*Journal of Phonetics* (1996) **24,** 295–312

# Acoustic and perceptual evidence for complete neutralization of manner of articulation in Korean

**Hyunsoon Kim**

*Department of Linguistics, Cornell University, Ithaca, NY 14853, U.S.A.*

**Allard Jongman***

*Cornell Phonetics Laboratory, Department of Modern Languages, Cornell University, Ithaca, NY 14853, U.S.A.*

*Received 12th September 1994, and in revised form 11th November 1995*

While most studies of neutralization have focused on word-final devoicing, the present study investigated a different kind of neutralization, namely that of *manner of articulation.* Korean has a rule of Coda Neutralization, whereby word-final coronal obstruents (e.g., /t, $t^h$, s/) are all phonetically realized as [t]. Experiment 1 shows that Korean vowels preceding non-final heterosyllabic fricatives are longer than when preceding non-final heterosyllabic oral stops. Making use of this fact, vowel and closure durations of word-final VC sequences were measured in Experiment 2 to determine whether the speech signal contained any acoustic cues to the underlying manner distinction. Data from four speakers suggest that neutralization of manner as reflected in vowel and closure duration is phonetically complete. Moreover, complete neutralization is observed despite the fact that Korean orthography distinguishes between the different underlying consonants. An additional finding is that 83% of all word-final stops in this study were followed by a brief burst. This is of particular interest given the long tradition in Korean phonology of considering coda neutralization to yield unreleased stops. Finally, perceptual results from Experiment 3 show that listeners were unable to reliably determine from which underlying form a given surface form had been derived, thus indicating that other potential cues besides duration had been neutralized. Taken together, the present results suggest that Korean manner neutralization offers a perhaps rare instance of the standard view of neutralization, producing outputs which are not distinguished in either production or perception. 

## 1. Introduction

One of the most basic concepts of phonological theory is that of neutralization whereby phonemic distinctions are eliminated in a particular phonological context

* Address all correspondence to: Dr. Allard Jongman.

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(e.g., Trubetzkoy, 1939). The phonological approach for merging distinctive phonemes into a single phoneme in a certain linguistic environment predicts that neutralization is phonetically manifested as complete. However, there is a lively debate in the current phonetic literature as to whether phonological neutralization is phonetically complete or incomplete (for reviews, see Dinnsen, 1985; Blumstein, 1991).

Almost all phonetic studies of neutralization have focused on word-final obstruent devoicing, with findings supporting either complete or incomplete neutralization. Specifically, research on languages with a phonological rule of word-final devoicing has shown that neutralization is phonetically incomplete as evidenced by phonetic distinctions between phonologically voiced and voiceless stops in terms of duration of voicing into closure, closure duration, and duration of the preceding vowel (e.g., Catalan: Dinnsen & Charles-Luce, 1984; German: Port & O'Dell, 1985; Charles-Luce, 1985; Port & Crawford, 1989; Polish: Slowiaczek & Dinnsen, 1985; Russian: Pye, 1986). Since in many languages vowels are longer when preceding voiced consonants relative to voiceless consonants (e.g., Chen, 1970; Laeufer, 1992 and references therein), incomplete voicing neutralization may be expected to manifest itself in the form of slightly longer vowels and shorter final consonant closures for those surface forms derived from stems with an underlying voiced final consonant.

On the other hand, there are studies which support complete voicing neutralization (e.g., German: Fourakis & Iverson, 1984; Polish: Jassem & Richter, 1989). These authors ascribed reports of the lack of complete neutralization in other studies to unnatural laboratory circumstances, which lead to hypercorrect productions. In particular, the results of Fourakis & Iverson (1984) and Jassem & Richter (1989) both suggested that voicing neutralization is complete if one manages to exclude orthographic information from the elicitation procedure. It should be noted, however, that Jongman, Sereno, Raaijmakers & Lahiri (1992) found complete voicing neutralization in word-final position in Dutch even when subjects read a wordlist where the contrasting underlying forms differed in their orthography.

While most phonetic studies to date investigated the acoustic correlates of devoicing, it is not clear whether their findings would extend to other instances of neutralization. For example, Lahiri, Schriefers & Kuijpers (1987) showed complete neutralization in their study of vowel length in Dutch. Namely, Lahiri *et al.* (1987) found no difference in duration between long vowels derived by an open-syllable lengthening rule and vowels that are underlyingly long. Neutralization was thus complete in that the underlying vowel length distinction was lost in the surface phonetic representation.

The present paper extends our knowledge of the phonetics of neutralization by examining a qualitatively different kind of neutralization, namely neutralization of manner of articulation. Specifically, the present study investigates whether the underlying distinction between Korean syllable-final fricative and stop is completely neutralized on the surface.

## 2. Korean coda neutralization

### 2.1. *The three types of coda neutralization*

Korean distinguishes three types of voiceless consonants: lax (p, t, k, tʃ), aspirated ($p^h, t^h, k^h, tʃ^h$) and reinforced (p′, t′, k′, tʃ′, s′).[1] The three-way consonant distinction is neutralized into lax consonants in coda position (Martin, 1951; Lee, 1972; Kim-Renaud, 1974; C-W. Kim, 1979; Chung, 1980).[2] Korean has three types of Coda Neutralization: laryngeal, manner, and palatal neutralization. Laryngeal neutralization merges all underlying laryngeal distinctions into homorganic lax stop consonants, as shown in (1a).

(1a) Laryngeal neutralization

| | | | | |
|---|---|---|---|---|
| $p, p^h]\sigma$ | $\rightarrow$ [p] | e.g., | /tʃip$^h$/ | [tʃip] "straw" |
| $t, t^h]\sigma$ | $\rightarrow$ [t] | | /mit$^h$/ | [mit] "bottom" |
| $k, k^h, k']\sigma$ | $\rightarrow$ [k] | | /pak'/ | [pak] "outside" |

Manner neutralization merges fricatives into a lax coronal stop [t], as shown in (1b).

