Articulatory variation of the alveolar tap and implications for sound change*

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1 Introduction

As a natural class, the label "rhotic" comprises an extremely heterogeneous set of sounds which often show little in common phonetically (Ladefoged and Maddieson, 1996). In the same way, individual rhotic phonemes in the world's languages have been shown to exhibit highly variable articulatory behavior. Several phonetic studies have revealed much subphonemic variation in the realization of individual rhotic phonemes, with different articulatory configurations corresponding to one categorical acoustic signature. An old aphorism says that the seeds of sound change can be found in the details of synchronic variation. If this insight is correct, then it follows that among variants of a phone or phoneme, possible seeds of of attested changes should be identifiable.

The aim of this paper is to make a tentative connection between rhotic articulatory variability and a particular sound change seen in unrelated language families. Observing lingual ultrasound data, I analyze features of the alveolar tap that vary within and across speakers. I then propose a provisional link between some articulatory patterns seen in the data and the development of progressive rhotic postalveolarization or retroflexion, a sound change that has come about independently in some dialects of Swedish and Norwegian, in some English dialects, in Sanskrit, in some East Iranian languages, and elsewhere. In an overwhelming number of situations, progressive rhotic retroflexion appears to have been triggered by an alveolar tap, a "non-retroflex" sound; such a development has been deemed "unnatural" in the literature, due to an overly abstract conception of the articulatory and acoustic properties of rhotics such as the alveolar tap. The variation uncovered in this study sheds light on a possible mechanism underlying the development of rhotic

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retroflexion.

1.1 Intrinsic allophony

Phonetic studies have shown in some cases that multiple articulatory variants correspond to one categorical acoustic signature. Differences between such variants, dubbed "intrinsic allophones"[1] in this paper, are generally imperceptible, or differ at very low acoustic levels.

Some studies have proposed a link between synchronic articulatory variation and sound change. One study of this type has proposed a basis for the development of unconditioned retroflexion of voiced stops. Hamann and Fuchs's (2008) electropalatographic (EPG) and electromagnetoarticulographic (EMA) study of German /d/ shows, in comparison with /t/, a more retracted and variable place of articulation; and a smaller percentage of tongue palatal contact patterns; and a lower tongue and jaw position, especially in low and back vowel contexts. The authors state (pp. 119-20) that "all these criteria are also used to distinguish retroflex from non-retroflex coronal articulations in languages like Norwegian, Hindi or Tiwi." For the authors, the subphonemic variation of German /d/ sheds light on a change [d] > [ɖ], seen in some unrelated languages.

This study, while related to the focus of this paper, is orthogonal to the issue of rhotic retroflexion, where retroflexion is triggered by a nearby *r*. A satisfactory account of the articulatory motivation of this sound change is currently absent the literature. A better understanding of how such a development came about may lie in the articulatory details of the alveolar tap, a rhotic that appears to have caused progressive rhotic retroflexion in the majority of cases.

1.1.1 Rhotic intrinsic allophony

Phonetic studies of individual rhotic phonemes have shed light on a great deal of articulatory and acoustic variability. A guiding belief of this paper is that comparable variation should be exhibited by the alveolar tap, some realizations of which might provide a possible articulatory or acoustic motivation for the development of rhotic retroflexion.

Most of the literature on rhotic articulatory variation concerns English /ɹ/, not the alveolar tap. Delattre and Freeman's (1968) seminal X-ray study of articulatory variation shows eight different tongue shapes used for American English /ɹ/. Differences between these intrinsic allophones are generally imperceptible.

[1] In the literature, we run into some terminological confusion. "Intrinsic allophones" were originally defined as "automatic" and "neurophysiologically-determined" as opposed to "programmed" and "language-specific" external allophones (Tatham, 1971). I use the term to refer to several articulatory configurations corresponding to one categorical acoustic signature—the same phenomenon as Mielke et al.'s (2006) "covert" allophony.

Other research revolves around differences between intrinsic allophones of American English /ɹ/, with interesting results. Mielke et al. (2006) found that with respect to variation in the articulation of /ɹ/, American English speakers fall into three categories, either (a) consistently using one tongue shape, (b) using multiple tongue shapes in free variation, or (c) using different tongue shapes in particular phonetic environments. Speakers who showed this last type of conditioned intrinsic allophony had their own individual codings with respect to the environments in which certain tongue shapes were used. Zhou et al. (2008) observed difference between dorsally-"bunched" *r* and retroflex *r*, and found that the two tongue shapes have the same categorical acoustic signature (for F1-3), they differ in terms of the spacing of F4 and F5—"bunched" *r*, with its longer front cavity, has a higher F4 and less spacing between F4 and F5. The authors suggest that these higher-formant differences may provide cues to speaker identity, providing a possible pragmatic or sociolinguistic ramification for this case of intrinsic allophony.

This paper aims to make a connection between articulatory variation underlying [ɾ] and the development of rhotic retroflexion, a phenomenon discussed in detail in §1.2.

1.2 Rhotic retroflexion

Rhotic retroflexion is a phonological development attested in unrelated languages. Its relationship with the alveolar tap presents somewhat of a puzzle in the phonetics and phonology literature, to be discussed in §1.3. Crosslinguistically, a rhotic segment can trigger retroflexion or postalveolarization of a coronal. Usually, the two segments are in contact, but this process can take place at a distance as well. Taxonomically, rhotic retroflexion can be divided into two types: ANTICIPATORY RHOTIC RETROFLEXION, where the rhotic trigger follows the segment undergoing retroflexion; and PROGRESSIVE RHOTIC RETROFLEXION, where the rhotic trigger precedes the segment undergoing retroflexion.

1.2.1 Anticipatory rhotic retroflexion

Some examples of anticipatory rhotic retroflexion follow:

(1) Pashto (Skjærvø, 1989b)

wāṣ̌ 'rope' < Proto-Iranian *bastra-

ṣ̌na 'hip bone' < Proto-Iranian *srauni-

ṣ̌ow-əl 'to show' < Proto-Iranian *srāu̯ai̯ati 'hear' caus. pres. 3sg

(2) Sicilian (Celata, 2006)

Sicilian [ʈˢɛni] 'train' (pl.) : Italian treni

Sicilian [aʈːˢovare] 'to find' : Italian atrovare

(3) Lushai (Matisoff, 2003)

traŋ ∼ ʈaŋ 'deny'

trap ∼ ʈap 'hungry'

Sicilian appears to preserve a trace of the rhotic as a retroflex sibilant release. Lushai dialects differ according to whether they show /tr/ or /ʈ/, both of which reflect the Proto-Tibeto-Burman initial cluster *kr- (Matisoff, 2003, p. 75).

1.2.2 Progressive rhotic retroflexion

Progressive rhotic retroflexion is as richly attested, if not more so. The Norwegian and Sanskrit examples below can be analyzed according to synchronic rules.

Many dialects of Norwegian (East Standard Norwegian, to name one) have a robust synchronic process of retroflexion or postalveolarization of coronals following *r*:

(4) Norwegian $[+cor] \rightarrow \begin{bmatrix} -ant \\ +cor \\ -dist \end{bmatrix}$ / ɾ __ (Kristoffersen, 2000, pp. 96-7)

/vor/	[ʋoɾ]	'spring'	/vor-li/	[ʋoːɭi]	'spring-like'
/vor-tejn/	[ʋoːʈœjn]	'spring sign'	/vor-dag/	[ʋoːɖɑg]	'spring day'
/brur/	[bɾuɾ]	'brother'	/brur-s/	[bɾuːʂ]	'brothers'
/spør/	[spœɾ]	'ask'	/spør-n/	[spœɳ]	'ask him'

A virtually identical process can also be seen in some Swedish dialects (Svantesson, 2000).

Sanskrit has several diachronic sources of retroflexion, and some interesting synchronically analyzable processes governing the distribution of retroflexes. For instance, *r* progressively triggers the process *n* → *ṇ* both locally and at a distance. This rule is blocked only if a segment of the dental, palatal or retroflex classes intervenes (forms and glosses taken from Monier-Williams (1956)):

(5)

pra+nāma-	→	praṇāma-	‘bowing (forth)’
prati+nāma-	→	pratināma-	‘by name’
pra+gāna-	→	pragāṇa-	‘singing’
pra+dhāna-	→	pradhāna-	‘prize’
a+tr̥p+nu+vant-	→	atr̥pṇuvant-	‘insatiable’
pra+āp+noti	→	prāpṇoti	‘obtain’ 3sg pres.
pr̥+nāti	→	pr̥ṇāti	‘protect’ 3sg pres.

As seen above, labial and velar segments do not block the retroflex rule. Incidentally, neither class of sounds involves coronal articulation.

Pashto, in addition to anticipatory rhotic retroflexion, shows progressive rhotic retroflexion as well. This can be seen in developments like *wəṛ* ‘carried’ < Proto-Iranian *br̥ta- (Skjærvø, 1989b, p. 404).

Brilioth (1913) describes a dialect of English spoken in the village of Lorton in present-day Cumbria, England. The study does not use the International Phonetic Alphabet, but all segments are described in full (and somewhat difficult to interpret) detail. The dialect has rhotic retroflexion, and Brilioth reports two rhotics which he calls $\mathbf{r}_1$ and $\mathbf{r}_2$. He describes $\mathbf{r}_1$ as “strongly trilled like the standard Swedish *r* and the *r* in the dialect of Picardy, and ‘the true trill as heard in Italy, Scotland, and Wales’” (p. 74); from the comparisons, it is not clear that this rhotic is a trill rather than a tap. This rhotic occurs “initially before a vowel” and “in the position *cons.* + **r** + *vowel*,” though “**r** in the position *dental* (**d, t**) + **r** + *vowel* is not quite so strongly trilled”; it is also found “in the combination *short vowel* + **r** + *final vowel*” and ”*vowel* + **r** + *voiced cons.* (except **d**).” Brilioth describes $\mathbf{r}_2$, using a definition taken from Ellis (1869, p. 85, *non vidi*), as “reverted *r*, the under surface of the tip of the tongue turned to the hard palate and the flap indistinct and less sharp than for *r*,” which we can interpret as [ɹ]. This variant appears intervocalically, in “the combination *long* (or *half-long*) *vowel* + **r** + *voiceless cons.*,” “after unaccented vowel in the ending **ər**,” though “**r** final after a preceding long vowel or diphthong is not quite as strong.” Rhotic + coronal clusters are described as having two different pronunciations:

> “(*a*) The original pronunciation with *short vowel* + $\mathbf{r}_1$ (strongly trilled) + dental, now mostly heard from old people: **bu̜r**$_1$**d** bird, **mu̜r**$_1$**dər** murder, **þu̜r**$_1$**d** third, **fu̜r**$_1$**niš** to furnish.
>
> (*b*) The **r** combines itself with the dental, thus forming a supradental **ɖ**, **ʈ** (occasionally **ɳ**, and the preceding vowel is lengthened: **bū̜ɖ** bird, **mū̜ɖər** murder, **þū̜ɖ** third, **fū̜ɳiš** to furnish, **dū̜ʈ** dirt, **šwōʈ** short.

