Non-native Locus Equations and the Unit of Phonetic Acquisition

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Oh, Eunjin. 2001. **Non-native Locus Equations and the Unit of Phonetic Acquisition.** *Korean Journal of English Language and Linguistics* 1-3, 497-508. This study tested whether non-native speakers approximated native-like locus equation slopes. Russian learners of English acquired native-like values of the locus equation slope for the English bilabial, and English learners of Russian made slight modifications to the locus equation slope of the Russian bilabial. The acquisition of the locus equations occurred gradually with experience. While English speakers, with limited experience with Russian, failed to approximate Russian-typical value of the locus equations slope, Russian speakers, with more extensive experience with English, succeeded in approximating the locus equation for English bilabial. The observation of locus equation transfer effect supports for the locus equation hypothesis as the unit of acquisition over CV-by-CV learning.

1. Introduction

Russian has complex consonant inventory, which complexity is mainly due to the existence of the full set of the plain and palatalized consonants for each stop place of articulation. For example, the Russian words for *to take* [brat] and *brother* [brat^j] are distinguished only by the palatalized and non-palatalized coronal consonant. In Russian, then, a large amount of consonantal undershoot would endanger its contrast with its corresponding palatalized consonant (e.g., Öhman 1966, Cohn 1988). In English, however, during the production of bilabial stops tongue body can anticipate the articulation of the following vowel, resulting in a large degree of coarticulation. This study investigates consonantal coarticulation due to the adjacent vowels of English and Russian, and more importantly consonantal coarticulation produced by non-native speakers of English and Russian.

As an index of the overall degrees of consonantal coarticulation, the *locus equation slope* was employed. Plotting the contextual vowel F2s on the X-axis and the consonantal F2s on the Y-axis, the function is strikingly linear, called the locus equation (originally found by Lindblom 1963). The reason why the slope value of the locus equation is a reasonable index of consonantal coarticulation is that, as discussed in Krull (1989), small coarticulation is associated with flatter slopes, since $F2_C$ remains fairly stable with adjacent vowels, while large coarticulation is associated with steeper slopes, since $F2_C$ changes more with vowel context. It was tested that the locus equation slopes were shallower in Russian, indicating less vocalic influence on adjacent stops, than in English.

This study further tests (1) whether non-native speakers approximate native-like locus equation slopes, (2) whether approximation to the locus equation slopes occurs gradually, and (3) whether the non-native locus equations are linear or not. The question (3) is particularly interesting because the answer to the question might be related to the issue of the units of acquisition. If the effect of learning is to adjust locus equation parameters for a consonant, the non-native locus equations will always be linear, while slope value can be intermediate between L1 and L2. If learning occurs on a CV-by-CV basis, e.g., $F2_C$ is learned for each CV independently rather than being generated from a locus equation, there will be a chance that the non-native locus equations are non-linear.

2. Experiment

Two groups of speakers, four native speakers of English who speak Russian (Group NE, mean age 26, range 23 to 29) and four native speakers of Russian who speak English (Group NR, mean age 25, range 22 to 26), were residing in California, U.S.A. at the time of recording. The English speakers began their formal study of Russian at age 19 and the Russians at age 12. The length of stay in the foreign language speaking country was less than a year for the English speakers and several years for the Russian speakers except NR4.

Speakers read randomized /CVt/ tokens in carrier phrases. The Russian vowels *i* and *ɨ* were not included because *i* surfaces as after non-palatalized consonants, and *ɨ* was produced as a diphthong so it is difficult to find a steady state. I tried to use real word stimuli, but nonsense words were constructed when I could not find a real word.

Say CVt to me.
(CVt = beat, bit, bet, bat, but, bot, boot, bought)
Povtori CVd eshche raz. "Repeat CVd one more time."
(CVt = bed, bad, bud, bod)

The subjects were asked to read the materials first for practice, then for recording. They read a one-paragraph short story in the appropriate language before reading the test sentences. Speakers read stimuli in their native language first, took a break, and then read the target language stimuli. Five tokens of each test sentence were produced.

