas @ Austin, USA
E-mail: golie@mail.utexas.edu, sussman@mail.utexas.edu

ABSTRACT

The goal of this research was to assess the effect of syllable structure and stop place on the strength of bidirectional coarticulation in VCV utterances. Frequencies of F2 transitions were measured at VC and CV boundaries in open (V.CV) and closed (VC.V) syllable forms in five speakers of American English. Medial stops varied across place and voicing (/bpdtgk/). Carryover and anticipatory coarticulation were measured by comparing the difference in F2 offsets of V1 (anticipatory) and F2 onsets of V2 (carryover) across four 'fixed' vowel (/i/, /e/, /u/, and /ɔ/) and two 'changing' vowel contexts (/i/, /ɔ/). Results showed a significant syllable x coarticulation interaction with closed syllables favoring carryover and open syllables favoring anticipatory coarticulation. Only alveolar stops /dt/ failed to reveal greater anticipatory than carryover effects in open syllables.

1. INTRODUCTION

The effect of bidirectional coarticulation on the acoustic speech signal is both difficult to quantify and perplexing to characterize in terms of speech motor conrol principles.Factors that contribute to this complexity in VCVs include: (1) different 'etiologies' for carryover and anticipatory coarticulation — mechano-inertial for former and preprogramming strategy in later; (2) variety of interacting segmental interactions — V-to-V effects (V1 on V2, V2 on V1), V on C effects (V1 on C, V2 on C), C on V effects (C on V1, C on V2); (3) conflicting results in the literature: anticipatory > carryover, carryover > anticipatory, anticipatory = carryover [1]; and (4) differences in biomechanical constraints across obstruents involving labial, velar, or lingual occlusions [2]. This study examines the issue of bidirectional coarticulation from the perspective of the articulatory cohesion of the CV/VC unit, rather than isolated C and V segments. By manipulating syllable forms between open (V.CV) and closed (VC.V) syllables, it is possible to compare CV to VC units. Locus equation [3] data has shown greater degrees of coarticulation (V on C) in CV units relative to VC across the stops /bdg/. In addition, the correlation of F2 onsets plotted against F2 vowel for stop-vowel sequences (CVs) greatly exceeds that found between F2 offsets plotted against F2 vowel (VCs). The greater articulatory precision of CVs relative to VCs ought to be reflected in the saliences of V-to-V coarticulation. The critical issue is whether the V engaged in coarticulation with a C exerts a greater effect onto the transconsonantal singleton V, or vice versa.

2. METHODOLOGY

Five male speakers, aged 27-38, served as subjects. VCV tokens were devised with the syllable boundary falling at two different positions: open [$C_iV_1.C_iV_2$], closed [$tV_1C.V_2t$]. All stimuli were bisyllabic nonsense words put in a carrier phrase "Say ___ again." The intervocalic C included /b,p,d,t,g,k/. Changing vowel contexts were always /i vs. ɔ/ and fixed vowel contexts alternated among /i/, /e/, /u/, and /ɔ/. In the production of open syllable forms speakers were instructed to syllabify the intervocalic C with V2, while in closed syllable forms speakers were instructed to syllabify the intervocalic C with V1 and introduce a period of pause between the C release and beginning of V2. Speakers were trained to release the syllable-final C and not produce flaps for intervocalic /t/.All acoustic analyses were performed on a Power Macintosh 7100/80 at 16 bits with a 20kHz sampling rate. Soundscope/16 speech analysis software was used for all display, editing, playback, and measurement procedures. FFT spectra were calculated with 1024 points using a filter setting of 45 Hz. LPC spectra were calculated with 25 coefficients and a 20ms frame length using 512 points. The second formant (F2) frequency was measured at V1 F2 offset and V2 F2 onset. In the case of voiceless aspirated stops, F2 onset was taken at the earliest visible F2 resonance after the burst release, which was judged to continue into the F2 of the vowel.

The coarticulation measure was assessed as follows:VCV pairs with a fixed and changing vowel context were used [4]. For example, in the pair [iCi] – [iCɔ], /i/ is the fixed vowel and /i/ versus /ɔ/ are the changing vowels. If the frequency of V1 F2 offsets differ in the above pair, then we attribute the frequency difference to contextual changes in V2. The effects of V2 ('changing vowel') on V1 offset ('fixed vowel') indicate anticipatory coarticulation. The effects of V1 ('changing vowel') on V2 onset ('fixed vowel') indicate carryover coarticulation. The relative differences in frequency in V1 F2 offsets (anticipatory coarticulation) and V2 F2 onsets (carryover coarticulation) were calculated across three repetitions of each token, for each speaker. This measure served as the dependent variable in an ANOVA analysis. The within-subjects factors were: syllable form (open vs. closed), coarticulatory direction (carryover vs. anticipatory), stop place (/bpdtgk/), and fixed vowel context (/ieuɔ/.

