X *Domain-initial articulatory strengthening in four languages*

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X.1. Introduction

This paper is about one way in which prosody affects individual speech segments, with segmental phonetics showing a perhaps surprising sensitivity to higher-level linguistic structure. By *prosody* we mean the phrasal and tonal organization of speech. We will show that phonetic properties of individual segments depend on their *prosodic position*, or position in prosodic structure.

It is well-known that in a monosyllabic CVC word, the initial consonant can be pronounced differently than the final consonant, the initial consonant being longer and having greater articulatory magnitude (e.g. Byrd, 1994; Keating, Wright & Zhang, 1999). Some interesting recent acoustic studies have extended this line of inquiry above the syllable and word level to phrasal levels. For example, at the LabPhonII conference, Pierrehumbert & Talkin (1992) presented a study in which they used acoustic measures of breathiness to show that /h/ is more consonant-like when it is phrase-initial than when it is phrase-medial ("The phrase boundary was found to shift articulation on both sides in a more consonantal direction", p. 116). Similarly, the Voice Onset Time (VOT) of /t/ is longer phrase-initially. This latter result was extended by Jun (1993), who compared the VOT of Korean /p^h/ in three positions: initial in a small phrase, initial in a word, medial in a word; VOT varied as shown in Figure X.1.

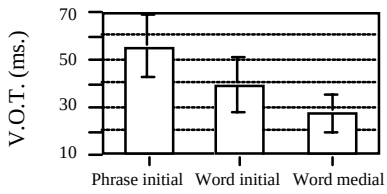

Figure X.1. VOT of Korean /p^h/ as a function of prosodic position. Our summary of data from Jun 1993:235 (Figure 6.2).

Then Dilley, Shattuck-Hufnagel & Ostendorf (1996) showed that higher phrasal levels can also differ. They tabulated the presence of glottalization of vowel-initial words in a radio-news corpus, and found that the likelihood of glottalization depends on the prosodic position of the word. Glottalization is most likely at the beginning of an Intonational Phrase (a large phrase), next most likely at the beginning of an Intermediate Phrase (a smaller phrase), and least likely phrase-medially.

Articulatory studies that compare positions in phrases include Stone (1981), van Lieshout, Starkweather, Hulstijn & Peters (1995), Byrd, Kaun, Narayanan & Saltzman (1996), Gordon (1996), Hsu & Jun (1997), and Byrd & Saltzman (1998). In our own earlier work (Fougeron & Keating, 1997), we compared the articulation of /n/s in different prosodic positions. The speech materials consisted of arithmetic expressions as in (1).

(1) 89 x (89 + 89 + 89) = a lot

Reiterant speech was used, with most syllables replaced by the syllable /no/, as in (2).

(2)	89	times	(89	plus	89	plus	89	) = a lot
	nonono	no	(nonono	no	nonono	no	nonono) = a lot	

The prosodic organization of the test utterances was characterized by transcribing groupings of words into smaller phrases and larger phrases (using the ToBI conventions (Silverman, Beckman, Pitrelli, Ostendorf, Wightman, Price, Pierrehumbert & Hirschberg, 1992; Beckman & Elam, 1997)). Each reiterant syllable was then coded as initial, medial, or final in each of the prosodic domains Word, small Intermediate Phrase (or PP), large Intonational Phrase (or IP), and Utterance. /n/s which were not initial within a word were also coded as initial in the Syllable (S). The Utterance-initial /n/s were always and only at the beginning of the sentence, but otherwise there was no *unique* relation between prosodic position above the word and linear position in the sentence.

The relevant result here, shown in Figure X.2a, is that in general, /n/s which were initial in higher domains had more total linguopalatal contact than /n/s which were initial only in lower domains. The effect of being in domain-initial position was generally cumulative. Each speaker showed a hierarchical pattern of peak contact, distinguishing at least three domains in this way. However, no speaker distinguished all the domains, and no distinction was reliable for all speakers. Speaker 1 distinguished IP, PP and W; Speaker 2 distinguished U, IP/PP, W and S, and Speaker 3 distinguished U, IP, PP/W, and S.

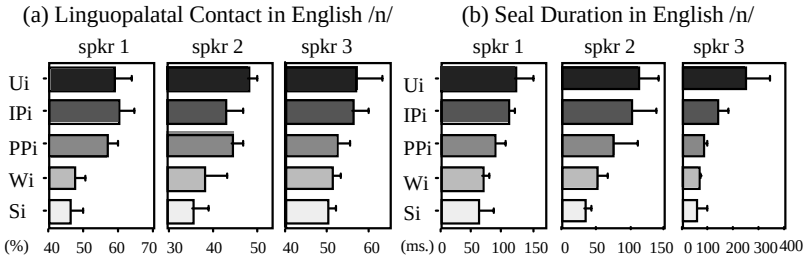

Figure X.2. English EPG data by speaker for (a) Peak contact, based on Fougeron & Keating (1997). The horizontal bars show the %electrodes (of 96) contacted. (b) Articulatory seal duration (not in Fougeron & Keating). The horizontal bars show duration in ms. All graphs show values for consonants in initial position (indicated by small "i" in the axis labels) in the domain indicated (U for Utterance, IP for Intonational Phrase, PP for Phonological or Intermediate Phrase, W for Word, S for Syllable).

