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THE ASYMMETRY OF C/V COARTICULATION IN CV AND VC STRUCTURES AND ITS IMPLICATIONS IN PHONOLOGY *

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In this paper, I investigate acoustic correlates of asymmetric coarticulatory effects of a vowel on a consonant in CVC structures, which, I argue, result from a different temporal coordination of vowel and consonant gestures in CV and VC sequences. I examine the variability of F2 values in CVC structures involving stop consonants, and compare F2 values at 5 different points in CVC sequences with fricatives. The results indicate that there are greater coarticulatory influences of a vowel on the preceding consonant than on the following consonant, and supplement the evidence in phonology that vowel place features are more easily imposed on prevocalic consonants, invoking place assimilation.

1. Introduction

This paper reports on experiments conducted to measure a vowel's coarticulatory effect on a consonant in a CVC structure, and demonstrates that coarticulation is asymmetric in CV and VC environments. I focus on the voiced obstruent consonants /b/, /d/, /g/, /z/, and /v/, and on the vowels /i/, /e/, /a/, /o/ and /u/. In CVC sequences with the same pre- and postvocalic consonants, coarticulation between a vowel and an adjacent consonant (hereafter, C/V coarticulation) is investigated by measuring F2 onset and offset transition value and by calculating spectral peak frequency corresponding to F2 in pre- and postvocalic consonants.

Although there are numerous studies — articulatory, acoustic and perceptual — on coarticulation between a vowel and a consonant, very few phonetic studies have compared a vowel's effects on the preceding and following consonants in CVC sequences. Much of the articulatory and acoustic literature has focused on coarticulation in a single direction: either right-to-left or left-to-right (Öhman 1966; Amerman & Daniloff 1977; Farnetani & Recasens 1993) and on exploring very specific mechanisms of coarticulation that can account for both consonant-to-vowel and vowel-to-consonant effects, including a consonant's effects on vowel articulation, and articulatory modifications induced by the effects of a vowel's tongue body gesture on consonants with different place and manner (House & Fairbanks 1953; MacNeilage & DeClark 1969; Carney & Moll 1971; Gay 1974; Kiritani, Itoh, Hirose, & Sawashima 1977; Fowler, Rubin, Remez & Turvey 1980; Perkell & Nelson 1985; Recasens 1991). None of these studies compare the coarticulatory effects of a vowel on consonants in mirror-image positions.

Perceptual studies on C/V coarticulation have been much debated. First of all, it has been argued that there are a significantly greater number of correct consonant identifications from the vocalic transition in VC syllables than from those in CV syllables (Sharf & Hameyer 1972; Sharf & Beiter 1974; Ohde & Sharf 1977). On the other hand, it has also been claimed that CV transition is perceptually stronger for consonant place cues than VC transition (Repp 1978; Fujimura, Maccini & Streeter 1978; Dorman, Raphael & Liberman 1979; Ohala 1990). The first findings suggest that a vowel influences the preceding consonant more than the following consonant, so that the place cues of the following consonant are more likely to be maintained and perceived. On the other hand, the second findings suggest that there are less coarticulatory effects of a vowel on the preceding consonant. However, the contradiction between these two groups of findings might be derived from different experimental designs. In the first case, experiments have tested the perception of an eliminated consonant from a CVC sequence on the basis of the remaining transition and vowel portion. The second case investigates the relative perceptual value of VC vs. CV transitions for intervocalic stops; when spliced CV and VC transitions differ, a listener generally hears only the consonant cued by the CV transitions. Significantly, the former experiments only look at the vocalic transition for identification of consonant place, but the latter ones investigate the whole VC and CV structure, of which the CV transition includes both consonant burst and transition cues. Presumably, the CV portion involving burst and transition may carry a greater amount of information for consonant place, which could explain why CV transitions are more salient for perception of consonant place.

In this paper, I will present acoustic evidence of greater coarticulatory influence of a vowel on the preceding consonant than on the following consonant, suggesting that the relative lack of coarticulation in VC structures renders the VC transition a salient cue for consonant place, in support of the findings of Sharf & Hameyer 1972, Sharf & Beiter 1974, and Ohde & Sharf 1977.