Acoustic measurements were taken from five tokens of each CVt produced by each speaker, using procedures similar to those of Sussman, McCaffrey, and Matthews (1991). The two formant measurement points were: (1) $F2_C$ as the F2 frequency measured at the first glottal pulse after the release burst, and (2) $F2_V$ as F2 at the midvowel nucleus. The criteria for $F2_V$ measurement points were: (i) if the F2 was uniformly or falling, the midpoint of vowel duration was chosen, and (ii) if the F2 contour was either u-shaped or the inverse, a minimum or maximum frequency, respectively, was taken as $F2_V$.

3. Results

The locus equation slope for the labial consonant was steep in native English (mean=0.85, range 0.84 to 0.86) with a low y-intercept (mean=185.99Hz, range 123 to 221), and characterized by a tight clustering of points around the regression line (mean R_2=0.97). The locus equation slopes for the native Russian bilabial stop (mean=0.53, range 0.45-0.57) were much shallower than those of English with a higher y-intercept (mean=406.35Hz, range 247-630). Data points were also tightly clustered around the regression line (mean R_2=0.95).

Comparison of slope and y-intercept for English and Russian bilabial stop consonants revealed flatter slopes in Russian than in English. The differences between English and Russian were statistically significant in slopes (by ANOVAs with speaker nested under group as a random factor, [$F(1,7)=139$; $p<0.0001$]) and were marginally significant in y-intercepts ([$F(1,7)=5.85$; $p=0.0519$]).

Each English speaker's slope value for Russian was shallower than the slope value for English, and each Russian speaker's slope value for English was steeper than the slope value for Russian. The differences between native and non-native speech, however, were much larger for the Russian speakers than for the English speakers (Figure 1 below). The non-native values of y-intercept were in general larger for the English speakers and smaller for the Russian speakers than their native values. The data points of their non-native speech were extremely tightly clustered around the regression lines. The R_2-values of their non-native speech were as large as those of their native speech. That is, the non-native locus equations are highly linear (sample locus equations in Figure 2).

Figure 1. Mean slope values: Left two bars for the English speakers native (left) and non-native (right) slopes, and right two bars for the Russian speakers native (left) and non-native (right) slopes.

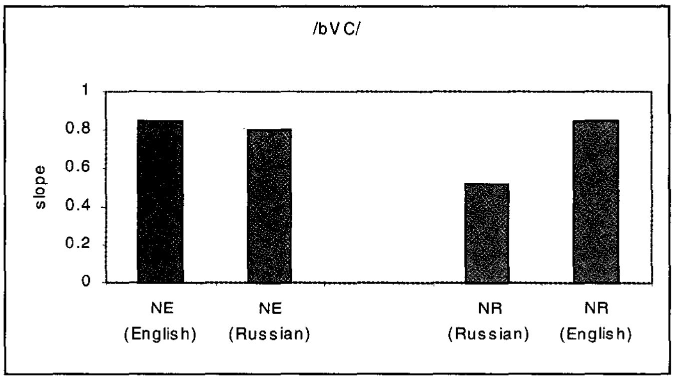
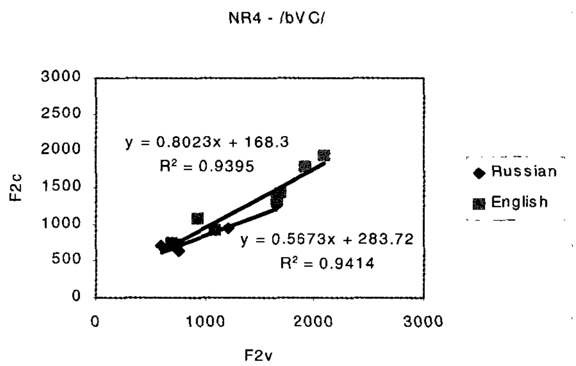


Figure 2. Sample locus equations of the English and Russian bilabials produced by NR4.