ISBN 1-876346-48-5 © 2003 UAB

3. RESULTS

Significant main effects were found for syllable form, coarticulation direction, stop place, and fixed vowel context (p <.0001). Figure 1 shows the interaction between syllable form x coarticulation direction (p<.0001). Anticipatory effects exceeded carryover in open syllables, but carryover effects were significantly greater in closed syllables.

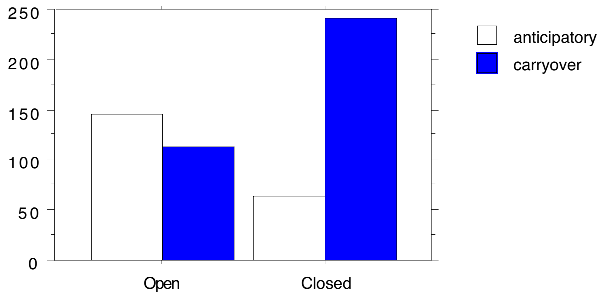

Figure 1: F2 delta's (Hz) for open and closed syllables showing extent of directional coarticulation.

A post hoc follow up using an independent groups t-test was performed on F2 delta (Hz) scores for open syllables comparing anticipatory to carryover coarticulation across all contexts. Anticipatory effects (mean delta = 140 Hz) were statistically different from carryover effects (mean delta = 113 Hz) (t = 2.616, df =359, p =.0093). Thus, the vowel directly engaged with the C exerted stronger transconsonantal effects relative to the singleton vowel's effect onto the CV or VC unit.

Figure 2 shows the three-way interaction among syllable form x coarticulation direction x stop consonant. In open syllables, differences were found in extents of bidirectional coarticulation as a function of stop place: both voiced and voiceless labials revealed greater anticipatory relative to carryover effects , but alveolar stops revealed the opposite effects with carryover exceeding anticipatory. Velar /g/ showed greater anticipatory effects, but velar /k/ had symmetrical effects. In closed syllables carryover effects greatly exceeded anticipatory effects across all six stop contexts.

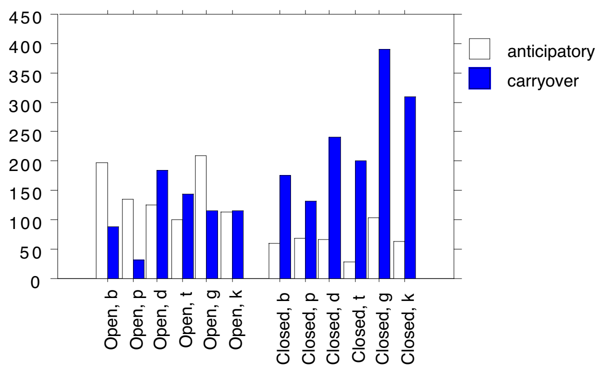

Figure 2: F2 delta's (Hz) across syllable forms showing bidirectional coarticulation for each stop consonant.

Post hoc independent groups t-tests were employed to test for statistical significances across coarticulation direction for each of the 12 syllable form x stop combinations. In closed syllables, all comparisons across the six stops were statistically significant as carryover values exceeded anticipatory. In open syllables, coarticulatory directional salience varied as a function of stop place. Both voiced and voiceless labials and velar /g/ revealed significant differences showing greater anticipatory than carryover coarticulation, while alveolars had statistically significant differences favoring carryover > anticipatory effects.

Figure 3 illustrates the effect of the individual fixed vowel contexts on bidirectional coarticulation. In open syllables, only /e/ and /i/ as fixed vowels revealed the greater salience of anticipatory coarticulation, while in closed syllables, all four fixed vowel contexts revealed greater salience for carryover coarticulation.

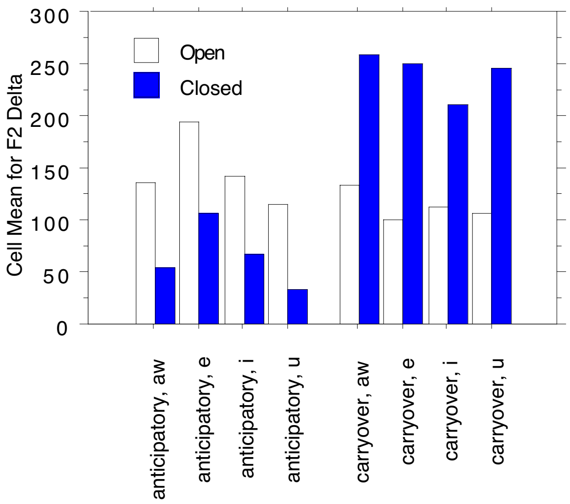

Figure 3: The effect of fixed vowel contexts on bidirectional coarticulation for open and closed syllables.

