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The effects of consonant contact constraints and syllable structure on speech perception in Korean assimilation contexts[*] [**]

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Sung, Eunkyung. 2018. The effects of consonant contact constraints and syllable structure on speech perception in Korean assimilation contexts. *Studies in Phonetics, Phonology and Morphology* 24.2. 147-172. This study investigated the effects of consonant contact constraints induced by L1 phonological rules and L1 syllable structure on speech perception in assimilation contexts. To this end, two Korean phonological rules (i.e. obstruent nasalization and lateralization) were tested, and three language groups (i.e. native Korean, English, and Chinese listeners) participated in a discrimination experiment. For obstruent nasalization, Korean listeners showed a clear compensation effect in a context-sensitive way, exhibiting much higher detection rates in the viable change context than in the unviable change context. However, English and Chinese listeners did not show a bias of compensation for the viable change context as clearly as Korean listeners. For lateralization, Korean listeners did not reveal language-specific compensation effects, and they showed low detection rates in both contexts. English listeners also discerned phonetic differences between [n] and [l] by showing very low detection rates in both contexts. On the other hand, Chinese listeners' performance was different from that of the other two groups. Chinese listeners' insensitivity to phonetic differences may be affected by highly restricted Chinese syllable structure in the coda position. Thus, it seems that speech perception involving assimilation contexts is strongly affected by L1 syllable structure along with consonant contact constraints and phonetic cues. **(Cyber Hankuk University of Foreign Studies, Professor)**

Keywords: syllable contact constraints, syllable structure, assimilation, obstruent nasalization, lateralization, perception, compensation

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1. Introduction

Assimilation is one of the phonological processes that change the acoustic or phonetic shape of speech sounds. Phonemes are modified and differently realized by the influence of adjacent sounds. For instance, the Korean word /pap/ (‘rice’) is pronounced as [pap] in the compound [pɑp.s’ɑŋ] (‘dining table’), but the same word is pronounced as [pɑk] in [pak.k’ɑp] (‘money for meals’) due to place assimilation. In addition, /pap/ is realized as [pɑm] in [pɑm.mɑt] (‘appetite’) due to nasalization.

Previous research has shown that when an assimilation rule is present in a native language, a compensation effect appears (Gaskell and Marslen-Wilson 1996, 1998, 2001, Mitterer and Blomert 2003, Mitterer et al. 2003, Lee 2005, Darcy et al. 2009, Key 2008, Sung 2018, and many others). When listeners compensate for assimilation, they recognize the original or canonical forms of words in assimilation contexts. For example, [grim] is recognized as ‘green’ in the phrase ‘green balls’ where coronal place assimilation is induced. Furthermore, Korean [kuŋ] is recognized as /kuk/ in the compound [kuŋ.mul] ‘soup’ where obstruent nasalization applies. If a different pattern is observed between native and non-native phonological processes, this will be evidence of using native language (L1) phonological knowledge.

It has also been shown that L1 syllable structure affects perception of second language (L2) (Carlisle 2001, Kabak and Idsardi 2007, Cheng and Zhang 2015). Kabak and Idsardi (2007) demonstrated that syllable structure restrictions rather than consonantal contact restrictions led to epenthetic vowels in perception of L2 speech. The authors compared the effects of consonant contact constraints due to L1 phonological rules and those of L1 syllable structure on L2 speech perception, but in their study they focused on epenthetic vowels rather than segmental perception. The present study investigated whether the stronger effect of syllable structure restrictions than that of consonant contact constraints on epenthetic vowels would be also shown in the perception of coda consonants. Cheng and Zhang (2015) found a strong effect of language experience at the syllable level alongside with phonetic and phonemic properties of individual consonants on L2 segmental perception and production.

The purpose of this study is to examine the effects of syllable contact constraints involving L1 phonological rules and L1 syllable structure constraints on the speech perception of consonant variability induced by assimilation. Much previous research on phonological assimilation has focused on the comparisons of compensation effects between L1 and L2 speakers. The effect of L1 syllable structure on perception in

assimilation contexts needs to be examined in order to explore factors affecting speech perception. In this study, two Korean phonological rules (i.e. obstruent nasalization and lateralization) were employed, and three language groups (i.e. native Korean, English, and Chinese listeners) took part in an AX discrimination experiment.

These three languages differ in phonotactic constraints in terms of distributional restrictions. In English except for /ŋ/ all other consonants are allowed to appear in the syllable-initial position. In the syllable-final position, except for /h/ all other single consonants appear. Also, two or three consonants can form clusters in the onset position (e.g. *pr-, bl-, spl-, str-*). Furthermore, maximally four consonants can appear together in the coda position (e.g. *-rp, -lt, -ŋθs, -mpts*). The inventory of coda structures in English is considerably richer than that of Korean or Chinese. In Korean and Chinese, consonant clusters are prohibited in either onset or coda positions. In Korean, among 19 consonants only seven (i.e. /p, t, k, m, n, ŋ, l/) are pronounced in the coda position. The other consonants undergo a neutralization process when they appear in coda. For example, /t, t', t^h, s, s', tʃ, tʃ', $tʃ^h$/ are neutralized as [t] in coda position. Thus, /k'otʃ/ ('flower') is pronounced as [k'ot]. In Mandarin Chinese (Chinese henceforth), only two nasal segments /n, ŋ/ are allowed in the coda position. The following table summarizes the syllable structure of the three languages.

Table 1. Syllable structure of three languages

Korean	English	Chinese
(C)V(C) coda: /p, t, k, l, m, n, ŋ/	(C)(C)(C)V(C)(C)(C)(C) singleton coda: all consonants except /h/	(C)V(C) coda: /n, ŋ/

As can be seen in Table 1, syllable structure in the coda position is much more restricted in Chinese compared to that of Korean or English. Moreover, in the syllable-final position, Korean has more restrictions than English.

In order to explore the effects of phonotactic constraints on speech perception in assimilation contexts, this study focused on two Korean phonological rules: obstruent nasalization and lateralization. The Korean obstruent nasalization rule turns coda obstruents into nasals before nasal segments across syllable boundaries, as shown in (1).

