Perception and production of English geminate consonants across word boundaries by Korean learners and native speakers of English*

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Shin, Seung-Hoon, and Hwang, Young. 2012. Perception and production of English geminate consonants across word boundaries by Korean learners and native speakers of English. *Studies in Phonetics, Phonology and Morphology* 18.1, 85-110. It is well-attested that consonant length is not lexically distinctive in English. However, the status of English geminate consonants has been in controversy as to whether they are phonetically distinctive over word or morpheme boundaries. Despite the controversy, there have been few studies that compare singletons and corresponding geminates with identical phrases and explore how L2 learners acquire them. This study investigated how native speakers of English (NE) and native speakers of Korean (NK) differently pronounced and perceived English singletons and geminates across word boundaries using 17 minimal pairs of English phrases. The results were analyzed in terms of manners and places of articulation, and voicing, and examined the relationship between perception and production of singleton and geminate pairs. In Experiment 1: Production, NK was almost as good as NE in terms of consonant duration. In Experiment 2: Perception, NK had difficulty differentiating between singletons and geminates perceptually, showing poor accuracy rates. The results of these two experiments showed a clear discrepancy between NK's perception and production of the singletons and geminates across words and imply that production of such pairs be very loosely related to perception for NK learners of English. **(Yeungnam University)**

Keywords: perception, production, singleton, geminate, consonant length

1. Preliminaries

It is well-documented that consonant length is not phonetically distinctive within a root in English (Chen 1970, Kingston et al. 2009, Kluender et al. 1988, Raphael 1981). Hence, though the first syllable is considered phonologically ambisyllabic or moraic in Suprasegmental (Halle 1998, Halle and Vergnaud 1987) or Moraic Phonology (Hayes 1989, 1995), respectively, the words with two letters such as *happy, letter, summer*, *Lennon* and *collect* are articulated with a single intervocalic consonant. Results of phonological rule applications clearly verify this phenomenon. The words with intervocalic -tt- or -dd- (e.g., *latter, ladder*) behave as if they had a single intervocalic consonant and undergo flapping even though the rule applies to an intervocalic single alveolar stop. This becomes even

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clearer when we compare the phrase *it is* that can undergo flapping and *hit tomatoes* where flapping never applies. Namely, the two *t*s over a word boundary in *hit tomatoes* unlike *letter* never participate in flapping even though the word-initial syllable [tə] is unstressed. Also, failure of aspiration in such a word as in *happy* and *hockey* further shows that the words have only one stop since aspiration is optional when a voiceless stop follows another voiceless stop while intervocalic stop is never aspirated (Selkirk 1982).

Unlike English, however, many other languages distinguish a geminate from a singleton consonant within a root. The most noticeable phonetic contrast among many acoustic cues such as VOT is their duration: closure portion for stops and random noise for fricatives, etc. (Lahiri and Hankamer 1988). Hence, based on Ladefoged and Maddieson (1996), geminate stops have approximately 1.5-3 times the closure duration of single stops in careful speech. Famous examples that reveal phonetic contrasts between singletons and geminates include Madurese, Buginese and Toba Batak (Cohn et al. 1999). The ratios of singleton and geminate consonants in those languages are given in Table 1, 2, and 3.

Table 1. Mean closure durations (ms.) for Madurese singleton and geminate consonants and closure ratios (Cohn et al. 1999)

	Singletons	Geminates	Ratio
Voiceless stops	107	165	1:1.5
Voiced stops	85	145	1:1.7
Aspirated stops	112	159	1:1.4
Voiceless fricatives	131	162	1:1.2
Nasals	90	145	1:1.6
Laterals	85	153	1:1.8

Table 2. Mean closure durations (ms.) for Buginese singleton and geminate consonants and closure ratios (Cohn et al. 1999)

	Singletons	Geminates	Ratio
Voiceless stops	102	169	1:1.7
Voiced stops	68	116	1:1.7
Voiceless fricatives	138	192	1:1.4
Nasals	88	144	1:1.6
Laterals	84	151	1:1.8

Table 3. Mean closure durations (ms.) for Toba Batak singleton and geminate consonants and closure ratios (Cohn et al. 1999)

	Singletons	Geminates	Ratio
Voiceless stops	58	114	1:2.0
Voiced stops	38	119	1:3.2.
Voiceless fricatives	76	132	1:1.7
Nasals	56	111	1:2.0
Laterals	53	108	1:2.0

Unlike the geminates within a root in English and phonetically distinctive geminate consonants in other languages, there has been a lot of controversy on phonetic contrast between singleton and geminate consonants over a word boundary in English. According to Kaye (2005: 45), degemination occurs in informal rapid speech; *white tie* sounds very much like *why tie*, and *gray tomb* sounds like *great tomb*. Also, Giegerich (1992: 288) notes that sequences of identical consonants at word and morpheme boundaries are usually simplified in connected speech (e.g., *bus-stop, weight-training, call Linda*). On the other hand, Kenyon (1977: 51) maintains that double consonants are often distinctive, as in *I do*, *I'd do*; *I owe none*, *I own none*; *I'm Ike, I'm Mike*; *top up*, *top pup*; *with a man*, *with the man*. Kreidler (2004: 116) also observes that when two instances of the same consonant come together, there is only one onset and one release; the hold lasts as long as two consonants as seen in the example of *home-made*. Similarly, Gussman (2002: 26-7) indicates that geminated [nn] appears phonetically in the examples of *ten names* and *tin knife*.

Despite these controversies, there have been few studies which systematically compared singleton and corresponding geminate consonants using minimal pairs. Moreover, there has been little research that investigated how nonnative speakers of English perceived and pronounced English singleton and geminate consonants. The goals of this study are three-folds. First, with regard to production, this study will investigate whether consonant length is phonetically distinctive in English. Second, it will explore how native speakers of English (NE) and native speakers of Korean (NK) differently perceive and pronounce such a geminate across words. Finally, this research will try to elucidate how perception and production of English geminate consonants across words are related to each other for the NK learners of English.

2. Methods

2.1 Subjects

The participants were 20 NK students majoring in English at a university

in Korea, ten males and ten females ranging in age from 19 to 27 years - mean age, 22.75 and three NE, born and raised in the United States who are teaching English at a university in Korea. The NK students were all born in Gyeongsang-do and spoke the Gyeongsang dialect. Also, as English majors, their English fluency might be better than the average Korean learners of English. 24 NK and four NE speakers originally participated in this study; however, the data from four Korean subjects and one native speaker were excluded either because of a recording error or difficulty in measuring. All the NK subjects had never lived in English-speaking countries. None of the participants reported any history of speech or hearing impairment at the time of testing.

