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The Role of Contrast in Prosodically Induced Acoustic Variation

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ABSTRACT

This paper presents results from speech production experiments on English, Korean, and Hindi that compare variation in the acoustic expression of dissimilar phonological laryngeal contrast in stops conditioned by prosodic prominence. Target stops are analyzed from utterance-initial, -medial, and -final positions, with a variation in contrastive focal accent, from the speech data by six male American English speakers, five male Seoul Korean speakers, and five male Delhi Hindi speakers. The results show that prosodic prominence conditions enhanced distinctiveness between contrastive segments in the three languages. The manner in which prosodic prominence and prosodic phrase structure is marked at the level of segmental variation is, however, found to be language-specific to some extent. In addition, a correlation between the size of the phonological inventory and the corresponding acoustic variation was found but the linear correlation was not strongly supported with the findings in the present study.

Keywords: laryngeal contrast, acoustic variation, prosody, size of inventory

1. Introduction

The current study examines patterns of variation in the acoustic expression of laryngeal phonological contrasts among stop consonants, and the role of systemic factors in governing such variation. A majority of languages employ laryngeal features such as voicing, aspiration, or glottalization in defining phonemic contrasts among stop consonants. Languages vary in the number of laryngeal contrasts employed, and in the acoustic expression of laryngeal contrasts. Furthermore, there is intra-language variation in the acoustic realization of laryngeal features due to phonological and phonetic context, pragmatic content, and speaking style. This study investigates the interplay of language-specific contrast system and such variation, focusing specifically on how variation reflects the influence of prosodic prominences in laryngeal speech gestures. Specifically, the focus lies in the correlation between the size of the phonological contrast system and the degree of acoustic variation of laryngeal features under various prosodic contexts.

Prosodic context plays a significant role in determining articulatory and acoustic variation. Prosodic prominences such as stress, accent, or boundary positions are found with enhanced articulatory and acoustic features. Speech gestures typically have greater magnitude and duration in an accented position. For example, lexically stressed vowels in English, (whether they bear a nuclear pitch accent or not), are found to exhibit greater opening of the vocal tract and featural enhancement, and are produced with longer and faster articulation in comparison to unstressed, reduced vowels (Beckman & Cohen, 2000; Beckman & Edwards, 1994). Research shows that prosodic domain boundaries condition segmental lengthening and gestural strengthening. Articulatory and acoustic studies show that vowels are lengthened in domain-final position (Crystal & House, 1988; Edwards, J. *et al.*, 1991), and that consonants are produced with longer and more extreme constrictions in domain-initial position, with enhanced VOT distinctions and greater linguopalatal contact (Cho, 2001; Cho & Jun, 2000; Cho & Keating, 2001; Fougeron & Keating, 1997; Jun, 1993; Pierrehumbert & Talkin, 1992). The prosodic effects have been reported from diverse languages in relation to the idiosyncratic structures of the prosody in the target languages.

Cross-linguistic studies on the effects driven by prosody are not trifling. For example, in domain-initial position, enhancement in the degree of linguopalatal contact in consonants depending on

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the level of the domain in the prosodic hierarchy has been reported in French (Fougeron, 2001), in Korean, and in Taiwanese (Keating *et al.*, 1999). Acoustic VOT patterns are similar to articulatory patterns in domain-initial position in Taiwanese (Hsu & Jun, 1998). Tamil shows similar boundary effects such that domain boundary positions at higher levels involve greater displacement with longer duration in opening-to-closing movements (Byrd *et al.*, 2000). Domain-final lengthening effects are attested for the final rhyme or syllable, in German, Hebrew and Dutch (Berkovits, 1993; Cambier-Langeveld, 1998; Kohler, 1983; cited in Turk, 1999). Accentual effects are shown in Swedish with longer and more extreme vowel qualities (Lindblom, 1963), or in Dutch with global lengthening in accented words (Cambier-Langeveld & Turk, 1999), similar to English stressed vowels. Durational effects from stress are also found in Estonian (Gordon, 1998).