Comparing spectrograms of Russian *bed* and English *bet* produced by a relatively less experienced and a relatively more experienced Russian speaker of English, the English bilabial stop produced by the more experienced learner shows extreme undershoot with the contextual vowel (exactly like the English native speakers production), while that of the less experienced learner shows less undershoot with still a bit of a rising F2 contour shape for English. The rest of the relatively experienced learners also succeeded in increasing the amount of consonant coarticulation. The data points for their *bed* were on regression lines with steeper slopes.

4. Some Asymmetries and the Unit of Acquisition

Returning to the questions addressed at the beginning of this study, I have shown that the locus equation slopes are language-specific, and that non-native speakers gradually change the locus equation slopes for their L2. The non-native locus equations were highly linear. The overall mean R_2 value for all locus equations obtained across all native speech was 0.92, and the one across all non-native speech was 0.94.

While most Russian speakers succeeded in acquiring the larger degree of coarticulation of the English bilabial stops due to the contextual vowels, the English speakers failed to acquire less coarticulation for Russian bilabial stops. This failure appears to be due to the limited extent of experience with Russian for English speakers, compared with the Russian speakers of English.

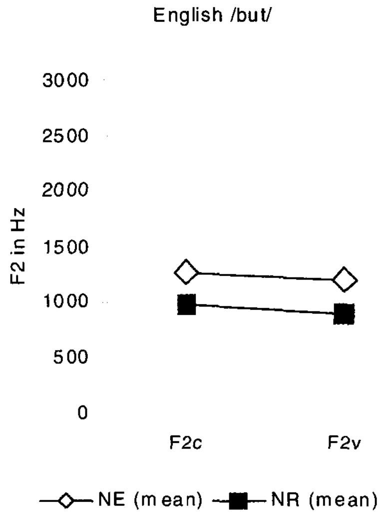
It is interesting to consider some individual data of the least experienced Russian speaker of English, NR4 (Figure 2). As discussed earlier, his English *bet* shows less undershoot of the consonant than it should. This can also be observed where the data point for English *bet* is under the regression line. But this learner produced the English *beat* and *bit* tokens correctly (i.e., showed extreme undershoot of the consonant with the contextual vowels), which played a crucial role in increasing the slope value of the L2 regression line for the bilabial stop of this speaker. Note that the deviation of *bet* has only a small effect on R_2-value (0.94 for NR4). A very high R_2 can be achieved even with one significant deviation from linearity, so R_2-value may not be an ideal index of linearity for present purposes.

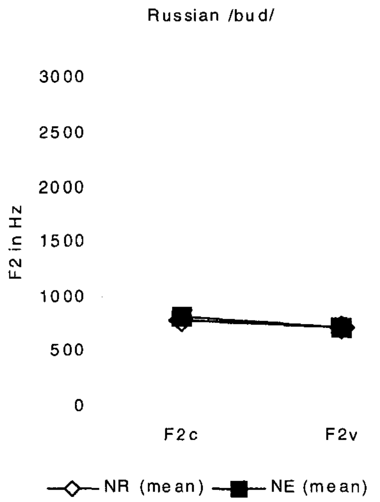
Why did the learner have difficulty in increasing coarticulation in the sequence *bet*, but not have any problem for the sequences *beat* or *bit*? For the latter case, it seemed that this learner transferred the contour shape of his native syllable *b^j^id*. Although speculative, there appears to be a general tendency to transfer an L2 segment in the segmental context *similar* to L1. The learner transferred the native palatalized *b^j^id* for producing the English /b/ in the context of /i/.

For NR4, the slope value, excluding the high front vowel contexts (which appeared to be transferred from Russian *b^j^id*), is 0.64, very close to his Russian slope for the bilabial stop (0.57). The slope value excluding the mid and low front vowels is 0.86, similar to the slope values produced by the more experienced Russian learners of English (NR1: 0.85, NR2: 0.87, NR3: 0.88). On the other hand, the bilabial stops in the context of mid and low front vowels produced by other Russian learners of English were on the L2 locus line and deviated from their L1 lines. It may be the case that, owing to the transfer of Russian *b^j^id* to English *beat*, even beginning learners produce increased values of bilabial slopes (even with still minimal coarticulation of consonant in English *bet*). With learning progressing, the data point for the English *bet* may be gradually more to the regression line with a steeper slope.

