THE TIMING OF SECONDARY DORSAL ARTICULATIONS ACROSS SYLLABLE POSITIONS IN IRISH

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ABSTRACT

All consonants in Irish are contrastively velarized /C^ɣ/ or palatalized /C^j/. This study investigates the timing of /C^ɣ C^j/ gestures across syllable positions in Irish. In Russian, which has a similar contrast, the dorsal gesture for /C^j/ seems to peak at the CV transition in prevocalic onset consonants. In postvocalic codas, /C^j/ gestures peak near the VC transition, may be held until C release, and may have more variable timing. We report comparable gestural timing in Irish, and propose that these patterns are grounded in perception. Both CV/VC transitions and C release carry important cues to /C^ɣ C^j/ contrasts. In onsets, aligning /C^ɣ C^j/ gestures at CV transition maximizes the salience of those cues. In codas, /C^ɣ C^j/ gestures must be aligned to both VC transitions and C release to achieve the same effect. Cross-linguistically, /C^ɣ C^j/ contrasts are often limited in coda position, plausibly reflecting these articulatory asymmetries.

Keywords: palatalization, velarization, Irish, articulatory coordination, syllable structure

1. THE TYPOLOGY OF SECONDARY PALATALIZATION CONTRASTS ACROSS SYLLABLE POSITIONS

Typologically, secondary dorsal contrasts involving palatalization are more likely to occur in syllable onsets ($\approx$ prevocalically) than in syllable codas ($\approx$ non-prevocalic) [1–4]. In Bulgarian, for example, palatalization contrasts only occur before (non-front) vowels: word-finally and before a consonant, there are no contrasts between plain /C/ and palatalized /C^j/ [5,6]. While there are some marginal exceptions to this typological generalization [7,8], the presence of a /C$^{(ɣ)}$ C^j/ contrast in coda position normally entails a corresponding contrast in onset position (but not vice-versa).

It has been argued that this asymmetry reflects perceptual factors: secondary dorsal contrasts like /C(^{ɣ}) C^j/ may be easier to perceive in onsets when compared to codas [2,3,9–12]. It has also been noted that the articulatory coordination of secondary dorsal articulations may vary across syllable positions [2, 4, 13–15]. In onset /C^j/, the palatalization gesture tends to continue fronting during the course of consonant constriction, peaking at the release of the consonant at the CV transition. Though coda palatalization contrasts are less commonly studied, in Russian the secondary dorsal gesture for /C^j/ seems to peak earlier in coda position, around the VC transition, and is sometimes maintained throughout the consonant constriction [2, 4]. Coda /C^j/ may also show more variability in the timing of the secondary dorsal constriction than onset /C^j/. These articulatory asymmetries plausibly contribute to differences in the relative perceptibility of /C(^{ɣ}) C^j/ contrasts across different syllabic contexts.

In this paper we examine the articulatory timing of secondary dorsal constrictions for palatalized /C^j/ and velarized /C^ɣ/ stops in Irish, in word-initial onset /#CV/ and word-final coda /VC#/ contexts. Since Irish, like Russian, maintains a /C^ɣ C^j/ contrast in both onsets and codas alike, it provides another language in which we can test the hypothesis that the typological dispreference for coda /C(^{ɣ}) C^j/ contrasts is at least partially grounded in articulatory asymmetries between onset and coda positions.

2. BACKGROUND ON IRISH

Irish (or 'Gaelic') is spoken daily by $\sim$74,000 people in Ireland [16]. These speakers are concentrated in Irish-speaking communities on the western coast, though significant speaker populations are also present in urban areas. Much of the Irish population reports at least some ability in the language ($\sim$1.75 million people). While Irish has some limited state support in the Republic of Ireland, the language is at risk even in traditional Irish-speaking communities, due to the centuries-long hegemony of English.

2.1. Secondary dorsal articulations in Irish

All consonants in Irish have contrastively palatalized /C^j/ and velarized /C^ɣ/ variants [10, 11, 17]. The /C^ɣ C^j/ distinction can be used to indicate grammatical as well as lexical contrasts (1). Palatalization and velarization are contrastive in pre-vocalic (≈ onset) position as well as in word-final (≈ coda) position.