2.2 Stimuli

The stimuli consisted of 17 minimal pairs of English phrases which included singleton and corresponding geminate consonants across words. The stimuli contained each voiced and voiceless sounds of stops, fricatives, affricates, laterals, and nasals. Three pairs of singleton and geminate voiced stops and the same number of voiceless stop pairs were chosen. In addition, three singleton and geminate pairs of each voiced and voiceless fricative, two pairs of affricates and nasals, and a pair of laterals were selected. To sum up, the stimulus list included 12 stops, 12 fricatives, 4 affricates, 4 nasals, and 2 laterals, totaling 34 phrases in all.

Since other factors such as stress, syntactic category, or speech rate could affect the length of each consonant, we tried to control the factors as much as possible. First of all, the participants were asked to read the phrases stressing the first words to prevent the durations from being affected by different stress. Moreover, in order to hinder the consonants from being influenced by different speech rate, the participants were instructed to produce at a constant rate (allegro, 120 bmp) via an electronic metronome (Storm Software's Professional Metronome, Version 1.9). Lastly, we tried to match the syntactic category (e.g., noun phrase, verb phrase) of each member of the pair as much as possible, but not all of them could be matched.

Also, in order to examine the one-to-one relationship, the same stimuli were used for both the perception and production tests. The following Table 4 shows the target items used for this study.

Table 4. Data[1]

	Singletons	Geminates
Stops	tie pumas	type pumas
	bay boy	babe boy
	buy toys	bite toys
	may drink	made drink
	lie kiss	like kiss
	law green	log green
Fricatives	be free	beef free
	dry vine	drive Vine
	rye seed	rice seed
	wry zoo	rise zoo
	tea thing	teeth thing
	sue this	soothe this
Affricates	ben chum	bench chum
	char jeep	charge jeep
Lateral	see leaf	seal leaf
Nasals	tea milk	team milk
	Cuba nail	Cuban nail

2.3 Experiment 1: Production

For the recording, the participants were asked to put each phrase in a conveyer sentence, "Say _____ again" and read it two times. Between the two readings, the second productions were used in this experiment. Since the number of NE was less than the number of NK, all the productions of the NE were utilized for a statistic purpose. The participants were given enough time to practice the stimuli to prevent making mistakes and were instructed beforehand to read the phrases naturally without inserting vowels between the words. They were asked to read the phrase again if it was wrongly produced. All phrases were given to the participants without titles of types and were shuffled using Excel. The recordings were made in a quiet room, using a Senheiser PC 166 headset and a Sony PCM-D50 recorder at the sampling frequency of 44,100 Hz. Each sound was saved as a wave file.

[1] Excluded in the data were the sounds that cannot appear in the onset (e.g., voiced postalveolar fricative and velar nasal) in English. The alveolar approximant /r/ is also excluded since its phonetic property might vary depending on the syllable position; the alveolar approximant in an onset may be labialized while the one in a coda is not.

2.4 Experiment 2: Perception

The perception data were recorded by a female NE and were confirmed by the two other NE who participated in this study. The participants were tested individually. They were instructed to listen to the stimuli through headsets and were told to choose the phrases they heard on the answer sheet. The phrases were randomized so that the phrases in the same pairs did not appear one after the other. The carrier sentence started with "What I said was ~," and the interstimulus interval was fixed at five seconds using Praat (Ver. 5.1.38). The participants were asked to respond to all the questions and were told to guess if uncertain. The multiple choice test consisted of 34 questions with three possible answers each, one of which was a filler; those who picked a foil answer were excluded from the analyses. Since the number of NE was less than the number of NK, the perception results of three NE were doubled for statistical analyses.

2.5 Measurements

Employed for acoustic analyses were 680 tokens produced by NK and 204 tokens by NE. All measurements were taken by hand with Praat. We first measured the duration[2] of a singleton and a corresponding geminate based on both waveform and spectrogram displays for precise boundary locations and measurements. The duration of a singleton or a geminate stop was measured from the stop gap to the voicing onset. This included the stop gap, the transient (a short burst of acoustic energy), frication and aspiration[3]. As for duration of fricatives, the random noise portions were measured. Duration of affricates was also measured from the stop gap to the onset of voicing. The durations of liquids were more difficult to measure because of their transient nature. The starting and endpoints of the laterals were perceived by low F2 and high F3. As Lee and Kang (2003) observe, given that formants of the lateral are heavily influenced by the neighboring vowels, we also checked formants of the vowel and measured the steady faint spectrograms with low F2 and high F3 including faint onset and offset periods. For a singleton and geminate nasal, we measured the nasal murmur marked by less energy than surrounding vowels and

[2] Even though the acoustic features of geminate consonants have been confirmed through various clues, not all of the acoustic features have been recognized as markers of geminates. For instance, although VOT and the duration of the following vowel obviously distinguish singletons and geminates in Turkish and Bengali respectively, they cannot be the main acoustic features, since the length of VOT and V1 does not only optionally observed in some participants, but also occurs independently in other languages. Following Lahiri and Hankamer (1988), this paper mainly concentrated on the aspect of duration, which has been verified as the universal acoustic cue.

[3] Following Kent and Read (2002: 144) who propose that the perceptual cue for the identification of stop includes the sequence of a stop gap, a burst, an aspiration interval and a formant transition, we measured duration of such a sequence.

imprinted by the first formant.

3. Results of Experiment 1: Production

3.1 Overall results

The average durations of each singleton and geminate consonant produced by NK and NE are shown in Figure 1.

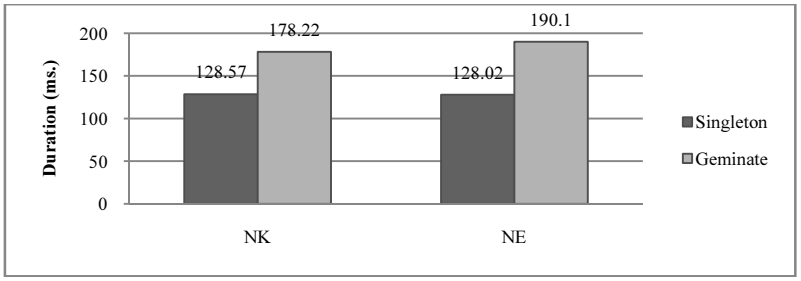


Figure 1. Mean durations (ms.) of singletons and geminates by NK and NE

There was a considerable difference between mean durations of singletons and geminates for both groups. It is interesting to note here is even though the durations of singletons both by NK and NE were almost the same, the two groups showed differences with regard to the durations of geminates.