These effects were limited to consonants in domain-initial positions. Because in this corpus there were often three or more syllables in each domain, we could test specifically whether this resulted from weakening of all non-initial syllables (that is, the first syllable's consonant is different from all others), vs. final-syllable weakening (that is, the last syllable's consonant is different from all others). The results clearly showed the former. We also found no evidence for articulatory declination (global, utterance-level trends, e.g. Krakow, Bell-Berti & Wang, 1994). Therefore in the present study we will focus only on domain-initial consonants.

We called the pattern seen in this study "domain-initial strengthening" because the lingual articulations appeared to be stronger for consonants at the beginning of each prosodic domain. However, the exact nature of domain-initial strengthening is not yet clear. In Fougeron & Keating (1997), we discussed some possible mechanisms, including articulatory undershoot of shorter segments, overshoot of consonants after lengthened domain-final vowels, coarticulatory resistance by segments in initial positions, and overall greater articulatory effort for initial segments. This last mechanism is explored more fully in Fougeron (1998). We also outlined how this strengthening could aid a listener in prosodic parsing and feature extraction. However, no perceptual experiments have been carried out, and Fougeron (1998) argues against a primarily perceptual motivation.

The idea that longer durations allow articulatory targets to be more closely approximated, while shorter durations result in undershoot of those targets (Lindblom 1963; Moon & Lindblom, 1994) can readily be related to initial strengthening. If initial segments are longer, then they would have more time to achieve more extreme articulations. For example, Soler and Romero (1999) relate duration and constriction degree in their account of Spanish stop lenition. This possibility can be explored by measuring consonant durations and testing

their correlations with linguopalatal contact. A strong relation between these variables would support the hypothesis that initial strengthening and lengthening arise from a single mechanism.

Therefore articulatory duration (the duration of the stop consonant seal, from EPG data) was measured for the same tokens. These data, not reported in Fougeron & Keating (1997) but shown in Figure X.2b, followed a similar pattern to linguopalatal contact. Speakers 1 and 3 distinguished IP, PP, and W/S; Speaker 2 distinguished IP, PP, W, and S. The within-speaker correlations between articulatory duration and linguopalatal contact for domain-initial tokens above the Word level were low to modest (with r from .3 to .52, and r^2 from .09 to .27). Although domain-initial /n/'s are both greater in linguopalatal contact and longer in seal duration than domain-medial ones, such weak correlations suggest that, at least for these English speakers, greater linguopalatal contact does not necessarily come from longer time given for articulation. This result weakens any articulatory undershoot hypothesis.

The present study follows up on our earlier results for English in Fougeron and Keating (1997) by comparing several languages. Not only do we want to know whether the results hold beyond English, but we want to know whether other prosodic differences among languages are reflected in any initial strengthening effect. Lehiste (1964) showed that languages differ in how they mark word boundaries. She proposed that this depends on a language's phonology; for example, a language with phonemic vowel length would not use vowel lengthening to mark boundaries. Initial strengthening at other levels could also depend on a language's phonology. Byrd *et al.* (1996) in their LabPhonV presentation found relatively little effect of phrasal position on spatial position of articulators in Tamil, though they did find effects on duration and timing. That is, in Tamil there are temporal effects without spatial effects. Thus, although these two kinds of effects co-occur in English, the Tamil study shows that they must be distinct, and their co-occurrence must be language-particular. The Tamil results also undermine any undershoot account in which spatial variation is a necessary consequence of temporal variation. However, it is not clear that Byrd *et al.*'s Tamil corpus included a sufficient range of different prosodic domains to ensure that all possible prosodic effects were seen. Therefore our study includes three languages and clear examples of larger and smaller phrasal domains.

Since English has such prominent lexical stress and nuclear pitch accent, it might be expected that its domain edges would be phonetically less marked than edges in languages with less prominent heads. The three languages studied here, French, Korean, and Taiwanese, allow such comparisons. Taiwanese is a lexical tone language, and thus, since it cannot use tones to mark domain heads, might be expected to show large edge-marking. On the other hand, Taiwanese tone sandhi is organized in a phrasal domain which does not seem to be prosodic

(Hayes, 1990; Hsu & Jun, 1996), and for that reason prosodic domains might be expected to receive little phonetic marking. French and Korean differ from both English and Taiwanese in having neither lexical tone nor lexical stress. They are prosodically similar to each other; both have a small prosodic domain defined by phrasal tones. At the same time, it has been proposed that these two languages differ in terms of pitch, duration and amplitude variation within that phrase. Fougeron and Jun (1998) posit a H* phrasal accent at the end of the French AP, which also shows final lengthening (see also Jun and Fougeron, to appear). Unlike French, Korean has no AP-final accent (Jun 1998), and Jun (1995a) observed no AP-final lengthening; instead, the beginning of the Korean AP is marked by accent and lengthening. In addition, a French AP-final accented syllable is realized with greater amplitude (Martin, 1982) while no discernible greater amplitude is found in Korean AP-final position (Jun, 1995b). In sum, it can be posited that Korean reinforces the beginning of the phrase but French the end. If this is so, we might expect French not to show domain-initial articulatory strengthening like Korean.