This pronunciation (*b*) of **r** + *dental* seems to me more common than (*a*)" (pp. 75-6).

The variation between pronunciations (a) and (b) according to generation may show the directionality of the change, that is to say, that "supradentals" are triggered not by the retroflex approximant, but by the "trill"—again, I question whether this was truly a trill and not a tap, given the nature of Swedish and Italian /r/. At the same time, it may be unwise to envision pronunciation (a) as the direct diachronic precursor of pronunciation (b), since it is possibly unrealistic to envision over the course of a maximum of fifty years the development of the three sound changes resulting in the telescoped rule V + *r* + *dental* → Vː + *supradental*. Pronunciation (a) could potentially represent a hypercorrective tendency, just as in some Swedish dialects, /r/ is optionally reinserted before supradentals, e.g., [çæːɭ] ∼ [çærl] 'vessel', [jɑːɭ] ∼ [jɑɾl] 'earl' (Eliasson, 1986, p. 279). Nevertheless, this picture makes it highly likely that the apical rhotic $\mathbf{r}_1$—a trill, if truly like that of Picard or Welsh; a tap, if similar to the rhotic of Italian and Swedish (the Scots phonetic realization of /r/ varies dialectally (Aitken, 1984))—triggered this process.

Shuken 1984 reports progressive rhotic retroflexion in Hebridean English, seen in forms like [pʰɛ̈ɭ] 'pearl', [pʰaʴʂəl] 'partial', 'parcel'. Hebridean dialects that show this type of retroflexion contain /r/ with the following distribution: "a retroflex approximant or fricative word-initially; a tap intervocalically; a fricative, or affricated tap (a tap followed by a fricative) word-finally ... an approximant occurs before alveolar consonant phonemes (which are usually retroflex after /r/)" (p. 160). Here, it seems that retroflex [ɹ] conditions retroflexion in following coronals.

1.3 The alveolar tap and rhotic retroflexion

A conspicuous fact about the nature of the present-day rhotic in many languages with rhotic retroflexion is that it is often *not* a retroflex /ɹ/, but an alveolar /ɾ/. Hebridean English, with its retroflex approximant, appears to be more the exception than the norm. To further investigate the mechanisms behind the development of progressive rhotic retroflexion, we need to address the following question: why is it generally triggered by [ɾ]?

Providing more support for the compatibility of [ɾ] with the development of retroflexion, in certain dialects of Norwegian and Swedish, the absence of /ɾ/ correlates with a lack of retroflexion. Svantesson (2000) gives a brief description of his own Swedish idiolect, a regional variant of southern Standard Swedish. His dialect's rhotic is uvular /ʁ/, while the default rhotic of central Standard Swedish is the tap /ɾ/. On the basis of rhotics, he divides Swedish dialects into three groups: "In most of the dialect area with apical *r*, combinations of *r* and a following dental [t d s n l] are realized as retroflexes [ʈ ɖ ʂ ɳ ɭ], but in areas with uvular *r*, the dentals are unchanged. In my idiolect, the dentals are slightly backed after etymological r, but not nearly as much as in Standard Swedish. They can be regarded as alveolars [t̠ d̠ s̠ n̠ l̠], as opposed to the dentals [t d s n l]" (p. 158).

Johnsen (2011) gives examples of certain Norwegian dialects that have as their rhotic /ʁ/ instead of /ɾ/, much like Svantesson's Swedish dialect. Some of these uvular dialects still show the retroflex rule (seen above), but for reasons that have nothing to do with phonetic naturalness. A sociolect of Oslo has both /ʁ/ and the retroflex rule because diachronically, the retroflex rule (triggered by /ɾ/) came into effect before /ɾ/ changed to /ʁ/; the retroflex rule shows a residual effect of the earlier alveolar rhotic. The dialect of Arendal, which shows the same synchronic behavior, was shown to have borrowed the retroflex rule from neighboring dialects that have /ɾ/.

The Scandinavian situation is a historically and sociolinguistically intriguing one. The dates are unclear, but Scandinavian retroflexion is believed to be fairly old; while the process of retroflexion may have begun circa the 14th century, it probably did not reach certain areas until after 1800 (Bandle, 2000, p. 1124). Uvular /ʁ/ has its own history in Europe. According to Chambers and Trudgill (1998, p. 170): "Beginning in Paris probably in the 1600s, uvular /r/ had reached Copenhagen by 1780, and by 1890 had spread to southern Sweden, where it has remained stationary since the 1930s." So there is a possibility that the spread of uvular /ʁ/ was enough to "undo" retroflexion in Svantesson's idiolect.

Cases in which [ɾ] appears to trigger retroflexion have greatly vexed phonologists. Retroflexion, with its low F3, should spread from other segments with low F3, according to the categorical view that continues to be prevalent in phonology, even though the subfield has recently tried to incorporate insights from acoustic phonetics and speech perception (e.g. Steriade, 2001). Many phonologists (Flemming, 1997; Steriade, 2001; Hall, 1997, p. 215 fn.; Hamann, 2003, p. 108 fn.) take our picture of Sanskrit rhotic retroflexion to be "natural" because they understand Sanskrit *r* to be "retroflex." But in reality, this is just a categorical phonological label employed by the Hindu grammarians, who classed the Sanskrit approximants as palatal *y*, cerebral *r*, dental *l* and labial *v*. It is possible that *r* was not necessarily retroflex (i.e., not the retroflex flap [ɽ]), but a trigger of retroflexion. Cf. Allen (1953, pp. 53-4): "Functioning phonologically as a member of the retroflex series we have also the semivowel **r**; on the phonetic value of this letter, however, widely diverse accounts are given, ultimately depending perhaps on dialectal variation...The retroflex pronunciation of both semivowel and vowel is in fact prescribed by the *PŚ* [= *Pāṇinīya-Śīkṣa*, a pronunciation manual apocryphally attributed to the Hindu grammarian Pāṇini], but is exceptional elsewhere. The Prātiśākhyas [primary phonetic treatises on the Vedas] generally require an alveolar articulation (which agrees with the present pronunciation of Sanskrit and the general practice of the modern Indo-Aryan languages)."[2]

In other contexts, when dealing with processes where rhotic retroflexion takes place in a language known to have /ɾ/, phonologists feel compelled to envision developments of the following sort, for anticipatory and progressive retroflexion, respectively:

(6) [tr] > [tɾ] ∼ [tɽ] > [tɹ] ∼ [tɻ] > [tˢ] (Celata, 2006, p. 59)

(7) [ɾt] > [ɽt] > [ɽʈ] > [ʈ] (Hamann, 2003, p. 87)[3]

Celata's proposal is tailored specifically to Sicilan, while Hamann's is intended to represent a typological universal.

Variation of the type [tɾ] ∼ [tɽ] is virtually unattested, but this is not grounds for ruling out Celata's proposed development as a cause of anticipatory rhotic retroflexion. But Hamann's proposal, the first step of which has a typological parallel (that does not appear to be particularly common), is virtually impossible due to articulatory considerations.

Typologically, the retroflex flap [ɽ] tends to develop from [ɖ], as is the widespread case in Indic (Masica, 1991); compare also Dhaasanac allophony: /ɗáɗiš/ → [ɗáɖiʃ] ∼ [ɗáɽiʃ] (Tosco, 2001, p. 22). Development of [ɽ] from [ɾ] is less common, unless it is conditioned by a back vowel (as in Nyawaygi (Hamann, 2005)) or another environmental factor, such as a following dental segment (to be discussed below). Nevertheless, the change [ɾ] > [ɽ] does happen; variation between an alveolar tap and a retroflex flap is seen in some varieties of Caribbean Spanish (Hammond, 1980). I do not see a reason to rule out the role of a hypothetical change [ɾ] > [ɽ] in the development of rhotic retroflexion—but only for Celata's hypothesis.

Elfenbein (1998, 2009) reports a development in Eastern Hill Balochi and neighboring dialects of Brahui where the tap *r* becomes retroflex before dental consonants, e.g., Balochi *mard* ∼ *maṛd* 'man', Brahui *lurd* ∼ *luṛd* 'turbid'. This appears to be a sort of dissimilation, or an enhancement of the retroflex-dental contrast. This sort of allophony should not lead to the retroflexion of the dental following the rhotic, due to articulatory considerations, which poses a large problem for Hamann's analysis.

"Flapping out" is a known trait of retroflex segments; the term refers to the fact that during the articulation of a retroflex stop or flap, the tongue tip moves forward from the position in which it started

[2] Atharva Veda Prātiśākhya 1.28 reads *rephasya dantamūlāni*, translated by Whitney (1962, p. 28) as "Of *r*, the roots of the teeth are the producing organs." Whitney further explains, "By 'roots of the teeth' must be understood, doubtless, the bases of the upper front teeth, at which, according to the [R̥k Prātiśākhya] (i. 9-10) and the [Taittirīya Prātiśākhya] (ii. 38, 42), the whole class called in our treatise simply "dentals"...is produced...The cited verse favors the substitution...'of *r*, the place is taught to be the roots of the teeth, or a place close to them."

[3] In some conventions, ɽ can be used to refer to a retroflex approximant, but Hamann consistently uses it to denote a retroflex flap, in accordance with the IPA.

(Simonsen et al., 2008). This movement is reflected acoustically in the fact that F3 decreases saliently going into a retroflex stop or flap, but is relatively flat afterward (Dave, 1977). So a retroflex flap should be virtually incapable of triggering retroflexion in a coronal that directly follows it, given the forward trajectory of the tongue; thus, the development [ɽt] > [ɽʈ] is untenable. Celata's proposal (that alveolar rhotics become retroflex rhotics in order to trigger retroflexion in a preceding coronal) provides a plausible explanation for most instances of anticipatory rhotic retroflexion, though it is worrisome that the development does not seem to have direct typological parallels. But an intermediate change [ɾ] > [ɽ] would not bring about retroflexion in a following coronal, so it is necessary to provide another explanation for progressive rhotic retroflexion. Not much literature is dedicated to the articulatory behavior of the alveolar tap; further research may uncover behavior of [ɾ] that is directly compatible with the retraction of a following coronal.

1.4 Previous studies of the alveolar tap

The alveolar tap is a fairly understudied rhotic, and many aspects of its variation within and between speakers as well as across languages are not fully known. While some traits shown could potentially explain why [ɾ] triggers retroflexion, no such links have been proposed in the literature. Two traits that could potentially trigger retroflexion in a following segment are retraction or backwards movement of the tongue, as well as flexion of the tongue—features that are identified for [ɾ] in some studies, but not linked to any sort of sound change by the authors.