(1b) Manner neutralization

| | | | |
|---|---|---|---|
| $s, s', h]\sigma \rightarrow$ [t] | e.g., | /kis/ | [kit] "feather" |
| | | /is′/ | [it] "to be located" |
| | | /tʃoh/ | [tʃot] "to like"[3] |

Finally, under palatal neutralization all palatal distinctions are merged into a lax coronal [t] as well, as shown in (1c).

(1c) Palatal neutralization

| | | | |
|---|---|---|---|
| tʃ, tʃ$^h$]$\sigma \rightarrow$ [t] | e.g., | /natʃ$^h$/ | [nat] "face" |
| | | /natʃ/ | [nat] "day" |

When followed by a vowel-initial suffix, the coda consonant of a lexical word is syllabified into the onset of the vowel-initial suffix, blocking Coda Neutralization from occurring, as in (2a). When the consonant syllabified into the onset is lax, it gets voiced in intervocalic position, as shown in (2b).[4] In contrast, when followed by a consonant-initial suffix, the final consonant of a lexical word is syllabified as a coda and undergoes Coda Neutralization. As the result of Coda Neutralization, the

[1] Following standard practice in the field of Korean linguistics, we use [C′] as the symbol for tense consonants. Korean tense consonants are [+constricted glottis] in the sense of Halle & Stevens (1971): ejective "glottalized" consonants.

[2] In Korean, /p′, t′, tʃ′/ are not attested in coda position.

[3] The merger of /h/ into [t] is limited to *word*-final position. In coda position, preceding an obstruent, /h/ will delete, with aspiration spreading to the following obstruent (1); in intervocalic position, the coda /h/ is deleted (2):

(1) /tʃoh/ + /ta/ → [tʃo.t$^h$a] "like" + Indicative

(2) /tʃoh/ + /a/ → [tʃo.a] "like" + "-ing"

[4] This holds for stop consonants. For the fricatives, /s/ remains unvoiced:

/kis/ "feather" kis + i → [ki.ʃi] "feather" + subj.

distinctive phonation types are all merged into lax stop counterparts, as shown in (2c).

| | | | | | |
|---|---|---|---|---|---|
| (2a) | /tʃip$^{h}$/ | "straw" | tʃip$^{h}$ + i ⟶ | [tʃi.p$^{h}$i] | "straw" + subj. |
| | /pak′/ | "outside" | pak′ + i ⟶ | [pa.k′i] | "outside" + subj. |
| (2b) | /tʃip/ | "house" | tʃip + i ⟶ | [tʃi.bi] | "house" + subj. |
| | /pak/ | "gourd" | pak + i ⟶ | [pa.gi] | "gourd" + subj. |
| (2c) | /tʃip$^{h}$/ | "straw" | tʃip$^{h}$ + to ⟶ | [tʃip.t′o] | "straw" + also |
| | /pak′/ | "outside" | pak′ + to ⟶ | [pak.t′o] | "outside" + also |

### 2.2. *Neutralization of manner*

Of the three types of Korean neutralization, the present study focuses on neutralization of manner of articulation. Korean has minimal contrasts, with members underlyingly ending in /t/, /t$^{h}$/, or /s/. The underlying representation of the coda consonants is determined on the basis of morphophonemic alternations. When followed by a vowel-initial suffix, underlying coda consonants remain intact. However, when followed by a consonant-initial suffix, these underlyingly distinctive consonants are merged on the surface in coda position, thus being realized as [t], as shown in (3):

| | | | | |
|---|---|---|---|---|
| (3) | /kət/ | "to collect" | /kət + ə/ | [kə.də] (with indicative marker /ə/) |
| | | | /kət + tʃi/ | [kət.tʃ′i] (with negative marker /tʃi/) |
| | /kət$^{h}$/ | "outside" | /kət$^{h}$ + ɨl/ | [kə.t$^{h}$ɨl] (with object marker /ɨl/) |
| | | | /kət$^{h}$ + kwa/ | [kət.k′wa] (with marker /kwa/ "and") |
| | /kəs/ | "thing" | /kəs + i/ | [kə.si] (with subject marker /i/) |
| | | | /kəs + kwa/ | [kət.k′wa] (with marker /kwa/ "and") |

Given the presence of such contrasts, the present study examines whether or not this type of manner neutralization is phonetically complete. Specifically, this study investigates whether there are acoustic differences in a surface form such as [kət], depending on the underlying form from which it has been derived.

For the present investigation, we follow a rationale similar to that used in phonetic studies investigating voicing neutralization. It has been shown for many languages that vowels preceding fricatives are longer than vowels preceding stops (e.g., German: Meyer, 1904; Italian: Metz, 1914; Spanish: Navarro Tomas, 1916; English: House & Fairbanks, 1953; Peterson & Lehiste, 1960; Umeda, 1975; French: Delattre, 1962; Dutch: Nooteboom & Cohen, 1984). Since underlying fricatives never surface as fricatives in coda position in Korean, it is impossible to directly confirm this generalization for Korean.

Nevertheless, there is evidence that Korean might pattern in a similar fashion. Chen (1970), for example, showed that Korean vowels preceding (heterosyllabic) voiceless aspirated stops are shorter than when preceding phonetically voiced lax stops. As for effects of manner of articulation, House & Fairbanks (1953) and Peterson & Lehiste (1960) reported for English and Nooteboom & Cohen (1984) for Dutch that vowel duration in words increases as the manner of the final consonant changes from stop to fricative to nasal. Similarly, for Korean, Yang (1978) shows that vowels preceding nasals are longer than those preceding stops at the same place of articulation.

Although Korean syllable structure precludes an analysis of the effects of syllable-final obstruents on preceding vowel duration, Korean does allow an analysis of the influence of heterosyllabic syllable-initial obstruents on the duration of preceding syllable-final vowels. The first experiment, therefore, systematically investigated the presence and magnitude of such effects.

