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Articulatory Variability of Phonological Rules by Korean EFL and Indian ESL Speakers*

Gwanhi Yun (Daegu University) **Jae-Hyun Sung** (Kongju National University)

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Gwanhi Yun (1st author)
Professor, Department of English Language and Literature, Daegu University
Tel: 053) 850-6025
Email: ghyun@daegu.ac.kr

Jae-Hyun Sung (corresponding author)
Assistant, Professor, Department of English Language and Literature, Kongju National University
Tel: 041) 850-8358
Email: jsung@kongju.ac.kr

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ABSTRACT

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The present study investigates how Korean EFL speakers (KS) and Indian ESL speakers (IS) apply their L2 English phonological rules to their production of coronal consonants. To this end, ultrasound imaging experiments were administered for both groups of L2 speakers with three English phonological rules: palatalization, place assimilation and word-final coronal deletion. First, the results showed that most of KS did not palatalize the target alveolars across word boundary. It was also found that place assimilation occurred for the half of the stimuli, showing phonological variations with three major variants. Additionally, word-final /t/ deletion was not common, amounting to only 36%. Second, the results from IS showed that palatalization was applied less than 50%. However, the likelihood of palatalization exhibited interspeaker variation. Additionally, IS applied place assimilation more frequently, compared to KS (56% vs. 50%). Like KS, IS also favored coronal-to-velar assimilation over coronal-to-labial assimilation (81% vs. 31%). Finally, IS showed a similar pattern in the likelihood of word-final /t/ deletion to KS, inducing deletion at 36%. Like KS, deletion occurred more frequently when the following consonant was a labial than when it was a velar. In summary, the gestural patterns from KS and IS suggest that both KS and IS produce English phonological rules gradiently, not in a categorical fashion. Furthermore, it is indicated that place assimilation is more frequent for IS than for KS conceivably due to more exposure to English as SL than as FL. In addition, it was observed that hyperarticulation or gestural overshoot is adopted for both speaker groups. Overall, the articulatory patterns from this study imply that phonological variation is quite common for EFL and ESL speakers like native English speakers. It is also suggested that the way speakers produce L2 phonological rules varies markedly according to individual phonological rules as well as across speaker groups, and the likelihood of occurrence of each of phonological variant differs in accordance with phonological rules, context or English-speaking groups.

KEYWORDS

phonological variation, foreign language, second language, English, place assimilation, palatalization, word-final coronal deletion, ultrasound imaging technique

1. Introduction

Recent studies have revealed that the spoken words exhibit variability in the acoustic or articulatory realization. This led to the speculation that phonological or phonetic rules apply either optionally or obligatorily. In addition to this bifurcated mode of application, even the obligatory application results in diverse surface forms, ranging from partial to complete modification of phonemes or subphonemes. This variability in mode of application is known to stem from many factors such as speaking rates, register styles, phonological context, etc (Pitt 2009, Pitt et al. 2007). In particular, the acoustic investigation of the surface realization of the spoken words have shown that many phonological rules apply in a gradient manner, not categorically (palatalization: Bush 2001; vowel reduction: Dell 1990, Harley and MacAndrew 1992; neutralization: Li 2012, Piroth and Janker 2004, Jongman 2003, Yun 2022; devoicing: Jongman et al. 1992, Warner et al. 2004). Furthermore, the incomplete application of phonological rules have been investigated across languages. For example, incomplete neutralization which was once assumed to be categorical has been documented in many languages (English: Braver 2013; German: Roettger et al. 2014; Spanish: Simonet et al. 2008; Japanese: Braver 2013).

Variability of the spoken words witnessed in the conversational speech emerges at the phonemic or subphonemic level. For instance, place assimilation optionally occurs in the conversational speech, creating the assimilated or non-assimilated variants (e.g., *cat paw* [...p p...] ≈ [...t p...]). Additionally, the probability of producting the assimilated variant is also contingent on many factors, including phonological context, lexical frequency, the speaking rate, etc. For example, Pluymaekers, Ernestus and Baayen's (2005) Dutch corpus study showed that Dutch affixes such as *ge*-, *Ver*, and *ont*- were produced shorter in high-frequency words spoken at a high speech rate than in low-frequency words uttered at a low speech rate. In the same vein, Dilley and Pitt's (2007) Buckeye Corpus study showed that the likelihood of coronal place assimilation in English varies, depending on the word-final target segment. They found that word-final /n/ undergoes place assimilation to the following labial or velar by 73%, whereas this segmental change occurs by 51% for word-final /d/ and by only 25% for word-final /t/ (e.g. *can put* [...m p...] vs. *cad plot* [...b p...] vs *cat picture* [...p p...]). Another example of the effect of phonological context on the different variants can be found in Raymond et al. (2006), which claimed that word-medial /t/ in English tends to be deleted when preceded by /n/ and followed by the reduced vowel more frequently than by full vowels (e.g., *counter* vs. *context*). Sometimes the variability may occur in the continuum along the phonemic category and phonetic fine details. For example, Jurafsky et al. (2001) showed that English word-final /t/ or /d/ is realized as the full segment, but in fast, casual style speech, it might be shorter, or is highly likely to be completely deleted (e.g., *shoot* [t^h] ≈ [t˺] ≈ [t] ≈ [ø]). In this case, word-final /t, d/ result in multiple variants such as aspirated, unreleased, short, and deleted forms.

Lexical frequency also exerts an influence on the likelihood of applying certain phonological rules, inducing the variability of pronunciations (Dalby 1986, Dilley and Pitt 2007, Mitterer and Ernestus 2006, Patterson and Connine 2001). In Cooper and Paccio-Cooper (1980) and Bush (2001), English /t/ or /d/ was palatalized before /j/ more often in high-frequency than in low-frequency words. Patterson and Connine (2001) found that more frequent English words showed flapped /t/ word medially more than less frequent words, indicating the higher variability between the canonical form [t] and the flap [ɾ]. Ernestus, Lahey, Verhees and Baayen (2006) showed that in the environment of Dutch regressive voice assimilation, higher-frequency words were perceived as voiced more than low-frequency words and the duration of the trigger and target obstruents as well as the period of glottal vibration during the plosive clusters were shorter for higher-frequency words than for lower-frequency words. This indicates that Dutch voicing assimilation is gradient, not categorical, depending on the word frequency. This finding shows that the types of variants emerging in the contexts of phonological rules lie on the continuum of the categorical features

[±voice]. These previous studies lend support to the claim that lexical frequency tends to induce not only the higher probability of the application of phonological or phonetic rules due to more gestural overlap in the abstract timing dimension but the reduction of articulatory efforts due to the repetition of relevant gestures.

Recently, in addition to the acoustic findings, articulatory evidence accrued to the validity of the phonological or phonetic variation created by the gradient application of the rules. For example, Wright and Kerswill's (1989) EPG study examined whether/how English coronal place assimilation is applied across word boundary. They found that word-final alveolars were realized as three types of variants, i.e., full alveolars, partial alveolars, and zero alveolars (e.g., *road collapsed, did gardens, bride must*). This finding indicates that English alveolars undergo no assimilation, partial assimilation or full assimilation according to how much the tongue tip or blade of the target coronals contact on the alveolar ridge of the palate. This articulatory evidence for gradient assimilation is buttressed by a great bulk of acoustic studies (Dilley and Pitt 2007, Ellis and Hardcastle 2002, Gow 2003). Cho and Keating's (2001) EPG study showed that in the production of Korean alveolars /t, t^h, t', n/, the amount of contact region on the pseudo-palate varied according to the prosodic position. The tongue blade of Korean alveolars contacted the palate with greater amount in the order of utterance-initial, intonational phrase-initial, accentual phrase-initial and word-initial position, exhibiting the domain-initial strengthening effect.

Turton (2017, 2021) investigated English /l/-velarization, i.e., /l/-darkening in a variety of dialects in the UK via ultrasound imaging technique. She suggested that not only traditional dichotomy between clear and dark /l/ but also gradient /l/-darkening co-exist in the same grammar. To be specific, clear-seeming categorical /l/ darkening was observed across English dialects, depending on the phonological context, and furthermore, variability was found within clear /l/ or dark /l/ phonetic categories. Hence, it is proposed that a grammar module should be searched enough to give accounts for the effects of categorical and gradient allophony.

These articulatory studies are significant in the sense that they reveal more accurate nature of the application mode of phonological rules, complementing the acoustic properties of their realizations and clearly depicting the phonetic-fine, detailed variation. Namely, the application of rules which used to be considered as purely categorical or complete is, in fact, gradient or incomplete or both.

Putting the previous studies together, it is in consensus that the optional mode of the application of rules itself produce variability, i.e., the canonical variant and other variants which undergo the rule application. However, the obligatory application mode does not guarantee the categorical change of phonemes couched in the change of featural values but creates the gradient outcomes due to many factors such as lexical frequency, speech rate, dialects, phonological contexts, etc., resulting in the different degrees of the likelihood for each variant.