X.2. General Methods

X.2.1. Prosodic Domains

We assume a hierarchical view of prosody in which smaller prosodic constituents or levels are nested within larger ones. (For a thorough review of theories of prosodic hierarchies, see Shattuck-Hufnagel & Turk (1996).) For present purposes, it does not matter whether these prosodic constituents are identical across languages. What is crucial is that each language has several domains, each with specific properties that allow it to be identified, and organized hierarchically. Where these properties seem comparable across languages we use the same name (e.g. Intonational Phrase), but no precise descriptive or theoretical claims about these languages are intended.

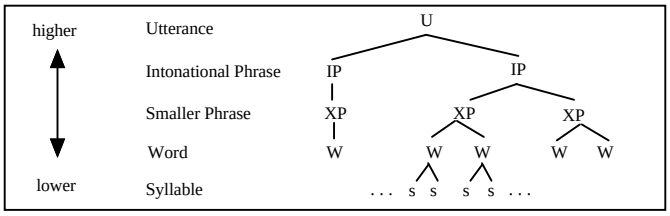

Figure X.3. A partial Prosodic Hierarchy adopted in this study. One or more instances of each level may appear under the level above it.

For each language, then, prosodic domains must be determined and defined. A schematic of a partial hierarchy of prosodic domains (mostly above the word level) is shown in Figure X.3.

One domain that seems comparable across languages is the Intonational Phrase, or IP. An IP is marked by a complete intonational contour, and can be set off naturally by pauses. An IP can comprise a full sentence, but in our experiments it usually comprised a clause or topic phrase within a longer sentence (punctuated by a comma or semi-colon). We also tested a possible higher domain, the Utterance, corresponding to the second of two sentences (punctuated by a period), and marked by a full pause, sometimes with a breath. Whether there is a systematic difference between Utterance and Intonational Phrase is somewhat controversial. Nespor & Vogel (1986) distinguished them on the basis of where some phonological rules apply. However, in terms of intonation and pausing, they need not be different; and Wightman, Shattuck-Hufnagel, Ostendorf & Price (1992) found no difference in their amounts of final lengthening. In our Korean and Taiwanese experiments we instructed subjects not to pause within a sentence, so that the Utterance break is marked by a pause but the IP break usually is not. In our French experiment, which did not give explicit instructions, subjects were more likely to pause between IPs, as they did between Us.

A phrasal domain smaller than the IP was also sought, corresponding to the Phonological or Intermediate Phrase studied for English in Fougeron & Keating (1997). Such a phrase would be marked by less than a complete intonational contour. In French and Korean the Accentual Phrase was chosen, as it is easy to transcribe from spoken utterances. An AP usually consists of a small number of content words, plus function words, with an associated phrasal tone pattern. Following the analysis of French prosody given by Jun & Fougeron (1995) and Fougeron & Jun (1998), the French AP has an underlying phrasal tone sequence LHLH. Following the analysis of Seoul Korean prosody given by Jun (1998), the Korean AP is also marked by an underlying phrasal tone sequence LHLH. For Taiwanese, there is no phrase smaller than the Intonational Phrase which is generally accepted to be part of that language's prosodic hierarchy. The tone sandhi group (the domain in which tone sandhi takes place, based on the Phonological Phrase, e.g. Chen 1987) would appear to be a candidate for such a domain, but this domain is not strictly layered under the IP, and Hsu & Jun (1996) concluded that the tone sandhi group is not a prosodic domain of Taiwanese. Instead, in this study a small phrase (SP) was identified that consists of a heavy subject Noun Phrase. This domain is not tonally marked, but is characterized by a break greater than that between words.

Finally, initial and medial positions within a Word domain were included in each experiment. What counts as a Prosodic Word in a given language is controversial. In English our Word was fairly large by some prosodic standards,

being lexically complex (e.g. “eighty-nine”), but nonetheless having only one primary lexical stress; similarly, in Taiwanese the Word was a morphologically complex resultative verb comprising two verbal roots (“stepped on”). In Korean, Words were mostly inflected nouns (e.g. “man”), while in French, Words were parts of larger names (e.g. “Auntie Nadia”). The Syllable-initial consonants were all Word-medial.

X.2.2. Corpora

The test consonants in the three languages were /n/ and unaspirated /t/, which in these languages are generally laminal dental stops. For all studies, the prosodic position of test consonants was varied; by varying the text around the test syllable, the prosodic structure is varied, while the absolute position of the test syllable is kept the same. (Since it is possible that some language other than English might show articulatory declination, we control for this in all studies.) Table X.1. shows the corpus for French /n/. The corpora for the other French consonant, /t/, and for the other languages are similar in design and are given in the appendix. The only exception is Taiwanese /n/, as described in the next section.

Table X.1. Corpus for French /n/. The test consonant is in bold, and the word containing it is underlined.