A fundamental finding from the cross-linguistic studies is that there are similar effects due to prosody on acoustic variation. But this does not mean the effects are uniform across languages. The details go beyond the general tendencies observed across languages. For example, Lindblom's (1963) study identifies English and Swedish together as heavy stress languages and reports on a vowel reduction effect in Swedish similar to that in English. Lubker & Gay (1982) compared rounding in vowel production in VCV sequences. Under a very similar prosodic condition, rounding in Swedish starts much earlier than in English, and this is understood in terms of the coarticulatory aggression[2], related to the system of contrast (Farnetani & Recasens, 1993; Recasens, 1991). Rounding in Swedish is contrastive for vowels, and thus, the gesture starts early to mark enough rounding on the target sound. In other words, the acoustic realization in the same prosodic context varies in accordance with the sound inventory of the language, such that the prosodic effects are restricted by language specific consideration of contrast.

Magen (1984) tested patterns of coarticulatory resistance under stress or accent in English and Japanese. The general tendency is that both languages show substantial coarticulatory effects between vowels in VCV sequences. However, the coarticulatory effects are greater in Japanese in detail. One explanation comes from de Jong (1995)'s claim that stress prominence is different from pitch accent prominence, and stress prominence in English entails greater coarticulatory resistance of the stressed vowel. Another reason for the difference between English and Japanese may be the relatively smaller size of the vowel inventory in Japanese, as suggested by Manuel (1999). Manuel finds negative correlation between the size of the phonological inventory and the corresponding degree of phonetic variation in cross-linguistic studies on English and three Bantu languages (Manuel, 1990; Manuel & Krakow, 1984). The more crowded vowel space in English occurs alongside less variation in the acoustic space of vowels. The classic study by Öhman (1966) on formant transitions in VCV sequences in Russian, Swedish, and English also supports the correlation between language specific patterns of contrast and coarticulatory variation. Öhman shows that anticipatory coarticulation, evidenced through patterns of vowel formant transitions, is inhibited by intervening stops in Russian, where the palatalized/velarized distinction is an important feature. The tongue body configuration that determines secondary palatalization and velarization in Russian is claimed to restrict the free interaction between the vowels. This finding on palatalization is extended to additional Slavic languages of Bulgarian and Polish (Choi & Keating, 1991).

In short, there are relatively few works studying the effect of inventory size on prosodically-governed variation across languages. But the existing results suggest a correlation between acoustic variation and language-specific sound systems. Therefore, the present study explores whether variation in prosodic effects can be correlated with different contrast systems of languages. Specifically, it is investigated how the acoustic correlates of the laryngeal contrast in stops demonstrate the systemic characteristics of a given language. English, Korean, and Hindi are selected for the research goal since the three languages employ different laryngeal contrast systems of stop consonants. English is a language with a two-way contrast between lenis and fortis stops. Voicing and aspiration are employed to mark the two contrastive stops allophonically such that voicing marks the lenis pair in some contexts, while aspiration is a feature of fortis stops in specific contexts. Korean employs a three way contrast among voiceless plain, voiceless aspirate, and voiceless tense stops. All the Korean stops are voiceless phonemically and thus, the laryngeal contrasts are marked differently than in English: tense stops show no aspiration, plain stops show some, and aspirate stops show greater aspiration. Voicing

2) The tendency for a segment to induce strong coarticulatory effects on neighboring segments is termed as coarticulatory aggression (Farnetani, E. & Recasens, D., 1993; Recasens, D., 1991).

signals the plain "voiceless" stop only in the intervocalic context in the absence of interrupting major prosodic boundaries (Jun, 1993, 1995). Hindi shows an even more crowded inventory of laryngeally contrastive stops with a four way contrast between voiceless plain, voiceless aspirated, voiced plain, and voiced aspirated stops. Voicing and aspiration are coupled to discriminate the four different stops, and prevoicing distinguishes voiced stops from voiceless stops. Aspiration follows the prevoicing phase in the voiced aspirated stops.

The dissimilar laryngeal contrast systems in English, Korean, and Hindi are predicted to show very different coarticulatory patterns and corresponding acoustic realizations under prosodic variation according to Manuel (1990). If phonetic variation is negatively correlated to the size of inventory, then the effects of prosodic factors on phonetic variation in each language is expected to be dissimilar. This general hypothesis is investigated in the current study through an examination of prosodic effects on acoustic variation

