

A three-way VOT contrast in final position: data from Armenian

Narineh Hacopian

Linguistics Department, University of Southern California, Los Angeles,

nhacopian@yahoo.com

Standard Eastern Armenian has a three-way VOT contrast among its oral stop series. While it is rare for such a 3-way contrast to be preserved in final position, Standard Eastern Armenian is claimed to do just this (Khachaturian 1988; Ladefoged & Maddieson 1996; Vaux 1998). This phenomenon provides an ideal opportunity to explore how prosodic structure influences the realization of a complex and delicate system of contrast maintained by temporal and saliency distinctions. The cues to this contrast, including VOT, closure duration, and burst amplitude, are examined in a variety of segmental and prosodic environments. The experiment evaluates effects of intonation phrase final, intermediate phrase final, word final, and syllable final positions. We find that the 3-way VOT contrast is maintained in those prosodic domains in which the stop consonants are final. Speakers make significant VOT distinctions among the target consonants within the same boundary condition, and across prosodic conditions, larger prosodic domains exhibit longer VOT values.

1 Introduction

It is experimentally verified and well accepted that prosody affects articulatory gestures in speech. That is, the relative position of a particular segment in an utterance plays a role in its production. This linguistic positioning is characterized prosodically. Prosody is defined by Beckman & Edwards (1992: 359) as ‘the organizational structure that measures off chunks of speech into countable units of various sizes’. Numerous studies have observed variations in the production of segments in different prosodic contexts. These variations have been described in the context of articulatory duration of the target, in the amount and duration of linguo-palatal contact of the target, in terms of the temporal coordination of the gestures of the target segment(s) and in Voice Onset Times (VOT) of the target segment (Beckman & Edwards 1992, Wightman, Shattuck-Hufnagel, Ostendorf & Price 1992, Shattuck-Hufnagel & Turk 1996, Keating & Fougeron 1997, Byrd, Kaun, Narayanan & Saltzman 2000, Cho & Jun 2000).

1.1 VOT and Prosody

Before proceeding to our own experiment, it is useful to briefly review what is known about how phrasal structure influences VOT. Cho & Jun (2000) explore the nature of these observed effects in the context of contrastive phonemes by examining aerodynamic data from minimal

triplets of voiceless stops in Korean. The authors found longer VOT values and greater airflow in increasingly higher prosodic positions for aspirated and lenis stops, and lowered VOT and airflow for fortis stops in higher prosodic positions. They dub these asymmetric effects 'enhancements' of laryngeal features in domain-initial position. Such effects in initial position have been referred to as processes of domain-initial strengthening, where strengthening refers to spatially larger gestures, such as consonants having increased linguo-palatal contact (Keating, Cho, Fougerson & Hsu (1998), and/or more generally, segments becoming more distinct from neighboring segments. Further, Cho & Jun conclude that domain-initial strengthening provides cues for prosodic structure by maximizing paradigmatic contrast. While additional study is required to determine whether these enhancements are salient perceptual cues, their results demonstrate that VOT of domain-initial segments are modified as a function of prosodic position.

Fougerson (2001) provides an examination of how segmental articulation is affected by prosodic structure with data from French. While she concedes that the relevance of her findings for perception remains to be seen, Fougerson shows that in French too, segments vary with respect to their production in initial positions of various prosodic domains. With respect to VOT, a common variation Fougerson found is that VOT for /t/ was shorter in syllable-initial position as opposed to initially in an accentual phrase and initially in an intonational phrase. On the other hand, Fougerson did not find any differences in VOT duration for /k/ depending on prosodic position. Fougerson does not explain or discuss this asymmetry. In general she shows that the articulation of various segments can be affected by their relative prosodic position, and that 'the magnitude of the variation observed between the segments in initial position [in various prosodic domains] tends to follow the prosodic level of the constituents' (Fougerson 2001: 125). Similarly, Pierrehumbert & Talkin (1992) found that in English, phrase-initial /h/s had a lower RMS than phrase-medial /h/s. This difference in RMS indicated to the authors 'that the gestural magnitude was greater in phrase-initial position' (p. 111). That is, /h/ was interpreted as having 'a more extreme consonantal outcome' initially after a phrase boundary than phrase-medially due to lower RMS values for the /h/ (p. 111).

Jun (1995) shows that the voicing of lenis stops in Korean is dependent on their prosodic position and suggests that voicing is a function of duration. That is, the presence of voicing is related to the duration of the stop closure. In addition, she finds that word-initial and word-final lenis stops are significantly longer than lenis stops in word-medial position. Jun proposes a gradient scale with the 'strong' (and therefore voiced) lenis stops associated with the onsets of Accentual Phrases on one end and the 'weak', voiceless lenis stops not associated with initial position on the other. Here, 'strong' refers to the longer duration and larger amplitude of the glottal opening gesture and oral gesture characteristic of the accentual-phrase initial lenis stops; and 'weak' refers to lenis stops anywhere else inside a word which typically have smaller amplitudes and shorter durations (Jun 1995: 248). Cho & Keating (2001) also show that various acoustic properties such as VOT, total voiceless interval, and stop burst energy vary depending on prosodic position and that the higher the prosodic position, the greater the change in the particular property. VOT, for example, was found to be longer when the voiceless unaspirated and aspirated Korean stops occurred in higher domain-initial positions.

Pierrehumbert & Talkin (1992: 109) note that 'phrase-final voiced consonants are also typically devoiced' in English. Additionally, in comparing their study to Beckman, Edwards & Fletcher's (1992) findings on phrase-final articulation, they note that Beckman, Edwards & Fletcher's interpretation 'leads to the conclusion that phrase-initial and phrase-final effects are different in nature' (p. 111).

These previous studies all focus on the effects of prosody on the initial segments of various phrasal domains. In general, the findings show that phrase-initially, segmental articulation is affected in terms of lengthening of the segment, greater articulatory magnitude, longer VOT values, etc. Moreover, the studies show that the higher the phrasal domain, the greater the magnitude of the observed effect. Few of these studies have explored what articulatory modification occurs phrase-finally, with the exceptions of Beckman & Edwards (1992) and

Byrd & Saltzman (1998). If it is the case that phrase-initial domains alone are the targets of these strengthening processes, then we might expect to find the opposite effects (i.e. weaker or shorter articulations, smaller VOT values), or no effect at all, in the production of segments in final positions of these domains. The present study seeks to explore this question with regard to stop realization. Are phenomena observed domain-initially, such as elaboration of VOT contrasts, mirrored domain-finally? How, if it all, does this interact with the lengthening we expect domain-finally?

1.2 VOT

Languages vary with respect to the number of contrasts in their stop series. These contrasts are often identified along a Voice Onset Time (VOT) continuum where VOT is defined as the time from the release burst of the stop consonant to the onset of vocal fold vibration. Long (positive) VOT durations correspond with the aspirated category of stops; zero or near zero VOT corresponds to the lack of aspiration or the unaspirated category of stops. Negative VOT defines the duration of voicing during the closure of a stop consonant preceding the release and corresponds to the category of voiced stops.

Phoneme inventories with three-stop series are not rare in the world's languages; Maddieson's (1984) study shows that 25 percent of the world's languages have them in their phonemic inventory. However, it is rare for a 3-way laryngeal contrast to be preserved in final position, and Eastern Armenian is cited as just that type of language (Khachaturian 1988; Ladefoged & Maddieson 1996; Vaux 1998). In their discussion of voiceless aspirated stops in the world's languages, Ladefoged & Maddieson (1996: 66) use Eastern Armenian as an example of a language where contrasts between voiced, voiceless unaspirated and aspirated stop occur in final position. Khachaturian (1988: 149) notes 'Armenian's voiced consonants are generally fully voiced in word-medial and word-final positions'. («Հայերենի ձայնեղ բաղաձայնները սովորաբար լիարժեք բաղաձայններ են բառամիջի և բառավերջի դիրքերում:»)

Ladefoged & Maddieson (1996) present waveforms of three words with velar stops in final position and note that 'the /g/ is voiced throughout the closure and vocal fold vibrations continue after closure is released, whereas /k/ has voicing for only a few periods immediately after the beginning of the closure' (p. 66). They also note that the voiceless closure has a longer duration and there is no difference between the lengths of the preceding vowels before either the voiced or voiceless unaspirated stops. As for the voiceless unaspirated and aspirated stops for their speaker, Ladefoged & Maddieson find that the difference between them lies in the strength of their release: 'the voiceless unaspirated stops are weakly released or (in other data from this speaker) not released at all, whereas the aspirated stop has a shorter closure and a noticeable burst followed by noisy airflow that is sustained for some considerable time' (p. 67).

Thai is also known for its voiceless aspirated, voiceless unaspirated and voiced series of stops (Ladefoged & Maddieson 1996, Tingsabadh, Kalaya & Abramason 1999), and Thai is particularly known for the processes of laryngeal neutralization this series undergoes (Vaux 1998: 15). Specifically, all syllable-final (oral) stops are voiceless unaspirated in Thai (Tingsabadh et al. 1999: 149). Vaux (1998) does not explicitly mention that Eastern Armenian has this 3-way contrast in all positions (word-initially, -medially, and -finally). He presents examples of words in Eastern Armenian where word-final voiced stops and affricates are devoiced following a vowel; however, he also presents examples of words which do not undergo any such neutralization (pp. 16–17). Vaux does not present any acoustic data to support the example words, nor does he mention in what context these processes are active (i.e. in connected speech or in isolation). With respect to other neutralization processes, Vaux talks about a process he calls 'R-Aspiration', where voiced stops and affricates change to voiceless aspirates following /r/. The present author does not disagree with Vaux's examples, but she believes that they are not from the dialect examined in this paper. Vaux also notes that some continuants devoice in final position, notably /r/, /ʒ/ and /ʁ/, and considers these

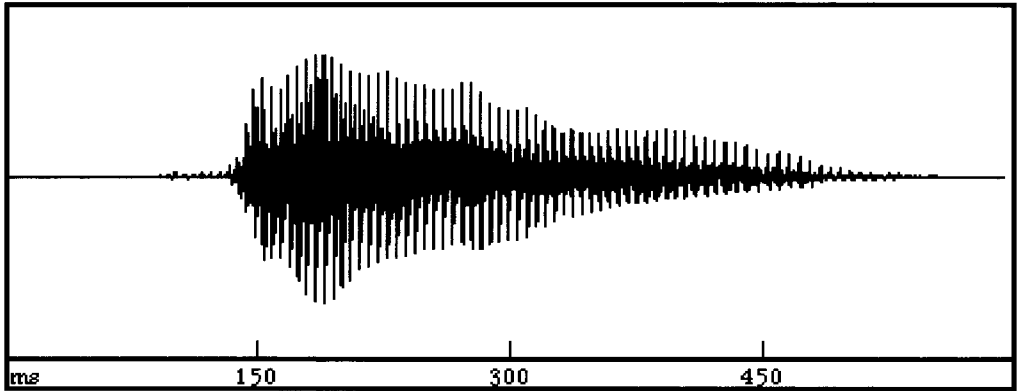


Figure 1 [bɑji] 'good'

examples of a more complicated variant of Thai in terms of the laryngeal neutralization processes it undergoes. In this case, his observations do not pertain to stop consonants and, as such, they do not conflict with our findings that follow. In summary, Eastern Armenian is one of a few languages, if not the only one, that is reported not to undergo laryngeal neutralization with respect to its 3-way VOT contrast in 'final' position.

1.3 Armenian

Armenian is an Indo-European language whose two major dialects are Standard Eastern Armenian and Standard Western Armenian. Standard Eastern Armenian is spoken in the Republic of Armenia and by the Armenian population of Iran. Standard Western Armenian is spoken by the Armenian populations in other Near and Middle Eastern countries. One of the notable differences between most Standard Eastern and Standard Western Armenian dialects is that Standard Eastern Armenian has three laryngeal contrasts in stops whereas most Standard Western Armenian dialects have only two. The three-stop series of the Eastern dialects includes voiced and voiceless unaspirated stops, and voiceless aspirated stops. The affricates pattern with the stops in also having three-member series. Standard Eastern Armenian (SEA) is the literary language of the Republic of Armenia, Iranian Armenians and Armenians of the former USSR. This paper will address Standard Eastern Armenian as it is used in Tehran, Iran (henceforth, Tehran SEA).

