THE RELATION BETWEEN VOWEL-TO-VOWEL COARTICULATION AND VOWEL HARMONY IN TURKISH

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ABSTRACT

Does the phonological process of palatal vowel harmony in Turkish parallel its patterns of vowel-to-vowel coarticulation even in words not subject to harmony? Acoustic analysis of disharmonic roots shows mainly anticipatory effects of coarticulation, a different direction from the left-to-right process of palatal harmony. Given current theories of interactions between phonological and coarticulatory organization, this outcome is perhaps not surprising, but all the same points to the complex phonetic and phonological patterns which co-occur in a language.

1. INTRODUCTION

Articulatory and acoustic studies have shown that the coarticulatory effects of vocalic gestures extend beyond adjacent consonants to vowels in flanking syllables (e.g., [1], [2], [3], [4], [5], [6], [7]). These vowel-to-vowel coarticulatory effects are often systematic and can be sufficiently robust that listeners are able to use the information on the coarticulated vowel in identifying the vowel that triggered the effects (e.g., [8], [9], [10], [11]).

This study examines the relation between the phonetic phenomenon of vowel-to-vowel coarticulation and the phonological process of vowel harmony. In vowel harmony systems, only a restricted set of vowels sharing certain features can co-occur in a given string (usually a word). For example, most words of Turkish, Hungarian, and Finnish are subject to 'palatal' harmony whereby all vowels have the same value for the feature [back].

While the coarticulatory effects of one vowel on another are phonetic and local, the effects of vowel harmony are phonemic over a relatively broad domain. Despite these differences, a central assumption underlying the present study is that there is a cause-and-effect relation between vowel-to-vowel coarticulation and many vowel harmony processes in the world's languages. Under this view, the dynamic articulatory behavior becomes 'phonologized' as a language-specific grammatical process. We expect, with Ohala [12], [13] (see also Fowler [14]), that listener misperceptions contribute to phonologization. With respect to vowel harmony, if listeners (particularly language learners) fail to adjust for the coarticulatory effects of one vowel on another, then a coarticulatory effect might be misinterpreted as an inherent property of the coarticulated vowel and in turn be produced as such. In this way, intended non-harmonic VCV sequences could be interpreted as harmonic.

If at least some harmony processes evolve as phonologized coarticulation, what relation holds between coarticulatory organization and vowel harmony in a language with an established harmony system? This study asks whether phonological harmony in a language influences — or, more neutrally, parallels — the current patterns of coarticulation in that language even in words not subject to phonological harmony. In addressing the relation between current phonetic and historically linked phonological patterns in a language, we aim for a better understanding of what types of phonetic and phonological patterns can co-occur in the same language.

Our focus is palatal vowel harmony, in part because vowel-to-vowel coarticulatory effects are reportedly strongest along the front-back dimension [6]. Turkish is a particularly appropriate language for comparison of palatal harmony and vowel-to-vowel coarticulation. Turkish has eight phonemic vowels, front /i, y, e, ø/ and non-front /ɯ, u, a, o/. In most words, all vowels agree in backness, giving rise to front-back alternations in suffix vowels (Turkish being non-prefixing), these alternations conditioned by the backness of the root vowel(s):

	'loaf'	'bone'
Nom. sg.	somun	kemik
Nom. pl.	somunlar	kemikler
Gen. pl.	somunlarɯ	kemikleri

(Turkish also exhibits labial harmony for high vowels; see Boyce [15] for study of the coarticulatory consequences of this process.)

As exhibited by the suffixation patterns above, Turkish palatal harmony is a left-to-right process. There is some controversy as to whether palatal harmony is exclusively progressive or is bidirectional in Turkish. Anderson [16] argues for the former view; Clements and Sezer [17] propose that spreading is bidirectional, with a bias towards spreading from the left.