(1) Obstruent nasalization in Korean

a. nasalization of bilabials

/ɑpʰ.nɑl/ → [ɑm.nɑl] ‘future’
/pɑp.mɑs/ → [pɑm.mɑt] ‘appetite’
b. nasalization of coronals [1]
/k’o tʃʰ.mɑl/ → [k’on.mɑl] ‘flower language’
/pis.mul/ → [pin. mul] ‘rainwater’
c. nasalization of velars
/kuk.mul/ → [kuŋ.mul] ‘soup’
/hɑk.mun/ → [hɑŋ.mun] ‘learning’

There is another kind of nasalization in Korean, liquid nasalization. In liquid nasalization, the onset liquid /l/ becomes the nasal sound /n/ after the coda nasals /m, ŋ/ (e.g. /dɑm.lyək/ → [dɑm.nyək] ‘courage’). Furthermore, both the coda consonants /p, t, k/ and the following onset liquid /l/ become nasal consonants in phonetic forms (e.g. /kuk.lɑn/ → [kuŋ.nɑn] ‘national disaster’). This paper concentrated on obstruent nasalization and did not deal with liquid nasalization.

Korean lateralization is also a mandatory phonological process. The alveolar coda /n/ becomes the lateral /l/ when /n/ is followed by the lateral /l/. Also, the onset /n/ changes into the lateral /l/ when /n/ is preceded by /l/. The following shows examples of regressive and progressive assimilations for lateralization.

(2) Lateralization in Korean
a. progressive lateralization
/səl.nɑl/ → [səl.lɑl] ‘lunar New Year’s Day’
/kɑl.nɑl/ → [kɑl.lɑl] ‘knife blade’
b. regressive lateralization
/tʃin.li/ → [tʃil.li] ‘truth’
/nɑn.lo/ → [nɑl.lo] ‘heater’

Only regressive lateralization was examined in this paper. Both nasalization and lateralization rules are manner assimilation phenomena and obligatory processes in Korean phonology. Also, the transfer of native nasalization process has been noticed in

[1] In articulatory phonetics, English consonants are categorized as labials (i.e. bilabials and labiodentals), coronals (i.e. dentals, alveolars, palato-alveolars, and retroflex “r”), and dorsals (i.e. palatals and velars) (Rogers 2013)

L2 speech (Kim 2004, Zsiga 2011). For instance, Korean speakers pronounce 'pop music' as [pɑm.myuzɪk] due to nasalization, and 'Finland' as [fɪl.lænd] due to lateralization. A previous acoustic study (Zsiga 2011) found Korean speakers' categorical nasalization in L1 productions, whereas both categorical and gradient nasalization, along with a high degree of inter-speaker variation, in L2 English productions. Obstruent nasalization and lateralization do not appear in other languages such as English or Chinese. The following table demonstrates the status of two rules in three languages.

Table 2. The status of two rules in three languages

Language	Obstruent nasalization	Lateralization
Korean	(obligatory) /p, t, k/ → [m, n, ŋ] before a nasal consonant	(obligatory) /l.n/ → [l.l] /n.l/ → [l.l]
English	None	None
Chinese	None	None

In this paper, I attempted to examine the effects of two phonotactic constraints, consonant contact constraints and syllable structure constraints, on the speech perception in assimilation contexts. There were two specific hypotheses motivated by two phonotactic constraints.

If consonant contact constraints involving phonological rules such as nasalization and lateralization affected listeners' perception, Korean listeners would reveal higher detection rates in the viable change context than English or Chinese listeners since these two phonological rules exist only in Korean. Therefore, Korean listeners would show a compensation effect in a context-sensitive way involving the two phonological rules. For example, Korean listeners would often recognize the original consonant sequence /k.m/ in /kuk.mul/ 'soup' when they hear the surface consonant sequence [ŋ.m] due to obstruent nasalization. Conversely, English and Chinese listeners would not show such a compensation effect for either nasalization or lateralization, exhibiting similar low detection rates in both the unviable and viable change contexts.

On the other hand, if syllable structure of L1 rather than L1 phonological rules affected perception, Chinese listeners' perceptual patterns would be different from the other two listener groups. Since in Chinese only two consonants /n, ŋ/ are allowed in the coda position, Chinese listeners would have hard time distinguishing between the

coda consonants /k/ and /ŋ/ for obstruent nasalization or between the coda consonants /n/ and /l/ for lateralization regardless of phonological contexts. Compared to Chinese listeners, Korean and English listeners were expected to more often distinguish between /k/ and /ŋ/ and between /n/ and /l/ in the coda position in both the unviable and viable change contexts.

2. Literature Review

2.1 Perceptual compensation for assimilation

The issue of compensation for assimilation is whether compensation for phonological assimilation in L1 depends on language-specific knowledge of phonological processes. There are three major approaches to perceptual compensation for phonological variation: language-specific compensation mechanisms, universal compensation mechanisms, and lexical compensation mechanisms.

Language-specific compensation mechanisms propose that listeners would compensate for phonological variations caused by L1 assimilation rules (Gaskell and Marslen-Wilson 1996, 1998, 2001, Mitterer and Blomert 2003, Mitterer et al. 2003, Lee 2005, Key 2008, Darcy et al. 2009). Gaskell and Marslen-Wilson (1996, 1998) investigated the context effect in assimilation. They demonstrated that surface variation in speech were perceptually more acceptable when the modified form appeared in the contexts where the modification is induced by their L1phonogical rules. For example, native English speakers showed higher percentage of recognizing ‘freigh[p]’ as ‘freigh[t]’ in the viable context (e.g. freigh[p] bearer) than in the unviable context (e.g. freigh[p] carrier). Key (2008) also pointed out that the source of perceptual compensation in assimilation contexts was language-particular phonological knowledge. Darcy et al. (2009) tested two different phonological rules. One is coronal place assimilation that exists in English and the other is voicing assimilation that exists in French. Both English and French speakers revealed a higher degree of compensation for phonological variations involving rules existing in their L1 than rules that were not present in L1. Thus, English speakers showed a higher compensation rate for place than voicing assimilation, whereas French speakers showed a higher compensation rate for voicing than place assimilation.