## 3. Experiment 1: vowel duration preceding intervocalic fricatives and stops

### 3.1. *Speakers*

Three Korean speakers, one male (1) and two females (2, 3), participated in this experiment. They were recruited from the Cornell student population. They had been in the U.S. for at most four years, and conducted most of their interactions outside the classroom in Korean. None of the speakers had any known speech or hearing disorders.

### 3.2. *Materials and procedure*

Test words consisted of 11 bisyllabic minimal word pairs (see Appendix A). For each pair, one member had the voiceless aspirated dental stop /$t^h$/ in medial position, while the other member contained the voiceless dental fricative /s/ in that position, as in the minimal pair [tso$t^h$a] "steering" *vs.* [tsosa] "investigation". Voiceless unaspirated /t/ was not examined since it is often realized as voiced /d/ in this context. Five repetitions of the stimuli were randomized and embedded in the carrier phrase [əsə ____ malhasejo] ("Please say ____ "). The sentences were presented in lists in Korean orthography. The total number of target words was 330 (22 words $\times$ 5 repetitions $\times$ 3 speakers).

Speakers were recorded in a sound-proofed booth in the Cornell Phonetics Laboratory, using a cardioid microphone (Electrovoice RE20) and high-quality cassette recorder (Carver TD-1700). Before recording, speakers practiced reading a few randomly chosen test sentences to familiarize themselves with the materials. Materials were read at a comfortable speed throughout the recording session.

### 3.3. *Analysis*

All sentences were digitized onto a Sun Sparcstation 2 at a sampling rate of 11 kHz with 16-bit resolution, and stored as files to be processed by the commercial software package WAVES + /ESPS. For each target word, the duration of the first vowel was measured on the basis of both wideband spectrograms and waveforms. Vowel onset was considered to be the onset of the first formant, which corresponded with the onset of periodicity in the waveform. Vowel offset was taken as the offset of the second formant. Some instances of the target word [sut$^h$o] "climate" did not contain the vowel /u/ due to vowel devoicing.[5] This was the case for all five tokens of the male speaker, and for one token of one of the female speakers. In all of these cases, data for the corresponding target [suso] "hydrogen" were excluded as well.

### 3.4. *Results*

Vowel duration measurements as a function of following consonant are shown for each speaker in Fig. 1. Across speakers, mean vowel duration preceding /t$^h$/ was 56 ms; that preceding /s/ was 89 ms. Pairwise two-tailed *t*-tests using subject means for each word (averaged across the five tokens) revealed that the duration of the vowel was significantly longer when preceding /s/ as compared to /t$^h$/ (Speaker 1:

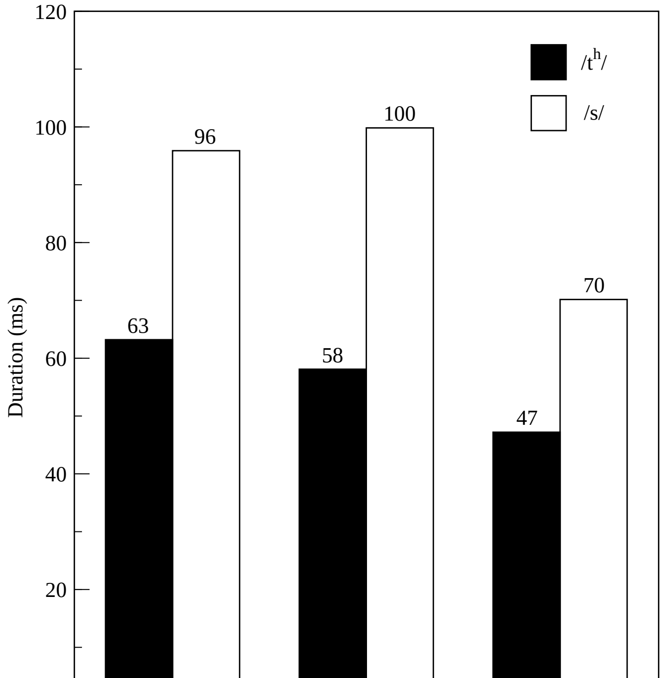


**Figure 1.** Mean vowel duration (in ms) for each speaker, for minimal pair members in which the medial consonant is either /t$^h$/ or /s/.

[5] While the devoicing of Japanese vowels has been well documented (e.g., Beckman & Shoji, 1984; Tsuchida, 1994), very little is known about vowel devoicing in Korean. Kim, Niimi, & Hirose (1993) present acoustic and articulatory data suggesting that of the three high vowels /i, u, ɯ/ only /i/ can be devoiced when occurring in between an /s/ or /tʃ$^h$/ and an aspirated stop or /tʃ$^h$/. While the present study was not designed to study vowel devoicing, it is of interest that vowel devoicing involved the vowel /u/ (the vowels /i/ and /ɯ/ were not used in the present experiment).

[$t(9) = 10.96$, $p < 0.001$]; Speaker 2: [$t(10) = 11.88$, $p < 0.001$]; Speaker 3: [$t(10) = 7.26$, $p < 0.001$]).

### 3.5. *Discussion*

The results of Experiment 1 clearly show that Korean can be added to the languages for which vowels preceding fricatives are longer than vowels preceding stops. The difference in vowel duration is quite large (on average 33 ms), particularly considering that such lengthening effects are usually smaller across a syllable boundary as compared to within the same syllable (cf. Klatt, 1973). The difference is of the same magnitude as the 28 ms difference reported by Chen (1970) for vowels preceding heterosyllabic voiced relative to voiceless stops.

Korean vowel duration is affected not only by whether the following consonant is a stop or a fricative but also by whether the following stop is lax or aspirated. Contrary to the traditional claim that Korean lax stops are always voiced in intervocalic position (e.g., Abramson & Lisker, 1972), recent work by Silva (1992) and Han (1994) has shown that there is considerable variability, both within and between speakers, in the extent to which lax stop voicing occurs. Silva (1992) has shown that in those cases in which Korean voiceless lax and aspirated stops occur contrastively, closure durations of the aspirated stops are 20–40 ms longer than those of the lax stops.

