# The perceptual assimilation of Korean obstruents by native Mandarin listeners[a)]

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The current study reports the results of a perception experiment in which 20 naive native Mandarin listeners classified and rated the goodness of Korean stops /p, t, k, $p^h$, $t^h$, $k^h$, p*, t*, k*/, affricates /tɕ, tɕ*, $tɕ^h$/, and fricatives /$s^h$, s*/ in terms of Mandarin segmental categories. It was found that listeners were sensitive to the voice onset time dimension of Korean stops and the presence of aspiration in Korean affricates, but Korean lenis and aspirated obstruents were generally assimilated to a single Mandarin category because the *f*0 cue differentiating them is not relevant to any Mandarin segmental contrast. The affricates were perceived as alveolopalatal and postalveolar more often than alveolar. The perception of fricatives was strongly influenced by vowel context, as the two fricatives were often perceived as different categories before /a/, but as the same category more often before /i/ and /u/. The results for the affricates and fricatives may be partly explained by Mandarin phonotactic constraints that prohibit alveolar and postalveolar consonants before /i/ and alveolopalatal consonants before /a/ or /u/.
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## I. INTRODUCTION

The purpose of this paper is to establish perceptual assimilation patterns for naive native (L1) Mandarin listeners of Korean obstruents. Perceptual assimilation occurs when a listener perceives a speech sound as an exemplar of an L1 phonological category. The assignment of an L1 category label is implicit in this process. Although listeners assign category labels during native speech perception as well, the term "perceptual assimilation" is often discussed in the context of non-native speech perception. When a speech sound of a foreign language is perceived to be similar or identical to some native speech sound, it is said to assimilate to the native category. For example, both American English (AE) /r/ and /l/ may be perceived by a naive native Japanese listener as exemplars of the Japanese /r/ category, in which case we would say that the listener assimilated both AE /r/ and /l/ to Japanese /r/. This particular case has been thoroughly investigated in a long line of studies (e.g., Goto, 1971; Miyawaki *et al.*, 1975; *inter alia*) and is probably the most widely cited example in discussions of perceptual assimilation and non-native speech perception. Although more recent studies (Aoyama *et al.*, 2004; Guion *et al.*, 2000; Hattori and Iverson, 2009) have suggested that native Japanese listeners may not assimilate both AE /r/ and /l/ equally to a single Japanese category, the case nonetheless retains much illustrative value.

Perceptual assimilation is one of several processes, including various forms of discrimination and identification, which are often tested to probe the perceptual ability of naive non-native listeners and second language (L2) learners. For example, in the perceptual assimilation model (PAM) (Best, 1995), naive non-native perceptual assimilation patterns are claimed to make predictions about the ease with which listeners will discriminate members of non-native phonological contrasts. Thus, to the extent that PAM can be validated, perceptual assimilation patterns can serve as an indirect measure of the similarity between individual L1 and L2 speech sounds. Evidence in support of this relationship has been shown in many studies (e.g., Best *et al.*, 2001; Levy, 2009), but other studies (e.g., Hattori and Iverson, 2009) have questioned whether assimilation patterns necessarily predict discrimination ability.

It has been argued (Schmidt, 2007, p. 187) that "broad cross-language comparisons of categorization… offer opportunities to develop testable hypotheses that will expand our understanding of general speech perception." Accordingly, part of the cross-language speech perception research enterprise should involve surveys of assimilation patterns from a broad range of L1s and L2s that can serve as empirical bases for more specific investigations. To this end, there are at least two reasons why the Korean obstruent system is a worthy object of study.

First, Korean presents a typologically unusual three-way voiceless laryngeal contrast in stops and affricates and a two-way contrast between lenis-aspirated and fortis fricatives. These obstruents have been extensively studied over the past several decades, and the acoustic correlates of the stops are well understood (Cho *et al.*, 2002; Han and Weitzman, 1970; Kim, 1965; Silva, 2006). Some more recent studies have focused attention on the Korean affricates (Anderson *et al.*, 2004; Kim, 1999) and fricatives (Chang, 2013; Holliday, 2012a; Kim *et al.*, 2010; Yoon, 1999). Few studies, however,

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have investigated how non-native listeners perceive Korean obstruents (although see Schmidt, 2007), and to our knowledge only Yasuta (2004) has investigated listeners of a non-English L1.

Second, while research on L1 English listeners and learners is extremely valuable, Korean is learned as an L2 in large numbers by native speakers of languages other than English. Most numerous among them are students from Mainland China, who in 2010 comprised 61.1% of the foreign students enrolled in intensive Korean language courses at universities in South Korea, far outnumbering the 3.5% from the U.S. and even lower percentages from students of other English-speaking countries (Korean Educational Development Institute, 2010).

Accordingly, the goal of the current study is to survey the perceptual assimilation of Korean obstruents by L1 Mandarin listeners. There has been at least one comprehensive study of the perceptual assimilation of Korean consonants by L1 English listeners (Schmidt, 2007), and so the current study is intended to replicate Schmidt as closely as possible. By using the same set of stimuli and a nearly identical procedure, the results of the L1 Mandarin listeners reported here can be meaningfully compared with the results from the L1 English listeners reported in Schmidt (2007). As background to the current study, we will first provide a survey of the obstruent inventories of both Korean and Mandarin, paying special attention to the articulatory and acoustic properties that signal phonological contrasts in each language.

### A. Korean obstruents

Korean has a three-way contrast between lenis ("lax"), fortis ("tense"), and aspirated stop and affricate consonants. The stops are produced at the bilabial (/p/, /p*/, /$p^h$/), alveolar (/t/, /t*/, /$t^h$/), and velar (/k/, /k*/, /$k^h$/) places of articulation, whereas the exact place of articulation of the affricates has been debated. Some acoustic evidence supports an alveolar place of articulation (Kim, 1999), whereas other acoustic evidence points towards a more posterior place of articulation (Pyo *et al.*, 1999). Kang (2013) suggests that they may be articulated further back than Korean alveolar stops and fricatives, but anterior to English affricates. They will be notated in this paper as alveolopalatal /tɕ/, /tɕ*/, and /$tɕ^h$/. Korean stops and affricates can occur in any vowel context, although in coda position they are all realized as homorganic unreleased stops.

Early acoustic studies (Han and Weitzman, 1970; Kim, 1965) investigated voice onset time (VOT) and the *f*0 of the following vowel as possible correlates of the stop contrast. Later studies (Cho *et al.*, 2002; Kim *et al.*, 2002) additionally incorporated a spectral measure of voice quality, the difference in amplitude between the first and second harmonic (H1-H2), which has been shown to correlate with breathy voice quality (Hanson, 1997). Kim (2004) showed that these acoustic correlates of the three-way stop contrast apply to the affricate contrast, as well. In summary, these studies showed that: the lenis stops and affricates were generally associated with intermediate lag VOT, low *f*0, and positive H1-H2; the fortis stops and affricates with short lag VOT, high *f*0, and negative H1-H2; and the aspirated stops and affricates with long lag VOT, high *f*0, and positive H1-H2. Later studies (Kang and Guion, 2008; Silva, 2006) showed that most speakers of the Seoul dialect born after around 1975 have merged their lenis and aspirated stops along the VOT dimension in word-initial position, with both lenis and aspirated stops having become associated with long lag VOT, and *f*0 having become the primary acoustic cue differentiating them from each other. The fortis stops, however, maintained short lag VOT, distinct from both lenis and aspirated stops, with *f*0 serving as an additional cue to separate fortis from lenis stops.