2. Method

2.1 Speech material

Target consonants were analyzed from the initial CV syllable of eight English words (with the target syllables underlined: pottery, botany, peter, beater, petter, bettor, pah, bah), nine existing Korean words (/pata/ 'the sea', /p^hata/ 'to dig', /p'ata/ 'butter', /pita/ 'to be empty', /p^hita/ 'to bloom', /p'ita/ 'to sprain', /pul/ 'fire', /p^hul/ 'grass', and /p'ul/ 'horn'), and eight existing Hindi words (/pag/ 'turban, anything boiled in syrup', /p^hag/ 'Holi festival, song sung during Holi', /bag/ 'garden', /b^hag/ 'part'; /p^hita/ 'shoe lace', /pital/ 'brass', /biti/ 'past', and /b^hiti/ 'wall'). All English target syllables bear the lexical stress in the present study, and thus there is no variation of prosodic prominence at the lexical level. The words were presented in different prosodic contexts, located in utterance-initial, -medial, and –final positions of carrier sentences. The words designed in phrase-initial position were used for the phrase-medial condition by adding modifiers in front. The edges of carrier sentences in the present study coincided with Intonational Phrase and Utterance boundaries. The carrier sentences also varied in their accentual condition with two different sets of dialogues for each carrier sentence: one with a contrastive focus on the target word, and the other with a contrastive focus on another word in the sentence[3)].

2.2 Subjects and Procedure

Speech data from six English, five Korean, and five Hindi subjects were analyzed. Six males (AL, BD, HE, JH, MC, and RF), who are monolingual and native speakers in American English, were all from the Chicago area and undergraduate students in University of Illinois at Urbana-Champaign. Five males (CS, HK, KS, PS, and YI), all monolingual and native speakers of Seoul Korean, were born in Seoul, South Korea and had stayed there until they moved to the United States. All of them were in their twenties and had been in the United States for less than one year. 5 Hindi male subjects (AG, NN, RN, SK, and SS) are native speakers in Delhi Hindi, who use Delhi Hindi to communicate with their parents and other family members. They are also fluent in English, and some of them are able to speak other Indo-Aryan language varieties. The subjects were all born in the Delhi area and had stayed there until they moved to the United States. All of them were in their twenties. The subjects had no phonetic training or knowledge and reported no speaking or listening impairment. They were paid for their participation.

To control the testing materials varying in focal and positional conditions, sets of dialogues were designed with the target sentence as an answer to a question. Target CV sequences were placed in the three different positions in the prosodic domain and contained the contrastive focus when they were in the focused condition. The complete materials were presented to the subjects in separate blocks on the basis of the prosodic condition of the target word. The focused and nonfocused groups were presented in separate blocks in order to sustain reasonable prosody, and different positions also conditioned separate blocks.

The blocked sets of dialogue were visually presented to the subjects without any markings for target CVs or focused items, and subjects were supposed to take the role of the answerer in the

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3) For example, in English, some tokens in the initial-nonfocused condition were observed from a dialogue set of a question, "Pottery is the title of your book?", and an answer of "Pottery is the main subject of my book", where the target CV is underlined. Corresponding medial tokens were observed from a dialogue set of "A yellow pottery book was on the desk?" and "A yellow pottery book was on the table." And the tokens in the final-focused condition were from "Pat's nickname is Funny Bah?" and "Pat's nickname is Funny Pah." The same patterns were used to design Korean and Hindi settings.

minimized discourse situation. The question and answer parts were presented as a set in a similar way, and subjects were instructed to read the questions silently and answer with the given target sentences supposing the discourse situation. Subjects practiced with whole set of materials until they were familiarized with all the situations.

Test sentences were presented in quasi-random order after a rehearsal session. The test stimuli in a block were provided in fixed order in one round, and the order was reversed in the next round. After two repetitions with converse order in a block, the subject moved to the next block until he finished all the blocks of stimuli. Afterwards, another repetition of the sets of blocks was started from the beginning in the same way, which provided the third and fourth repetitions for each stimulus. In the English experiment, the final repetition of the blocks consisted of one repetition for each block, which was the fifth repetition for each stimulus. However, in the Korean and Hindi settings, the whole procedure was repeated once more for sets of blocks in the same way, which provided fifth and sixth repetitions for each stimulus. Optional breaks were provided after each block upon the subjects' request. Each block was repeated five times for six English speakers and six times for five Korean and five Hindi subjects over the course of the experiment, varying within-block sentence order across repetitions, for a total of 840 tokens in English, for a total of 1080[4] recorded tokens, a total of 960[5] recorded tokens for analysis.

The recording procedure was done in a sound-attenuated booth in the phonetics laboratory in University of Illinois at Urbana-Champaign. All sound stimuli were recorded through a head-mounted microphone and a Tascam DAT recorder and transferred to a PC for the analysis.