An acoustic and cineradiographic study by Monnot and Freeman (1972) shows that acoustically, English and Spanish alveolar taps are indistinguishable from each other. Articulatorily, they describe English [ɾ] as being anticipated earlier than in Spanish; in contrast, they claim that the Spanish speaker shows an earlier anticipation of the vowel following /ɾ/. They say also that "in English, the tongue tip seems to include a wider part of the dorsum" and makes more contact with the alveolar ridge, whereas in Spanish, only the tip is involved (p. 412-3). They find similar durations across languages (roughly 1/24 of a second), and conclude that there is "no critical difference" between English and Spanish taps (p. 414).

An electropalatographic (EPG) study by Recasens (1991) found that Catalan alveolar taps are highly sensitive to vowel-to-consonant coarticulation, while the articulatory constraints of the alveolar trill permit less vowel-to-consonant coarticulation. Recasens and Pallarès (1999, p. 156) found in another EPG study that Catalan taps are produced with more alveolar contact fronting when adjacent to /i/ *vs.* /a/. They find that the trill involves more pre-dorsal lowering and more of a concave shape than the tap, according to differing degrees of contact at the front of the palate—but concave shape is identified as a feature that both manners of articulation display.

In another EPG study, Saw (1993) investigated differences between English flaps and taps (with the assumption that *party* is phonetically [pɑɽi]) as realized by one speaker, and found the following: flaps consistently showed contact in the post-alveolar region, while taps consistently had contact with the alveolar ridge. Oral flaps and taps had roughly the same duration of contact, while nasal taps (like that in *Pontiac*) were on average around 5 milliseconds longer. Flaps were found to show back-to-front movement on the palate, on average around 5 mm; oral taps showed average back-to-front movement of .88 mm on the palate, while nasal taps showed front-to-back movement of .6 mm. Note that EPG can only measure movement of the tongue when it is in contact with the palate, and these figures do not represent the overall trajectory of the tongue.

In his "R-tickle," (Barry, 1997, pp. 38-40) discusses the confusion between taps and flaps in the literature. Both manners of articulation at separate points in time have been called "ballistic" in nature, seeing as taps and flaps can involve short contractions of the superior and inferior longitudinal muscles, respectively.

In the fifth edition of *A Course on Phonetics*, Ladefoged (2006) says the following about the tongue's trajectory: "In a tap [ɾ], the tip of the tongue simply moves up to contact the roof of the mouth in the dental or alveolar region, and then moves back to the floor of the mouth along the same path...Flaps are distinguished from taps by the direction of the movement—from back to front for flaps, up and down for taps—rather than by the exact point of contact" (p. 168). So, for at least some speakers, the tongue travels up to the alveolar ridge, then down along the same path. However, is this true for all speakers? Ladefoged's generalization here may not be entirely in line with some data presented in *The sounds of the world's languages*, where Ladefoged and Maddieson (1996, p. 238) "deduce" the following tongue positions from palatograms of [ɾ] and [ɽ] produced by a Hausa speaker:

Figure 1: Hausa [ɾ]

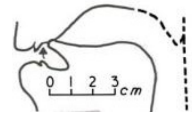
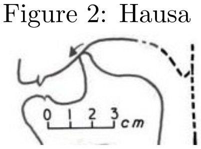


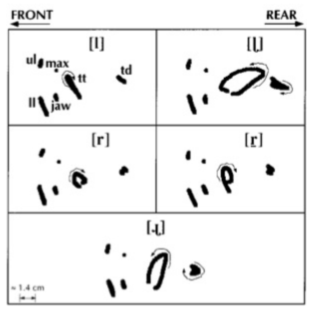
Figure 2: Hausa [ɽ]



The direction of the arrow for [ɾ] is unclear. Does it point upward, or inward as well? If it points inward, then it would seem that some alveolar taps show the same dynamic complexity as flaps, and horizontal as well as vertical movement.

Narayanan et al. (1999, p. 1998) report magnometric (EMMA) data showing that a Tamil speaker's retroflex liquids exhibit counterclockwise or back-to-front movement, and that alveolar [r] and postalveolar [r̲] show clockwise front-to-back movement (all in an a_a vocalic context), as shown below in Figure 3:

Figure 3: Trajectories of the tongue tip for 5 Tamil liquids (Narayanan *et al.*, 1999, p. 1999)



The manners of articulation of [r] and [r̲] are unspecified in this article, but stimuli given by the authors containing [r] (namely *param* 'almighty' and *kari* 'coal') correspond to transcriptions elsewhere in the literature that show a sound described as an alveolar tap, e.g., [pʌɾʌm] 'supreme being' (McDonough and Johnson, 1997) and [kaɾi] 'charcoal' (Keane, 2004). McDonough and Johnson's study is on the Brahmin dialect, Keane's is on the Standard (non-Brahmin) dialect, and Narayanan *et al.* do not specify their dialect; but it is likely that [r̲] as analyized by Narayanan *et al.* is a tap.

As mentioned above, "flapping out," is a well-attested trait of most retroflex segments. It is found as a unifying trait of Norwegian postalveolars (Simonsen et al., 2008), and reported for the flaps analyzed in Saw's study. But what about the "tapping in" that here seems to be ascribed to [ɾ] in some cases? This observation is not consistent with the generalization previously made by Ladefoged in *A Course on Phonetics* (albeit not necessarily about Hausa) or in Saw's findings (though nasal stops showed front-to-back movement of less than 1 mm along the palate). The Tamil data from Narayanan *et al.* shows salient "clockwise" movement of the tongue tip, in upward and backward directions. Retraction of the tongue tip, as seen for Tamil, could hypothetically cause a following coronal to be realized in a more posterior place of articulation, making such taps likely conditioners of postalveolarization or retroflexion.

In the following phonetic study, I analyzed ultrasound images of alveolar taps and other segments to see if speakers show retraction of the tongue, as well as flexion of the tongue, which could potentially trigger the retroflexion of a following coronal.

2 Phonetic Study

2.1 Objective

This study is part of a larger project that aims to analyze articulatory variation of the alveolar tap within speakers, between speakers, and across languages. The data analyzed in this paper is Spanish language data collected from a Spanish-English bilingual subject. For the purposes of this study, it was necessary to use articulatory imaging technology that can capture relevant and necessary details of tongue's shape and movement during the articulation of this sound.

A large number of articulatory studies have employed EPG, and have generally been successful in capturing intrinsic allophony, at least in terms of place of articulation. However, EPG is not particularly well suited to the study of certain liquids, for instance American English [ɹ], since the observation of tongue shapes is crucial, more so than points of contact along the palate; EPG can only tell us about the tongue when it is in contact with the palate, and cannot even tell us much about what part of the tongue is in contact with it (herein lies one advantage that static palatography has over EPG, since different portions of the tongue's surface can be painted with charcoal-oil solution (Ladefoged, 2003)). For the purposes of this paper's investigation, articulatory imaging of the tongue prior to and following contact with the alveolar ridge is necessary as well.

Lingual ultrasound is an ideal means of collecting articulatory information about tongue shape and movement, as it provides a sagittal view of the vocal tract. 3D imaging of the tongue is even possible (Bressmann, 2008) but it is not clear that a coronal view is crucial to a study of the tap's movement. Ultrasound is valuable to the study of phenomena where the tongue makes contact with articulators, but even more so in observing phenomena where the tongue does not come into contact with articulators at all. Studies of vowel harmony and ATR harmony have used ultrasound to collect data (Gafos and Benus, 2006; Whalen and Gick, 2001). Miller (2010) used it in her study of tongue root and tongue body shape of N|uu clicks.

Clinical diagnostic B-mode ultrasound is also ideal in that it presents minimal risk to the subjects under study; thermal effects and acoustic radiation forces are minimal. Epstein (2005, p. 571) concludes, "B-scan ultrasound as used for imaging structures in the oral cavity is a minimal risk procedure and there is no record of adverse events associated with this application of ultrasound."

2.2 Hypothesis

The hypothesis of this study was twofold: since the articulatory configuration of the tongue during the course of the realization of [ɾ] might at some point resemble a tongue configuration characteristic of a "retroflex" sound at the beginning of its utterance, I expected to see some instances of tongue flexion (the "concave" shape identified by Recasens and Pallarès (1999); the two terms will be used interchangeably throughout this paper), where the tongue surface showed a visible maximum and minimum—i.e., a discernible change from a negative to a positive slope—similar to cubic functions with two points of inflection. See Figure 4 for examples of a tongue shape exhibiting flexion (dark) and a flat tongue shape (light), as seen during realizations of [ɾ]. Additionally, figures 5 and 6 show sequences (at 30 frames per second) of ultrasound images of the tongue uttering [eɾe] and [oɾo]. I predicted also that such tongue shapes might show acoustic correlates of retroflexion, viz., a lower F3. Given that the languages under observation are not known to show retroflexion conditioned by an alveolar tap, I expected such tongue shapes to be marginal and few in number.

To further investigate this acoustic pattern, I observed the relationship between tongue flexion and formant value for a subset of taps uttered by another speaker of Spanish and a speaker of English. The purpose of this measure was to test whether tongue shapes showing flexion correlated with lower F3 and F4, both of which have been identified as traits of retroflexion in the literature.

Additionally, I predicted that back and front vowels would cause backward and forward movement of the tongue, respectively, and that the tongue blade and tip would show backwards movement during a large proportion of low vowels (/ə a/ for English, /a/ for Spanish); additionally retraction of the root is an intrinsic property of a vowel like /a/, which involves a constriction at the pharynx.

2.3 Methods

This paper observes preliminary data (178 utterances) from one Spanish language condition subject (Speaker A) selected out of a larger group of eleven, analyzed in §§2.4.1-2.4.2. Additionally, to serve as a basis of comparison, a subset of 30 utterances from another Spanish language condition subject (Speaker B), and a subset of 100 utterances from an English language condition subject (Speaker C) were analyzed as well. Speakers A, B, and C are discussed in §2.4.3, while Speakers A and C are discussed in §2.4.4.