4. DISCUSSION

The results of this study strongly suggest that both syllable form and place can significantly affect bidirectional coarticulation. Vowels are thus not unconstrained in their V-to-V trajectories. This finding suggests a segment-by-segment motor programming sequence in VCVs rather than an independent diphthongal V1-to-V2 trajectory as claimed by the original coproduction account of Öhman [5]. The main finding of the study showed that the vowel engaged with a C (VC in closed syllables and CV in open syllables) dominated the bidirectional effects relative to the transconsonantal vowel. A clue to explain this finding may reside in examining the single segmental context in which it did not occur – alveolar stops in open syllables. Recasens' DAC model [2] predicts that obstruents maximally engaging the tongue dorsum for the occlusion gesture would increase C-to-V effects and decrease V-C and V-to-V effects. Clearly the stops engaging the tongue blade/dorsum had larger coarticulatory effects relative to labials. The rank ordering

ISBN 1-876346-48-5 © 2003 UAB

of overall coarticulation across stops was /g/ > /k/ = /d/ > /t/ > /b/ > /p/. However, only /d/ and /t/ resisted anticipatory coarticulation in open syllables as velar /g/ behaved similarly to the labials /b/ and /p/. Thus, biomechanical constraints cannot be the only answer. Measuring anticipatory coarticulation in the open syllable form was the only instance where the effect of the changing vowel contexts (V2 in this instance) was measured on V1 offsets. All other conditions involved the effect of changing vowel contexts on either the CV or VC interface, not a singleton vowel. Alveolars are the only stop consonants that possesses a quasi-stationary onset locus [6]. Locus equation slopes, obtained across many languages, have confirmed this by consistently reporting that alveolars in CV contexts have minimal coarticulation effects of the V onto the C [7]. Since CV coarticulation is universally minimized in alveolar stop contexts, perhaps the V2 vowel's influence is 'blocked' from transconsonantally affecting the singleton V1. Under such constraints, carryover effects (V1 onto V2) can dominate in alveolar contexts in open syllables.

4. CONCLUSIONS

The present study has uncovered an interesting principle underlying the salience of bidirectional coarticulation effects in VCV utterances. This principle is tightly linked to the structure of the syllable. Remniscent of Kozhevnikov and Chistovich [8], the bonding of the C and V elements of a syllable appear to be crucially important in determining segmental interactions that traverse syllable boundaries. In addition, the specific place of articulation of the intervocalic stop was shown to strongly influence the directionality of coarticulation effects across syllable boundaries.

REFERENCES

[1] D. Sharf and R.Ohde, "Physiologic, acoustic and perceptual aspects of coarticulation: Implications for the remediation of articulatory disorders," in *Speech and Language: Advances in Basic Research and Practice*, N. Lass, Ed., pp. 153-247. New York, N.Y.: Academic Press, 1981.

[2] D. Recasens, "An EMA study of VCV coarticulatory direction," *Journal of Acoustical Society of America*, vol. 111, pp. 2828-2841, 2002.

[3] H. Sussman, N. Bessell, E. Dalston, and T. Majors, "An investigation of stop place of articulation as a function of syllable position: A locus equation perspective," *Journal of the Acoustical Society of America*, vol. 101, pp. 2826-2838, 1997.

[4] D. Recasens,"An electropalatographic and acoustic study of temporal coarticulation for Catalan dark /l/ and German clear /l/," *Phonetica*, vol. 55, pp.53-79,1998.

5.Öhman, S.E.G. "Numerical model of coarticulation," *Journal of the Acoustical Society of America,*vol.41,pp.310-319, 1967.

6. Delattre, P.C., Liberman, A.M., and Cooper, F.S. "Acoustic loci and transitional cues for consonants," *Journal of the Acoustical Society of America*, vol. 27, pp. 769-773, 1955.

7. Sussman, H.M., Hoemeke, K. and Ahmed, F. "A cross-linguistic investigation of locus equations as a relationally invariant descriptor for place of articulation," *Journal of the Acoustical Society of America,* vol. 94, pp.1256-1268, 1993.

8. Kozhevnikov, V. and Chistovich, L. "*Speech: Articulation and Perception*," Translation 30, 543, Washington, DC: Joint Publications Research Service.

Acknowledgements

This research was funded by a National Institute of Health grant (R01 DC02014).

ISBN 1-876346-48-5 © 2003 UAB