There are a number of acoustic studies that investigate the extent to which a vowel's acoustic structures extend into the consonant region of CV structures. Spectral analysis of stop burst in a CV syllable shows that stop place of articulation is primarily cued by the gross spectral shape of the short-time spectrum sampled at the onset of the prevocalic stop burst, and that formant transitions also provide cues of consonant place of articulation (Blumstein & Stevens 1979, 1980). According to Blumstein and Stevens, an invariant spectral peak of the burst spectrum is strongly associated with place of articulation, whereas vowel information is carried by the formant frequency of the CV transition. However, results from perceptual studies using the voiceless burst portions of natural stop-vowel syllables indicate that the vowel can be identified from the beginning of the release burst (Winitz, Scheib & Reeds 1972; Suomi 1985). These findings demonstrate that a vowel's acoustic structures extend to the beginning of stop burst, which contradicts the claim of the invariant burst configuration of stop consonants suggested by Blumstein and Stevens.

In this paper, I attempt to compare the F2 influence oowel on stop burst involved in the prevocalic and the postvocalic stop, and present the result that a vowel is anticipated by the burst articulation of the preceding consonant, rather than by that of the following consonant, in support of the argument of Winitz, Scheib & Reeds 1972 and Suomi 1985.

Kewley-Port 1982 examines the acoustic correlates of the consonant place of articulation in the vowel formant transitions in stop-vowel sequences. Contrary to the traditional view that formant transitions serve as the primary cues of stop place articulation (through the effects of stop locus, Liberman et al. 1967), she concludes that transition measurement shows little evidence of invariant acoustic correlates of consonant place. This conclusion derives from the observation that the formant transition values are variable across various vowel contexts in stop-vowel sequences. Kewley-Port further asserts that information contained in the formant transitions in stop-vowel sequences was not sufficient to distinguish place across all the vowel contexts. Therefore, the transition is not a determinant place cue for stop consonants. Thus we find conflicting evidence from acoustic studies as to the salience of place cues in the transition region. In this paper, I claim that the conflicting evidence reflects the variability of C/V coarticulation as evidenced through variation in the formant values of the CV transition region.

The existing perceptual and acoustic studies all focus on CV structures with stop consonants. There have been very few comparison studies on C/V coarticulation between CV and VC structures. Acoustically, coarticulation in VC structures is detectable only in the formant values in the vocalic region, leading up to stop closure. There is no portion of the VC structure analogous to the burst in CV structures, which may account for why only a CV syllable has been studied in previous research.

In this paper, I will compare the vowel's coarticulatory effect on the pre- and postvocalic consonant in a CVC structure. I assume in this experiment that C/V coarticulation arises due to gestural overlap, and will be indicated in the formant transitions into and out of the vowel. If gestural overlap is symmetric in CV and VC structures, I expect to find acoustic parallels. Specifically, I expect to find the same range of variation in F2 values in CV and VC transitions.

In the subsequent sections, I present and discuss the results of two experiments, comparing F2 values in CV and VC structures. In experiment I, I measure F2 values at the F2 onset and offset but also at the CV-burst and VC-burst to see the extent to which a vowel extends its gestures in CVC sequences with stops. I compare the range of F2 values across 5 vowel contexts at F2 onset vs. F2 offset and in CV-burst vs. VC-burst. The F2 values are measured based on the fact that there is a main correlation between F2 and the degree and location of stop consonant contact (Fant 1960). Also, F2 gives some indication of the articulatory configuration used to generate the consonant such as a stop or fricative (Heinz & Stevens 1961). I discuss the statistical analysis of the F2 ranges in each context of a bilabial, alveolar and velar stop. Furthermore, I discuss the correlation of a vowel's F2 with that of onset and offset of transitions and with that of CV and VC-burst to identify how much the F2 at four different points is articulatorily correlated with the vowel's F2. In the second experiment, I show the F2 mean values at 5 different points in CVC structures with fricatives, and also demonstrate which articulation point manifests the most independent F2 value from vowel's F2 as obtained from an ANOVA test. In section 3, I discuss some phonological implications of the results.

2. Experiment I

For the first experiment utilizing CVC sequences with stop consonants, I hypothesize that the range of F2 will be more variable under greater influence of the neighboring vowel. Variation in F2 values may be interpreted as the acoustic manifestation of greater gestural overlap between a vowel and a consonant. When vowel and consonant gestures overlap, I assume that the vowel gestures will invoke dominant coarticulatory effects over a consonants, based upon Recasens' claim (1991:178):

> 'Vowels are resistant to coarticulation because they are produced by means of global vocal tract shapes which require articulatory control upon the entire tongue body configuration whereas consonants involve only local constrictions which leave other articulatory regions free to coarticulate.'