All subjects were recorded over a period of two days in the Phonetics Lab at the University of California, Santa Cruz. Seven subjects were female, and four were male. Three of the subjects (two males and one female) were bilingual native speakers of both English and Spanish, and were tested according to the Spanish

Figure 4: Tongue shape showing flexion (dark); flat tongue shape (light)

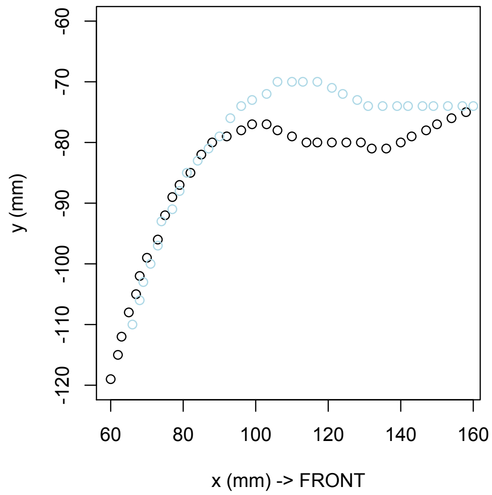


Figure 5: The sequence [eɾe] (no flexion)

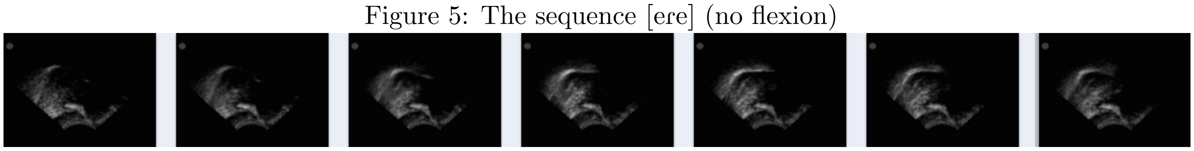
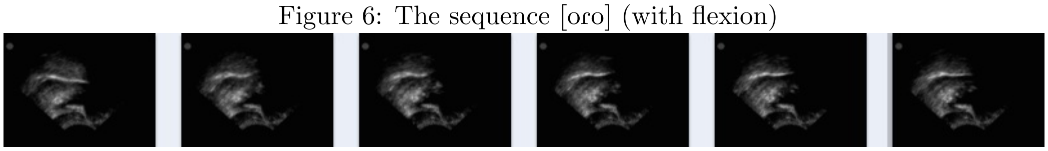


Figure 6: The sequence [oɾo] (with flexion)



condition. The ultrasound machine used to observe them was a Terrason t3000™.

Each subject underwent an hour-long procedure. They were fitted with a helmet that allowed an ultrasound probe to be secured underneath the chin. They were presented with 178 auditory prompts via E-Prime (version 2.0, Psychology Software Tools) and instructed to repeat the tokens back in a carrier sentence. For the English condition, the carrier sentence was "Stop [TOKEN], man." For the Spanish condition, it was "Díme [TOKEN], pues" ("Tell me [TOKEN], then"). The carrier sentence was presented visually on the computer screen. The phonotactics of English made it possible to use a carrier sentence where a labial consonant could be at the left and right edges of each token (under the assumption that other places of articulation might cause coarticulatory effects); this was not possible for the Spanish carrier sentence, since in Spanish, labial consonants are virtually nonexistent in coda position. Additionally, there was a trading relation between the linguistic naturalness of the carrier sentence and the presence of vowels that might cause coarticulation in the carrier words. The former was privileged over the latter, given the fear that unnatural elements in the carrier sentence might interfere with speech rate.

Tokens elicited consisted of real words (with some exceptions discussed below) in English or Spanish (according to condition), most of which were two syllables, none of which were longer than three syllables. Following each real word token, the subjects were presented with an auditory prompt consisting of a VCV echo of the preceding real word, e.g., they would hear a sequence of *ruddy* followed by [ˈə.ɾi]. The echo was employed to control for any coarticulatory effects that the first consonant of the real word token might create.

The intervocalic consonants ɾ, p, and n were elicited in VCV tokens employing every possible combination of the vowels /a (ə) e i o u/ that is phonotactically permissible in the condition language, so V1 and V2 at least represented every possible permutation of the dimensions LOW[-MID] /a (ə)/, FRONT /e i/, and BACK /o u/ (this yields at least nine potential token types: LOW-LOW, LOW-FRONT, LOW-BACK, BACK-BACK, BACK-LOW, BACK-FRONT, FRONT-FRONT, FRONT-LOW, FRONT-BACK). Initial stress was controlled for. Certain VCV combinations had to be omitted according to language condition. For instance, Spanish lacks unstressed word-final /u/, as well as /ə/. Certain real words were altered to fulfill the need for a particular VCV combination, but remained phonotactically legal in English; in one such example, the proper name *Napa*, pronounced correctly as [ˈnæ.pə], was presented as [ˈneɪ.pə]. To obtain data about English [ɾ] before /ə/, two words were presented as running speech, e.g., *but a* [ˈbə.ɾə]. A palatal trace was obtained for each subject (by instructing them to hold a mouthful of water) at the beginning of their recording session. Ultrasound video and audio were recorded simultaneously using Ultraspeech 1.1 (Hueber et al., 2008).

2.4 Results

2.4.1 Articulatory results

This section presents the acoustic results for Speaker A. One token (*sone*) was excluded due to a speech error; another token (*line*) was excluded because too much of the ultrasound image was obscured by mandible shadow.

For each token, the movement of different parts of the tongue was coded before and after the articulation of the consonant. These measures were categorical in nature, and intended to accurately describe the quality of the overall movement of each lingual component. The following labels were used during the first pass: F for forward movement, B for backward movement, U for upward movement, D for downward movement, N for no movement, FB for forward movement followed by backward movement, and BF for backward movement followed by forward movement. Tongue articulators were coded according to the dimensions across which they showed the greatest magnitude of movement. For instance, in some cases, the root and/or blade of the tongue showed movement both along the x-axis and y-axis, but movement along the y-axis was of a greater magnitude; hence, the articulator was coded as U (upward) or D (downward).

During the realization of the consonant itself, I noted whether or not the tongue exhibited flexion. The token was coded Y if the shape of the tongue's surface showed a visible maximum and minimum, similar to the curve of a cubic function with two points of inflection. Otherwise, it was coded N. Figure 4 above gives examples of tongue shapes with and without flexion.

The movement of the tongue tip (at least, what was visible of it, in some cases) was completely in line with Ladefoged's generalization about the tap: the first measure of the tongue tip was consistently U (upward), and the second measure of the tongue tip was consistently D (downward).

At the same time, the tongue root and blade showed a great deal of variety in terms of their movement, especially before the onset of the tap. Following the tap, there was a general trend towards backward movement of both articulators. This may be an effect of the fact that the final word of the carrier sentence, although it began with a labial consonant [p], contained a labiovelar glide [w]. In some cases, the tongue blade and root seemed to move backward rapidly in anticipation of the glide. This may be a flaw of the experiment's design; the carrier sentence was intended to minimize coarticulatory effects, but at the same time was designed to be pragmatically sound (hence, it ended with the discourse marker *pues*)

The presence of flexion was marginal, as expected. Only 12 out of 120 tokens containing taps were coded Y for flexion. Of these, only 6 were non-word VCV tokens. While this is quite a small number, tongue shapes showing flexion are no less real as intrinsic allophones of the alveolar tap, and the potential bearing that this behavior has on sound change should not be discounted. A Pearson's chi-squared test was carried out measuring the presence of flexion in all tokens according to the dimension of V1, and flexion was seen to occur at significance in front vowel contexts ($p = .03$); a Fisher's exact test of the same measure was also significant ($p = .04$). This same measure was not significant for nonwords alone ($p > .1$), nor was significance reported for the presence of flexion according to the dimension of V2.

Statistical analysis was carried out to determine if there was disproportionate back or front movement according to vowel environment. For the purposes of Pearson's chi-squared and Fisher's exact tests, the data was normalized such that only tokens involving unidirectional back/front movement of the tongue root and blade were included in the analysis.

Chi-squared tests were carried out measuring proportions of back/front movement according to vowel dimension for the blade and root. I measured dimensions of V1 and V2 against root and blade movement both before and after the consonant, to see if V2 might have an effect on the initial movement of the tongue, and vice versa, if V1 might have an effect on the final movement of the tongue.

All measures of the dimensions of V1 against the initial movement of the blade and root were significant ($p < .05$) for chi-squared tests carried out for all tokens and non-word tokens, as were Fisher's tests carried out for subsets of non-word tokens. The same was true for measures of the dimensions of V2 against the movement of the blade and root after the realization of the consonant. Measures between V2 dimensions and initial movement of the blade and root were not significant ($p > .1$). Measures of V1 dimensions against movement of the blade and root after the realization of the consonant were significant, however. This significance appears to be coincidental, due to the fact that the blade and root move backwards a disproportionate amount when V1 happens to be a front vowel; we should not infer any coarticulatory information from the results of this particular statistical test.

Additionally, tests were carried out to compare patterns of behavior between taps and nasals. I measured proportions of movement in any direction for stops and nasals in an unmarked vocalic context, i.e., in the presence of /a/. Movement of the tongue root was not measured, as the pharyngeal constriction required for /a/ should cause retraction of the tongue root, just as the tongue root should be advanced for /e i/ and retracted for /o u/.

The initial blade movements for nasals and taps when V1 was /a/ were measured, as were final blade movements for nasals and taps when V2 was /a/. Both measures were highly insignificant ($p > .2$). So taps do not appear to show disproportionate backward movement compared to nasals in a low vowel context. The same tests were carried out for back and high vowel contexts, and were also found to be insignificant. So, much of the differentiated behavior shown by alveolar taps is highly at chance.

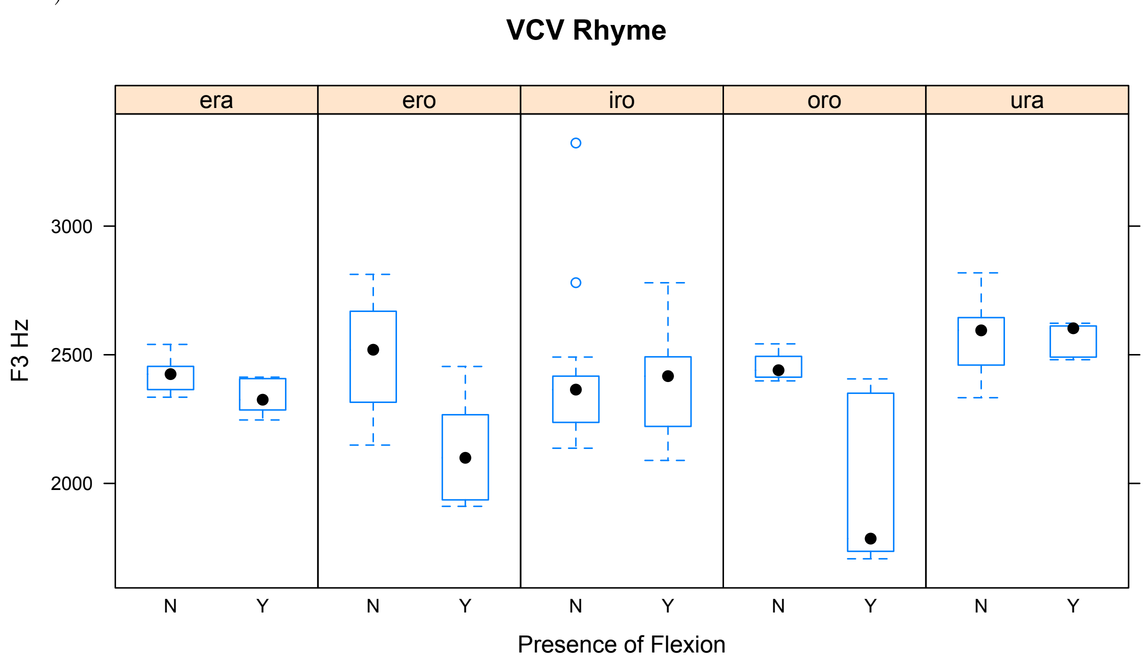
2.4.2 Acoustic Results

This section presents acoustic results for Speaker A. For the six nonword tokens that showed flexion (one instance each of [eɾa], [eɾo], [oɾo] and [uɾa], and two of [iɾo]), the formant values for five spectral slices, each a millisecond apart, were taken from the center of the tap's duration using Praat (Boersma 2011), and tabulated. These measures were made possible by the fact that the spectrogram of a tap shows formant structure throughout. These same values were recorded for instances of the same nonword tokens that did not display flexion. These values are shown for F3 in Figure 7.

