# ARTICULATORY AND ACOUSTIC MEASUREMENTS OF COARTICULATION IN IRISH (GAELIC) STOPS

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## ABSTRACT

The rich consonantal system of Irish offers a testing ground for the hypothesis that the phonology of a specific language may constrain otherwise (presumed) universal coarticulatory tendencies. Articulatory and acoustic measures of coarticulation for VCV sequences are presented, where V = each of 5 tense vowels, and C = voiced stops for each of 6 contrasting places of articulation (involving primary and/or secondary places of articulation). Results do in general support the hypothesis; coarticulation of Irish stops is very limited when compared with known data from other languages. Such coarticulation as was found, tended to be carryover rather than anticipatory. Fairly extensive acoustic (but not articulatory) evidence for coarticulation was found for /g/. F2 for articulations in this region may be particularly sensitive to lip rounding.


## 1. INTRODUCTION

Irish (Gaelic) stops offer a means of testing the hypothesis that a phonological system with a large number of contrasts will constrain the extent to which coarticulation is "allowed". The consonantal system of Irish involves a dichotomy into a palatalised series (phonologically symbolised with /'/) and a velarised series of segments. The opposition of palatalised and velarised pairs may involve simply the secondary articulation (e.g., /b, b'/ = [bˠ, bʲ]), the primary articulation (e.g., /g, g'/ = [ɟ, g]) or a combination of both (e.g., /d, d'/ = [d̪ˠ, dʲ]). Given that Irish has a six way contrast, one would predict that coarticulation for these stops would be much more limited than in a language with, say, a three way contrast.

## 2. METHODS AND MATERIALS

Recordings were of evenly stressed VCV utterances, where C = one of the stops /b', b, d', d, g', g/ and V = one of the tense vowels /i, e, a, o, u/, spoken by a male speaker of Connemara Irish. Two separate recordings were made; one with simultaneous EPG and speech waveform, and a second high quality acoustic recording, on which our spectrographic measurements are based. In the latter, there were five repetitions of each consonant in each vocalic environment, i.e. a total of 750 items. The EPG recording was similar excepting the omission of labial consonants.

From our spectrograms we measured in each instance the frequency of F2 at the following four points: the V1 steady state, the V2 steady state, the endpoint of the transition from V1 to the consonant which we term locus 1 (L1), and the starting point of the transition from consonant to V2, which we term locus 2 (L2). Our procedures were intentionally modelled on those used in Öhman's classic study of coarticulation [3], and our results are compared below with some of his. In the EPG data we measured the contact pattern at the first frame for which there was evidence of full closure (C) and at the last frame for which there was full closure prior to the consonant's release (R). As for the velar stops, the occlusion was further back than the last row on the palate, points C and R were determined from the acoustic recording.

## 3. RESULTS

### 3.1 Articulatory measures

The results largely support our hypothesis. Fig. 1 illustrates the frequency of



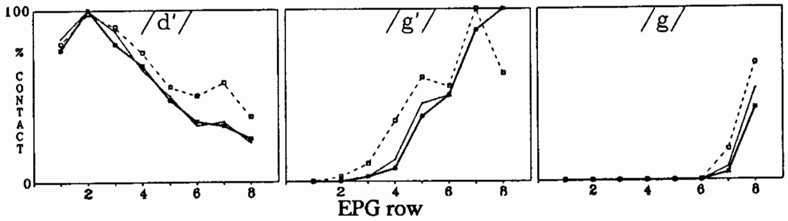


Fig. 1. % contact per EPG row for /d', g', g/ of Irish at time point C. Contexts: □- - -□ = /i-i/, ——— = /a-a/ and *——* = /u-u/.

EPG activation per row for /d', g', g/ at point C in the symmetrical vowel contexts /i-i/, /a-a/ and /u-u/, which serve to illustrate the maximum likely range of coarticulation. (Note that row 1 of the EPG palate corresponds to the dental region, and row 8 to the back of the hard palate.) Data for the dental /d/ in the first two of these environments is similarly shown in Fig. 2 along with roughly comparable data for dental stops in French and Italian, taken from [2]. The comparison gives only a general impression of differences, as the data for the latter two languages differed somewhat from the Irish. They involved voiceless consonants measured in /ˈbVtV/ words. Furthermore, the low vowel has a more front quality in these languages.