In initial position, these stops present a canonical three-way contrast, as exemplified for the speaker shown in figures 1, 2, and 3. The voiced stop [b] in figure 1 has a VOT of -139.1 milliseconds. The voiceless unaspirated stop [p] in figure 2 has a VOT of 13.1 ms, and the voiceless aspirated stop in figure 3 has a VOT of 69.8 ms. These words were produced in isolation.

Previous studies have classified the unaspirated voiceless stops of Eastern Armenian in various categories. Allen's (1950) account of the Eastern Armenian dialect of New Julfa identifies the voiceless unaspirated stops as ejectives. According to Fairbanks (1975) the Eastern Armenian voiceless unaspirated stops are glottalized stops because 'there is no release of breath, or aspiration' and because 'during the production of these consonants the vocal cords are closed and then released' (p. xvi). Fairbanks does not provide any acoustic data to verify his description. Fairbanks's sources include a speaker of Eastern Armenian from the (then) Armenian S.S.R. and a speaker from Tabriz, Iran. However, most other accounts of Eastern Armenian (Khachaturian 1988, Vaux 1998) do not classify the voiceless series as ejectives. According to her experimental data, Khachaturian (1996) says that while

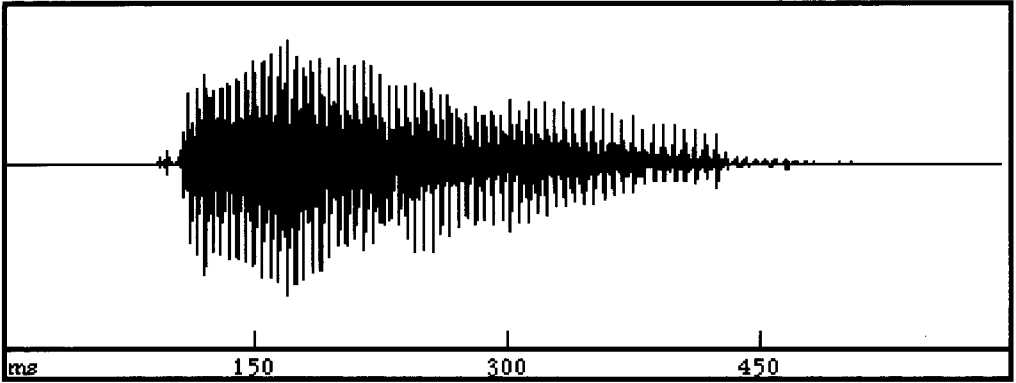


Figure 2 [pa:ɪ] 'dance (gen.)'

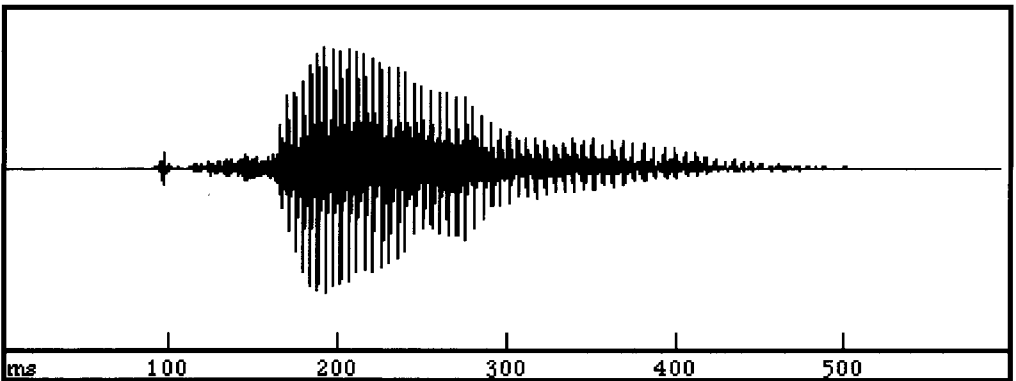


Figure 3 [pʰa:ɪ] 'first fruit a tree bears (gen.)'

'ejective articulation does exist in Armenian, it is not the norm' (p. 187). Along the same lines, Ladefoged & Maddieson (1996: 67) mention that several of their speakers probably had a 'glottal closure accompanying final unaspirated stops, and in some cases these sounds are weakly ejective'. However, Henton, Ladefoged & Maddieson (1992) classify these stops as voiceless unaspirated. The author, a native speaker of the SEA dialect spoken in Tehran and a trained phonetician, views these stops by Tehran SEA speakers to be simply voiceless unaspirated.

There are several descriptive accounts of the preservation of this contrast in final position (Allen 1950, Khachaturian 1988, Ladefoged & Maddieson 1996, Vaux 1998). While these studies report this three-way contrast to be present in word-initial, -medial, and, notably, -final contexts, these reports are based largely on data collected in citation form, with words spoken in isolation. Ladefoged & Maddieson's (1996) data was elicited in citation form (P. Ladefoged, p.c.) from an unspecified number of speakers (p. 67). Allen (1950: 180) notes that his study 'is based on a dozen listening sessions with a single informant and should not be considered as exhaustive nor as necessarily applicable to all speakers of the dialect in question', and he goes on to say that 'with a few exceptions, the present description does not go beyond the word-level of analysis'. Few studies provide a systematic and in-depth acoustic account of these contrasts, and few describe what is meant by 'final position'. Final position

can refer to various positions, for example, word-final, phrase-final (but utterance-medial), and utterance-final. In addition, 'final position' alone does not explain in detail the context of the target segment; what type of segment, if any, follows the target segment must also be considered. It is not clear, therefore, whether (and how) these contrasts persist in various prosodic contexts in continuous speech.

1.4 Overview and experiment

This study seeks to explain the precise nature of the Eastern Armenian contrast by examining the acoustic characteristics of the stop consonants in various prosodic and segmental conditions in the speech of native speakers of Tehran SEA. It is possible that these contrasts are not maintained in the various conditions we test. Neutralization of such contrasts is often observed in final positions (i.e. coda, word-final, phrase-final, utterance-final, etc.). Neutralization processes have been demonstrated for example, in the well-known case of coda devoicing in Dutch (Kager 1999: 14). Steriade (1997) presents a survey of neutralization processes in several languages. Steriade's approach argues against a syllable-based account of neutralization. For Lithuanian, Greek, Sanskrit, Russian, and Polish, Steriade shows that syllable-based analyses do not account for all the neutralization data, and she shows that 'any observable connection between being a coda and being laryngeally neutralized represents an accidental by-product of facts unrelated to syllable structure' (p. 25). Steriade shows that laryngeal gestures are licensed or neutralized not based on their syllabic position but on the availability of perceptual cues for those contrasts. Likewise, Flemming (1995; J. Jun 1995; and Kirchner 1995, 1997 'argue that perceptual information should be directly stated in grammars, thus allowing reference to gradient and non-contrastive phonetic features' (Kager 1999: 408).

On the other hand, phonologists such as Lombardi (1995) and Beckman (1997a, b) support the notion of positional faithfulness, in which syllable position determines whether segments retain contrastive features. Lombardi (1999) presents an Optimality Theoretic account (Prince & Smolensky 1993) of laryngeal neutralization in various languages with a positional neutralization approach.

Eastern Armenian, with its reported maintenance of a 3-way contrast, provides an ideal testing ground to explore how suprasegmental structure such as phrasal structure influences the realization of a complex and delicate system of contrast maintained by temporal distinctions – one of the primary aspects of segmental articulation that has been demonstrated to be affected by prosodic structure. We will examine the acoustic characteristics of the consonants in various prosodic and segmental conditions.

The following questions are investigated:

How is this 3-way stop contrast preserved acoustically?

- a) How is the realization of this 3-way contrast affected by the particular prosodic domain in which stop consonants are final?
- b) How is the realization affected by the voicing of the following sound or the lack of a following segment?

Oral stop consonants are examined in the following prosodic contexts:

- word-internally
- word-finally, phrase medially
- finally, in an intermediate phrase boundary
- finally, in an intonational phrase
- pre-pausally (i.e. at the end of an intonational phrase, followed by silence)

Additionally, in order to answer question (b) above, the stops in each of these conditions (except pre-pausal) will be followed by a vowel ([a]), a voiceless aspirated stop ([k^h]), and a (voiced) nasal stop ([ŋ]). This is of interest because we have observed in unrelated

Table 1 Prosodic and segmental contexts of target consonants.

Word-internal	Word Boundary (#)	Intermediate Phrase	Intonational Phrase	Pre-pausal
#...VC _a ...#	VC#a	VC] _{sp} sp[a	VC] _{IP} IP[a	VC _a] _{IP} ∅
#...VC _{k^h} ...#	VC#k ^h	VC] _{sp} sp[k ^h	VC] _{IP} IP[k ^h	VC _{k^h}] _{IP} ∅
#...VC _n ...#	VC#n	VC] _{sp} sp[n	VC] _{IP} IP[n	VC _n] _{IP} ∅

denotes a word boundary, [] denotes a phrase boundary, C denotes the target consonant (/p/, /p^h/ or /b/) and V is the vowel.

work processes in the language where consonant clusters involving the uvular fricative show agreement with an adjacent segment with respect to laryngeal gestures. It is of potential importance to determine whether the context of a following (voiced) vowel, voiceless consonant, or voiced consonant affects the realization(s) of the target segment.

This study of the three-way stop contrast in various segmental and prosodic conditions investigates whether or not the contrasts are maintained and, if so, in which conditions. Further, we are able to determine what acoustic parameters participate in maintaining the contrasts, and which acoustic variables are affected when a contrast is neutralized. While previous studies have looked at the effects of prosodic structure on segmental articulation, few have done so in the context of phonemic contrasts, with the exception of Cho & Jun (2000).

2 Methods

2.1 Stimuli

Table 1 shows the various prosodic contexts in which the contrasts are examined, where C, the target consonant, is at the bilabial place of articulation (/p/, /p^h/ and /b/), and V represents a vowel. With a few exceptions, the vowel preceding and following the target junctures is /a/ (see appendix B). (Note that in the word-internal VC [a] condition, the consonant is a syllable onset, rather than a coda, as in the other conditions.)

All of the stimuli are shown in appendix A; they were prepared by the investigator and reviewed by another native speaker to ensure well-formedness. The sentences were constructed such that there were approximately the same number of syllables before and after the target sequence in the sentence. Within each block, the sentences were kept as similar as possible with respect to content. With four exceptions, the vowels before and after the target juncture were all /a/. Of the exceptions, two were /ə/ and two were /o/. See appendix B for a complete chart with the target sequences, syllable counts and adjacent segment information. The word-internal target consonants appear within a single word followed by /a/, /n/, and /k^h/. In the word boundary condition, the target consonant is the final consonant of a word and the following word begins with either /a/, /n/, or /k^h/. In these sentences, it is not well formed to pause between the two words at the boundary. In the intermediate phrase boundary condition, the target consonant precedes the boundary between two intermediate phrases. (Beckman describes the intermediate phrase as a 'phrase [that] groups together words into stretches of speech having at least one accented syllable') Here, one target consonant is the final segment in one intermediate phrase and the following segment (an /a/, /n/, or /k^h/) is the first segment in the subsequent intermediate phrase. (The use of the ToBI terminology in reference to the phrases only serves to distinguish between the relative sizes of the phrases. Specifically, 'intermediate phrase', as it is used here, refers to a phrase larger than a word and smaller than an intonation phrase. There are no theoretical

claims being made with respect to Armenian phrasal structure, nor are there any assumptions being made for an Armenian ToBI system.)

A pause at the intermediate phrase juncture would result in a sentence that is not well-formed. The intonation phrase (IP) boundary condition has the target consonant at the end of one intonation phrase followed by /a/, /n/, or /k^h/ at the beginning of the next intonation phrase. An 'intonation phrase' is defined by Beckman & Elam (1997: 12) as a 'phrase [that] contains one or more intermediate phrases'. Additionally, 'the end of an intonation phrase is by definition the end of an intermediate phrase'. Intonation phrases are potentially separated by pauses, and their boundaries are associated with or marked by pitch modulations, or tone. Also, as reported by some of the studies reviewed above, their boundaries are marked by lengthening.

