Perception of Flaps in American English and Korean

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1. Introduction

Linguistic experience influences the mind of a listener. Listeners pick up the same acoustic signals and may interpret the signals differently according to their language backgrounds. Linguistic experience in a particular language decreases sensitivity for some phonetic contrasts that are not used in the language. One way to examine the effect of linguistic experience on speech perception is to compare the perceptual patterns of phonetically relevant segments by two groups of speakers who have different linguistic experiences. A number of cross-language studies have revealed language-specific patterns of perception by examining American English (AE) /r/ and /l/ (Goto, 1971; Miyawaki, Strange, Verbrugge, Liberman, Jenkin & Fujimura, 1975; MacKain, Best & Strange, 1981; Polka & Strange, 1985), voice onset time (VOT) of stop consonants (Lisker & Abramson, 1964; Williams, 1977; Flege & Eefting, 1988; Bohn & Flege, 1993), and vowels (Beddor & Strange, 1982; Gottfried, 1984; Flege, Munro & Fox, 1994).

Most cross-language studies have focused on native language interference in the perception of non-native contrasts, and are restricted to the perception of certain phones such as stops or liquids. There has been little investigation of the perception of sounds that are classified as different categories such as sonorants and obstruents in two languages. Flaps in AE and Korean provide an appropriate case since flaps are differently categorized in the two languages. The central question of this paper is: How do the different functions of flaps in the L1 phonology affect the perception of the flaps? That is, the present research explores the role of the first language experience by comparing different perceptual patterns of a phonetically similar segment by two groups of speakers.

Flaps in Korean and AE are phonetically very similar. In a pilot study, I found that when the flaps from the two languages were put into the same vowel contexts, neither American nor Korean listeners could discriminate between them. In fact, since the flaps in the two languages are so similar, a frequently used technique in teaching AE flaps to Korean students is to focus attention on the physical similarity between the flaps in the two languages.

Although the AE and Korean flaps are perceptually similar, the functions of the flaps in the phonological systems of the two languages are crucially different. The flap in Korean is an allophone of the lateral liquid /l/ found when /l/ comes between vowels, e.g., *pu/i* [pu.ɾi] 'beak'. It contrasts with the alveolar lax stop /t/, as we can see in a minimal pair, e.g., *muli-ta* [mu.ɾi.da] 'unreasonable' vs. *muti-ta* [mu.di.da] 'blunt, dull'. It should be noted that Korean /t/ further contrasts with /t'/ and /t^h/, alveolar tense and aspirated stops, respectively, e.g., *sato* [sa.do] 'an apostle' vs. *sat'o* [sa.t'o] 'mayor (archaic)' vs. *sat^{h}o* [sa.t^ho] 'sandy soil'. By contrast, the flap in AE is an allophone of the alveolar stops /d/ and /t/, e.g., *latter* and *ladder*, both pronounced [læðɚ]. It contrasts with the liquids /l/ and /r/, e.g., *Betty* vs. *berry* vs. *belly*. While both the flap [ɾ] and the approximant retroflex /r/ in AE are considered as "rhotics" (r-sounds), the two sounds belong to different phonemic categories. Figure 1 shows the relationship of flaps and the main variants of liquid and alveolar stop sounds in Korean and AE.

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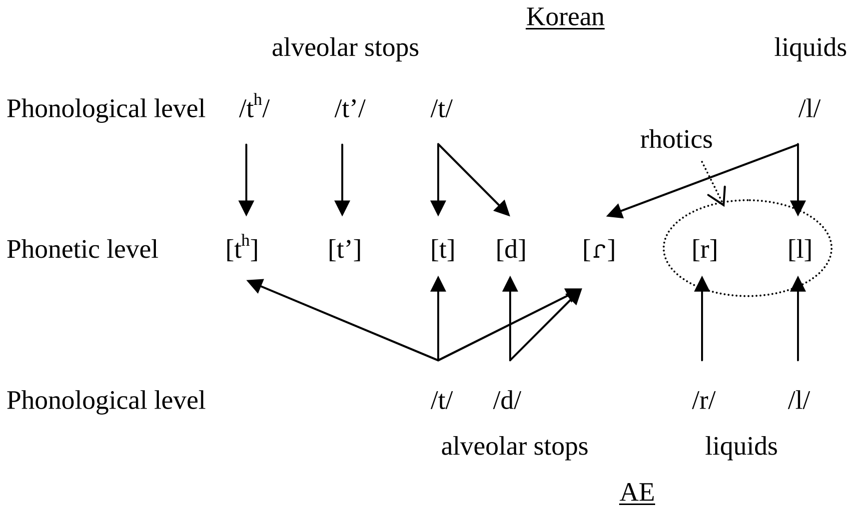

Figure 1 Partial phonological status of flaps, alveolar stops and liquids in Korean and AE[1]

The effects of the phonological function of flaps are investigated through a series of perception experiments on phonetically relevant sounds in Korean and AE. Two experiments examine the ability of the Korean and AE speakers to discriminate among: a) AE flaps, alveolar stops and liquids, and b) Korean flaps, alveolar stops and liquids. These experiments are designed to determine whether flaps and stops, or flaps and liquids are discriminable under sensitive testing conditions. Two other experiments investigate the ways in which the AE and Korean speakers categorize the AE and Korean flaps, alveolar stops, and liquids.

The present study investigates whether or not the phonological or phonetic status of sounds in the L1 phonological system is able to predict the perceptual difficulty in the discrimination tasks. Also, it is examined what phonetic properties are used as a cue to discriminate between two sounds. Further, this study explores whether exposure to the phones as allophonic variants facilitates discrimination among the phones. Moreover, this study investigates whether categorization tasks involve he higher-order linguistic (phonological) processing of speech sounds to a greater extent than discrimination tasks.

2. Discrimination experiments

2.1 Hypotheses

The hierarchy of the perceptual difficulty is hypothesized based on the phonological status of sounds. A phonemic difference means that two phones of a pair occur systematically and signal differences in meaning in L1. Thus, the two phones are categorized into two different phonemes. An allophonic difference indicates that two phones of a pair occur systematically, but do not signal differences in meaning in L1. Thus, the two phones are categorized into the same phoneme. Speakers of the language are routinely exposed to the phones involving the phonemic or allophonic difference. A partially phonemic difference shows that two phones in a pair contrast meaning in a certain context, but not in other contexts. Therefore, although the two phones are categorized as the same phoneme in the L1 phoneme inventory, the two phones are contrastive in a certain position. A non-native difference means that the pair represents neither phonemic nor phonetic difference since one of the phones in a pair does not occur in L1. Speakers of the language depend on the acoustic difference to discriminate between two phones in a pair. The amount of acoustic difference varies depending on each pair. The following shows the hypothesized hierarchy of the perceptual difficulty (from the least to the most):

[1] Coda neutralization in the Korean phonology is not considered here.

Perceptual difficulty
phonemic difference (separate phonemes in L1) → least
partially phonemic difference (phonemic contrast in a context) → less
allophonic difference (allophonic variants in L1) → more
non-native difference (native vs. non-native phones) → most

2.2 Experiment 1: discrimination of AE flaps, alveolar stops and liquids
2.2.1 Methodology
2.2.1.1 Subjects

The subjects were twenty native speakers of AE (eight males and twelve females) and twenty native speakers of Korean (ten males and ten females). The AE subjects were undergraduate students who were in an introductory linguistics course at the University of Delaware (UD). They received extra credit points for their participation in the experiment. The Korean subjects were ELI students at UD, and participated in the experiment voluntarily. They were raised in Korea, and had come to the U.S. to study English. Every member of the Korean group had studied English for at least 10 years in Korea, while none of the AE speakers had studied Korean. None of the Korean subjects were exposed to AE from early childhood. The age-range of both the AE and Korean speakers was from 19 to 35 years old. All subjects reported having normal hearing. AE speakers who had significant experience in Spanish (more than 4 years) were excluded from the subjects. The reason for their exclusion is explained in section 3.3.1.1.

2.2.1.2 Stimuli

The stimuli in the present experiment were constructed using edited natural speech that was derived from the productions of two female AE speakers. Each pair consisted of two very short pieces of words produced by two speakers with standard pronunciation. Each token included an intervocalic flap [ɾ], an alveolar stop [d] or [t^h], or a liquid [r] or [l] between the preceding vowel [u] and the following vowel [i], e.g., [uɾi], [udi]. In the stimuli including [ɾ], [r] and [l], the preceding vowel was always stressed. In the stimuli including [d] and [t^h], however, the following vowel was always stressed, otherwise the sounds in question would be pronounced as a flap. In AE, voiceless alveolar stops are aspirated when followed by a stressed vowel. In each token, 40 ms of each vowel were included, and the other part of the vowel was cut off.

The reasons for using the truncated stimuli are to reduce the effect of the stress patterns, and to obviate the different effects of vowels for native and non-native speakers. Only two high vowels, [u] and [i], were used in the present experiment because these two vowels were perceptually very similar in AE and Korean according to the author and several AE speakers. Also, both Korean and AE flaps can occur in this environment, [uCi].

In total, 80 test pairs and 80 fillers were used. The test pairs consisted of 40 same pairs [5 consonants (ɾ, d, t^h, r, l) x 4 repetitions x 2 speakers], and 40 different pairs [5 contrasts (ɾ-d, ɾ-t, ɾ-l, ɾ-r, r-l) x 4 repetitions x 2 speakers]. The fillers also consisted of 40 same pairs and 40 different pairs, and each item in a pair included [b], [p] or [s] between vowels. Since every pair consisted of two items produced by two speakers, no item was paired with itself. There was a 1500ms interval between the two members of a pair, and a 3000ms interval between the pairs.

The following are the stimuli used in this experiment. The words in parentheses are the words from which the stimuli were extracted. Stressed vowels are indicated by bold letters. The numbers beside each word indicate whether each word is an utterance of the first speaker or the second speaker, and whether the item is the first utterance or the second utterance of a speaker, e.g., '11' - first speaker, first utterance, '12' - first speaker, second utterance, '21' - second speaker, first utterance, '22' - second speaker, second utterance.