Having established that Korean vowels preceding fricatives are longer than those preceding stops, we can now make the following predictions about Korean manner neutralization: if Korean manner neutralization is incomplete, we might expect differences in vowel and consonant durations. Namely, the vowel preceding underlying fricative /s/ should be longer than that preceding underlying stops /t, $t^h$/. In addition, stops derived from /$t^h$/ may be longer than those derived from /t/. Conversely, if Korean manner neutralization is complete, no differences in terms of vowel or consonant duration would be expected.

## 4. Experiment 2: neutralization of manner of articulation

### 4.1. *Methods*

Four Korean speakers, two males (Speakers 1, 2) and two females (Speakers 3, 4), participated in this experiment. Speaker 1 also participated in Experiment 1 as Speaker 1. Speakers were recruited from a similar population as in Experiment 1. None of the speakers had any known speech or hearing disorders.

### 4.2. *Materials and procedure*

Test words consisted of 17 minimal word pairs. As shown in the Appendix, of these 17 pairs, nine exemplify the neutralization of underlying /t, s/ into [t], while eight pairs exemplify the neutralization of underlying /$t^h$, s/ into [t]. Importantly, the underlying forms do surface in non-neutralizing contexts. Three underlying forms, /mis/, /mas/, and /kəs/, served a dual purpose as they were contrasted with underlying forms ending in both /t/ and /$t^h$/. Therefore, there were six /t, s/ minimal pairs, five /$t^h$, s/ minimal pairs, and three /t, $t^h$, s/ minimal triplets. Five repetitions of the stimuli were randomized and embedded in the carrier phrase [əsə ____ kwa sap malhasejo] ("Please say ____ and a shovel"). As discussed above, when followed by the consonant-initial suffix /kwa/ "and", the coda consonant of the CVC target word is expected to be a lax stop. The sentences, interspersed with unrelated filler sentences, were presented in lists in Korean orthography. Korean orthography distinguishes the three underlying consonants /t, $t^h$, s/. The total number of target words was 620 (31 words × 5 repetitions × 4 speakers). Recording procedures were the same as those described for Experiment 1.

### 4.3. *Analysis*

All sentences were digitized using the same procedures as described for Experiment 1. Each sentence was stored under a numeric code which contained no information about the underlying form of the target word in order to avoid any biased measurements. For each target word, vowel duration and closure duration of the coda consonant were measured on the basis of both wideband spectrograms and waveforms. Vowel onset and offset were defined as described in Experiment 1. Closure duration was defined as the interval between vowel offset and burst release. For words without bursts (17%), only vowel duration was measured since the closure duration for those words could not be measured. Vowel and consonant durations were first measured by the first author. In order to evaluate the consistency of these measurements, a subset of the stimuli (34 stimuli per speaker, distributed across the different underlying forms) was measured by the second author. The correlation between the two sets of measurements was high (Pearson's $r = 0.9809$, $p < 0.0001$), suggesting that there was a high degree of consistency in the application of segmentation criteria.

### 4.4. *Results*

Vowel duration measurements and consonant duration measurements for each speaker are shown in Figs. 2–5. Figs. 2 and 3 show vowel and consonant duration, respectively, for minimal pair members ending in underlying /t/ and /s/. Mean vowel duration preceding /t/ was 66 ms, preceding /s/ 66 ms; mean closure duration of /t/ was 102 ms, and of /s/ 100 ms.

Separate pairwise two-tailed *t*-tests for vowel duration and closure duration, using subject means for each word (averaged across the five tokens), revealed that none of the relevant comparisons was significant, with one exception: Speaker 2's closure duration was significantly shorter for underlying /s/ (108 ms) than for underlying /t/ (119 ms) [$t(8) = -2.48$, $p < 0.04$]. This difference was thus in the expected direction.

Pooling the data for /t/ and /s/ pairs for all four speakers, two-way ANOVAs with Underlying Consonant as the within factor and Speaker as the between factor