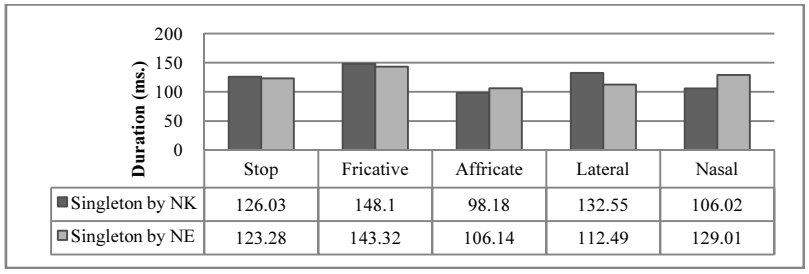
In order to analyze the results statistically, a repeated measure ANOVA was carried out. The results indicated that there was a significant difference between the durations of singletons and those of geminates when read by NK (Wilks' $\lambda[3.21]=280.851$, $p=.000$), and the comparison between the singleton and geminate durations by NE was also significant (Wilks' $\lambda[3.21]=264.937$, $p=.000$). These results demonstrated that geminates by NK and NE were significantly different from their singleton counterparts in duration. In order to compare durations of each singleton and geminate consonant between NK and NE, we conducted a t-test. No significant difference was found to exist between the singleton durations ($t=.102$, $df=440$, $p=.918$). However, the geminate durations between NK and NE was significantly different ($t=-1.749$, $df=440$, $p=.040$).

3.2 Production results by manners of articulation

In order to investigate whether manners of articulation have an equal influence on singleton and geminate consonants over a word boundary, we examined the differences in the mean durations and the divergences of the ratios between singleton and geminate consonants in the respective manners of articulation.

3.2.1 Singleton consonants

The following table in Figure 2 presents the mean durations of each singleton depending on the manner of articulation.



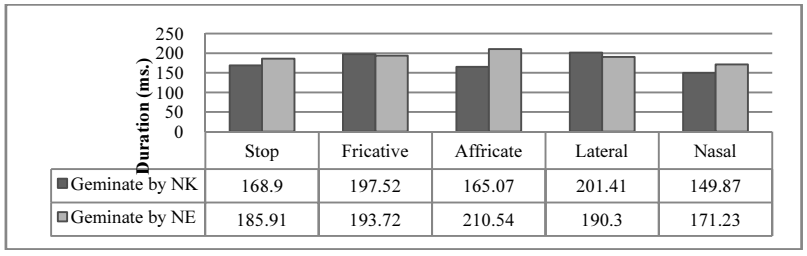
	Stop	Fricative	Affricate	Lateral	Nasal
Singleton by NK	126.03	148.1	98.18	132.55	106.02
Singleton by NE	123.28	143.32	106.14	112.49	129.01

Figure 2. Mean durations of singletons by NK and NE

The durations of singletons by both groups were nearly similar. There was no significant difference between single stops by NK and NE (t=.269, df=154, p=.789), nor between fricative singletons (t=.670, df=154, p=.504). In addition, durations of affricate singletons between NK and NE were not significantly different (t=-.773, df=50, p=.443). Similarly, the results of lateral singletons between the participants indicated that there was no statistical difference (t=1.520, df=24, p=.141); however, the durations of nasal singletons by NK and NE produced a significant result (t=-2.616, df=50, p=.012)[4].

3.2.2 Geminate consonants

The following table in Figure 3 illustrates the mean durations of each geminate consonant depending on the manner of articulation.



	Stop	Fricative	Affricate	Lateral	Nasal
Geminate by NK	168.9	197.52	165.07	201.41	149.87
Geminate by NE	185.91	193.72	210.54	190.3	171.23

Figure 3. Mean durations of geminates by NK and NE

[4] This might be because NK have a relatively shorter voicing period for word-initial nasals compared to the corresponding nasal productions by NE.

There was no considerable difference between the mean durations of geminates by NK and NE on the whole; however, the mean durations by NE looked a little longer. The results from t-tests showed that geminate stops by NK and NE did not differ significantly (t=-1.335, df=154, p=.097), and the comparison between the NK and NE also had no significant difference in fricative durations (t=.362, df=154, p=.718). However, the difference between the two groups was significant in the durations of affricate geminates (t=-2.143, df=50, p=.037). The lateral geminates were not significantly different from each other (t=.526, df=24, p=.604), and the same was true for the result of nasal geminates (t=1.520, df=24, p=.061).

3.2.3 Discussion

The overall results revealed that the NK participants produced both singleton and geminate consonants similarly as NE did in terms of consonant duration. This might result from the fact that they are currently majoring in English. Although there was no significant difference in the mean durations between the groups, we compared the ratios of singletons and geminates to discern the dissimilarities as illustrated in Table 5.

Table 5. Mean durations and the ratios by NK and NE

	Singletons/ NK	Geminates/ NK	Ratio	Singletons/ NE	Geminates/ NE	Ratio
Stops	126.03	168.90	1 : 1.4	123.28	185.91	1 : 1.7
Fric.	148.10	197.52	1 : 1.3	142.32	193.72	1 : 1.4
Affr.	98.18	165.07	1 : 1.7	106.14	210.54	1 : 2.2
Laterals	132.55	201.41	1 : 1.5	112.49	190.30	1 : 1.7
Nasals	106.02	149.87	1 : 1.5	129.01	171.23	1 : 1.4

As shown in the ratios produced by NE, the mean duration for the affricate geminates was more than twice as long as that for the affricate singletons, whereas the ratios of other geminate consonants were about 1.4 to 1.7. This result might be phonetically grounded since an affricate is a complex sound, involving a sequence of stop and fricative articulations. Hence, while most consonants can be prolonged easily in gemination, an affricate cannot since it involves a series of a period of complete obstruction and a period of frication. Consequently, contrary to other consonants, the durations of affricate geminates were doubly prolonged compared to single affricates. This means that degemination does not apply to affricate geminates, whereas others tend to get somewhat degeminated, and that the consonant length for affricates is distinctive.