Table 1 AE stimuli in the discrimination experiment

Stimuli (same, 5 x 2 x 4 = 40)			**Stimuli** (different, 5 x 2 x 4 = 40)	
1.	**u**ɾi-**u**ɾi	(moody 11 – moody 21)	11. **u**ɾi–ud**i**	(moody 11 – Houdini 21)
2.	**u**ɾi-**u**ɾi	(moody 22 – moody 12)	12. **u**ɾi–ud**i**	(moody 21 – Houdini 11)
3.	ud**i**–ud**i**	(Houdini 11 – Houdini21)	13. **u**ɾi–ut^h**i**	(moody 12 – routine 21)
4.	ud**i**–ud**i**	(Houdini 22 – Houdini12)	14. **u**ɾi–ut^h**i**	(moody 22 – routine 11)
5.	ut^h**i**–ut^h**i**	(routine 11 – routine 21)	15. **u**ɾi–**u**li	(moody 13 – Julie 21)
6.	ut^h**i**–ut^h**i**	(routine 22 – routine 12)	16. **u**ɾi–**u**li	(moody 23 – Julie 11)
7.	**u**li–**u**li	(Julie 11 – Julie 21)	17. **u**ɾi–**u**ri	(moody 14 – jury 21)
8.	**u**li–**u**li	(Julie 22 – Julie 12)	18. **u**ɾi–**u**ri	(moody 24 – jury 11)
9.	**u**ri–**u**ri	(jury 11 – jury 21)	19. **u**li–**u**ri	(Julie 12 – jury 22)
10.	**u**ri–**u**ri	(jury 22 – jury 12)	20. **u**li–**u**ri	(Julie 22 – jury 12)

The pairs in the present experiment were chosen based on the phonological or phonetic status of the phones in each pair. The following table shows the phonemic relations of pairs of segments in AE stimuli.

Table 2 Phonemic status of the pairs of segments in the AE stimuli

AE pairs	Korean	AE
[ɾ] – [d]	**phonemic** difference (different phonemes)	**allophonic** difference (same phoneme)
[ɾ] – [t^h]	**phonemic** difference (different phonemes)	**allophonic** difference (same phoneme)
[ɾ] – [l]	**partially phonemic** difference (same phoneme, but **phonemic** difference intervocalically in [ɾ-ll])	**phonemic** difference (different phonemes)
[ɾ] – [r]	**non-native** difference ([r]; non-native phone)	**phonemic** difference (different phonemes)
[l] - [r]	**non-native** difference ([r]; non-native phone)	**phonemic** difference (different phonemes)

All the stimuli were recorded onto the TEAC RW-800 CD recorder in a sound attenuated chamber. The recording was converted into a digital waveform (44.1-kHz sampling, 16-bit resolution) using the EAC program. Each sound was saved as an AIFF file, and sound editing was conducted using the Praat program, version 3.9.3. Fade-in and fade-out effects were added using the Soundwave program. The sound files were later converted using the SoundApp program and transferred to the PsyScope program, version 2.5.1. All the items were automatically randomized for each subject.

2.2.1.3 Procedure

All the subjects were tested individually in a sound-attenuated chamber. They listened to 160 pairs of short pieces of naturally produced AE words through the Psyscope program on a Macintosh computer. An AX paradigm was employed with truncated stimuli to assess the subjects' ability to acoustically discriminate two items in each pair. The stimuli were presented through headsets in the following patterns: AA, BB, AB, and BA. The subjects indicated whether the two items were repetitions of the same word or pronunciations of two different words by pressing the “f” or the “j” button, respectively. They were also told that although the task was difficult for some pairs, they should try to listen carefully for differences between the items.

Before the experiment began, the subjects were familiarized with the tasks by doing a practice session. The design of the practice session was the same as that of the actual experiment, except that only fillers were used. This practice session contained 10 items. The subjects were asked if the task was clear after the practice trial. After the subjects understood the procedure, the real stimuli were given to them. No feedback was given during the practice session or the real experiment. Their answers were recorded by the computer.

2.2.2 Results

2.2.2.1 Signal detection theory

In order to investigate the subjects' performance in discrimination tasks, sensitivity was measured for each stimulus pair for each subject by applying signal detection theory (Green & Swets, 1966, Macmillan & Creelman, 1991, Macmillan, 2002). Signal detection theory (SDT) is a framework for understanding accuracy that makes the role of decision clear by providing a single sensitivity index from any discrimination paradigm. In discrimination experiments, subjects are asked to say “different” when the signal is present, and “same” when it is not, leading to the four possible outcomes on any trial as shown in table 3. A Comparison of the percentage of hits and false alarms allows for orthogonal measurement of sensitivity (d’) and response bias for each pair of tokens. The range of a d’ value can be from zero to any value, but in practice there is an upper limit, "4" in this experiment. The value of zero means that sensitivity to difference in the signal is random.

Table 3 Possible Outcomes on a Trial of a Discrimination Experiment

Stimuli	Responses	
	Different	Same
Different	**Hits**	Misses
Same	**False Alarm**	Correct Rejection

2.2.2.2 Discrimination sensitivity

Figure 2 and Table 4 display the mean discrimination sensitivity for each pair by the AE and Korean speakers.

Whereas the AE speakers show variation among the pairs, between the [ɾ-d] pair and all other pairs in particular, the Korean speakers’ performance is more or less consistent across the pairs. In general, the AE speakers performed well on all the pairs except the [ɾ-d] pair, and individual data show that all the AE speakers uniformly performed poorly on the [ɾ-d] pair. Although the Korean speakers' performance on the AE stimuli does not show much variation, their performance is not as good as that of the AE speakers on all the pairs except [ɾ-d]. When the data were submitted to a repeated measures ANOVA with groups (2 levels: AE vs. Korean) as the between-subjects factor, and pairs (5 levels: [ɾ-d], [ɾ-t^h], [ɾ-l], [ɾ-r], [l-r]) as the within-subjects factor, the results confirmed that there was a significant effect of pair [$F(4, 152) = 31.04$, $p < .001$]. Group was not significant [$F(1, 38) = .154$, $p > .05$], but there was a significant pair x group interaction [$F(4, 152) = 19.92$, $p < .001$]. Group as a whole did not show a significant effect since although the AE speakers performed much worse than the Korean speakers on the [ɾ-d] pair, the AE speakers performed better than Korean speakers on all other pairs. Thus, the group effect on one pair, [ɾ-d], was obscured by the opposite group effect on the other pairs, [ɾ-t^h], [ɾ-l], [ɾ-r] and [l-r].

A one-way repeated measures ANOVA was conducted for the AE and Korean speakers separately with pair as the within-subject factor. For the AE speakers, there was a significant effect of pair [$F(4, 76) = 51.11$, $p < .001$]. Bonferroni post hoc tests showed that the AE speakers' mean d' scores of the [ɾ-d] pair was significantly lower than those of all other pairs ($p < .001$ for all comparisons). There was no significant difference among the other pairs. For the Korean speakers, a one-way repeated measures ANOVA also showed that there was a significant effect of pair [$F(4, 76) = 4.198$, $p < .01$]. Bonferroni post hoc tests showed a marginal difference between [ɾ-r] and [l-r] ($p = .40 < .05$). That is, Korean speakers' performance on [l-r] was a little worse than that on [ɾ-r]. There were no significant differences among the other comparisons.

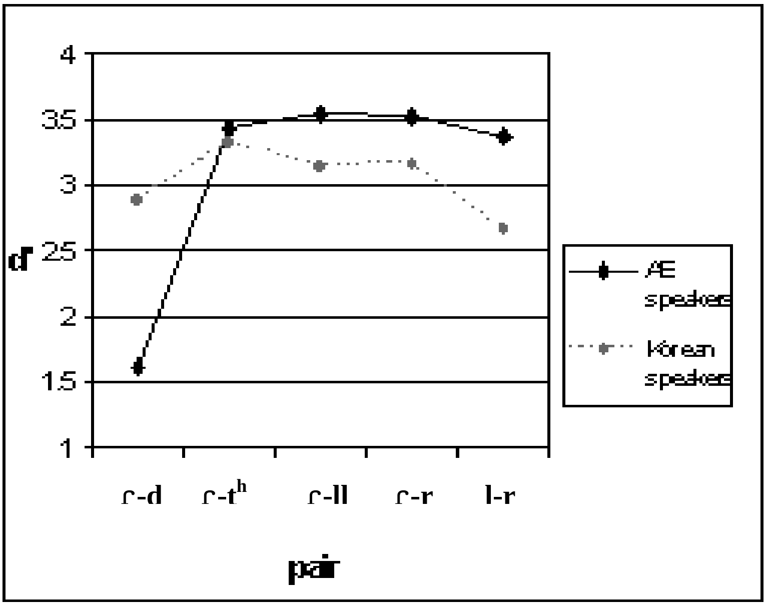

Figure 2 Distribution of mean sensitivity (d') functions for the AE stimuli

Table 4 Mean sensitivity (d') functions for the AE stimuli

Groups	Pairs				
	ɾ-d	ɾ-t^h	ɾ-l	ɾ-r	l-r
AE speakers	1.61	3.43	3.54	3.52	3.37
Korean speakers	2.88	3.33	3.15	3.16	2.67

In order to compare the groups for each pair, a between-subject one-way ANOVA was conducted. When the Bonferroni correction was applied, there was a significant difference between groups in two pairs, [ɾ-d] and [l-r] [$F(1, 38) = 24.274$, $p < .001$; $F(1, 38) = 9.614$, $p = .004 < .005$, respectively]. The performance of AE speakers on the [ɾ-d] pair was worse than that of Korean speakers, while the performance of AE speakers on the [r-l] pair was better than that of Korean speakers. Both the AE and Korean speakers performed well on the [ɾ-t^h] pair. I interpret the AE speakers' good performance on this pair as an indication that the difference between [ɾ] and [t^h] is acoustically very salient for AE speakers.

2.2.3 Discussion

In general both the AE and Korean speakers' sensitivity to the various pairs is not particularly low with the exception of the AE speakers' performance on the [ɾ-d] pair. The d' values for all the pairs except the [ɾ-d] pair are above 2.5. These results indicate that the experimental procedure itself was not too difficult for the subjects although they heard very short pieces of sounds.