The near-minimal triplet [kɑrɑp] ('swan'), tarɑp^h ('rain torrent') and [ɑrɑb] ('Arab') were the words in which the acoustic properties of the final contrast were examined. In the word-internal condition, the plural and adjectival forms of these words contain the target sequences because the plural suffix in Armenian begins with a [n] and one adjectival suffix begins with [a]. In order to produce words with the necessary target sequence with [p^h], the carrier words are either real or plausible surnames. In the word boundary condition, the target sequence was at the boundary of either an adjective-noun sequence, or a noun-adjective sequence, where the adjective was descriptive of a state (e.g. awake, asleep) and where none of the word sequences would be uttered with a pause in between. The intermediate phrase boundaries were at the juncture of two 'small phrase' type constructions, where the last word in the first intermediate phrase was one of the three from the minimal triplet and the first word in the next intermediate phrase was either an adjective or an adverb. In the intonation phrase condition, the boundary was the end of one intonation phrase ending in one of the three words from the minimal triplet and the next intonation phrase beginning with a noun or adjective. The pre-pausal condition simply had an intonation phrase that ended with the word from the minimal triplet at the end and nothing more.

Examples of the contrastive phonemes were recorded in word-initial, -medial, and -final position in isolation in order to provide a benchmark against which to evaluate the same segments in connected speech.

2.2 Subjects

All subjects were native speakers of Tehran SEA from the greater Los Angeles area. Speaker 1 was a 56-year-old female who had lived in Los Angeles for 18 years. Speaker 2 was a 26-year-old female who had lived in Los Angeles for 18 years. Speaker 3 was a 65-year-old female who had lived in Los Angeles for 24 years. The author was not one of the subjects.

2.3 Data collection

Eight repetitions were collected from seven native speakers using a SHURE® unidirectional head-mounted dynamic microphone. The first three recordings are included in this study. The stimuli were separated into five blocks according to the prosodic boundaries shown in table 1 above. This was done in order to limit the variability of the readings of the utterances within any particular prosodic condition. Each subject read the blocks in a random order with the utterances also randomized in each block for each subject. Finally, a repetition of a block did not begin with the same block as the last one from the previous repetition. No instruction was given as to how the various utterances should be produced other than a natural conversational style. Where a subject stumbled over the words in the course of reading a sentence, the subject was asked to repeat that particular sentence if and only if their reading error took place before or at the target sequence.

2.4 Data analysis

The recordings were digitized on a Macintosh G4 with Macquiner by Scicon R&D. In order to investigate the acoustic cues to this contrast, the following were measured for each token:

1. VOT (negative (prevoicing) and positive (aspiration) duration)
2. closure duration
3. burst presence/absence
4. burst amplitude
5. preceding vowel length

Depending on the particular token, three, five, or seven timepoint measurements were made of each stimulus. If the stimulus had a target sequence which consisted of two consonants, then there were seven data points that were measured (where Consonant₁ is the target stop consonant). The data points were:

1. Vowel₁ beginning
 - cues: initiation of voicing, initiation of formants
2. Consonant₁ Closure
 - cues: sudden amplitude drop, loss of formants
3. Release Burst for Consonant₁
 - cues: transient (first burst if double)
4. Consonant₂ Closure
 - cues: sudden amplitude drop, loss of formants
5. Release Burst for Consonant₂
 - cues: transient (first burst if double)
6. Vowel₂ beginning
 - cues: initiation of voicing, initiation of formants
7. Vowel₂ end
 - cues: sudden amplitude drop, loss of formants
8. Burst Amplitude
 - cues: intensity reading from burst interval on waveform

If the stimulus was one from the pre-pausal condition, then there were only three data points that were measured. Burst amplitude was measured in the waveform from the intensity data as calculated by the Macquiner software. The intensity was set to be calculated in steps of 5 ms. The actual burst amplitude value is the difference between the amplitude for each target consonant's release burst and the baseline amplitude for each token. If the target sequence consisted of a consonant and a vowel, measurements 4 and 5 were not available, and so there were only 5 measurements for those tokens. In cases where the subjects stumbled over the words in the stimuli before the target sequence and this stumble affected their production of the target sequence, those tokens were excluded from the analyses. The author estimates there is an average of 3–6 such tokens for each subject. The numbers reported here reflect the excluded tokens. Of the 895 tokens (sentences) that were analyzed, 309 were from Speaker 1, 303 were from Speaker 2, and 283 were from Speaker 3.

The data were analyzed using StatView 5.1 to generate ANOVAs and Fisher's PLSD post-hoc tests to identify whether there was an effect of the independent variables. A 2-factor full-interaction ANOVA was generated for each speaker separately. The two Independent variables for the ANOVA are Phrase Boundary and Target Consonant, where Phrase Boundary has 4 levels: Word Internal (WI), Word Boundary (WB), Intermediate Phrase (abbreviated as SP so as not to be confused with IP) and Intonation Phrase (IP); and Target Consonant has three levels (voiceless aspirated [p^h], voiceless unaspirated [p], and voiced [b]). Closure Duration, VOT, and Burst Amplitude are the three dependent variables for which ANOVAs were generated to evaluate the effects of the independent variables of Phrase Boundary and Target Consonant. For the effects on VOT, only the tokens where the following context was a

Table 2 Target Consonant effects on VOT.

Effect	Speaker 1	Speaker 2	Speaker 3
Target Consonant	F(2, 82) = 36.65, p < .0001	F(2, 71) = 138.09, p < .0001	F(2, 74) = 90.91, p < .0001

vowel were included in the ANOVA. Note that closure duration and (negative) VOT are the same for the voiced target consonants as these were always fully voiced.

An additional 3-factor ANOVA was generated separately for each speaker for the tokens whose following context was not vocalic. This is to determine the effects of Phrase Boundary and Following Consonant on the Pre-consonantal Boundary Interval – defined as the interval from the target stop release to the onset of the following consonant closure. The independent variables were Phrase Boundary, Target Consonant, and Following Context (where Following Context has two levels, [k^h] or [n]). The dependent variable in this analysis was boundary interval.

3 Results

3.1 Target Consonant effects

Tables 2, 3, and 4 show the expected effects of Target Consonant (p, p^h, b) on (pre-vocalic) VOT, Pre-consonantal Boundary Interval, Closure Duration, and Burst Amplitude, respectively. Significant effects are in bold. (Recall that these were separate two-factor, or three-factor in the case of the boundary interval, full interaction ANOVAs for each subject for each dependent variable.)

3.1.1 Target Consonant effects on VOT

As can be seen in table 2, for Speaker 1, Fisher's PLSD post-hoc comparisons show that there is a significant distinction between aspirated and voiced ($p < .0001$), aspirated and unaspirated ($p = .0136$), and voiced and unaspirated ($p < .001$) target consonants with respect to VOT. Fisher's post-hoc comparisons show that Speaker 2 has a significant distinction between aspirated and voiced target consonants ($p < .0001$), and between aspirated and unaspirated target consonants ($p < .0002$), and between unaspirated and voiced target consonants ($p < .0001$) with respect to VOT. Speaker 3 also shows a significant distinction between the three target consonants: aspirated and voiced ($p < .0001$), aspirated and unaspirated ($p = .0004$), and voiced and unaspirated ($p < .001$) target consonants in the post-hoc comparisons.

This means that each speaker significantly distinguishes the three target consonants with respect to VOT, even in final positions of various prosodic types. The VOT varies in decreasing order, $p^h > p > b$. That is, across all three speakers, the aspirated target consonant has the longest VOT and the voiced target consonant has the shortest VOT, and the unaspirated VOT falls in-between. Figure 4 illustrates this pattern.

The case is the same within each individual speaker, as shown in figure 5. This effect is regardless of the following context, i.e. main effects are present for vocalic and consonantal following contexts.

3.1.2 Target Consonant effects on pre-consonantal boundary interval

Next we look at the boundary interval, that is, the interval between the target consonant release and the following consonant closure (where the following consonant was not vocalic). A

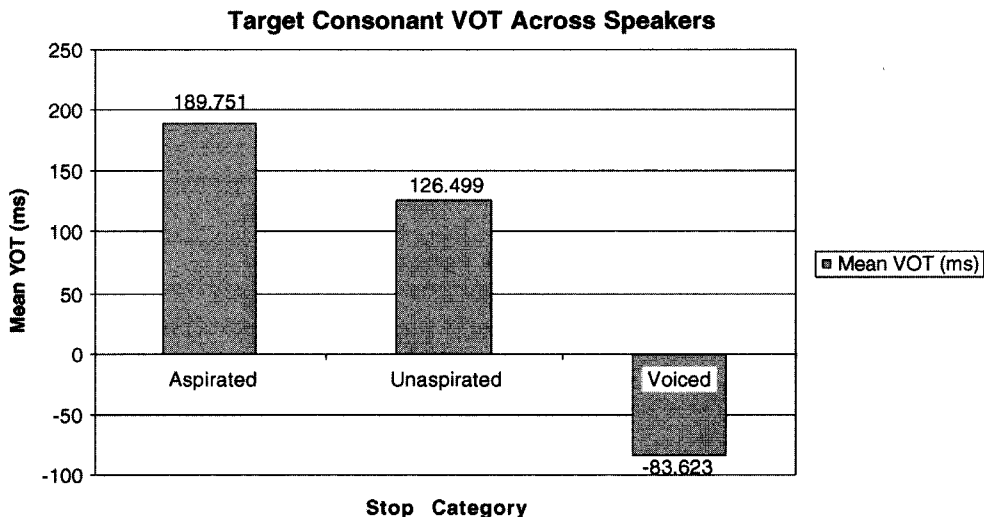


Figure 4 Target Consonant VOT pooled across all speakers.

3-factor full-interaction ANOVA was generated separately for each speaker. The independent variables were phrase boundary (4 levels: IP, SP, WB, and WI), target consonant (3 levels: aspirated, unaspirated, and voiced), and the following context (two levels: [k^h] or [n]). Table 3 shows the effects of Phrase Boundary, Target Consonant and Following Context on VOT. Significant effects are in bold.

Table 3 shows that all three speakers had a significant main effect of target consonant on the pre-consonantal boundary interval. Fischer's post-hoc comparisons show significant distinctions between aspirated, unaspirated, and voiced target consonants for all three speakers. Thus, all three speakers show significant main effects of target consonant on pre-consonantal boundary interval (all $p < .0001$). Consequently, all three speakers are consistent with respect to having a main effect of target consonant on VOT regardless of the nature following context (i.e. whether the following context is vocalic or not).

3.1.3 Target Consonant effects on closure duration

Table 4 shows that only Speakers 1 and 3 have a main effect of target consonant on closure duration.

Fischer's post-hoc comparisons for Speaker 1 and Speaker 3 showed significant distinctions between aspirated and voiced target consonants and voiced and voiceless target consonants at the level of $p < .0001$. No speaker shows significant distinctions among all three target consonants with respect to closure duration.

3.1.4 Target Consonant effects on burst amplitude

As table 5 shows, none of the speakers show main effects of Target Consonant on Burst Amplitude (in contrast to Ladefoged & Maddieson's (1996: 67) informal observation).

In summary, as for target consonant effects, there was a significant main effect of target consonant on VOT and pre-consonantal boundary interval for the all three subjects, with subjects having significant distinctions in most categories in the post-hoc comparisons. There were no main effects of target consonant on burst amplitude for any speaker.

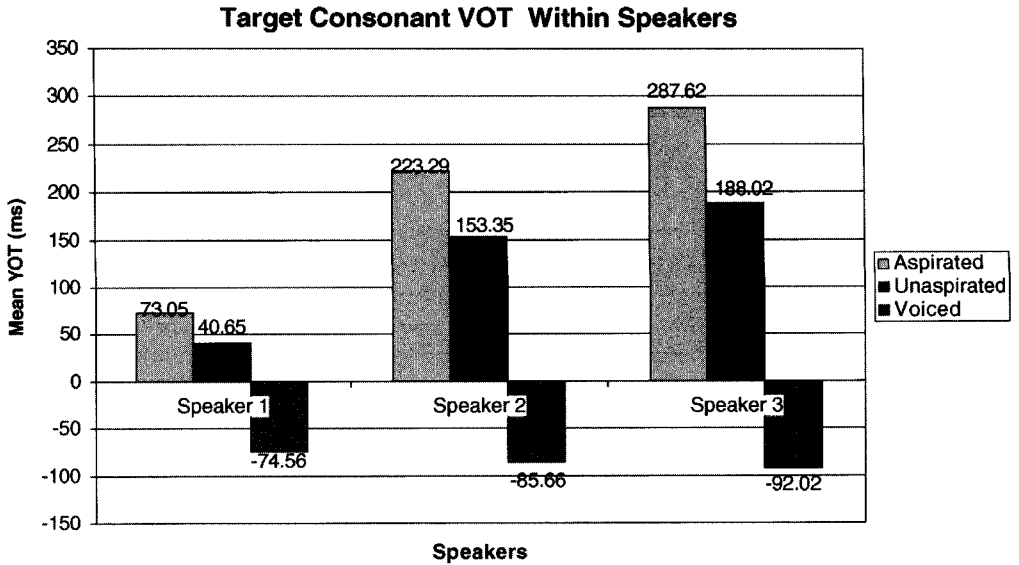


Figure 5 Target Consonant VOT for individual speakers pooled across conditions.