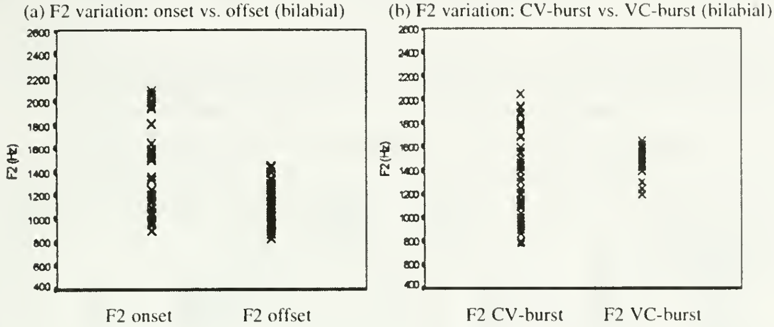
2.1 Data and methods

Nonsense C_iVC_i syllables with /b, d, g/ and /i, e, a, o, u/ were produced 12 times by a male speaker, and the tokens were read in a randomized order.[1] Only the voiced stops were employed in the experiment since the voiced stops more distinctly show voiced formant transitions than do voiceless stops (Kewley-Port 1982). The CVC tokens were recorded in 16-bit and 8 Khz onto a Sparc station by a Sony F-VX30 microphone. Among formant trajectories, F2 was calculated using Entropic's Waves program at 5 different points: at the steady state of a vowel, at the onset and offset of a transition, and at the pre- and postvocalic stop burst.

2.2 Result

The results of the F2 range at four different points in CVC sequences involving a bilabial stop are shown in Figure 1. All the F2 values are overlaid from the five vowels at F2 onset and offset in Figure 1 (a) and in CV-burst and VC-burst in Figure 1 (b). The F2 onset transition values are more variable than the offset values in the bilabial stop context. The difference in variation in onset vs. offset is statistically significant by Levene's test for equality of variance ($F = 45.990$, $p < 0.0005$). As Figure 1 (b) shows, the range of F2 values in CV-burst is greater than that in VC-burst, and the variance of F2 values in CV-burst is statistically different from the F2 variance in VC-burst ($F = 111.313$, $p < 0.0005$). Moreover, the variability difference is much greater between burst points than between onset and offset points.

These results indicate that gestural overlap between a vowel and consonant is greater in CV structures than in VC structures, and the vowel's articulation may extend to the burst of the preceding stop. Especially in sequences involving a bilabial stop is sequenced with a vowel, the tongue body is significantly free to coarticulate with a vowel during the production of the stop due to the fact that the bilabial stop involves only the lips as the primary articulators. This is indicated by the bigger range of F2 in CV-burst and at the onset of F2 transition. On the other hand, the small range of F2 in VC-burst and at the offset of transition indicates that the bilabial stop is more likely articulated independent of the preceding vowel.

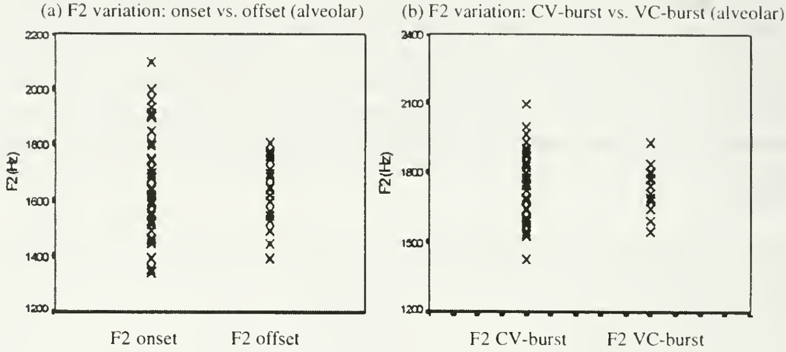

(a) F2 variation: onset vs. offset (bilabial)

(b) F2 variation: CV-burst vs. VC-burst (bilabial)