Universal compensation mechanisms are based on acoustic or phonetic processes, and do not link to specific language experience (Lahiri and Marslen-Wilson 1991, Gow

2001, 2003, Gow and Im 2004, Weeldon and Waksler 2004). Gow (2001, 2003) proposed that feature cue parsing can account for coarticulatory compensation and compensation for incomplete assimilation. The assimilated sounds often include phonetic traces or partial cues of the original unassimilated form. Gow (2001) found compensation effect for place assimilation from coronals to labials, but not for place assimilation from labials to coronals. However, feature cue parsing may not work when assimilation is complete. Previous research has demonstrated that compensation effect appeared when tokens were intentionally produced with complete assimilation of the target sounds (Gaskell and Marslen-Wilson 1998, 2001, Mitterer and Blomert 2003).

According to lexical compensation mechanisms, incoming sound signals are matched with listeners' stored list of words, and the most relevant item is picked. In fluent speech, lexical recognition is so robust that listeners might not even detect mispronunciations by speakers (Marslen-Wilson and Welsh 1978, Samuel 2001). Lexical compensation mechanisms may explain part of phonological compensation effects, but they fail to account for compensation effects for nonce words. Many studies found results with nonce words that were parallel to those of real words, although the compensation effect was less robust (Gaskell and Marslen-Wilson 1998, 2001, Mitterer and Blomert 2003, Mitterer et al. 2003, Lee 2005).

2.2 Effects of consonant contact constraints and syllable structure restrictions on perception

Kabak and Idsardi (2007) investigate the effects of two phonotactic constraints on perceptual epenthesis in L2. They conducted an experiment that tested the perception of English consonant clusters by Korean speakers. Two kinds of phonotactic restrictions in Korean were employed. The first restrictions are syllable structure restrictions that prevent the occurrence of some consonants in the coda position (e.g. *[c.], *[g.]). The other restrictions are consonantal contact restrictions that prohibit the co-occurrence of certain consonants (e.g. *[k.m], *[l.n]) due to phonological processes such as nasalization and lateralization. The results showed that Korean syllable structure restrictions, rather than consonantal contact restrictions involving L1 phonological rules, induced the perception of epenthetic vowels. These findings suggest that the Korean phonological rules do not play a role in Korean listeners' adaptation of illicit consonant sequences. These results provide some evidence that the nasal/lateral contrast is robust even in the environment where the process of

lateralization eliminates the contrast.

Cheng and Zhang (2015) examined the effects of syllable structure differences between L1 and L2 on L2 consonant perception and production in syllable-initial and syllable-final positions. The results revealed significant positional asymmetry effects on perceptual performance. Chinese speakers performed significantly better in the syllable-initial position than in the syllable-final position in both perception and production of English phonemes. The results of previous studies indicate a strong effect of language experience at the syllable level along with acoustic and phonetic properties of individual consonants.

The present study compared the effects of consonant contact constraints and syllable structure constraints on speech perception in assimilation contexts. Previous research involving assimilation contexts has focused on compensation effects for assimilation by comparing detection rates between L1 and L2 listeners. In the present study the effects of two phonotactic constraints were compared by employing three different language groups. This study also considered phonological context type effects as did many previous studies on compensation for assimilation. The assimilated form of target tokens occurred in either an appropriate (viable change) context or an inappropriate (unviable change) context. Phonological context type effects are important since they reveal how the same sound can be perceived differently when its phonological context is considered. Additionally, a phonological context where the canonical form of target tokens surfaced without any change (no change) was included in order to make sure that the detection of the original sound was robust.

3. Method

3.1 Participants

Fifteen native Korean, twelve English, and fifteen Chinese participants took part in the discrimination experiment. One English participant did not complete the experiment and was dropped from the statistical analyses. The Korean participants were between 20 and 28 years old (9 women and 6 men). Six of them were undergraduate students, and the others were graduate students. None of them majored in English related fields such as English literature or English education.

The English participants were recruited from a university and an elementary school in the Seoul area. They were between 21 and 40 years old (6 women and 6 men). Five

of them were undergraduate or graduate students. Five of them were professors who taught English to Korean students. The other two of them were elementary school English teachers. Their Korean proficiency levels were considered intermediate or low based on their self-reporting in a questionnaire and a short interview before the experiment. Two of them had TOPIK (Test of Proficiency in Korean) scores, and their scores were 2 and 4 on a scale from 1 (lowest) to 6 (highest). Except for one participant who had lived in Korea for ten years, the other English participants had lived in Korea for less than three years at the time of experiment.

The Chinese participants were native speakers of Mandarin Chinese. They were between 20 and 28 years old (11 women and 4 men). Two of them were graduate students and the others were undergraduate students who majored in various subjects at a university in Seoul. All of them were learning Korean at the time of experiment. Ten of them had TOPIK scores, and their scores ranged from 1 to 4. All of them had lived in Korea for less than five years.

3.2 Stimuli

Two Korean phonological processes, obstruent nasalization and lateralization, were employed, and only regressive assimilation was investigated. The target tokens consisted of two sets of 120 items (i.e. the obstruent nasalization set and the lateralization set).

For obstruent nasalization, 120 target tokens (30 Korean real words, 30 Korean nonce words, 30 English real words, and 30 English nonce words) were selected. All the target tokens were monosyllabic with a (C)CVC(C) structure, and the coda consonants were bilabial, coronal, or velar segments. Each target token was associated with three context types: no change, unviable change, and viable change. For the no change context the original form of a target token occurred in the first part of the compound structure (e.g. [kok.sən] ‘curve’, [bʊk.sɛlər] ‘book seller’). For the unviable change context, the modified (assimilated) form of a target token occurred in the compound structure where the modification was not conditioned by the phonological process of nasalization (e.g. [koŋ. ʧəl] ‘reason’, [bʊŋ.seɪlz] ‘book sales’). For the viable change context the modified form of a target token occurred in the compound structure where the modification is conditioned by the phonological process of nasalization (e.g. [koŋ. mul] ‘grain’, [bʊŋ.mɑrk] ‘bookmark’).