Positions	Test Consonant /n/ in /a_a/
Ui	Paul aime Tata. **N**adia les protège en secret.
	Paul loves Auntie. Nadia protects them in secret
IPi	La pauvre Tata, **N**adia et Paul n’arriveront que demain.
	Poor Auntie, Nadia and Paul won’t arrive until tomorrow
APi	Tonton, Tata, **N**adia et Paul arriveront demain.
	Uncle, Auntie, Nadia and Paul will arrive tomorrow
Wi	Paul et Tata-**N**adia arriveront demain matin.
	Paul and Auntie Nadia will arrive tomorrow morning
Si	Tonton et A**n**abelle arriveront demain matin.
	Uncle and Anabelle will arrive tomorrow morning

X.2.3. Data Collection

The primary measure of strengthening reported here will be the maximum amount of contact between the tongue and the palatal surface, as recorded by electropalatography (EPG). The amount of contact is an index of tongue height at the point of contact, and thus is considered a measure of the strength of an articulation. All studies used the Kay Elemetrics Palatometer. With the Palatometer, a talker wears an individual, custom-made pseudopalate that covers the surface of the hard palate and the inner surfaces of the upper teeth with 96 contact electrodes. For French, Korean, and Taiwanese speakers, the frontmost row of electrodes extends onto the back surface of the upper teeth, and two electrodes were placed at the middle of the front two incisors, so that at least some dental contact could be registered. This arrangement of electrodes is shown in Figure X.4. The Palatometer records the pattern of tongue-pseudopalate contact every 10 ms. The audio signal was recorded with a head-mounted microphone, at 12.8 kHz, into the same data file.

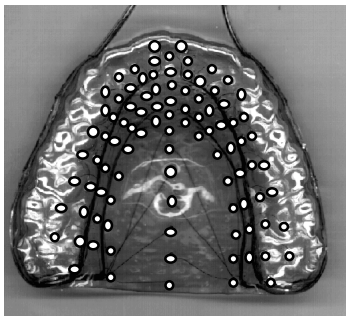

Figure X.4. Scanned image of pseudo-palate, with special layout of the 96 contact electrodes.

Subjects were not given overt instructions about the phrasing or prosody to be used in their readings of the sentences, except that Korean and Taiwanese speakers were asked to pause at a period but not pause at a comma. A native speaker experimenter monitored subjects' productions during the recording sessions and asked for repetitions of any sentences that did not have the desired phrasing. If a subject read, for example, a sentence testing an AP boundary with a larger break, the experimenter asked the subject to read that sentence again, though still without giving any overt instructions.

Subjects produced 20 repetitions of each sentence for the French and Korean studies. Because we wanted to obtain reasonably consistent prosody for each sentence type without overt instruction, sentences were not randomized. Instead, for a given test consonant, a subject produced 5 or 6 repetitions of one sentence, then 5 or 6 repetitions of another sentence, etc. through the set of sentences for

that consonant; then the same again, until all the repetitions of all the sentences for that consonant had been recorded, at which point the sentences for the other test consonant were begun. (The procedure for Taiwanese was slightly different and is described below.)

X.2.4. Data Measurement

Maximum linguopalatal contact was determined by calculating, for each data frame, the percentage of contacted electrodes over the 96 electrodes. The maximum value in each test consonant was recorded as the peak contact for that token. (Additional contact measures are reported in the papers describing the studies of French and Korean: Fougeron 1998, 1999, Cho & Keating 1999). Temporal measures were also made, including the number of frames showing a complete stop closure (articulatory seal duration), acoustic closure duration, and for voiceless stop /t/, acoustic VOT.

Reliable differences were determined by ANOVA and Fisher PLSD *posthoc* tests at the .05 level of significance. Separate ANOVAs were conducted for each consonant for each speaker, with the single factor Prosodic Position (i.e. the test sentence type). Regressions of peak contact on seal duration were calculated separately for each consonant x language x speaker condition.

X.3. Methods and results for each language

X.3.1. French

X.3.1.1. Methods

Experiments on French have been reported in Fougeron & Keating (1996), and much additional data is included in Fougeron (1998, 1999). Two subjects participated in this study: one of the authors (female, Speaker 1) plus one other subject (male, Speaker 2). The test consonants reported on here were unaspirated /t/ and /n/. /n/ was in a /a_a/ context, /t/ in a /ɔ̃_ɔ̃/ context.

X.3.1.2. Results

EPG results are shown in Figures X.5a-b. First, for the peak contact data, in Figure X.5a, there was an effect of prosodic position for both speakers, with a generally cumulative increase of contact from lowest to highest domains. More distinctions are made for /n/: both speakers distinguish all domains except IP from Utterance. For /t/, not only is the distinction between Utterance and IP unclear (in fact, it is reliably reversed for one speaker), but also the distinction between Word-initial and Syllable-initial is not made. The reliable differences,

then, are those between a large phrasal domain (IP, Utterance), a small one (AP), and something smaller (Word or Syllable). Detailed analysis of contact in the front region of the palate showed that the greater contact in higher prosodic positions was mainly located in the posterior part of that anterior region. This difference is seen in the sample tokens shown in Figure X.6, along with other differences presumably reflecting the height of the tongue body.