Figure 1. F2 variation in CVC structures with a bilabial stop

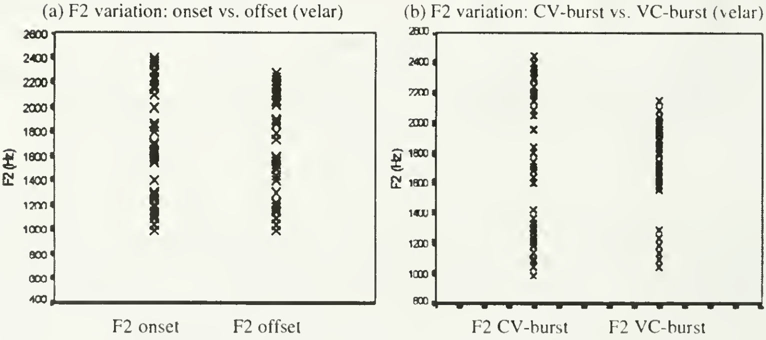
Figure 2 displays the range of F2 onset and offset in (a) and the range of F2 in CV-burst and VC-burst in (b) among the CVC sequences with an alveolar stop. The F2 onset values are more variable than offset values, and the variance is significantly different between transition onset and offset ($F = 13.176$, $p < 0.0005$). Figure 2 (b) indicates that the F2 variability is notably lower in VC-burst, and that the articulatory effect of the vowel on the preceding consonant is also statistically significant ($F = 14.071$, $p < 0.0005$). Although the variance difference is not as great as the case of bilabial stop contexts, the vowel's coarticulatory effect on a consonant is greater in CV structures than in VC structures, which derives from greater gestural overlap in CV structures. Since the main articulator is the tongue tip for an alveolar stop, the tongue body is somewhat free to coarticulate with a vowel, but not as completely as the case of bilabial stops since the tongue body is still involved secondarily for the production of the stop.

Figure 3 illustrates the ranges of F2 in the velar stop context. (3a) shows that the range of F2 onset values are slightly more variable than that of offset values ($F = 0.941$, $p < 0.5$), but there is not a big difference in variability between onset and offset for the velar stop environment. Since a velar stop and a vowel involve the same articulator, which is the tongue body, the velar stop easily coarticulates with a vowel as discussed in Sapir 1921, Heffner 1950, Ladefoged 1975, Keating 1993. That may be the reason why the variance of F2 onset and offset values is not as different as with bilabial and alveolar stop consonants. However, as shown in Figure 3 (b), F2 is more variable in CV-burst than in VC-burst and the difference in variability is statistically significant ($F = 19.240$, $p < 0.0005$).


(a) F2 variation: onset vs. offset (alveolar)

(b) F2 variation: CV-burst vs. VC-burst (alveolar)

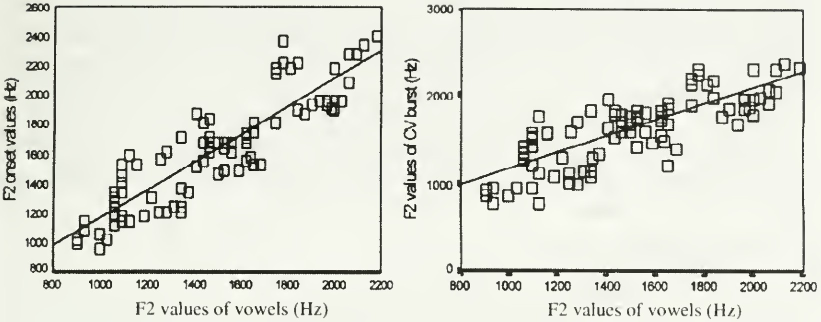
Figure 2. F2 variation in CVC structures with an alveolar stop


(a) F2 variation: onset vs. offset (velar)

(b) F2 variation: CV-burst vs. VC-burst (velar)

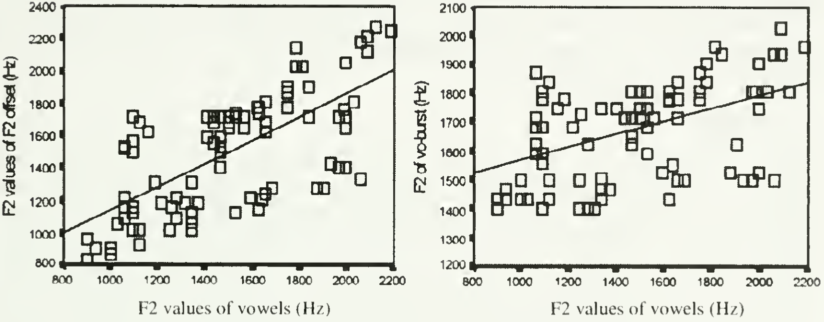
Figrue 3. F2 variation in CVC structures with a velar stop

The correlation results indicate how the F2 in the stop consonant regions varies with vowels as illustrated in Figure 4. If a consonant is influenced by a vowel's articulation, F2 in the stop regions would be expected to change with the vowel's F2. As shown in Figure 4, the vowels' F2 values are more strongly correlated with F2 values in CV structures than in VC structures, which can be interpreted as greater gestural overlap of a vowel with a consonant in CV structures. Furthermore, the correlation of a vowel with onset and offset transition is stronger than with CV and VC-burst, and the correlation of a vowel is greater with F2 in CV-burst than in VC-burst. This indicates that the degree of gestural overlap of a vowel with a preceding consonant is sufficient enough to invoke a burst configuration containing similar F2 values as vowel's F2.