Although most Turkish words obey palatal harmony, the vowels of a large class of polysyllabic 'disharmonic' roots in Turkish violate this process. Importantly, as discussed in detail by Clements and Sezer [17], although these roots are exceptions to palatal harmony, they are not exceptions to other phonological rules of Turkish and are judged to be well-formed by native speakers in psycholinguistic tests.

The class of disharmonic roots is the testing ground for our study, as these roots provide a means for investigating front-back coarticulation in a language with palatal harmony. An acoustic analysis was conducted to determine the coarticulatory structure of Turkish disharmonic roots. If vowel-to-vowel coarticulation in disharmonic roots were to parallel the (exclusively or primarily) left-to-right direction of palatal harmony in Turkish, then carryover coarticulation should be the predominant pattern.

2. METHOD

Three native speakers of Turkish, 2 male and 1 female, were recorded reading multiple repetitions of a randomized list of CVCV(C) roots embedded in two carrier phrases, either [ʤem __ temizle] ('Cem clean __') or [ʤan __ tanɯmla] ('Can identify __'). (Cem and Can are proper names. The vowels are all front in the first carrier and non-front in the second.) The target words in the reading list involved 58 real-word minimal pairs in which the vowels of one pair member differed in backness (i.e., were disharmonic) and the vowels of the other were identical (hence harmonic). (Sample disharmonic/ harmonic pairs are: [bira] 'beer'/ [bara] 'bar (dative)'; [misal] 'example'/ [misil] 'similar'; [deva] 'remedy'/ [deve] 'camel'.) To disguise the purpose of the experiment from the speakers, the reading list also included a large number of filler words.

Vowels in the minimal pair target words were /i, e, a/. Grouping these vowels into corresponding disharmonic - harmonic pairs yields 8 comparison types:

1. a. C$\underline{a}$Ci – C$\underline{a}$Ca	2. a. CiC$\underline{a}$ – CaC$\underline{a}$
b. C$\underline{a}$Ce – C$\underline{a}$Ca	b. CeC$\underline{a}$ – CaC$\underline{a}$
c. C$\underline{i}$Ca – C$\underline{i}$Ci	c. CaC$\underline{i}$ – CiC$\underline{i}$
d. C$\underline{e}$Ca – C$\underline{e}$Ce	d. CaC$\underline{e}$ – CeC$\underline{e}$

Each of these comparison types was represented in the total set of 58 pairs by 6-9 word pairs.

For each subject, 3 tokens (2 from the back-vowel carrier and 1 from the front-vowel carrier) of each target word were analyzed acoustically. Analysis was restricted to the underscored vowels ($\underline{i}$, $\underline{e}$, or $\underline{a}$) in 1a-d and 2a-d above. Spectral measures of V_1 (in 1a-d) test anticipatory coarticulation and measures of V_2 (in 2a-d) test carryover coarticulation. Formant frequencies were measured at vowel midpoint for both V_1 and V_2, as well as vowel offset for V_1 and vowel onset for V_2 (i.e., offset and onset measures flanked the medial consonant). Measurements were based on superimposed FFT and LPC analyses. Prior to measurement, all vowels (plus a short portion of the adjacent consonants) were extracted from their original context and assigned an arbitrary label, so that experimenters were unaware of the harmonic or disharmonic context in which the vowels were produced.

F2 measurements are reported here, F2 being taken as a primary acoustic correlate of front-back tongue body constriction. Our primary measure of coarticulation is an F2 difference score: for each minimal pair, F2 of a vowel in the harmonic root was subtracted from F2 of the corresponding vowel in the disharmonic root (i.e., [$F2_{disharmonic} - F2_{harmonic}$]). If /a/ were to exhibit coarticulatory effects of a flanking front vowel, then the F2 difference score should be positive (i.e., F2 of /a/ in the context of disharmonic /i, e/ should be higher than F2 of /a/ in the context of /a/). If /i/ and /e/ were to show coarticulatory effects of flanking /a/, then the F2 difference score should be negative (i.e., F2 of front vowels should be relatively low in the context of non-front /a/).