Most of previous studies have been dedicated to examining the variations either phonological or phonetic level with regard to L1 production, and much attention has not been paid to the production patterns for L2 speakers. Assuming that L1 speakers produce variant forms for spoken words, L2 phonological variation, if observed, is important because it might provide interesting implications as to L2 acquisition of phonology. First, if FL or SL speakers produce the variability of pronunciations of their L2 words, it might imply that they have successfully mastered the exact nature of phonological rules and implemented them as gradient. However, under the purely categorical application of phonological rules, L2 speakers' variability in phonological shapes leads us to expect the incomplete or incorrect acquisition of L2 rules. Second, if phonological variation is commonly observed across L1 and L2 speakers' pronunciations, it might be conjectured that the gradient production of phonological rules is universal or inherent by nature. Against this background, the present study delves into three research questions addressing L2 speakers' phonological variation.

1) Do foreign language or second language speakers show variability in the application of phonological

rules of their target language?
2) Does phonological variation occur in the different patterns according to the different phonological rules?
3) Do foreign language users and second language speakers produce different patterns of phonological variation?

In order to answer these questions, we first have to establish the nature of two speaker groups, depending on how English is used in their daily lives. Following the traditional dichotomy, we refer to foreign languages (henceforth, FL) as the language used mainly in restricted settings, including educational institutes, but used outside the classrooms. In contrast, second languages (henceforth, SL) are spoken in a variety of areas like businesses, schools, trade, politics, etc as native or first languages. Due to more frequent use of SL over FL as well as greater exposure to SL over FL, chances are that SL speakers have higher proficiency than FL speakers. Given this rationale, in our study, we expect that there are different patterns of phonological variations between FL and SL speakers' productions. To see if this is the case, we randomly chose Korean learners of English as EFL group and Indian speakers as ESL group. In Korea, English has been enjoying the status of foreign language because it is spoken mostly in formal education institution for pedagogical purposes, but not used in daily conversations. However, English definitely belongs to the category of second language for Indians because English is spoken widely in education, business, administration, etc. and considered as a secondary official language although Hindi is designated as national language and Tamil is also a native language in Tamil Nadu region. We examined whether Korean EFL speakers (KS) and Indian ESL speakers (IS) show different phonological variations in view of articulatory realizations of English phonological rules.

To handle the second question, we investigated whether the mode of the application of English phonological rules is affected by specific rules. We restricted ourselves to three English phonological rules: palatalization, coronal place assimilation, and /t/ deletion. As previously mentioned, it turned out that the likelihood of the application of palatalization is influenced by lexical frequency for native speakers of English and high-frequency strings are more prone to palatalization than low-frequency word strings (e.g., *don't you, would you* >> *has your, sees you*, Booij 1995, Bush 2001, Ernestus 2000). In the present study, we explored whether the application of English palatalization rule is gradient or categorical for Korean EFL and Indian ESL speakers and whether, if it is gradient, its mode is affected by lexical factors such as string frequency or phonological factors such as word-final target consonants (/t, d, s, z/). If palatalization is realized as gradient, the current articulatory study might reveal to what extent the tongue tip or blade of the target consonants approaches the palate. This study contributes to drawing more comprehensive pictures of palatalization by complementing acoustic studies of palatalization for L2 as well as L1 speakers (Sung 2018, Yun 2012). Another phonological rule we probe into is English coronal place assimilation. Like palatalization rule, place assimilation has been extensively studied with native English speakers as reported (Dilley and Pitt 2007, Ellis and Hardcastle 2002, Gow 2003, Wright and Kerswill 1989). Both categorical and gradient application modes have been documented for native speakers of English. As for the categorical application, the rates of the application of place assimilation were found to vary as a function of word-final coronal type (/t, d, n/). On the other hand, when the place assimilation arose in the gradient mode, three types of variants were observed: full alveolars, partial alveolars, and zero alveolars. In the present study, we examined whether categorical and/or gradient application fashions are found for the production of place assimilation rule for KS as well as IS. If place assimilation turns out to be incomplete or gradient in view of the positioning of articulatory gestures for alveolars, it would indicate that the place assimilation is perceptual illusion created by the overlapping of tongue gestures of alveolars and the following consonants along the timing dimension. Finally, we examined whether word-final /t/ deletion occurs gradiently or categorically or in both manners for EFL and ESL speakers. In spontaneous, casual speech, word-final alveolars tend to be deleted when preceded by one consonant and followed by another word-initial consonant (e.g., *blind man*, *next day*, *must go*, *best man,* Raymond, Brown, and Healy 2016, Walker 2012). This process has also been reported to be affected by many factors, including preceding and following segments and morphological class of the target coronals, etc., though these are still controversial (Baranowski and Turton 2020). For example, the rates of coronal deletion was reported to be higher when the preceding consonants are /n, s/ conceivably due to a strategy to avoid the homorganic ones (Temple 2009). The present study restricted our focus on the likelihood of deletion of /t/ in word-final /-st/ to see if this process is stable or variable for EFL and ESL speakers (e.g., *must pad, must cat*). The judgment of the coronal deletion was based on the phonetician's auditory, impressionistic evaluation and it was interpreted that this process naturally arise in that the unmarked coronals are deleted in marked position to avoid the marked structures, i.e., complex coda clusters. However, recent articulatory studies have found that the tongue tip of the coronal touches the alveolar ridge, suggesting that it is not audible because it is actually not deleted but perceptually elided due to the shortening of intergestural timing between the two consonants (Browman and Goldstein 1995, Byrd 1995). In linkages with these findings for L1 speakers, this ultrasound study investigated whether English coronal deletion is a type of perceptual illusion or genuinely articulatory and whether this process is categorical or gradient by looking into the presence/absence of tongue tip gesture.

The last question to be addressed is to see whether both Korean EFL and Indian ESL speakers show different patterns of production of English phonological rules in association with categorical or gradient manner of application and probability of application. Following the assumption that ESL speakers have more native-like norms of phonological rules than EFL speakers due to higher proficiency of English and a greater amount of exposure to English, it is expected that different patterns emerge in relation to the type or number of phonological variants or to the degrees of rates of the three rules.

2. Ultrasound Experiment 1: Korean EFL Speakers

2.1 Participants

Four Korean native speakers participated in the ultrasound imaging experiment. At the time of experiment, they were majoring in English at Daegu University in Korea. Two were female and two male. They were aged 20-28 years (mean: 22, SD: 2.2). All participants were paid a certain amount of monetary compensation. Average period of learning English at formal education institute was 11.5 years, ranging from 7 to 17 years. They were studying English as a foreign language on average for 1.6 hours on a daily basis, ranging from 0 to 4 hours (SD: 1.2). Their TOEIC score was on average 626, ranging from 580 to 830 (SD: 251). They had experience of staying in the English-speaking country on average for 0.8 year, ranging from 0 to 10 years. Their self-evaluation of English proficiency was on average 5.9 out of 10 point scale, ranging from 4 to 9 (SD: 1.4).

2.2 Stimuli

In order to investigate the patterns of production of three phonological rules by EFL and ESL speakers, we randomly chose three groups of stimuli containing the potential contexts where these rules might apply. One group of tokens were selected to elicit the palatalized phrases. All the thirty two words consist of monosyllables and are categorized into four sub-groups according to the word-final consonants (/t,d,s,z/), which are potential targets for palatalization. Eight words in each of sub-groups end with one of the four alveolars (/t,d,s,z/). To control the preceding vowel effect on the likelihood of palataliation, the vowel preceding the word-final alveolar is fixed as one of /i,æ,u,ɔ/. Thus, two words in each sub-group contain these four preceding vowels as illustrated in (1). To elicit palatalization from these words, they were embedded within a nonsensible carrier sentence, i.e., "I ______ you, too". Target words were chosen to make the palatalizable sequence along with the following word "you" semantically or grammarically illegitimate to preempt the potential factors of semantic or syntatic familiarity. In this context, the target alveolar is followed by the glide /j/ triggering palatalization across the word boundary.

(1) Materials for palatalization

V-type/C-type	/t/	/d/	/s/	/z/
/i/	beat	seed	cease	seize
	meet	need	piece	knees
/æ/	bat	mad	mass	spaz
	fat	bad	pass	as
/u/	shoot	rude	moose	lose
	fruit	food	news	choose
/ɔ/	sought	ward	moss	pause
	thought	sword	loss	cause

Another group consits of thirty six phrases,i.e., contexts in which coronal place assimilation might occur. To see whether the word-final coronal is assimilated to the place of articulation of the following labial or velar, two-word strings were created by juxtaposing a coronal /t,d,n/) and a labial or velar (/p,b,m,k,g,ŋ) across the word boundary (e.g., *set put*). To create assimilable context, nine two-word sequences were made by combining a coronal with a labial across word boundary (/t,d,n/ × /b,p,m/) to elicit coronal-to-labial assimilation (e.g., *set put*) and another nine two-word strings were created by adjoining word-final coronal with word-initial velar to facilitate coronal-to-velar assimilation (/t,d,n/× /k,g,ŋ/, e.g., *bet case*). To assess whether the word-final coronal is closer to the underlying coronal or assimilated to the place of the following velar, we created control stimuli, i.e., two-word sequences of a coronal+a coronal and a velar + a velar. These eighteen control stimuli were also included to compare with eighteen experimental stimuli as exemplified in (2). In total, thirty six tokens were also embedded in a carrier sentence "This is ________." to elicit assimilated surface forms as naturally as possible.