Unlike the stops and affricates, Korean alveolar fricatives present a two-way contrast whose members do not fit neatly into the lenis, fortis, and aspirated categories found in Korean stops and affricates. In this paper the Korean sibilant fricatives will be referred to as "lenis-aspirated" and "fortis," following Chang (2013), and notated as /$s^h$/ and /s*/, respectively. Both fricatives can occur in any vowel context, but they are typically palatalized before /i/ or /j/ and are realized as /t/ in coda position.

Several acoustic correlates have been suggested as cues to the Korean fricative contrast. Frication duration has been shown to be longer in /s*/ than in /$s^h$/, whereas /$s^h$/ is often followed by a longer period of aspiration before the following vowel (Kagaya, 1974; Cho *et al.*, 2002; Chang, 2007; Kim *et al.*, 2010). These duration differences, however, are greatly reduced before high vowels (Yoon, 1999; Chang, 2007), with the aspiration of /$s^h$/ being almost or entirely absent before /i/. Unlike the stop or affricate contrasts, *f*0 has not been shown to cue any contrast between the fricatives (Chang, 2007; Holliday, 2012a). Voice quality as measured by H1-H2, on the other hand, has been found to differ across fricative categories, with /$s^h$/ generally having a more positive H1-H2 value than /s*/ (Cho *et al.*, 2002; Holliday 2012a), although this difference has also been shown to be reduced before high vowels (Chang, 2007).

### B. Mandarin obstruents

Mandarin contrasts unaspirated (/p, t, k/) and aspirated (/$p^h$, $t^h$, $k^h$/) voiceless stops at the bilabial, alveolar, and velar places of articulation. Some previous studies (e.g., Liu *et al.*, 2000) have reported the VOT values of native Mandarin speakers' stop productions and showed that the unaspirated and aspirated stops can be characterized by short lag and long lag VOT, respectively.

Additionally, Mandarin contrasts unaspirated (/ts, tɕ, ʧ/) and aspirated (/$ts^h$, $tɕ^h$, $ʧ^h$/) affricates and sibilant fricatives (/s, ɕ, ʃ/) at three places of articulation. While the most posterior set of sibilants is often referred to as "retroflex" and written as /tʂ, $tʂ^h$, ʂ/, several articulatory studies have concluded that these sounds are not articulated with any retroflexion (Ladefoged and Wu, 1984; Lee, 1999; Stokes and Zhen, 1998; Toda and Honda, 2003), and for this reason we refer to them simply as "postalveolar." Mandarin sibilant affricates and fricatives are subject to a phonotactic restriction by which the alveolar and postalveolar sibilants can

appear before any Mandarin vowel except /i/ or /y/, whereas the alveolopalatal sibilants appear only before /i/ and /y/. The alveolopalatal sibilants do appear before other vowels, such as /a/ or /ɛ/, but such cases are typically analyzed as having an /i/ or /y/ onglide between the fricative and vowel (e.g., /tɕia/ as opposed to /tɕa/), an analysis that is reinforced by the pinyin representation of such sequences (e.g., "jia").

Very few studies have looked at the acoustic correlates of the contrast between the two sets of Mandarin affricates. Liu *et al.* (2000) compared just the aspirated affricates and their homorganic sibilant fricatives and found the mean frication duration of the fricatives, 167 ms, to be longer than that of the affricates, 131 ms. They also found that 72% of the aspirated affricate productions began with a burst, whereas only 1% of the sibilant fricative productions did. Although the aspirated affricate may be strongly cued by the presence of a burst, it is difficult to conclude from the results what, other than aspiration, may cue the difference between the aspirated and unaspirated affricates, which were not investigated. In a later study, Tsao *et al.* (2007) used synthetic stimuli to investigate the contribution of frication duration and amplitude rise time in native discrimination of the Mandarin /tɕʰ/-/ɕ/, tɕʰ/-/tɕ/, and /tɕ/-/ɕ/ contrasts. They found that while frication duration may cue the /tɕʰ/-/tɕ/ and /tɕ/-/ɕ/ contrasts, only amplitude rise time contributed significantly to the discrimination of the /tɕʰ/-/ɕ/ contrast. Finally, acoustic studies of Mandarin sibilant fricatives (e.g., Li *et al.*, 2007) have shown that a measure of spectral shape, such as centroid frequency, can separate Mandarin /s/ and /ʃ/ quite reliably, but that an additional measure, such as the F2 at vowel onset, is needed to differentiate /ɕ/ from /s/ and /ʃ/.

### C. Predictions

Given the acoustic correlates of the obstruents in both Korean and Mandarin, several predictions can be made regarding how L1 Mandarin listeners will assimilate Korean obstruents. First, because Mandarin stops are characterized by either short lag or long lag VOT, it is predicted that listeners will perceive Korean fortis stops as Mandarin unaspirated stops and both Korean lenis and aspirated stops as Mandarin aspirated stops. That is, listeners will perceive both members of the Korean lenis-aspirated contrast as good exemplars of Mandarin aspirated stop categories and ignore the *f*0 cue that differentiates them. We predict the results for the affricates should be similar in that the Korean fortis affricate should assimilate to one of the Mandarin unaspirated affricate categories and the Korean lenis and aspirated affricates should assimilate to one of the Mandarin aspirated affricate categories. We make no prediction regarding the perceived place of articulation of the affricates, as there is no consensus on where Korean affricates are articulated, and Mandarin has a phonotactic constraint that may interact with perceived place of articulation anyway. Last, we predict that both Korean fricatives will be assimilated to Mandarin /s/ before /a/ and /u/, and to Mandarin /ɕ/ before /i/, as L1 Mandarin listeners should not be sensitive to voice quality or aspiration differences in the context of a fricative.

## II. METHODS

### A. Participants

Twenty native Mandarin speakers participated in the experiment, all of whom were students or visiting scholars at The Ohio State University, and whose mean and median length of residence in the U.S. was 6.2 and 3 months, respectively. The participants' home provinces were located all across mainland China. Although some participants were bilingual in a variety of Chinese other than Mandarin, all reported speaking Mandarin natively.

### B. Stimuli

The stimuli recording and selection processes used in this experiment are presented in more detail in Schmidt (2007), but will be briefly summarized here. Four adult female Korean talkers who were residing in the U.S. produced the stimuli. Three were from Seoul and one was from Chungcheong province, and all talkers reported using English during 30% or less of a typical day and encountering native speakers of English only after arriving in the U.S. Two of the talkers had been in the U.S. for 8 months. The other two talkers had been in the U.S. for 3 and 2.4 yr, but those two talkers (in addition to one of those who had arrived 8 months prior to recording) were wives of graduate students who reported using English less than 10% of any given day.