2.3 Measurements

The recorded sounds were transferred to a PC at a sampling rate of 22050 Hz and analyzed with the Praat program (Version 4.0.13, Boersma & Weenink, 2000). Acoustic measurements of VOT and F0 at the onset of the following vowel were employed as acoustic correlates of stop voicing contrast. VOT is widely accepted as a feature to mark a laryngeal contrast of stop consonants in most languages including English (Lisker & Abramson, 1964), such that English voiceless stops show greater VOT values than their voiced counterparts. F0 at the following vowel onset is also reported as a cue to English stop voicing. Whalen *et al.* (1993) reports from their perception study that F0 at the vowel onset assists voiced/voiceless distinction of the preceding stops even with unambiguous VOT values.

The duration from the stop release to the onset of the second formant in the following vowel was measured as VOT. Fundamental frequency values were manually calculated from the mean period over the initial three periodic cycles of the wave forms after the stop release, 3/D, where D is the duration of the 3 measured pitch period. The calculated values were compared with the results from the autocorrelation pitch analysis function in Praat, which showed similar values but reported some missing values that could be analyzed with the manual measurement. The major measurement points are visibly depicted in <Figure 1>.

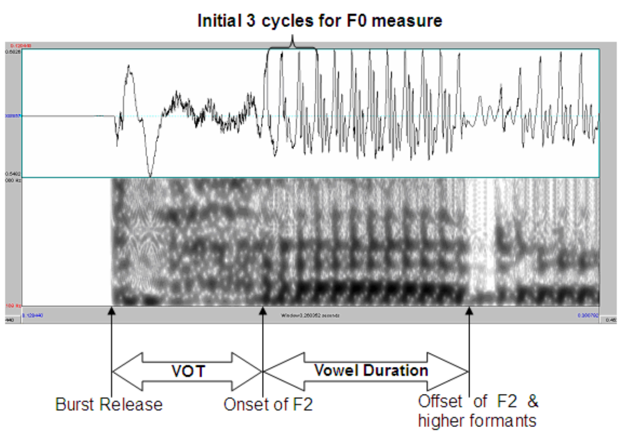

Figure 1. Points and intervals for the acoustic measurement.[6]

4) The number of tokens that are actually reported with measured values is reduced to 1064 because of the clear devoicing pattern in the target CVs for certain subjects.

5) The number of tokens that are actually reported with measured values is reduced to 753 for stop consonants due to the fricativization in certain tokens which is popular among Delhi Hindi speakers.

6) In the figure, all points were very exactly marked in a highly zoomed-in data representation. Spectrographic view was taken first to get the information of landmark points such as major onset and offset points and then, the exact marking was decided further based on the information from the wave form. For Hindi voiced tokens, the negative VOTs were measures from the onset of prevoicing to the stop release. In particular, to study the clear aspiration break after prevoicing in aspirated voiced tokens, I introduce a distinct measure, the Breathy Voice Interval, as a correlate of aspiration for the voiced aspirates.

2.4 Statistical analysis

The influence of each prosodic factor was evaluated based on Analyses of Variance (ANOVAs) in the Univariate General Linear Model. The unit of the statistical analysis was limited to acoustic measures of one individual subject in order to prevent possible idiosyncratic effects from a specific subject when all subjects' data are pooled. The Univariate ANOVAs were performed for each individual subject's data on each acoustic measurement as a dependent variable, and the obtained results were compared across speakers. This statistical analysis reveals not only the possible significant between-language differences but also the degree of significance of the independent variables in each language by reporting results from individual conditions.

Three factor variables were generally employed for the ANOVA analysis in the present setting: Position (i.e., Initial, Medial, Final), Focus (i.e., Focused, Nonfocused), and Target Cs. The data sets were further grouped to examine more detailed patterns of the prosodic effects, and the factors were varied depending on the intended comparison. For example, the positional effect across initial, medial, and final positions was compared for English /pa/ and /ba/ tokens in the three different positions, which employed only two levels of variations under the factor of Target CVs.

For more detailed analysis of the observed factors, post hoc comparisons were performed at the significance level of .05. The SPSS statistical package (SPSS for windows, Standard Version, Release 10.0.1, 27 Oct 1999, SPSS Inc.) was used for the statistical measurement.