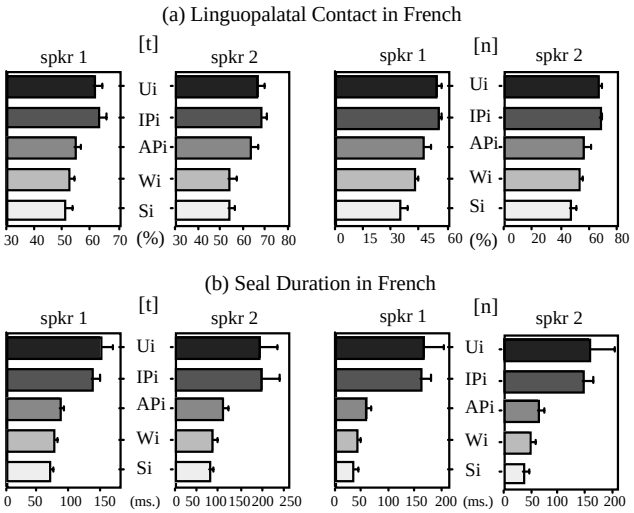

Figure X.5. Data for French, displayed as in Figure X.2. (a) Peak EPG contact for /t, n/; (b) Articulatory duration for /t, n/.

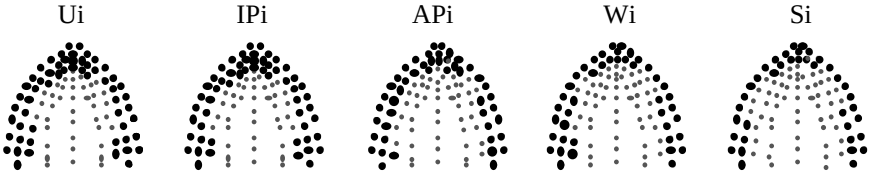

Figure X.6. Sample French tokens for /n/ showing contact patterns across prosodic positions.

The duration data show fewer distinctions. The duration of the articulatory closure or seal, in Figure X.5b, shows a large difference between U/IP and the smaller domains. Which of the further, smaller, differences are reliable varies between the speakers. However, the overall lengthening pattern is cumulative like that for contact, and indeed the two measures are well-correlated (r^2 from .6 to .76). Acoustic duration of /n/ (not shown in the figure) shows lengthening at beginnings of lower domains, but IP- and U-initial /n/s are very short. Acoustic closure duration of /t/ (not shown in the figure), measured only for the lower

domains because they involve no pause, patterns similarly to /n/ (and to articulatory duration, not surprisingly). For VOT of unaspirated /t/, shown in Figure X.7a, there was little effect of prosodic position. The only difference found for both speakers was between Syllable-initial and IP-initial positions.

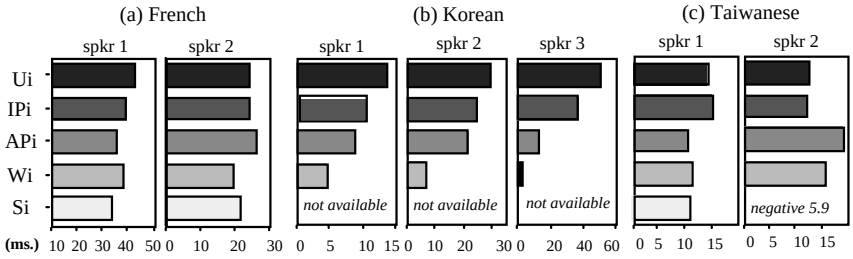

Figure X.7. (a) French VOT, (b) Korean VOT & (c) Taiwanese VOT for /t/ across prosodic positions.

X.3.2. Korean

X.3.2.1. Methods

Three subjects participated in this study, one of the authors (male, Speaker 2) and two others (one male, Speaker 1, and one female, Speaker 3). The complete study included test consonants /n t t^h t*/ (where /t*/ refers to a fortis stop); here we report on only /t/ (the lenis stop) and /n/ as these are the consonants most comparable across the three languages. Detailed comparisons of the four test consonants, are reported elsewhere (Cho & Keating, 1999). All of the domains in Figure X.3 were included; however, two corpora were used for each consonant, one for comparison of higher-level domains, another for word-level domains. Otherwise we could not construct meaningful and grammatical sentences. In the higher-level corpus, for domains Utterance, IP, AP, and Word, both /t/ and /n/ were in a /a_a/ context. In the lower-level corpus, for domains Word vs. Syllable, /n/ was in a /o_ɛ/ context and /t/ was in a /a_a/ context.

X.3.2.2. Results

EPG results are shown in Figures X.8a-b. First, in the overall contact data, shown in Figure X.8a, all prosodic levels are generally distinguished by all the speakers for both test consonants, except that Speaker 3 does not have more contact for AP-initial than for Word-initial for either consonant and Speakers 1 and 3 do not differentiate W-initial from S-initial /t/.

Figure X.9 shows sample tokens. Here we can see that higher domains have more front contact, as well as more back contact. Figure X.9 also shows a shift in the nominal place of articulation (which depends on the location of the frontmost

contact), due to a loss of dental contact as the stop moves from higher to lower domains. This difference is consistent for all three speakers for /n/. When this consonant has more contact, its nominal place of articulation is denti-alveolar, but when it has less contact, its place is palato-alveolar. There is a similar, but less dramatic, effect for /t/: when /t/ has less contact, its place is alveolar.