Each talker recorded a list of 57 different Korean consonant-vowel sequences (CVs), constructed from 19 consonants (/p, t, k, pʰ, tʰ, kʰ, p*, t*, k*, tɕ, tɕʰ, tɕ*, sʰ, s*, m, n, r, j, h/) in three different vowel contexts (/a/, /i/, /u/). The list was blocked by vowel and read three times, yielding a set of 171 CVs per talker. The productions from the four talkers were combined into a set of 684 CVs which was then separated according to vowel context, yielding three sets of 228 CVs. Each of these sets was randomly divided into two subsets of 114 CVs each, yielding six subsets of 114 CVs. Three native Korean listeners who met the same criteria as the talkers then judged two of each of these subsets, identifying each consonant and assigning a goodness rating to each CV. For each CV produced by each talker, the token that was always identified correctly and received the highest rating was selected to be included in the final set of stimuli.

Like Schmidt (2007), the current study contained 19 consonants in three vowel contexts produced by four talkers, yielding a total of 228 CVs. Stimulus presentation was blocked by vowel in the order /a/-/i/-/u/, with 76 randomized tokens per block. In this paper we will only discuss the results for the set of 14 Korean stops, affricates, and fricatives (/p, t, k, pʰ, tʰ, kʰ, p*, t*, k*, tɕ, tɕʰ, tɕ*, sʰ, s*/), yielding a total of 168 responses per listener.

### C. Procedure

The experiment was built and run using OpenSesame version 0.24 (Mathôt *et al.*, 2012). Listeners were seated in front of a Dell Vostro 1400 notebook computer in a quiet

room in the Department of Linguistics at The Ohio State University. Instructions were displayed on the screen and the listeners could advance through them at their own pace. The instructions were displayed in both Chinese and English. Listeners were paid $10 for their participation.

Audio stimuli were presented through headphones (Denon AH-D1001) connected to the computer. The listeners were told that they would be listening to Korean sounds spoken by native Korean talkers. For each trial, listeners heard one stimulus and were asked to identify the Mandarin category to which the stimulus sounded most similar. For the remainder of this paper this part of the procedure will be referred to as "classification."

After the classification part of each trial, listeners were instructed to rate the Korean sound they had just heard in terms of how similar it was to the Mandarin sound they selected. That is, if the listener classified a sound as Mandarin /p/, then the listener was asked to rate how similar the Korean sound they had just heard was to Mandarin /p/. The rating was done on an integer scale with 1 representing "totally different" and 5 representing "exactly the same." Listeners used the number keys of a keyboard to input the ratings.

The listeners were given 24 possible Mandarin categories to choose from (23 initial consonants plus the null onset), and were instructed to type the pinyin letter(s) of the Mandarin sound that was closest to the Korean sound they had just heard. In order to promote association with Mandarin categories, the 24 possible choices were displayed on the screen with both the pinyin letter and two or three Chinese characters that began with the relevant sound. If they could not hear any consonant at the beginning of the Korean sound, then they were asked to enter just the vowel for the block, i.e., "a," "i," or "u." They were further instructed to pay attention only to the beginning of the syllable and to ignore the vowel quality and tone as much as possible.

## III. RESULTS

There were a total of 3360 responses, of which 27 were discarded as unusable due to a blank response or an uninterpretable typo in either the classification ($n = 24$) or the rating ($n = 3$). After these responses were removed we were left with 3333 responses, which are compiled in Tables I, III, IV, and V as follows. The columns of each table correspond to the Korean consonant contained in the stimulus shown in the top row, and the rows correspond to the Mandarin category to which the listener assimilated the Korean consonant shown in the far left column. The first number in each cell represents the percentage of responses of that Korean consonant (i.e., of that column) that were assimilated to the Mandarin category of that row. Rows that contained no cell with a percentage greater than 1, which represents a single trial, were excluded to simplify presentation. Additionally,

TABLE I. Perceptual assimilation results for Korean stop stimuli. The first number in each cell represents the percentage of trials for that Korean CV that were assimilated to the Mandarin consonant of that row. Percentages greater than 50 are in boldface. The number in parentheses is the goodness rating averaged over those trials. The Count row indicates the number of trials that were included for each Korean CV.

| | Korean | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Mandarin | /pa/ | /$p^h$a/ | /p*a/ | /pi/ | /$p^h$i/ | /p*i/ | /pu/ | /$p^h$u/ | /p*u/ |
| Count | 80 | 79 | 78 | 79 | 79 | 77 | 77 | 80 | 79 |
| /$p^h$/ | **99 (4.0)** | **99 (4.6)** | | **77 (4.1)** | **100 (4.5)** | | **88 (3.6)** | **98 (4.2)** | |
| /p/ | | | **100 (4.5)** | 22 (4.0) | | **95 (4.1)** | 9 (2.9) | | **85 (4.1)** |
| /$t^h$/ | 1 (3.0) | 1 (2.0) | | | | | | 2 (4.0) | |
| /t/ | | | | 1 (3.0) | | 4 (3.0) | | | |
| /f/ | | | | | | | 3 (2.0) | | 14 (2.8) |
| | /ta/ | /$t^h$a/ | /t*a/ | /ti/ | /$t^h$i/ | /t*i/ | /tu/ | /$t^h$u/ | /t*u/ |
| Count | 80 | 79 | 80 | 80 | 80 | 80 | 80 | 80 | 80 |
| /$p^h$/ | 16 (3.3) | 1 (4.0) | | | | | 1 (4.0) | 2 (2.5) | |
| /p/ | | | 8 (4.0) | | | | | | |
| /$t^h$/ | **82 (4.1)** | **92 (4.3)** | | **99 (4.2)** | **99 (4.3)** | | **82 (3.2)** | **96 (3.8)** | |
| /t/ | | | **92 (4.2)** | | | **99 (4.4)** | 15 (3.2) | | **100 (4.2)** |
| /$k^h$/ | 1 (1.0) | 4 (1.7) | | | 1 (3.0) | | | | |
| | /ka/ | /$k^h$a/ | /k*a/ | /ki/ | /$k^h$i/ | /k*i/ | /ku/ | /$k^h$u/ | /k*u/ |
| Count | 80 | 78 | 79 | 80 | 80 | 80 | 79 | 79 | 80 |
| /$t^h$/ | | | | 22 (3.7) | 9 (4.3) | | | | |
| /t/ | | | | | | 36 (3.9) | | | |
| /$k^h$/ | **99 (3.8)** | **96 (3.7)** | 1 (2.0) | **65 (3.6)** | **79 (3.4)** | | **84 (4.1)** | **99 (4.2)** | |
| /k/ | | | **99 (3.7)** | 1 (2.0) | | **62 (3.1)** | 15 (3.3) | 1 (5.0) | **98 (4.4)** |
| /$ts^h$/ | 1 (4.0) | 4 (2.0) | | | | | | | |
| /$tɕ^h$/ | | | | 6 (2.0) | 10 (2.3) | | | | |
| /tɕ/ | | | | 2 (3.0) | | | | | |
| /$tʃ^h$/ | | | | 2 (2.5) | 2 (2.0) | | | | |