The hypothesis about the perceptual difficulty based on the phonological relation of the sounds in each pair was not verified here. It was predicted that the AE speakers would have difficulty in discriminating the sounds in both the [ɾ-d] and [ɾ-t^h] pairs since each pair involves an allophonic difference. The results, however, show that whereas the AE speakers could not discriminate between [ɾ] and [d] at all, they did not show any difficulty in discriminating between [ɾ] and [t^h]. Although the AE flap [ɾ] is an allophone of both /t/ and /d/, the relation between [ɾ] and [d] is different from that between [ɾ] and [t^h]. It seems that there is another stage between [ɾ] and [t^h]. While [d] becomes [ɾ] by shortening the closure duration, [t^h] is changed into [ɾ] by two processes, i.e., neutralization and shortening of the closure duration, as schematized in (1).

(1) [t^h] ——neutralization——▶ [d] ——shortening——▶ [ɾ]

Thus, the concept of an allophonic relation should be carefully considered. The allophonic relation varies in each pair, and the perceptual difficulty cannot be predicted based solely on the phonemic or allophonic status of the sounds. For example, since [t^h] should undergo one more stage than [d] in order to be flapped, the discrimination of the [ɾ-t^h] pair is easier than that of the [ɾ-d].

The hypothesis regarding the Korean speakers' perceptual difficulty was also not verified. It was predicted that the Korean speakers would show low sensitivity to both the [ɾ-r] and [l-r] pairs since both pairs include the non-native phone [r], and the two sounds in each pair are categorized as the same phoneme in their L1. These speakers, however, experienced some difficulty only on the [l-r] pair; their performance on the [ɾ-r] pair was as good as that on the other pairs involving the phonological differences. Thus, the pairs including native and non-native phones that are categorized as the same phonemes in L1 do not necessarily induce poor performance. In other words, the subjects' sensitivity to the pairs involving non-native phones is not always lower than that to the pairs involving allophonic variants or two separate phonemes in their L1. It is, rather, assumed that listeners retain some sensitivity to pairs involving non-native phones since native and non-native phones are not completely categorized as the same L1 phoneme.

Furthermore, the results failed to confirm the hypothesis that the Korean speakers' perceptual difficulty is greater on the pairs involving the partially phonemic difference than on the pairs involving the fully phonemic difference. That is, the Korean speakers' sensitivity to the [ɾ-l] pair is not lower than to the [ɾ-d] or [ɾ-t^h] pair. Thus, the fully or partially phonemic relation between two sounds is not able to predict the perceptual difficulty.

The presence or absence of a sound in the L1 phonological system is not able to account for the results of the present experiments. If the perceptual difficulty is not predicted based on the phonological or phonetic status of the pairs, what factors are able to explain the perceptual patterns? To what phonetic cues do the AE and the Korean speakers show sensitivity?

Considering the acoustic properties of [ɾ] and [d], the AE speakers ignore the difference of closure duration between these two sounds, whereas the Korean speakers perceive the difference. Although the closure duration of [d] is almost three times as large as that of [ɾ], AE speakers' L1 experience prevents them from discerning the difference. In AE, the values of closure duration are not used to indicate the phonemic difference, whereas in Korean they are used for the phonemic difference.

In Korean stops, VOT values distinguish aspirated stops from lax and tense stops, but lax and tense stops show overlapping values (Lisker & Abramson, 1964; Han & Weitzman, 1970). According to Han (1992, 1996), closure duration is a primary cue to the distinction between tense and lax stops. Intervocalic tense consonants are three times longer than lax consonants (54 ms vs. 145 ms). Thus, for the Korean speakers, both VOT and closure duration cues are used for the phonemic difference.

In AE, VOT is a well-known phonetic cue to voicing, although closure duration provides an additional cue to voicing in intervocalic position. Kent and Read (1992) report that VOT ranges from about –20 ms to about +20 ms for the voiced stops, and it ranges from 25 ms up to 100 ms for the voiceless stops. Zue (1976) also found that 95 % of the voiceless stops have greater VOT values than 40 ms. Thus, the AE speakers could not distinguish between [ɾ] and [d] since the difference of VOT between these two sounds is not large enough, and the difference of closure duration is not a primary cue to them.

The AE speakers' good performance on the [ɾ-t^h] pair can be explained in two ways. First, it can be explained by the intermediate stage in the process of flapping as mentioned above. Second, it can also be explained by the phonetic cues to features contrastively used in their L1. The two sounds are distinguished by the phonetic cues such as VOT and closure duration. Since VOT is a primary cue to voicing in the L1 phonology, the AE speakers can easily detect the large VOT difference between [ɾ] and [tʰ] although they are not sensitive to the difference of closure duration. In the AE phonological system, VOT plays a primary role in the phonemic contrast while closure duration does not. Thus, the AE speakers can discriminate between [ɾ] and [tʰ] based on the phonetic cue relevant to a phonemic contrast although the two sounds are not separate phonemes in their L1.

The results of the present study also show that the Korean speakers’ performance on the [l-r] pair is slightly worse than the AE speakers’ performance on that pair. Korean and Japanese speakers' difficulty in discriminating between AE [l] and [r] has been well documented in previous studies (Goto, 1971; Miyawaki, Strange, Verbrugge, Liberman, Jenkin & Fujimura, 1975; MacKain, Best & Strange, 1981; Polk & Strange, 1985, Brown, 2000). In the present study, if the Korean speakers’ performance on AE [l] and [r] is separately considered for the same and different pairs, the percentage of correct responses on AE [l] is 78.7 % and that on [r] is 81.2 % in the same pairs, and for [l-r] is 83.1 % in the different pairs. The lower percentage of the correct responses for the same pairs than for the different pairs indicates that the Korean speakers show sensitivity to the acoustic variation of individual speakers and tokens in AE [l] and [r]. In other words, within-category variation as well as the L1 phonological system prevented Korean speakers from judging AE [l] and [r] like native AE speakers. In addition, the phonetic cue between [l] and [r], the lowering of F3, is not available to the Korean speakers since the cue is not used in their phonological system.

The present results, however, also reveal that it is not the case that the Korean speakers are entirely unable to discriminate between these sounds since the Korean speakers' performance on the [l-r] pair is not as low as the AE speakers' performance on the [ɾ-d] pair. In other words, the Korean speakers do not show a total lack of perceptual sensitivity to the acoustic differences of [l] and [r]. It seems that the L1 phonetic model for these two sounds in intervocalic position helps Korean speakers retain a certain level of sensitivity to these sounds. AE [r] is possibly mapped to the Korean flap in intervocalic position whereas AE [l] is mapped to the native geminate lateral [ll] in this position. This mapping is shown in loan words in Korean, e.g., *orange* → [o.ɾɛn.ǰi] vs. *igloo* → [i.gɨl.lu]. It is assumed that the feature [lateral] is somehow represented phonologically in Korean.

Moreover, the Korean speakers’ good performance on the [ɾ-r] pair can also be explained by the influence of the phonetic cue that is active in the L1 phonological system. Presumably, the Korean speakers perceive the durational difference between [ɾ] and [r] since the durational cue is relevant to a phonemic contrast in their L1. In addition, [r] is not completely categorized as a native phoneme since it is a non-native phone. Thus, the Korean speakers may retain sensitivity for the [ɾ-r] pair.

In addition, although [ɾ] and [l] are not fully separate phonemes in Korean, the Korean speakers did not show any difficulty in discriminating between the two sounds. That is, the Korean speakers’ performance on this pair is as good as that on the other pairs involving the phonological difference, i.e., the [ɾ-d] and [ɾ-tʰ] pairs. The Korean speakers' good performance on [ɾ-l] can also be explained by their sensitivity to a phonetic cue. That is, the Korean speakers may perceive the durational difference between the sounds since the durational cue is used for the contrastive features in their L1 phonology.

In sum, the L1 phonological system strongly affects listeners' performance in a discrimination task. The hypothesis on the hierarchy of the perceptual difficulty based on the phonological or phonetic status of sounds, however, was not verified in the present experiments. That is, the listeners’ performance on the pairs involving allophonic differences is not always poorer than that on the pairs involving phonemic differences. Also, the pairs involving native and non-native phones do not necessarily reduce the perceptual sensitivity.

It seems that listeners do not hear a whole phoneme. They hear, rather, phonetic cues if the cues are used for contrastive features in their L1. For example, whereas the Korean speakers are sensitive to the difference of duration, the AE speakers do not perceive the difference since the duration is not used to contrast meaning in their L1. Further, although the AE speakers are sensitive to the VOT cue, they do not detect the difference of VOT if the VOT values of both sounds are below 30 ms since the boundary between voiced and voiceless stops in AE is known to be around 30 ms. Therefore, sensitivity to phonetic cues depends on how the cues are used in their L1 phonology. Moreover, the overall results of this experiment show that L1 stimuli may affect subjects' performance. The AE speakers' performance shows a ceiling effect on all the pairs in the AE stimuli except the [ɾ-d] pair. It seems that the AE speakers’ performance was enhanced by L1 stimuli.

2.3 Experiment 2: discrimination of Korean flaps, alveolar stops and liquids
2.3.1 Methodology
2.3.1.1 Subjects

The same subjects who performed Experiment 1, participated in Experiment 2.

2.3.1.2 Stimuli

The stimuli were constructed using edited natural speech which was derived from the productions of two female Korean speakers with standard pronunciation. Each pair consisted of two very short pieces of words produced by the two speakers. The short pieces of words included intervocalic flap [ɾ], alveolar lax stop [d], alveolar aspirated stop [t^h], alveolar tense stop [t'], or geminate lateral [ll] between the preceding vowel [u] and the following vowel [i], e.g., [uɾi], [udi]. The same vowel editing procedures as those used for the AE stimuli were employed for the Korean stimuli. Thus, only 40 ms of each vowel was included in each token.

The stimuli consisted of 80 test items and 80 fillers. The test items contained 40 same items [5 consonants (ɾ, d, t', t^h, ll) x 2 speakers x 4 repetition] and 40 different items [5 contrasts ([ɾ-d], [ɾ-t'], [ɾ-t^h], [ɾ-ll], [d-t']) x 2 speakers x 4 repetition]. In the same pairs, no item was paired with itself since every pair consisted of two items produced by two speakers. In the different pairs, the last pair [d-t'] was included to check whether AE speakers had more difficulty discriminating allophonic variants of a native phoneme than pairs involving native and non-native phones possibly categorized as the same phoneme in L1. The fillers also consisted of 40 same items and 40 different items, and each item in a pair included [b], [p^h] [p'], [s] or [s'] between vowels. There was a 1500 ms interval between the two tokens in a pair, and a 3000 ms interval between the pairs.