(1) a. *bó* /bˠoː/ 'cow'
beo /bʲoː/ 'alive'
b. *súil* /sˠuːlʲ/ 'eye'
siúl /sʲuːlˠ/ 'walk'
c. *casúr* /kˠasˠuːrˠ/ 'hammer'
casúir /kˠasˠuːrʲ/ 'hammers'

In Irish, palatalized /Cʲ/ is consistently associated with tongue body raising and fronting (= an [i]-like gesture), while velarized /Cˠ/ is consistently associated with tongue body backing, and some degree of raising (= an [u]- or [o]-like gesture) [13]. This is true across places and manners of articulation, as well as different vowel contexts (at least before [iː uː]). Coronal and velar consonants shift their primary place of articulation depending on their secondary articulations: /Tˠ/ tends to be dental or alveolar, and /Tʲ/ tends to be alveo-palatal or postalveolar; while /Kˠ/ tends to be velar or uvular, and /Kʲ/ palatal [18, 19].

Acoustically, palatalized consonants have raised second formants (F2) in neighboring vowels relative to their velarized counterparts [10, 18]. Velarized consonants are frequently produced with lip rounding, which likely enhances F2 differences associated with the /Cˠ Cʲ/ contrast [20]. Palatalized stops have louder and longer bursts, with higher spectral center of gravity in their release noise, especially when comparing coronal to labial stops. The spectral shape of fricative noise very audibly distinguishes the coronal and velar fricatives /sˠ sʲ xˠ xʲ/. [10, 11] report that speakers of Irish perceive /Cˠ Cʲ/ stop contrasts more reliably in onset position than in coda position.

2.2. Timing of /Cˠ Cʲ/ in Irish onsets

[13] examine tongue body position in /CVː/ sequences in Connacht Irish on the basis of ultrasound tracings of stops and fricatives, analyzed using principal component analysis. They find that palatalized /Cʲ/ tends to have more extreme tongue body fronting at C release (= CV transition) than at the beginning of C constriction, or at C midpoint. In contrast, velarized /Cˠ/ does not show any clear, consistent asymmetries across these timepoints: the magnitude of dorsal backing tends to be comparable between the beginning of C constriction, C midpoint, and C release. [13] only examine consonants in word-initial, prevocalic (onset) position, and so do not address the timing of secondary dorsal constrictions in word-final (coda) consonants.

3. METHODS

We recorded two native speakers of Ulster Irish (24, M; 40, M), three of Connacht Irish (42, F; 50, F; 43, F), and two of Munster Irish (34, M; 56, M). The materials were monosyllabic words with a target stop consonant controlled for secondary articulation (/Cʲ/ or /Cˠ/), place of articulation (labial, coronal, dorsal), position (word-initial or -final) and adjacent vowel /iː uː ɔː/. (We do not address the vocalic environment here for lack of space.) Speakers repeated the 36 experimental items five times each in the frame sentence [ˈdˠuːrʲtʲ ˈiːfˠə __ əˈnˠʊrˠə] 'Aoife said ___ last year'. Midsagittal images of the tongue body were obtained with a portable Terason T3000 ultrasound system and model 8MC3 probe (≈ 60 fps, or 1 frame every 17 ms). The probe was held in place with an Articulate Instruments ultrasound stabilization headset [21]. Using a time-synchronized audio recording, we extracted video frames closest to the onset and offset of closure of the target consonant. These ultrasound images were then traced using EdgeTrak [22], and trace coordinates were range-normalized by speaker. The analyses reported here are based on the position of the highest point of the tongue body in each frame. (If this was a plateau, the plateau's center was used).

4. HYPOTHESES

Considering prior research on Russian and Irish [2, 4, 10, 13, 14], we expect that the secondary dorsal articulation for /Cʲ/ in onset position will reach a maximum at the C release, which coincides with the CV transition. Stop releases are known to be important landmarks for articulatory alignment [23]; further, aligning secondary /Cʲ/ articulations to the consonant release should maximize the acoustic cues to the /Cˠ Cʲ/ contrast at the perceptually-important CV transition [4, 12, 24–26]. We expect particularly consistent release alignment for labial consonants: secondary lingual articulations like /Cˠ Cʲ/ are for the most part biomechanically independent from labial gestures, and so there is greater freedom for labial consonants to implement a perceptually-optimal /Cˠ Cʲ/ alignment pattern [2].

Our expectations for coda position, and for velarization, are less firm. In coda position, the VC transition does not align with stop release. Both the VC transition and stop release carry potentially important acoustic cues to /Cˠ Cʲ/ contrast. Hence, we may find more variable patterns of alignment in coda position, depending on whether speakers prioritize the acoustic expression of /C^{γ} C^{j}/ contrasts during the VC transition, or during stop release instead. (Non-stop consonants also have steady-state cues to /C^{γ} C^{j}/ contrasts, which may lead to different expectations about their internal gestural timing.) Speakers may also align the peak of /C^{γ} C^{j}/ gestures at the VC transition, and maintain that gesture until C release. As for velarization, past work has not found any consistent tendency for /C^{γ}/ gestures to align with consonant release in onset position, as observed for /C^{j}/. Regardless of syllabic position, velarization seems fairly static over the duration of the consonant. However, relevant data are limited.