Table 3 Target Consonant effects on Pre-Consonantal Boundary Interval.

Effect	Speaker 1	Speaker 2	Speaker 3
Target Consonant	F(2, 145) = 312.568, p < .0001	F(2, 129) = 669.427, p < .0001	F(2, 141) = 143.315, p < .0001

Table 4 Target Consonant effects on Closure Duration.

Effect	Speaker 1	Speaker 2	Speaker 3
Target Consonant	F(2, 82) = 14.31, p < .0001	F(2, 71) = 2.15, p = .1244	F(2, 74) = 23.83, p < .0001

Table 5 Target Consonant effects on Burst Amplitude.

Effect	Speaker 1	Speaker 2	Speaker 3
Target Consonant	F(2, 82) = .402, p = .6701	F(2, 71) = 2.913, p = .0608	F(2, 74) = 2.768, p = .0693

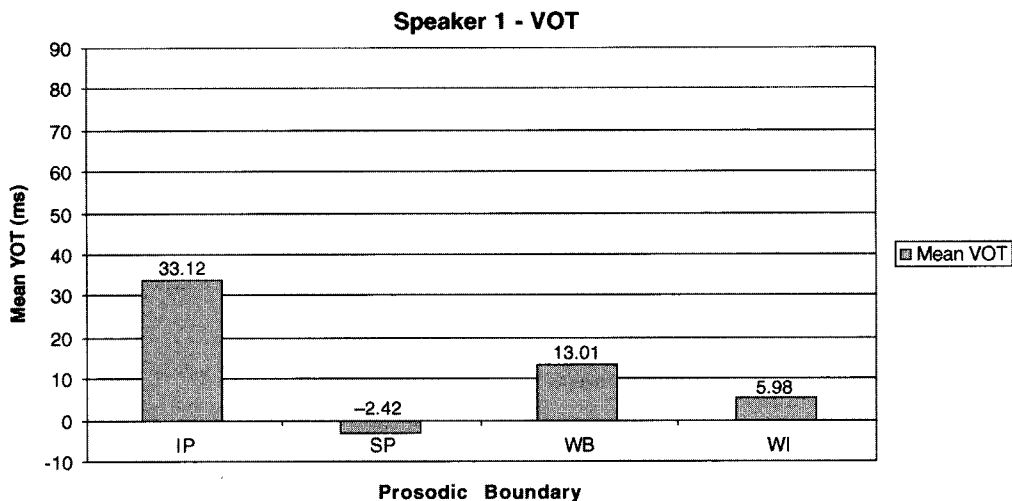
3.2 Phrase Boundary effects

3.2.1 Phrase Boundary effects on VOT

Table 6 shows that only Speakers 2 and 3 have main effects of Phrase Boundary on VOT, and Fisher's post-hoc comparisons for Speakers 2 and 3 show significant distinctions between various phrase boundaries. Speaker 2 significantly distinguishes between IP (Intonation Phrase) > SP (Intermediate Phrase), IP > WB (Word Boundary) and IP > WI

Table 6 Phrase Boundary effects on VOT.

Effect	Speaker 1	Speaker 2	Speaker 3
Phrase Boundary	$F(3, 82) = 1.01, p = .3907$	$F(3, 71) = 61.38, p < .0001$	$F(3, 74) = 35.17, p < .0001$

**Figure 6** Mean VOT by Phrase Boundary for Speaker 1 (pooled across consonants).

(Word-Internal) ($p < .0001$) and between $SP > WI$ ($p = .0290$). That is, Speaker 2 distinguishes the intonational boundaries from the others pre-consonantly and pre-vocally. Speaker 3 shows a significant distinction between $IP > SP$, $IP > WB$, $IP > WI$ and $SP > WI$ at the level of $p < .0001$; and $SP > WB$ ($p = .0157$) and $WB > WI$ ($p = .0292$). Thus, for Speaker 3, all phrase boundaries are significantly distinguished from one another with respect to VOT in the following order: Intonation Phrase (IP) > Intermediate Phrase (SP) > Word boundary (WB) > Word-Internal (WI).

Figures 6–8 show the mean VOTs of the target consonants by phrase boundary for each speaker. As can be seen in figure 6, Speaker 1 has an abnormal pattern in that the mean VOT for the intermediate phrase boundary condition is not greater than that of the word boundary condition. The author has no explanation for this aberration and, at this point, attributes it to the idiosyncrasy of Speaker 1's speech. As seen in section 3.2.1, Speaker 1 does not show a main effect of phrase boundary on VOT, likely due to this unusual result.

Figure 7 presents the mean VOT values for each phrase boundary condition for Speaker 2. Likewise, figure 8 shows that for Speaker 3, VOT decreases as the phrase boundary becomes smaller. Table 6 in Section 3.2.1 shows that Speakers 2 and 3 have significant main effects of phrase boundary on VOT. Figures 7 and 8 illustrate those effects: VOT decreases as the phrase boundary condition changes from larger boundaries to the smaller ones because speakers 2 and 3 make significant distinctions between the various boundary conditions with respect to VOT.

3.2.2 Phrase Boundary effects on pre-consonantal boundary interval

As table 7 shows, only Speaker 2 shows a main effect of Phrase Boundary on the Pre-Consonantal Boundary Interval (Speaker 1's effect is marginal $p = .0547$). Post-hoc

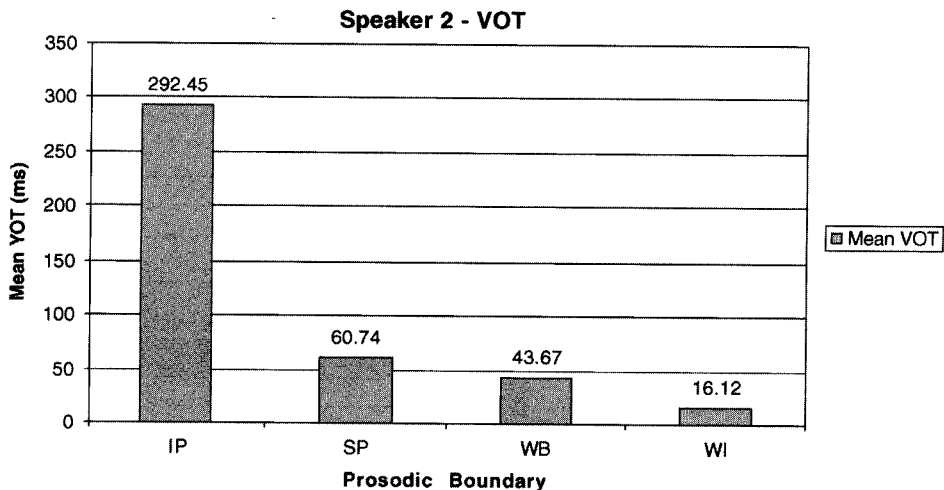


Figure 7 Mean VOT by Phrase Boundary for Speaker 2 (pooled across consonants).

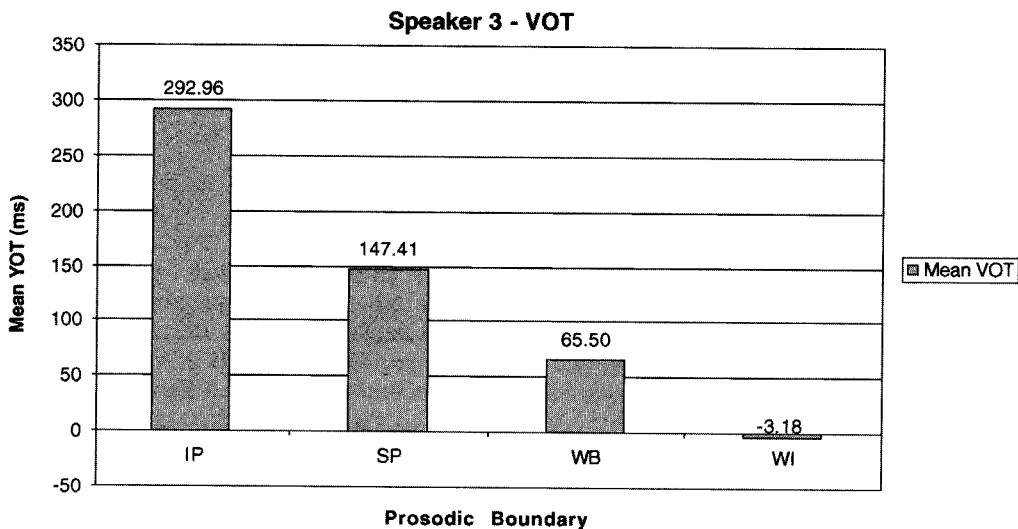


Figure 8 Mean VOT by Phrase Boundary for Speaker 3 (pooled across consonants).

comparisons for Speaker 2 show significant distinctions at three phrase boundaries: IP > WB ($p = .0165$), SP > WB ($p = .0003$) and WB > WI ($p < .0001$).

3.2.3 Phrase Boundary effects on closure duration

Table 8 shows that only Speaker 3 has a main effect of Phrase Boundary on Closure Duration. Post-hoc comparisons of Phrase Boundary effect on Closure Duration for Speaker 3 shows significant distinctions in closure duration between all but one pair of boundaries (no significant distinction between closure duration for SP > WB). Significant distinctions were made between IP > SP at a level of $p = .0003$; IP > WB and IP > WI at $p < .0001$; SP > WI at $p = .0007$ and SP > WI at $p = .023$.

Table 7 Phrase Boundary effects on Pre-Consonantal Boundary Interval.

Effect	Speaker 1	Speaker 2	Speaker 3
Phrase Boundary	$F(3, 145) = 2.596,$ $p = .0547$	$F(3, 129) = 7.183,$ $p = .0002$	$F(3, 141) = 1.624,$ $p = .1865$

Table 8 Phrase Boundary effects on Closure Duration.

Effect	Speaker 1	Speaker 2	Speaker 3
Phrase Boundary	$F(3, 82) = 2.69, p = .0517$	$F(3, 71) = .995, p = .4004$	$F(3, 74) = 21.15,$ $p < .0001$

Table 9 Burst Amplitude.

Effect	Speaker 1	Speaker 2	Speaker 3
Phrase Boundary	$F(3, 82) = 10.77,$ $p < .0001$	$F(3, 71) = 1.33, p = .2713$	$F(3, 74) = 17.39,$ $p < .0001$

Table 10 VOT.

Effect	Speaker 1	Speaker 2	Speaker 3
Phrase Boundary * Target Consonant	$F(6, 82) = .266,$ $p = .9510$	$F(6, 71) = 16.99,$ $p < .0001$	$F(6, 74) = 11.20,$ $p < .0001$

3.2.4 Phrase Boundary effects on burst amplitude

As seen in table 9, the effect of Phrase Boundary on Burst Amplitude is significant only for Speakers 1 and 3. Recall that target consonants themselves weren't distinguished by burst amplitude. For Speaker 1, Fischer's post-hoc comparisons show a distinction between phrase boundaries $IP > SP$ and $SP > WI$ ($p < .0001$), and for $SP > WB$ ($p = .0001$). Post-hoc tests for Speaker 3 show significant distinctions between the various phrase boundaries with respect to burst amplitude. With the exception of $SP > WB$, Speaker 3 shows a significantly distinct pattern of $IP > SP$, $SP > WI$, $WB > WI$.

3.3 Interaction effects

3.3.1 Interaction effects for VOT

As seen in table 10, there was a main effect of the interaction of Phrase Boundary and Target Consonant for Speakers 2 and 3.