The following are the stimuli used in this experiment. The words in parentheses are the words from which the stimuli were extracted. All the words are existing words except [put'i] since there is no existing Korean word including [t'] between [u] and [i]. Thus, [put'i] is a nonce word. A number beside each word indicates whether each word is an utterance of the first speaker or the second speaker, and whether the item is the first utterance r the second utterance of a speaker.

Table 5 Korean stimuli in the discrimination experiment

Stimuli (same, 2 x 5 x 4 = 40)		**Stimuli** (different, 2 x 5 x 4 = 40)	
1. uɾi–uɾi	(puɾi 11-puɾi 21)	11. uɾi–udi	(puɾi 11–pudi 21)
2. uɾi–uɾi	(puɾi 22-puɾi 12)	12. uɾi–udi	(puɾi 21–pudi 11)
3. udi–udi	(pudi 11-pudi 21)	13. uɾi–ut'i	(puɾi 12–put'i 21)
4. udi–udi	(pudi 22-pudi 12)	14. uɾi–ut'i	(puɾi 22–put'i 11)
5. ut^hi–ut^hi	(put^hi 11–put^hi 21)	15. uɾi-ut^hi	(puɾi 13-put^hi 21)
6. ut^hi–ut^hi	(put^hi 22–put^hi 12)	16. uɾi-ut^hi	(puɾi 23-put^hi 11)
7. ut'i–ut'i	(put'i 11–put'i 21)	17. uɾi-ulli	(puɾi 14-pulli 21)
8. ut'i–ut'i	(put'i 22–put'i 12)	18. uɾi-ulli	(puɾi 24-pulli 11)
9. ulli-ulli	(pulli 11-pulli 21)	19. udi-ut'i	(pudi 12-put'i 21)
10. ulli-ulli	(pulli 22-pulli 12)	20. udi-ut'i	(pudi 22-put'i 11)

All the stimuli were recorded onto the TEAC RW-800 CD recorder in a sound attenuated chamber. Each sound was saved as an AIFF file, and sound editing was conducted using the Praat program, version 3.9.3. Fade-in and fade-out effect was added using the Soundwave program. All the items were automatically randomized for each subject

The pairs in the present experiment were also chosen based on the phonological or allophonic relationship between items in each pair. The following table shows the phonemic and phonetic status of the phones in each pair used in the Korean stimuli.

Table 6 Phonemic status of the pairs of segments in the Korean stimuli

Korean pairs	Korean	AE
[ɾ] – [d]	**phonemic** difference (different phonemes)	**allophonic** difference (same phoneme)
[ɾ] – [t^h]	**phonemic** difference (different phonemes)	**allophonic** difference (same phoneme)
[ɾ] – [t']	**phonemic** difference (different phonemes)	**non-native** difference ([t']; non-native phone)
[ɾ] – [ll]	**partially (phonemic)** difference (same phoneme, but **phonemic** difference intervocalically)	**phonemic** difference (different phonemes)
[d] – [t']	**phonemic** difference (different phonemes)	**non-native** difference ([t']; non-native phone)

2.3.1.3 Procedures

The same procedures as those used for the previous perception experiment involving the AE stimuli were employed for this experiment. The subjects listened to 160 pairs of short pieces of naturally produced Korean words through the Psyscope program in the Macintosh computer using the AX paradigm. AE stimuli and Korean stimuli were counterbalanced across the subjects.

2.3.2 Results

Figure 3 and Table 7 display the mean discrimination sensitivity for each pair by the AE and the Korean speakers.

Whereas the Korean speakers did not show variation between the pairs in the Korean stimuli, the AE speakers showed considerable variation between the pairs. In general, the Korean speakers performed uniformly well on all the pairs. The AE speakers showed low sensitivity to the [ɾ-d] pair in the Korean stimuli as they did in the AE stimuli. Six out of twenty subjects' performance on this pair was extremely poor (d' = 0) (see Appendix D). AE speakers also showed low sensitivity to the [d-t'] pair, although their sensitivity to [ɾ-d] was much lower than that to [d-t'].

The data were submitted to a repeated measures ANOVA with groups (2 levels: AE vs. Korean speakers) as the between-subjects factor and pairs (5 levels: [ɾ-d], [ɾ-t'], [ɾ-t^h], [ɾ-ll], [d-t']) as the within-subjects factor. The results confirmed that there was a significant effect of pair [$F(4, 152) = 44.69$, $p < .001$], group [$F(1, 38) = 41.95$, $p < .001$], and pair x group interaction [$F(4, 152) = 28.75$, $p < .001$].

A one-way repeated measures ANOVA was conducted for the AE and the Korean speakers separately with pair as the within-subjects factor. On the one hand, for the AE speakers, the results showed a significant effect of pair [$F(4, 76) = 47.49$, $p < .001$]. Bonferroni post hoc tests showed that AE speakers' mean d' scores of the [ɾ-d] pair were significantly lower than those of all the other pairs ($p < .001$ for the comparisons of [ɾ-d] vs [ɾ-t'], [ɾ-d] vs. [ɾ-t^h], [ɾ-d] vs. [ɾ-ll]; $p < .01$ for the comparison of [ɾ-d] vs. [d-t']). In addition, the mean d' scores of the [d-t'] pair was significantly lower than those of three other pairs, [ɾ-t'], [ɾ-t^h] and [ɾ-ll] ($p < .001$ for all comparisons), and significantly higher than those of the [ɾ-d] pair ($p < .01$). On the other hand, for the Korean speakers, the results of a one-way repeated measures ANOVA revealed that pair was marginally significant [$F(4, 76) = 3.85$, p

= .007 < .05]. The follow-up Bonferroni post hoc test, however, did not reveal any significant difference between pairs (p > .05 for all comparisons).

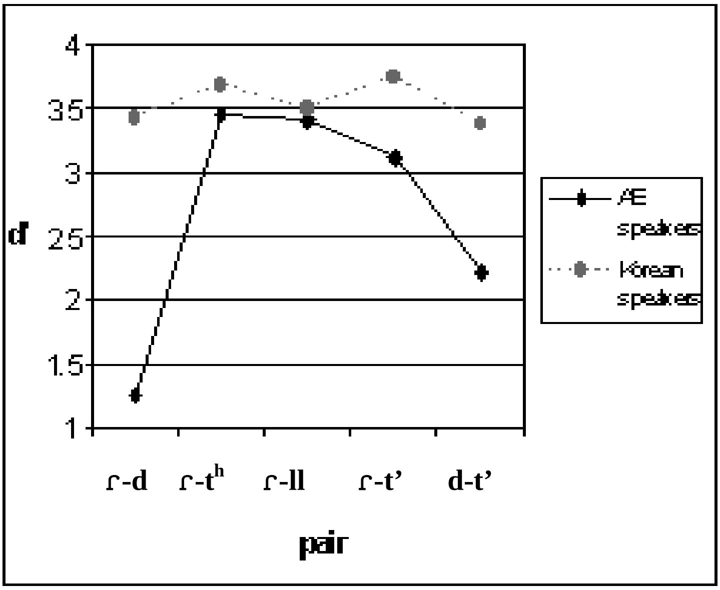

Figure 3 Distribution of mean sensitivity (d') functions for the Korean stimuli

Table 7 Mean sensitivity (d') functions for the Korean stimuli

Groups	Pairs				
	ɾ-d	ɾ-tʰ	ɾ-ll	ɾ-t'	d-t'
AE speakers	1.25	3.45	3.40	3.12	2.21
Korean speakers	3.43	3.69	3.49	3.73	3.37

In order to compare the groups for each pair in the Korean stimuli, a between-subject one-way ANOVA was conducted. The results showed that the Korean speakers performed better than the AE speakers on three pairs, [ɾ-d], [ɾ-t'], and [d-t'] [F(1, 38) = 68.17, F(1, 38) = 17.76, F(1, 38) = 24.62, respectively, p < .001 for all three pairs). The AE speakers' performance on [ɾ-tʰ] and [ɾ-ll] was as good as the Korean speakers' performance. The AE speakers, however, did not perform better than the Korean speakers on any pairs.

In order to compare the AE pairs and the Korean pairs for each group separately, paired t-tests were conducted. Only three pairs, [ɾ-d], [ɾ-tʰ], and [ɾ-l], were compared between the AE and the Korean stimuli since both the AE and the Korean stimuli included these three pairs, despite fine phonetic differences between the two sets of stimuli. The AE speakers did not show any difference between the AE and Korean stimuli regarding these three pairs (p > .05 for all three pairs). Their sensitivity to the [ɾ-d] pair was low in both the AE and Korean stimuli, and their sensitivity to the [ɾ-tʰ], and [ɾ-l] pairs was high in both sets of stimuli. By contrast, the Korean speakers showed a significant or marginal difference between the AE and the Korean stimuli regarding these pairs (p = .003 < .005 for [ɾ-d], p = .024 < .05 for [ɾ-tʰ], and p = .023 < .05 for [ɾ-l]). Their sensitivity to these pairs in the Korean stimuli was higher than in the AE stimuli.

2.3.3 Discussion

The overall results of the discrimination experiments show that an abstract phonological system, rather than the numerical values of the acoustic parameters, most strongly affects listeners' perception of sounds. Listeners show difficulty in discriminating between two sounds if the two sounds are not categorized as two separate phonemes in their L1 phonological system. For example, the AE speakers had difficulty with the [ɾ-d] pair in both the AE and Korean stimuli, and the [d-t'] pair in the Korean stimuli. In addition, the Korean speakers' performance was somewhat impaired with the [l-r] pair in the AE stimuli.

As noted above, the absence of presence of a sound in the L1 phonological system is not able to account for all the perceptual patterns observed. The hypotheses about perceptual difficulty based on the phonological relation of sounds were not verified in the results of the discrimination tasks involving the AE and Korean stimuli. It was predicted that in the Korean stimuli, the AE speakers would have difficulty in discriminating the sounds in both the [ɾ-t'] and [d-t'] pairs since each pair includes a non-native sound. Although their performance was impaired with the [d-t'] pair, they did not show any difficulty in the [ɾ-t'] pair. Further, it was expected that the AE speakers would have more or less the same degree of difficulty in discriminating the sounds in the [ɾ-d] and [ɾ-t^h] pairs. Their responses for these two pairs however, are very different. While they could not discriminate the sounds in the [ɾ-d] pair at all , their performance on the [ɾ-t^h] pair was as good as that on the pairs involving a native phonemic contrast.