It has been reported for English that more open constrictions (e.g. secondary velarization in /l/) tend to precede more narrow constrictions (e.g. tongue tip closure for /l/) for articulatorily complex consonants in coda position [14, 27, 28]. This tendency may reflect anti-phase coordination of gestures in the coda [29], and could lead to a greater bias toward VC alignment of /C^{γ} C^{j}/ gestures in coda position. However, [2, 4, 14] cast doubt on this notion for Russian, finding that peak constriction for secondary /C^{γ} C^{j}/ articulations often aligns with consonant closure in codas, and may be maintained through the entire consonant.

5. RESULTS

Fig. 1 plots the difference in tongue body backness (measured at the highest point of the tongue body) between consonant end (= release) and consonant start (= beginning of closure). A value of zero indicates that the peak of the dorsum has the same backness at C start and C end. Distributions significantly different from zero are marked with a boxed (REL) or (VC), indicating their apparent temporal alignment with C release or VC transition, respectively. Statistical significance was assessed with Bonferroni-corrected one-way t-tests, with the significance threshold $\alpha = 0.05/12 = 0.0042$.

For palatalized /C^{j}/, a *positively* shifted distribution reflects a more extreme *fronting* gesture at C release than at the beginning of closure. This is the expected distribution in syllable onsets, where the C release coincides with the CV transition: the gestural maximum for the palatalization gesture should occur at C release. As expected, the distributions for onset /C^{j}/ are all significantly positively shifted in onset position.

For velarized /C^{γ}/, a *negatively* shifted distribution reflects a more extreme *backing* gesture at C release than at the beginning of closure. This is a plausible expectation for onset position:

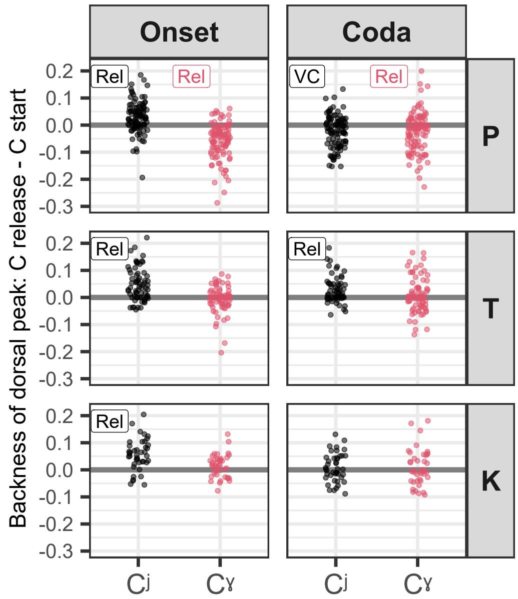

Figure 1: Backness of dorsal peak at C release (C end) − beginning of closure (C start). Units are in speaker-normalized [0,1] range. Distributions significantly different from zero (= no difference) are marked with 'Rel' for alignment with C release, or 'VC' for alignment with VC transition.

dorsal backing for /C^{γ}/ should peak at C release, as fronting for /C^{j}/ does. However, prior work has not clearly shown asymmetries across consonant landmarks for /C^{γ}/ [13]. In fact, we find a negative shift in onset position only for /P^{γ}/; onset /T^{γ} K^{γ}/ show no significant shift at all.

We now turn to coda position. Coda /P^{j}/ has a negative shift, suggesting that the greatest fronting of the palatalization gesture for /P^{j}/ tends to occur at the VC transition rather than at C release. In contrast, coda /T^{j}/ has a positive shift, suggesting that palatalization peaks at C release instead. Coda /K^{j}/ shows no significant shift in either direction.

Coda /P^{γ}/ has a negative shift, which indicates that the backing gesture for coda /P^{γ}/ tends also to peak at C release. Otherwise, there are no significant shifts for coda /T^{γ} K^{γ}/.

In summary, onset /C^{j}/ shows alignment to the C release = CV transition, across places of articulation. The same is true of onset /P^{γ}/, but not onset /T^{γ} K^{γ}/. In coda position, alignment patterns are less consistent. Coda /P^{j}/ shows VC alignment, while coda /T^{j}/ shows release alignment. Coda /P^{γ}/ shows release alignment, but coda /T^{γ} K^{γ}/ do not show any particular alignment pattern.