(a) F2 correlation: F2 onset vs. vowels
r = 0.891 (p < .0005)

(b) F2 correlation: CV-burst vs. vowels
r = .905 (p < .0005)



(c) F2 correlation: F2 offset vs. vowels
r = .687 (p. < .0005)

(d) F2 correlation: VC-burst vs. vowels
r = .544 (p. < .0005)

Figure 4. F2 Correlation

These results indicate that there is greater gestural overlap between a vowel and a preceding stop consonant; vowel gestures can be anticipated as early as the burst of the stop. This coarticulatory effect might cause a listener to identify the articulation of the vowel from the release burst, and the perception associated with consonant place will be expected to be more correct in VC transition than in CV transition, due to less influence of a vowel on a following consonant. Thus, the findings of the present experiment support the perceptual studies that conclude that there are a greater number of correct consonant identifications from VC transitions than CV transitions.

3. Experiment II

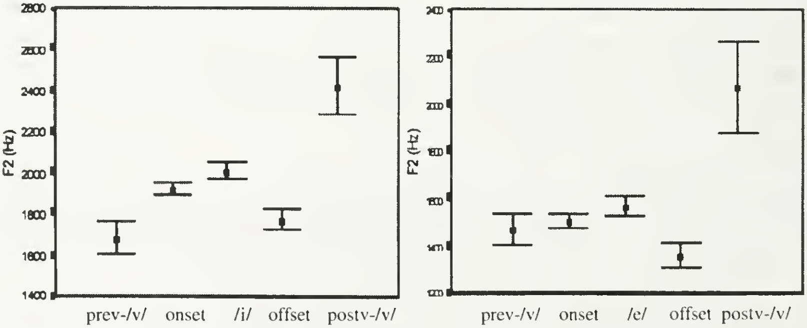
In this experiment, I investigate coarticulatory effects of a vowel on the neighboring fricatives. Fricatives are produced by noise at the site of constriction and by the resonance of the oral cavity in front of the constriction (Soli 1981). The front cavity determines the place cue of fricatives. While the alveolar fricatives /s, z/ have a major energy prominence near 6 kHz (due to a shorter front resonance cavity), the palatal fricatives /ʃ, ʒ/ have energy near 2.5 kHz. This is attributed to the articulatory mechanism of the production of palatal fricative; the constriction itself is shorter and more open (Stevens 1971), and the front cavity is longer due to the palatal place of articulation and to the occurrence of slight lip rounding and protrusion (Fant 1960). It can be hypothesized that the vocal tract shape gives rise to resonance in the back cavity behind the constriction, possibly affected by an adjacent vowel. If a vowel is articulated even during the fricative production, it is predicted that the back cavity resonance will be determined by the tongue shape of a vowel and that the spectral peaks of fricatives will reflect this phenomenon, presenting similar F2 patterns as the vowel's superimposed over the fricative noise.

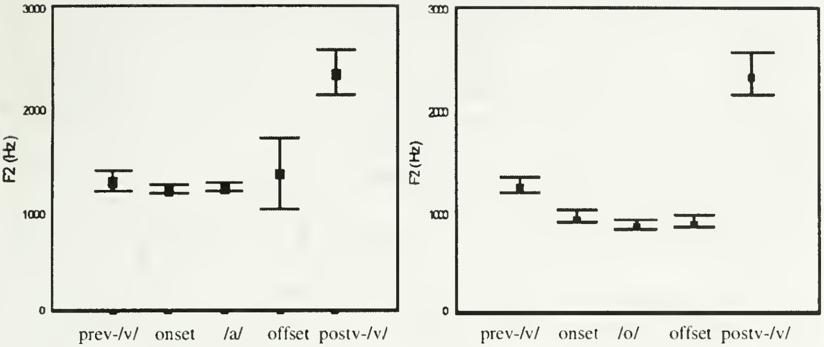
3.1 Data and methods

Nonsense C_iVC_i syllables with voiced fricatives /v, z/ and vowels /i, e, a, o, u/ were produced 12 times by a male speaker. The fricative tokens were recorded in 16-bit and 16 Khz onto a Sparc station by a Sony F-VX30 microphone. The same program, Entropic's Waves, was used for analysis. Among formant trajectories, only F2 is measured at 5 different points: in the onset and offset of F2 transitions, at the steady state of a vowel, at the beginning of a prevocalic fricative and at the end of a postvocalic fricative.