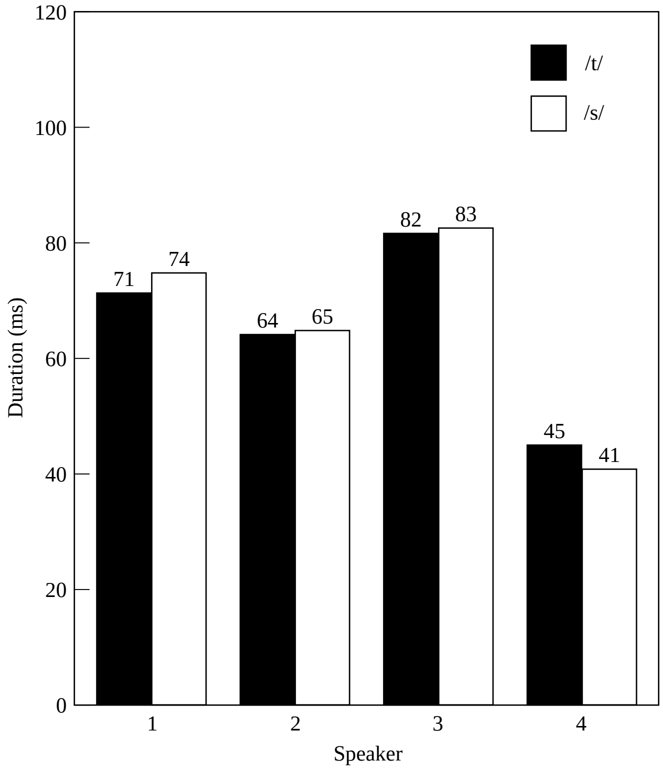


**Figure 2.** Mean vowel duration (in ms) for each speaker, for minimal pair members underlyingly ending in /t/ and /s/.

were conducted separately for vowel and closure duration. For vowel duration, this analysis revealed a significant effect for Speaker [$F(3, 32) = 10.91$, $p < 0.0001$], indicating that speakers differed in terms of their average vowel durations. More importantly, however, there was no effect for Underlying Consonant [$F(1, 32) = 2.93$, $p > 0.11$]. Finally, there was no significant Underlying Consonant × Speaker interaction [$F(3, 32) = 1.49$, $p > 0.24$]. For closure duration, the ANOVA revealed a significant effect for Speaker [$F(3, 32) = 23.22$, $p < 0.0001$], indicating that speakers differed in terms of their average closure durations. However, there was no effect for Underlying Consonant [$F(1, 32) = 1.65$, $p < 0.21$] and no significant Underlying Consonant × Speaker interaction [$F(3, 32) = 1.94$, $p > 0.14$].

Figs. 4 and 5 show vowel and closure duration, respectively, for minimal pair members ending in underlying /$t^h$/ and /s/. Across speakers, mean vowel duration preceding /$t^h$/ was 55 ms, preceding /s/ 57 ms; mean closure duration of /$t^h$/ was 101 ms, and of /s/ 101 ms. Pairwise two-tailed *t*-tests revealed that none of the relevant comparisons was significant.

Pooling the data for /$t^h$/ and /s/ pairs for all four speakers, two-way ANOVAs were conducted separately for vowel and closure duration. For vowel duration, this analysis revealed no significant effects (Speaker: [$F(3, 28) = 1.61$, $p > 0.21$]; Underlying Consonant: [$F(1, 28) = 2.53$, $p > 0.12$]; Underlying Consonant × Speaker: [$F(3, 28) = 1.45$, $p > 0.25$]. For closure duration, the ANOVA revealed a significant effect for Speaker [$F(3, 28) = 16.82$, $p < 0.0001$], again indicating that

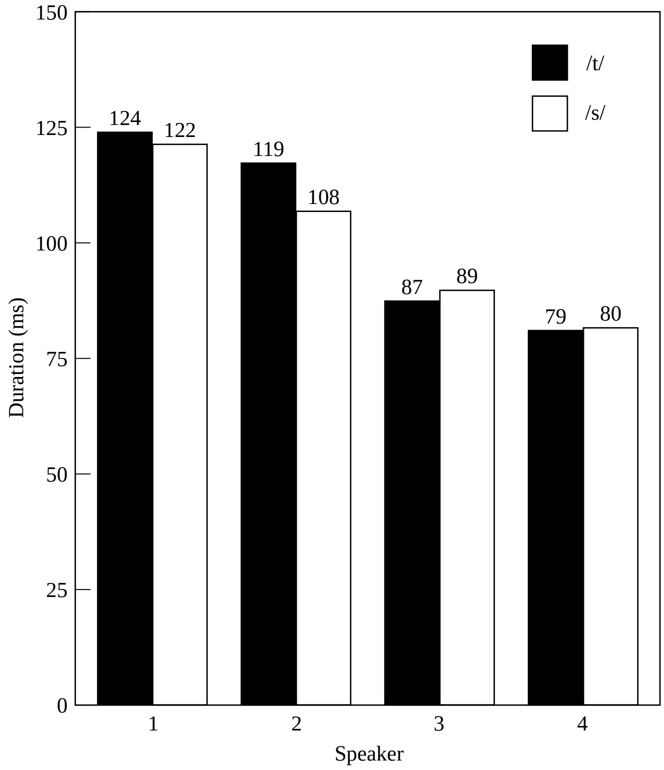


**Figure 3.** Mean closure duration in (ms) for each speaker, for minimal pair members underlyingly ending in /t/ and /s/.

speakers differed in terms of their average closure durations. However, there was no effect for Underlying Consonant [$F(1, 28) = 0.00$, $p > 0.96$] and no significant Underlying Consonant × Speaker interaction [$F(3, 28) = 1.03$, $p > 0.39$]. The combined results for the /t/ – /s/ and /tʰ/ – /s/ sets of minimal pairs clearly show that neither vowel nor closure duration differed significantly as a function of the underlying manner of the coda consonants /t, tʰ, s/.

The test words also contained three minimal triplets ([mit, kət, mat]) which allowed us to directly evaluate neutralization of underlying /t, tʰ, s/. Figs. 6 and 7 show vowel and closure duration, respectively, for minimal triplet members ending in underlying /t/, /tʰ/, and /s/. Across speakers, mean vowel duration preceding /t/ was 74 ms, preceding /tʰ/ 74 ms, and preceding /s/ 73 ms; mean closure duration of /t/ was 100 ms, of /tʰ/ 94 ms, and of /s/ 99 ms.

Separate ANOVAs were conducted for vowel duration and closure duration. For vowel duration, a two-way ANOVA with Underlying Consonant as the within factor and Speaker as the between factor, revealed no significant effects (Speaker: [$F(3, 8) = 1.03$, $p > 0.43$]; Underlying Consonant: [$F(2, 16) = 0.05$, $p > 0.95$]; Underlying Consonant × Speaker: [$F(6, 16) = 0.31$, $p > 0.92$]. Similarly, for closure duration, the ANOVA revealed no significant effects (Speaker: [$F(3, 8) = 3.74$, $p > 0.06$]; Underlying Consonant: [$F(2, 16) = 1.54$, $p > 0.24$]; Underlying Consonant × Speaker: [$F(6, 16) = 0.63$, $p > 0.71$]. In sum, there were no significant differences between triplet members, either in terms of vowel or consonant duration.