Another interesting contrast observed is that while all the English speakers produced a native-like Russian back vowel [u] (in *bud*), all the Russian speakers failed to produce native-like English [u] (in *boot*), as shown in Figure 3. This was rather surprising, considering that Russian speakers had substantially more experience in L2 than did English speakers.

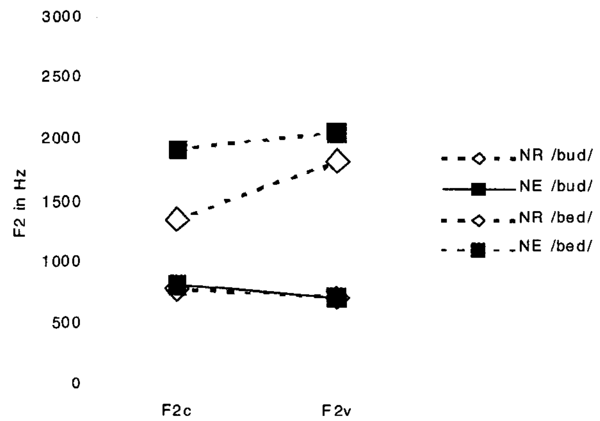
Figure 3. Non-native production of back vowel [u] (in the bilabial contexts); filled squares for non-native F2c's and F2v's and open diamond for native F2c's and F2v's.





All the English speakers learned the $F2_C$ in Russian *bud*, but failed to learn the $F2_C$ of Russian *bed* (Figure 4). This is interesting, considering that absolute acoustic differences in the $F2_C$'s between English *bet* and Russian *bed* and between English *boot* and Russian *bud* are 431Hz and 474Hz, respectively, which are very similar. The faithfully correct acquisition of $F2_C$'s in Russian *bud* can be interpreted as the acquisition of the vowel /u/ but transfer of the locus equation (i.e., consonant undershoot patterns of their native language). The transfer of the native locus equation slope into the second language production also resulted in the failure of the proper acquisition of the $F2_C$'s in the Russian *bed*.

Figure 4. English speakers production of Russian syllables *bud* and *bed* (filled squares) compared with native Russian production (open diamonds).



An issue raised at the beginning was whether non-native locus equations would be linear or not. This question was related to the issue of units of acquisition. If a second-language acquisition is the locus equation for a consonant, the non-native locus equations will be always linear, while its slope can have any intermediate value between L1 and L2. However, as discussed above, if linearity is indexed by R_2, linearity itself may not provide conclusive evidence for the locus equations as the unit of acquisition, because some clear deviations from the locus equation lines do not give a bad R_2-value. Rather, the locus equation transfer discussed in the last paragraph seems to suggest the locus equation possibility as the unit of acquisition, since this learner acquired the correct vowel /u/ but fed the acquired vowel value into his L1 locus equation. If $F2_C$ *per se* was transferred from the closest English CV, we would have observed a much higher $F2_C$ in his Russian productions. This observation seems to oppose acquisition of $F2_C$ or a V-by-V basis to acquisition of locus equation parameters.

If we had observed strikingly non-linear locus equations in non-native speech, the CV-by-CV hypothesis (that $F2_C$ is learned independently rather than being calculated from a locus equation) may have been considered as a possibility. However the non-native locus equations were very linear (although the one exception, transfer of Russian *bʲid* to English *beat*, was analyzed as context-dependent transfer of L1 phones). On the other hand, the observation of locus equation transfer effect supports for the locus equation hypothesis as the unit of acquisition over CV-by-CV learning. Learners learn vowel F2s, but the contextual consonant F2s were calculated from the native-language locus equation.