For lateralization, stimuli were made with a similar process. Another 120 target

tokens (30 Korean real words, 30 Korean nonce words, 30 English real words, and 30 English nonce words) were selected. All the target tokens were monosyllabic with a (C)CVC structure, and the coda consonants were nasal segments. Each target token was associated with three context types: no change (e.g. [ʃin.sɑ] 'gentleman', [gʌn. ʃɑp] 'gun shop'), unviable change (e.g. [ʃil. tʃɑk] 'new work', [gʌl. tɑɹp] 'gun type'), and viable change context (e.g. [ʃil. lɑŋ] 'groom', [gʌl. lɔ] 'gun law'). In the viable change contexts, the second part of context tokens had the lateral [l] in the onset position that triggered regressive lateralization. The following tables present examples of Korean and English stimuli for obstruent nasalization and lateralization (see more examples in appendices).

Table 3. Examples of obstruent nasalization stimuli

Language	Word type	Target form		Context type		
		Original form	Changed form	No change	Unviable change	Viable change
Korean	Real words	go[**k**]	go[**ŋ**]	go[**k**] seon 'curve'	go[**ŋ**] jeol 'reason'	go[**ŋ**] mul 'grain'
	Nonce words	deo[**k**]	deo[**ŋ**]	deo[**k**] dang	deo[**ŋ**] shim	deo[**ŋ**] mo
English	Real words	shi[**p**]	shi[**m**]	shi[**p**] dip	shi[**m**] dog	shi[**m**] milk
	Nonce words	kroo[**p**]	kroo[**m**]	kroo[**p**] daff	kroo[**m**] tibe	kroo[**m**] moof

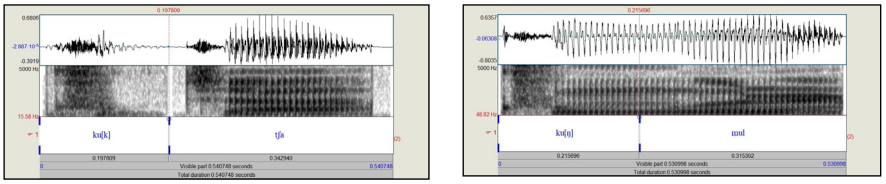
Table 4. Examples of lateralization stimuli

Language	Word type	Target form		Context type		
		Original form	Changed form	No change	Unviable change	Viable change
Korean	Real words	shi[**n**]	shi[**l**]	shi[**n**] sa 'gentleman'	shi[**l**] jak 'new work'	shi[**l**] lang 'groom'
	Nonce words	hu[**n**]	hu[**l**]	hu[**n**] jeom	hu[**l**] jam	hu[**l**] lan
English	Real words	gu[**n**]	gu[**l**]	gu[**n**] shop	gu[**l**] type	gu[**l**] law
	Nonce words	bru[**n**]	bru[**l**]	bru[**n**] shoch	bru[**l**] tyfe	bru[**l**] lawf

In total 720 stimulus items were created (120 target tokens * 3 phonological contexts * 2 phonological rules), and 360 filler items were added. Each stimulus item was made

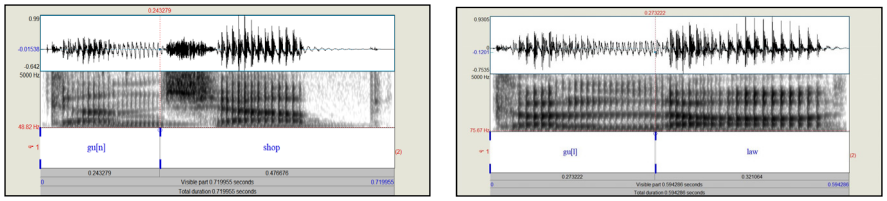
of a target token and context token (e.g. [ʃin], [ʃin.sɑ] ‘gentleman’). The Korean stimuli were recorded by two native Korean female and male speakers who had standard Seoul accents, and the English stimuli by two native English female and male speakers who had American accents. All tokens were recorded in a carrier sentence of “Nɑnɨn onɨl _____ mɑlhɑmnidɑ” for Korean stimuli, and “I’m saying _____ today” for English stimuli. All context tokens were made by splicing the target token syllable and the following context syllable (e.g. [ʃin.sɑ] ‘gentleman’), and two syllables in the token were from different recordings. All stimulus items were digitized at a sampling rate of 44,100Hz and saved as WAV files. The sounds were edited using the sound editing software *Praat* (Boersma and Weenink 2012).

Korean stimuli that were listed in the dictionary at National Institute of Korean language (http://www.korean.go.kr), and English stimuli that were listed in Corpus of Contemporary American English (https://corpus.byu.edu/coca), were used for this experiment. The following figures illustrate the waveforms and spectrograms of example items in Korean and English stimuli.



(a) ku[**k**] tʃɑ (b) ku[**ŋ**] mul

Figure 1. The waveforms and spectrograms of example items for obstruent nasalization in Korean stimuli



(a) gu[**n**] shop (b) gu[**l**] law .

Figure 2. The waveforms and spectrograms of example items for lateralization in English stimuli

3.3 Procedure

Each participant was tested in the AX discrimination task. They were told that they would hear real and nonce words in Korean or English separately. The experiment was run using *PsychoPy* software (Peirce 2007). Each participant heard 540 English items split into 4 blocks, and 540 Korean items split into 4 blocks. The participants heard the stimuli through Sennheiser PC330 headset at a comfortable intensity. Before the experiment, the participants had a practice session, and feedback was given to them during the practice session. The experimental trials consisted of a target token in isolation, followed by a 1500ms of silence, and then a context token. The following figure illustrates the procedure.