because the percentages in each cell are rounded to the nearest integer, each column may not add up to exactly 100. The number in parentheses following each percentage is the mean goodness rating, which was calculated across all listeners and all trials that fall within the same cell. For example, the cell in the upper left corner of Table I reads "99 (4.0)." This entry can be read as, "99% of the Korean /pa/ trials were perceived as /$p^h$/ and their mean goodness rating was 4.0." Finally, the number in the "Count" row immediately below each Korean consonant represents the number of responses included for that consonant. Recall that some responses were discarded, and so in order to meaningfully interpret the percentages it is necessary to know how many responses they are calculated from.

### A. Perception of Korean stops

The results for the Korean stops are given in Table I. When discussing the perception of Korean stops by native Mandarin listeners, we should first clarify the terminology used to describe the stop categories in both languages. Mandarin contrasts voiceless unaspirated (/p, t, k/) and aspirated (/$p^h$, $t^h$, $k^h$/) stops, and Korean contrasts lenis (/p, t, k/), fortis (/p*, t*, k*/), and aspirated (/$p^h$, $t^h$, $k^h$/) stops. Although we use the same phonetic symbols for the Mandarin unaspirated stops and the Korean lenis stops, the Mandarin unaspirated stops can be characterized by short lag VOT whereas the Korean lenis stops are best characterized by long lag VOT. To avoid any confusion, in our discussion of the assimilation patterns will use the "unaspirated" to refer to Mandarin /p, t, k/ and "lenis" to refer to Korean /p, t, k/. We will use the term "aspirated" for both Mandarin and Korean /$p^h$, $t^h$, $k^h$/.

#### 1. Lenis and aspirated stops

Generalizing across place of articulation and vowel context, Korean lenis and aspirated stops were both perceived as fair to good exemplars of Mandarin aspirated stops. Some trends are particularly strong. For example, listeners perceived both Korean /pa/ and /$p^h$a/ to be most similar to Mandarin /$p^h$a/ 99% of the time, with mean goodness ratings of 4.0 and 4.6, respectively. In fact, both lenis and aspirated stops at all places of articulation in all vowel contexts received mean goodness ratings of at least 3.0. Recall that the scale represented 1 as "totally different" and 5 as "exactly the same," suggesting that a rating of at least 3 should indicate a moderate level of similarity.

To better understand the role of VOT in the listeners' perception of Korean stops, the VOT of the stop stimuli were measured, and the mean values for each Korean stop consonant are given in Table II. For tokens with multiple bursts, the first burst that occurred within 25 ms of the last burst was counted as the beginning of the VOT period. Some stops, especially velar stops, can have multiple bursts that appear long before the strongest burst that typically signals the stop, and including all such bursts could potentially skew the VOT values and render the perceptual assimilation patterns difficult to interpret. According to Table II, the lenis stops had shorter lag VOT than the aspirated stops, suggesting that the talkers who produced the stimuli did not have as complete a merger between lenis and aspirated stops as the youngest talkers in Silva (2006). However, the results in Table I indicate that the L1 Mandarin listeners still overwhelmingly perceived Korean lenis stops as aspirated.

TABLE II. Mean VOT values of the Korean stop stimuli averaged across vowel context. Because these VOT values were measured by the current author they differ slightly from what was reported in Schmidt (2007).

| stop | VOT (ms) | stop | VOT (ms) | stop | VOT (ms) |
|---|---|---|---|---|---|
| /p/ | 46 | /t/ | 57 | /k/ | 71 |
| /$p^h$/ | 80 | /$t^h$/ | 78 | /$k^h$/ | 96 |
| /p*/ | 10 | /t*/ | 12 | /k*/ | 20 |

There were, however, several unexpected results related to the lenis stops. First, Korean /pi/ was sometimes perceived as a comparably good unaspirated stop (i.e., Mandarin /p/). A closer look at the VOT values of the individual stimuli showed that the /pi/ token from Talker 1 had an exceptionally short VOT of 8 ms, and indeed all of the Mandarin /p/ responses were in response to that particular token. The fact that this token was selected based on its prototypicality perceived by native Korean listeners suggests that another cue, such as its low *f*0, may have overridden its unusually short VOT for native listeners.

Second, the listeners' perception of Korean /tu/ and /ku/ differed from the pattern that would be expected based on the acoustic correlates reported in previous studies of Korean and Mandarin stops. A straightforward mapping based on expected VOT values in the two languages would predict that Korean /tu/ and /ku/ should be perceived as Mandarin /$t^h$/ and /$k^h$/, respectively. Instead, we found that 15% of Korean /tu/ and /ku/ trials were perceived as Mandarin unaspirated /t/ and /k/. In the case of Korean /ku/, 10 of the 12 /k/ responses were in response to the token produced by Talker 2, which had a VOT of 59 ms. This VOT is indeed the shortest among the Korean /ku/ tokens, but still well within the documented VOT values of Mandarin voiceless unaspirated velar stops. The remaining two /k/ responses to Korean /ku/ were in response to the token produced by Talker 1, which had a VOT of 67 ms. It is unclear why these tokens were not perceived as aspirated stops by L1 Mandarin listeners.

The results for Korean /tu/ are similar. The stimuli perceived as Mandarin unaspirated /t/ were produced by Talkers 2 and 4, whose productions had VOT values of 38 and 31 ms, respectively. These were also the shortest VOT values among the Korean /tu/ stimuli, but still long enough that we might expect them to be perceived as Mandarin /$t^h$/.

#### 2. Fortis stops

The Korean fortis stops (/p*, t*, k*/), on the other hand, were generally perceived as the unaspirated stops of Mandarin (/p, t, k/). Except for some minor confusion of place of articulation (e.g., /p*u/, /t*a/, and /k*i/), the Korean fortis stops were classified as Mandarin unaspirated stops at rates of 98% to 100%, with goodness ratings almost always

between 4.0 and 4.5. Thus, here too it appears that listeners were attending primarily to VOT in making their classifications. Korean fortis stops are produced with short lag VOT, usually less than 20 ms (Silva, 2006; Kang and Guion, 2008), which would place them within the same perceptual space as Mandarin voiceless unaspirated stops. The VOT values of the stimuli used here follow this trend, although the majority of the fortis velar stops had VOT values between 20 and 30 ms.

To summarize, the general pattern shown here is that Korean lenis and aspirated stops are assimilated to Mandarin aspirated stop categories, and Korean fortis stops are assimilated to Mandarin unaspirated stop categories. These results suggest that L1 Mandarin listeners primarily attend to VOT in classifying stops. The possible implications of this perceptual pattern are discussed in Sec. IV D.