(2) Materials for coronal place assimilation

	Assimilable contexts		Nonassimilable contexts	
Wd-final C1	WI lab	WI vel	WI alv	WI vel
/t/	set put	bet case	pet toad	beg case
	cat boy	pot girl	fat day	pack king
	net mall	shoot goal	jet neck	shoot cat
/d/	red paint	bad Kate	aid terror	bag Kate
	sad bean	hood kick	lead deed	hook gap
	lead mope	good cook	side near	cook can
/n/	ten pats	sane cradle	man tie	sang cap
	loan bats	clean kit	pin deck	cling cook
	den mats	fine grade	soon nerve	thing grape

The last articulatory data come from the production of 24 two-word strings in English in which word-final /t/ can be deleted when followed by word-initial obstruent. Eight experimental as well as four control stimuli were created by combining two words. To obtain the experimental stimul and elicit the token which might undergo /t/-deletion, the first word ends with /st/ and the second word begins either with a labial (/p,b,f,v/) or with a velar (/k,g/) (e.g., *must pad, last cot*). In addition, to evaluate word-final /t/-deletion, control tokens were created, consisting of words ending with /st/ neighboring word-initial vowel (e.g., *must act*). By comparing the tongue position of the /t/ in a deletable context with the tongue contour of the nondeletable /t/, we attempted to judge whether word-final /t/ in the triconsontal cluster is genuinely deleted or partially preserved. To garner as natural data as possible, 24 tokens were read in the embedding phrase "Please say ___________".

(3) Materials for word-final /t/ deletion

Deletable context		Nondeletable context
C1: /t/ + C2: labials	C1: /t/+ C2: velars	C1: /t/ + V1
must pad	must cat	must act
last ball	last cot	beast earth
last foot	last gap	most income
most vat	most got	most on

2.3 Procedures

Two ultrasound imaging experiments were performed with two speaker groups, i.e., Korean EFL and Indian ESL speakers to extract the entire body of the tongue. Ultrasound is known to be conducive for imaging tongue root advancement (Ahn 2018, Gick et al. 2006). The ultrasound imaging task was conducted in a quiet phonetics room at a university in Korea. Recordings of articulatory and acoustic stimuli were conducted, and both data were obtained simultaneously using the Articulate Assistant Advanced (AAA) software. Each participant was seated before a computer that installed AAA software. The software was connected to an EchoB ultrasound machine. The machine had a 5 to 10 MHz convex-curved transducer, which took 82 frames per second across a 92° field of view. The transducer was connected to a microphone and fixed to the chin within the headset.

The subjects were instructed to read a list of stimuli embedded in the carrier sentences to a microphone fixed within the headset. The list of stimuli was written down in Korean or English orthography on several sheets of paper, and it contained three repetitions of the same tokens. The order of the stimuli was randomized; accordingly, the participants were asked to read it at a normal speaking rate. The AAA software recorded midsagittal images of the tongue along with acoustic data of the stimuli. The auditory signal from the microphone and the ultrasound visual signals from the ultrasound machine were synchronized using a SyncBrightUp unit (Articulate Instruments Ltd, 2010). The depth was set to 80 mm with a 5 to 10 MHz transducer.

After recording ultrasound images as well as audio data, midsagittal images of the alveolars from English stimuli were extracted because all the target segments for three phonological rules are alveolars (/t,d,n/). By scanning the spectrogram and waveforms visually presented on the AAA, the midpoint of the stop closure for alveolars or palatoalveolars was selected, and the frame of the closure was extracted. In the beginning phase of the stop closure, the tongue blade or tip does not reach the gestural peak—in particular, the complete closure and at its end point—so the tongue tip is more likely to be abducted from the alveolar ridge or more susceptible to strong anticipatory coarticulation with the following vowel. For this reason, the midpoint seems to reflect the gestural peak of alveolars.

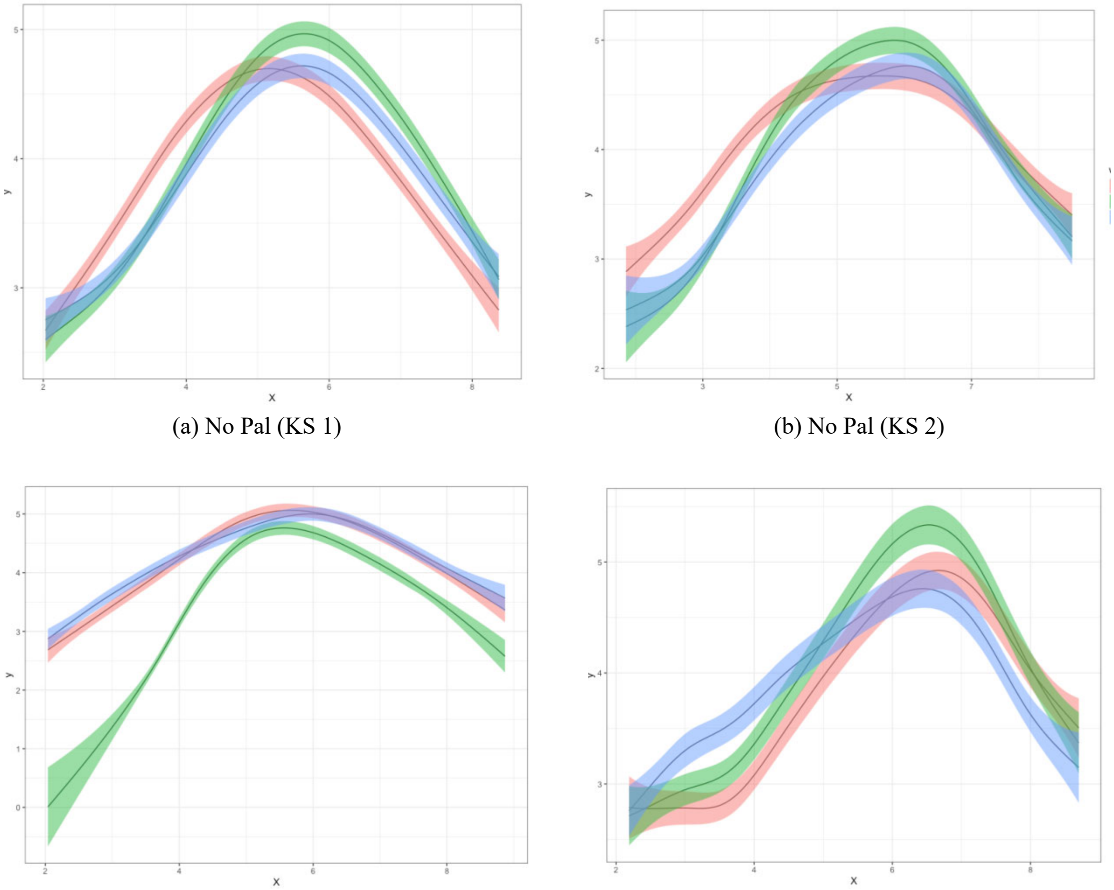
To quantify the tongue configuration, the extracted images were overlaid with the tongue contours by drawing the tongue body lines via the function of "Edit Splines" in AAA, as illustrated in Figure 2(a). Then, the tongue contours were again extracted in a series of x-y coordinates, as shown in Figure 2(b). These x-y coordinates were exported to the Excel files using AAA.

The adjusted tongue contours were subjected to a smoothing spline analysis of variance (henceforth, SSANOVA) for the statistical analyses (Davidson 2006, Gu 2002, 2014). An SSANOVA was used to test the significant differences between two or three tongue contours obtained from one speaker. Based on the (x-y) coordinate plots of the average tongue contours, the contour sets are calculated as significantly different when the confidence intervals (95%) from the set of contours do not overlap. This non-overlap of the tongue contours was evaluated as significantly different ($p < .05$).

2.4 Results

2.4.1 English palatalization

Ultrasound images obtained from Korean EFL speakers (KS) show that palatalization does not arise for a majority of KS. Figure 1 represents KS' tongue shapes of three types of consonants: (i) tongue contours of word-final alveolar (pink curve), (ii) tongue contours of word-final targets /d, t/ placed in a palatalization context (green curve), and (iii) tongue contours of the affricates /ʧ, ʤ / placed word finally in isolation words. (Note that it is sufficient to compare blue curves with green curves in order to check whether the target alveolar is realized as the derived palatal.) The x-axis represents the frontness dimension where the leftmost point is the tongue root and the rightmost point is the tongue tip. The y-axis refers to relative tongue body height in pixels. It is conceivable to interpret that palatalization has not occurred for KS 1, 2 or 4. As seen in Fig. 1(a, b, d), tongue contours of the word-final alveolars (marked as green lines) followed by a glide do not overlap with those of the underlying affricates (blue lines) placed in a non-palatalization context (e.g., *ma**d** you* >> *ju**dg**e*) and the former are placed further front than the latter. However, we found that one speaker (KS 3) palatalized most word-final alveolars followed by a glide. This is seen in Fig. 1(c) where the tongue contour of the alveolar neighboring a glide is positioned further back than that of the palatal in a non-assimilation context. Overall, it seems that the application or nonapplication of palatalization is contingent on the individual KS.