Some coarticulation does occur for the Irish stops. For /g'/ and for /g/ (insofar as one can determine from the limited contact pattern in the latter) the primary place of articulation appears to be more advanced in /i-i/ as compared to /u-u/ and /a-a/ environments. For /g'/ the front of the tongue forward of the constriction is also relatively higher in the /i-i/ context. A greater raising of the tongue front can also be observed for /d'/ in this environment. Of the four stops, /d/ exhibited least coarticulation. For all, the difference is negligible by time point R: the /i-i/ and /u-u/ environments yield almost identical contact patterns, whereas a slightly lower tongue body is in some cases observed in the /a-a/ environment.

Fig. 2 illustrates the striking lack of coarticulation in Irish /d/, as compared to the other languages. For Italian and French, the tongue front would appear to be much higher in the /i-i/ than in the /a-a/ environment (as can be deduced from the relative degree of EPG activation in rows 4 to 8). The tongue body behind the primary constriction is free to coarticulate to the vowel's configuration. This contrasts sharply with the Irish pattern, which shows virtually no contextual difference for these rows. In French, the primary place of articulation is also affected by the vocalic context: one would infer a lamino postalveolar articulation in /i-i/, as compared to a more apical dental-alveolar articulation in the /a-a/ context. In Irish, the differences that emerge in the three anterior rows of the

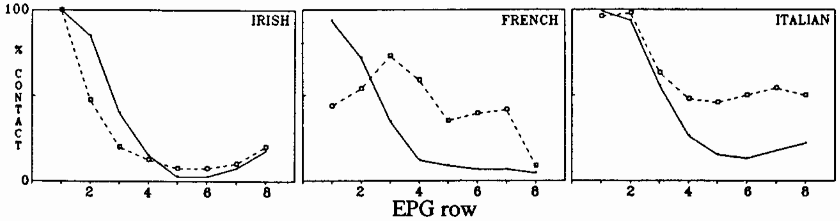


Fig. 2 % contact per EPG row for dental stops: /d/ in Irish; /t/ in French and Italian. Contexts: □- - -□ = /i-i/ and ——— = /a-a/ (Irish) and /a-a/ (French and Italian). Further differences in contexts are explained in text. French and Italian data from Farnetani et al. [2].

palate suggest a greater depression of the tongue blade in the /i-i/ context. This is the opposite of what might be expected if coarticulation were to occur, and suggests considerable coarticulatory resistance for this stop. Note that in terms of primary and secondary articulation, the dental phoneme of French occupies about the same phonetic space as the dental *and* postalveolar phonemes of Irish.

The asymmetrical vowel contexts permit inferences on the direction of coarticulation. Carryover coarticulation is clearly dominant. V1 effects are seen at time point C but only marginally at time point R. V2 appears to have little effect at either point. Even in the symmetrical vowel contexts, differences noted at time point C were largely absent at point R.

### 3.2 Acoustic measures

The acoustic measures also suggest considerable constraint on coarticulation. Fig. 3 shows overall averages for L1 and L2 as a function of V1 and V2 respectively. This shows the correlation between L1 and V1 (or between L2 and V2). As the vowels are arranged in the order of descending F2, coarticulation would be indicated by a negative slope for the line connecting L averages: the steeper the slope, the greater the degree of coarticulation to the "near" vowel. The range of variability in L1 (or L2) due to the transconsonantal vowel is also shown by the vertical lines which run through the average values. For example, a longer line for L1 reflects a greater degree of coarticulation to V2. The same would hold for L2 ranges as a reflection of carryover V1 influence. The right hand panel in this figure shows similar data for Swedish, calculated from Tables II and IV in [3]. The two sets of data differ in that for Swedish, only rounded vowels were used. Öhman estimated that if the near vowel is kept constant, an L1 or L2 range of over 100 Hz can with confidence be attributed to a coarticulatory influence of the transconsonantal vowel.