NK experienced difficulty in pronouncing geminated affricates. Even though affricates had the largest ratio contrast between singletons and

geminates among the consonants produced by NK, NK could not have enough discrepancy between the affricate singletons and geminates when compared to NE. They tended to remove one of the two affricates since they had difficulty articulating the consecutive affricates properly, which caused the large discrepancy in the affricate ratios between NK and NE.

The result of fricatives was also interesting. The ratios of the mean durations between fricative singletons and geminates were the smallest in both NK and NE; however, this was not caused by the short duration of fricative geminates. In terms of absolute durations, fricatives marked the second longest when geminated both in NK and NE. The reason for this was that, when compared in an equivalent context, a fricative inherently has longer durations than other consonants (Kent and Read 2002:161). Hence, although a fricative singleton is lengthened to make a geminate, its lengthening can be restricted. Strong support for this claim is also provided by Blevins (2004a, b) who observes that cross-linguistically, sibilant geminates /s:/ and /z:/ are more likely to be missing than stops in a geminate inventory, because their inherent durations are longer, and thus are more susceptible for neutralization.

From the results in Table 5, we could further reason that Korean phonology affects the production of English affricate geminates. In Korean, affricates in a coda position are neutralized to the alveolar stop, [t]; /nac/ 'day' and /nac^{h}/ 'face' are both produced as [nat]. This means that Korean does not have consecutive affricates over a syllable boundary, while English has. This neutralization may explain the poor production results of affricate geminates by NK. Namely, since NK participants are not accustomed to pronouncing a series of affricates, they may tend to shorten English affricate geminates.

3.3 Production results by place of articulation

In order to investigate the role of places of articulation in consonant gemination, we examined the differences in the durations of singleton and geminate consonants in the respective places of articulation.

3.3.1 Singleton consonants

The following results in Figure 4 show the mean durations of each singleton depending on the different place of articulation.

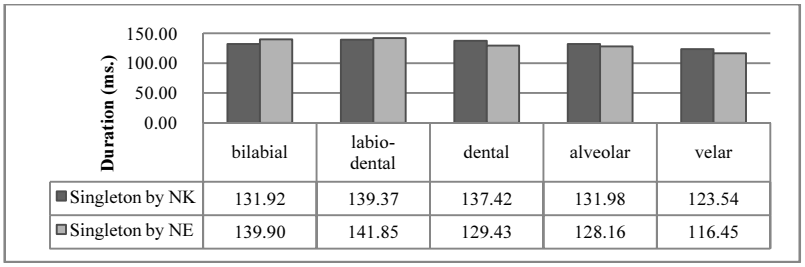


Figure 4. Mean durations of singletons in different places of articulation[5]

There was little difference between NE and NK productions when they read single consonants. The results from t-tests also showed that places of articulation did not play a role in lengthening the geminated consonants; there were no statistical differences in length between NK and NE, as shown in Table 6.

Table 6. Results of t-tests

	t	df	Asymp. Sig. (2-sided)
Bilabials	-.671	76	.504
Labiodentals	-.138	50	.890
Dentals	.580	50	.565
Alveolars	.440	154	.660
Velars	.363	50	.718

A tendency was observed in the mean durations of singleton consonants: when the articulation places were moved from the back to the front, the mean durations by both groups became longer. Consequently, the mean duration of velars was considerably shorter compared to the other places of articulation.

3.3.2 Geminate consonants

Given in Figure 5 are the results from geminate consonants by different places of articulation.

[5] The affricates were excluded since they have two different places of articulation.

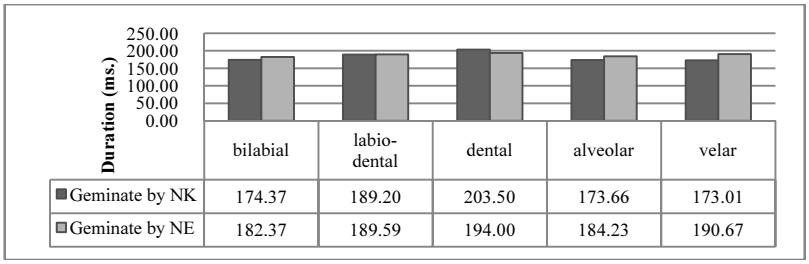


Figure 5. Mean durations of geminates in different places of articulation

Not unlike the previous results, no considerable dissimilarity was observed by different places of articulation when read by NK and NE. Yet, the mean durations of dentals had the longest durations in both groups, which is different from singletons. According to t-tests, no significant difference was shown between NK and NE productions in all the geminate results as illustrated in Table 7.

Table 7. Results of t-test

	t	df	Asymp. Sig. (2-sided)
Bilabials	-.656	76	.514
Labiodentals	-.019	50	.985
Dentals	.456	50	.650
Alveolars	-.937	154	.350
Velars	-.785	50	.436

3.3.3 Discussion

From these results, we recognized that places of articulation have different influences on singletons and geminates. Whereas the mean duration of singletons was shortest at velars becoming gradually longer moving from the back side to the front, geminates had the longest mean duration at dentals. To confirm the differences in duration, we compared the ratios between singletons and geminates in the respective places of articulation, which are shown in Table 8.

Table 8. Mean durations and the ratios in different places of articulation

	Singletons/NK	Geminates/NK	Ratio	Singletons/ NE	Geminates/ NE	Ratio
Blabials	131.92	174.37	1 : 1.3	139.90	182.37	1 : 1.3
Labio-dentals	139.37	189.20	1 : 1.4	141.85	189.59	1 : 1.3
Dentals	137.42	203.50	1 : 1.5	129.43	194.00	1 : 1.5
Alveolars	131.98	173.66	1 : 1.3	128.16	184.23	1 : 1.4
Velars	123.54	173.01	1 : 1.4	116.45	190.67	1 : 1.6

In both groups, singletons recorded considerably short mean duration in velars, which resulted in the large discrepancy in ratio. On the other hand, dentals were also conspicuous due to the longest durations in geminates, which caused a big difference in ratio. Although NK and NE had longer durations at dentals compared to other places, the length of duration was especially prominent in NK. This result indicated that NK overpronounced the dental sounds, prolonging them a little longer, since Korean lacks English dentals /θ/ and /ð/.

3.4 Production results by voicing

We explored how voicing affected the lengths of singletons and geminates across words.

3.4.1 Overall results

Figure 6 shows the total average durations of voiceless and voiced singletons and geminates produced by NK and NE.