In addition to statistical comparisons, distributions of individual subjects' tokens in each language and the corresponding standard deviations were compared to assess more detailed cross-linguistic variation.

3. Results and Discussion

The effect of prosody is reported in the observed languages as significant according to the statistical analysis. In English, Korean, and Hindi speech tokens, the focal accented segments are represented with a distinctive pattern from the unaccented counterparts with significantly greater VOT and F0 values, and domain-initial consonants are marked rather differently but not always with enhanced acoustic values. The present investigation, however, shows that the manner in which prosodic prominence and prosodic phrase structure is marked at the level of segmental variation is found to be language-specific. The acoustic variation conditioned by prosody is overall not very significantly marked in Hindi consonants, whereas English and Korean stops are marked with a distinctive effect due to prosodic factors, particularly a focal accent. Results from 3-way ANOVAs (Position × Focus × CV syllable) for each subject show that Focus is a significant factor for most English and Korean subjects in both VOT and F0 measurements while only three cases are found with a significant effect by the factor of Focus in the acoustic measures for Hindi stops (NN's VOT ($F(1,188)=4.104$, $P<.05$); NN's F0 ($F(1,188) = 4.786$, $P<.05$); SS's F0 ($F(1,191)=11.52$, $P<.01$)). A reason of the minimized variation due to prosodic contexts in Hindi may be found in the relatively crowded contrast system of Hindi stops, following Manuel's suggestion on correlation between language inventories and coarticulatory patterns (Manuel, 1990; Manuel & Krakow, 1984). Under an assumption of 'output constraints', languages are understood to have a tendency to tolerate less coarticulation or to show smaller variation in order to prevent confusion of contrastive phones. Hindi employs a four-way laryngeal system, and thus, the relative variability in a segment is a lot more limited because of the crowd contrast system compared to English and Korean, in order that confusion of contrastive phones shall be minimized, and a minimum distinction between the four categories might be maintained.

The explanation based on language inventory systems further predicts asymmetric prosodic effects in English and Korean for the same reason. With a less crowded laryngeal system, English stops should involve a greater range of variation than Korean stops, which overrides individual idiosyncrasies. Statistical results, however, suggest that the acoustic measures for Korean stops are affected by prosodic factors, i.e., accentual and boundary contexts, as significantly as the acoustic measures for English stops. One difference in these two languages with respect to accentual effects is that English shows both paradigmatic and syntagmatic changes under focus in the sense that the VOTs are greater for both of the contrastive stops but it is even greater for the voiceless one[7]. On the other hand, Korean involves rather paradigmatic changes with

7) Keating (1984) and Pierrehumbert & Talkin (1992) provide evidence for the enhancement at the onset consonant of the accented syllable such that the onset consonants generally involve greater VOT under accent. Greater VOT is considered as a more obstruent-like pattern which can be an acoustic strengthening of consonantal features under accent.

one category fixing less variable.

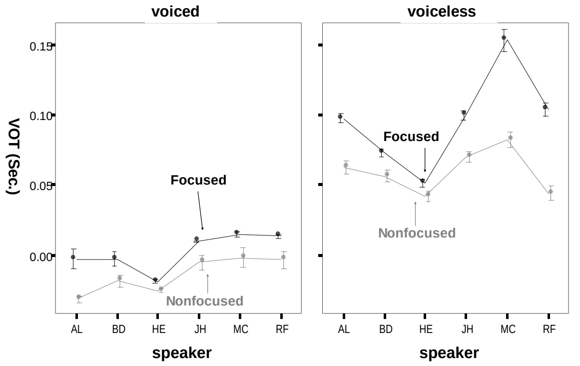

Figure 2. Variation by Focal Accent on VOT values of English voiced and voiceless stops in medial position.[8)]