3.2 Results

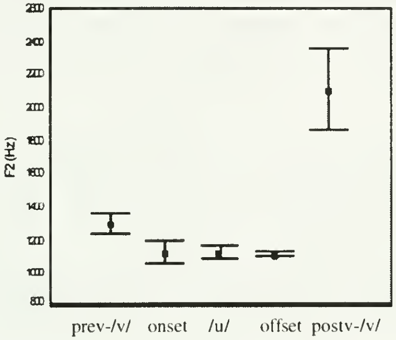
Figure 5 displays the mean values of F2 at the 5 different points in the /CVC/ sequences involving fricative /v/ (the bar represents standard error of mean). According to a one-way ANOVA test, the F2 mean values at four points – (1) at the steady state of a vowel, (2) at the onset of transitions and (3) at the offset of transitions, and (4) at the beginning of a fricative - are not significantly different within each vowel context ($p < 0.0001$). In the case of the /viv/ sequence, the mean difference between F2 in CV-burst and F2 at the steady state of the vowel is significant ($p < 0.001$). However, it is worth noting in Figure5 that the average value of F2 in VC-burst is significantly different from those in the other four points ($p< 0.0001$ for /e, o, a, u/ and $p < 0.001$ for /i/).


(a) F2 mean values in /viv/
(b) F2 mean values in /vev/



(c) F2 mean values in /vav/

(d) F2 mean values in /vov/

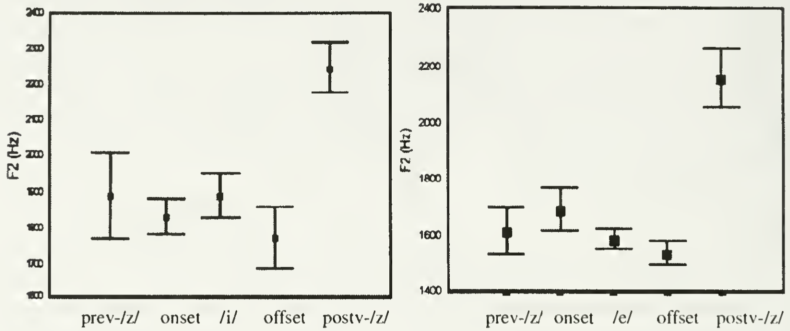


(e) F2 mean values in /vuv/

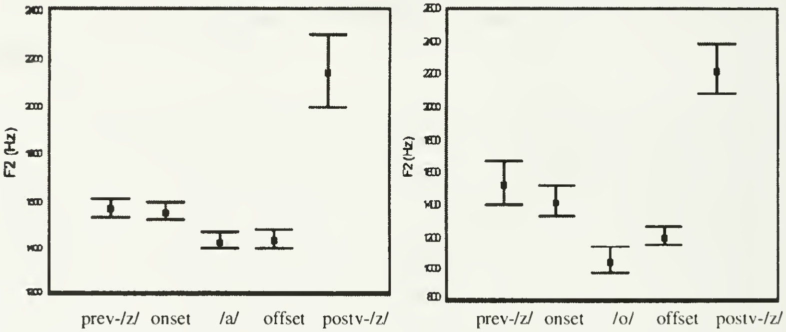
Figure 5. Mean values at 5 points in /vVv/ sequences

In figure 6, the mean values at 5 points are shown in /zVz/ sequences. Again, F2 values at the four points, at the onset and offset of a transition, at the steady state of a vowel and in CV-burst, are not statistically different within vowel contexts ($p < 0.0001$). In the environment of the /o/ vowel, the mean difference between F2 of CV-burst and vowel's F2 is significant ($p < 0.0001$). However, the /zVz/ sequences with all the five vowels show that F2 values of VC-burst are significantly different from those of the other four points ($p < 0.0001$).

These results indicate that a prevocalic fricative anticipates the articulation of a following vowel, even from the beginning of the fricative production. In other words, an extended timing of gestural overlap in CV structures gives rise to a spectral peak near the vowel's F2 frequency early from the stages of a fricative production. No significant dependence between F2 at the end of the postvocalic fricative and the preceding vowel (i.e. in VC structures) can be interpreted as an indication of very limited gestural overlap during the VC transition. Overlap in VC structures influences the tongue body gestures in the back cavity behind a fricative constriction during the VC transition, but not through the whole production of the postvocalic fricative.