The hypothesis regarding the Korean speakers' performance was also disconfirmed. That is, the Korean speakers performance on the [ɾ-ll] pair involving the partial phonemic difference was as good as that on the other pairs involving the full phonemic difference. Therefore, in both the AE and Korean stimuli, the phonemic or phonetic status of the sounds cannot predict the perceptual difficulty. In other words, the performance on the pairs involving an allophonic difference is not necessarily worse than that on the pairs involving a phonemic difference. In addition, the performance on the pairs involving a non-native difference is not always worse than that on the pairs involving an allophonic difference. Further, there is no difference in the performance between the pairs involving a partially phonemic relation and the pairs involving a fully phonemic relation.

Again, it seems that listeners do not hear a whole phoneme. They, rather, show sensitivity to a phonetic cue that is used for the contrastive features in their L1. The AE speakers could not detect the acoustic difference between [ɾ] and [d] at all in both the AE and Korean stimuli since in AE the acoustic difference between these sounds is never used to contrast meaning. In other words, the AE speakers could not perceive the difference of closure duration and VOT between these two sounds since closure duration is not a primary cue to distinguish stops in their L1. Although VOT is an important cue to the voicing contrast of AE stops, the VOT values of both [ɾ] and [d] are within a boundary that distinguishes between voiced and voiceless stops in AE. Thus, the AE speakers do not seem to be attuned to the difference of VOT if the VOT values of both sounds are below 30 ms.

The AE speakers also had difficulty with the [d-t'] pair in the Korean stimuli since [d] and [t'] are differentiated by the closure duration, and the closure duration is irrelevant in their L1 phonology. The Korean speakers' difficulty with the [l-r] pair can also be explained by their L1 phonological system since the acoustic cues to distinguish between these two sounds, such as lowering F3, are not used to contrast meaning in their L1.

The AE speakers' high sensitivity to the [ɾ-t^h] pair in both the AE and Korean stimuli is also explained by their sensitivity to a phonetic cue. These two sounds are acoustically different in terms of both VOT and closure duration. It seems that AE speakers are able to perceive the difference of VOT between [ɾ] and [t^h] since VOT is related to the phonemic distinction in AE. In addition, as mentioned in the previous section, we should reconsider the conception of "allophones". The relationship between allophones and underlying phonemes is not always the same. For example, in the present study, the relationship between [ɾ] and /d/ is different from that between [ɾ] and /t/. Whereas /d/ is flapped by just reducing the closure duration, /t/ undergoes an intermediate stage, neutralization, before the duration is reduced. Thus, although [ɾ] is an allophone of both /d/ and /t/, the process is different between the /d/ flapping and the /t/ flapping. It is assumed that this different process is also related to the different results in the perception of the [ɾ-d] and [ɾ-t^h] pairs.

The AE speakers' high sensitivity to the Korean [ɾ-t'] pair can be explained in two ways. First, although the AE speakers are insensitive to the durational difference in general, they may perceive the large difference of the duration. In the present stimuli, the closure duration values of [t'] are almost four times those of [ɾ]. The question of how much length difference affects the AE speakers' perception, however, is left to future study. Second, the AE speakers may perceive phonetic characteristics of Korean [t’] involving the [constricted] gesture. Although, in general, it is assumed that the [constricted] gesture is not employed in AE phonology, the gesture is not completely absent. According to Zue and Laferriere (1979), in the nasal-release context (i.e., V́Cn̩), the phonetic realization of [t] in *sweeten* is different from that of [d] in *Sweden.* That is, [t] is realized as a glottal stop by forming the constriction at the glottis, whereas [d] is released through the nasal cavity. Presumably, the experience of glottalization as the cue to distinguish /t/ from /d/ in this context, may help the AE speakers perceive the [constricted] gesture in the Korean tense alveolar stop [t’], enhancing their perception of the [ɾ-t’] pair.

Further, the perception of the phonetic characteristics of constriction in [t’] may facilitate the AE speakers’ performance on the Korean [d-t’] pair. That is, the AE speakers had more difficulty with [ɾ-d] than with [d-t’] in the Korean stimuli although they experienced difficulty with both pairs. It is not the case that acoustic differences in the [d-t'] pair are larger than those in the [ɾ-d] pair since the acoustic properties show that [ɾ] and [d] are distinguished by both closure duration and VOT, while [d] and [t'] are distinguished only by closure duration, and closure duration is not a primary phonetic cue in AE phonology. The AE speakers’ perception of the constriction cue may explain the difference in the sensitivity between the [ɾ-d] and [d-t’] pairs. In addition, the difference in the sensitivity between the [ɾ-d] and [d-t’] pairs may be attributed to the different perceptual patterns between the pair involving the native and non-native phones and the pair involving two allophonic variants. That is, in AE, [ɾ] and [d] are allophonic variants of the same phoneme, and the AE speakers have been routinely exposed to these phones. Thus, these sounds are completely categorized as one phoneme for them. It is, however, not clear whether [d] and [t'] are categorized as the same phoneme since [t'] is a non-native phone to AE speakers. It may be the case that [d] and [t'] are sometimes categorized as the same phoneme, and sometimes categorized as two separate phonemes, /d/ and /t/, respectively. Accordingly, the discriminability of [d-t'] is higher than that of [ɾ-d]. The very poor performance of the AE speakers on [ɾ-d] also indicates that simple exposure may not be sufficient to maintain discriminability.

The performance on the [ɾ-d] pair reveals the different perceptual sensitivity between the AE and Korean speakers to the durational difference. Further, it is speculated that the Korean speakers’ sensitivity to the durational difference facilitates the Korean speakers’ performance on the [ɾ-r] pair. Their sensitivity to this pair is also enhanced by the non-native phone, [r], since [ɾ] and [r] cannot be completely categorized as the same phoneme. It seems that both the AE and Korean speakers retain a certain sensitivity to the phonetic differences when they hear a pair including native and non-native phones.

The results of the experiments also indicate that in general L1 stimuli facilitate native speakers' performance. While in the AE stimuli, the Korean speakers did not perform better than the AE speakers on any pairs except [ɾ-d], in the Korean stimuli the AE speakers did not perform better than Korean speakers on any pairs. In addition, when three pairs, [ɾ-d], [ɾ-t^h], and [ɾ-l], were compared between AE and Korean stimuli for each group separately, Korean speakers performed better on all three pairs in Korean stimuli than in AE stimuli. AE speakers did not differentiate between AE and Korean stimuli. Korean speakers' different sensitivity to the two languages may be attributed to the fact that Korean speakers had learned AE for several years, and they were more sensitive to subtle acoustic differences between AE and Korean stimuli than AE speakers. AE speakers, however, had not experienced Korean before, and did not differentiate between the two kinds of stimuli.

In addition, it seems that subtle acoustic differences that may exist between AE and Korean flaps did not make any difference in the subjects’ performance on the pairs involving the AE and Korean flaps. It was not the case that the AE speakers had more difficulty in discriminating between flaps and alveolar stops in the AE stimuli than in the Korean stimuli since flaps are categorized as obstruents in the AE sound system. On the one hand, while the AE speakers showed low sensitivity to the [ɾ-d] pair in both the AE and Korean stimuli, their sensitivity to the [ɾ-t^h], and [ɾ-l]/[ɾ-ll] pairs was high in both kinds of stimuli. On the other hand, the overall Korean speakers' sensitivity to the three pairs, [ɾ-d, ɾ-t^h, ɾ-l/ɾ-ll], was high in both native and non-native stimuli, although their sensitivity to these pairs was a little higher in the Korean stimuli than in the AE stimuli. It seems that the Korean speakers’ better performance on these pairs in the Korean stimuli than in the AE stimuli may be attributed to the general effect of L1 stimuli, rather than to the fine acoustic differences between the AE and Korean flaps since the Korean speakers' performance on all the pairs in Korean stimuli is better than the AE speakers' performance.

In sum, the L1 phonological system plays a primary role in the discrimination tasks. The L1 phonemic inventory itself, however, is not able to account for all the perceptual patterns. Further, the phonological or phonetic relation between sounds does not predict the perceptual patterns of the sounds. It seems that both the AE and Korean speakers perceive phonetic cues if the cues are used in their L1 phonological system. While the Korean speakers show sensitivity to both VOT and closure duration, the AE speakers are only sensitive to the difference of VOT. In addition, the Korean speakers may use durational sensitivity to discriminate sounds such as [ɾ] and [r] although these sounds are categorized as one phoneme. Furthermore, the listeners' experience of sounds as allophonic variants does not facilitate their perception of those sounds. Also, in general, the L1 stimuli facilitate listeners' sensitivity to the sounds in discrimination tasks. Additionally, it seems that the subtle acoustic differences between the AE and Korean flaps do not affect the perception of the flaps. Finally, we should carefully reconsider the concept of allophones. The relationship between allophones and underlying phonemes varies in each case, and the term “allophones” is not able to cover the relationship.

3. Categorization experiments

3.1 Introduction

In this section, two additional perceptual experiments are described that investigate the role of the L1 phonological system. Specifically, two categorization tasks examine how listeners interpret acoustic signals according to their prior linguistic experience by comparing judgments of phonetically similar but phonologically different sounds.

The previous discrimination tasks showed how prior phonological learning affected the subjects' performance. The L1 phonological system, however, is not able to account for all the perceptual patterns. It seems that listeners perceive phonetic cues to features that are contrastively used in their L1.

The present categorization experiments explore whether or not the AE and Korean speakers categorize flaps as obstruents or sonorants regardless of acoustic similarity or difference between flaps and alveolar stops, or between flaps and liquids. Different patterns in categorizing flaps between the AE and Korean speakers would indicate the effects of their L1 phonological systems since in their L1 phonological systems flaps belong to different phonemic categories. Thus, we might expect that the AE speakers would categorize flaps as obstruents, and the Korean speakers as sonorants.

Further, the results of the categorization tasks are compared with those of previous discrimination tasks in light of multiple levels of representation in speech perception. Previous research shows that phonological processing is more involved in categorization or identification tasks than in discrimination tasks (Mann, 1986; Ingram & Park, 1998). It should be noted that in the present study, the results of the discrimination tasks cannot be directly compared statistically with those of categorization tasks since the types of stimuli were different in the two tasks. In the discrimination tasks, truncated stimuli were used, while in the categorization tasks, non-edited nonce words were used. The general perceptual patterns, however, can be compared between the two tasks.