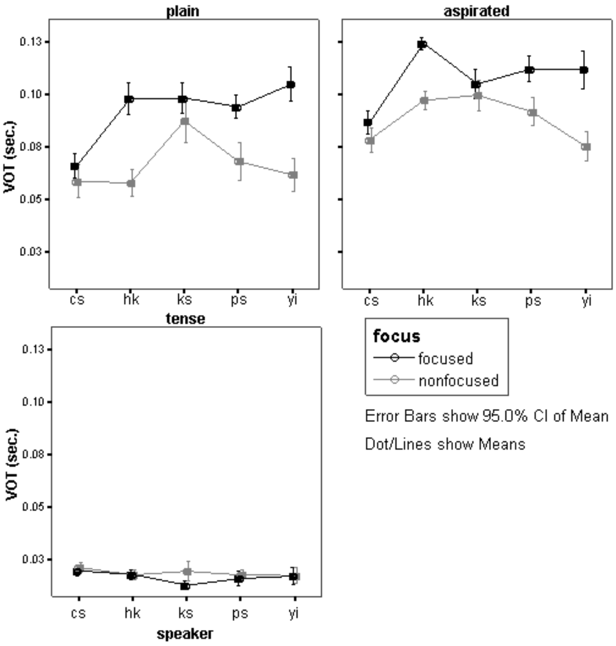

Figure 3. Effects of Focal Accent on VOT values of plain, aspirated and tense stops in Korean.

In <Figure 2> and <Figure 3>, variation by a focal accent is very visible for both voiced and voiceless stops in English, but the variation is limited to plain and aspirated stops in Korean. This discrepancy may be understood as a result of the so-called ‘output constraints’ to keep the distinctiveness in the contrastive segments in a system. That is, instead of reducing the ranges of variation for each constituent in the whole system with more competing members, a strict restriction on one member may be implemented to yield further variability in the other members of the system[9)]. Enhancement in F0 values due to a focal accent also depicts a discrepant pattern in two languages in such a way that English involves both syntagmatic and paradigmatic enhancement of the contrastive segments as in <Figure 2> whereas Korean shows enhancement for the limited segments in <Figure 3>.

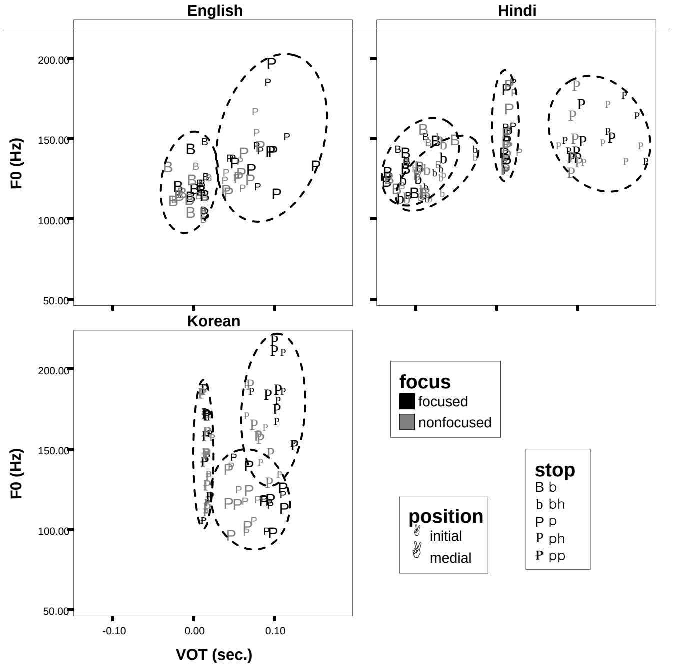

Figure 4. Variation in stop laryngeal contrast as a function of VOT and F0.[10)]

For a simplified visual comparison of the prosodically induced acoustic variation in the three languages, a view as a function of VOT and F0 for laryngeal stop contrast under the uniform scale is provided similarly to Manuel (1990). <Figure 4> presents a relative variation of the acoustic measures for the stop laryngeal contrast of three languages investigated in the present studies. Each symbol indicates contrastive stop categories in the language such that ‘B’ and ‘P’ in English mark voiced and voiceless stops, and ‘P’, ‘P’, and ‘p’ in Korean denote plain, aspirated and tense,

8) In <Figure 2> and <Figure 3>, boxes show means, and each error bar corresponds to 95% confidence interval of mean, which are marked for each individual speaker. The darker boxes, which are generally greater in y-axis for all the speakers, correspond to the Mean value of focused ones in both voiced and voiceless stops.

9) This semi-paradigmatic patterning of contrastive stops by separating one member more distinctively against the others in Korean is also reported in Choi (2002).