3. RESULTS

3.1. Anticipatory Coarticulation

The average F2 difference scores for V_1 are shown in Fig. 1. (There was no apparent effect of front- vs. back-vowel carrier; results are averaged over carriers, word pairs, and subjects.) The

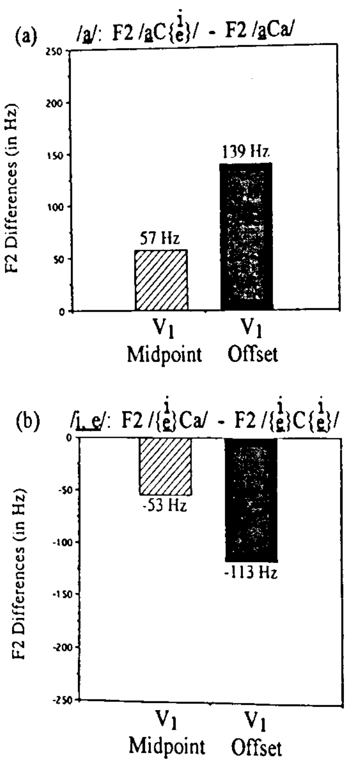

Figure 1. Average F2 difference scores for V_1 measurements at midpoint and offset. Top (a): V_1 = /a/; bottom (b): V_1 = /i, e/.

F2 difference scores for both non-front /a/ (Fig. 1a) and front /i, e/ (Fig. 1b) are in the direction expected if horizontal tongue body constriction for V_2 influenced that for V_1. Specifically, at vowel midpoint and offset, F2 in disharmonic roots was relatively high when /a/ was followed by /i, e/ and was relatively low when /i, e/ were followed by /a/. As would also be expected if these measures reflect coarticulatory effects, the F2 difference scores were smaller (about half as large) at vowel midpoint than at vowel offset. Presumably, the diminishing acoustic effects of V_2 on V_1 reflect the decreasing overlap between gestures for V_2 and V_1 over time.

The data in Fig. 1 also suggest that the magnitude of the coarticulatory effects of V_2 on V_1 is comparable for non-front and front vowels. At both midpoint and offset, the increase in F2 of /a/ attributed to following /i, e/ was roughly the same size as the decrease in F2 of /i, e/ due to following /a/.

Fig. 1 sums across the data for /i/ and /e/ both as *triggers* (Fig. 1a) and *undergoers* (Fig. 1b) of anticipatory coarticulation. The averaged data are representative of the individual behavior of /i/ and /e/ as undergoers of anticipatory coarticulation. Specifically, at vowel offset, the mean F2 difference of -113 Hz is also the mean for each of /i/ and /e/; at vowel midpoint, the F2 difference of -53 Hz is the mean of -44 Hz for /i/ and -62 Hz for /e/.

In contrast, /i/ and /e/ exhibit systematic differences in their behavior as triggers of anticipatory coarticulation. These differences can be seen in Fig. 2, which separates the averaged results for /a/ in Fig. 1a into the results for /a/ followed by /i/ (Fig. 2a) and /a/ followed by /e/ (Fig. 2b), for the 3 speakers (male speakers S1 and S3; female speaker S2). Particularly noteworthy is that, for each of the three speakers, the F2 difference score at /a/ midpoint is considerably greater in the /e/ context than in the /i/ context, with the latter context exerting a negligible influence at midpoint. These results are consistent with a difference in gestural timing in /aCi/ and /aCe/ sequences, with the vowels in /aCe/ sequences having greater temporal overlap.

3.2. Carryover Coarticulation

Of central interest here is whether the carryover effects of vowel-to-vowel coarticulation are as great as or exceed the anticipatory effects. Fig. 3 gives the average F2 difference scores for the midpoint and onset of V_2. For /a/ (Fig. 3a), as expected if preceding /i, e/ exert a coarticulatory influence, F2 in disharmonic roots is relatively high. Comparison of the data in Fig. 3a and Fig. 1a suggests that the carryover and anticipatory effects, respectively, of a flanking front vowel on /a/ are similar at vowel midpoint and approaching the medial consonant (i.e., vowel onset/offset).