5. Concluding Remarks

To conclude, the overall degree of coarticulation in a bilabial consonant across all following vowels (indexed by locus equation slope) was larger in English than in Russian. Russian learners of English acquired native-like values of the locus equation slope for the English bilabial, and English learners of Russian made slight modifications to the locus equation slope of the Russian bilabial. The acquisition of coarticulation occurred gradually with experience. While English speakers, with limited experience with

Russian, failed to approximate Russian-typical value of the locus equations slope, Russian speakers, with more extensive experience with English, succeeded in approximating the locus equation for English bilabial.

A hypothesis is suggested in relation to these facts: Non-native learners target points of confusion first. It would be crucial for the L2 learners to accurately learn the phonetic categories more quickly than any other categories if it helps L2 learners effectively communicate with native speakers of L2. The rapid acquisition of English speakers production of native-like Russian back vowel [u] will help speakers avoid confusion with another L2 category, that is, with the central vowel for Russian. On the other hand, the acquisition of English [u] by Russian speakers would not have the effect. Evidence from English hyperarticulation (Johnson, Flemming, and Wright 1994) suggests that backing /u/ is not likely to cause great problems in English since there is no other vowel in the back vowel space. In French, however, it is likely that the existence of the front rounded vowel causes the confusion problem.

References

Cohn, A. 1988. Quantitative characterization of degree of coarticulation in CV tokens. *UCLA Working Papers in Phonetics*, 51-9.

Crowther, C. S. 1994. Modeling coarticulation and place of articulation using locus equations. *UCLA Working Papers in Phonetics* 88, 127-48.

Flege, J. E. 1995. Second language speech learning: theory, findings and problems. In W. Strange, ed., *Speech perception and linguistic experience: Issues in Cross-Language Speech Research*, 233-77. Timonium, MD: York Press.

Johnson, K., E. Flemming, and R. Wright. 1993. The hyperspace effect: phonetic targets are hyperarticulated. *Language* 69, 505-28.

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*, 451-70, Cambridge University Press.

Klatt, D. H. 1987. Review of text-to-speech conversion for English.

Journal of the Acoustical Society of America 82, 737-93.

Krull, D. 1987. Second formant locus patterns as a measure of consonant-vowel coarticulation. *PERILUS* V, 43-61. University of Stockholm.

Krull, D. 1989. Second formant locus patterns and consonant-vowel coarticulation in spontaneous speech. *PERILUS* X, 87-108. University of Stockholm.

Lindblom, B. 1963. Spectrographic study of vowel reduction. *Journal of the Acoustical Society of America* 35, 1773-81.

Nittrouer, S., M. Studdert-Kennedy, and R. S. McGowan. 1989. The emergence of phonetic segments: evidence from the spectral structure of fricative-vowel syllables spoken by children and adults. *Journal of Speech and Hearing Research* 32, 120-32.

Oh, E. 2001. Explaining phonetic variation of consonants in vocalic context. *The Korean Journal of Speech Sciences* 8, 31-41.

Öhman, S. E. G. 1966. Coarticulation in VCV utterances: spectrographic measurements. *Journal of the Acoustical Society of America* 39, 151-68.

Sereno, J. A. and P. Lieberman. 1987. Developmental aspects of lingual coarticulation. *Journal of Phonetics* 15, 247-57.

Stevens, K. N. and A. S. House. 1963. Perturbation of vowel articulations by consonantal context: an acoustical study. *Journal of Speech and Hearing Research* 6, 111-28.

Stevens, K. N., A. S. House, and A. P. Paul. 1966. Acoustical description of syllabic nuclei: an interpretation in terms of a dynamic model of articulation. *Journal of the Acoustical Society of America* 40, 123-32.

Sussman, H. M., H. A. McCaffrey, and S. A. Matthews. 1991. An investigation of locus equations as a source of relational invariance for stop place categorization. *Journal of the Acoustical Society of America* 90, 1309-25.

Sussman, H. M., K. A. Hoemeke, and F. S. Ahmed. 1993. A cross-linguistic investigation of locus equations as a phonetic descriptor for place of articulation. *Journal of the Acoustical Society of America* 94, 1256-68.

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