(a) No Pal (KS 1) (b) No Pal (KS 2)

(c) Pal (KS 3) (d) No Pal (KS 4)

Figure 1. SSANOVA plots of tongue contours from Korean speakers. Blue line refers to the range of tongue contour for the underlying affricates /ʧ, ʤ/ placed in a non-assimilation context, green line to the range of tongue contour for the alveolars placed in palatalization context, and pink line to the range of tongue contour for the underlying alveolars. (The x-axis refers to the frontness of the tongue body and the y-axis refers to the height of the highest point of the tongue body).

Furthermore, it was found that KS' applicability of palatalization is not affected by phonological or lexical factors such as target type (/t,d/), preceding vowel (/i, æ, u, ɔ /) or word frequency.

2.4.2 English coronal place assimilation

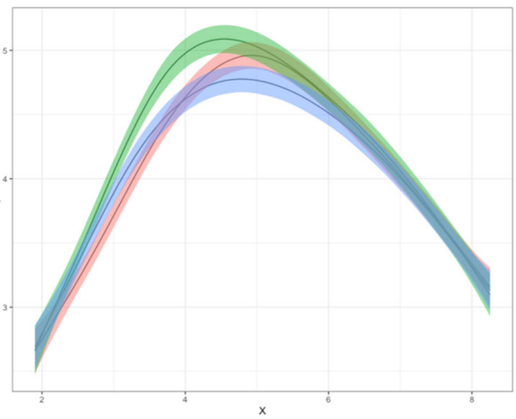
We classified articulatory patterns of tongue body contours into three types of variants by comparing tongue contours of the target consonants, i.e., word-final alveolars with those of the underlying alveolars: (i) PA (place assimilation), (ii) NPA (non-place assimilation), and (iii) HA (hyperarticulation). First, PA is the variant where the tongue front of an alveolar followed by a labial is articulated further front than that of an underlying alveolar. It is estimated that coronal-to-labial assimilation takes place because the tongue front of the coronal has moved backward (e.g., *set put* << *pet toad*, << represents "is placed further back than"). Second, we define NPA as the variant where the contour of tongue front region for the word-final alveolar preceding word-initial labial or velar overlap with that for the underlying alveolar (e.g., *se**t** put≈ pe**t** toad, be**t** case ≈ pe**t** toad*). The rationale behind this judgment is that the coronal-to labial or velar assimilation has not been applied from the fact that the tongue front part of the alveolar placed in the assimilation context is articulated in the same position as that of the underlying alveolar. The third type of variant is identified as HA because the tongue front of the alveolar preceding a labial or velar is placed further front than that of the underlying alveolar (e.g*., se**t** put >> pe**t** toad, be**t** case >> pe**t** toad*).

Table 1 shows the mean rates of three types of variants of word-final alveolars in place assimilation context elicited from KS. Overall, assimilated variants were dominant at 50%, non-assimilation forms were also common at 31%, and hyperarticulation variants were least frequent, amounting to 19%. As clearly seen below, the production pattern varies as the function of the place of the triggering consonants, i.e., a labial or velar. Articulatory results showed that coronal-to-labial assimilation occurred at 63% whereas coronal-to-velar assimilation was applied only at 38%. Interestingly, when a velar was a trigger, it drove hyperarticulation of the target alveolars quite frequently at 38% rather than place assimilation.

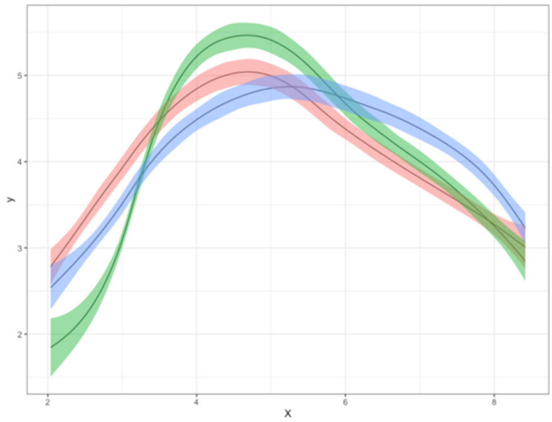
Table 1. Mean Rates (%) of Variants of Word-final Target Coronals in an Assimilation Context for KS

Variants	Word-initial consonants (C2)		
	Labials (e.g., *set put*)	Velars (e.g., *bet case*)	Total
PA	63	38	50
Non-PA	37	24	31
Hyperarticulation	0	38	19

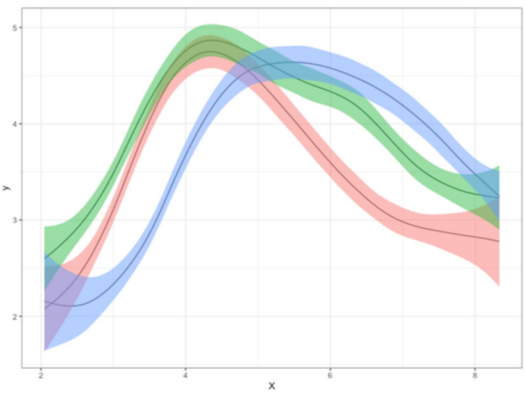
Figure 2 represents KS' tonguge shapes for assimilable word-final alveolars and non-assimilable alveolars. First, we focus on the mode of place assimilation that arises when the triggering consonant is a labial. The articulatory patterns seem to demonstrate that the applicability of coronal-to-labial assimilation depends on individual speakers. For example, the triggering labial did not induce assimilatioin at all for KS 1 as seen in Fig. 2(a) (e.g., *se[t] put*). This is evident from the complete overlapping of tongue contours between blue line and pink line in (2a). Conversely, KS 3 and KS 4 yielded place assimilation for a majority of the trigger as illustrated in (c) and (d) (e.g., *cat boy => ca[p] boy*). This coronal-to-labial assimilation can be easily confirmed from the further backing of tongue front region for the assimilable coronal (pink curve) than that for the non-assimilable coronal (blue curve) (e.g., *ca[p] boy* vs. *fa[t] day*). Furthermore, KS 2 exhibited alternation between assimilation and non-assimilation (b) (e.g., *se[p] put ≈ ca[t] boy*). Unlike the finding of Dilley and Pitt's (2007) corpus study, our results show that the likelihood of place assimilation does not seem to be affected by word-final consonant type or lexical frequency.



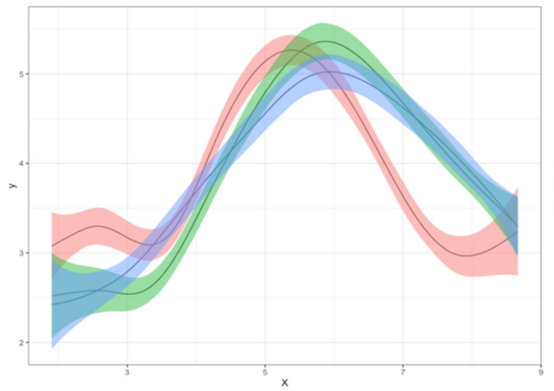
(a) No PA (KS 1)



(b) PA (KS 2)



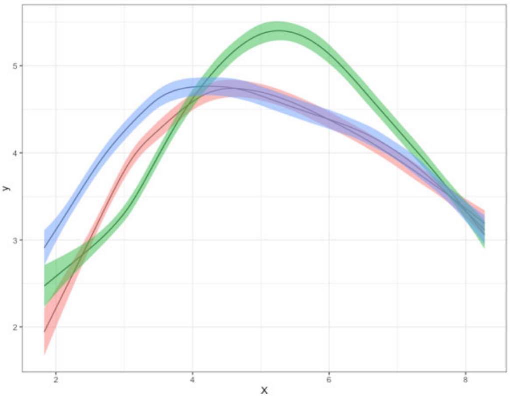
(c) PA (KS 3)



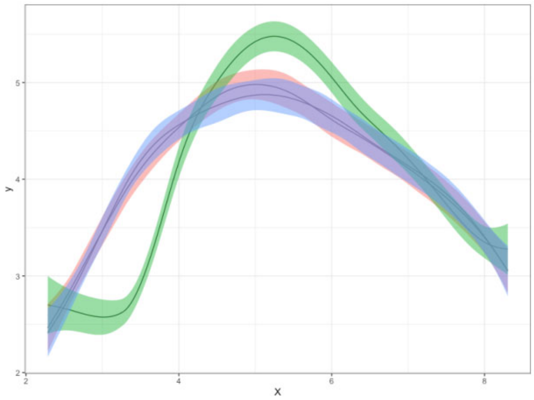
(d) PA (KS 4)

Figure 2. Tongue contours of the word-final alveolars (pink curve) and velars (green curve) placed in an assimilation context and those of word-initial alveolars placed in a non-assimilation context (blue curve) by production variants