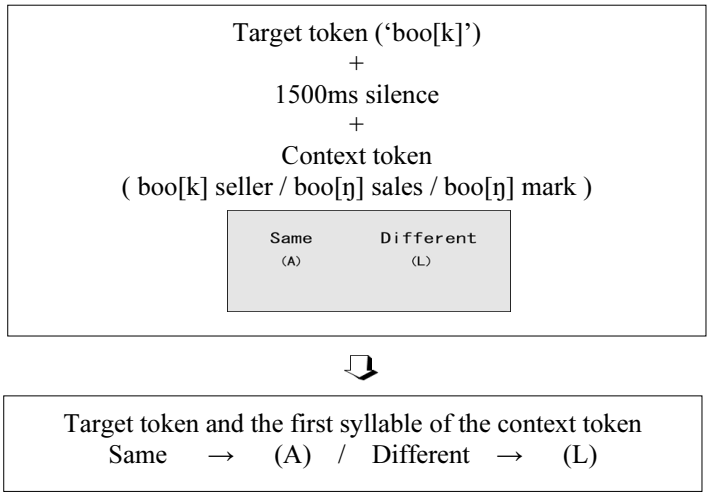


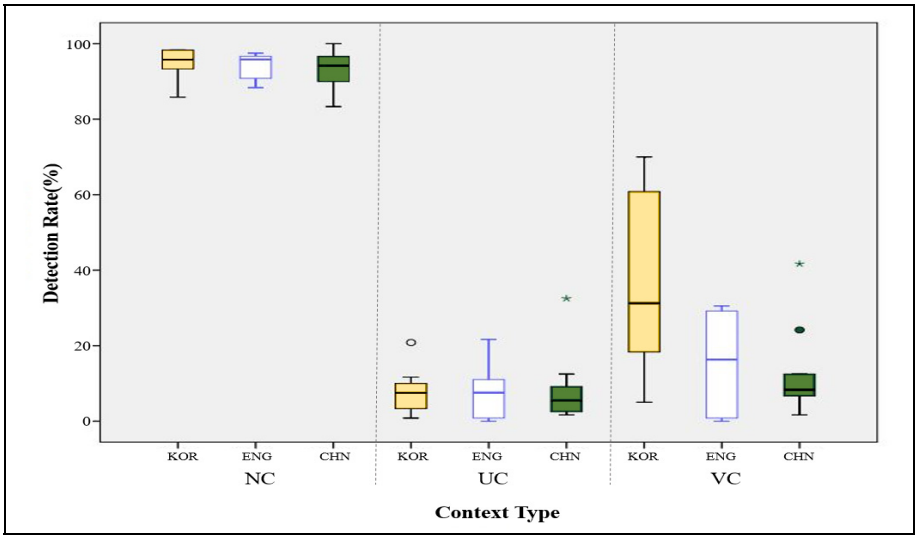
Figure 3. Procedure of the AX discrimination experiment

The participants were required to indicate whether the target token and the first syllable of the context token were the same or different by pressing 'A' for same, and 'L' for different on a keyboard.

4. Results

All the 'same' responses were collected to calculate the detection rates in three contexts. In the no change context, the original form of a target token was used, whereas in both unviable and viable change contexts, the modified form of a target token was used. Thus, the 'same' responses in the unviable and viable change contexts indicated that listeners were insensitive to phonetic differences between two sounds in the coda position. In other words, if listeners discerned the phonetic differences between the original form and the modified form of a target token (e.g. pea[k] vs. pea[ŋ]), they might provide low 'same' responses in both contexts. When detection rates of a target token were higher in the viable context (e.g. pea[k] in pea[ŋ] margin) than those in the unviable context (e.g. pea[k] in pea[ŋ] season), it was interpreted that listeners showed the compensation effect for assimilation.

The following boxplots display mean detection rates of three listener groups involving obstruent nasalization. Responses to real and nonce words, and Korean and English stimuli, were combined to compute detection rates.



(NC=no change, UC=unviable change, VC=viable change / KOR=Korean listeners, ENG=English listeners, CHI=Chinese listeners)

Figure 4. Mean detection rates for obstruent nasalization by three listener groups

As can be seen in Figure 4, all three listener groups revealed high detection rates in the no change context, suggesting that all of the listeners performed the discrimination task correctly. Conversely, in the unviable change context, all of the three groups showed low detection rates by perceiving phonetic differences between an original form and a changed form of a target token. In the viable change context, Korean listeners demonstrated higher detection rates and their detections rates were more spread out than those of the other two listener groups. The fact that the Korean listeners had higher detection rates in the viable change condition than the other listener groups is attributed to phonological compensation for assimilation, involving a language-specific phonological rule. Both English and Chinese listeners also showed a small difference between the unviable and viable change contexts, but their compensation effect was not as strong as that of Korean listeners.

The following table shows mean detection rates for obstruent nasalization based on listener group, stimulus language, word type, and context type, separately.

Table 5. Mean detection rates in nasalization (%)

Listener group	Stimulus language	Word type	Context type		
			No change	Unviable change	Viable change
Korean listeners	Korean	Real words	96.44	5.12	39.31
		Nonce words	95.56	6.00	35.78
	English	Real words	93.56	7.33	30.44
		Nonce words	92.22	8.00	24.22
	Average		94.44	6.61	32.44
English listeners	Korean	Real words	93.33	9.67	17.67
		Nonce words	94.67	13.75	23.26
	English	Real words	95.33	1.67	11.01
		Nonce words	93.67	5.07	7.00
	Average		94.25	7.54	14.74
Chinese listeners	Korean	Real words	93.57	5.71	7.86
		Nonce words	95.71	7.62	9.05
	English	Real words	93.57	9.05	15.99
		Nonce words	91.43	10.95	12.86
	Average		93.57	8.33	11.44

As shown in Table 5, the Korean listeners consistently revealed perceptual compensation for nasalization regardless of stimulus language (Korean vs. English

stimuli), and word type (real vs. nonce words). In other words, the Korean listeners were able to restore original unassimilated form in the viable context even when they were presented with a non-native speech or nonce words. However, the degree of compensation for assimilation was highest when they heard Korean real words. The English and Chinese listeners also revealed a little higher degree of compensation in the viable context than in the unviable context. These two listener groups, however, did not show a bias of compensation for the viable context as clearly as the Korean listeners. Specifically, the Chinese listeners did not reveal the obvious differences between the unviable and viable contexts in all conditions.

