Absolute and Proportional Undershoot Values as Indices of Coarticulation*

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ABSTRACT

The aim of this paper is to suggest an index of coarticulation, proportional undershoot values, given the observation that absolute undershoot within a language tends to be proportional to target-locus difference. The target-locus proportionality predicts that a large difference between the consonant locus and the vowel target will result in a large amount of vowel undershoot, while a small difference a small amount of vowel undershoot. It turns out that the proportional undershoot is a potentially more appropriate way of comparing degree of undershoot across languages. However, even though the proportional undershoot measurement may provide a useful index comparing the overall coarticulation degree in a CV token for cross-linguistic data, it is concluded that it may potentially wrongly predict the cases of transfer or error as a progress in learning.

Keywords: index of coarticulation, absolute undershoot, proportional undershoot.

1. Introduction

When a native speaker of American English produces the English word *two*, it is general that the back vowel [u] is produced farther forward than the same vowel in the English word *who* due to the influence of the adjacent coronal consonant. An acoustic consequence of such articulatory modification is that the F2 frequency at the steady state of the vowel in *two* is higher than the F2 in *who*.

These coarticulatory effects go beyond simple universal factors, and the amount of coarticulation is language-specific. It has been suggested that the degree of coarticulation is constrained by the language-specific system of phonological contrasts (e.g., Manuel 1990). This hypothesis leads to the prediction that the languages in which the vowel /u/ contrasts with the front round vowel /y/ in the front/back F2 dimension show less

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fronting in coronal contexts than the languages in which /u/ does not contrast with /y/ (Flemming 1997).

The acoustic experiment in Oh (2003) demonstrated support for language-specific differences in the amount of back vowel fronting in coronal contexts between English which lacks /y/ and French which has /y/. It was also shown that English learners of French (at least partially) reduce the degree of coarticulation when producing French /u/ in coronal contexts as they become more experienced with the language.

As an index for measuring the degree of vowel undershoot, the previous study used an absoluste undershoot value, simply taking the difference between a target value of the vowel and a value of the vowel in context. This index is potentially problematic in that it misses the observation that absolute undershoot within a language tends to be proportional to (vowel) target - (consonant) locus difference. This study attempts to suggest another index of coarticulation, proportional undershoot values, taking the target-locus difference into account. Sections 2 and 3 introduce the absolute and the proportional undershoot values of coarticulation, respectively, and section 4 discusses some assets and disadvantages of the two indices of coarticulation.

2. Absolute Undershoot Values

Articulatory 'target' of a vowel is defined as the configuration in which a vowel is pronounced "under ideal steady-state conditions (Lindblom 1963: 1779)". *Undershoot* is then defined as deviation of a speech sound from its target value toward contextual segments.

A simple index for measuring the degree of vowel undershoot is the calculation of an *absolute undershoot value*, the difference between an estimated target F2 value of a vowel (i.e., $F2_T$) and an F2 value at the steady state of the vowel in a specific consonantal context (i.e., $F2_V$). The absolute undershoot value of [u] in coronal contexts will then be calculated by taking the difference between the $F2_T$ of [u] in a neutral context and the $F2_V$ of [u] in a coronal context (e.g., in *two*) (Flemming 1997; see Figure 1 below).

(1) Absolute undershoot=$F2_V$(*two*)−$F2_T$(*who*)

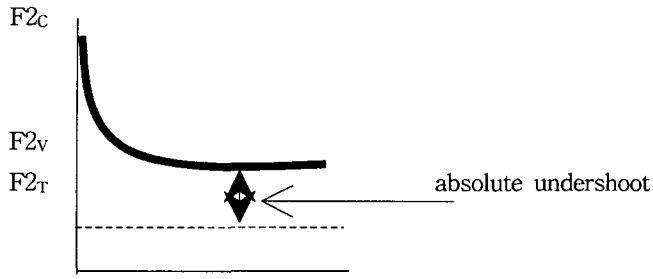

Figure 1. A schematic representation of F2 transition in [tu] (Flemming 1997).

The absolute undershoot value will be large when there is a large degree of deviation from the estimated target value, and small when there is a small degree of deviation from the target.

In the experiment of Oh (2003), four groups of female speakers participated, five native speakers of English (Group NE), three native speakers of French (Group NF), five advanced English learners of French (Group AEF), and five beginning English learners of French (Group BEF). As speech materials, "Say *who* to me" (target) and "Say *two* to me" (coarticulation) in English, and "Dites-moi *où* deux fois" (target) and "Dites-moi *tous* deux fois" (coarticulation) in French were used. (For the detailed procedure of the experiment, see Oh 2003).

The mean results for the native groups are summarized in Figures 2 and 3 and Table 1. Figure 2 represents the lines connecting the two points, the $F2_C$ and $F2_V$, and a steeper slope of the line indicates a larger formant transition, and thus a larger articulatory movement, made in [tu]. Horizontal lines in the figures represent the target value of the vowel in each language. The absolute undershoot degrees are represented as heights in the bar graph of Figure 3.