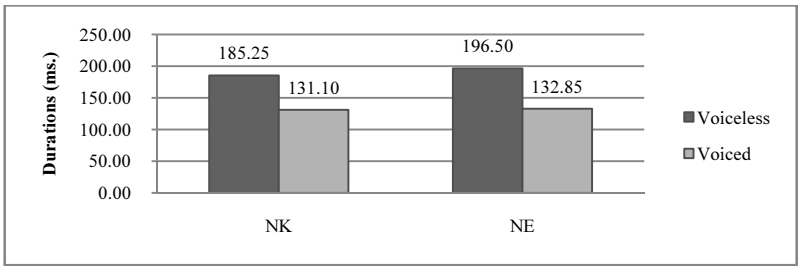


Figure 6. Mean durations of voiceless and voiced counterparts

The status of voicing clearly affected the length of the consonants over word boundary; voiceless consonants had longer mean durations than

voiced for both NK and NE. The mean durations of voiceless consonants by NK were a little shorter than those by NE, while durations of voiced consonants were almost similar in those two groups. T-tests were conducted for confirmation. The difference between NK voiceless and voiced consonants were significant (t=12.591, df=678, p=.000). The mean durations of voiceless and voiced consonants by NE also had a significantly different result (t=9.532, df=202, p=.000). However, there was no significant difference in the mean durations of voiceless consonants by NK and NE (t=-1.704, df=362, p=.089) and in the mean duration of the voiced consonants by the two groups (t=-.314, df=518, p=.754).

3.4.2 Singleton consonants

In order to analyze the effects regarding voicing more specifically, we subdivided each voiceless and voiced group into singletons and geminates. Figure 7 shows the mean durations of voiceless and voiced singletons by NK and NE.

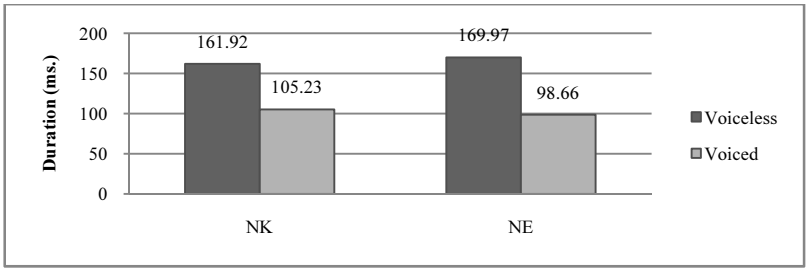


Figure 7. Mean durations of voiceless and voiced singletons by NK and NE

It is apparent that voicing affected the length of singleton consonants, making voiceless consonants longer than voiced consonants in both NK and NE. The results were examined in t-tests. There was a highly significant difference between voiceless and voiced by NK (t=13.474, df=338, p=.000) and by NE (t=10.935, df=100, p=.000). However, the voiceless singletons by NK did not differ from those by NE (t=-1.188, df=180, p=.236). The mean duration of voiced singletons also had no significant difference between the two groups (t=1.246, df=258, p=.214).

3.4.3 Geminate consonants

Figure 8 displays the mean durations of voiceless and voiced geminates produced by NK and NE.

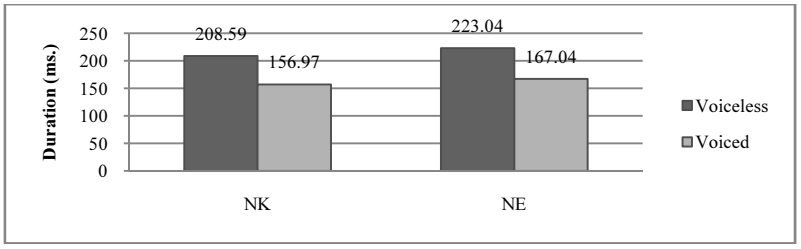


Figure 8. Mean durations of voiceless and voiced geminates by NK and NE

Similar to singletons, the mean durations of geminates also had no large difference between NK and NE, and there were large gaps between the mean durations of voiceless and voiced geminates in both groups. A t-test result revealed that the groups were not found to differ in terms of their average duration of voiceless geminates (t=-1.499, df=180, p=.063) nor in the voiced geminates they produced (t=-1.266, df=258, p=.113). Yet, the mean durations of voiceless geminate were found to differ significantly from the voiced geminate for NK (t=8.021, df=338, p=.000), as well as for NE with an obviously significant difference (t=7.422, df=100, p=.000).

3.4.4 Discussion

Even though voicing is not distinctive in Korean, NK produced both voiceless and voiced consonants very well, distinguishing their differences in length. In order to examine the results more concretely, we divided the mean durations into singletons and geminates for both voiceless and voiced consonants, and compared their ratios. The results are given in Table 9.

Table 9. Mean duration ratios between singletons and geminates

Voiceless	Singleton	Geminate	Voiced	Singleton	Geminate
Duration by NK	161.92	208.59	Duration by NK	105.23	156.97
Ratio	1 : 1.3		Ratio	1 : 1.5	
Duration by NE	169.97	223.04	Duration by NE	98.66	167.04
Ratio	1 : 1.3		Ratio	1 : 1.7	

In both NK and NE, the ratio between voiceless singletons and voiceless geminates was smaller than the ratio between voiced counterparts. That is, even though the mean durations of the voiced were shorter than the durations of the voiceless, the differences in ratio between voiced singletons and voiced geminates were bigger than those between voiceless

singletons and voiceless geminates.

We also classified the results between NK and NE. As for the voiceless consonants, there was no difference between the groups. However, in the comparison of the voiced consonants, the divergence of the mean durations between singletons and geminates was larger in the ratio of NE. Namely, while the ratios between singletons and geminates in voiceless consonants were the same in both groups, NK had a smaller difference in the ratio for voiced consonants. This means that NK produced proper duration ratio between singletons and geminates when producing the voiceless consonants, while they could not lengthen the geminate durations properly for voiced geminates.

4. Results of Experiment 2: Perception

4.1 Overall results

The purpose of Experiment 2 was to examine how NK and NE perceived singletons and geminates differently over word boundaries and which difficulties, if any, they had in perceiving them. Also, we tried to find out the relationship between production and perception of both singletons and geminates. For the goal, we first counted the number of correct answers by the 20 NK and the three NE participants. The following figure shows the overall accuracy rates in the perception test by NK and NE participants.