#### 3. Exceptional patterns

One source of variable assimilation was the perception of Korean velar stops before /i/. As shown in Table I, 22%, 9%, and 36% of Korean /ki/, /k$^h$i/, and /k*i/ trials were perceived as an alveolar stop. The misperception of [ki] as [ʧi] or [ti] is a well-documented phenomenon (e.g., Winitz *et al.*, 1972; Guion, 1998) and does not warrant further discussion here. What is important to note is that although the place of articulation was misperceived, the presence or absence of aspiration was not. Only 3%, none, and 1% of Korean /ki/, /k$^h$i/, and /k*i/ trials, respectively, were classified as an obstruent with incongruent aspiration.

Another source of variable assimilation was Korean /p*u/, of which 14% of trials were perceived as Mandarin /f/. This represents 11 trials that were classified as such, and a closer examination of listener responses revealed that 10 of these 11 were in response to the token produced by Talker 1. While the 22 ms VOT of this token was within the typical range for a Korean fortis stop, this token had several bursts, with one burst preceding the onset of voicing by approximately 48 ms. This extended period of aperiodic noise could have been perceived as frication to the listeners, as it also is to the current author. It is notable that although this token was selected by the native Korean judges as the best of Talker 1's /p*u/, it is not unusual for a native Korean listener to perceive English /f/ as Korean /p*/ (Schmidt, 1996; Park and de Jong, 2008). Thus, even if this particular /p*u/ token sounded like Mandarin /f/ to the listeners in the current sturdy or like English /f/ to the current author, it could still be considered a good /p*/ to a native Korean listener.

### B. Perception of Korean affricates

The results for the Korean affricates are shown in Table III. Compared to the responses for the Korean stops, the Korean affricate responses appear to be spread over more Mandarin categories, suggesting a less clear mapping from Korean to Mandarin perceptual categories. It is important to remember that while the Korean affricate contrast covers three phonation types at a single place of articulation, Mandarin contrasts affricates at three places of articulation cross-cut by another contrast in aspiration. Given that the three Korean affricates are ostensibly produced at the same place of articulation as each other, we might expect L1 Mandarin listeners to perceive them at the same place of articulation as well.

Instead, we found that while the mapping of Korean affricates to Mandarin affricates is clear with respect to aspiration, it is unclear with respect to place of articulation. We can see these trends more clearly by separately collapsing responses according to perceived aspiration and perceived place of articulation. In the following sections we will discuss the results for aspiration and place of articulation separately.

#### 1. Aspiration

In the top half of Table IV, the trials classified as a Mandarin affricate have been categorized as either aspirated or unaspirated, ignoring place of articulation. 87% and 90% of Korean /tɕa/ and /tɕ$^h$a/ trials were perceived as an aspirated affricate, whereas 81% of Korean /tɕ*a/ trials were perceived as an unaspirated affricate. If we ignore differences in both place and manner (e.g., include /t$^h$/ as aspirated and /t/ as unaspirated), then 93% and 100% of Korean /tɕa/ and /tɕ$^h$a/ trials were perceived as aspirated and 100% of Korean /tɕ*a/ trials were perceived as unaspirated.

These trends hold for Korean aspirated /tɕ$^h$/ and fortis /tɕ*/ in both the /i/ and /u/ vowel contexts, with 93% and

TABLE III. Perceptual assimilation results for the Korean affricate stimuli.

| | Korean | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Mandarin | /tɕa/ | /tɕ$^h$a/ | /tɕ*a/ | /tɕi/ | /tɕ$^h$i/ | /tɕ*i/ | /tɕu/ | /tɕ$^h$u/ | /tɕ*u/ |
| Count | 78 | 80 | 78 | 79 | 80 | 79 | 79 | 80 | 80 |
| /ts$^h$/ | 36 (2.3) | 31 (2.7) | | | 1 (2.0) | | 1 (3.0) | 5 (3.5) | |
| /tɕ$^h$/ | 17 (2.5) | 22 (3.1) | | **72 (3.9)** | **82 (4.2)** | | 4 (2.3) | 6 (1.4) | |
| /ʧ$^h$/ | 35 (2.6) | 36 (3.1) | | 8 (2.7) | 10 (3.0) | | 47 (2.8) | **85 (3.1)** | |
| /ts/ | | | 23 (2.9) | | | | 5 (3.8) | | 5 (4.8) |
| /tɕ/ | 4 (3.3) | | 45 (3.9) | 18 (2.6) | | **85 (4.0)** | 10 (2.8) | | 40 (3.3) |
| /ʧ/ | 1 (4.0) | | 13 (2.4) | | | | 32 (3.4) | | **55 (3.5)** |
| /t$^h$/ | 6 (2.6) | 10 (3.3) | | | 5 (3.5) | 1 (3.0) | 1 (2.0) | 4 (2.0) | |
| /t/ | | | 19 (3.1) | | | 3 (3.5) | | | |
| /k/ | | | | 3 (3.0) | | 11 (3.7) | | | |

TABLE IV. Perceptual assimilation results from Table III with the trials perceived as an affricate collapsed across perceived aspiration and place of articulation.

| | Korean | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Mandarin | /tɕa/ | /tɕʰa/ | /tɕ*a/ | /tɕi/ | /tɕʰi/ | /tɕ*i/ | /tɕu/ | /tɕʰu/ | /tɕ*u/ |
| Count | 78 | 80 | 78 | 79 | 80 | 79 | 79 | 80 | 80 |
| Aspirated | **87 (2.4)** | **90 (3.0)** | | **80 (3.8)** | **93 (4.1)** | | **52 (2.8)** | **96 (3.0)** | |
| Unaspirated | 5 (3.5) | | **81 (3.3)** | 18 (2.6) | | **85 (4.0)** | 47 (3.3) | | **100 (3.5)** |
| /tʰ/ | 6 (2.6) | 10 (3.3) | | | 5 (3.5) | 1 (3.0) | 1 (2.0) | 4 (2.0) | |
| /t/ | | | 19 (3.1) | | | 3 (3.5) | | | |
| /k/ | | | | 3 (3.0) | | 11 (3.7) | | | |
| | /tɕa/ | /tɕʰa/ | /tɕ*a/ | /tɕi/ | /tɕʰi/ | /tɕ*i/ | /tɕu/ | /tɕʰu/ | /tɕ*u/ |
| Count | 78 | 80 | 78 | 79 | 80 | 79 | 79 | 80 | 80 |
| Alveolar | 36 (2.2) | 31 (2.7) | 23 (2.9) | | 1 (2.0) | | 6 (3.6) | 5 (3.5) | 5 (4.8) |
| Alveolopalatal | 21 (2.7) | 22 (3.1) | 45 (3.9) | **90 (3.6)** | **82 (4.2)** | **85 (4.0)** | 14 (2.6) | 6 (1.4) | 40 (3.2) |
| Postalveolar | 36 (2.6) | 36 (3.1) | 13 (2.4) | 8 (2.7) | 10 (3.0) | | **78 (3.0)** | **85 (3.1)** | **55 (3.5)** |
| /tʰ/ | 6 (2.6) | 10 (3.3) | | | 5 (3.5) | 1 (3.0) | 1 (2.0) | 4 (2.0) | |
| /t/ | | | 19 (3.1) | | | 3 (3.5) | | | |
| /k/ | | | | 3 (3.0) | | 11 (3.7) | | | |