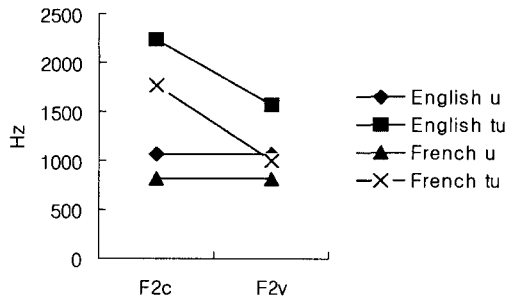

Figure 2. The $F2_T$, $F2_C$, and $F2_V$ of Group NE and Group NF.

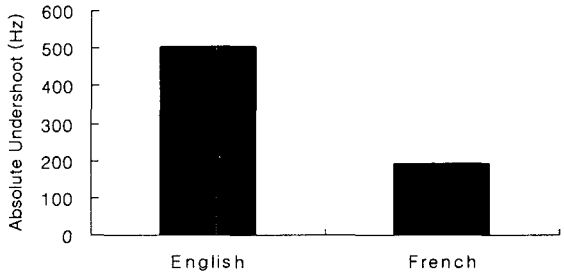

Figure 3. The degree of vowel undershoot of Group NE and Group NF.

Table 1. Group NE and Group NF.

	NE	NF	F-ratio; p-value [F(1, 38)]
$F2_T$	1061 Hz	817 Hz	30.41*; $p<0.0001$
$F2_C$	2234 Hz	1760 Hz	220.39*; $p<0.0001$
$F2_V$	1564 Hz	1006 Hz	107.44*; $p<0.0001$
AU	503 Hz	189 Hz	29.65*; $p<0.0001$

(AU=absolute undershoot)

The $F2_T$, $F2_C$, and $F2_V$ values were higher in Group NE than in Group NF. The degrees of vowel undershoot were larger in Group NE than in Group NF by absolute undershoot measurements. All the differences in the $F2_T$, $F2_C$, $F2_V$, and absolute undershoot values by language were statistically significant, as shown in Table 1.

As for the production of the English learners of French, both Group AEF and Group BEF produced lower $F2_T$, $F2_C$, and $F2_V$ values for French than for English, as demonstrated in Figure 4. However, the reduction of the undershoot degree occurred only in Group AEF, and Group BEF even increased the degree of the absolute undershoot for French, as seen in Figure 5.

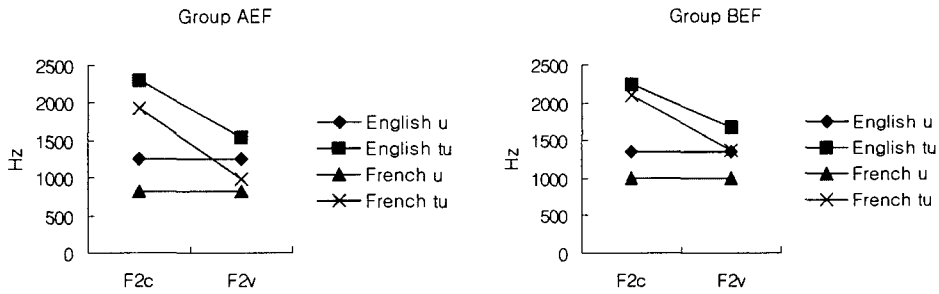

Figure 4. The English and French F2T, F2C, and F2V produced by Group AEF (above) and Group BEF (below).

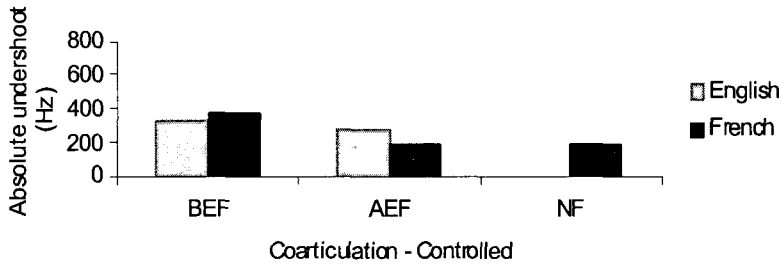

Figure 5. The degree of vowel undershoot produced by Group BEF, Group AEF, and Group NF.

Both in Group AEF and in Group BEF, the lowering of $F2_C$ is a bit smaller than the lowering of $F2_V$, resulting in steeper slopes of the French [tu] line than the English [tu], as seen in Figure 4. However, by lowering the F2 value at the release of the consonant as well as at the steady state of the vowel, learners both in Group AEF and Group BEF managed to reduce the overall articulatory movement in producing French [tu].