However, when V_2 is a front vowel, a quite different picture emerges. Recall that if front vowels show coarticulatory

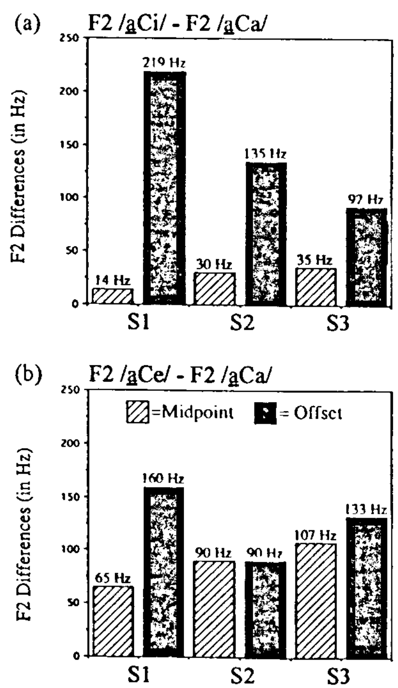

Figure 2. F2 difference scores for three speakers (S1, S2, S3) for V_1 = /a/. Top (a): V_2 of disharmonic root = /i/; bottom (b): V_2 of disharmonic root = /e/.

effects of a flanking non-front vowel, then [$F2_{disharmonic} - F2_{harmonic}$] should yield a negative value. The positive values in Fig. 3b are clearly inconsistent with this expectation and suggest that /a/ does not exert a coarticulatory influence on following front vowels. (That the F2 difference scores here are positive rather than more nearly hovering around zero is due largely to Speaker 2's vowels. When $V_1 = V_2$ (i.e., /iCi/, /eCe/, /aCa/), Speaker 2 tended to centralize both vowels. Thus what might appear to be dissimilation -- i.e., a relatively high F2 for /i, e/ preceded by /a/ -- is rather lack of centralization when $V_1 \neq V_2$.)

Are the data in Fig. 3, which sum across /i/ and /e/, representative of these

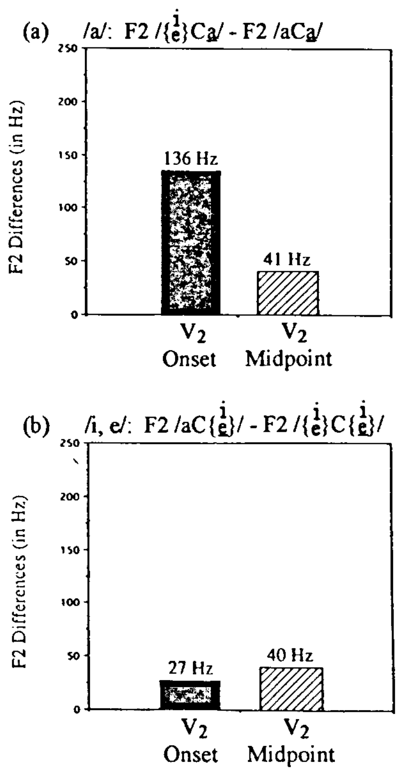

Figure 3. Average F2 difference scores for V_2 measurements at onset and midpoint. Top (a): V_2 = /a/; bottom (b): V_2 = /i, e/.