96% of Korean /tɕʰi/ and /tɕʰu/ trials perceived as an aspirated affricate and 85% and 100% of Korean /tɕ*i/ and /tɕ*u/ trials perceived as an unaspirated affricate. Again, collapsing across manner as well boosts the /tɕʰi/ and /tɕʰu/ rates to 98% and 99% and both of the /tɕ*i/ and /tɕ*u/ rates to 100%. The Korean lenis affricate /tɕ/ is perceived as less aspirated before the high vowels /i/ and /u/, which is likely due to the shortened period of aspiration in high vowel contexts. These results show that the perception of aspiration in Korean affricates may be moderately vowel-dependent, with /tɕa/ perceived as definitely aspirated (and thus similar to /tɕʰa/) and /tɕu/ perceived as less aspirated (and thus more similar to /tɕ*u/).

In summary, the results show that L1 Mandarin listeners perceive Korean /tɕ/ and /tɕʰ/ as aspirated and Korean /tɕ*/ as unaspirated, although /tɕ/ is perceived as less aspirated before the high vowels /i/ and /u/.

#### 2. Place of articulation

Next, in the bottom half of Table IV, we can see the same set of responses categorized according to perceived place of articulation. Kim (1999) provided a broad review of studies on the articulation of Korean affricates and concluded that they are strictly alveolar, a finding corroborated by Anderson *et al*. (2004). Because Mandarin has both aspirated and unaspirated alveolar affricates, it was unexpected that the majority of the Korean affricates were perceived as alveolopalatal or postalveolar. Collapsing across vowel context, only approximately 30% of the lenis affricates, essentially none of the fortis affricates, and approximately 5% of the aspirated affricates were perceived as alveolar. Furthermore, it does not seem to be the case that an individual talker or a small subset of listeners skewed the results. For example, there were a total of 28 Korean /tɕa/ trials perceived as a postalveolar Mandarin affricate (/ʧa/ or /ʧʰa/), and these 28 tokens were spread across all four talkers and 16 of the 20 listeners. A total of 29 Korean /tɕʰa/ trials were perceived as postalveolar, and these tokens were spread across four talkers and 11 of the 20 listeners. These findings thus do not appear to be idiosyncratic patterns representing only one particular talker, listener, or dialect region.

Broadly, the perceived place of articulation can be summarized as follows. The Korean affricates before /a/ are perceived at all three possible places of articulation for Mandarin affricates (alveolar, alveolopalatal, and postalveolar), the Korean affricates before /i/ are perceived as Mandarin alveolopalatal affricates, and the Korean affricates before /u/ are perceived as alveolopalatal or postalveolar.

### C. Perception of Korean fricatives

The results for the Korean fricatives are shown in Table V. One difference between the results for the fricatives and stops is that vowel context plays a much larger role in fricative perception. The listeners perceived Korean stops somewhat consistently across vowel contexts: lenis and aspirated stops were perceived as aspirated, and fortis stops were perceived as unaspirated. In this sense, L1 Mandarin listeners' perception of Korean fricatives and affricates are similar, but we will see that vowel context plays an even bigger role in fricative perception. Accordingly, we will present the fricative results by vowel context instead of fricative type.

#### 1. The /a/ context

The listeners perceived Korean /s*a/ as quite similar to Mandarin /s/, with an 80% classification rate and a mean goodness rating of 4.3. The variability in responses for Korean /sʰa/, however, suggests the presence of conflicting cues. The low classification rate of Korean /sʰa/ as a sibilant fricative (15% for /s/ and 10% for /ʃ/) may be due to aspiration. Many listeners perceived /sʰa/ tokens as an aspirated affricate (62% for /tsʰ/ and 11% for /ʧʰ/), but never as an unaspirated affricate. This result implicates aspiration as the cue that discouraged listeners from classifying those tokens

TABLE V. Perceptual assimilation results for the Korean fricative stimuli.

| | Korean | | | | | |
|---|---|---|---|---|---|---|
| Mandarin | /s$^h$a/ | /s*a/ | /s$^h$i/ | /s*i/ | /s$^h$u/ | /s*u/ |
| Count | 79 | 80 | 80 | 79 | 80 | 80 |
| /ts$^h$/ | **62 (3.2)** | 1 (1.0) | 1 (2.0) | 39 (3.0) | 12 (2.8) | 1 (3.0) |
| /tɕ$^h$/ | | | 6 (3.6) | | | |
| /ʧ$^h$/ | 11 (2.2) | | 2 (3.5) | | 5 (2.8) | |
| /ts/ | | 2 (2.5) | | 1 (5.0) | | 2 (1.5) |
| /s/ | 15 (3.1) | **80 (4.3)** | | 28 (3.4) | **65 (3.8)** | **81 (4.3)** |
| /ɕ/ | | | **86 (3.8)** | 32 (3.6) | | |
| /ʃ/ | 10 (3.0) | 15 (3.8) | 4 (3.7) | | 15 (3.0) | 15 (3.4) |

as a sibilant fricative, which are always unaspirated in Mandarin.

It is not clear why /s*a/ was sometimes classified as Mandarin /ʃ/, because L1 Mandarin listeners should be able to easily identify /s/ and /ʃ/ based on the spectral mean of the frication. These responses may have been due to dialectal influence, as the four listeners who contributed such responses were from regions whose dialect of Mandarin has been claimed to lack /ʃ/ (Yan, 2006). It is possible that some listeners from these dialect regions may lack a robust perceptual distinction between /s/ and /ʃ/, but it could also be idiosyncratic variation. We do not have enough data to explore such claims here further.

### 2. The /i/ context

Korean /s$^h$/ shows a more straightforward assimilation pattern before /i/. 86% of Korean /s$^h$i/ tokens were classified as Mandarin /ɕ/, with a mean goodness rating of 3.8. Remember that in this vowel context Korean /s$^h$/ becomes alveolopalatal (Yoon, 1999) and aspiration is either greatly reduced or omitted completely (Kagaya, 1974; Yoon, 1999; Chang, 2007). These processes render Korean /s$^h$i/ acoustically quite similar to Mandarin /ɕi/ and provide a reasonable explanation for the pattern seen here. Korean /s*/ displays a more variable assimilation pattern before /i/. The palatalization of /s*/ before /i/ has been both assumed (e.g., Yoon, 1999) and denied (e.g., Baik, 1998). In the current study, only the /s*i/ stimulus from Talker 2 was palatalized as judged impressionistically by the current author. Although Table V shows that 32% of the /s*i/ trials were classified as /ɕ/, 64% of those were from trials involving the token from Talker 2, which 16 out of 20 listeners classified as /ɕ/. The remaining /s*i/ trials were classified as Mandarin /s/ or /ts$^h$/. One reason why /s*i/ could be perceived as /ts$^h$i/ is that the tight lingual constriction in /s*/ (Baik, 1998; Kim, 2001) could have been perceived as the stop closure in /ts$^h$/, although it is not clear why listeners would choose aspirated /ts$^h$/ instead of unaspirated /ts/ given that the /s*i/ stimuli were not aspirated at all.