(a) F2 mean values in /ziz/

(b) F2 mean values in /zez/


(c) F2 mean values in /zaz/

(d) F2 mean values in /zoz/

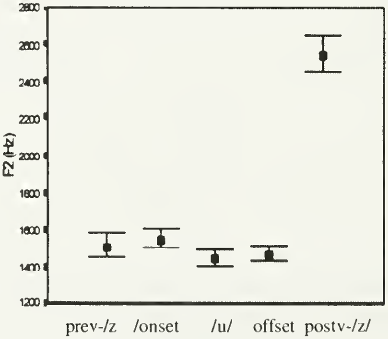

(e) F2 mean values in /zuz/

Figure 6. Mean values at 5 points in /zVz/ sequences

4. Phonological implications and conclusion

I have shown the acoustic correlates of greater coarticulatory effects of a vowel on a consonant in CV structures than in VC structures. In the examination of CVC sequences with stops, considerable variability in F2 values in CV structures was observed, and contrasts with lesser variability in VC structures. F2 values in VC-burst were the least variant, which is indicative of little or no coarticulation in the production of the postvocalic stop burst. Similarly, the correlation results indicate that F2 values in the region of the preceding consonant are strongly correlated with the vowel's F2 values. These findings result from a different temporal coordination of vowel and consonant gestures in CV and VC sequences; an extended overlap timing in CV transitions vs. a very limited overlap timing in VC transitions.

In the investigation of CVC sequences involving fricative consonants, the F2 values are significantly different from the vowel's F2 only at the end of the production of a postvocalic fricative. In spite of a certain degree of gestural overlap between a vowel and the following fricative, the fricative seems to be articulated in an independent manner of the vowel in VC structures. Therefore, I would conclude that a vowel shows asymmetrical coarticulatory effects on a consonant such that CV sequences are more likely to achieve coarticulation than VC sequences.

I argue that the asymmetry of C/V coarticulation supplements the evidence in phonology that vowel place features are more easily imposed on prevocalic consonants, invoking place assimilation such as secondary articulation of consonants. Crosslinguistically, it is very common that place assimilation between a consonant and a vowel occurs in a CV structures rather than in VC structures. To the best of my knowledge, however, there are fewer examples showing that a postvocalic consonant assimilates to the place of a preceding vowel. This implies that the coarticulatory effect of a vowel on the following consonant is not significant to promote an assimilation process in phonology. Experimental and phonological evidence suggest that CV combinations are closely integrated and constitute a coarticulatory unit.

NOTES

* I would like to thank Jennifer Cole for her valuable comments and discussion. I also thank Khalil Iskarous for helpful suggestions.

[1] His first language is English.

REFERENCES

AMERMAN, J. D., & R. G. DANILOFF. 1977. Aspects of lingual coarticulation. *Journal of Phonetics* 5.107-13.

BLUMSTEIN, S. E. & K. N. STEVENS. 1979. Acoustic invariance in speech production: evidence from measurement of the spectral characteristics of stop consonants. *Journal of the Acoustic Society of America* 66.1001-17.

——. 1980. Perceptual invariance and onset spectra for stop consonants in different vocal environments. *Journal of the Acoustic Society of America* 67. 648-62.

BROWMAN, C. P., & L. GOLDSTEIN. 1986. Towards an articulatory phonology. *Phonology Yearbook* 3.219-52.

——. 1990. Tiers in articulatory phonology with some implications for casual speech. *Papers in Laboratory Phonology I: Between the Grammar and Physics of Speech*, ed by Kingston, J & M. E. Beckman, 341-76. Cambridge: Cambridge University Press.

——. 1992. Articulatory phonology: an overview. *Phonetica* 49.155-180.

CARNEY, P. J., & K. L. MOLL. 1971. A cinefluorographic investigation of postconsonantal vowels on the short-term recall of preconsonantal vowels. *Language and Speech* 16.67-76.

DORMAN, M. F., L. J. RAPHAEL, & A. M. LIBERMAN. 1979. Some experiments on the sound of silence in phonetic perception. *Journal of the Acoustic Society of America* 65.1518-32.

FANT, F. 1960. *Acoustic Theory of Speech Production*. Mouton, The Hague.

FARNETANI, E., & D. RECASENS. 1993. Anticipatory consonant-to-vowel coarticulation in the production of VCV sequences in Italian. *Language and Speech* 36.279-302.

FUJIMURA, O. M., J. MACCHI, & L. A. STREETER. 1978. Perception of stop consonants with conflicting transitional cues: A cross-linguistic study. *Language and Speech* 21.337-46.