10) Unlike Manuel’s (1990) figure that depicts average values over individual subjects, <Figure 4> plots the average values for each speaker separately for each focal and positional condition to examine more detailed distribution. Darkness marks two focal conditions and size depict the two positions. The focused one are marked with the darker symbols and the medial ones are bigger than the initial ones.

whereas ‘B’, ‘P’, ‘b’, and ‘P’ in Hindi mark voiced unaspirated, voiceless unaspirated, voiced aspirated, and voiceless aspirated respectively. Mean values for each prosodic condition are marked for individuals. Unlike Manuel’s figure that depicts average values over individual subjects, <Figure 4> designates individuals’ results separately with average values under each focal and positional condition to see more details of the actual distributions. For consistency, the final tokens are excluded from all data since Hindi does not have final tokens.

One thing apparent in <Figure 4> is that each token in English is spread over a wide acoustic space with less overlap between competing constituents. Comparatively, Hindi and Korean tend to display a rather concentrated distribution within smaller areas with a very restricted variation in one constituent at least. English tokens look to vary to a great extent in both x- and y-axes, whereas Korean and Hindi prefer one-dimensional changes for certain constituents. Still, it is not very straightforward to deduce a firm linear negative correlation between the number of contrastive members in a system and the degree of variation. Comparison between Korean and Hindi is particularly problematic because Hindi makes use of wider acoustic spaces in x-axis with negative VOTs. A general trend in <Figure 4> may suggest an interaction between the number of contrastive constituents in a system and the degree of variation, but the evidence is not strong enough to infer a direct influence of language-specific contrast systems. Furthermore, the wide variance of the distribution in English data is due to rather few outliers while the majority of English tokens demonstrate a good concentration in a small range, which can be compared to the less concentration and wider distribution of the certain tokens in Korean and Hindi. The standard deviations as an additional measure of variation in acoustic values demonstrate a very equivalent size of variations in English and Korean.

<Figure 5> provides the average of standard deviations of six English speakers’ VOTs for the two contrastive stop consonants, and the average standard deviation values of five Korean speakers’ VOTs for the three stops. The values show the rather restricted variation in the Korean tense stop tokens, which may suggest the effect from the size of the inventory system. However, contrary to the prediction based on the output constraints or the correlation hypothesis by Manuel and the related researchers, the contrastive Korean plain and aspirated stops with an additional contrastive member display even greater variations compared to the two contrastive English stop tokens. If there exists a firm linear negative correlation between the number of contrastive members in a system and the degree of variation, the members of the two-way system, namely English tokens, should involve greater variation in the distribution than all the Korean tokens, and this is not confirmed in the present study. The correlation, if any, is more complicated than what is discussed in the previous studies.

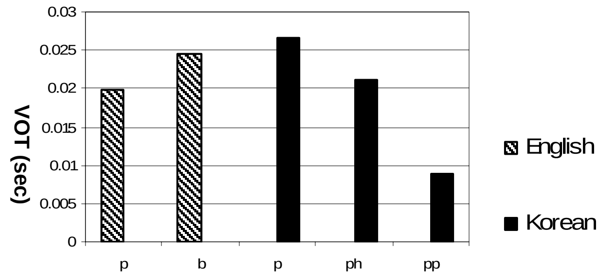

Figure 5. Average of the standard deviations across the spoken tokens of laryngeally contrastive stops in English and Korean.

4. Conclusion

A primary goal of this study is to provide a rather comprehensive account of effects from language-specific contrast systems on acoustic variation in terms of prosodic conditioning. Prosodically prominent contexts were found to be depicted with distinctive patterns from neighboring constituents in all the observed languages. On the whole, these results suggest that phonetic realization is systematically controlled by prosodic factors, and the prosodically conditioned acoustic variations, in turn, can manifest high level prosodic structure in different languages. The interactive patterns between prosody and phonetics are also found true to not only English but also Korean and Hindi. However, the systematic influence on acoustic variation is quite language-dependent due to language specific features. The influence of language inventory systems, as one presumable feature, was predicted a negative correlation between the complexity of a system and the degree of variation, and some possible correlations are discussed based on the limited prosody-induced variation in the Hindi data. The related question is, therefore, how prosody is processed in Hindi with less marked segmental cues. One possibility can be discussed perceptual compensation by listeners, which requires future research. The difference between Korean and English acoustic variation is also discussed relating to the difference in the inventory systems. However, the expectation of greater restriction on Korean acoustic variation was not supported uniformly from all the contrastive segments, and the evidence for the negative linear correlation could not be simply generalized under the present settings. Thus, the effect of the contrast system on acoustic variation should be understood in a different approach. Subsequent work is, therefore, necessary in the fields of cross-language and language perception studies.

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