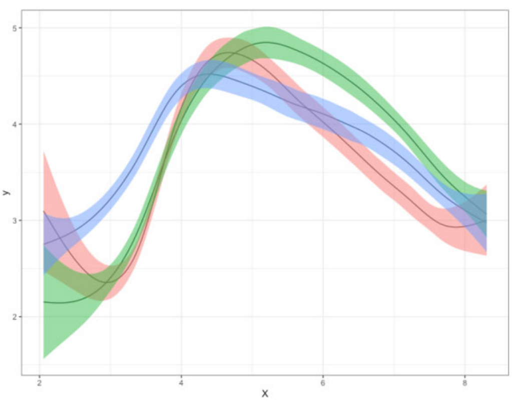
Compared to the applicability of coronal-to-labial assimilation, coronal-to-velar assimilation exhibited a wider spectrum of variation forms (e.g., assimilation, hyperarticulation, non-assimilated (canonical) forms). Assimilation variants and hyperarticulation forms were most frequent both at 38% whereas canonical (non-assimilated) forms constituted 24%. Hyperarticulation forms were observed uniformly across KS as seen in Figure 3. To be specific, tongue front part of the alveolar preceding a velar was articulated further front than that of the identical alveolar placed in a non-assimilation context (e.g., *se[t] put* vs. *pe[t] load*) (To confirm this, compare the frontness of green line ([t] in "set put") with that of blue line ([t] in "pet load") below).



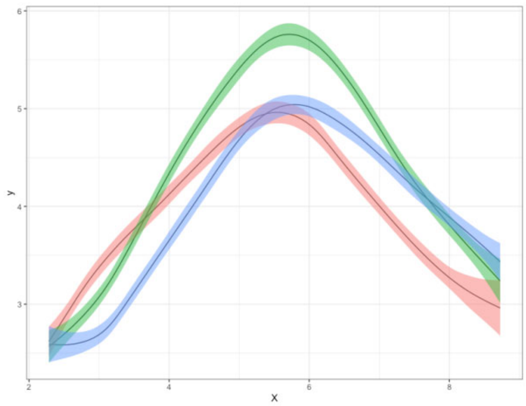
(a) HA (KS 1)



(b) HA (KS 2)



(c) HA (KS 3)



(d) HA (KS 4)

Figure 3. Tongue contours of the word-final alveolars (pink curve) and velars (green curve) placed in an assimilation context and those of word-initial alveolars placed in a non-assimilation context (blue curve) across subjects

In summary, KS assimilated word-final alveolars to labials more frequently than to velars, suggesting that coronal-to-labial assimilation is rather categorical whereas coronal-to-velar assimilation is applied in somewhat gradient fashion for KS.

2.4.3 English /t/-deletion

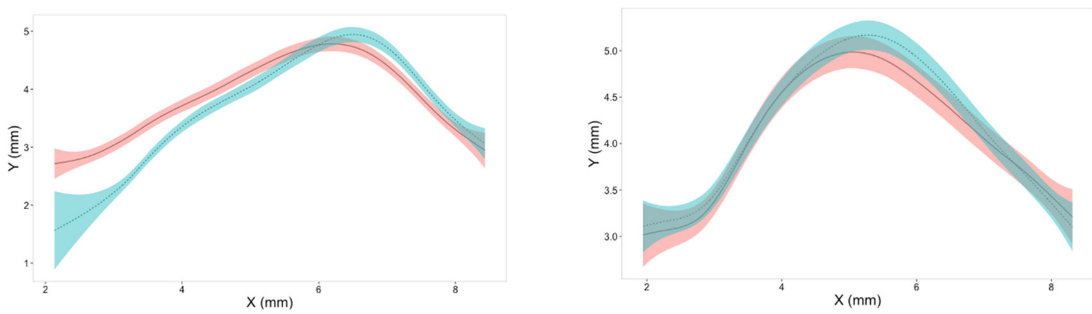
We investigated whether KS articulatorily delete word-final alveolar /t/ which is preceded by /s/ and followed by word-initial labial or velar. Furthermore, it was examined whether such deletion arises categorically or gradiently, if /t/-deletion occurs. We categorized the mode of /t/-articulation into three types: (i) deletion, (ii) no deletion, and (iii) hyperarticulation. Deletion refers to the variant where the tongue contour of the portion between /s/ and a following labial or velar does not overlap with that of the alveolar /t/ embedded in a non-deletion context (e.g., *mus**t** pad* << *mus**t** act*). Rather, the tongue body of the segment between consonants is positioned further back than that of the alveolar followed by a vowel. No Deletion variant can be characterized as the case where tongue contour of the alveolar /t/ portion between /s/ and the following labial or velar overlaps with that of /t/ preceding word-initial vowel. The last type of variant is hyperarticulation case where the tongue front region of the segment occupying the /t/ position is further front than that of /t/ placed in a non-deletion context. This articulation might be classified as target overshoot.

Table 2 shows mean rates of variants of word-final coronal /t/ placed in a deletion context for KS. It demonstrates that, C2 condition being collapsed, overall, the realization of /t/ was gradient, exhibiting three variants. The most dominant variant was a canonical form (i.e., no-deletion) at 43% and deletion arose quite frequently at 36% and the least common variant was a hyperarticulation form. The articulatory result suggests that word-final /t/-deletion for KS is gradient, not categorical. Addimitionally, what is of interest is the finding that 43% of tokens turned out to be no-deletion variants, suggesting that a great bulk of seemingly assimilated forms from auditory judgment are actually non-assimilated realizations from the articulatory perspective. This might be referred to as perceptual illusion. As seen in Table 2, the likelihood of /t/ deletion was affected by the type of the consonant following the target alveolar. Deletion occurred at 43% when the following consonant is a labial whereas the following velar induced /t/-deletion less frequently at 29%. Furthermore, for the labial condition, no-deletion varaints were dominant over deletion variants (57% vs. 43%). Interestingly, when the following consonant was a velar, the target was realized as hyperarticulation variant most frequently (42%).

Table 2. Mean Rates (%) of Variants of Word-final Target Coronals in a Deletion Context for KS

Variants	Word-initial consonants (C2)		
	Labials (e.g., *must pad*)	Velars (e.g., *must call*)	Total
Deletion	43	29	36
No-deletion	57	29	43
Hyperarticulation	0	42	21

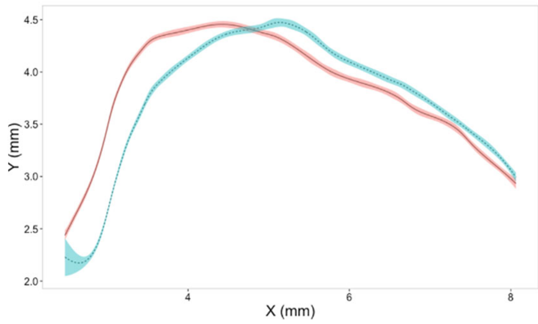
Figure 4 illustrates two types of word-final /t/ placed in a deletion context when the following consonant is a labial: (i) /t/-deletion, and (ii) no /t/-deletion (i.e., a canonical form). Figure 4(a) demonstrates that word-final /t/ flanking /s/ and a labial (pink curve) does not overlap with word-final /t/ following a vowel (blue curve), which suggests that the former undergoes deletion (e.g., "mus**t** pad" vs. "mus**t** act"). This deletion variant was realized for KS 1 and 4. Conversely, Figure 4(b) demonstrates that word-final /t/ followed by a labial (pink curve) is not deleted as is evident from its complete overlapping with word-final /t/ followed by a vowel (blue curve). This no-deletion form was found for KS 1, 2, and 3.



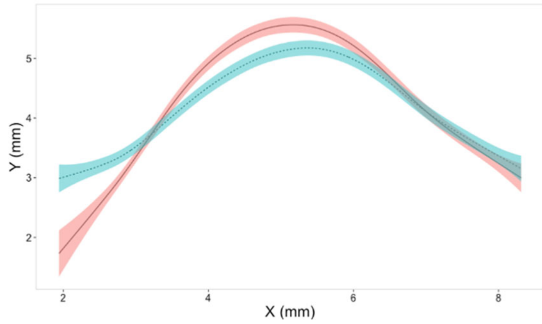
(a) /t/-deletion (KS1, 4) (b) No /t/-deletion (KS 1, 2, 3)

Figure 4. (a) SSANOVA tongue contours representing /t/ deletion before a labial, and (b) no-deletion (Blue curve refers to the tongue contour of /t/ followed by a vowel, and pink curve to that of the part corresponding to word-final /t/ before a labial.)