With articulatory seal duration, in Figure X.8b, the phrasal domains are consistently distinguished by lengthening, but lower levels (AP vs. Word, Word vs. Syllable) are generally not distinguished. Nonetheless, articulatory duration is well-correlated with peak contact (r^2 from .77 to .91). Acoustic duration (not shown in the figure) is consistently cumulative when pooled across speakers, but the individual speaker data are not so consistent. Finally, VOT for /t/, shown above in Figure X.7b, distinguishes all four levels tested in Korean.

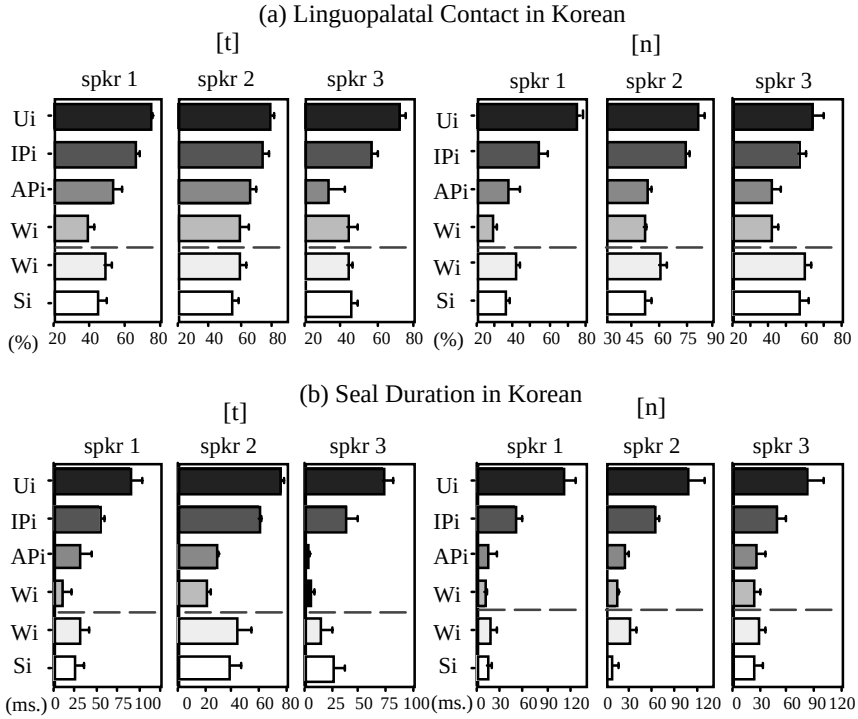

Figure X.8. Data for Korean, displayed as in Figure X.2. (a) Peak EPG contact for /t, n/; (b) Articulatory duration for /t, n/. Dashed horizontal line in each panel separates data from two different speech corpora; the two Word-initial conditions are not directly comparable.

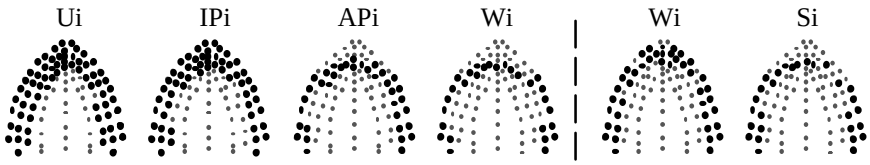

Figure X.9. Sample Korean tokens for /n/ showing contact patterns across prosodic positions.

X.3.3. Taiwanese

X.3.3.1. Methods

Two subjects participated in this study, reported in Hayashi et al. (1999): one of the authors (female, Speaker 1) plus one other subject (male, Speaker 2). The test consonants were unaspirated /t/ and /n/, followed by /a/ with a surface mid-level tone, preceded by another /a/. The corpus for /t/ consisted of sentences containing real words, as in French and Korean, but the corpus for /n/ consisted of reiterant versions of the /t/ corpus, in which all syllables in the model sentences were instead pronounced as /na/.

The sentences were presented to the subjects written in Mandarin, to be translated by the speaker. Because the speakers were reading Mandarin and translating into Taiwanese, all the repetitions of a test sentence were done in a single block. Speaker 1 read ten repetitions of each test sentence containing /t/ and six repetitions of the reiterant versions with /n/. Speaker 2 read fifteen repetitions of each test sentence containing /t/ and ten repetitions of the reiterant versions with /n/.

X.3.3.2. Results

Results are shown in Figures X.10a-b. The overall effect of position on peak contact was highly significant for both speakers for both consonants. Differences are larger for /t/ than for /n/, but posthoc comparisons were generally significant at the .0001 level. Nonetheless, Speaker 1 failed to distinguish most levels for /n/ (distinguishing only one pair of domains, IP vs Small Phrase SP), and did not distinguish U from IP for /t/. In contrast, Speaker 2 distinguished all four pairs of levels for /t/ and three for /n/, SP vs W being the only exception. The effect of position on articulatory seal duration was less consistent. Both speakers made at least a two-way distinction, between higher domains (U and IP) vs. lower domains, for both test consonants. Speaker 1 additionally distinguishes SP, W, and S for both consonants except between W and S for /t/, while Speaker 2 distinguishes all levels but SP vs W for both consonants. In contrast, VOT for /t/, shown above in Figure X.7c, does not vary systematically with prosodic position.