FOWLER, C. A., P. RUBIN, R.E. REMEZ, & M. T. TURVEY. 1980. Implications for speech production of a general theory of action. *Language Production*, ed by B. Butterworth, 373-420. New York: Academic Press.

GAY, T. 1974. A cinefluorographic study of vowel production. *Journal of Phonetics* 2.255-66.

HALLE, M., G. W. HUGHES, & J. P. RADLEY. 1957. Acoustic properties of stop consonants. *Journal of the Acoustic Society of America* 29.107-16.

HOUSE, A. S., & G. FAIRBANKS. 1953. The influence of consonant environment upon the secondary acoustical characteristics of vowels. *Journal of the Acoustic Society of America* 25.105-13.

HEFFNER, R.-M. S. 1950. *General Phonetics*. Madison: University of Wisconsin Press.

HEINZ, J. H., & K. STEVENS. 1961. On the properties of voiceless fricative consonants. *Journal of the Acoustic Society of America* 33.589-96.

KEATING, P. 1993. Fronted velars, palatalized velars, and palatals. *Phonetica* 50.73-101.

KEWLEY-PORT, D. 1982. Measurement of formant transition in naturally produced stop consonant-vowel syllables. *Journal of the Acoustic Society of America* 72.379-89.

——. 1983. Time-varying features as correlates of place of articulation in stop consonants. *Journal of the Acoustic Society of America* 73.322-55.

KIRITANI, S., K. ITOH, H. HIROSE, & M. SAWASHIMA. 1977. Coordination of the consonant and vowel articulations — X-ray microbean study on Japanese and English. *Annual Bulletin of the Research Institute of Logopedics and Phoniatrics*, University of Tokyo 11.11-21.

LADEFODGED, P. 1975. *A Course in Phonetics*; 2nd ed. Harcourt, Brace, Jovanovich, New York.

LIBERMAN, A. M., F. S. COOPER, D. P. SHANKWEILER, & M. STUDDERT-KENNEDY. 1967. Perception of the speech code. *Psychological Review* 74.431-61.

MACNEILAGE, P. E., & J. L. DECLERK. 1969. On the motor control of coarticulation in CVC monosyllables. *Journal of the Acoustic Society of America* 45. 1217-33.

OHALA, J. J. 1990. The phonetics and phonology of aspects of assimilation. *Papers in Laboratory Phonology I: Between the Grammar and Physics of* Speech, ed by J. Kingston & M. E. Beckman, 258-75. Cambridge: Cambridge University Press.

OHDE, R. N., & D. J. SHARF. 1977. Order effect of acoustic segments of VC and CV syllables on stop and vowel identification. *Journal of Speech and Hearing Research* 20.543-54.

ÖHMAN, S. E. 1966. Coarticulation in VCV utterances: Spectrographic measurements. *Journal of the Acoustic Society of America* 39.151-68.

OSTREICHER, H. J., & D. J. SHARF. 1976. Effects of coarticulation on the identification of deleted consonant and vowel sounds. *Journal of Phonetics* 4. 285-301.

PERKELL, J. S., & W. L. NELSON. 1985. Variability in production of the vowels /i/ and /a/. *Journal of the Acoustic Society of America* 77.1889-95.

REPP, B. H. 1978. Perceptual integration and differentiation of spectral cues for intervocalic stop consonants. *Perception and Psychophysics* 24.471-85.

RECASENS, D. 1991. An electropalatographic and acoustic study of consonant-to-vowel coarticulation. *Journal of Phonetics* 19.177-92.

SHARF, D. J., & H. HEMEYER. 1972. Identification of place of consonant articulation from vowel formant transitions. *Journal of the Acoustic Society of America* 51.652-8.

SHARF, D. J., & R. C. BEITER. 1974. Identification of consonant from formant transitions presented forward and backward. *Language and Speech* 17.110-18.

SOLI, S. 1981. Second formants in fricatives: Acoustic consequences of fricative-vowel coarticulation. *Journal of the Acoustic Society of America* 70.976-84.

STEVENS, K. N. 1971. Airflow and turbulence noise for fricative and stop consonants: Static considerations. *Journal of the Acoustic Society of America* 50.1180-92.

SUOMI, K. 1985. The vowel-dependence of gross spectral cues to place of articulation of stop consonants in CV syllables. *Journal of Phonetics* 13.267-85.

WINITZ, H., M. E. SHEIB, & J. A. REEDS. 1972. Identification of stops and vowels for the burst portion of /p, t, k/ isolated from conversational speech. *Journal of the Acoustic Society of America* 51.1309-17.