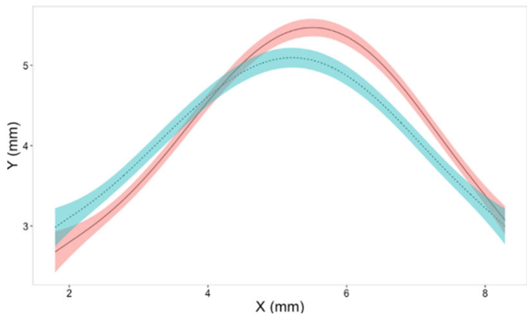
Figure 5 represents examples of tongue body contours for the word-final /t/ followed by a velar in a deletion context and for the identical /t/ placed in a non-deletion context. Unlike the labial C2 context, deletion in a velar context created three types of variants. First, /t/-deletion varaints emerge for KS 3 and 4 as seen in Figure 5(a). This can be seen from word-final /t/ (pink curve) articulated further back from word-final /t/ placed in a non-deletion context (blue curve). Additionally, another varaint was a canonical form (i.e., the underlying /t/) as is evident from Figure 5(b). There was no overlapping of the tongue contour of the /t/ followed by a velar (pink curve) with that of the /t/, which is indicative of no-deletion. Finally, KS 1 showed hyperarticulation or target overshoot where word-final /t/ placed in a deletion context (pink curve) is articulated further front than the identical /t/ place in a non-deletion context (blue curve). This gestural overshoot variant was not observed when the following consonant is a labial.



(a) /t/-deletion (KS 3, 4)



(b) no /t/-deletion (KS 1, 2)



(c) hyperarticulation (KS 1)

Figure 5. (a) SSANOVA tongue contours representing /t/ deletion before a velar, (b) no-deletion and (c) hyperarticulation (Blue line refers to the tongue contour of /t/ followed by a vowel, and pink line to that of the part corresponding to word-final /t/ before a velar.)

Our articulatory results show individual speaker patterns for word-final /t/ deletion as to what type of deletion is favored by individual speakers. Specifically, KS 1 deleted word-final /t/ only when the following consonant is a labial, not a velar. KS 2 did not realize /t/ deletion. KS 3 favored /t/ deletion in a velar context, not in a labial context. KS 4 applied /t/ deletion both in a labial and velar condition.

3. Experiment 2: Indian ESL Speakers

3.1 Participants

Eight Indian subjects (henceforth, IS) participated in the ultrasound imaging experiment. Before they participated, they were asked to fill out a questionnaire form to garner their background information. All of the participants are from Tamil Nadu, India, whose official language is known to be Tamil, a Dravidian language. Tamil is widely spoken mostly in the southern states of India, including Tamil Nadu and northern and eastern part of Sri Lanka. All participants are native speakers of Tamil. They all reported that their L1 is Tamil and their L2 is English and they are fluent in both languages. They were born and raised in the families who spoke Tamil at home. Since they started to receive formal education, they learned English and used it in their day lives. Their ages were on average 22.4 years old, ranging from 20 to 25 (SD: 2.1). All of them were male. At the time of participaing in this experiment, they were living in Korea and working for a private enterprise.

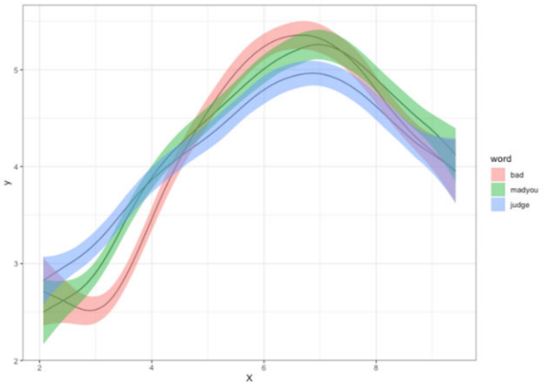
3.2 Materials and Procedure

The materials and procedure were the same as in Experiment 1.

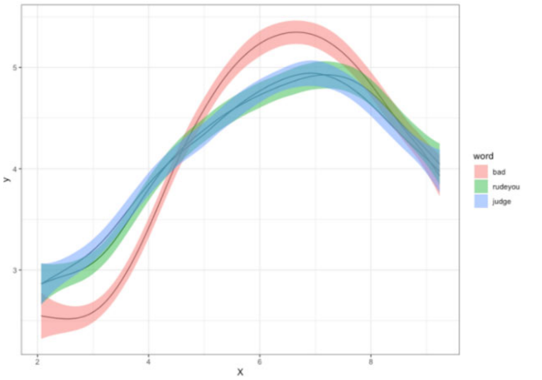
3.3 Results

3.3.1 English palatalization

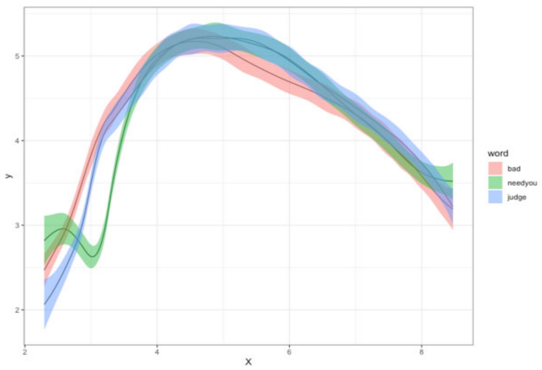
The results show that a great majority of Indian Tamil speakers do not yield palatalization across word boundary. However, some speakers exhibited variations between the palatalization and its non-application (IS 1) whereas others palatalized most of the word-final alveolars (IS 2). Others did not apply palatalization (IS 3, IS 4). Figure 6 presents 3-way comparison of tongue contours for underlying alveolars, alveolars placed in a palatalization context (or derived palatals), and underlying palatals produced by Indian ESL speakers. The applicability of palatalization can be classified into three types, depending on individual speakers as illustrated below. The first type is the case shown by IS 6 (a) and (b) where palatalization occurs for some stimuli whereas it does not arise for other stimuli. To be specific, no palatalization is confirmed as evident in Fig. 6(a) where tongue contours of word-final alveolars (green line) overlap with those of underlying alveolars (pink line) but do not overlap with those of underlying palatals (blue line). Fig. 6(b) shows that the tongue contours for the word-final alveolar /d/ completely overlap with those for the underlying palatal /ʤ/; both these contours do not overlap with those for the underlying alveolar /d/ with respect to the central, highest region of the tongue. This suggests that palatalization occurred categorically. The second individual type is shown in Fig. 6(c) and (d), i.e., the production by IS 2. IS 2 palatalized word-final alveolars across word boundary. As in Fig. 6(c), tongue contours of the alveolars placed in a palatalization context substantially overlap with those of underlying palatals with reference to the region of tongue front. The third type of individual variation in the application of palatalization is seen in Fig. 6(e) and (f) showing the production pattern for IS 4. As is visualized, tongue contours of word-final alveolars are not significantly different from those of underlying alveolars, suggesting that palatalization does not occur at all.



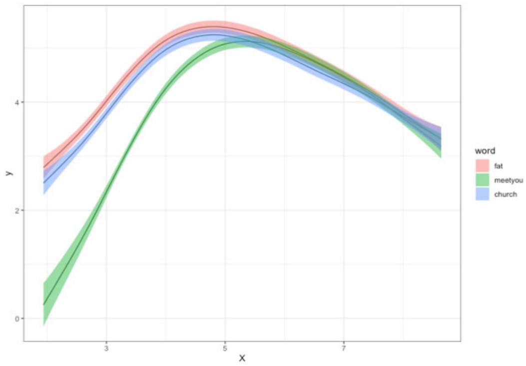
(a) No pal. (IS 1)



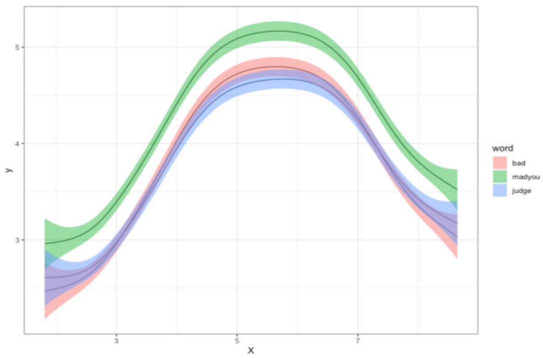
(b) Pal. (IS 1)



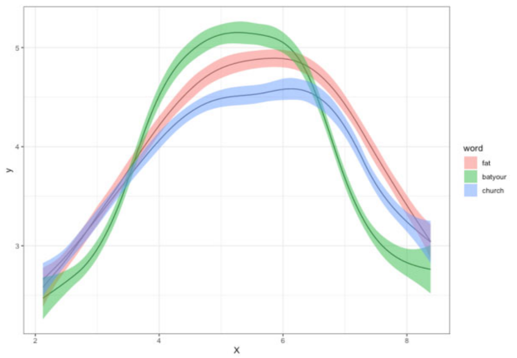
(c) Pal. (IS 2)



(d) Pal. (IS 2)



(e) No pal. (IS 4)

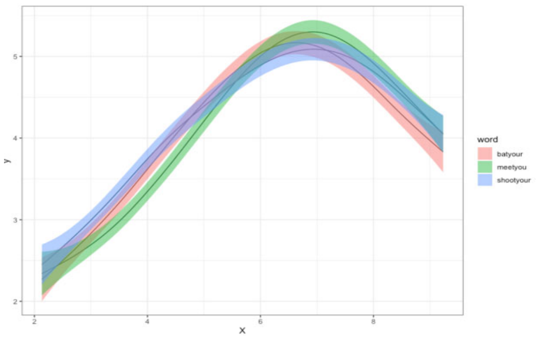


(f) No pal. (IS 4)

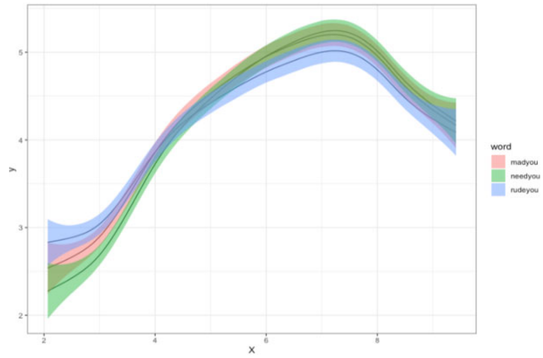
Figure 6. SSANOVA plots of tongue contours from Indian speakers (Blue line refers to the range of tongue contour for the underlying affricates /ʧ, ʤ/, green line to the range of tongue contour for the alveolars placed in palatalization context, and pink line to the range of tongue contour for the underlying alveolars.)