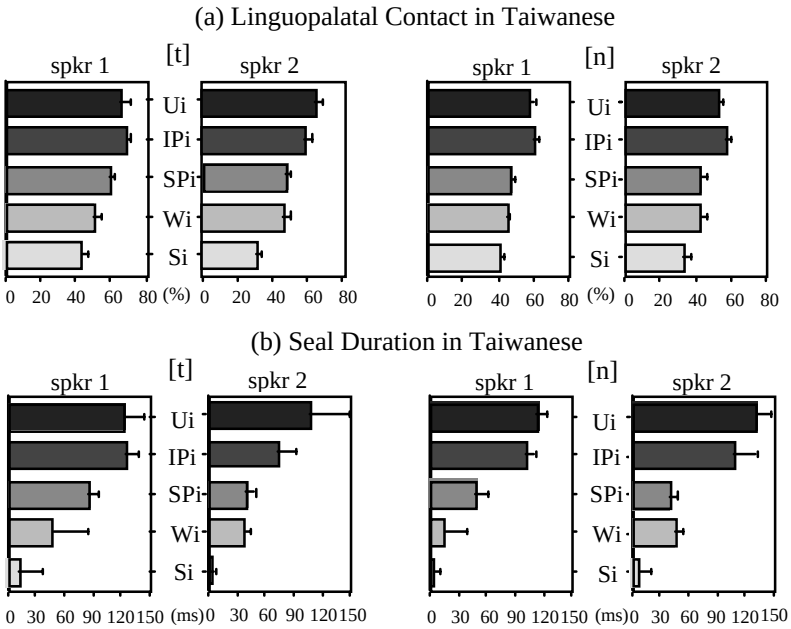

Figure X.10. Data for Taiwanese, displayed as in Figure X.2. (a) Peak EPG contact for /t, n/; (b) articulatory duration for /t, n/.

X.4. Discussion

X.4.1. Domains

These experiments show clearly that there is phrasal/prosodic conditioning of articulation across languages: every subject makes at least one distinction (Word-internal vs. phrase-initial) and all speakers but one make at least one further distinction above the Word level, for every consonant studied. This conditioning generally affects both linguopalatal contact, which reflects overall height of the tongue, and also duration, so the total effect is on contact-over-time. At the same time, the prosodic effects can be seen to differ across speakers and consonants within a language. It differs enough that we cannot say that any single prosodic hierarchy is exhibited by all languages and speakers, or that speakers are marking every level of a hierarchy.

In general, the distinction between two phrasal levels is robust, with all speakers distinguishing between a “high” phrasal domain and a “low” phrasal domain. In contrast, some other differences are not so robust. Most notably, Utterance is not consistently distinguished from Intonational Phrase. A phonetic distinction was found most clearly in Korean, where the difference between

Utterance and IP was specifically linked to pausing. Thus our Korean results support a break level "5" above the IP based on pausing, as posited for English by Price, Ostendorf, Shattuck-Hufnagel & Fong (1991). However, this difference was not consistently found in Taiwanese.

Also in our results, Word-initial position is not consistently distinguished from both Syllable-initial and Small Phrase-initial positions, and this is so whether our "words" are morphologically complex (English, Taiwanese) or simpler (French, Korean).

The experiments presented here allow some comparisons of the relative sizes of different effects on linguopalatal contact. First, since results are reported for two consonants, we can ask how the prosodic effect compares with the inherent segmental effect. In general, nasals have less contact than voiceless orals. It turns out that this difference is about the same in magnitude as the difference between pairs of prosodic positions. Compare, for example, French AP-initial /t/ for Speaker 2 with both Word-initial /t/ (prosodic comparison) and AP-initial /n/ (inherent segmental comparison) in Figure X.5a. The scales of the figures are not identical, but there is about a 10% difference in both comparisons. Another comparison is found in the two corpora for "higher" and "lower" domains in Korean, in Figure X.8a. In the "higher" corpus, the Word is the lowest domain tested, while in the "lower" corpus it is the highest domain. The Word-initial consonants in the two corpora appear in different vowel contexts for /n/, which affect the contact location and extent. Again, this effect of vowel context turns out to be about the same as the difference between pairs of prosodic positions.

We have also presented data on articulatory and acoustic duration, and on VOT. In all of the languages, prosodic position affects consonant duration, but articulatory duration seems to reflect fewer prosodic distinctions than does peak contact. That may be in part because of the coarser grain of the duration measure (10 ms intervals) compared to % contact (96 electrodes). Similarly, our other temporal measure, VOT of /t/, is also not especially sensitive to prosodic position, varying with prosodic position in Korean but not in French or Taiwanese.

X.4.2. Languages

Despite the various predictions made about possible language differences, the languages in this study show quite similar effects of prosodic position. As noted already, the French, Korean, and Taiwanese speakers all distinguished IP from the smaller phrase by the peak linguopalatal contact of the domain-initial consonants. The only systematic difference in the results from the various languages is the more consistent distinction between Utterance and Intonational Phrase in Korean compared to Taiwanese, even though the speech materials and instructions were similar in the two cases.