vowels both as triggers (Fig. 3a) and undergoers (Fig. 3b) of carryover coarticulation? Once again, the averaged data are representative of the individual behavior of the two front vowels as undergoers of coarticulation. (F2 difference scores for both /i/ and /e/ were slightly positive at vowel onset and midpoint.) However, also once again, the averaged data in Fig. 3 are not characteristic of both /i/ and /e/ as triggers of coarticulation. The different patterns of behavior are shown in Fig. 4, which gives the results for /a/ preceded by /i/ (Fig. 4a) and /a/ preceded by /e/ (Fig. 4b) for the three speakers. For all speakers, the F2 difference scores indicate that /i/ has a much greater coarticulatory influence than does /e/ on following /a/. Indeed, Speaker 3's

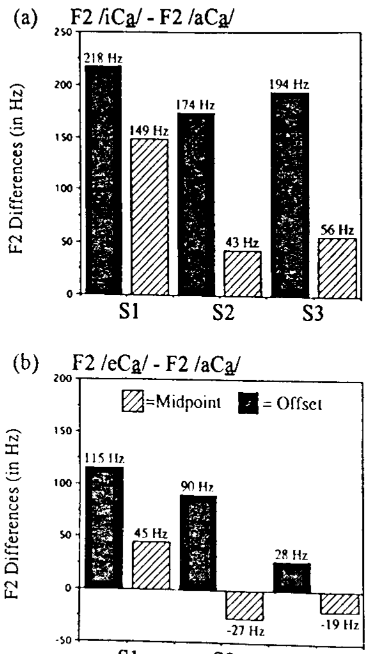

Figure 4. F2 difference scores for three speakers (S1, S2, S3) for V_2 = /a/. Top (a): V_1 of disharmonic root = /i/; bottom (b): V_1 of disharmonic root = /e/.

vowels show no carryover coarticulatory effects of /e/ on /a/.

4. DISCUSSION

Using [$F2_{disharmonic}$ – $F2_{harmonic}$] scores as the measure of vowel-to-vowel coarticulation, the patterns of anticipatory and carryover coarticulation in Turkish VCV sequences were found to differ. All three vowels, /i, e, a/, exhibited effects of anticipatory coarticulation at V_1 offset and to a lesser extent at V_1 midpoint. Moreover, the magnitude of the anticipatory effects was roughly comparable for the three vowel categories. The effects of carryover coarticulation onto V_2 were much more restricted. Only /a/ was susceptible to carryover effects of a preceding vowel, with the strongest effects being due to a preceding /i/.

We evaluate these findings first relative to those of previous studies of vowel-to-vowel coarticulation. Many studies report differences in the coarticulatory patterns of /i/ and /a/, few coarticulatory studies having analyzed /e/. /i/ tends to be a stronger trigger of coarticulation and more resistant as an undergoer of coarticulation than does /a/. One or both of these patterns have been reported for Japanese [18], German [2], Italian [19], Spanish and Catalan [5], Swahili and Shona [20]. The Turkish data reported here corroborate these patterns for carryover coarticulation: /i/ conditioned large frequency shifts in F2 of following /a/, and /i/ (as well as /e/) showed no coarticulatory effects of preceding /a/. However, the pattern does not hold for anticipatory coarticulation: /i, e, a/ behaved similarly as undergoers of anticipatory coarticulation and there was no overall tendency for /i/ to be stronger trigger of anticipatory coarticulation.

Previous studies have also shown that the primary direction (anticipatory or carryover) of vowel-to-vowel coarticulation differs across languages. The Turkish data reported here exhibit a predominantly anticipatory pattern and in this respect are more like the relatively strong anticipatory effects reported for Japanese [18] and Swahili and Shona [20] than like the stronger carryover effects found for English [3] and Catalan [4].

Of particular interest here is assessment of Turkish coarticulatory patterns relative to Turkish phonological structure. Recall that if the primarily left-to-right phonological pattern of vowel harmony in Turkish were to reflect active phonetic patterns of vowel-to-vowel coarticulation, then carryover should exceed anticipatory coarticulation in Turkish disharmonic roots. However, the reverse phonetic pattern holds for the set of roots tested here in that anticipatory coarticulation was found to be a much more general phenomenon than carryover coarticulation.