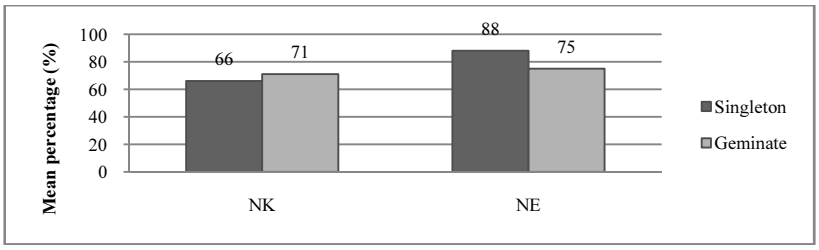


Figure 9. Mean percentages of singletons and geminates by NK and NE

The result from the perception test with a 50% probability rating (excluding foil answers) showed that NK had difficulty perceptually differentiating between singletons and geminates. In comparison to NK, NE were found to discriminate English single and geminate consonants more accurately, even though the geminate perception rate was lower than the singleton rate. This relatively low rate might result from the fact that the duration of voiced geminates by NE is similar to that of voiceless singletons as illustrated in Table 9. In addition, even though a large gap existed between the mean percentages of singletons by the two groups, the comparison between geminates by the two groups had small difference

since NK, unlike NE, perceived geminates better than singletons.

A chi-square was carried out to determine the statistical relation. The result showed that the accuracy rates for singletons had a highly significant difference between NK and NE (x^2=19.471, p=.000); yet, the comparison of geminates had no significant difference (x^2=.030, p=.863). Also, there was no significant difference between singletons and geminates by NK (x^2=2.728, p=.099) while, significant difference was observed in the comparison of those percentages by NE (x^2=6.339, p=.012). It is interesting to note here is, while NK pronounced both singletons and geminates very well, they have difficulty in perceiving them, ending up with only 66% and 71%.

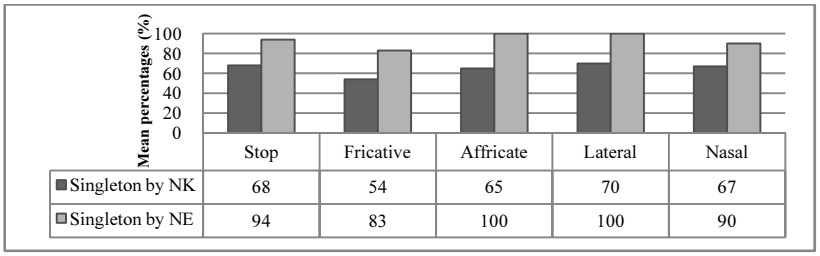
Also, considering NK articulated geminates shorter than NE and thus were worse at pronouncing geminates, the results of perception and production in Figure 9 were not what we had expected. Such an opposite result might imply that speech production can precede speech perception as proposed by Kabak (2003), Kabak and Idsardi (2007), Sheldon and Strange (1982) and Shin (2011). Namely, it has been well-attested that speech perception is influenced by mother tongue, and speech production by speech perception. However, in these experiments, NK pronounced geminates without difficulty even though their perception was relatively bad, which is contrary to the traditional belief and further means that there is only very loose relation between speech perception and production.

4.2 Perception results by manners of articulation

This section investigates whether various manners of articulation have a different effect on singletons and geminates, and then to compare the results with the results of production.

4.2.1 Singleton

Figure 10 illustrates the accuracy rates of singleton perception by NK and NE in respective manners of articulation.



	Stop	Fricative	Affricate	Lateral	Nasal
Singleton by NK	68	54	65	70	67
Singleton by NE	94	83	100	100	90

Figure 10. Mean percentages of singletons in different manners of articulation

The results show that NK participants had poor accuracy rates in general, while NE participants perceived even more correctly. These comparisons were analyzed using a chi-square. The result indicated that single stops by NK and NE differed significantly (x^2=9.902, p=.002) as well as fricative singletons (x^2=9.893, p=.002). Moreover, perceptions of affricate singletons had a significant difference between NK and NE (x^2=5.747, p=.017). Both laterals and nasals also revealed similar results.

4.2.2 Geminate

Figure 11 shows the mean percentages of geminates by NK and NE in respective manners of articulation.

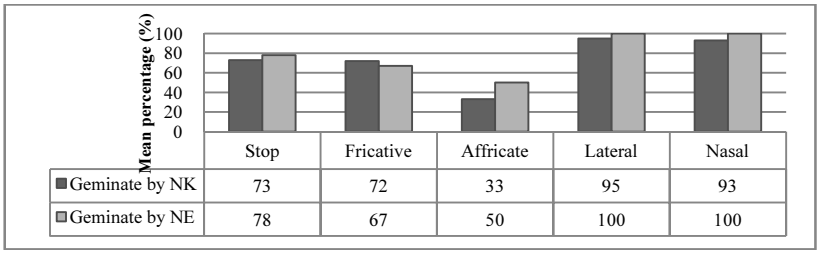


Figure 11. Mean percentages of geminates in different manners of articulation

There was no large gap between the mean percentages of each geminate perception by NK and NE: NK perceived geminates better than singletons, and NE perceived geminates worse. According to a Chi-square, the overall results were not significantly different between the two groups as shown in Table 10.

Table 10. Results of Chi-Square tests

	Value	df	Asymp. Sig. (2-sided)
Stops	0.287	1	0.592
Fricatives	0.333	1	0.564
Affricates	1.219	1	0.270
Laterals	0.312	1	0.576
Nasals	0.995	1	0.328

4.2.3 Discussion

With regard to production of singleton consonants, NK presented excellent results showing native-like performances, except nasals. However, this was diametrically opposed to perception, where NK revealed poor results at

generally 50-60% of perception accuracy rates (Recall that the probability rating is 50%). As for geminates, the production and perception results were almost identical for NK.

Though there was no great difference in the statistical results among each consonant, the accuracy rate for the affricate perception was noteworthy compared to other consonants: both groups perceived affricates at a less than 50% accuracy rate. The reason for this was that the affricate geminate recorded by a female NE was not as fully lengthened as compared to the affricate singleton. This discrepancy in duration, which was less than two times difference in duration, must have been an obstruction for both NK and NE.

NK had the worst perception rate in fricatives among all the singleton and geminate results (except affricate), since fricatives tend to get easily degeminated due to its inherent nature of long duration as discussed earlier.