Figures 9, 10, and 11 illustrate the interaction effects of Phrase Boundary and Target Consonant on VOT for Speakers 1, 2, and 3, respectively. As shown in table 10, only Speakers 2 and 3 show main effects for this interaction. Thus, not only do all the speakers show

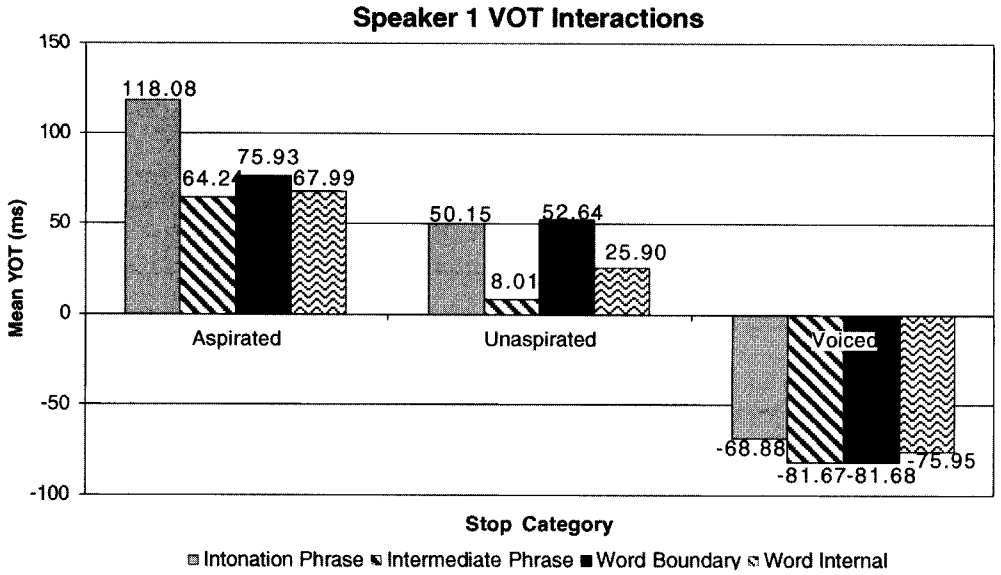


Figure 9 Speaker 1 - interaction of Phrase Boundary x Target Consonant on VOT.

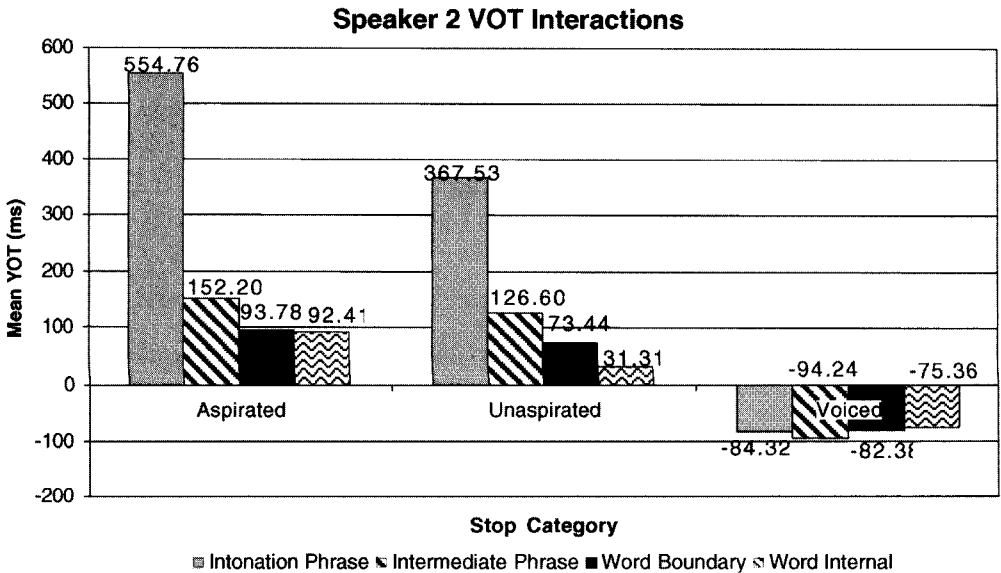


Figure 10 Speaker 2 - interaction of Phrase Boundary x Target Consonant on VOT.

main effects for prosodic position and consonant type, two of the three speakers also have significant interaction of these two conditions. That is, the VOT varies in increasing order, $p^h > p > b$ AND in increasing order of phrase boundary size (IP > SP > WB > WI) – generally, IP-asp(irated) > SP-asp > WB-asp > WI-asp, etc.

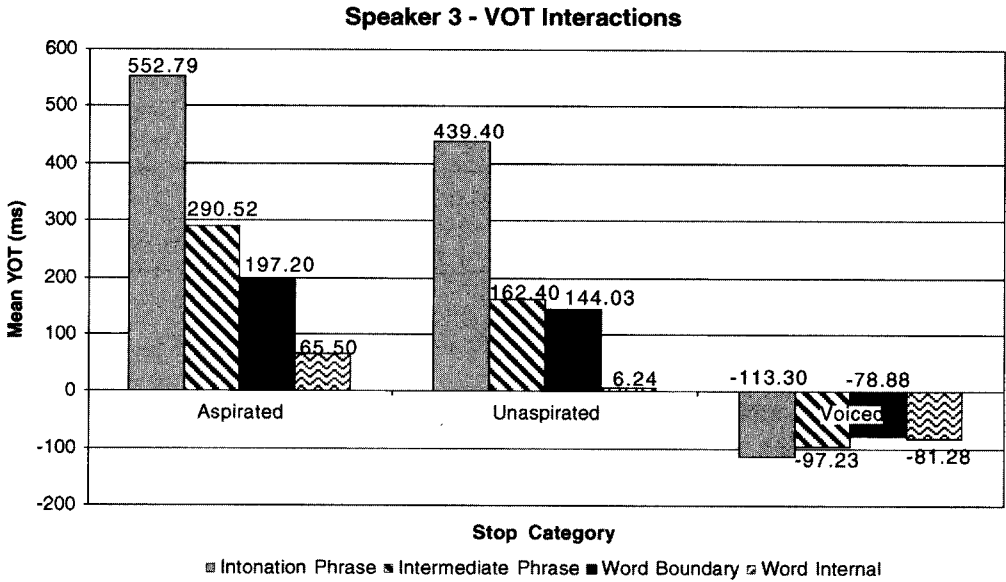


Figure 11 Speaker 3 - interaction of Phrase Boundary x Target Consonant on VOT.

Table 11 Pre-Consonantal Boundary Interval.

Effect	Speaker 1	Speaker 2	Speaker 3
Phrase Boundary * Following Context	$F(3, 145) = .192$, $p = .9020$	$F(3, 129) = .553$, $p = .6472$	$F(3, 141) = 1.420$, $p = .2396$
Phrase Boundary * Target Consonant	$F(6, 145) = .699$, $p = .6506$	$F(6, 129) = 1.047$, $p = .3984$	$F(6, 141) = 2.750$, $p = .0147$
Following Context * Target Consonant	$F(2, 145) = .440$, $p = .6447$	$F(2, 129) = .873$, $p = .4203$	$F(2, 141) = 1.924$, $p = .1498$
Phrase Boundary * Following Context * Target Consonant	$F(6, 145) = 1.911$, $p = .0827$	$F(6, 129) = 1.223$, $p = .2939$	$F(6, 141) = .946$, $p = .4641$

3.3.2 Interaction effects for Pre-Consonantal Boundary Interval

The only interaction effect on Pre-Consonantal Boundary Interval was in the interaction of Phrase Boundary with Target Consonant for Speaker 3. Table 11 shows this significant interaction. Recall that the Pre-Consonantal Boundary Interval is defined as the interval from the target stop release to the onset of the following consonant closure. The table shows that Speaker 3 has a significant distinction ($p = .0147$) between the target consonants at different prosodic boundaries on the basis of their Pre-Consonantal Boundary Interval.

3.3.3 Interaction effects on Closure Duration

Closure Duration for Speaker 3 is the last interaction effect observed. Table 12 shows that the interaction of Phrase Boundary and Target Consonant on Closure Duration was significant for Speaker 3. This means Speaker 3 makes a significant distinction ($p = .0040$) between the target consonants at the different prosodic boundaries on the basis of their closure duration.

Table 12 Closure Duration.

Effect	Speaker 1	Speaker 2	Speaker 3
Phrase Boundary * Target Consonant	F(6, 82) = .755, $p = .6074$	F(6, 71) = .866, $p = .5240$	F(6, 74) = 3.52, $p = .0040$

Table 13 Burst Amplitude.

Effect	Speaker 1	Speaker 2	Speaker 3
Phrase Boundary * Target Consonant	F(6, 82) = 1.127, $p = .3538$	F(6, 71) = .597, $p = .7318$	F(6, 74) = 1.61, $p = .1553$

Table 14 Effects of Target Consonant on VOT by Phrase Boundary condition for Speaker 1.

	Intonation Phrase	Intermediate Phrase	Word Boundary	Word-internal
Target Consonant	F(2, 64) = 25.395, $p < .0001$	F(2, 64) = 112.68, $p < .0001$	F(2, 57) = 134.665, $p < .0001$	F(2, 67) = 400.07, $p < .0001$

Table 15 Effects of Target Consonant on Closure Duration by Phrase Boundary condition for Speaker 1.

	Intonation Phrase	Intermediate Phrase	Word Boundary	Word-internal
Target Consonant	F(2, 64) = 3.771, $p = .0283$	F(2, 64) = 1.073, $p = .3480$	F(2, 57) = 2.689, $p = .0765$	F(2, 67) = 11.079, $p < .0001$

3.3.4 Interaction effects for Burst Amplitude

As table 13 shows, there was no significant interaction of Phrase Boundary and Target Consonant on Burst Amplitude.

3.4 Neutralization

A primary question set forth in this study is whether the target consonants (which have a 3-way VOT contrast) are neutralized or not. To evaluate this for each speaker, for EACH (pre-vocalic) phrase boundary type, an ANOVA was generated with target consonant as the independent variable (3 levels: aspirated, unaspirated, voiced). The dependent variables were VOT and closure duration, which were shown to be significantly effected in the above 2-factor ANOVAs.

3.4.1 Speaker 1

Tables 14 and 15 show the effects of Target Consonant on VOT and Closure Duration for Speaker 1, respectively. Significant effects are in bold.

Table 15 shows that Target Consonant has a main effect on VOT for Speaker 1 in all four phrase boundary conditions ($p < .0001$). Post-hoc comparisons show that Speaker 1 has a significant distinction between aspirated and voiced, aspirated and unaspirated, and voiced and unaspirated target consonants with respect to VOT in all Phrase Boundary categories except

Table 16 Effects of Target Consonant on VOT by Phrase Boundary condition for Speaker 2.

	Intonation Phrase	Intermediate Phrase	Word Boundary	Word-internal
Target Consonant	F(2, 54) = 14.08, p < .0001	F(2, 58) = 61.01, p < .0001	F(2, 51) = 84.13, p < .0001	F(2, 66) = 341.04, p < .0001

Table 17 Effects of Target Consonant on Closure Duration for Speaker 2.

	Intonation Phrase	Intermediate Phrase	Word Boundary	Word-internal
Target Consonant	F(2, 54) = 3.18, p = .0496	F(2, 58) = 2.102, p = .1314	F(2, 51) = .339, p = .7141	F(2, 66) = 1.014, p = .3683

Intonation Phrase. Thus no neutralization occurs word- and intermediate phrase-finally. In the Intonation Phrase-final Boundary condition, Speaker 1 significantly distinguishes between aspirated and voiced ($p < .0001$), and voiced and unaspirated ($p < .0001$) target consonants, but not between aspirated and unaspirated target consonants ($p = .1706$, *ns*).

With respect to Closure Duration, however, Speaker 1 shows main effects of Target Consonant in only two of the Phrase Boundary conditions, IP-final ($p = .0283$) and word-internal ($p < .0001$). Post-hoc comparisons for effects on Target Consonant on Closure Duration for Speaker 1 show there is a significant effect in the distinction between aspirated and voiced ($p = .0182$), and voiced and unaspirated ($p = .0242$) target consonants in the Intonation Phrase-final boundary. In the word-internal condition, Speaker 1 has a significant distinction between all 3 pairs of target consonants: aspirated and voiced ($p = .0209$), aspirated and unaspirated ($p = .0195$), and voiced and unaspirated ($p < .0001$). Speaker 1 does not show significant difference of Target Consonant on Closure Duration in the Intermediate Phrase Boundary and in the Word Boundary conditions.