In addition to the investigation of interspeaker variation in the applicability of palatalization among IS, we looked into the variation of palatalization within speakers whether the degree of palatalization differs in view of tongue body configuration, depending on the preceding vowels, target consonants, individual token, etc. Figure 7 shows tongue contours of the word-final alveolars, the target of palatalization produced by some individual IS.

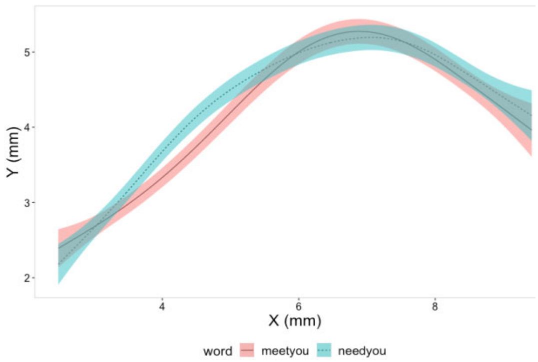
For example, Fig. 7(a-b) show that tongue contours for the alveolars /t, d/ placed in a palatalization context completely overlap, suggesting that they are not significantly different. This is indicative of no variation, i.e., the degree of palatalization is not divergent in accordance with the preceding vowels /æ, i, u/, the target consonants being equal. Furthermore, Fig. 7(c, d, e) obtained from IS 1, IS 2 and IS 3 show that /t/-derived and /d/-derived palatals seem to be substantially overlapped in tongue contours, suggesting that the target consonant is not a factor determining the degree of palatalization.



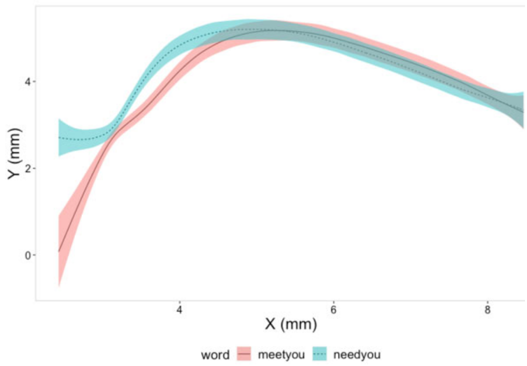
(a) bat you vs. meet you vs. shoot your (IS 1)



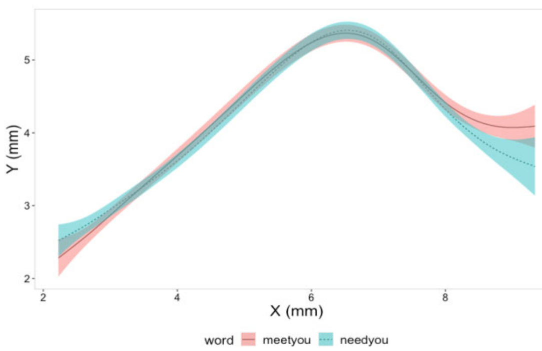
(b) mad you vs. need you vs. rude you (IS 1)



(c) meet you vs. need you (IS 1)



(d) meet you vs. need you (IS 2)



(e) meet you vs. need you (IS 3)

Figure 7. SSANOVA plots of tongue contours from Indian speakers

In summary, our articulatory results show that interspeaker variation arises in the mode of production of English palatalization by Indian ESL speakers. Furthermore, we found that the word-final target consonants or preceding vowels do not contribute to the variation in tongue body placement within the individual IS.

3.3.2 English coronal place assimilation

We examined whether and how IS apply coronal place assimilation to a word-final alveolar followed by a labial or velar. To this end, we looked into the tongue contours of the alveolars placed in an assimilation context. We classified articulatory results of tongue body contour images into three types of variants by comparing tongue contours of the target consonants, i.e., word-final alveolars with those of the underlying alveolars: (i) PA (place assimilation), (ii) NPA (non-place assimilation), and (iii) HA (hyperarticulation). This classification is the same as the one made with respect to the results found for KS (refer to Section 2.4.2).

Table 3 shows mean rates of production variants of word-final coronals (/t,d/) articulated in a place assimilation context. As is evident, the production pattern for the target coronals differs according to the triggering consonants, i.e., a labial or velar. When the triggering consonants are labials, coronal-to-labial assimilation arose at 81% and the type of non-assimilation variants constituted only 19%. On the other hand, the dominant variants were non-assimilated ones at 50% when the following consonant is a velar. Coronal-to-velar assimilation occurred at 31% and interestingly enough, hyperarticulation variant reached 19%.

Table 3. Mean Rates (%) of Variants of Word-final Target Coronals in an Assimilation Context for IS

Variants	Word-initial consonants (C2)		
	Labials (e.g., *set put*)	Velars (e.g., *bet case*)	Total
PA	81	31	56
Non-PA	19	50	35
Hyperarticulation	0	19	9.5

Most of IS applied coronal-to-labial assimilation, changing word-final coronals to labials as illustrated in Figure 8 below. This can be drawn from the finding that the tongue contours of the coronals do not overlap with those of the underlying alveolars placed in a non-assimilation context and the tongue body of the target alveolars are articulated further back than those of the non-assimilated alveolars. This is illustrated in Figure 8 below from seven IS' production. To be specific, for all speakers, the tongue contour of target consonant /t/ in "se**t** put" is placed further back than that of /t/ embedded in non-place assimilation context in "pe**t** toad". (Note that pink lines do not overlap with blue lines and the former are positioned virtually further back than the latter.) The finding that word-final coronal is articulated as labials is consistently and clearly observed across all the Indian speakers (IS 1 to IS 8).