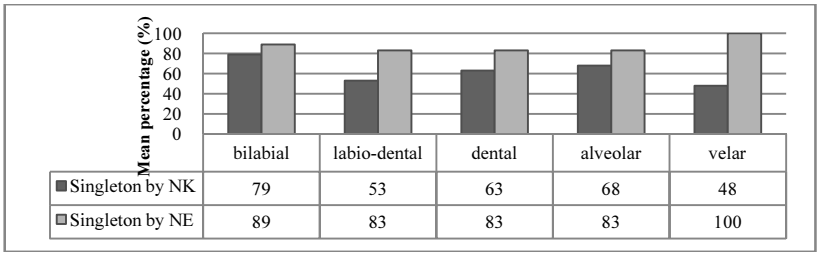
Another piece of evidence that proves transfer of Korean phonology to English production with regard to perception of English geminates is found in the phenomenon of degemination in Korean, where a noun compound can be optionally realized as the one with a single tense correspondent. Namely, as Kim-Renaud (1987) points out, a sequence of homorganic obstruents in Korean is often degeminated. For example, ak+ki 'musical instrument' is often pronounced as *akk'i* or *ak'i*, and tok+ki 'poison' can be produced as *tokk'i* or *tok'i*, and tat+ta 'to close' is producted as *tatt'a* or *tat'a*. Therefore, degemination in their mother tongue may distract NK, making them misperceive singleton consonants as geminate consonants.

4.3 Perception results by places of articulation

In order to analyze the perception results more precisely, we compared the accuracy rates in various places of articulation, matching the results with the production results.

4.3.1 Singleton

Figure 12 shows the mean percentages of each singleton and geminate by NK and NE.



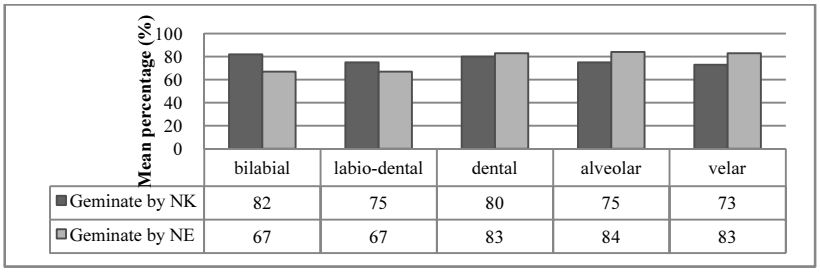
	bilabial	labio-dental	dental	alveolar	velar
Singleton by NK	79	53	63	68	48
Singleton by NE	89	83	83	83	100

Figure 12. Mean percentages of singletons in different places of articulation

NE showed much higher mean percentages than NK in singleton perception except for bilabials, where the gap was much closer. NK and NE revealed 53% and 83% accuracy rates respectively in labio-dentals. With regard to dentals and alveolars, NK had 63% and 68% whereas NE had 83% for both, showing a considerable between the two groups. Furthermore, NK had 48% of the accuracy rate for velars, while NE had 100%. All in all, NK recorded approximately 50-60%, whereas NE marked much higher rates at more than 80% of mean percentages in all categories.

4.3.2 Geminate

Illustrated in Figure 13 are the results of geminate perception.



	bilabial	labio-dental	dental	alveolar	velar
Geminate by NK	82	75	80	75	73
Geminate by NE	67	67	83	84	83

Figure 13. Mean percentages of geminates in different places of articulation

The mean percentage of each geminate did not show significant differences between NK and NE. As for bilabials, NK and NE had 82% and 67% accuracy rates, respectively. With regard to labio-dentals and dentals, NK had 75% and 80% whereas NE had 67% and 83%, showing no considerable difference between the two groups. Moreover, there was not a substantial divergence between NK and NE in alveolars and velars.

4.3.3 Discussion

As for production of singletons, there was no large difference between NE and NK; however, whereas NE had more than 80% high accuracy rates in all the places of articulation, NK had only 50-60% rates in all except bilabials. The results indicated that production was irrelevant to perception for singletons. On the other hand, as the production results did not show any differences in mean durations of geminates between NK and NE, the results of geminate perception also did not show considerable differences between the two groups.

Regarding places of articulation, dentals and velars marked the biggest differences in ratios by NK and NE. Specifically, velar singletons had the shortest mean duration and had a big difference in ratio between singletons and geminates in both NK and NE. Consequently, the results led us to infer that the participants would have little or no difficulty in discriminating the single velars from the geminated velars, whereas they would experience some difficulty in discriminating other consonants. NK, however, had the worst perception accuracy rates, only 48%, at velars while NE had a perfect accuracy rated for velars. This result again refutes the traditional assumption that perception precedes production.

4.4 Perception results by voicing

This section investigates the roles of voicing in singleton and geminate perception.

4.4.1 Comparison in mean percentages

Figure 14 shows the total accuracy rates of voiceless and voiced consonants perceived by NK and NE.

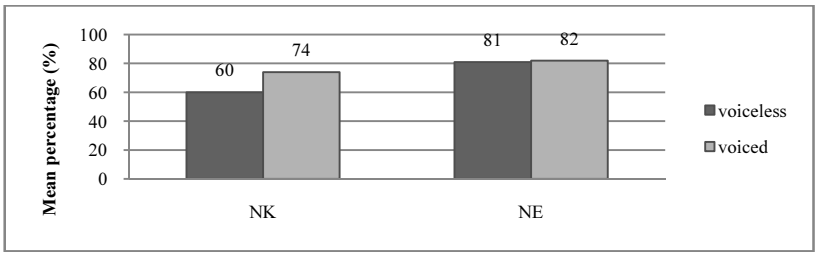


Figure 14. Mean percentages of voiceless and voiced consonants by NK and NE

NE perceived both voiceless and voiced consonants very well, showing more than 80% accuracy rates, while NK did poorly. For NE, there was little difference between voiceless and voiced; however, NK had almost 15%

higher mean percentages in voiced over voiceless perception. In order to confirm the results statistically, a chi-square was performed. NE showed no significant difference in accuracy rates between voiceless and voiced (x^2=.017, p=.897); however, NK comparison showed a highly significant difference (x^2=12.625, p=.000). This indicated that voicing had a relation to the accuracy rate in NK, while it is irrelevant to NE. Also, NK significantly differed from NE in perceiving voiceless consonants (x^2=12.824, p=.000). Yet, the voiced results by both groups did not differ significantly (x^2=2.955, p=.086).

4.4.2 Singleton

We examined how voicing affects perception of singletons by NE and NK. This is illustrated in Figure 15.