To observe overall formant values between tokens with and without flexion, the dataset of formant values was normalized so that it included an equal number of values for each V×V context. Two-sample t-tests carried out using this data did not show significant differences between mean formant values for tokens with and without flexion.

Two-sample t-tests were carried out for mean F3 of tokens with and without flexion, according to each individual V×V context. Mean F3 was significantly lower for concave tongue shape in the tokens [oro] ($p = .017$) and [era] ($p = .049$), but not for the remaining three contexts.

Figure 7: Values of F3 for nonword tokens according to V×V context and presence of flexion (Spanish speaker)

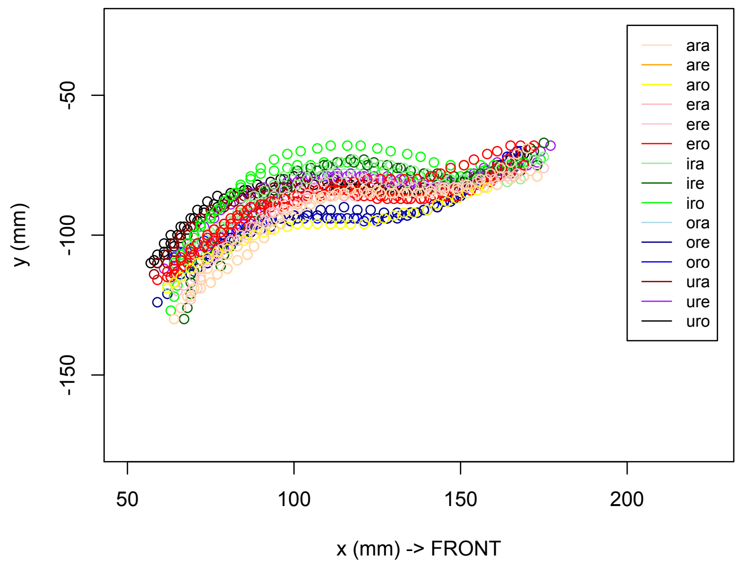


2.4.3 Inter-speaker comparisons

The purpose of the inter-speaker comparison was to determine whether other subjects showed the same individual variation between flat and concave tongue shape, and whether the presence of a concave tongue shape correlated with a lower F3. Given the fact that acoustic values and vocal tract types vary between speakers, the most reliable way to test the correlation between concave tongue shape and lowering of F3 is to measure within-speaker differences.

A preliminary sample of 30 tokens from a second Spanish language condition subject, Speaker B, were observed. Speaker B did not provide a good basis for comparison, as he consistently showed a concave tongue shape. These shapes can be seen in Figure 8.

Figure 8: Speaker B tongue shapes, according to V×V rhyme

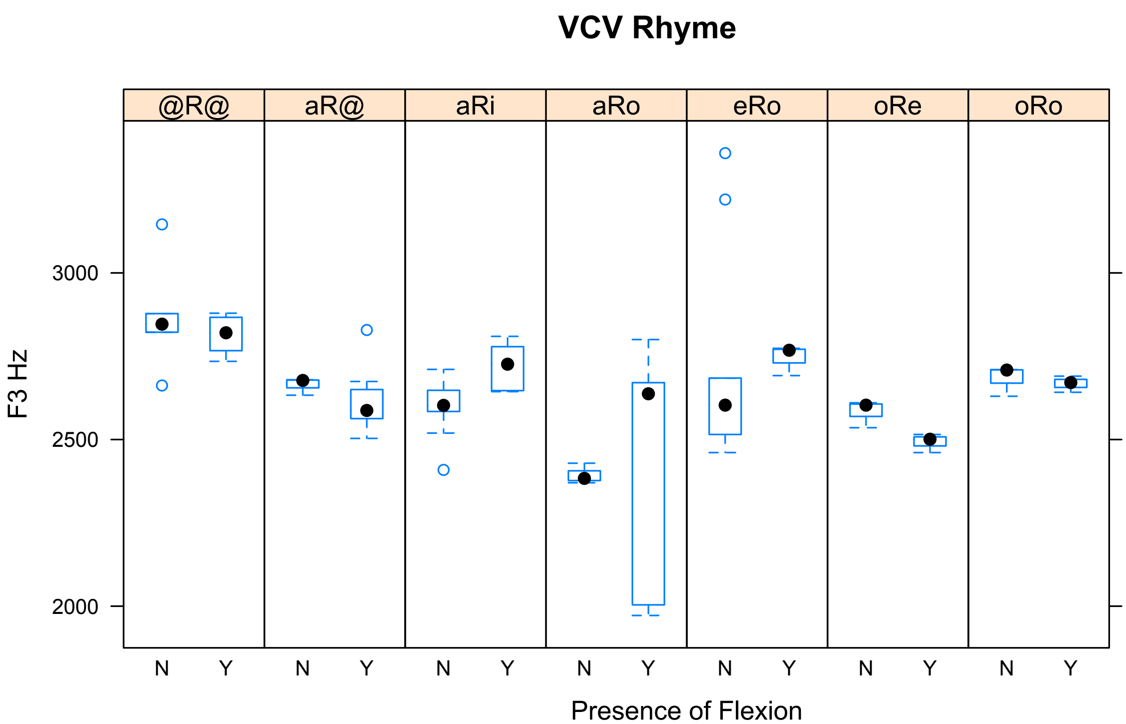


A subset of 100 tokens from an English language condition subject, Speaker C, were analyzed; 67 of these tokens contained taps. Speaker C showed discernible variation between flat and concave tongue shapes. Pearson's chi-squared and Fisher's exact tests were carried out for measures of the proportion of flat to concave shapes according to the dimensions of V1 and V2. The highest proportion of concave to flat tongue shapes was seen when V1 was low (/a ə/); chi-squared and Fisher's tests for V1 were significant ($p = .0002; p = 0001$). The same measure for V2 showed no significance. This suggests that the lowering of the tongue body involved for the vowels /a ə/ carries over into the articulation of the tap.

27 tokens served as a basis of comparison between tongue shapes showing flexion or lack thereof, since certain V×V rhymes showed one pattern or the other consistently, and not in variation. For acoustic measures, formant values from three spectral slices, each a millisecond apart were recorded for each tap uttered in a V×V environment that showed variation between concave and flat tongue shapes. A Welch's

two-sample t-test carried out over a subset of tokens from the two speakers under comparison showed that Speaker C's speaking rate was generally faster than that of Speaker A (Speaker A = .37 sec, Speaker B = .37 sec; p = .0004), hence the use of three values per token rather than five. These values, arranged by token rhyme, can be seen in Figure 9.

Figure 9: Values of F3 for nonword tokens according to V×V context and presence of flexion (English speaker); @ =ə, R=ɾ

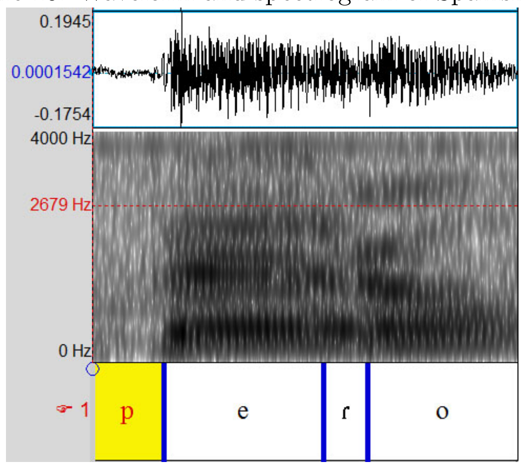


Two-sample t-tests were carried out for mean F3 of tokens with and without flexion, according to each individual V×V context. F3 was significantly lower for concave tokens of [oɾe] (mean F3 of ɾ without flexion = 2583 Hz, without flexion = 2493 Hz; p = .04), but was significantly *higher* for [aɾo] (mean F3 of ɾ without flexion = 2394 Hz, without flexion = 2630 Hz; p = .002). All other differences were insignificant. The higher value for [aɾo] is inconsistent with the patterns shown by tongue shapes with flexion in Speaker A's data.

2.4.4 F3 and F4 Transitions

Measures of the acoustic nucleus of [ɾ] were abandoned, given the absence of coherent information. Instead, I chose to measure the following differences: F3 and F4 at the steady state of V1 against F3 and F4 taken from the midpoint of the VC transition into [ɾ], and F3 and F4 taken from the midpoint of the CV transition out of [ɾ] against F3 and F4 at the steady state of V2. This was to test the observation that F3 and F4 of taps can have generally flat VC transitions, but positive CV transitions.[4] This behavior is exemplified by a spectrogram of the Spanish word *pero* (a token which showed flexion) in Figure 10.

Figure 10: Waveform and spectrogram of Spanish *pero*



The dataset was expanded to include both word and non-word tokens, yielding 48 tokens for Subject A and 26 tokens for Subject C that could serve as a basis for comparison between tongue shapes showing flexion and a lack thereof, according to V×V rhyme.

First, statistical analysis was used to confirm that positive CV transitions were a consistent feature of [ɾ]. For both F3 and F4, paired t-tests were carried out for subjects A and C between, respectively, the values at the VC transition and the steady state of V1, and at the steady state of V2 and the CV transition. For both speakers, the mean F3 values of V1 and the VC transition were not significantly different, but the mean F3 values of V2 and the CV transition were ($p < .01$). Mean F4 values of V1 and the VC transition, as well as V2 and the CV transition, were insignificant for Speaker A, but were significant for Speaker C ($p < .01$).

Secondly, I wished to determine whether tongue flexion had any bearing on the magnitude of the difference between F3 and F4 at the midpoint of the CV transition and at the steady state of V2, according to token rhyme. For each token rhyme, two-sample t-tests were carried out for F3 and F4 differences between the VC transition and V2 steady state for tokens with and without flexion. For Speaker A, F3 differences were significantly higher for tokens with flexion, but only for the rhyme [eɾo]; all other measures were insignificant. For Speaker A, no F4 differences were significantly different according to the presence of flexion. For Speaker

[4]Recasens (1991) reports symmetrical VC and CV transitions for F2 in taps.

C, F3 differences and F4 differences were not significant according to the presence of flexion.