3.4.2 Speaker 2

Tables 16 and 17 show the effects of Target Consonant on VOT and Closure Duration, respectively, for Speaker 2. Significant effects are in bold.

Table 16 shows that Target Consonant has a main effect ($p < .0001$) on VOT for Speaker 2 in all four phrase boundary conditions. Fisher's post-hoc comparisons for Target Consonant effects on VOT show that Speaker 2 distinguishes between aspirated and voiced, and voiced and voiceless target consonants ($p < .0001$) in all the phrase boundary conditions. In addition, Speaker 2 significantly distinguishes between aspirated and unaspirated target consonants in the word-internal ($p < .0001$) and intermediate (SP) phrase-final ($p = .0352$) boundary conditions. Thus, for Speaker 2, there is no neutralization of the 3-way VOT contrast word-internally or at an intermediate phrase boundary. However, at least with respect to VOT, Speaker 2 does not differentiate between aspirated and unaspirated voiceless stops in the Intonation Phrase-final and word-final conditions.

As shown in table 17, Speaker 2 has a main effect ($p = .0496$) for Target Consonant on Closure Duration only for the Intonation Phrase-final condition. Fisher's post-hoc comparisons show that this main effect is in distinguishing between aspirated and voiced target consonants ($p = .0152$).

3.4.3 Speaker 3

Table 18 shows that Target Consonant has a main effect on VOT for Speaker 3 in all 4 phrase boundaries. Fisher's post-hoc comparisons present similar results for Speaker 3 as

Table 18 Effects of Target Consonant on VOT by Phrase Boundary condition for Speaker 3.

	Intonation Phrase	Intermediate Phrase	Word Boundary	Word-internal
Target Consonant	F(2, 69) = 22.57, p < .0001	F(2, 44) = 20.04, p < .0001	F(2, 59) = 68.08, p < .0001	F(2, 67) = 397.86, p < .0001

Table 19 Effects of Target Consonant on Closure Duration for Speaker 3.

	Intonation Phrase	Intermediate Phrase	Word Boundary	Word-internal
Target Consonant	F(2, 69) = 5.19, p = .0080	F(2, 44) = 1.802, p = .1770	F(2, 59) = 9.391, p = .0003	F(2, 67) = 669.20, p = .0034

for Speaker 2. Speaker 3 also distinguishes between aspirated and voiced, and voiced and unaspirated target consonants in all the phrase boundary conditions ($p < .0001$). In addition, Speaker 3 distinguishes between aspirated and unaspirated target consonants in the word-internal condition ($p < .0001$). But unlike Speaker 2, Speaker 3 does not make any further distinctions between aspirated and unaspirated target consonant VOTs at the other phrase boundary conditions. This indicates that, at least with respect to VOT, Speaker 3 does not differentiate in VOT between aspirated and unaspirated voiceless stops in the Intonation Phrase-final, Intermediate Phase-final and Word-final conditions. In the syllable-final condition, the aspirated and unaspirated voiceless stops are significantly distinguished ($p < .0001$) with respect to VOT. Although the aspirated vs. unaspirated VOT value differences in the three remaining prosodic conditions do not reach significance, the mean values (see figure 5 above) are in the expected direction and the pooled means are highly significantly different.

However, unlike Speaker 2, Speaker 3 DOES HAVE a main effect for Target Consonant on Closure Duration for three of the four boundary conditions. Table 19 shows that with the exception of the Intermediate Phrase Boundary condition, Speaker 3 has a main effect of Target Consonant on Closure Duration. Fisher's post-hoc comparisons show that this main effect in the Intonation Phrase-final condition is due to distinguishing between aspirated and voiced ($p = .0428$), and voiced and unaspirated target consonants ($p = .0022$). In the Word Boundary condition, the main effect is also due to distinguishing between aspirated and voiced ($p = .0115$) and voiced and unaspirated target consonants ($p < .0001$). And in the Word-Internal condition, the main effect is once again due to distinguishing between aspirated and voiced ($p = .0014$), and voiced and unaspirated target consonants ($p = .0096$). Speaker 3 does not distinguish between the target consonants with respect to Closure Duration in the Intermediate Phrase-final (SP) condition.

Tables 14–19 show that none of the speakers neutralize their 3-way contrasts in the target consonants in the various prosodically-final conditions. This contrast is maintained largely through VOT (tables 14, 16, and 18), but closure duration also contributes.

3.5 Results summary – neutralization

Finally, as detailed in section 3.3, with a few exceptions, the three speakers show significant main effects of target consonant on VOT for each phrase boundary. In other words, none of the speakers neutralize the 3-way VOT contrast in all of the domain-final conditions.

Speaker 1 shows this effect for all phrase boundaries except for the distinction between aspirated and unaspirated targets at the Intonation Phrase-final condition ($p = .1706$). Speaker

2 shows main effects for all Phrase-final conditions except for the distinction between aspirated and unaspirated in the Intonation Phrase-final condition ($p = .5362$), and in the Word-final condition ($p = .0935$). And Speaker 3 shows main effects for the target consonants, except for the distinction between aspirated and unaspirated at the Intonation Phrase ($p = .1566$), Intermediate Phrase ($p = .3399$) and Word Boundary ($p = .1945$) intervals.

4 Discussion

4.1 Findings summary

This study has taken a systematic look at a 3-way stop contrast in various segmental and prosodic conditions. At the outset, we asked how the 3-way contrast might be preserved acoustically. We find that the 3-way VOT contrast is indeed maintained in the various prosodic domains in which the stop consonants are final. And the contrast is maintained, with one exception from Speaker 1, such that larger prosodic domains have longer VOT values for all speakers. Moreover, the speakers make significant distinctions (with respect to VOT) between the target consonants within the same boundary condition, and these distinctions follow the same pattern for all three speakers.

We also find that the realization of the target consonant is not affected by the voicing of the following sound. Closure duration does not play as prominent a role in distinguishing between the consonants and, contrary to Ladefoged & Maddieson's (1996) reports, burst amplitude does not factor into the distinction of the 3-way VOT contrast.

One theoretical issue this bears on is our understanding of strengthening and junctures. Recent work has concentrated on the effects of phrase boundary type on the realization of domain-initial segments. Findings often show that parameters such as VOT, segment length, and articulatory magnitude increase in increasingly larger (or stronger) prosodic domains. If it is the case that phrase-initial domains specifically are the targets of these properties, then one might expect to find the opposite effect or no effect at all in the phrase-final conditions of these domains. This study, however, shows that some of these phenomena, namely elaboration of VOT contrast, are mirrored domain-finally in Teheran SEA.

4.2 Articulatory strengthening and domain-initial processes

Cho & Jun (2000) summarize a number of studies focusing on domain-initial processes, notably domain-initial strengthening. These studies emphasize the role and the importance of initial position in various prosodic domains in the perception of segmental contrasts and prosodic boundaries. They note, however, that 'it has not been clear exactly what is strengthened domain-initially' (Cho & Jun 2000: 32). They offer that the 'most commonly agreed upon characteristic of the domain-initial effect . . . is syntagmatic contrast enhancement' (p. 32). That is, the contrast between the initial segment and its neighbors is enhanced. In addition, Cho & Jun note that consonants may also undergo another type of domain-initial enhancement known as paradigmatic contrast enhancement, where the phonemic distinction between contrastive sounds is maximized. They note Hsu & Jun (1998) conclude that 'some features are enhanced paradigmatically and some are enhanced syntagmatically, depending on the sound system of the language and the type of contrasts the language may choose to enhance' (p. 33).

In their own examination of domain-initial Korean voiceless triplets in various prosodic boundaries, Cho & Jun (2000) found longer VOT values and greater airflow in increasingly higher prosodic positions for aspirated and lenis stops, and lowered VOT and airflow for fortis stops in higher prosodic positions. They dub these asymmetric effects 'enhancements' of laryngeal features in domain-initial position. They note that the enhancement of laryngeal features in domain-initial position appears to maximize the paradigmatic contrast among

stops. That is, the different stops in the same position will pattern more differently from each other with respect to laryngeal features such that fortis stops are at one end of the (VOT) spectrum and aspirated stops at the other, and lenis stops fall in between. Cho and Jun (2000) conclude that their study, along with existing data, shows that domain-initial strengthening brings about both 'syntagmatic contrast enhancement between neighboring segments (for example C-V contrast enhancement) [and] also paradigmatic contrast maximization among phonetically contrastive sounds (for example, in Korean, fortis vs. lenis vs. aspirated stops)' (p. 41). Moreover, Cho & Jun (2000) assert that domain-initial strengthening 'seems to help listeners to segment the incoming flow of speech into smaller units, and recover the meaning of the utterance and the speaker's intention' (p. 41). They do not, however, provide any evidence from perceptual studies to support this claim.

The domain-final Teheran SEA data in this study follow the same pattern as Cho & Jun's findings in that voiceless unaspirated VOT values fall in between those of the voiceless aspirated and voiced consonants for all speakers and all boundary types. In addition, the findings presented here are consistent with Cho & Jun (2000) in that VOT values for the target stop consonants are longer when the target consonants appear in larger prosodic domains. That is, the larger the prosodic domain, the larger the Voice Onset Times for the target consonants. However, it is important to note that whereas Cho & Jun's (2000) findings are for phrase-initial target consonants, the data in this study is of domain-FINAL consonants. Thus, while the VOT data presented here replicates those of Cho & Jun (2000) and previous studies cited above, these findings are different in one very important aspect: the target consonants in this study are domain-final.

These findings challenge recent bias in featuring or emphasizing the importance and productivity of the domain-initial processes and bring to light the fact that enhancement and lengthening are not confined to domain-initial positions. Rather, as we have shown with Teheran SEA, languages can employ these processes at either domain-edge. The Teheran SEA data here shows that domain-final contrasts also vary systematically with respect to prosodic boundary type. Further perceptual studies can determine the role of this domain-final variation with respect to perception of contrasts and perception of prosodic structure. In the meantime, the nature and contribution of domain-final processes can be examined further.

4.3 Prosodic gestures

In contrast to previous studies, including Cho & Jun (2000), Byrd et al. (2000) present a more symmetrical approach to the analysis of prosodic structure by taking into consideration both initial and final domains and focusing on prosodic junctures. They seek to identify articulatory correlates of prosodic structure, which they call 'prosodic signatures' (p. 70). Byrd et al. (2000) suggest that, like articulatory gestures, phrasal boundaries 'can also be seen as displaying inherent duration'. That is, phrasal boundaries also have a 'temporal domain over which they exert their influence on parameter values of the active articulatory gestures' (p. 84). Accordingly, they propose a boundary element that 'occurs at prosodic edges and has its activity governed by prosodic constituency' (p. 84). They call these prosodic boundary units ' π -gestures'.

The suggestion is that π -gestures act independently of tract-variable gesture activations and that they directly affect 'the values of gestural parameters such as stiffness or target position for all the tract-variable gestures with which it is concurrently active', or they affect 'the clock rate (local speaking rate) such that a stronger π -gesture yields more slowing of the clock rate than a weaker one' (pp. 84–85).

A significant aspect of their hypothesis is that there is one type of π -gesture that exists for both final and initial domain edges. The notions of 'left' or 'right' edges or 'initial' versus 'final' processes are not elements of the model. The prediction is that different levels of the prosodic hierarchy will exhibit edge effects that are qualitatively identical in their dynamic source.

The results of the present study support such a view. Teheran SEA domain-final contrasts, in ways exactly paralleling their domain-initial counterparts in other languages, vary systematically with respect to prosodic boundary type. This parallelism supports the Byrd et al. (2000) proposal that there is one uniform mechanism, the π -gesture, that is responsible for these processes regardless of at which boundary edge they occur. More generally, we have found processes analogous to those presented under the domain-initial articulatory strengthening paradigm in domain-final positions.

5 Conclusion

At the outset of this study, we asked the following questions:

How is the 3-way stop contrast in Teheran SEA preserved acoustically?

- a) How is the realization of this 3-way contrast affected by the particular prosodic domain in which stop consonants are final?
- b) How is the realization affected by the voicing of the following sound or the lack of a following segment?