Of course, it does not follow from the apparent mismatch between the directionality of palatal harmony and front-back coarticulation in Turkish that coarticulatory organization is not linked to phonological structure. It is tempting to speculate that the more consistent effects of anticipatory coarticulation may be linked to word-final stress in Turkish. We suggest this in light of results of previous coarticulatory studies which have systematically manipulated stress location. Although the effects of stress on coarticulatory structure are complex (e.g., [21]), findings generally indicate that stressed vowels exert more of a coarticulatory influence than do unstressed ones on flanking vowels (e.g., [3], [18], [19]).

In view of our speculation on the possible link between patterns of coarticulation and final stress in Turkish, and our assumption of a historical link between coarticulation patterns and vowel harmony, we note with interest that phonological studies have proposed a relation between location of word stress and the development/ demise of progressive vowel harmony [22], [23].

5. CONCLUSION

These acoustic findings suggest that current patterns of vowel-to-vowel coarticulation in Turkish, as measured in disharmonic roots, do not parallel that language's phonological process of palatal harmony. The implications of this outcome for our understanding of the relation between phonetics and phonology are of course subject to debate. One interpretation to be considered is that perhaps this outcome should cause us to question our underlying assumption of a cause-and-effect relation between vowel-to-vowel coarticulation and vowel harmony. That is, perhaps coarticulatory organization does not reflect the left-to-right phonological pattern simply because there is no historical link between the two. A well-argued rejection of this interpretation is beyond the scope of this paper, although we observe that vowel harmony systems tend to be phonetically motivated (e.g., [16], [17]) in that they are organized in terms of features such as [back], [high], [round], which in turn are based on articulatory organization.

The alternative interpretation that we offer of the directional difference between the coarticulatory data and Turkish palatal harmony is that, once a phonetic behavior is phonologized, it becomes a phenomenon largely distinct from the behavior which gave rise to it. This is not surprising. If current theories about the interactions of phonological and coarticulatory structure are correct (see, for example, Fowler [14], Keating [24], and Manuel [7], [21]), then changes in segment inventories, prosodic structure, and other aspects of phonological structure should lead to changes in coarticulatory structure. It does not follow, however, that all historically linked phonological phenomenon would in turn be affected. But while not surprising, this outcome points to the complexity of the phonetic and phonological patterns which can co-occur in a language.

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REFERENCES

[1] Öhman, S. E. G. (1966), "Coarticulation in VCV utterances: spectrographic measurements", *Journal of the Acoustical Society of America*, vol. 39, pp. 151-168.