However, care must be taken in interpreting non-significant differences between C start and C end (apart from the general risks of interpreting null results). A null result in Fig. 1 could reflect at least three different scenarios. First, it could be that the gestural alignment of /C^{ɣ} C^{j}/ varies rather categorically between C start and C end. In this scenario, we might expect a wide, bimodal distribution with both positive and negative clusters, corresponding to a mix of VC vs. C release alignment in coda position. No such distribution is evident in Fig. 1.

Second, it could be that the peak dorsal gesture is inconsistently timed, landing anywhere between the closure and release of the primary constriction, depending on the utterance. In this scenario we would expect a loose and unimodal distribution of points around zero in Fig. 1.

Third, it is possible that some /C^{ɣ} C^{j}/ gestures are held mostly consistent across the consonant closure. In coda position this pattern would reflect VC alignment, but with the dorsal gesture maintained until release. Given that important perceptual cues to coda /C^{ɣ} C^{j}/ contrasts occur at *both* C start (= VC transition) and C end (= C release), we might in fact expect exactly this alignment pattern for coda consonants. In this scenario we would expect a tight spread of points around zero in Fig. 1.

To tentatively explore our null results, we computed Shapiro-Wilk tests to assess whether any of the distributions in Fig. 1 might be more spread out than a normal distribution (with Bonferroni-corrected $\alpha = 0.05/12 = 0.0042$). Onset /T^{ɣ}/ significantly departs from normality according to this test, along with onset /P^{j} P^{ɣ} T^{j}/ and coda /T^{j}/ (which are also shifted away from zero). We also computed Hartigan's dip test to investigate whether any of the distributions in Fig. 1 are multimodal: this test did not reject the hypothesis of unimodality for any of those distributions, even with uncorrected $\alpha = 0.05$. All of the distributions in Fig. 1 appear to be unimodal, and most distributions centered at zero appear to be normal in shape. We thus cautiously conclude that coda /C^{ɣ} C^{j}/ may show either VC alignment of the dorsal gesture, maintained until C release, or inconsistent alignment of the dorsal gesture across different landmarks (scenarios two and three above). However, we reiterate that we are drawing these conclusions mostly from null results, and so they should be interpreted cautiously.

6. DISCUSSION

Our main finding is a difference in gestural timing in syllable onset vs. coda position (corresponding to word-initial vs. -final position in our experiment) for palatalized consonants in Irish. While the peak of tongue body frontness in /C^{j}/ coincides more with the release of a consonant's primary constriction (= CV transition) in syllable onsets, timing in the coda is more ambiguous, not clearly favoring alignment with either C closure or C release.

As noted earlier, /C^{ɣ} C^{j}/ contrasts are more stable in syllable onset (or word-initial) position compared to syllable-final (or word-final) position, and the contrast is also harder to perceive in coda (word-final) position. It is possible that our different findings for syllable onset vs. coda gestural timing bear on these facts. In syllable onset position, all cues to stop palatalization vs. velarization coincide at the CV transition point; in such a case, it seems adaptive to time the peak dorsal gesture for palatalization with the CV transition. In coda position, on the other hand, formant transition cues and consonant release cues are necessarily *disjoint* in time, separated by the consonantal closure. If gestural timing can serve to optimize cues to contrast, then uniform alignment to consonant release will not accomplish this goal in the case of coda consonants. Articulatorily, anti-phase gestural coordination patterns in codas could also lead to greater variability in timing [29]. In future work we plan to further explore the nature of the more ambiguous alignment facts in coda position.

As a separate question, why is it that labial stops stand out in our results as showing more consistent alignment with a consonantal landmark? This may be due to articulatory constraints: in the case of /T^{j} T^{ɣ}/ or /K^{j} K^{ɣ}/, there is tongue coupling or direct articulatory competition between the primary articulator and a secondary dorsal one, while this is not true of /P^{j} P^{ɣ}/. This might allow other factors, such as constraints on perceptibility, to more freely determine timing in the latter case. In addition, perception of the secondary contrast may depend more on formant transition cues for /P^{j} P^{ɣ}/ than for /T^{j} T^{ɣ}/ or /K^{j} K^{ɣ}/, because the former contrast has less robust support from cues associated with a release burst [10]. It is interesting in this context to note that palatalization contrasts are typologically less stable in labials than in coronals or dorsals [1,2]. How far these ideas go in illuminating our results for labials is a matter for future research.

Finally, why has prior work (discussed above) found more ambiguous alignment of velarization gestures compared to palatalization ones, regardless of position, something that may be true also of our current results? This is also a question for future research, but we note that lip rounding is known to play a role in velarization, at least in Irish [20]. A fuller understanding of the timing facts may require attention to the lips as well as the tongue.

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