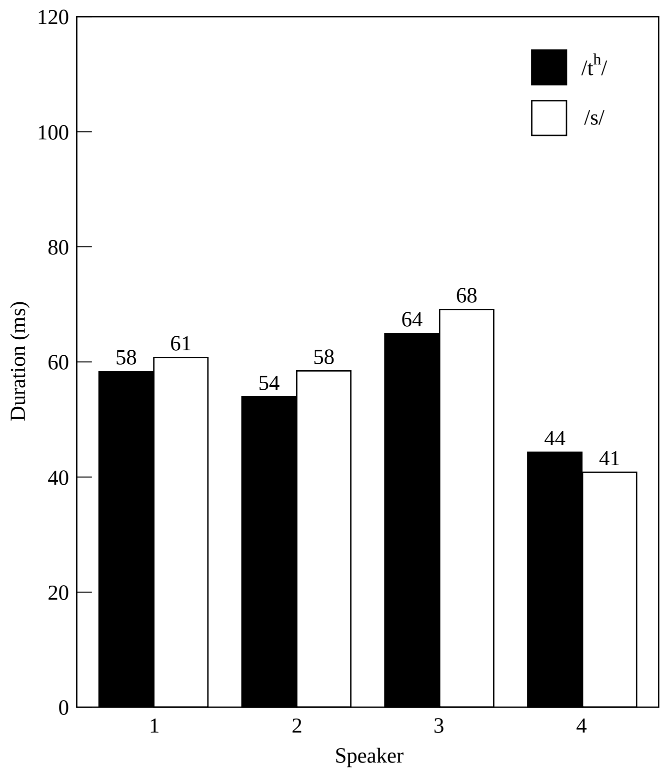


**Figure 4.** Mean vowel duration (in ms) for each speaker, for minimal pair members underlyingly ending in /tʰ/ and /s/.

As mentioned before, stimuli in which the final [t] was not released were not included in our closure duration analysis, since it was impossible to measure closure duration for these tokens. Overall, 17% of all tokens were excluded for this reason. It is conceivable that the frequency of release in itself could be a cue to the consonant's underlying manner of articulation. The frequency of released instances of [t] was 88% for underlying /t/, 80% for underlying /tʰ/, and 81% for underlying /s/. A Chi-square test was conducted to establish whether frequency of release and underlying final consonant were independent. This test was not significant [$\chi^2 = 5.35$, ns], indicating that the two variables, frequency of release and underlying manner, are indeed independent. Thus, whether a final [t] is or is not released does not provide any cue to underlying manner of articulation.

## 5. Experiment 3: perception

Acoustic analysis established that there was no phonetic difference between words which underlyingly ended in /s/, /t/, and /tʰ/ in terms of vowel and closure duration. These two parameters had been selected since cross-linguistic studies suggested that phonetic differences might most likely surface in terms of the duration of the final consonant and its preceding vowel.

While no such differences were found in the present study, it is possible that underlying distinctions might be preserved through other phonetic parameters (e.g.,

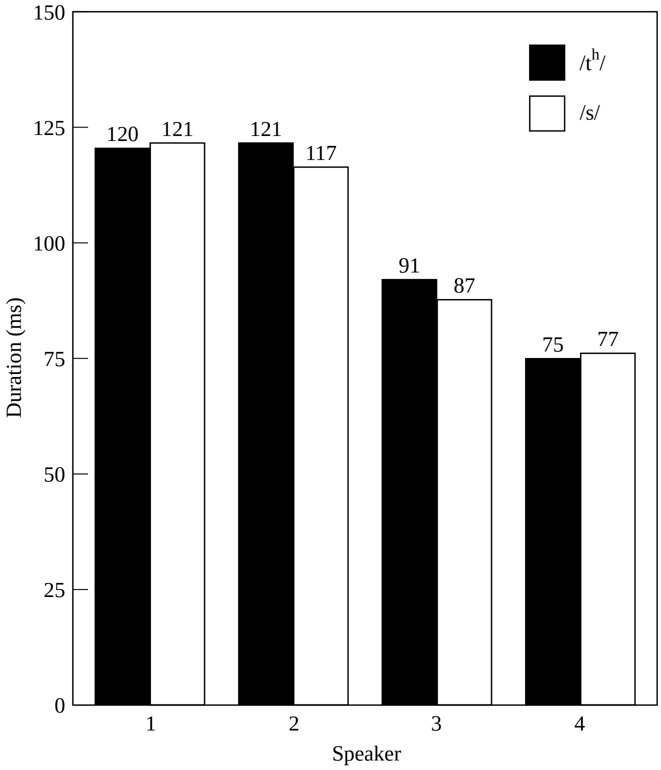


**Figure 5.** Mean closure duration (in ms) for each speaker, for minimal pair members underlyingly ending in /tʰ/ and /s/.

burst amplitude, formant transitions into the coda consonant). In order to investigate this possibility, a perception experiment was conducted to determine whether or not there exist additional cues which enable listeners to distinguish minimal word triplets.

### 5.1. *Methods*

Sixteen Korean listeners, eight males and eight females, participated in this experiment. They were recruited from the same population used in Experiment 1. None of the listeners had any known hearing disorders.

### 5.2. *Materials and procedure*

Test words consisted of the three minimal triplets examined in Experiment 2. For each of the four speakers, the first three productions were selected. If one of these tokens did not have a release burst, the next production was chosen. The test words were excised from their original carrier phrase. Two repetitions of each production were included. The 216 stimuli (9 words × 4 speakers × 3 productions × 2 repetitions) were presented to listeners in random order.