If subjects showed the same perceptual patterns in the categorization and discrimination tasks, the percentage of the AE speakers’ categorization of flaps as “d” would be much higher than that of Korean speakers’ categorization of flaps as “r” or “l”. In the discrimination tasks, the AE speakers could not detect the acoustic difference between [ɾ] and [d], whereas the Korean speakers did discriminate the [ɾ-r] or [ɾ-l] pair. If the subjects, however, showed the different perceptual patterns in the discrimination and categorization tasks, and phonological processing was more apparent in categorization tasks than in discrimination tasks, AE speakers would categorize [ɾ] as "d", while Korean speakers would categorize [ɾ] as "r" or "l" despite their high sensitivity in discriminating flaps and liquids. We expect that phonological processing would be more obvious in the categorization tasks than in the discrimination task.

Furthermore, the categorization patterns of flaps between AE and Korean stimuli are compared. If the AE and Korean speakers show similar categorization patterns between the AE and Korean flaps,

i.e., categorizing both AE and Korean flaps as obstruents by AE speakers and categorizing both AE and Korean flaps as sonorants by Korean speakers, that would indicate that fine acoustic differences that may exist
between the AE and Korean flaps do not affect the subjects' perception of the flaps.

Previous research involving perception of flaps reveals that subjects from different linguistic backgrounds show different patterns in categorizing flaps. Monnet & Freeman (1972) indicate that AE flaps in the sentences, *he bit him; he beat him*, are interpreted as either liquids or stops depending on the listeners' linguistic backgrounds. Kim & Park (1995) found that the Australian English speakers transcribe Korean flaps in intervocalic position as the English retroflex approximant [r] rather than the English voiced alveolar stop [d] although English [d] is the closest counterpart of Korean flaps.

In the present experiments, not only flaps but also alveolar stops and liquids were included in the stimuli since alveolar stops and liquids are phonetically or phonologically related to flaps in these languages. When the subjects heard all these items – flaps, alveolar stops, and liquids – in the stimuli, they would detect some acoustic differences between the items more easily than when they heard only flaps in the stimuli although each item was presented separately. If acoustic differences between the items affect the speakers' perception, the percentage of the Korean speakers' categorization of flaps as liquids would not be high.

In Experiment 3, both the Korean and AE speakers heard AE flaps, alveolar stops (voiced and voiceless) and liquids between vowels in nonce words, and their task was to write down the nonce words with normal English spelling. The following results were expected. First, the AE speakers would categorize AE flaps as either "t" or "d" since flaps are allophonic variants of alveolar stops in the AE phonological system. The responses may be biased in favor of "d" rather than "t" since acoustic differences between the [ɾ] and [t] are larger than those between [ɾ] and [d]. Second, the Korean speakers would show a tendency to categorize AE flaps as AE liquid "r" or "l" rather than AE alveolar stop "d" or "t" since flaps are categorized as liquids in the Korean phoneme inventory, although the Korean speakers could discriminate between AE [ɾ] and [r], and between [ɾ] and [l] in the previous discrimination experiment. In addition, the responses would be biased in favor of "r" rather than "l" since in intervocalic position, AE "r" is mapped to the Korean flaps, whereas AE "l" is mapped to the Korean geminate laterals. This mapping is well known in loan words, e.g., *orange* [o.ɾɛn.ǰi], *olive* [ol.li.vɨ]. Since AE and Korean flaps are phonetically very similar, Korean speakers would map both AE flaps and [r] onto Korean flaps. Thus, it is assumed that the Korean speakers would connect AE flaps with AE "r" rather than "l".

Third, it was also expected that the Korean speakers would inconsistently categorize the AE retroflex approximant [r] as either AE "r" or "l" since [r] is a non-native phone for the Korean speakers. They, however, would more or less consistently categorize AE [l] as AE "l" since AE [l] has a phonetic model in the Korean phoneme inventory in intervocalic position. In a previous study, the Korean speakers' response pattern for a synthetic [r] and [l] continuum was highly biased toward "l" in an identification task (Komaki & Choi, 1999). In another study, however, Korean speakers did not show response preference for "l" when they identified a target sound in intervocalic position, e.g., *arrive* vs. *alive* (Ingram & Park, 1998).

In Experiment 4, both the Korean and AE speakers heard Korean flaps, stops (lax, aspirated and tense) and geminate laterals between vowels in nonce words, and the Korean speakers wrote down the nonce words with Korean spelling, and the AE speakers with English spelling.

First, it was expected that AE speakers would show a tendency to categorize Korean flaps as AE "d" or "t" rather than AE "r" or "l". Thus, regardless of the language used in the stimuli, the AE speakers would categorize flaps as stops. In addition, responses by AE speakers would be biased in favor of "d" rather than "t" for both AE and Korean flaps. Further, the percentage of AE speakers' categorization of Korean flaps as AE stops would be lower than that of their categorization of AE flaps as AE stops since when AE speakers hear Korean flaps, they would be influenced by foreign language experience. In general, flaps are categorized as sonorants, r-sounds in particular, rather than as obstruents (Maddieson, 1984)[2].

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[2] According to Maddieson (1984), laterals and r-sounds are grouped together as "liquids" in phonetic tradition, and trills, taps and flaps comprise the core membership of the r-sounds.

Second, it was expected that the Korean speakers would consistently categorize Korean flaps as Korean liquids when they were instructed to categorize Korean flaps using Korean spelling. Third, the AE speakers would categorize Korean [t'] as either AE "d" or "t" since [t’] is a non-native phone for them. Although the Korean alveolar lax stop [d] and aspirated [t^h] would be categorized as "d" and "t", respectively without confusion, tense [t'] would be mapped to either AE "d" or "t". In the previous task, AE speakers showed difficulty in discriminating the Korean [d-t'] pair since they could not perceive the difference of the closure duration. Thus, their categorization of Korean [t’] would be biased for AE “d” rather than “t”.

3.2 Hypotheses

The AE speakers categorize the flaps as alveolar stops, whereas the Korean speakers would categorize the flaps as liquids. In addition, both the AE and Korean speakers show inconsistent patterns in categorizing the non-native phones. Further, the influence of the L1 phonological system is greater in the categorization tasks than in the discrimination tasks.

3.3 Experiment 3: categorizing AE flaps, alveolar stops and liquids

3.3.1 Methodology

3.3.1.1 Subjects

The subjects were the same as those in the discrimination experiments. Twenty native speakers of AE (eight males and twelve females) who were undergraduate students at UD, and twenty native speakers of Korean (ten males and ten females) who were ELI students at UD, took part in this experiment. All of them participated in the present experiments after they completed the previous discrimination tasks. It should be noted that among the AE speakers who were originally recruited, six speakers who had substantial experience in Spanish (more than four years during high school and college) were eliminated from the previous and present experiments. Spanish has a flap (tap) which is acoustically very similar to AE flaps, and the Spanish flap is spelled as "r", so the subjects with significant Spanish experience may be influenced by Spanish spelling. This tendency was, in fact, observed in the pilot study. Another six AE speakers were recruited and they participated in the discrimination and categorization experiments.

3.3.1.2 Stimuli

The stimuli in the present study consisted of 40 test words and 40 fillers which were all nonce words in AE. The stimuli were produced by a female AE speaker with standard pronunciation. Nonce words were used to prevent the subjects' perceptions from being influenced by their familiarity with particular lexical items. The 40 test words included AE flap [ɾ], alveolar stops [d] and [t^h], and liquids [r] and [l] between various vowels, e.g., [niɾo], [fot^hu]. The preceding vowels were chosen among /i, a, o, u/, and the following vowels among /i, o, u/. The vowel [a] was excluded from the following vowels since words which end with [a] are very rare in AE. Approximately the same number of each vowel was used in both preceding and following vowels. The onset of each nonce word was chosen among the AE consonants with the exception of a flap, alveolar stops and liquids.

Since the stimuli were AE nonce words, the AE stress pattern was employed. In other words, AE flaps were produced between a preceding stressed vowel and a following unstressed vowel, whereas the AE alveolar stops [d] and [t^h] were produced between a preceding unstressed vowel and a following stressed vowel. AE liquids [r] and [l] were produced either with the preceding or following vowel stressed. The filler items included [s, z, b, p, g, k] between various vowels. The following are the stimuli used in this experiment.

Table 8 AE stimuli in the categorization experiment

	V_1 is stressed		V_2 is stressed			
(C)**V**ɾV	(C)**V**lV	(C)**V**rV	(C)Vl**V**	(C)Vr**V**	(C)Vt**V**	(C)Vd**V**
[faɾu]	[hilu]	[foru]	[nalu]	[mori]	[pʰitʰu]	[tʰido]
[niɾo]	[nalo]	[pʰuri]	[tʰilo]	[siro]	[fotʰu]	[hido]
[pʰuɾo]	[muli]	[saro]	[mulo]	[tʰuri]	[natʰi]	[fadu]
[miɾu]	[tʰoli]	[niru]	[kʰolu]	[huri]	[kʰutʰo]	[pʰodi]
[pʰaɾo]	[fulo]	[kʰori]	[sali]	[kʰaro]	[sutʰi]	[midu]
[tʰoɾi]						
[kʰoɾu]						
[saɾi]						
[hoɾu]						
[huɾi]						

All the AE stimuli were recorded onto the TEAC RW-800 CD recorder, and the recordings were digitized at 44.1 kHz sampling frequency and 16 bit resolution using the EAC software program. Each nonce word was saved as a separate AIFF file using the Praat program, version 3.9.3. The sound files were later converted using the SoundApp program and transferred to the PsyScope program, version 2.5.1. All the items were automatically randomized for each subject.

3.3.1.3 Procedure

Each subject was seated in a sound-attenuated chamber. All the subjects heard 80 English nonce words through headphones in the Psyscope program on a Macintosh computer. They were also told that they were listening to AE stimuli and they were instructed to write down each word with normal English spelling on the response sheet. All the words were randomized for each subject. Each target word was repeated after a pause of 1000 ms. The subjects heard the next item by clicking the mouse, and there was no fixed intertrial interval. After the experiments ended, the subjects had a brief informal interview with the experimenter about whether the task was difficult and whether they were influenced by foreign language spellings.