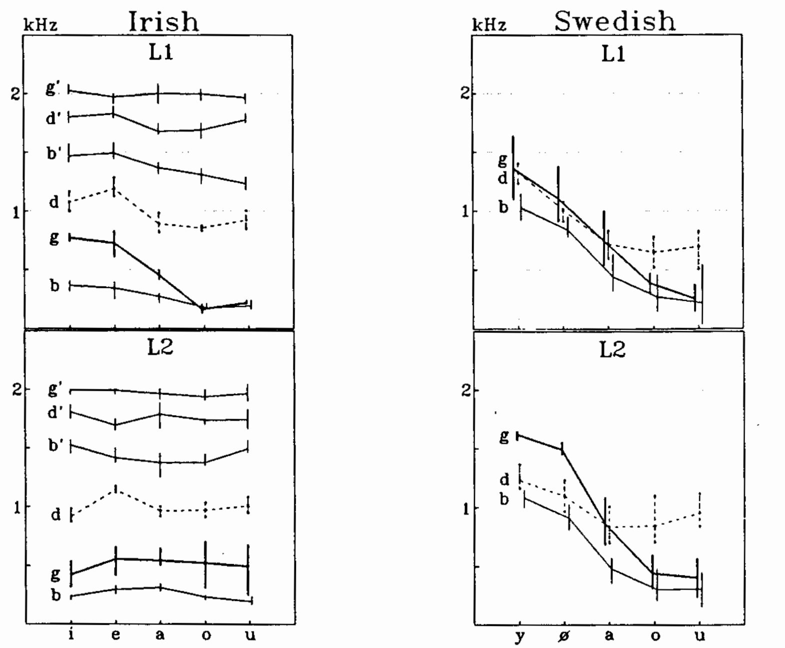


Fig. 3 L1 average values as a function of V1 (upper panels), and L2 averages as a function of V2 (lower panels). Vertical lines through average values show range of variation in any VC- (or -CV) sequence as a function of the transconsonantal vowel. Swedish data calculated from Öhman [3].



Locus variation is very limited in Irish, as comparison with Swedish shows. Considering first the effects of the near vowel, one can see major locus shifts in Swedish (i.e. L1 varies greatly with V1; L2 covaries with V2). In Irish, a much more limited coarticulation is found for L1 as a function of V1. Only with /g/ is the extent striking. There is virtually no evidence of L2 coarticulation to V2.

The effect of the transconsonantal vowel is also generally very limited in Irish, judging by the length of the vertical lines. The velar stop is again the exception. Note also the marked difference in directionality: L2 ranges (for /g/) are large, showing the carryover effect of V1; L2 ranges are typically very restricted (for all stops, including /g/), indicating a general absence of anticipatory coarticulation. The average range of locus variation (L1 and L2) as a function of the transconsonantal vowel is 122 Hz for all the consonants (97 Hz if one omits L2 of /g/). Öhman gives a comparable average of 280 Hz for the Swedish data. This is very close to that obtained in this study for L2 of /g/, which was 290 Hz.

Taking both the effects of the near and the transconsonantal vowel into account one can observe that F2 locus values are much more unique for the Irish stops than for the Swedish. As pointed out by Öhman, for a given VC- (or -CV) sequence, there is typically considerable overlap of locus values, particularly for Swedish /d/ and /g/. The only striking case of overlap in Irish is for /g/ and /b/ when V1 = /o/ or /u/.

### 4. CONCLUSIONS

Both the acoustic and articulatory measures point to stops in Irish being relatively resistant to coarticulation. This broadly supports the hypothesis that coarticulation is constrained by the phonology of a particular language, and that the propensity to coarticulation can to some extent, be predicted from the size of the phonological inventory. Some limited carryover effects are found: V1 affects C and L1, but generally has little effect on R and L2 (excepting L2 of /g/). There is virtually no evidence of anticipatory coarticulation.

Not everything, however, can be accounted for in terms of phonological constraints. The much greater acoustic evidence of coarticulation for /g/ than for the other consonants would not be predicted on phonological grounds. Nor would it be expected on the basis of the articulatory data. Looking back at Fig. 1, there would appear to be at least as much articulatory evidence of coarticulation for /g'/ as for /g/ (although the articulation of the latter can only be inferred on the basis of EPG data). Yet it is striking how different the acoustic measures are for these two stops, with /g/ showing by far the most variability, and /g'/ almost least.

An explanation of this apparent acoustic/articulatory "mismatch" would probably need to invoke the role of lip rounding as a contributory factor to the acoustic coarticulation in /g/. Fant's [1] nomograms suggest that for constrictions in the velar region, F2 would be very sensitive to lip rounding on the one hand and to tongue advancement/retraction on the other. If this line of explanation is correct, it suggests in turn that palatals may be characterised by a high degree of acoustic stability. We hope to investigate this area more fully in the future, using additional techniques for measuring lip movement.


### ACKNOWLEDGEMENTS

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