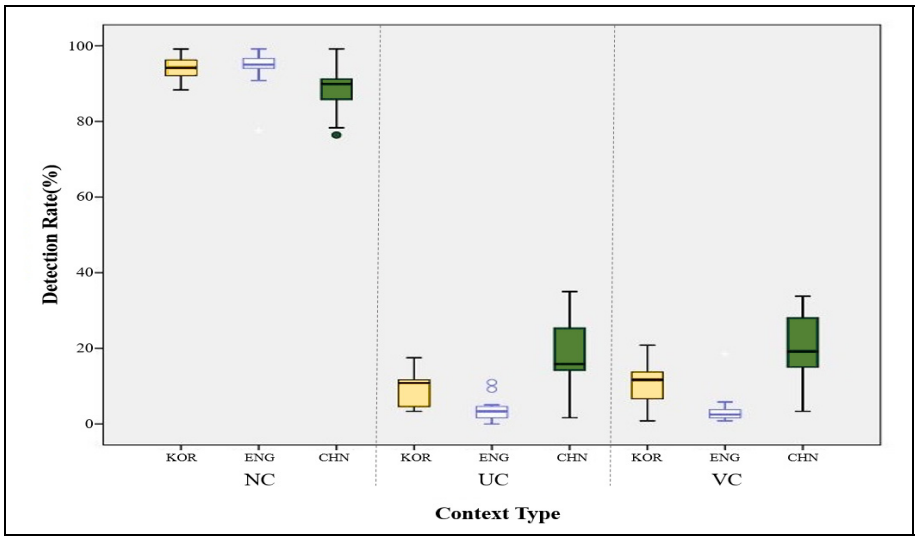
A repeated-measures ANOVA for detection rates in obstruent nasalization was conducted in order to examine the effects of the listener group and the phonological context. Listener group (Korean vs. English vs. Chinese listeners) served as the between-subjects factor, and phonological context (unviable change vs. viable change) as the within-subject factor. All the analyses were carried out using SPSS Statistics 22.

The results combined with word type (real words and nonce words) and stimulus language (Korean and English) showed that there was a significant effect of phonological context [$F(1, 39)=37.558$, $p<.0001$] and interaction between phonological context and group [$F(2, 39)=14.295$, $p<.0001$]. Furthermore, there was a significant effect of listener group [$F(2, 39)=3.307$, $p<.05$]. Post hoc paired comparisons confirmed that the Korean listeners behaved differently from Chinese listeners ($p<.05$). There were no significant differences either between the Korean and English listeners or between the English and Chinese listeners.

The following boxplots show mean detection rates of three listener groups involving lateralization. As can be seen in Figure 5, the Korean listeners did not compensate for lateralization in the viable change context, revealing similar detection rates for both unviable and viable change contexts. In other words, their compensation for assimilation was not biased for the viable change context. These results of lateralization were clearly different from the results of nasalization. The detection rates in the viable context were higher in nasalization than in lateralization (mean detection rate: 32.4% vs. 10.5%). The Korean listeners seemed to discern phonetic differences between nasal and lateral sounds involving lateralization. Their perception patterns were not affected by L1 phonological rule. Thus, consonant contact constraints due to L1 assimilation rule could not account for these results.

Similarly, the English listeners showed very low detection rates in both the unviable and viable change contexts. That is, they successfully discriminated all the original

form from the changed form of target tokens. Like Korean listeners, English listeners demonstrated higher detection rates in the viable change context of obstruent nasalization than lateralization (mean detection rate: 14.7% vs. 4.0%). Differences in phonetic cues between nasals and laterals involving lateralization were clearly perceived by both the Korean and English listeners.



(NC=no change, UC=unviable change, VC=viable change / KOR=Korean listeners, ENG=English listeners, CHI=Chinese listeners)

Figure 5. Mean detection rates for lateralization by three listener groups

On the other hand, the Chinese listeners' detection rates were much higher than those of the other listener groups in both the unviable and viable change contexts. In addition, the Chinese listeners' detection rates in lateralization were higher than those in nasalization in both phonological contexts. The Chinese listeners had hard time discerning phonetic differences between nasals and laterals. These results are consistent with those of previous research. Rogers and Dalby (2005), and Cheng and Zhang (2015) reported that the coda /n/and /ŋ/ sounds in English were a difficult contrast for Chinese ESL learners. Furthermore, Chen (2000) and Hsieh et al. (2009) pointed out that Chinese coda nasals could be a part of the syllable nucleus rather than the syllable coda.

The following table shows mean detection rates in lateralization based on listener

group, stimulus language, word type, and context type, separately.

Table 6. Mean detection rates in lateralization (%)

Listener group	Stimulus language	Word type	Context type		
			No change	Unviable change	Viable change
Korean listeners	Korean	Real words	97.62	9.78	15.48
		Nonce words	94.29	8.81	7.14
	English	Real words	93.57	12.62	11.90
		Nonce words	93.09	7.14	7.62
	Average		94.64	9.59	10.54
English listeners	Korean	Real words	92.71	4.85	3.98
		Nonce words	90.26	3.03	3.65
	English	Real words	97.58	3.66	3.65
		Nonce words	94.84	3.69	4.87
	Average		93.85	3.81	4.04
Chinese listeners	Korean	Real words	89.03	9.78	18.44
		Nonce words	86.89	9.56	19.11
	English	Real words	88.44	34.22	34.54
		Nonce words	91.70	34.15	33.23
	Average		89.02	21.93	26.33

Contrary to the results of obstruent nasalization shown in Table 5, Table 6 presents that Korean listeners did not demonstrate perceptual compensation for lateralization in all kinds of stimuli. Korean listeners showed similar detection rates in the unviable and viable change contexts in all kinds of stimuli except for the Korean real word stimuli. The effects of consonant contact constraints due to L1 phonological rules were not revealed for lateralization. Phonetic differences between /n/ and /l/ involving lateralization were so noticeable that Korean listeners did not need to use their knowledge of phonology to determine whether the change was licensed in a particular context. The English listeners also showed very low detection rates in both the unviable and viable change contexts regardless of stimulus languages or word types.