We found that the 3-way stop contrast is maintained by all three speakers by significant distinctions in Voice Onset Time. Specifically, all three speakers make significant VOT distinctions between target consonants within the same boundary condition, and these distinctions follow the same pattern for all three speakers. More importantly, we found that the 3-way contrast is preserved in VARIOUS prosodic domains in which the stop consonants are FINAL, and that this contrast is maintained such that larger prosodic domains have longer VOT values for all speakers. We also found that the realization of the target consonant is not affected by the voicing of the following sound. In addition, closure duration and burst amplitude do not factor into the distinction of the 3-way VOT contrast.

With these findings we have shown that a 3-way VOT contrast in various domain-final contexts is not neutralized in Teheran Standard Eastern Armenian. These findings are significant in that (1) they set apart Teheran SEA as one of the few languages in the world, if not the only language, that maintains its 3-way VOT contrast in domain-final conditions, and (2) they show that processes previously attributed to and identified in domain-initial positions are present and active in domain-final conditions as well.

Acknowledgements

Many people have contributed to the improvement of this work. I am especially grateful to Dani Byrd for her guidance and support throughout. Many thanks to Abigail Kaun and Shrikanth Narayanan for their help and guidance as members of my screening committee. I also thank Peter Ladefoged, Rachel Walker, and the USC PhonLunch attendees for their helpful comments and suggestions on earlier drafts. Thanks to all my volunteer subjects for their time. Thank you to Joe for his unwavering support and enthusiasm for my pursuits. This work was supported in part by National Institutes of Health Grant DC 03172.

Appendices

Appendix A: List of all stimuli

Appendix A consists of five parts, each part contains the stimuli for each of the five boundary conditions. Each stimulus is shown first in IPA transcription, then in the Armenian orthography, followed by a word-for-word gloss of the sentence and finally a literary translation.

Intonation Phrase condition (IP)

- b-a vosta f^hejinj haj e t^he arab anahitə motetsav jev haits^hjets^h
Վստահ չէինք Հայ է թէ Արաբ: Անահիտը մօտեցաւ և Հարցրեց:
 sure weren't sure if he/she was Armenian or Arab. Anahit approached and asked
 'We weren't sure if he/she was Armenian or Arab. Anahit approached and asked.'
- p-a meŋk^h ləfji mefj tesanj mi spitak kəlap alik^hne:ji mefj^h ʷaχ loxum e:ɹ
Մենք լճի մէջ տեսանք մի սպիտակ կարապ: Ալիքները մէջ ուրախ լողում էր:
 we lake in saw a white swan waves+PLU+GEN in happy swimming was
 'We saw a white swan in the lake. It was swimming happily in the waves.'
- p^h-a jɛ:kənk^hi:ts^h t^hap^hvet^h mi ahagin andzɛvi təlap^h amboχ tʃ ʰoʰovɹut^hə vɹɹkjanapɛs t^hərtʃ^həvets^h
Երկնքից թավեց մի ահագին անձրևի տարախ: Ամբողջ ժողովուրդը վարկանակէս թրջւեց:
 sky+from fell a heavy rain torrent. whole crowd immediately got-drenched
 'A heavy torrent of rain fell from the sky. The whole crowd was immediately drenched.'
- b-k^h vosta f^hejinj haj e t^he arab k^hat^hi:inə motets^hav jev haits^hjets^h
Վստահ չէինք Հայ է թէ Արաբ: Քաթրինը մօտեցաւ և Հարցրեց:
 sure weren't sure if he/she was Armenian or Arab Kathrin approached and asked
 'We weren't sure if he/she was Armenian or Arab. Kathrin approached and asked.'
- p-k^h meŋk^h ləfji ap^hin tesanj mi spitak kəlap k^hə:ɹɹ və:ɹ nəstəts^h haŋgəstənum e:ɹ
Մենք լճի ափին տեսանք մի սպիտակ կարապ: Քարերը վրայ նստած Հանգստանում էր:
 we lake shore saw a white swan rocks on seated resting was
 'We saw a white swan on the lake shore. It was seated, resting on the rocks.'
- p^h-k^h jɛ:kənk^hi:ts^h t^hap^hvet^h mi ahagin andzɛvi təlap^h k^həfvets^hiŋk tsə:ɹɹ tak tʃə t^hərtʃ^həvɛlu hamɹ
Երկնքից թափվեց մի ահագին անձրևի տարախ Քաղցեցինք ծառերի տակ չը թրջւելու Համար:
 sky+from fell a heavy rain torrent pulled trees under not get-wet to/for
 'A heavy torrent of rain fell from the sky. We moved under the trees so as not to get wet.'
- b-n vosta f^hejinj haj e t^he arab no:ɹɹɹə motets^hav jev haits^hjets^h
Վստահ չէինք Հայ է թէ Արաբ: Նորայրը մօտեցաւ և Հարցրեց:
 sure weren't sure if he/she was Armenian or Arab. Norayr approached and asked.
 'We weren't sure if he/she was Armenian or Arab. Norayr approached and asked.'
- p-n meŋk^h ləfji ap^hin tesanj mi spitak kəlap na anta:ɹɹ e:ɹ ma:ɹt^hkants^h handɛp
Մենք լճի ափին տեսանք մի սպիտակ կարապ: Նա անտարբեր էր մարդկանց Հանդէպ:
 we lake shore saw a white swan. it indifferent was people towards.
 'We saw a white swan on the lake shore. It was indifferent towards people.'
- p^h-n jɛ:kənk^hi:ts^h t^hap^hvet^h mi ahagin andzɛvi təlap^h no:ɹɹsil tsə:ɹɹɹi tɛ:ɹvne:ɹə iskujn t^hap^hets^hin
Երկնքից թափվեց մի ահագին անձրևի տարախ: Նորածիլ ծառերի տերևները իսկույն թափվեցին:
 sky+from fell a heavy rain torrent new trees leaves immediately fell
 'A heavy torrent of rain fell from the sky. The new leaves on the trees immediately fell to the ground.'

Intermediate Phrase condition (SP)

- b-a ba:ts^hɹabɹ mar^hə umin ko:ɹ^he:ɹi ejin arab, ɹa:ɹə:ɹen ɹənat^h depi χanut^h
Բարձրաբոյ մարդը ումին կոչել էին Արաբ արագորէն գնաց դէպի խանութ:
 tall man who named had Arab quickly went towards store
 'The tall man they called 'Arab' quickly went to the store.'
- p-a ha:ɹevani mar^hə vo:ɹ pahum e:ɹ mi kəlap amen jɛ:ɹeko k^hə:ɹlelu e:ɹ ɹənum
Հարևանի մարդը որ պահում էր մի կարապ ամեն երեկոյ քայլելու եր գնում:
 the neighbor's husband who had a swan every evening walking went
 'The neighbor's husband who had a swan went walking every evening.'
- p^h-a hajastani afjan jɛ:ɹp^h tɛ:kum en andzɛvi təlap^h amboχ tʃ tsə:ɹɹə:ɹ me:ɹkanum en
Հայաստանի աշնան երբ տեղում են անձրևի տարախ ամբողջ ծառերը մերկանում են:
 Armenia's autumn when occur rain torrents all trees get bare
 In Armenia's autumn when there are rain torrents all the trees get bare.'

- b-k^h barts^hjabov mart^hə umin koŋ^hei ejin arab, k^harozit^h ei ient^h jekeʁets^hum
Բարձրաբոյ մարդը ումին կոչել էին Արաբ քարոզիչ եր իրենց եկեղեցում:
 tall man who named had Arab preacher was their church-in
 'The tall man they called 'Arab' was a preacher in their church.'
- p-k^h haevani mart^hə voi pahum ei mi karap k^harozit^h ei ient^h jekeʁets^hum
Հարևանի մարդը որ պահում էր մի կարապ քարոզիչ եր իրենց եկեղեցում:
 neighbor's husband who had a swan preacher was their church-in
 'The neighbor's husband who had a swan was a preacher in their church.'
- p^h-k^h hajastani afnan jεp^h tεxum en andzevi tarap^h k^hamot oxi en^h unenum
Հայաստանի աշնան երբ տեղում են անձրևի տարափ քամօտ օրեր ենք ունենում:
 Armenia's autumn when occur rain torrents windy days we have
 In Armenia's autumn when there are rain torrents we have windy days.'
- b-n barts^hjabov mart^hə umin koŋ^hei ejin arab, najets^h dimats^hum nosta^h maatkan^h
Բարձրաբոյ մարդը ումին կոչել էին Արաբ նայեց ղիմացում նստած մարդկանց:
 tall man who named had Arab looked in-front sitting people
 'The tall man they called 'Arab' looked at the people sitting out front.'
- p-n haevani mart^hə voi pahum ei mi karap namak ei gəjum iə kənoŋ^h hamai
Հարևանի մարդը որ պահում էր մի կարապ նամակ եր գրում իր կնոջ Համար:
 neighbor's husband who had a swan letter was writing his wife for
 'The neighbor's husband who had a swan was writing a letter to his wife.'
- p^h-n hajastani afnan jεp^h tεxum en andzevi tarap^h navasart toni zamanakən e
Հայաստանի աշնան երբ տեղում են անձրևի տարափ Նաւասարդ տօնի ժամանակն է:
 Armenia's autumn when occur rain torrents Navasart holiday time it is
 In Armenia's autumn when there are rain torrents is the time of the Navasart holiday.'

Word Boundary condition (WB)

- b-a mei dasarani arab afakeitə handes uni
Մեր դասարանի Արաբ աչակերտը Հանդէս ունի:
 our class's Arab student recital has
 'The Arab student in our class has a recital.'
- p-a mi geʁets^hik spitak karap art^hun ei mi mets^h isari tak
Մի գեղեցիկ սպիտակ կարապ արթուն էր մի մեծ ծառի տակ:
 a beautiful white swan awake was a big tree under
 'A beautiful white swan was awake under a big tree.'
- p^h-a mi uʁε andzevi tarap^h aravotə jut indz k^hənit^h art^hna^hts^hjets^h
Մի ուժեղ անձրևի տարափ առաւօտը շուտ ինձ քնից արթնացրեց:
 a strong torrent of rain morning early me sleep woke
 'A strong torrent of rain woke me up early in the morning.'
- b-k^h gərasenjakum arab k^hartuxai e afχatum
Գրասենակում Արաբ քարտուղար է աշխատում:
 office+LOC Arab secretary does work
 'An Arab secretary works in the office.'
- p-k^h mi geʁets^hik spitak karap k^hənat^h ei mi mets^h isari tak
Մի գեղեցիկ սպիտակ կարապ քնած էր մի մեծ ծառի տակ:
 a beautiful white swan asleep was a big tree under
 'A beautiful white swan was asleep under a big tree.'
- p^h-k^h mi uʁε andzevi tarap^h k^hare pati himk^hə t^hulats^hjets^h
Մի ուժեղ անձրևի տարափ քարէ պատի Հիմքը թուլացրեց:
 a strong torrent of rain stone wall foundation weakened
 'A strong torrent of rain weakened the foundation of the stone wall.'

Word Boundary condition (WB) (continued)

- b-n Յօժովի ընդհանրական Արաբ Նախարարը դասախոսեց՝
meeting during Arab advisor lectured
'The Arab advisor lectured during the meeting.'
- p-n մի ջեթեֆիկ սպիտակ կարապ նստած էր քարերի վրայ:
A beautiful white swan seated was sitting on the rocks.
'A beautiful white swan was sitting on the rocks.'
- p^h-n մի սքեք անձրևի տարածքում արևը քայքայեց օրնգե պարիսպները:
A strong torrent of rain orange walls ruined
'A strong torrent of rain ruined the orange walls.'