In summary, this experiment demonstrated support for language-specific differences in the amount of back vowel fronting in coronal contexts between English which lacks /y/ and French which has /y/. English learners of French (at least partially) reduced the degree of coarticulation when producing French /u/ in coronal contexts as they become more experienced with French. The speakers' experience correlated with the production of native-like L2 coarticulation, i.e., advanced learners, but not beginning learners, achieved L2 coarticulation.

3. Proportional Undershoot Values

Assume that a vowel of language A has a larger degree of absolute undershoot than the same vowel of language B. However, in the CV syllable, if the language A has a smaller degree of consonant undershoot than the language B to the extent to which A has a larger difference between the consonant F2 and the vowel target than B, the *proportional* difference between A and B will become smaller, or the pattern may even be reversed (i.e., the language B may show a larger proportional undershoot value). Since there is empirical evidence that, as well as the $F2_V$, the $F2_C$ value also depends on the F2 of the adjacent vowel (e.g., Crowther 1994), the proportional undershoot measurement may be a useful index for estimating the overall degree of coarticulation in a CV syllable, including the amount of consonant undershoot as well as the degree of vowel undershoot.

Therefore, a potentially more appropriate way of comparing degree of undershoot

across languages may be a *proportional undershoot value*, given the observation that absolute undershoot within a language tends to be proportional to target-locus difference. See Figure 6 below. The proportional undershoot value is estimated by absolute undershoot value divided by a difference between a consonant F2 (the $F2_C$) and a vowel target.

(2) Proportional undershoot = $\frac{F2_V - F2_T}{F2_C - F2_T}$

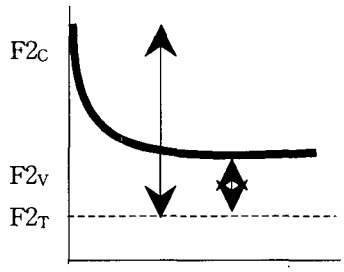

Figure 6. A schematic representation of proportional undershoot.

This form of equation is adapted from 'target-locus proportionality' (Lindblom 1963, Broad and Clermont 1987):

(3) $F2_V = k(F2_C - F2_T) + F2_T$ (where k is a slope in the linear equation.)

(See Flemming 1997 for a review.) The target-locus proportionality is based on the observation that $F2_V$ undershoots toward an adjacent consonant by a proportion k of the difference between the vowel target and the $F2_C$. The target-locus proportionality predicts that a large difference between the consonant F2 and the vowel target will result in a large amount of vowel undershoot, while a small difference a small amount of vowel undershoot. Accordingly, the vowel [u] will show a larger amount of undershoot in a context of coronal consonant, which has a relatively high F2 locus, than in a context of labial consonant, which has a relatively low F2 locus.

In a cross-linguistic comparison of coarticulation degree, when would the equations for absolute undershoot and proportional undershoot give different prediction? Take the example of the English and French data collected in the previous experiment. Since the difference between the vowel target and the consonantal F2 was larger in English (1173 Hz) than in French (943 Hz) (Figure 2 and Table 1 above), the absolute undershoot values was divided by a larger number in English than in French. As a result, the proportional

difference between Group NE and Group NF was a bit smaller in the proportional undershoot values than in the absolute undershoot values. This is illustrated in Figure 7, the absolute undershoot in the above and the proportional undershoot in the below.

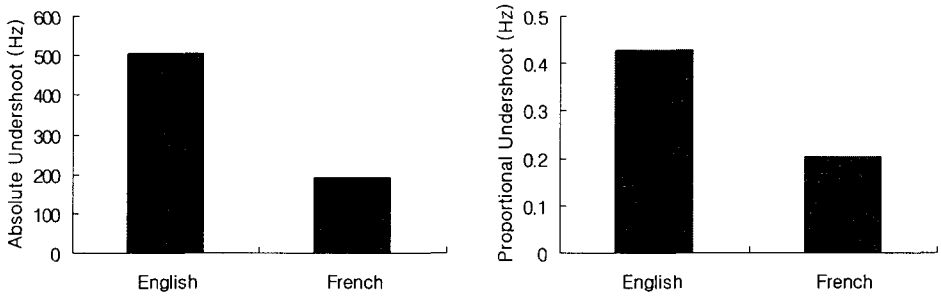

Figure 7. Absolute (above) *vs.* proportional (below) undershoot values produced by the native groups.

In this case, the proportional undershoot measurement takes the difference between the consonant and the vowel value in a CV token into account, and provides a useful index comparing the overall degree of coarticulation in a CV syllable for cross-linguistic data.

As a next step, it will be interesting to see if the proportional undershoot measurements appropriately represent the degrees of coarticulation acquisition. Suppose the following hypothetical situation, where "EF" indicates a native English speaker of French and "NF" indicates typical values produced by native speakers of French.