We had predicted differences between French and Korean because of the differences in other aspects of the realization of their Accentual Phrases; in particular, we expected Korean to reinforce AP beginnings more than French. It is true that the Korean speakers distinguished all the prosodic domains in terms of contact more consistently than did the French speakers. However, with respect to the Accentual Phrase, the two languages are very similar, and the only lack of a distinction was by a Korean speaker. Thus our prediction was not borne out.

An intriguing difference between these two languages, though, concerns the strength of the correlations between initial consonant duration and contact across all the prosodic domains: these are higher in Korean. We interpret a strong relation between these variables as suggesting a temporal basis for strengthening, with shorter consonants undershooting the contact pattern shown by longer consonants. This relation in Korean is explored by Cho & Keating (1999), who provide support for an undershoot account. Interestingly, Korean was also the only language to show an effect of prosodic position on the VOT (a temporal measure) of /t/. So there may well be a special pairing of temporal and spatial properties in domain-initial position in Korean compared to other languages.

We had also predicted that initial strengthening could be stronger in Taiwanese than in other languages because, as a lexical tone language, it should have less recourse to pitch to mark domain edges. There is no support for such a hypothesis in these data.

In conclusion, we have shown that consonant articulation is subtly sensitive to a range of prosodic domains in similar ways in several languages. Linguistic structure is relevant for even fine phonetic detail, and prosodic constituency can be marked by details of articulation as well as by the traditional prosodic parameters.

Notes

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Appendix

Table X.2. Corpus for French /t/

Positions	Test Consonant /t/ in /õ_õ/
Ui	J'ai vu Tonton. **Th**on lui parlait.
	I have seen Uncle. Thon was speaking to him
IPi	Le pauvre Tonton, **Th**on et Jacques sont déja partis.
	Poor Uncle, Thon and Jacques have already left
APi	Tata, Tonton, **Th**on et Jacques sont là-bas.
	Auntie,Uncle, Thon and Jaques are over there
Wi	C'est bien Tonton-**Th**on qui est là-bas.
	It's indeed Uncle Thon who is over there
Si	C'est bien ton ton**t**on qui est là-bas..
	It's indeed your uncle who is over there

Table X.3. Corpus for Korean /t/ ('*' refers to fortis series of obstruents)

Positions	Test Consonant /t/ in /a_a/
Ui	igosin patak***a.** **ta**mbiga jəgisə nɛɾinda
	This place is the seashore. 'Sweet-rain' falls down here.
IPi	igosin patak***a,** **ta**mbiga nɛɾinin koʃida
	This place the seashore, where the 'sweet-rain' falls down.
APi	idiɾin modug**a** **ta**mbiɾil tʃoahanda
	These people all like 'sweet-rain.'
Wi	idiɾin patak***a** **ta**mbiɾil tʃoahanda.
	These people like 'seashore sweet-rain.'
(word-level)	
Wi	idiɾin kogjesa **ta**ɾiɾil tʃabat*a.
	These people held the legs of the acrobat.
Si	idiɾin kogje sa**ta**ɾiɾil tʃabat*a.

These people held the circus ladder.

Table X.4. Corpus for Korean /n/ ('*' refers to fortis series of obstruents)

Positions	Test Consonant /n/ in /a_a/ and /o_ɛ/
Ui	igosɨn patak***a.** **na**mdʒuga jəgisə sanda.
	This place is the seashore. Namjoo lives here.
IPi	igosɨn patak***a,** **na**mdʒue kohjaŋida.
	This place is the seashore,(which is) Namjoo's hometown.
APi	igosɨn patak***a** **na**mtʃ*oge it*a
	This place is located to the south of the seashore.
Wi	igosɨn patak***a** **na**mdʒaga sanin koʃida.
	This place is where the seashore man lives.
(word-level)	
Wi	kɨjədʒanin maɾimm**o** **nɛ**giɾil tʃɛanhɛt*a.
	The woman suggested betting with the parallelogram (on it)
Si	kɨjədʒanin jərim m**onɛ**giɾil tʃɛanhɛt*a.
	The woman suggested fall harvest.

Table X.5. Corpus for Taiwanese /t/

Positions	Test Consonant /t/ in /a_a/
Ui	wa u k^huã-tiɤ papa^{55}. **ta^{23}ta^{55}** k^hai iaʔ be lai?
	I can see Dad. Why isn't Tata here yet?
IPi	wa k^huã-tiɤ a! papa^{55}, **ta^{23}ta^{55}** k^hai iaʔ be lai?
	I see it. Dad, why isn't Tata here yet?
APi	hit e laŋ e papa^{55} **ta^{31}-tiɤ^{31}** tsit-tsia katsuaʔ.
	That person's dad stepped on a cockroach.
Wi	wa ka li kɥŋ, papa^{55} **ta^{31}-tiɤ^{31}** tsit-tsia katsuaʔ.
	Let me tell you, Dad stepped on a cockroach.
Si	wa kina k^huã-tiɤ **ta^{33}ta^{33}** tsim a kɤ iŋ kiã.
	Today I saw Auntie Tata and her child.