In sum, any effect that the presence of flexion has on F3 appears to be incomplete. However, taps as a whole, for both Speakers A and C, appear to be characterized by positive F3 transitions into the following vowel.

3 Discussion

Broadly speaking, the analysis of Speakers A-C's alveolar taps conforms to observations already made in the literature. The movement of the tongue tip is exclusively vertical. Movement of the root and blade is highly dependent on vowel context, similar to the patterns of vowel-to-consonant coarticulation reported by Recasens (1991); Recasens and Pallarès (1999).

Given these results, it would be easy to overlook the variability seen in terms of tongue shape. A portion of realizations by Speaker A of [ɾ] show a concave or inflected tongue shape, while the remainder show a relatively flat tongue shape; this is the same for Speaker C, but Speaker B consistently shows a concave tongue shape. This feature was largely unrelated to vowel quality. Any correlation between this feature and lowering of F3, a feature associated with retroflexion, is incomplete, and limited to one or two discontiguous vowel environments in only one of the speakers. At the same time, all taps acoustically seem to show flat VC transitions and positive CV transitions. Though this observation would benefit from further testing, it seems that some speakers' realizations of the alveolar tap show acoustic properties that in a sense are the mirror image of that of a retroflex segment, which according to Dave (1977) should show negative VC transitions and flat CV transitions. Low F4 is interpreted in the literature as an indicator of retroflexion and/or posteriority (Celata, 2006; Zhou et al., 2008). Only Speaker C showed a significant rise in F4 following [ɾ]. Further studies are needed to confirm this acoustic trait in other speakers and to investigate an articulatory relationship with posterior place of articulation.

Though this tongue shape is a marginally attested articulatory detail with an inconsistent acoustic correlation, could it potentially foreshadow a sound change? While the articulatory pattern it shows is not nearly as striking as the clockwise tongue tip movement shown in Narayanan *et al.*'s study, the concave tongue shape with lower F3 seen for [ɾ] is a candidate for a seed of retroflexion, highly underrepresented in the performance of a speaker of a language that lacks phonologized retroflexion. Data from additional subjects may offer support to the idea that this tongue shape could be a force behind progressive rhotic retroflexion. A richer corpus of data comparable to that compiled by Delattre and Freeman (1968) may provide us with the information to make interesting sociolinguistic generalizations.

The concave shape of the tongue as well as the lowering of F3 lends credence to the idea that the alveolar tap in certain manifestations can potentially work as "retroflector." This frees us from the assumption that progressive rhotic retroflexion is necessarily triggered by a categorically "retroflex" sound, as is widely assumed in the literature. This is not to say that retroflex segments cannot trigger retroflexion, however—the retroflex approximant [ɹ] appears to do so in Hebridean English. But it is virtually impossible that the retroflex flap [ɽ] could trigger retroflexion in a segment that follows it, given that flaps are produced by a quick, "ballistic" contraction of the inferior longitudinal muscle, causing it "to strike the roof of the mouth as it moves forward" (Barry, 1997, p. 39).

The tendency of concave tongue shapes to correlate with lower F3 also works in tandem with the observation made by Ohala (1983, p. 200) that retroflexes could hypothetically develop from implosives. Noting that the retroflex implosive of Sindhi developed from a Middle Indic dental geminate, Ohala suggests that the enlargement of the oral cavity involved in retroflexion could better facilitate the rarefaction of supraglottal air pressure aerodynamically needed to produce an implosive. Given the short duration of a tap, concave tongue shape is probably not motivated by a need for prolonged voicing, but the lowered tongue body and raised tongue tip have been identified as correlates of retroflexion in other articulatory literature. Incidentally, Ohala doesn't cite any acoustic correlates of retroflexion inherent in implosive [ɗ]. And although lengthening of the back cavity of the vocal tract (by lowering the larynx) should decrease half-wavelength back cavity resonances like F3 and F4, phonetic studies on Bantu languages such as Mpiemo (Thornell and Nagano-Madsen, 2004) show flat VC and CV transitions for /ɗ/. Perhaps in the early stages of a process driven by articulatory variation, acoustic cues of the sounds developing out of said process are not yet fully present. At some point, when low level articulatory traits drift toward an extreme, then acoustic cues become perceptually salient, resulting in the actuation of categorical phonetic change. For the speakers observed in this study, flexion is not currently strong enough to influence the acoustic signal of a tap.

The acoustic data seen for taps, if confirmed in other speakers, fits into Ohala's (1993) view of sound change. We can view East Standard Norwegian and other languages that show progressive rhotic retroflexion as having undergone HYPOCORRECTION, as they have failed to attribute the low F3 in post-rhotic coronals to the preceding segment, and moreover, the conditioning environment has been lost. I know of no cases of HYPERCORRECTION in the domain of rhotic retroflexion, but can hazard a guess as to what this would entail. In some Hindi words, /ɾ/ precedes a retroflex segment. A good retroflex-dental minimal pair is /haɾɖaː/ 'myrobalan, astringent nut' and /haɾd̪aː/ 'mildew, smut (in corn)' (Platts, 1884, p. 1224). Hypothetically, if listeners attributed the retroflex /ɖ/ in the first word to the preceding /ɾ/ and reinterpreted it as a dental, this behavior would instantiate hypercorrection.

The data observed here could potentially lend itself to models that emphasize phonetic detail in phonology, such as Flemming's (1997; 2001) Dispersion Theory of Contrast, which models coarticulation according to acoustic cost.[5] Retroflexion would (hypothetically) minimize the acoustic cost presented by the low F3 at the beginning of the CV transition of an alveolar tap. Flemming (2001) models the fronting of back vowels before coronal consonants in terms of a ranking of three constraints: MinimizeEffort, which he also expresses as *F2(C)=F2(V)*, meaning that F2 of a consonant equals that of the preceding vowel; Ident(C), otherwise expressed as *F2(C)=L[ocus]*; and Ident(V), otherwise expressed as *F2(V)=T[arget]*. If MinimizeEffort is ranked highest, then Ident(V) can be violated, causing vowel fronting, as in Cantonese and English. In a language like German, which shows a lower degree of vowel fronting, MinimizeEffort is ranked lower. With reference to the F3 of [ɾ] and a following coronal, the constraint MinimizeEffort could be violated by too great a magnitude of change in F3 between [ɾ] and the following segment. If MinimizeEffort is ranked high, it could cause input coronals to surface with a lower F3. However, this assumes that all taps (or all taps showing flexion) should synchronically exhibit this coarticulatory effect. The results of this paper are too tentative and varied to suggest that the alveolar tap would have this acoustic effect for all speakers in all environments.

Given the incomplete nature of the effect that tongue shapes with flexion have on F3 according to vowel environment, I think it is more realistic to envision progressive rhotic retroflexion as originating in a small locus within a language's coronal inventory. This locus could then serve as a pivot for the spread of lower F3 to the rest of the coronals. I give the following purely speculative illustration of this idea: /n/ is a phoneme that generally shows a great deal of coarticulation, though it is generally anticipatory. In many languages, even if the coronal stops are dentals, the coronal nasal will be alveolar in its place of articulation (as seen in *The Handbook of the International Phonetic Association* 1999, *passim*). This asymmetry in place makes [n] more susceptible to coarticulation from a tap with flexion, whereas dentals would not be. Coarticulation could first influence [n] and then spread to other coronals, although the spread of retroflexion throughout a coronal inventory probably depends on the nature of the coronals in the language in question: for example, in Sanskrit, the process that retracts *n* in the presence of *r* does not affect dentals (although in later Sanskrit, there is sporadic retroflexion of dental plosives following *r*, usually attributed to Middle Indic interference).

[5]Flemming (2001) bases his theoretical model off of fine-grained acoustic data from the phonetics literature. While I do not doubt the veracity of the reported data that Flemming takes into account, his schematic representation of these phonetic insights assumes the absence of individual variation. He himself admits that his analysis is "highly simplified" (p. 26), meaning that exceptions and outliers are not taken into account.

An alveolar series would probably yield to retroflexion more readily. The question of how retroflexion is regularized is outside of the scope of this paper. To shed light on probable phonological loci of retroflexion, a study of the coarticulatory effect of the alveolar tap on different coronal sounds is needed.

4 Conclusion

This provisional study highlights a low-level tendency that, if identified in the speech of a number of other speakers, may help flesh out the possibility that certain articulatory realizations of the alveolar tap had a role in the development of retroflexion. Of course, as with all paleophony, to use the term coined by Catford (2001) to describe the process of making inferences about past phonetics, any evidence that we gather is purely circumstantial.

Detailed study of other rhotics will help to explain particular asymmetries. For instance, all Scandinavian dialects that contain a uvular fricative or trill as their rhotic do not show retroflexion. It would be informative to determine whether there is an articulatory incompatibility between dorsal trilling and retroflexion of the tongue tip (as Kavitskaya et al. (2009) have shown for alveolar trilling and palatalization, explaining the diachronic instability of the palatalized trill in Slavic languages) or if the absence of retroflexion is due to another factor.

This line of research could help explain some curious asymmetries in the domain of anticipatory rhotic retroflexion as well. In languages of the Loloish subgroup of Tibeto-Burman, clusters of the type *Cy generally become palatal affricates, and clusters of the type *Cr become retroflex affricates, as in Sani (Matisoff, 1979). But Luquan shows the opposite effect, with *Cr becoming palatal, and historical palatal clusters becoming retroflex. This opposition has yet to be explained. Additionally, while Proto-Iranian *sr yields *ṣ̌* in Pashto, Yidgha, Munji, and Sanglechi-Ishkashmi, and Wakhi, it develops into non-retroflex *š* in Ormuri, Parachi, and Yaghnobi (Skjærvø, 1989a). Could there have been historical dialectal variation in early East Iranian articulatory realizations of Proto-Iranian *r?

It will be impossible to know for sure, but questions like these can direct our investigation of rhotic articulatory variation and help us identify likely paleophonic behavior that we can take to have led to certain sound changes. All this will aid the development of a unified articulatory and acoustic account of rhotic retroflexion and postalveolarization.