All subjects were tested individually. Stimuli were played from disk over Sony (MDR-7506) headphones, using BLISS software (Mertus, 1989). Subjects received

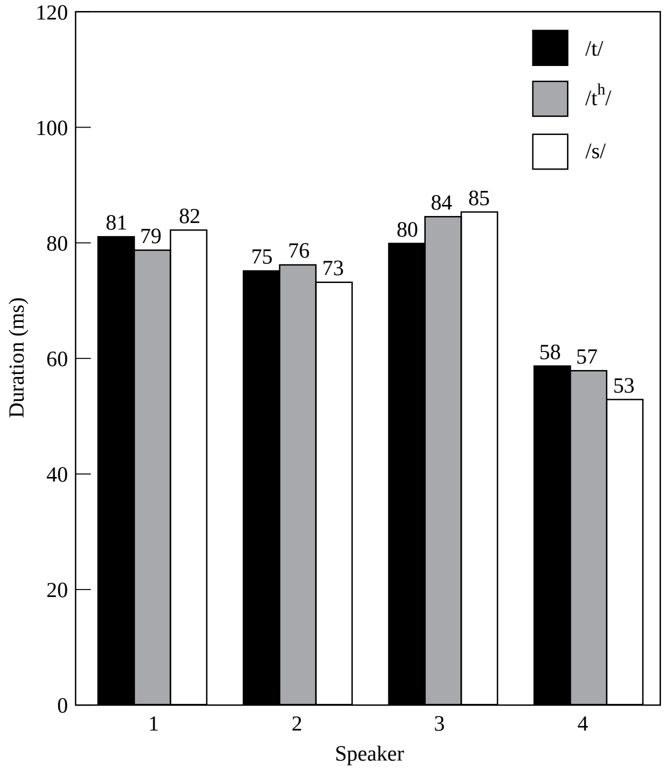


**Figure 6.** Mean vowel duration (in ms) for each speaker, for minimal triplet members underlyingly ending in /t/, /$t^h$/, and /s/.

all instructions in Korean. They were told that for each trial they had to decide which Korean word (ending in either /s/, /t/, or /$t^h$/) they heard; subjects responded by pressing one of three buttons on a response box placed in front of them. The buttons were labeled, in Korean orthography, as s, t, and $t^h$. Following instructions, subjects were given a set of 12 practice items to introduce them to the procedure.

### 5.3. *Results*

Results of the perception experiment are shown in Table I. Chance level is 33%. The overall percent correct performance, 32%, was not significantly different from chance [$t(15) = 0.43$, ns]. Percent correct classification for each underlying final consonant was also at chance for /s/ at 36%, [$t(15) = -1.2$, ns]; and for /$t^h$/ at 34%, [$t(15) = -0.17$, ns]. Percent correct classification for /t/ was 27%, which was significantly below chance [$t(15) = 3.77$, $p < 0.005$].

### 5.4. *Discussion*

The perceptual results indicate that listeners performed at chance level in their identification of Korean surface forms ending in [t]. That is, listeners were unable to reliably determine whether those forms had been derived from words underlyingly ending in /s/, /t/, or /$t^h$/. These results suggest that these forms did not contain any

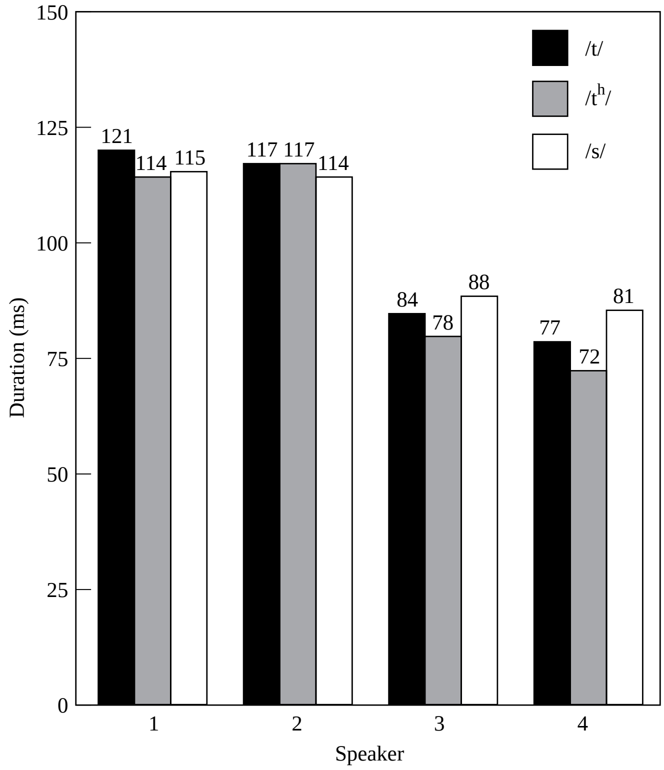


**Figure 7.** Mean closure duration (in ms) for each speaker, for minimal triplet members underlyingly ending in /t/, /$t^h$/, and /s/.

TABLE I. Mean identification scores (in percent) for surface forms underlyingly ending in /t/, /$t^h$/, or /s/. Correct responses are underlined. Chance level is at 33%

| Stimulus-final underlying consonant | Response | | |
|---|---|---|---|
| | t | $t^h$ | s |
| /t/ | <u>27</u> | 29 | 39 |
| /$t^h$/ | 29 | <u>34</u> | 33 |
| /s/ | 30 | 30 | <u>36</u> |

acoustic cues to their underlying final consonants, or at least that listeners were not sensitive to such cues.

## 6. Conclusions

This study investigated the acoustic and perceptual correlates of neutralization of manner of articulation in Korean. In coda position, underlying /t, $t^h$, s/ are all neutralized to [t]. Experiment 1 established that, in words in which vowels can be followed by fricatives and stops on the surface, Korean patterns like many other languages: vowels preceding fricatives are longer than those preceding stops. Experiment 2 subsequently examined whether the vowel and consonant durations of minimal word pairs produced by four speakers of Korean revealed acoustic differences as a function of the manner of articulation of the underlying consonant. No such differences were found. Finally, a perception experiment established that Korean listeners were unable to determine whether the surface forms they were presented had been derived from words underlyingly ending in /s/, /t/, or /$t^h$/. The perceptual results suggest that, although we focused on durational measures in Experiment 2, other cues that listeners might use to distinguish the different underlying forms had not been overlooked.