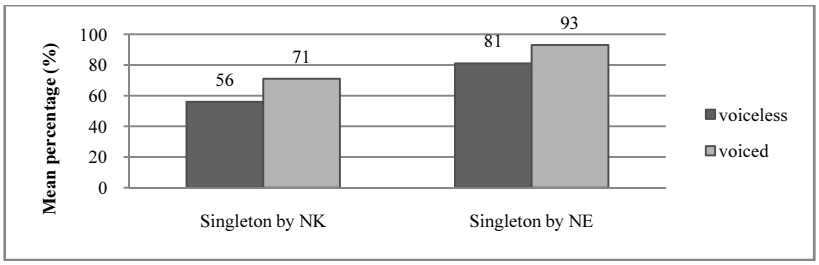


Figure 15. Mean percentages of singleton perception by NK and NE

Both NK and NE had better accuracy rates in voiced consonants compared to voiceless. According to a chi-square, a significant difference was observed between voiceless and voiced by NK (x^2=8.426, p=.004); however, there was no significant difference by NE (x^2=3.648, p=.056). It was also seen that the accuracy rates for voiceless singletons were significantly different for the two groups (x^2=12.824, p=.000), while voiced singletons had no significant difference (x^2=2.955, p=.086).

4.4.3 Geminate

Given in Figure 16 are the mean accuracy rates of perception by NK and NE.

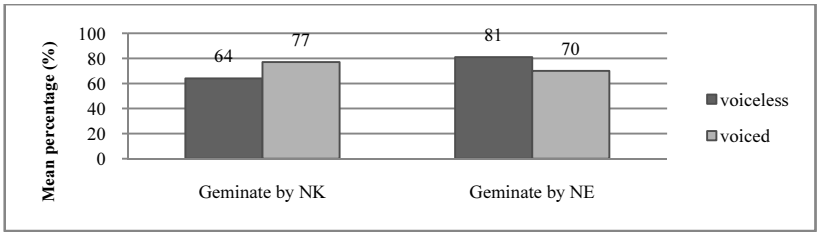


Figure 16. Mean percentages of geminate perception by NK and NE

NK marked a higher accuracy rate for voiced geminates while NE had a higher rate for voiceless. A chi-square confirmed the results. Voiceless geminates by NK differed significantly from the voiced (x^2=7.283, p=.007), whereas no significant difference was found to exist between the two by NE (x^2=1.560, p=.212). This demonstrated that voicing was relevant to the perception result in NK. Also, the comparison of voiceless geminates between NK and NE had a significant difference (x^2=4.455, p=.035), while the voiced geminates did not (x^2=1.219, p=.270).

4.4.4 Discussion

Recall that NK produced both singletons and geminates very fluently. Nonetheless, they brought very poor results in perception. In particular, 56% of the accuracy rate for voiceless singletons demonstrated that NK rarely perceived voiceless singleton. These results might again mean that production and perception do not always go together.

Also, it is noteworthy that NK had the worst perception result for voiceless singletons with 56% of the mean accuracy rate. We contend that such a pool perception rate results from inherent length difference between voiced and voiceless consonants. Lisker (1957) contends that the voiced-voiceless contrast of English stops may have a difference in the duration of closure. Hence, according to Lisker, in intervocalic position within trochaic words /p/ is regularly longer than /b/. The Experiment 1 of this study also showed that voiceless consonants had longer durations than voiced consonants, having 1:1.7 in singletons and 1:1.3 in geminates. As a consequence, given that a voiceless consonant is much longer than its voiced counterpart in English, such a difference in duration might have influenced perception in a bad manner, making them misperceive voiceless singletons as geminates.

With regard to production results, we have seen that voiced consonants had bigger differences in ratio even though voiceless consonants were longer than voiced consonants (Table 9). This means distinguishing voiced singletons from voiced geminates is easier than discriminating voiceless singletons from voiceless geminates. Consequently, in perception, NK perceived voiced consonants better than voiceless consonants, having 15%

of higher mean percentage than perception of voiceless consonants.

5. Summary and Conclusion

There has been much controversy on phonetic contrasts between singleton and geminate consonants across words in English. This study has aimed to look at these contrasts in terms of perception and production by NE and NK, and to examine the relationship between perception and production. In Experiment 1: Production, it turned out that consonants were phonetically lengthened from 1.4 to 2.2 times longer when geminated by NE, and NK produced singletons and geminates very well when compared with NE. They, however, pronounced geminates a little shorter than NE, making statistical distinction. Experiment 2: Perception showed that NK had poor accuracy rates in perception in general, while NE perceived singletons and geminates with high accuracy rates. NK had a tough time perceiving singletons and geminates correctly, especially singletons, recording only a 66% accuracy rate. On the whole, the results discovered that speech production might not mirror speech perception, which is against traditional theories, but is partly congruent with recent studies mentioned earlier in 4.1.

The results from different manners of articulation disclosed that NK generally produced both singletons and geminates in a proper manner, except for affricate geminates. However, there was practically no relationship between overall perception and production results in manners of articulation. Whereas there is no difference between NK and NE in discriminating geminate consonants, NK revealed poor results in singleton perception with 50-60% accuracy rates. This does not agree with the production results wherein NK displayed almost native-like performances in both singletons and geminates.

As for the roles of places of articulation, NK pronounced singletons and geminates as well as NE. Yet, not unlike to manners of articulation, there was also seen a very loose relationship between perception and production in overall results of places of articulation since NK had 50-60% poor accuracy rates in all the places except bilabials.

Even though voicing is not a distinctive feature in Korean, NK produced both voiceless and voiced consonants well, distinguishing their difference in length. In perception, however, they showed poor accuracy rates in both voiceless and voiced consonants. Particularly, the 56% rate in voiceless singletons attested that NK rarely perceived them, implying that the results of production and perception had little interrelation with regard to voicing.

The poor production and perception results by NK can be inferred partly by the transfer of the two Korean phonological phenomena: coda neutralization and degemination[6]. In Korean, fricatives and affricates are

[6] One of the reviewers pointed out that tensification in Korean might have exerted a bad influence on those poor results.

neutralized to the alveolar stop consonant, [t] when appearing in the coda. Also, a sequence of homorganic obstruents in Korean is often degeminated. These phonological regularities in Korean might have distracted NK, making them misperceive singleton consonants as geminate consonants and shorten durations of geminated fricatives, affricates, and stops.

This study has shown that geminate consonants are phonetically distinctive over word boundaries in English. Also, it has shown that there was a clear discrepancy between NK perception and production of the geminates. In conclusion, with regard to perception and production of English singletons and geminates, it has contended that perceptual mastery of a foreign contrast does not necessarily precede the ability of production, and may sometimes lag behind production mastery.

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