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5 Appendix

Table 1: Speaker A data

	TOKENS	V_V	V1	V2	V1dim	CONS	V2dim	WORD?	ROOT1	BLADE1	TIP1	FLEXION?	ROOT2	BLADE2	TIP2
1	muere	ere	e	e	FRONT	TAP	FRONT	Y	F	F	U	Y	B	B	D
2	ere	ere	e	e	FRONT	TAP	FRONT	N	N	N	U	N	B	B	D
3	hiere	ere	e	e	FRONT	TAP	FRONT	Y	F	F	U	Y	B	B	D
4	ere	ere	e	e	FRONT	TAP	FRONT	N	B	B	U	N	B	B	D
5	tipo	ipo	i	o	FRONT	LAB	BK	Y	F	F	U	N	B	B	D
6	ipo	ipo	i	o	FRONT	LAB	BK	N	F	B	U	N	B	B	D
7	espera	era	e	a	FRONT	TAP	LO	Y	FB	F	U	Y	B	B	D
8	era	era	e	a	FRONT	TAP	LO	N	FB	F	U	Y	B	B	D
9	dejara	ara	a	a	LO	TAP	LO	Y	BF	F	U	N	B	B	D
10	ara	ara	a	a	LO	TAP	LO	N	B	F	U	N	B	B	D
11	cure	ure	u	e	BK	TAP	FRONT	Y	F	F	U	N	B	F	D
12	ure	ure	u	e	BK	TAP	FRONT	N	BF	B	U	N	FB	FB	D
13	dispare	are	a	e	LO	TAP	FRONT	Y	B	U	U	N	B	B	D
14	are	are	a	e	LO	TAP	FRONT	N	BF	U	U	N	B	B	D
15	pepe	epe	e	e	FRONT	LAB	FRONT	Y	B	B	B	N	B	B	B
16	epe	epe	e	e	FRONT	LAB	FRONT	N	B	B	U	N	F	F	D
17	rara	ara	a	a	LO	TAP	LO	Y	F	F	U	N	B	B	D
18	ara	ara	a	a	LO	TAP	LO	N	D	U	U	N	B	B	D
19	mapa	apa	a	a	LO	LAB	LO	Y	N	N	N	N	B	B	N
20	apa	apa	a	a	LO	LAB	LO	N	N	N	N	N	B	B	N
21	tire	ire	i	e	FRONT	TAP	FRONT	Y	B	B	U	N	B	B	D
22	ire	ire	i	e	FRONT	TAP	FRONT	N	D	D	U	N	B	B	D
23	llene	ene	e	e	FRONT	NAS	FRONT	Y	N	N	U	N	B	B	D
24	ene	ene	e	e	FRONT	NAS	FRONT	N	N	F	U	N	B	B	D
25	clara	ara	a	a	LO	TAP	LO	Y	F	F	U	N	B	B	D
26	ara	ara	a	a	LO	TAP	LO	N	F	F	U	N	B	B	D
27	core	ore	o	e	BK	TAP	FRONT	Y	B	R	U	N	B	B	D
28	ore	ore	o	e	BK	TAP	FRONT	N	F	F	U	N	F	F	D
29	tiro	iro	i	o	FRONT	TAP	BK	Y	B	B	U	N	B	B	D
30	iro	iro	i	o	FRONT	TAP	BK	N	B	B	U	F	B	B	D
31	llano	ano	a	o	LO	NAS	BK	Y	B	B	U	N	B	B	D
32	ano	ano	a	o	LO	NAS	BK	N	F	F	U	N	B	B	D
33	espere	ere	e	e	FRONT	TAP	FRONT	Y	N	N	U	N	B	B	D
34	ere	ere	e	e	FRONT	TAP	FRONT	N	B	B	U	N	B	B	D
35	pure	ure	u	e	BK	TAP	FRONT	Y	F	F	U	N	F	F	D
36	ure	ure	u	e	BK	TAP	FRONT	N	F	F	U	N	F	F	D
37	amaro	aro	a	o	LO	TAP	BK	Y	F	F	U	Y	B	B	D
38	aro	aro	a	o	LO	TAP	BK	N	B	B	U	N	B	B	D
39	bruno	uno	u	o	BK	NAS	BK	Y	F	F	U	N	B	B	D
40	uno	uno	u	o	BK	NAS	BK	N	F	F	U	N	B	B	D
41	aspire	ire	i	e	FRONT	TAP	FRONT	Y	B	B	U	N	B	B	D
42	ire	ire	i	e	FRONT	TAP	FRONT	N	F	F	U	N	B	B	D
43	adora	ora	o	a	BK	TAP	LO	Y	F	F	U	N	B	B	D
44	ora	ora	o	a	BK	TAP	LO	N	F	F	U	N	B	B	D
45	toro	oro	o	o	BK	TAP	BK	Y	B	B	U	N	B	B	D
46	oro	oro	o	o	BK	TAP	BK	N	B	B	U	Y	B	B	D
47	dure	ure	u	e	BK	TAP	FRONT	Y	B	B	U	N	F	F	D
48	ure	ure	u	e	BK	TAP	FRONT	N	B	B	U	N	F	F	D
49	bare	are	a	e	LO	TAP	FRONT	Y	B	B	U	N	F	F	D
50	are	are	a	e	LO	TAP	FRONT	N	B	B	U	N	F	F	D
52	one	one	o	e	BK	NAS	FRONT	N	B	B	U	N	F	F	D
53	vaquero	ero	e	o	FRONT	TAP	BK	Y	F	F	U	N	B	B	D
54	ero	ero	e	o	FRONT	TAP	BK	N	F	F	U	N	B	B	D
55	mire	ire	i	e	FRONT	TAP	FRONT	Y	F	F	U	N	B	B	D
56	ire	ire	i	e	FRONT	TAP	FRONT	N	B	B	U	N	D	D	D
57	liro	iro	i	o	FRONT	TAP	BK	Y	F	F	U	N	B	B	D

58	iro	iro	i	o	FRONT	TAP	BK	N	F	F	U	N	B	B	D
59	sonora	ora	o	a	BK	TAP	LO	Y	F	F	U	N	B	B	D
60	ora	ora	o	a	BK	TAP	LO	N	B	F	U	N	B	B	D
61	fora	ora	o	a	BK	TAP	LO	Y	B	B	U	N	B	FB	D
62	ora	ora	o	a	BK	TAP	LO	N	F	F	U	N	B	B	D
63	coro	oro	o	o	BK	TAP	BK	Y	F	F	U	N	B	B	D
64	oro	oro	o	o	BK	TAP	BK	N	F	F	U	N	B	B	D
65	pare	are	a	e	LO	TAP	FRONT	Y	F	F	U	N	B	B	D
66	are	are	a	e	LO	TAP	FRONT	N	F	F	U	N	B	B	D
67	moro	oro	o	o	BK	TAP	BK	Y	N	N	U	N	B	B	D
68	oro	oro	o	o	BK	TAP	BK	N	F	F	U	N	B	B	D
69	cope	ope	o	e	BK	LAB	FRONT	Y	B	B	N	N	F	F	N
70	ope	ope	o	e	BK	LAB	FRONT	N	B	B	N	N	F	F	N
71	mentira	ira	i	a	FRONT	TAP	LO	Y	B	B	U	N	B	B	D
72	ira	ira	i	a	FRONT	TAP	LO	N	F	F	U	N	D	D	D
73	ahora	ora	o	a	BK	TAP	LO	Y	F	F	U	N	B	B	D
74	ora	ora	o	a	BK	TAP	LO	N	F	F	U	N	B	B	D
75	faro	aro	a	o	LO	TAP	BK	Y	N	N	U	N	B	B	D
76	aro	aro	a	o	LO	TAP	BK	N	N	N	U	N	B	B	D
77	cura	ura	u	a	BK	TAP	LO	Y	B	B	U	N	B	B	D
78	ura	ura	u	a	BK	TAP	LO	N	F	F	U	N	B	B	D
79	para	ara	a	a	LO	TAP	LO	Y	B	D	U	N	B	B	D
80	ara	ara	a	a	LO	TAP	LO	N	B	D	U	N	B	B	D
81	chupa	upa	u	a	BK	LAB	LO	Y	B	B	N	N	D	D	N
82	upa	upa	u	a	BK	LAB	LO	N	B	B	N	N	F	D	N
83	seguro	uro	u	o	BK	TAP	BK	Y	B	B	U	N	B	B	D
84	uro	uro	u	o	BK	TAP	BK	N	B	F	U	N	B	B	D
85	agura	ura	u	a	BK	TAP	LO	Y	B	B	U	N	B	B	D
86	ura	ura	u	a	BK	TAP	LO	N	B	B	U	N	B	B	D
87	lore	ore	o	e	BK	TAP	FRONT	Y	B	B	U	N	F	F	D
88	ore	ore	o	e	BK	TAP	FRONT	N	B	B	U	N	F	F	D
89	impune	une	u	e	BK	NAS	FRONT	Y	B	B	U	N	F	F	D
90	une	une	u	e	BK	NAS	FRONT	N	B	B	U	N	F	F	D
91	cadera	era	e	a	FRONT	TAP	LO	Y	B	B	U	N	F	F	D
92	era	era	e	a	FRONT	TAP	LO	N	B	B	U	N	B	B	D
93	madera	era	e	a	FRONT	TAP	LO	Y	F	F	U	N	B	B	D
94	era	era	e	a	FRONT	TAP	LO	N	N	N	U	N	B	B	D
95	cena	ena	e	a	FRONT	NAS	LO	Y	N	N	U	N	B	B	D
96	ena	ena	e	a	FRONT	NAS	LO	N	N	N	U	N	B	B	D
97	caro	aro	a	o	LO	TAP	BK	Y	N	N	U	N	N	N	D
98	aro	aro	a	o	LO	TAP	BK	N	B	B	U	N	B	B	D
99	grupo	upo	u	o	BK	LAB	BK	Y	B	B	N	N	B	B	N
100	upo	upo	u	o	BK	LAB	BK	N	B	B	N	N	D	D	N
101	mono	ono	o	o	BK	NAS	BK	Y	B	B	U	N	B	B	D
102	ono	ono	o	o	BK	NAS	BK	N	B	B	U	N	B	B	D
103	topo	opo	o	o	BK	LAB	BK	Y	B	B	B	N	N	N	N
104	opo	opo	o	o	BK	LAB	BK	N	B	B	N	N	N	N	N
105	tira	ira	i	a	FRONT	TAP	LO	Y	F	F	U	N	B	B	N
106	ira	ira	i	a	FRONT	TAP	LO	N	N	N	U	N	B	B	N
107	claro	aro	a	o	LO	TAP	BK	Y	D	D	U	N	B	B	N
108	aro	aro	a	o	LO	TAP	BK	N	B	B	U	N	B	B	N
109	sepa	epa	e	a	FRONT	LAB	LO	Y	F	F	N	N	B	B	N
110	epa	epa	e	a	FRONT	LAB	LO	N	N	N	N	N	B	B	N
111	gane	ane	a	e	LO	NAS	FRONT	Y	B	B	U	N	F	F	D
112	ane	ane	a	e	LO	NAS	FRONT	N	B	B	U	N	F	F	D
113	casera	era	e	a	FRONT	TAP	LO	Y	F	F	U	N	B	B	D
114	era	era	e	a	FRONT	TAP	LO	N	N	N	U	N	B	B	D
115	vira	vira	v	a	v	i	LO	Y	F	F	U	N	D	D	D
116	ira	ira	i	a	FRONT	TAP	LO	N	F	F	U	N	B	D	D
117	china	ina	i	a	FRONT	NAS	LO	Y	F	F	U	N	D	D	D
118	ina	ina	i	a	FRONT	NAS	LO	N	F	F	U	N	B	D	D
119	gane	ane	a	e	LO	NAS	FRONT	Y	F	F	U	N	F	F	D