3.3.2 Results and discussion

The following figure and table show the percentage and frequency of responses for AE flaps by AE and Korean speakers.

The AE speakers show a strong tendency to categorize the AE flaps as an AE alveolar stop ("d" or "t") (93%), "d" in particular (85%), while the Korean speakers most often categorize the AE flaps as an AE liquid ("r" or "l") (86%), "r" in particular (77%). These results are consistent with those in previous perceptual experiments involving flaps (Monnet & Freeman, 1972; Price, 1981; Kim & Park, 1995), indicating that the L1 phonological system strongly affects subjects' performance.

The Korean speakers' responses are particularly interesting. The Koreans could distinguish between the AE flaps and AE liquids in the previous discrimination tests, showing that they were sensitive to the acoustic difference between AE [ɾ] and [r]. They were also familiar with the flapping of AE alveolar stops since they had studied AE for more than ten years in Korea, and were continuing their study of AE in the U.S. at the time they participated in the experiment. In addition, in a brief informal interview after the experiments, they told the experimenter that they were familiar with AE flaps used for “t” or “d”. They, however, still show a strong tendency to categorize AE flaps as AE liquids when the AE flaps were presented in an isolated nonce word. Thus, the differences in phonetic cues and knowledge of the AE flapping rule do not prevent the Korean subjects from categorizing AE flaps as “r”.

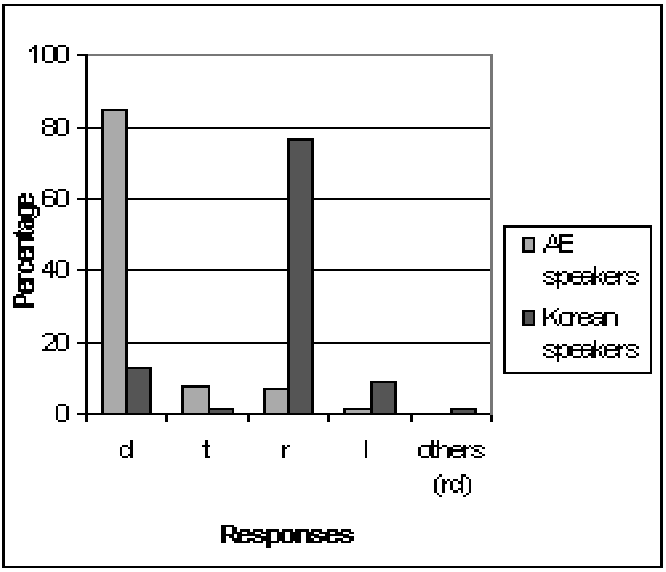

Figure 4 Percentage of responses in categorizing AE flaps

Table 9 Frequency of responses in categorizing AE flaps
(percentage in parentheses)

Responses	AE speakers	Korean speakers
d	169 (85%)	26 (13%)
t	16 (8%)	2 (1%)
r	14 (7%)	154 (77%)
l	1 (1%)	17 (9%)
others (rd)	0	1 (1%)

It seems that the two tasks, discrimination and categorization, demand different levels of perceptual processing, and phonological processing is employed more in the categorization task. The discrimination tasks, with the AX paradigm in particular, minimize memory load since the information from only two successive intervals needs to be stored. The categorization tasks, by contrast, involve matching a phone to internally stored abstract representations, and impose greater memory loads than discrimination tasks (Carney, Widin & Viemeister, 1977; Ingram & Park, 1998).

As expected, both the AE and Korean speakers had more "d" responses than "t" responses for the flaps. This result can be explained by the acoustic properties of flaps. In other words, flaps are acoustically more similar to "d" than "t" in terms of closure duration and VOT as was shown in the previous chapter. Although in AE both "d" and "t" are pronounced as flaps, the acoustic properties of flaps made the subjects biased for the "d" responses.

3.4 Experiment 4: categorizing Korean flaps, alveolar stops and liquids

3.4.1 Methodology

3.4.1.1 Subjects

The subjects were the same as those in Experiment 3.

3.4.1.2 Stimuli

The stimuli consisted of 30 test words and 30 fillers which were all nonce words in Korean. The stimuli were produced by a female Korean speaker with standard pronunciation. The 30 test words included the Korean flap [ɾ], alveolar plain stop [d], alveolar tense stop [t’] and alveolar aspirated stop [t^h], and geminate lateral [ll] between vowels, e.g., [niɾa], [sat^hi]. The vowels preceding and following the flaps, alveolar stops and laterals were /i, a, o, u/. The onset of each item was chosen among the Korean consonants with the exception of flaps, alveolar stops and liquids. Fillers included [p^h, b, k^h, g, s, n] between vowels. All the items were automatically randomized for each subject. The following are the stimuli used in this experiment. No specific stress patterns were employed in the Korean stimuli, as Korean does not contrast lexical positions for stress. Recording procedures were the same as those used in the previous categorization experiment.

Table 10 Korean Stimuli in the Categorization Experiment

(C)VɾV	(C)VllV	(C)VdV	(C)Vt^hV	(C)Vt’V
[saɾu]	[s’alli]	[idi]	[nat^hi]	[hut’i]
[p’iɾo]	[nallu]	[p^hadi]	[mut^ha]	[k^hit’o]
[muɾu]	[hullo]	[modo]	[ut^ho]	[nit’a]
[niɾa]	[k^hollu]	[k^huda]	[sat^hi]	[mot’u]
[k^hiɾo]	[polli]	[hidu]	[p^hot^hu]	[sut’a]
[t^haɾi]				
[p^hiɾu]				
[puɾo]				
[k^huɾi]				
[hiɾi]				

3.4.1.3 Procedure

The subjects heard 60 Korean nonce words through headphones presented in the Psyscope program on a Macintosh computer in a sound-attenuated chamber. They heard automatically randomized stimuli and were instructed to write down each word with normal English spelling (for AE speakers), or with normal Korean spelling (for Korean speakers) on the response sheets. Each word was repeated after a pause of 1000ms. The subjects heard the next word by clicking the mouse, and there was no fixed intertrial interval.

3.4.2 Results and discussion

The following figure and table show the percentage of responses for the Korean flaps by the AE and Korean speakers.

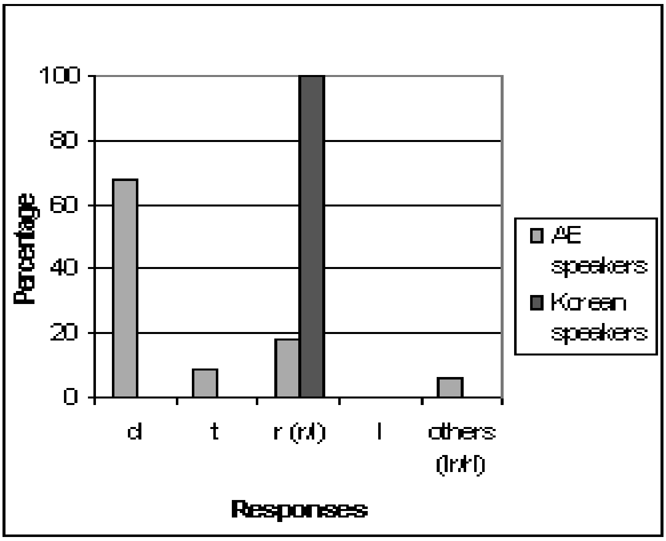

Figure 5 Percentage of responses in categorizing Korean flaps
cf) (r/l) = ㄹ , others= ‘dr’ or ‘rd’

Table 10 Frequency of responses in categorizing Korean flaps
(percentage in parentheses)

Responses	AE speakers	Korean speakers
d	136 (68%)	0
t	17 (9%)	0
r (r/l)	36 (18%)	200 (100%)
l	0	0
others (dr, rd)	11 (6%)	0

The AE speakers show a tendency to categorize the Korean flaps as the AE alveolar stops (77%), "d" in particular (68%). As expected, the Korean speakers always categorize the Korean flaps as the Korean liquid, The percentage of the AE speakers’ responses of alveolar stops for the Korean flaps is lower than that for the AE flaps (77% vs. 93%). Thus, the AE speakers’ responses for the Korean flaps are less consistent than those for the AE flaps although their responses are biased for the alveolar stops for both the AE and Korean flaps. The general patterns of the present results along with those in the previous experiments indicate that the L1 phonological system predominates over the acoustic properties of sounds in subjects’ performance in categorizing both the AE and Korean stimuli. It seems, furthermore, that the L1 phonological effect is more apparent in the native stimuli than in the non-native stimuli.

The following crosstabulation table combining the AE and Korean stimuli, shows the relationship for two variables, groups and responses. In the table, a separate section appears for each set of stimuli, one for the AE and the other for the Korean stimuli. The responses of "d" and "t" were merged into obstruents, and those of "r" and "l" were merged into sonorants. The responses merged into others, e.g., "dr" and "rd", were excluded from the table since the percentages of responses of 'other' were low in both the AE and Korean flaps.

Table 11 Stimuli * groups * responses crosstabulation

Stimuli	Group		Responses		Total
			obstruent	sonorant	
AE Flaps	AE	Count	185	15	200
		Expected Count	106.8	93.2	200.0
	Korean	Count	28	171	199
		Expected Count	106.2	92.8	199.0
	Total	Count	213	186	399
		Expected Count	213.0	186.0	399.0
Korean Flaps	AE	Count	153	36	189
		Expected Count	74.3	114.7	189.0
	Korean	Count	0	200	200
		Expected Count	78.7	121.3	200.0
	Total	Count	153	236	389
		Expected Count	153.0	236.0	389.0

In order to determine whether or not there was a relationship between variables in the table, and how strong the relationship was, statistical tests were conducted for the two types of stimuli (AE vs. Korean) separately. The chi-square tests show that there is a strong relationship between the two variables, groups and responses for both the AE and Korean stimuli [$\chi^2(1) = 246.56$ for AE stimuli, and $\chi^2(1) = 266.87$ for Korean stimuli, $p < .0001$ for both stimuli]. In both the AE and Korean stimuli, the AE speakers are more likely to categorize flaps as obstruents, and the Korean speakers as sonorants.