(4)

	$F2_C$	$F2_V$	$F2_T$
EF's French	2000 Hz	1200 Hz	900 Hz
NF	1600 Hz	1200 Hz	900 Hz
EF's English	2000 Hz	1600 Hz	

Absolute undershoot value of EF = 1200 Hz − 900 Hz = **300Hz**
Absolute undershoot value of NF = 1200 Hz − 900 Hz = **300Hz**
Proportional undershoot value of EF = 300 Hz / (2000 − 900) Hz = **0.27**
Proportional undershoot value of NF = 300 Hz / (1600 − 900) Hz = **0.43**

Here, since EF acquired the native-like $F2_V$ value and the native-like $F2_T$ value, according to the absolute undershoot measure this learner attained a native-like degree of coarticulation (i.e., 300 Hz). However, the $F2_C$ of this learner is transferred from English, resulting in excessive articulatory movement in the CV token. This fact is reflected in the

smaller proportional undershoot of EF than of NF. The proportional undershoot measure would reflect this incomplete acquisition of coarticulation in a CV token better than the absolute undershoot measure in this hypothetical situation.

Let us compare then real values of the absolute and the proportional undershoot produced by the learner groups of the previous experiment. See Figure 8 below. Notice that, by the index of proportional undershoot, the coarticulation degree of Group BEF is smaller for French than for English, which is exactly the reverse of the pattern indicated by the absolute undershoot index. A main contributor to this reversal between absolute and proportional undershoot values is that the $F2_C$ is not lowered enough for French in the speech of Group BEF (see Figure 4 above). That is, the difference between the $F2_C$ and the vowel target is larger in French than in English, hence the absolute undershoot value was divided by a larger number for French than for English. This reduction in the undershoot amount (by approximately 0.058) should not directly be interpreted as resulting from the acquisition of L2 coarticulation, since it resulted mainly from the incomplete acquisition of the proper $F2_C$ value of French. This result leads to two-fold interpretations. While the proportional undershoot index is useful in that it reflects the acquisition of the faster transition velocity from the $F2_C$ to $F2_V$ in French by Group BEF, it is disadvantageous in that it may provide a misleading index for the acquisition of L2 vowel undershoot, i.e., better approximation to French $F2_C$ would yield apparently worse proportional undershoot.

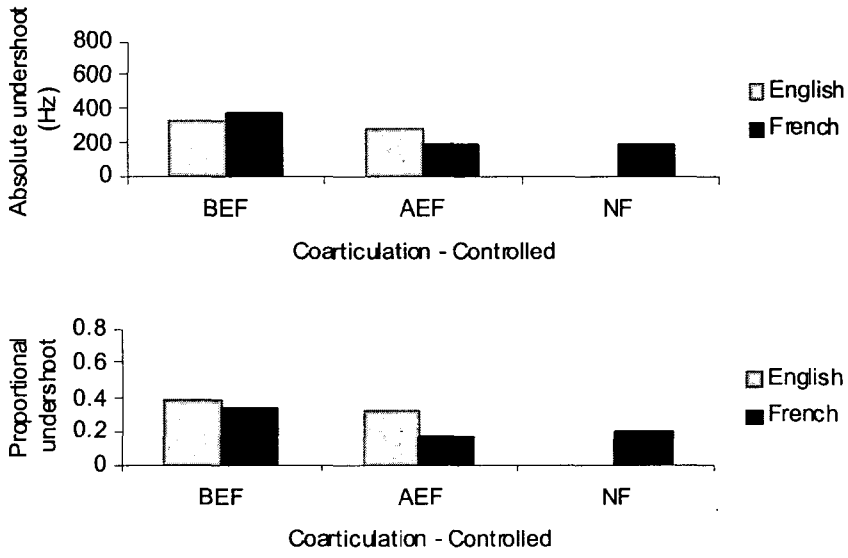

Figure 8. Absolute (above) vs. proportional (below) undershoot values produced by the learner groups.

4. Summary and conclusions

While the absolute undershoot value provides a simple and straightforward index for measuring the degree of vowel and consonant coarticulation, it was pointed out that it may miss the fact that the undershoot within a language tends to be proportional to the vowel-target and consonant-locus difference in a CV token. Proportional undershoot values were suggested as another index of coarticulation, taking the difference between the consonant and the vowel affecting the degree of CV coarticulation into account. It turned out to be that the proportional undershoot measurement provides a more appropriate way of comparing degrees of undershoot across languages. For the non-native data, the proportional undershoot index was useful in that it reflects the acquisition of the transition velocity from the $F2_C$ to the $F2_V$. However, it was pointed out that the proportional undershoot may potentially wrongly predict the cases of transfer or error as a progress in learning. Hence, it appears to be important to consider both the absolute undershoot and the proportional undershoot as indices of the degree of CV coarticulation.

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