Interestingly, the Chinese listeners' results were different from those of Korean and English listeners. They showed different patterns between Korean and English stimuli. In Korean stimuli, they showed higher detection rates in the viable change context than in the unviable change context. Their compensation for lateralization in Korean stimuli could not be explained by consonant contact constraints because there was no

lateralization process in Chinese phonology. In English stimuli, the Chinese listeners showed relatively high detection rates in both the unviable and viable contexts. In other words, the Chinese listeners often responded that the target token in isolation (e.g. sca[n]) is same with the changed form of the target token in the context (e.g. sca[l] time). They seemed to have difficulties discerning phonetic differences between /n/ and /l/ in the coda position in lateralization. These results were partly accounted for by their L1 syllable structure.

A repeated-measures ANOVA for detection rates in lateralization was conducted in order to examine the effects of the listener group and the phonological context. The results combined with word type (real words and nonce words) and stimulus language (Korean and English) showed that there was no effect of either phonological context [$F(1, 39)=2.690$, $p>.05$] or interaction between phonological context and group [$F(2, 39)=1.351$, $p>.05$]. However, there was a significant effect of listener group [$F(2, 39)=15.076$, $p<.0001$]. Post hoc paired comparisons confirmed that the Chinese listeners behaved differently from both the Korean listeners ($p<.001$) and the English listeners ($p<.0001$). There was no significant difference between the Korean and English listeners.

The following table summarizes the statistical results of both nasalization and lateralization.

Table 7. Summary of statistical results

Phonological rules	Variables	
	Context type	Listener group
Obstruent Nasalization	$p<.0001$	$p<.05$ Post hoc paired comparisons Korean = English ($p>.05$) Korean ≠ Chinese ($p<.05$) English = Chinese ($p>.05$)
Lateralization	$p>.05$	$p<.0001$ Post hoc paired comparisons Korean = English ($p>.05$) Korean ≠ Chinese ($p<.001$) English ≠ Chinese ($p<.0001$)

As can be seen in Table 7, the effect of phonological context was shown only in nasalization. However, the effect of listener group was revealed in both phonological

rules, and the effect of listener group was much stronger for lateralization than for nasalization.

5. Discussion and conclusion

The main goal of this study is to examine the effects of consonant contact constraints induced by language-specific phonological rules and syllable structure restrictions on speech perception in assimilation contexts. Two phonological rules, Korean nasalization and lateralization, were tested with three listener groups, native Korean, English, and Chinese listeners, in an AX discrimination experiment.

The Korean listeners showed a clear compensation effect for obstruent nasalization, exhibiting much higher detection rates in the viable change context than in the unviable change context. The differences of detection rates between the viable and unviable change contexts by the English or Chinese listeners were not as robust as those by the Korean listeners. Statistical comparisons in obstruent nasalization showed that the results of the Korean listeners were significantly different from those of the Chinese listeners. The Korean listeners' higher detection rates in the viable change context than in the unviable change context can be attributed to language-specific compensation for assimilation involving the L1 phonological rule, obstruent nasalization, rather than language independent use of phonetic cues or L1 syllable structure. The two relevant sounds in obstruent nasalization, obstruents and nasals, are phonetically and acoustically distinct sounds. Nevertheless, the results that Korean listeners often recognized an original obstruent sound when they heard an assimilated nasal sound in the viable context suggest a strong influence of the L1 phonological rule.

However, language-specific compensation effects were not shown for lateralization. The Korean listeners exhibited similar low detection rates in both the unviable and viable change contexts involving lateralization. They were able to clearly distinguish /n/ and /l/ even in the viable change context where /n/-/l/ sequences are legally changed into /l/-/l/ sequences. In other words, the /n/ and /l/ contrast in the cod position was so robust to Korean listeners even in the context where the L1 phonological rule removed the contrast. Furthermore, the Korean listeners' performance seemed to be aided by the use of clearly articulated exemplars as stimuli. Thus, the Korean listeners easily perceived the phonetic differences between /n/ and /l/, and they were not influenced by the native phonological rule, lateralization.

It is likely that differences between obstruents and nasals are perceptually more

salient than differences between nasals and laterals. Nevertheless, the Korean listeners in the present study perceived phonetic differences between nasals and laterals more easily than those between obstruents and nasals. Consonant contact constraints due to L1 phonological rules did not affect the Korean listeners' perception involving lateralization. Presumably, obstruent sounds are not fully released in the coda position whereas nasal or lateral sounds are clearly articulated in the coda position. Therefore, the differences between the original form and the assimilated form in the coda position were less noticeable in the context of nasalization than in the context of lateralization to the Korean listeners.

In addition, the English listeners revealed even lower detection rates in both the unviable and viable contexts in lateralization than the Korean listeners. The results that the English listeners were highly sensitive to phonetic differences between /n/ and /l/ reflected the relative ease of the perception tasks for the English speakers.

On the contrary, Chinese listeners showed much higher detection rates than the other two listener groups in both phonological contexts, suggesting that they had a hard time discerning phonetic differences between /n/ and /l/ in the coda position. In other words, due to a highly restricted syllable structure in the coda position, Chinese speakers' perceptual performance was significantly different from the other two listener groups' performance. Although the nasal sounds /n/and /ŋ/ are permissible in the syllable-final position in Chinese, the Chinese speakers had difficulty perceiving the acoustic differences between /n/ and /l/. Similar findings were reported in previous research in which the coda /n/and /ŋ/ sounds in English were a difficult contrast for Chinese ESL learners (Rogers and Dalby 2005, Cheng and Zhang 2015). Cheng and Zhang (2015) pointed out that the coda /n/ and /ŋ/ sounds in English were a difficult contrast for Chinese ESL learners since the English /n/ and /ŋ/ sounds in the coda were not consistently matched with the Chinese /n, ŋ/ contrast in either perception or production. Aoyama (2003) also found that adult Japanese ESL learners showed considerable difficulty in distinguishing between /n/and /ŋ/ despite the fact that nasals are allowed in the coda position of Japanese.