[2] Butcher, A. and Weiher, E. (1976), "An electropalatographic investigation

of coarticulation in VCV sequences", *Journal of Phonetics*, vol. 4, pp. 59-74.
[3] Fowler, C. A. (1981), "Production and perception of coarticulation among stressed and unstressed vowels", *Journal of Speech and Hearing Research*, vol. 46, pp. 127-139.
[4] Recasens, D. (1984), "V-to-V coarticulation in Catalan VCV sequences", *Journal of the Acoustical Society of America*, vol. 76, pp. 1624-1635.
[5] Recasens, D. (1987), "An acoustic analysis of V-to-C and V-to-V coarticulatory effects in Catalan and Spanish VCV sequences", *Journal of Phonetics*, vol. 15, pp. 299-312.
[6] Farnetani, E. (1990), "V-C-V coarticulation and its spatiotemporal domain", in W. J. Hardcastle and A. Marchal (eds.) *Speech production and speech modelling*, pp. 93-130, Dordrecht: Kluwer.
[7] Manuel, S. Y. (1990), "The role of contrast in limiting vowel-to-vowel coarticulation in different languages", *Journal of the Acoustical Society of America*, vol. 88, pp. 1286-1298.
[8] Alfonso, P. J. and Baer, T. (1982), "Dynamics of vowel articulation", *Language and Speech*, vol. 25, pp. 151-173.
[9] Martin, J. G. and Bunnell, H. T. (1982), "Perception of anticipatory coarticulation effects in vowel-stop consonant-vowel sequences," *Journal of Experimental Psychology: Human Perception and Performance*, vol. 8, pp. 473-488.
[10] Fowler, C. A. & Smith, M. R. (1986), "Speech perception as 'vector analysis': an approach to the problems of segmentation and invariance", in J. Perkell and D. Klatt (eds.), *Invariance and variability of speech processes*, pp. 123-139, Hillsdale, NJ: Erlbaum.
[11] van Heuven, V. J. and Dupuis, M. C. (1991), "Perception of anticipatory VCV-coarticulation: effects of vowel context and accent distribution", *Proceedings of the 12th International Congress of Phonetic Sciences*, vol.4, pp. 78-81, Université de Provence Aix-Marseille I.
[12] Ohala, J. J. (1981), "The listener as a source of sound change", in C. S. Masek, R. A. Hendrick, and M. F. Miller (eds.) *Papers from the Parasession on Language and Behavior*, pp. 178-203, Chicago: Chicago Linguistic Society.
[13] Ohala, J. J. (1993), "Coarticulation and phonology", *Language and Speech*, vol. 36, pp. 155-170.
[14] Fowler, C. A. (1990), "Some regularities in speech are not consequences of formal rules: comments on Keating's paper," in J. Kingston and M. E. Beckman (eds.) *Papers in laboratory phonology I: between the grammar and physics of speech*, pp. 476-489, Cambridge: Cambridge University Press.
[15] Boyce, S. E. (1990), "Coarticulatory organization for lip rounding in Turkish and English", *Journal of the Acoustical Society of America*, vol. 88, pp. 2584-2595.
[16] Anderson, S. R. (1980), "Problems and perspectives in the description of vowel harmony", in R. M. Vago (ed.) *Issues in vowel harmony*, pp. 1-48, Amsterdam: John Benjamins.
[17] Clements, G. N. & Sezer, E. (1982), "Vowel and consonant disharmony in Turkish", in H. van der Hulst and N. Smith (eds.) *The structure of phonological representations (Part II)*, pp. 213-255, Dordrecht: Foris.
[18] Magen, H. (1984), "Vowel-to-vowel coarticulation in English and Japanese", *Journal of the Acoustical Society of America*, Suppl. 1, vol. 75, p. S41.
[19] Farnetani, E., Vagges, K., and Magno-Caldognetto, E. (1985), "Coarticulation in Italian /VtV/ sequences: a palatographic study", *Phonetica*, vol. 42, pp. 78-99.
[20] Manuel, S. Y. and Krakow, R. A. (1984), "Universal and language particular aspects of vowel-to-vowel coarticulation", *Haskins Laboratories Status Reports on Speech Research*, vol. SR-77/78, pp. 69-78.
[21] Manuel, S. Y. (In press), "Cross-linguistic studies of coarticulation II: relating language- particular coarticulation patterns to other language-particular facts", in W. J. Hardcastle (ed.) Coarticulation, Cambridge: Cambridge University Press.
[22] Rédei, K. (1987), "The development of vowel harmony in Proto-Uralic and Proto-Finno-Ugrian", *Finnisch-Ugrische Forschungen: Zeitschrift fur Finnisch-Ugrische Sprach- und Volkskunde*, vol. 48, pp. 39-50.
[23] Binnick, R. I. (1980), "The underlying representation of harmonizing vowels: evidence from Modern Mongolian", in R. M. Vago (ed.) *Issues in vowel harmony*, pp. 113-132, Amsterdam: John Benjamins.
[24] Keating, P. A. (1990), "The window model of coarticulation: articulatory evidence", in J. Kingston and M. E. Beckman (eds.) *Papers in laboratory phonology I: between the grammar and physics of speech*, pp. 451-470, Cambridge: Cambridge University Press.