### 3. The /u/ context

In this context /s*/ once again displayed an assimilation pattern more consistent than /s$^h$/. Eighty one percent of /s*u/ trials were classified as Mandarin /s/ with a mean goodness rating of 4.3, and the remaining 15% of trials were classified as Mandarin /ʃ/ with a mean goodness rating of 3.4. Again, this is probably evidence for the acoustic similarity between Korean /s*/ and Mandarin /s/ when unaffected by possible palatalization before /i/. Eleven of the 12 /s*u/ trials categorized as Mandarin /ʃ/ were from the same listeners who classified some /s*a/ trials as /ʃ/. Following from the discussion above, it remains unclear whether this reflects dialectal or idiosyncratic variation.

The assimilation of /s$^h$u/ is similar to that of /s$^h$a/ in that classification was split between the fricatives /s/ and /ʃ/ and the aspirated affricates /ts$^h$/ and /ʧ$^h$/. In the case of /s$^h$u/, however, listeners were much more likely to assimilate it to a fricative than to an aspirated affricate. Just as in the /a/ context, the reason for this pattern probably lies in the aspiration cue. The /s$^h$u/ tokens were more aspirated than Mandarin fricatives are (since Mandarin fricatives are not aspirated at all), but they were not as aspirated as the Korean /s$^h$a/ tokens. If aspiration was indeed the cue that pushed listeners to assimilate them to their aspirated affricate categories, then in the case of the less aspirated /s$^h$u/ tokens we should expect less assimilation to /ts$^h$/ and /ʧ$^h$/ and more assimilation to /s/ and /ʃ/, and this is exactly what we see here.

In summary, Korean /s$^h$a/ was perceived more often as an aspirated affricate than /s$^h$u/ was, and Korean /s$^h$u/ was perceived more often as a sibilant fricative than /s$^h$a/ was. Both Korean /s*a/ and /s*u/ were consistently perceived as a sibilant fricative. Korean /s$^h$i/ was most frequently perceived as /ɕ/, whereas Korean /s*i/ was perceived as /ɕ/, /s/, or /ts$^h$/. The assimilation of Korean /s*i/ may have depended on whether or not the stimulus was palatalized.

## IV. GENERAL DISCUSSION

The aim of this study was to establish some preliminary perceptual assimilation patterns upon which predictions about the discrimination and eventual L2 acquisition of Korean obstruents by L1 Mandarin listeners could be based. The results can be broadly summarized as follows. We found that L1 Mandarin listeners classified Korean stops primarily in terms of VOT, which effectively neutralizes the Korean contrast between lenis and aspirated stops. Korean lenis stops were classified as Mandarin aspirated stops only slightly less than Korean aspirated stops were, with comparable mean goodness ratings. We also found that L1 Mandarin listeners primarily attended to aspiration when classifying Korean affricates, as well, with Korean lenis and aspirated affricates assimilating to Mandarin aspirated categories and Korean fortis affricates assimilating to Mandarin unaspirated categories. This trend was less strong for the lenis affricates, however, which were assimilated to Mandarin unaspirated categories at higher rates before the high vowels /i/ and /u/. Last, we found that aspiration played a role in the perception of Korean fricatives, as well, with the Korean lenis-aspirated fricative /s$^h$/ assimilating to a Mandarin aspirated affricate category in 73% of /a/ trials. This trend was weaker in the /u/ context and absent in the /i/

context, which we assume to be due to reduced or absent aspiration. As a result, the Korean fricatives assimilated to the same Mandarin category (/ɕ/ before /i/ and /s/ before /u/) more often in these vowel contexts.

### A. Limitations

There were several limitations to this study. First, there is a necessary trade-off between the number of different CVs that can be tested and the number of trials that can be done for each CV. In the current study each listener heard the entire Korean obstruent inventory in three different vowel contexts, but this came at the cost of having each listener only hear four tokens of each CV. While the low number of trials per CV reduces our ability to make inferences about individual CVs, it has the benefit of making it possible to test the entire consonant system in a single sitting.

Second, we must be careful in interpreting the goodness ratings in combination with classification percentages. How should we interpret one consonant that assimilates to a category 70% of the time with a goodness rating of 4.0 and another consonant that assimilates to the same category 90% of the time with a goodness rating of 3.0? Is an L2 sound more similar to an L1 sound if it is selected more often or if it is rated more highly when selected? It is important to remember that the lower the classification percentage is, the less reliable the goodness rating becomes, as it reflects a smaller number of trials. What remains unclear is exactly how much lower the classification percentage can be before it becomes meaningless to compare goodness ratings.

Last, although the listeners were naive to Korean, they were not monolingual. All listeners had studied English for several years before coming to the U.S. and all had used English after arriving. However, L1 Mandarin learners of L2 Korean in South Korea are also bilingual in English, and so the findings presented may still be used to make predictions regarding the perceptual abilities of L1 Mandarin learners of L2 Korean in South Korea. Furthermore, the perceptual assimilation patterns we observed here were for the most part in line with what we would expect given the acoustic properties of Korean and Mandarin obstruents.

### B. Mandarin phonotactic restrictions and Korean affricates

One complication introduced by our methodology is that Mandarin affricates (and fricatives) are subject to certain phonotactic restrictions that could bias L1 Mandarin listeners' perception of Korean affricates. Specifically, the Mandarin alveolopalatal affricates /tɕ/ and /tɕ$^h$/ can only appear before the vowels /i/ and /y/ or the glide /j/, and so if a Korean affricate appears before /a/ or /u/, the listener could be biased against classifying it as alveolopalatal because alveolopalatal affricates in Mandarin cannot occur in those vowel contexts. Conversely, a Korean affricate before /i/ may be more likely to be classified as alveolopalatal because alveolar and postalveolar affricates in Mandarin cannot occur before /i/. The results from the current study showed that L1 Mandarin listeners perceived Korean affricates as alveolar only approximately 40% of the time before /a/, and rarely before /i/ or /u/.