Although the AE speakers categorize both the AE and Korean flaps as obstruents rather than as sonorants, the percentage of categorizing the AE flaps as obstruents is higher than that of categorizing the Korean flaps as obstuents (93% vs. 77%). The following crosstabulation table shows the observed number of tokens and the expected number of tokens for two variables, stimuli and responses by the AE speakers.

Table 12 Stimuli * responses crosstabulation (by AE speakers)

Stimuli		Responses		Total
		obstruent	sonorant	
AE Flaps	Count	185	15	200
	Expected Count	173.8	26.2	200.0
Korean Flaps	Count	153	36	189
	Expected Count	164.2	24.8	189.0
Total	Count	338	51	389
	Expected Count	338.0	51.0	389.0

In order to examine whether or not there was a relationship between two variables, stimuli and responses by the AE speakers, and how strong the relationship was, another chi-square test was conducted. The chi-square test shows that there is a strong relationship between the two variables [$\chi^2(1) = 11.375$, $p < .005$]. That is, the AE speakers consistently categorized the AE flaps as obstruents, but their responses were inconsistent when they listened to the Korean flaps.

In a brief informal interview after the experiment, the AE speakers explained that they were more influenced by the spellings of foreign languages when they heard the Korean stimuli than when they heard the AE stimuli. In other words, they knew that the stimuli were not English when they heard the Korean stimuli. They sometimes provided obscure responses like "rd" or "dr" for the Korean flaps, while they did not provide such responses at all for the AE flaps. Although some AE speakers fluent in

Spanish were excluded from the experiments, many AE subjects still had some knowledge of foreign languages such as Spanish, German, or French. Thus, the difference in AE speakers' responses between AE and Korean stimuli might not reflect only the subtle acoustic difference between the AE and Korean flaps. Other factors may influence the AE speakers' responses for the Korean flaps as opposed to the AE flaps, including experience with foreign languages, difference in vowel quality between the AE and Korean stimuli, or difference between native and non-native stimuli in general. These factors were apparently more engaged in the categorization experiments than in the discrimination experiments, since in the discrimination tasks the AE speakers did not show any difference between the AE and Korean stimuli involving flaps. Since truncated stimuli were used in the discrimination tasks, the effects of the differences between the native and non-native stimuli were reduced.

4. General Discussion

4.1 Summary of this study

<u>Discrimination Experiments</u>

(1) Hypothesis

- Perceptual difficulty (from the least to the most)
  - i Phonemic difference (separate phonemes in L1) → least
    [ɾ-l]/[ɾ-ll], [ɾ-r], [l-r] for the AE speakers
    [ɾ-d], [ɾ-t^h], [ɾ-t'], [d-t'] for the Korean speakers
  - ii Partially phonemic difference (phonemic contrast in a context in L1) → less
    [ɾ-l]/[ɾ-ll] for the Korean speakers
  - iii Allophonic difference (allophonic variants in L1) → more
    [ɾ-d], [ɾ-t^h] for the AE speakers
  - iv Non-native difference (native vs. non-native phones) → most
    [ɾ-t'], [d-t'] for the AE speakers
    [ɾ-r], [l-r] for the Korean speakers

(2) Results

- The AE speakers show very low sensitivity to [ɾ-d] in both the AE and Korean stimuli. Their performance on the [d-t'] pair in the Korean stimuli is also impaired.
- The Korean speakers show a little low sensitivity to [l-r].

(3) Conclusions

- The L1 phonological system strongly affects the perception.
- Perceptual difficulty based on the phonological or phonetic status of sounds was not verified.
- Listeners are sensitive to contrastive phonetic cues.
  e.g., AE speakers are sensitive to the VOT cue (voiced/voiceless distinction)
  Korean speakers are sensitive to both the VOT and closure duration cues (aspirated/lax/tense distinction)
- Experiencing sounds as allophonic variants do not facilitate the discrimination of the sounds.
- Similar discrimination patterns are found between the AE and Korean stimuli.

<u>Categorization Experiments</u>

(1) Hypotheses

- The AE speakers categorize flaps as alveolar stops, whereas the Korean speakers categorize the flaps as liquids.
- The influence of the L1 phonological system is greater in the categorization tasks than in the discrimination tasks.

(2) Results

- The AE speakers categorize flaps as alveolar stops, "d" in particular, whereas the Korean speakers categorize the flaps as liquids, "r" in particular.
- The percentage of the AE speakers' categorizing flaps as alveolar stops is higher in the AE stimuli than in the Korean stimuli.

(3) Conclusions

- The L1 phonological system strongly affects the subjects’ categorizing flaps.
- More consistent responses are found for the native stimuli.
- The phonological processing is more involved in the categorization tasks than in the discrimination tasks.

4.2 Discussion of results

The overall results of the categorization tasks along with those of the previous discrimination tasks suggest that the L1 phonological system influence both tasks, though the categorization tasks are more influenced by the L1 phonological system than the discrimination tasks. In other words, the phonemic status of sounds takes precedence over acoustic discriminability in categorization tasks. For example, Korean speakers often categorized AE flap [ɾ] as AE retroflex approximant "r" although they could discriminate between AE [ɾ] and [r] in the discrimination test, and [ɾ] is acoustically more similar to [d] than to [r]. The greater effect of the L1 phonological system in the categorization tasks than in the discrimination tasks can be attributed to the difference of demand on memory load in the two tasks (Carney et al., 1977; Ingram & Park, 1998). Another possible explanation for the stronger effect of the L1 phonological system in the categorization tasks than in the discrimination tasks would be that vowel length in the stimuli is different in the present two tasks. Whereas in the present discrimination tasks, L1 phonetic information in vowels may be degraded due to the truncated stimuli, in the categorization tasks, no phonetic information involving vowels is missing.

In the discrimination tasks, the subjects’ performance cannot be explained by the phonological or phonetic status of sounds in the L1 phonological system. It is assumed that the subjects are sensitive to phonetic cues relevant to their phonology. If a phonetic cue is used for the contrastive features in their L1, listeners will perceive the phonetic cue without any difficulty. If the phonetic cue, however, is not related to any contrastive features in their L1, the listeners will have difficulty in perceiving the phonetic cue distinguishing between the two sounds. Although the AE alveolar flap [ɾ] is an allophone of both the voiceless alveolar stop /t/ and its voiced counterpart /d/, perceptual difficulty is shown only in the [ɾ-d] pair, but not in the [ɾ-t^h] pair. This difference appears to be due to the nature of the phonetic characteristics in the pairs. When we consider VOT, we find that the AE speakers have no difficulty in discriminating between the two sounds in the [ɾ-t^h] pair since there is a substantial difference in the VOT values in this pair, i.e., 1 ms vs. 100 ms in the AE stimuli. By contrast, the AE speakers have difficulty with the [ɾ-d] pair since the VOT difference is not large enough for them to perceive. In addition, they are not able to perceive the durational difference in the pair, since the durational difference is not used for any contrastive features in their phonology.

We speculate that the Korean speakers’ good performance on the [ɾ-r] pair is due to their sensitivity to the durational cue. Although these two sounds are categorized as the same phoneme in their L1, they do not show any difficulty in discriminating between the two sounds. In order to verify the Korean speakers’ use of the durational difference in discriminating between [ɾ] and [r], we may need perception experiments involving duration continua made from [ɾ] and [r].

These results are also consistent with findings that have shown that partially contrastive L1 features can be extended to new classes of sounds in the L2 (Brown, 2000). That is, the presence or absence of a feature in the L1 can explain the different performance on L2 contrasts among different language groups. For example, Chinese speakers’ ability to discriminate /l/ and /r/ can be attributed to the presence of the feature [coronal] in their L1, whereas Korean and Japanese speakers’ inability to perceive this contrast can be explained by the absence of the feature in their L1s. Since all three languages lack the /l/-/r/ phonemic contrast, the results cannot be understood as a direct consequence of L1 phoneme inventories. Brown argues that not phonemes, but features, guide the mapping process between the L2 input and the L1 grammar.

The results of the present study also indicate that experiencing sounds as allophonic variants may actually reduce the perceptibility of the sounds. Indeed, it seems that listeners pay more attention to a phonetic difference between native and non-native phones in a pair than between two allophonic variants of the same phoneme in their L1. As shown above, the AE speakers have no difficulty with the [ɾ-t'] pair, and their performance on the [d-t'] pair is significantly better than on the [ɾ-d] pair. These results cannot be attributed simply to the phonetic cues used in their L1 such as VOT since the VOT values of all three phones, [ɾ], [d] and [t'] are below 30 ms. Thus, listeners seem to detect a phonetic difference when the sounds involve native and non-native phones, while they fail to distinguish between allophonic variants whose differences that they have routinely ignored in their L1 phonology.

There is another factor that facilitates the AE speakers' performance on the pairs involving the Korean alveolar tense stop [t']. As mentioned in the previous section, the AE speakers' perceiving the [constricted] cue in this sound may enhance their performance on the [ɾ-t'] and [d-t'] pairs although they have some difficulty with the latter pair. That is, it seems that the AE speakers readily perceive the [constricted] cue since they have experienced this cue as the sole cue to the voicing contrast of the underlying phonemes in the nasal-released environment. Conversely, the AE speakers are not at all able to detect the difference between [ɾ] and [d] since they have never experienced the phonetic difference distinguishing between the sounds as a contrastive cue in their L1, and they have been trained to ignore the difference. .

In addition, the L1 phonological influence is stronger when the subjects hear the native stimuli than when they heard the non-native stimuli in the categorization tasks. For example, the AE speakers show more obstruent responses for the AE flaps than for the Korean flaps although their responses were strongly biased for obstruents for both the AE and Korean flaps. Although the AE speakers' performance is not different between the native and non-native stimuli in the discrimination tasks, they differentiate between the two kinds of stimuli in the categorization tasks. That is, they are aware that the stimuli are not the native language when they hear Korean stimuli in the categorization tasks.

In sum, the AE and Korean speakers' different perceptual patterns involving flaps clearly show that the L1 phonological system plays a dominant role in the perception of the sounds. They perceive sounds through their mental representation rather than on the basis of acoustic properties of the sounds. In addition, the subjects are generally sensitive to phonetic cues to features that are contrastively used in their L1 in the discrimination tasks. Further, their different perceptual patterns between the discrimination and categorization tasks indicate different underlying mechanisms for the two tasks. The precise picture of the interaction of acoustic, phonetic and phonological factors in the two tasks is a subject for future study.

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