120	ane	ane	a	e	LO	NAS	FRONT	N	B	D	U	N	F	F	D
121	tripe	ipe	i	e	FRONT	LAB	FRONT	Y	F	F	U	N	B	B	D
122	ipe	ipe	i	e	FRONT	LAB	FRONT	N	F	F	U	N	D	D	D
123	freno	eno	e	o	FRONT	NAS	BK	Y	N	N	U	N	B	B	D
124	eno	eno	e	o	FRONT	NAS	BK	N	F	F	U	N	B	B	D
125	quiere	ere	e	e	FRONT	TAP	FRONT	Y	F	F	U	N	N	N	D
126	ere	ere	e	e	FRONT	TAP	FRONT	N	N	N	U	N	N	N	D
127	pipa	ipa	i	a	FRONT	LAB	LO	Y	N	N	N	N	D	D	N
128	ipa	ipa	i	a	FRONT	LAB	LO	N	N	N	N	N	D	D	N
129	lupe	upe	u	e	BK	LAB	FRONT	Y	B	B	U	N	F	F	D
130	upe	upe	u	e	BK	LAB	FRONT	N	B	B	U	N	F	F	D
131	zona	ona	o	a	BK	NAS	LO	Y	B	B	U	N	F	F	D
132	ona	ona	o	a	BK	NAS	LO	N	B	B	U	N	F	F	D
133	ropa	opa	o	a	BK	LAB	LO	Y	B	B	N	N	N	N	N
134	opa	opa	o	a	BK	LAB	LO	N	B	B	N	N	N	N	N
136	ine	ine	i	e	FRONT	NAS	FRONT	N	N	N	U	N	B	B	D
137	lira	ira	i	a	FRONT	TAP	LO	Y	F	F	U	N	B	B	D
138	ira	ira	i	a	FRONT	TAP	LO	N	F	F	U	N	D	D	D
139	luna	una	u	a	BK	NAS	LO	Y	B	B	U	N	B	B	D
140	una	una	u	a	BK	NAS	LO	N	B	B	U	N	FB	FB	D
141	jura	ura	u	a	BK	TAP	LO	Y	B	B	U	N	F	F	D
142	ura	ura	u	a	BK	TAP	LO	N	B	B	U	Y	F	F	D
143	serape	ape	a	e	LO	LAB	FRONT	Y	N	N	N	N	F	F	N
144	ape	ape	a	e	LO	LAB	FRONT	N	N	N	N	N	F	F	N
145	pero	ero	e	o	FRONT	TAP	BK	Y	F	F	U	Y	B	B	D
146	ero	ero	e	o	FRONT	TAP	BK	N	F	F	U	Y	B	B	D
147	pura	ura	u	a	BK	TAP	LO	Y	B	B	U	N	B	F	D
148	ura	ura	u	a	BK	TAP	LO	N	B	B	U	N	B	F	D
149	miro	iro	i	o	FRONT	TAP	BK	Y	F	F	U	N	B	D	D
150	iro	iro	i	o	FRONT	TAP	BK	N	F	F	U	N	B	B	D
151	tesoro	oro	o	o	BK	TAP	BK	Y	B	B	U	N	B	B	D
152	oro	oro	o	o	BK	TAP	BK	N	B	D	U	N	N	U	D
153	pure	ure	u	e	BK	TAP	FRONT	Y	B	B	U	N	F	F	D
154	ure	ure	u	e	BK	TAP	FRONT	N	B	B	U	N	F	F	D
155	oscuro	uro	u	o	BK	TAP	BK	Y	B	B	U	N	B	D	D
156	uro	uro	u	o	BK	TAP	BK	N	B	B	U	N	B	B	D
157	cepo	epo	e	o	FRONT	LAB	BK	Y	N	N	N	N	B	B	N
158	epo	epo	e	o	FRONT	LAB	BK	N	N	N	N	N	B	B	N
159	duro	uro	u	o	BK	TAP	BK	Y	B	B	U	N	B	B	D
160	uro	uro	u	o	BK	TAP	BK	N	B	B	U	N	B	B	D
161	enero	ero	e	o	FRONT	TAP	BK	Y	N	N	U	N	B	B	D
162	ero	ero	e	o	FRONT	TAP	BK	N	N	N	U	N	B	B	D
163	quiero	ero	e	o	FRONT	TAP	BK	Y	B	B	U	N	B	B	D
164	ero	ero	e	o	FRONT	TAP	BK	N	B	B	U	N	B	B	D
165	puro	uro	u	o	BK	TAP	BK	Y	B	B	U	N	B	B	D
166	uro	uro	u	o	BK	TAP	BK	N	B	B	U	N	B	B	D
167	mejore	ore	o	e	BK	TAP	FRONT	Y	B	B	U	N	F	F	D
168	ore	ore	o	e	BK	TAP	FRONT	N	B	B	U	N	F	F	D
169	aclare	are	a	e	LO	TAP	FRONT	Y	D	D	U	N	F	U	D
170	are	are	a	e	LO	TAP	FRONT	N	D	D	U	N	F	U	D
171	lire	ire	i	e	FRONT	TAP	FRONT	Y	F	F	U	N	B	B	D
172	ire	ire	i	e	FRONT	TAP	FRONT	N	F	F	U	N	B	B	D
173	tiro	iro	i	o	FRONT	TAP	BK	Y	F	F	U	Y	B	B	D
174	iro	iro	i	o	FRONT	TAP	BK	N	F	F	U	Y	B	D	D
175	guapo	apo	a	o	LO	LAB	BK	Y	N	N	N	N	B	B	B
176	apo	apo	a	o	LO	LAB	BK	N	N	N	N	N	B	B	B
177	llore	ore	o	e	BK	TAP	FRONT	Y	B	B	U	N	F	F	D
178	ore	ore	o	e	BK	TAP	FRONT	N	B	B	U	N	F	F	D

Table 2: Subset of Speaker C data

NUMBER	TOKEN	VV	V1	V2	V1feat	CONS	V2feat	FLEXION?	WORD?
4	toddy	aRi	a	i	LO	TAP	FRONT	N	Y
5	aRi	aRi	a	i	LO	TAP	FRONT	N	N
10	theta	eR@	e	@	FRONT	TAP	LO	N	Y
11	eR@	eR@	e	@	FRONT	TAP	LO	N	N
14	kudu	uRu	u	u	BK	TAP	BK	N	Y
15	uRu	uRu	u	u	BK	TAP	BK	N	N
16	cuta	@R@	@	@	LO	TAP	LO	N	Y
17	@R@	@R@	@	@	LO	TAP	LO	N	N
20	body	aRi	a	i	LO	TAP	FRONT	Y	Y
21	aRi	aRi	a	i	LO	TAP	FRONT	N	N
22	Buddha	uR@	u	@	BK	TAP	LO	N	Y
23	uR@	uR@	u	@	BK	TAP	LO	N	N
24	shoddy	aRi	a	i	LO	TAP	FRONT	Y	Y
25	aRi	aRi	a	i	LO	TAP	FRONT	N	N
26	payday	eRe	e	e	FRONT	TAP	FRONT	N	Y
27	eRe	eRe	e	e	FRONT	TAP	FRONT	N	N
28	gotta	aR@	a	@	LO	TAP	LO	Y	Y
29	aR@	aR@	a	@	LO	TAP	LO	Y	N
30	cody	oRi	o	i	BK	TAP	FRONT	N	Y
31	oRi	oRi	o	i	BK	TAP	FRONT	N	N
32	lotta	aR@	a	@	LO	TAP	LO	Y	Y
33	aR@	aR@	a	@	LO	TAP	LO	N	N
34	Rhoda	oR@	o	@	BK	TAP	LO	Y	Y
35	oR@	oR@	o	@	BK	TAP	LO	Y	N
38	Plato	eRo	e	o	FRONT	TAP	BK	N	Y
39	eRo	eRo	e	o	FRONT	TAP	BK	N	N
40	noday	oRe	o	e	BK	TAP	FRONT	N	Y
41	oRe	oRe	o	e	BK	TAP	FRONT	Y	N
44	data	eR@	e	@	FRONT	TAP	LO	N	Y
45	eR@	eR@	e	@	FRONT	TAP	LO	N	N
48	shuta	@R@	@	@	LO	TAP	LO	Y	Y
49	@R@	@R@	@	@	LO	TAP	LO	Y	N
50	Rita	iR@	i	@	FRONT	TAP	LO	N	Y
51	iR@	iR@	i	@	FRONT	TAP	LO	N	N
60	motto	aRo	a	o	LO	TAP	BK	Y	Y
61	aRo	aRo	a	o	LO	TAP	BK	N	N
62	Haiti	eRi	e	i	FRONT	TAP	FRONT	N	Y
63	eRi	eRi	e	i	FRONT	TAP	FRONT	N	N
64	Judah	uR@	u	@	BK	TAP	LO	N	Y
65	uR@	uR@	u	@	BK	TAP	LO	N	N
66	vita	iR@	i	@	FRONT	TAP	LO	N	Y
67	iR@	iR@	i	@	FRONT	TAP	LO	N	N
68	Bermuda	uR@	u	@	BK	TAP	LO	N	Y
69	uR@	uR@	u	@	BK	TAP	LO	N	N
72	speedo	iRo	i	o	FRONT	TAP	BK	N	Y
73	iRo	iRo	i	o	FRONT	TAP	BK	N	N
76	toady	oRi	o	i	BK	TAP	FRONT	N	Y
77	oRi	oRi	o	i	BK	TAP	FRONT	N	N
78	lotto	aRo	a	o	LO	TAP	BK	Y	Y
79	aRo	aRo	a	o	LO	TAP	BK	Y	N
82	mayday	eRe	e	e	FRONT	TAP	FRONT	N	Y
83	eRe	eRe	e	e	FRONT	TAP	FRONT	N	N
84	beta	eR@	e	@	FRONT	TAP	LO	N	Y
85	eR@	eR@	e	@	FRONT	TAP	LO	N	N
86	beady	iRi	i	i	FRONT	TAP	FRONT	N	Y
87	iRi	iRi	i	i	FRONT	TAP	FRONT	N	N
90	fido	iRo	i	o	FRONT	TAP	BK	N	Y
91	iRo	iRo	i	o	FRONT	TAP	BK	N	N
92	photo	oRo	o	o	BK	TAP	BK	Y	Y

93	oRo	oRo	o	o	BK	TAP	BK	N	N
95	iRi	iRi	i	i	FRONT	TAP	FRONT	N	Y
96	potato	eRo	e	o	FRONT	TAP	BK	Y	N
97	eRo	eRo	e	o	FRONT	TAP	BK	N	Y
98	hoodoo	uRu	u	u	BK	TAP	BK	N	N
99	uRu	uRu	u	u	BK	TAP	BK	N	Y
100	lady	eRi	e	i	FRONT	TAP	FRONT	N	N