This result is seemingly at odds with previous studies (Kim, 1999; Anderson *et al.*, 2004) that have argued that Korean affricates are alveolar. If we assume that the Korean affricate stimuli used here were alveolar, the results for the /a/ context in Table IV are difficult to explain because (combining the alveolopalatal and postalveolar numbers) 57%, 58%, and 58% of the /tɕa/, /tɕ$^h$a/, and /tɕ*a/ trials, respectively, were not perceived as alveolar. The 21%, 22%, and 45% perceived as alveolopalatal could be explained by the possibility of a phonotactically driven perception bias, but the trials perceived as postalveolar remain unaccounted for. Turning to the /i/ context, the majority of tokens were perceived as alveolopalatal. This trend can be easily explained by appealing to the phonotactic restriction on Mandarin affricates, but then we need to explain why this restriction did *not* apply so strongly in the /a/ context. Last, in the /u/ context, 78%, 85%, and 55% of the /tɕu/, /tɕ$^h$u/, and /tɕ*u/ were perceived as postalveolar. Here, no appeal can be made to the Mandarin phonotactic restriction, because we would still need to explain why so few of the trials were perceived as alveolar. Although we saw in our fricative results that some dialectal influence may account for the apparently less robust /s/-/ʃ/ contrast for two of the Mandarin listeners, these affricate results are representative of the entire listener pool and not just two individual listeners.

An alternative analysis is that the Korean affricate stimuli used here were actually alveolopalatal. Under this assumption, the failure of L1 Mandarin listeners to perceive Korean affricates as alveolopalatal more often in the /a/ context can be attributed to the phonotactic restriction on Mandarin affricates: They chose the phonotactically legal alveolar or postalveolar affricates even though the frication noise, for example, might have been more similar to their alveolopalatal affricate. The results for the /i/ context would need little explanation, since an alveolopalatal affricate in a phonotactically legal environment should be perceived as alveolopalatal. The results for the /u/ context can again be explained by the phonotactic restriction: Because Mandarin alveolopalatal affricates cannot occur before /u/, listeners were more likely to choose the acoustically similar postalveolar affricate.

While cross-language perception data cannot speak directly to the place of articulation of Korean affricates, these data should nonetheless be integrated into the findings of more direct investigations, such as Anderson *et al.* (2004) and Kim (1999), to provide a general account of Korean affricates. It was suggested in Anderson *et al.* (2004) that some of the variability across studies could be attributed to age differences. Given that neither these studies nor the current study employed more than a few speakers, echoing the call of Anderson *et al.* (2004, p. 23), there remains a "need for a larger scale socio-phonetic study of Korean coronals." The lack of consensus regarding the difference in place between Korean and English affricates was also noted by Kang (2013, p. 57), who suggested that a more thorough study of affricates in both languages is needed.

### C. Comparison with L1 English listeners

Because English contrasts pre-voiced or short lag VOT stops with long lag VOT stops, we should expect L1 Mandarin and L1 English listeners to exhibit similar perceptual assimilation patterns for Korean stops. The L1 English listeners in Schmidt (2007) mostly assimilated Korean lenis and aspirated stops to English voiceless stops and Korean fortis stops to English voiced stops. Together with the results from the current study, these results suggest that VOT alone can predict how both L1 English listeners and L1 Mandarin listeners will perceive Korean stops.

The L1 English listeners in Schmidt (2007) also perceived aspiration in Korean affricates in the same way as L1 Mandarin listeners: both Korean lenis and aspirated affricates assimilated to a voiceless obstruent category, whereas Korean fortis affricates assimilated to a voiced obstruent category. It is more difficult to conclude how L1 English listeners perceived place of articulation, however, because English, unlike Mandarin, does not contrast affricates at different places of articulation. Thus, even if the Korean affricates were perceived as alveolar, because /ts/ is not an option for L1 English listeners they would have to choose either /t/ (and ignore manner) or choose /ʧ/ (and ignore place).

Last, the L1 English listeners' perception of Korean fricatives in Schmidt (2007) differed from that of the L1 Mandarin listeners in the current study in that both Korean /s$^{h}$/ and /s*/ were perceived as English /s/ before /a/ and /u/. Because the L1 Mandarin listeners often perceived Korean /s$^{h}$a/ as an aspirated affricate and /s*a/ as a sibilant fricative, these results predict that L1 Mandarin listeners should be better than L1 English listeners at discriminating between /s$^{h}$a/ and /s*a/. Their discrimination ability in the /u/ context, however, should be similar because both listeners groups assimilated both Korean fricatives to a single L1 category.

### D. Conclusion

Although this study has provided additional evidence that non-native listeners only attend to acoustic cues that are relevant in identifying native phonological contrasts, how should these results be viewed in terms of the predictions made by PAM (Best, 1995)? If members of a non-native contrast are assimilated to the same native category, PAM predicts that discrimination should be poor. Both Korean lenis and aspirated stops and affricates assimilated to Mandarin aspirated stop and affricate categories, but this was probably not because the listeners, who were native speakers of a tonal language, were insensitive to differences in *f*0. The more likely reason is that the listeners were not given the option to specify which tonal category the Korean stimuli assimilated to, and were thus forced to map what may be a tonal contrast onto segmental categories that do not represent tone. These results highlight the complicated relationship between perceptual assimilation and discrimination. Even native speakers of non-tonal languages, such as French, are able to discriminate between some tone contrasts with reasonable accuracy (Hallé *et al.*, 2004). Because French has a stop contrast cued by VOT, L1 French listeners should assimilate both Korean lenis and aspirated stops to a single L1 stop category (just like L1 English and L1 Mandarin listeners do), but given the results of Hallé *et al.* (2004) it should also be predicted that L1 French listeners would have no trouble discriminating between Korean lenis and aspirated stops, contra PAM. To account for L1 French listeners' ability to discriminate between Mandarin tones in terms of PAM, Hallé *et al.* (2004) argued that a Mandarin tone contrast would need to be viewed as a UU-type (uncategorized-uncategorized) contrast. PAM predicts the discrimination of such contrasts can be quite good as long as the members of the contrast have some acoustically salient difference.

Because PAM, in its original formulation (Best, 1995), was only intended to account for the perceptual assimilation and discrimination of segments, L1 French listeners' perception of Mandarin tones could be considered outside its purview. But because Korean stops and affricates are segments themselves and partly cued by *f*0, they force us to consider things other than the L1 segmental inventory when using PAM to make predictions about how well non-native listeners will discriminate them. One possible direction for future work would be to explicitly compare speakers of tonal and non-tonal languages in their perceptual assimilation and discrimination of Korean lenis and aspirated obstruents. While speakers of non-tonal languages would probably not consistently assimilate them to different categories, their discrimination of them may be much better. It is predicted that speakers of tonal languages would be excellent at discrimination.

Last, the current findings also predict that L1 Mandarin listeners should be somewhat skilled at discriminating Korean /s$^{h}$a/ and /s*a/, given that the former was often perceived as an aspirated affricate and the latter as a sibilant fricative. Results from Holliday (2012b) have shown that L1 Mandarin learners of L2 Korean are very poor at identifying Korean /s$^{h}$/ and /s*/ in any vowel context, and so more work is needed to investigate whether the ability to assimilate /s$^{h}$a/ and /s*a/ to different Mandarin categories is maintained after L2 instruction has begun.


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