Taken together, the present results suggest that manner neutralization of /t, $t^h$, s/ offers an instance of complete neutralization. Coda neutralization of coronal consonants in Korean is phonetically complete regardless of their underlying manner of articulation. These results support the standard phonological treatment of neutralization in which underlying distinctions are removed during the course of the phonological derivation. Thus, Korean coda neutralization seems to be an instance of what Dinnsen (1985) referred to as Type A neutralization, namely a neutralization rule which yields surface forms which cannot be distinguished acoustically nor perceptually. Dinnsen (1985) claimed that this classic type of neutralization is ''unfortunately without empirical support'' (p. 275). The present findings challenge this claim.

It is also of interest to note that the present study provides an instance of complete neutralization despite potential cues for underlying manner in the orthography. Fourakis & Iverson (1984) argued that incomplete neutralization in earlier studies of German resulted from hypercorrect pronunciation of differences between minimal pair members in terms of orthography. Like German, Korean also differentiates the minimal pair members in terms of orthography. Nevertheless, complete neutralization was obtained.

The fact that 83% of all word-final stop consonants were followed by a brief release burst is particularly interesting in view of the long tradition in the phonological literature on Korean according to which coda neutralization yields unreleased stops (e.g., Martin, 1951; Lee, 1972; Kim-Renaud, 1974; Chung, 1980). The consonants in the present study are alveolar stops in stem-final position, followed by the velar stop /k/. It is important to note that many phonetics textbooks similarly claim that in English the first stop consonant in a sequence of two stops is unreleased (e.g., MacKay, 1978; Ladefoged, 1993). However, Henderson & Repp (1982) have shown that while in such sequences the release burst is often difficult to detect auditorily, it clearly shows up in acoustic analyses. Henderson & Repp (1982) found that in English clusters where the first stop is an alveolar and the second is a velar, the alveolar was released in 85% of all cases, comparable to the 83% release rate in the present study for similar Korean clusters.

Interestingly, regarding the issue of release *vs.* nonrelease, H. Kim (1994) proposed, based on acoustic analyses of Korean and English, that the terms release and nonrelease are associated with the airstream mechanism, rather than with oral closure and release as is usually assumed in the literature. Under this account, release is assumed to be the removal of oral closure followed by a pulmonic egressive airstream before or during the articulation of a following segment; if a stop does not meet this condition, it is unreleased. An unreleased stop can thus be realized as either the absence of an oral burst or as a low-amplitude burst involving an ingressive airstream.

In conclusion, while most of the phonetic debate regarding neutralization has focused on the voicing distinction, the present results show that Korean neutralization of manner of articulation is phonetically complete. Dinnsen (1985) presented four logically possible types of phonological neutralization rules (i.e., no distinction maintained, only acoustic or only perceptual distinction maintained, and both types of distinctions maintained). Dinnsen argued that of these four types, only one is well-established in the phonetic literature, namely the type which maintains distinctions in both the acoustic and perceptual domains. However, the present study provides evidence for complete neutralization both in production and perception. These data suggest that a wider range of neutralization phenomena should be investigated, both in terms of production and perception, to document the occurrence of Dinnsen's four types of neutralization. Such empirical data will crucially inform the debate concerning the nature of phonological rules and representations.

We thank Nick Clements, Abby Cohn, Dick Pastore, Joan Sereno, John Whitman, and the editor for their comments and suggestions. We are grateful to Joy Ahn, Scott Gargash, and Jeong-Im Han for their experimental assistance.

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## Appendix A

Minimal pairs used in Experiment 1.

| | | | |
|---|---|---|---|
| [kit$^h$a] | "etc." | [kisa] | "newspaper article" |
| [tɛːt$^h$a] | "pinch-hit" | [tɛːsa] | "ambassador" |
| [sat$^h$o] | "private land" | [saso] | "(be) trivial" |
| [sat$^h$u] | "personal strife" | [sasu] | "receive lessons from a well-known scholar" |
| [hoːt$^h$u] | "good pitching" | [hoːsu] | "good defense" |
| [kot$^h$o] | "fertile soil" | [koso] | "sardonic smile" |
| [ts$^h$ot$^h$o] | "burnt ground" | [ts$^h$oso] | "checkpoint" |
| [tsot$^h$a] | "steering" | [tsosa] | "investigation" |
| [kut$^h$a] | "assault" | [kusa] | "commanding (a language)" |
| [put$^h$ə] | "from" | [pusə] | "place of duty" |
| [sut$^h$o] | "water and soil" | [suso] | "hydrogen" |

## Appendix B

Surface and underlying representations of the minimal pairs used in Experiment 2.

| Surface | Underlying /t/ | Underlying /s/ | Surface | Underlying /$t^h$/ | Underlying /s/ |
|---|---|---|---|---|---|
| [pat] | /pat/ "to receive" | /pas/ "to break" | [mut] | /$mut^h$/ "land" | /mus/ "many" |
| [pət] | /pət/ "to spread" | /pəs/ "friend" | [put] | /$put^h$/ "to paste" | /pus/ "to pour" |
| [tat] | /tat/ "to close" | /tas/ "five" | [sat] | /$sat^h$/ "inside" | /sas/ "straw hat" |
| [tot] | /tot/ "to sprout" | /tos/ "straw" | [sut] | /$sut^h$/ "thickness" | /sus/ "pure" |
| [kot] | /kot/ "soon" | /kos/ "place" | [kat] | /$kat^h$/ "to be the same" | /kas/ "straw hat" |
| [kut] | /kut/ "to harden" | /kus/ "exorcism" | | | |
| [kət] | /kət/ "to collect" | /kəs/ "thing" | [kət] | /$kət^h$/ "outside" | /kəs/ "thing" |
| [mit] | /mit/ "to trust" | /mis/ "tasteless" | [mit] | /$mit^h$/ "underneath" | /mis/ "tasteless" |
| [mat] | /mat/ "elder" | /mas/ "taste" | [mat] | /$mat^h$/ "to smell" | /mas/ "taste" |