Word-internal condition (WI)

- b-a anapatum zanazan arabakan հոսովիտները kajin
Անապատում զանազան Արաբական Հնու-թիւններ կային:
desert+loc various Arabic artifacts were
'There were various Arabic artifacts in the desert.'
- p-a կարապներին տեսնելուց յետոյ կարապային վարքեր ընդունեցին բադերը:
swans seeing after swan-link behavior displayed the-ducks
'After seeing the swans the ducks displayed swan-like behavior.'
- p^h-a արժ ցօմսի տեքոմ դոկտօր արաբանյանի հետ ծանօթացայ:
Այսօր գործի տեղում Դոքտոր Արաբանյանի հետ ծանօթացայ:
today work place doctor Arab^hanian with acquainted
'I met Dr. Arab^hanian at work today.'
- b-k^h արժ ցօմսի տեքոմ դոկտօր արաբանյանի հետ ծանօթացայ:
Այսօր գործի տեղում Դոքտոր Արաբքարեանի հետ ծանօթացայ:
today work place doctor Arabk^harian with acquainted
'I met Dr. Arabk^harian at work today.'
- p-k^h արժ ցօմսի տեքոմ դոկտօր արաբանյանի հետ ծանօթացայ:
Այսօր գործի տեղում Դոքտոր Արաքքարեանի հետ ծանօթացայ:
today work place doctor Arapk^harian with acquainted
'I met Dr. Arapk^harian at work today.'
- p^h-k^h արժ ցօմսի տեքոմ դոկտօր արաբանյանի հետ ծանօթացայ:
Այսօր գործի տեղում Դոքտոր Արափքարեանի հետ ծանօթացայ:
today work place doctor Araph^hk^harian with acquainted
'I met Dr. Araph^hk^harian at work today.'
- b-n ցօք տօրաքանները արաբներին գիւղերը թալանեցին:
thieving nomads Arab+PLU+GEN villages looted
'Thieving nomads looted the Arab villages.'
- p-n մերկ լճի արևի սպիտակ կարապներին հացով էինք կերակրում:
we lake shore white swans bread were feeding
'We fed bread to the white swans on the lake shore.'
- p^h-n արժ ցօմսի տեքոմ արաբանյանի հետ ծանօթացայ:
Այս աշնան ուժեղ անձրևի տարածքները վտանգալու են բույսերի համար:
these autumn strong rain torrents dangerous are the plants for
'These strong autumn rain torrents are dangerous for the plants.'

Intermediate Phrase condition (SP)

Pre-pausal condition (PB)

- b- \emptyset vəsta ʃ^hejɨŋk haj ɛ t^hɛ arab
Վստահ չէինք Հայ է թէ Արաբ:
 sure weren't Armenian was or Arab
 'We weren't sure if he/she was Armenian or Arab.'
- p- \emptyset meŋk^h ʔəʃi meʃ tɛsəŋk mi spitak kaɪap
Մենք լճի մէջ տեսանք մի սպիտակ կարապ:
 we lake-acc in saw a white swan
 'We saw a white swan in the lake.'
- p^h- \emptyset jɛ:kəŋk^hiʃ^h t^hap^hvɛʃ^h mi ahagin anɔʒɛvi tɪap^h
Երկնքից թափվեց մի ահագին անձրևի տարափ:
 sky-from fell a heavy rain torrent
 'A heavy torrent of rain fell from the sky.'

Appendix B: Stimuli context chart

A chart of the target sequences of each phrasal condition in the context of their adjacent segments. Also included is a syllable count in the form or #/#, where the first number is the number of syllables up to but not including the target segment and the second number represents the number of syllables following the target segment.

Word-internal (WI)			Word Boundary (WB)			Intermediate Phrase (SP)			Intonation phrase (IP)		
VC:CV	Syllables	Word	VC#(C)V	Syllables	Words	VC#(C)V	Syllables	Words	VC#(C)V	Syllables	Words
b-a	a.ba	8/7	ab.a	6/7	arab aʃakεtə	ab.a	12/9	arab aragoren	ab.a	8/8	arab anahitə
p-a	a.pa	10/7	ap.a	7/7	karap aʃtʰun	ap.a	12/10	karap amen	ap.a	10/9	karap alikner
p ^h -a	a.p ^h a	9/7	ap ^h .a	7/9	tarap ^h arantʃ ^h	ap ^h .a	14/8	tarap ^h amboχʃ	ap ^h .a	13/12	tarap ^h amboχʃ
b-k ^h	abk ^h a	9/7	abk ^h .a	6/6	arab k ^h artuxaɪ	abk ^h .a	12/9	arab k ^h arozif ^h	abk ^h .a	8/8	arab k ^h at ^h jinə
p-k ^h	apk ^h a	9/7	apk ^h .ə	7/7	karap k ^h ənaf ^h	apk ^h .a	12/9	karap k ^h arasun	apk ^h .a	11/11	karap k ^h are.i
p ^h -k ^h	ap ^h k ^h a	9/7	ap ^h .k ^h a	7/8	tarap ^h k ^h are	ap ^h .k ^h a	14/7	tarap ^h k ^h amot	ap ^h .k ^h a	13/13	tarap ^h k ^h aʃvetʃ ^h inj
b-n	abna	8/9	ab.na	7/7	arab naχaɪaɪə	ab.na	12/8	arab najetʃ ^h	ab.no	8/8	arab noɪaɪə
p-n	apna	6/8	ap.nə	7/7	karap nəstaf ^h	ap.na	12/9	karap namak	ap.na	9/8	karap na
p ^h -n	ap ^h na	6/11	ap ^h .na	7/9	tarap ^h naɪəndʒagujɪn	ap ^h .na	14/9	tarap ^h navasat	ap ^h .no	13/14	tarap ^h noɪafʃil
b-ə	.ab.	9			arab						
p-ə	.ap.	11			karap						
p ^h -ə	.ap ^h .	14			tarap ^h						

References

- ALLEN, W. S. (1950). Notes of the Phonetics of an Eastern Armenian Speaker. *Transactions of the Philological Society*, 180–206.
- BECKMAN, J. N. (1997a). Positional Faithfulness, positional neutralization and Shona vowel harmony. *Phonology* 14, 1–46.
- BECKMAN, J. N. (1997b). *Positional Faithfulness*. Ph.D. dissertation. University of Massachusetts, Amherst. [ROA-234].
- BECKMAN, M. E., EDWARDS, J. & FLETCHER, J. (1992). Prosodic structure and tempo in a sonority model of articulatory dynamics. In Doherty & Ladd (eds.), 68–86.
- BECKMAN, M. E. & EDWARDS, J. (1992). Intonational categories and the articulatory control of duration. In Tohkura, Y., Vatikiotis-Bateson, E. & Sagisaka, Y. (eds.), *Speech Perception, Production and Linguistic Structure*, 359–375. Amsterdam: IOS Press.
- BECKMAN, M. E. & ELAM, G. A. (1997). *Guidelines for ToBI Labelling* (version 3). Copyright (1993), The Ohio State University Research Foundation, Ohio State University. http://ling.ohio-state.edu/~tobi/ame_tobi/labelling_guide_v3.pdf
- BECKMAN, M. E. & PIERREHUMBERT, J. B. (1986). Intonational structure in Japanese and English. *Phonology Yearbook* 3, 255–309.
- BYRD, D., KAUN, A., NARAYANAN, S. & SALTZMAN, E. (2000). Phrasal signatures in articulations. In Broe, M. & Pierrehumbert, J. (eds.), *Papers in Laboratory Phonology V: Language Acquisition and the Lexicon*, 70–87. Cambridge: Cambridge University Press.
- BYRD, D. & SALTZMAN, E. (1998). Intra-gestural dynamics of multiple phrase boundaries. *Journal of Phonetics* 26, 173–199.
- CHO, T. & JUN, S.-A. (2000). Domain-initial strengthening as enhancement of laryngeal features: Aerodynamic evidence from Korean. In Boyle, J. & Okrent, A. (eds.), *Chicago Linguistic Society 36: Papers from the Main Session*, 31–44. Chicago, IL: Chicago Linguistic Society.
- CHO, T. & KEATING, P. (2001). Articulatory and acoustic studies on domain-initial strengthening in Korean. *Journal of Phonetics* 29, 155–190.
- DOCHERTY, G. & LADD, D. R. (eds.) (1992). *Papers in Laboratory Phonology II: Gesture, Segment, Prosody*, 90–117. Cambridge: Cambridge University Press.
- FAIRBANKS, G. H. (1975). *Spoken East Armenian*. Ithaca, NY: Spoken Language Services, Inc.
- FLEMMING, E. (1995). *Auditory Representations in Phonology*. Ph.D. dissertation. University of California, Los Angeles.
- FOUGERON, C. (2001). Articulatory properties of initial segments in several prosodic constituents in French. *Journal of Phonetics* 29, 109–135.
- HENTON, C., LADEFOGED, P. & MADDIESON, I. (1992). Stops in the world's languages. *Phonetica* 49, 65–101.
- HSU, C.-S. & JUN, S.-A. (1998). Prosodic strengthening in Taiwanese: Syntagmatic or paradigmatic? *UCLA Working Papers in Phonetics* 96, 69–89.
- JUN, J. (1995). *Perceptual and Articulatory Factors in Place Assimilation: An Optimality Theoretic Approach*. Ph.D. dissertation. University of California, Los Angeles.
- JUN, S.-A. (1995). Asymmetrical prosodic effects on the laryngeal gesture in Korean. In Connell, B. & Arvaniti, A. (eds.), *Papers in Laboratory Phonology IV: Phonology and Phonetic Evidence*, 235–253. Cambridge: Cambridge University Press.
- KAGER, R. (1999). *Optimality Theory* (Cambridge Textbooks in Linguistics). Cambridge: Cambridge University Press.
- KEATING, P., CHO, T., FOUGERON, C. & HSU, C.-S. (1998). Domain-initial articulatory strengthening in four languages. Paper presented at the 6th Conference on Laboratory Phonology, July 1998. (To appear in Local, J., Ogden, R. & Temple, R. (eds.), *Papers in Laboratory Phonology VI: Phonetic Interpretation*. Cambridge: Cambridge University Press.)
- KEATING, P. & FOUGERON, C. (1997). Articulatory strengthening at edges of prosodic domains. *Journal of the Acoustical Society of America* 101.6, 3728–3740.
- KHACHATURIAN, A. (1988). zamanakakits^h hajerēni hontʰ^huj^habanatʰ^hun [Phonetics of Contemporary Armenian]. Yerevan: Hajkakan SSH gitutʰ^hunneɾi akademijai hətataɾakutʰ^hun.

- KHACHATURIAN, A. (1996) The Armenian sound system from typological aspect [sic]. In Sakyan, D. (ed.), *Proceedings of the Fifth International Conference on Armenian Linguistics*, 177–189. Delmar, NY: Caravan Books.
- KIRCHNER, R. (1995). Contrastiveness is an epiphenomenon of constraint ranking. In Ahlers, J., Bilmes, L., Guenter, J. S., Kaiser, B. A. & Namkung, J. (eds.), *Proceedings of the 21st Berkeley Linguistics Society* 21, 198–208. Berkeley, CA: Berkeley Linguistics Society.
- KIRCHNER, R. (1997). Contrastiveness and faithfulness. *Phonology* 14, 83–111.
- LADEFOGED, P. & MADDIESON, I. (1996). *Sounds of the Worlds Languages*. Oxford: Blackwell.
- LOMBARDI, L. (1995). Why place and voice are different: constraint interactions and feature faithfulness in Optimality Theory. Ms., University of Maryland, College Park. [ROA-105].
- LOMBARDI, L. (1999). Positional faithfulness and voicing assimilation. *Natural Language and Linguistic Theory* 17, 267–302.
- MADDIESON, I. (1984). *Patterns of Sounds*. Cambridge: Cambridge University Press.
- PIERREHUMBERT, J. & TALKIN, D. (1992). Lenition of /h/ and glottal stop. In Docherty & Ladd (eds.), 90–117. Cambridge: Cambridge University Press.
- PRINCE, A. & SMOLENSKY, P. (1993). *Optimality Theory: constraint interaction in generative grammar*. Ms., Rutgers University & University of Colorado, Boulder.
- SHATTUCK-HUFNAGEL, S. & TURK, A. (1996). A prosody tutorial for investigators of auditory sentence processing. *Journal of Psycholinguistics Research* 25.2, 193–247.
- STERIADE, D. (1997). Phonetics in phonology: The case of laryngeal neutralization. Ms., UCLA.
- TINGSABADH, M., KALAYA, R. & ABRAMSON, A. S. (1999). Thai. In *Handbook of the International Phonetic Association*, 147–150. Cambridge: Cambridge University Press.
- VAUX, B. (1998). *The Phonology of Armenian*. Oxford: Clarendon Press.
- WIGHTMAN, C. W., SHATTUCK-HUFNAGEL, S., OSTENDORF, M. & PRICE, P. J. (1992). Segmental durations in the vicinity of prosodic phrase boundaries. *Journal of the Acoustical Society of America* 91.3, 1707–1717.