Furthermore, previous research on the acoustic analysis of Chinese words and English loanwords (Chen 2000, Hsieh et al. 2009) indicated that Chinese coda nasals could be categorized as part of the syllable nucleus rather than a consonantal coda. Moreover, Tse (1992) and Lai (2012) reported the perception saliency hierarchy in discrimination between /n/ and /ŋ/ (i.e. [aN] > [əN] > [iN]). That is, the [in]-[iŋ] pair was the greatest challenges for Chinese speakers to discriminate. This perspective of

syllabification can partly explain the present results of Chinese speakers' poor performance on the perception of /n/ and /l/. In addition, He (2014) found Chinese speakers had great difficulties in producing syllable-final /l/. They used three strategies to change syllable-final /l/: vocalization, deletion, and retroflexion. Hansen (2001) also pointed out that the syllable-final /l/ was one of the most difficult consonants for Chinese speakers. Thus, the Chinese speakers in the present study showed very low sensitivity to the /n/and /l/ contrast in the coda position.

However, the effect of syllable structure restrictions in Chinese was not shown in perception involving obstruent nasalization. They revealed sensitivity to phonetic differences between obstruent and nasal sounds. It is presumed that in Chinese syllable structure obstruents are not allowed in the coda position, and this complete absence of obstruents in L1 enhances perceptual sensitivity to phonetic differences between obstruents and nasals.

The general findings of this study are consistent with previous studies showing the strong impact of syllable structure on speech perception (Eckman 1991, Carlisle 2001, Kabak and Idsardi 2007, Cheng and Zhang 2015). The structural difference at the syllabic levels between L1 and L2 revealed a direct impact on the perceptual accuracy of individual coda consonants.

In sum, although both nasalization and lateralization are native Korean phonological rules, Korean listeners' perceptual patterns are very different between these two rules. Moreover, despite high perceptual salience between /n/ and /l/ shown by the Korean and English listeners, the Chinese listeners demonstrated low sensitivity to the phonetic cues of these sounds. These results indicate that speech perception involving assimilation is not mainly driven by acoustic or phonetic cues, although phonetic cues cannot be ruled out. Speech perception in assimilation contexts is rather affected by consonant contact constraints due to L1 phonological rules and by L1 syllable structures.

Appendix A. Stimulus examples for obstruent nasalization

Language	Word type	Target Token	Target form		Context type		
			Original form	Changed form	No change	Unviable change	Viable change
Korean	Real words	국	[국]	[궁]	자	산	물
		복	[복]	[봉]	사	습	날

		꽃	[꼳]	[꼰]	씨	집	말
		앞	[압]	[암]	산	뒤	날
		집	[집]	[짐]	중	단	념
	Nonce words	먹	[먹]	[멍]	송	첨	문
		색	[색]	[생]	찬	작	망
		콧	[콛]	[콘]	신	삼	문
		입	[입]	[임]	숨	삼	망
		업	[업]	[엄]	정	충	물
English	Real words	cake	[keɪk]	[keɪŋ]	sales	shop	mix
		shock	[ʃɑk]	[ʃɑŋ]	time	sound	mark
		root	[rut]	[run]	shape	sign	node
		good	[gʊd]	[gʊn]	time	sense	night
		sheep	[ʃip]	[ʃim]	dip	dog	milk
	Nonce words	plobe	[ploʊb]	[ploʊm]	geem [gim]	dosp [dɑsp]	masp [mæsp]
		poog	[pʊg]	[pʊŋ]	selce [sɛls]	sheld [ʃɛld]	malk [mælk]
		treef	[trif]	[trim]	sheece [ʃis]	doog [dug]	mirt [mərt]
		sleed	[slid]	[slin]	soat [soʊt]	seesk [sisk]	nige [naɪdʒ]
		kroop	[krup]	[krum]	daff [dæf]	tibe [tɑɪb]	moof [muf]

Appendix B. Stimulus examples for lateralization

Language	Word type	Target Token	Target form		Context type		
			Original form	Changed form	No change	Unviable change	Viable change
Korean	Real words	권	[권]	[궐]	세	총	력
		논	[논]	[놀]	설	술	리
		반	[반]	[발]	성	숙	려
		신	[신]	[실]	사	작	랑
		훈	[훈]	[훌]	제	장	련
	Nonce words	권	[권]	[궐]	심	촌	령
		논	[논]	[놀]	성	중	로
		반	[반]	[발]	술	솔	뢰
		신	[신]	[실]	삼	잔	류
		훈	[훈]	[훌]	점	잠	란

English	Real words	scan	[skæn]	[skæl]	search	time	line
		keen	[ki:n]	[ki:l]	sense	sight	love
		gun	[gʌn]	[gʌl]	shop	type	law
		brain	[breɪn]	[breɪl]	size	death	life
		moon	[mun]	[mul]	shot	suit	light
	Nonce words	smoon	[smun]	[smul]	dat	tibe	lisk
		brun	[brʌn]	[brʌl]	shoch [ʃɑtʃ]	tyfe [tɑɪf]	lawf [lɔf]
		shren	[ʃrɛn]	[ʃrɛl]	dat [dɑt]	dage [deɪdʒ]	leesk [lisk]
		frain	[freɪn]	[freɪl]	sawk [sɔk]	shoth [ʃɑθ]	limge [lɪmdʒ]
		dren	[drɛn]	[drɛl]	shoth [ʃɑθ]	sooch [sutʃ]	lenge [lɛndʒ]

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