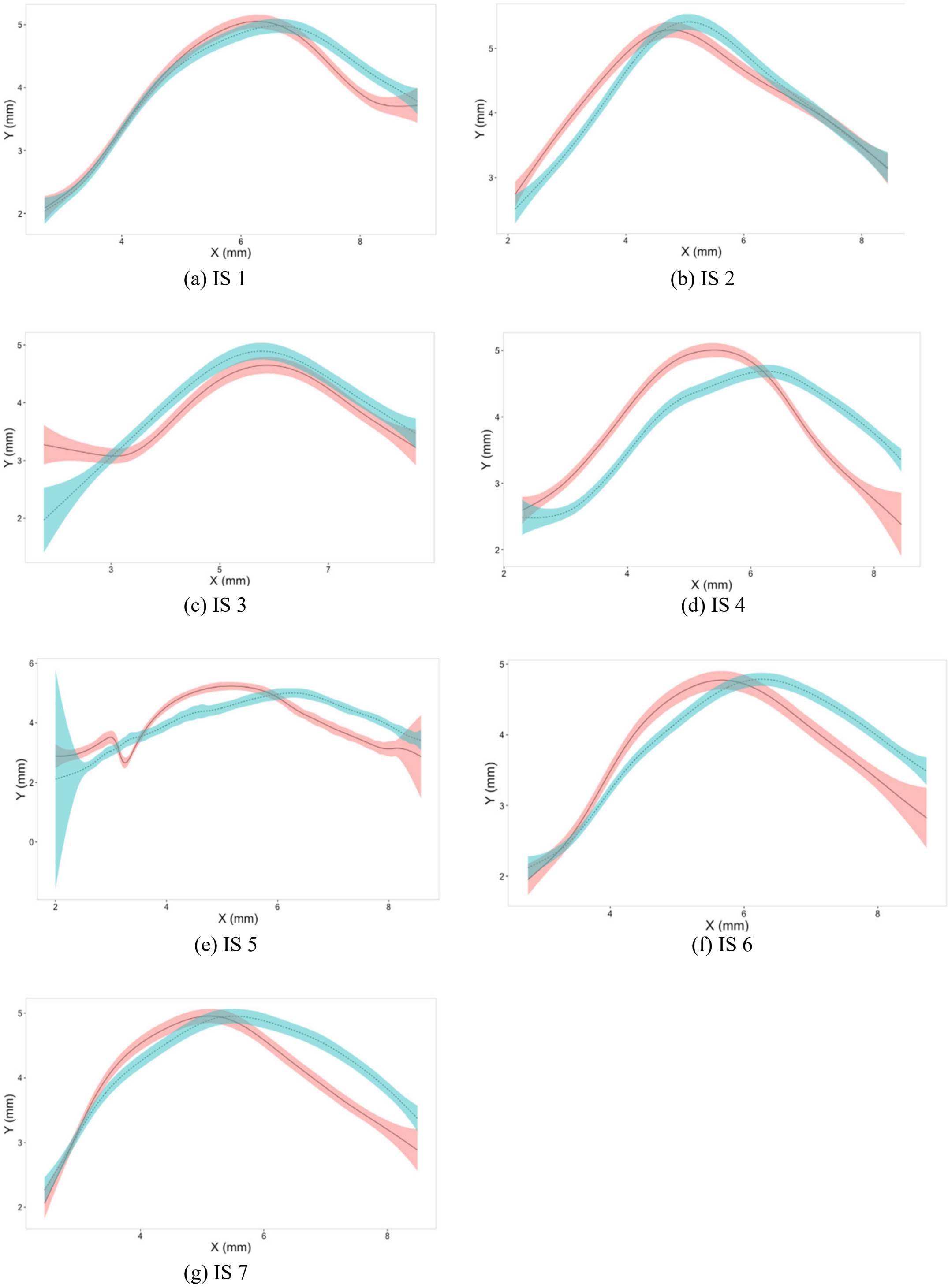
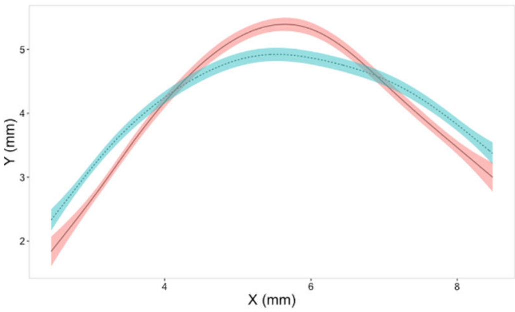
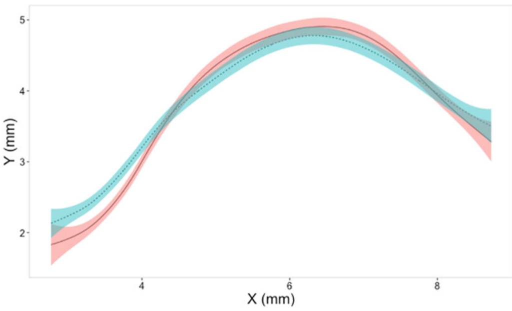


Figure 8. Tongue contours of the word-final alveolars (pink line) and placed in an assimilation context and those of word-initial alveolars placed in a non-assimilation context (blue line) (The x-axis refers to the frontness of the tongue body and the y-axis refers to the height of the highest point of the tongue body).

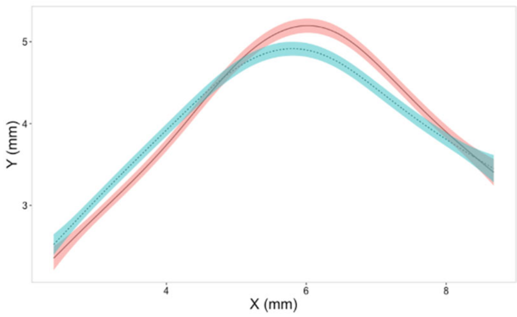
Unlike the strikingly uniform pattern of coronal-to-labial assimilation across word boundary, coronal-to-velar assimilation exhibits a wider range of inter-speaker variation concerning the tongue contours of the target coronals. As previously described, we classified their productionn into three types: (i) coronal-to-velar assimilation, (ii) non-assimilation and (iii) hyperarticulation. For instance, coronal-to-velar assimilation is observed for IS 7 in Figure 9(a) below. The region of tongue back for word-final coronal befor a velar is articulated higher and further back, compared to the tongue contour of the coronal placed in a non-assimilation context. This type is evident in Fig. 9(a) below that the pink curve is positioned higher than the blue curve. The second variant corresponds to non-place assimilation where the tongue contour of the word-final coronal before word-initial velar overlaps with that placed in the non-assimilation context. This is observed in IS 1 (a) and IS 6 (f) as illustrated in Figure 9 (b). The last type of variant is hyperarticulation where tongue contour of the coronal followed by an velar is placed further front than that of the coronal couched in the non-assimilation context unlike our expectation. This is observed in two speakers (IS 3 and IS 4) as is evident in Fig. 9 (c).



(a) Assimilation (IS 7)



(b) Non-assimilation (IS 1, IS 6)



(c) Hyperarticulation (IS 3, IS 4)

Figure 9. Variants of coronals placed in a place assimilation context

Put together, our results reveal that Indian ESL speakers seem to produce coronal-to-labial assimilation categorically and uniformly whereas coronal-to-velar assimilation is applied gradiently across speakers.

3.3.3 English /t/-deletion

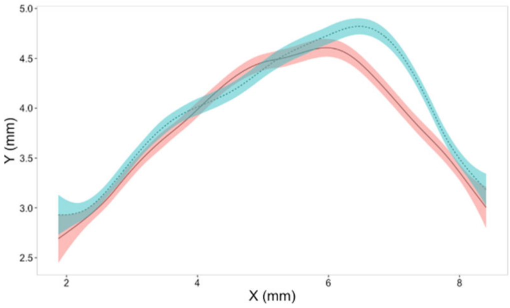
We focused on whether IS articulatorily delete word-final alveolar /t/ which is preceded by /s/ and followed by word-initial labial or velar. The same criteria as used to categorize KS' production data hold true for IS' production results. (Refer to Section 2.4.3 for the types of classsification.)

Based on this criteria, we calculated the mean rates of each variant regarding the production of the alveolar target placed in a /t/ deletion context. As seen, deletion variants constituted 38%, non-deletion variants were also quite frequent, accounting for 36%, and hyperarticulation cases were least 28%. The realization pattern of word-final /t/, i.e., the target for deletion differed according to the place of the following consonants. To be specific, deletion variants were dominant at 50% when the following consonant was a labial and the next frequent ones were non-deletion forms, amounting to 31%. Hyperarticulation variants were the least frequent at 19%. However, a divergent pattern emerged when the following consonant is a velar. For this condition, non-deletion variants arose most frequently at 41% and hyperarticulation variants were also common, reaching 34%. Word-final /t/ was deleted at 25% when followed by a velar.

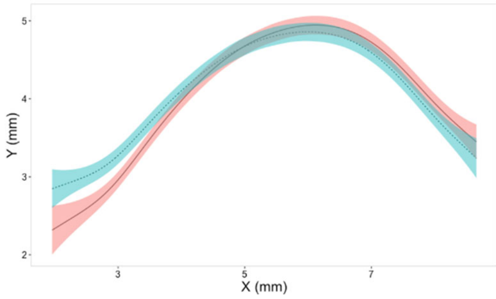
Table 4. Mean Rates (%) of Variants of Word-final Target Coronals in a Deletion Context for IS

Variants	Word-initial consonants (C2)		
	Labials (e.g., *must pad*)	Velars (e.g., *must call*)	Total
Deletion	50	25	38
No-deletion	31	41	36
Hyperarticulation	19	34	28

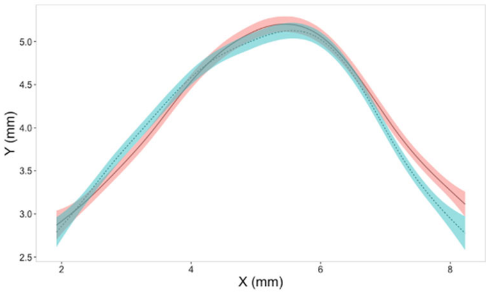
Figure 10 illustrates SSANOVA tongue contours for /t/ deletion (a), no-deletion of /t/ (b), and hyperarticulation of /t/ (c) when word-final /t/ is preceded by /s/ and followed by a labial (/p, b, f, v/). We observed the tongue contours for /t/-deletion for all IS (1 to 8). As seen in (a), the region of tongue front of the /t/-corresponding segment (pink curve) is placed substantially further back than that of the /t/ followed by a vowel, i.e., surface [t] in a non-deletion context (blue curve). No deletion variant is also observed in six out of eight Indian speakers (IS 1, 3, 4, 6, 7, 8). Tongue contours for the /t/-part before a labial and for the /t/ placed in a non-deletion context overlap as is clearly delineated in Fig. 10(c) represents the tongue contour for hyperarticulation of /t/. The /t/ placed in a deletion context is not virtually deleted but rather is articulated further front than /t/ embedded in a non-deletion environment. This seemingly “target overshoot” occurs for 5 speakers (IS 2, 3, 4, 5, 6). No deletion variants are also found when /t/ is followed by a velar across many speakers (IS 1, 2, 3, 4, 5, 7, 8).



(a) /t/ deletion



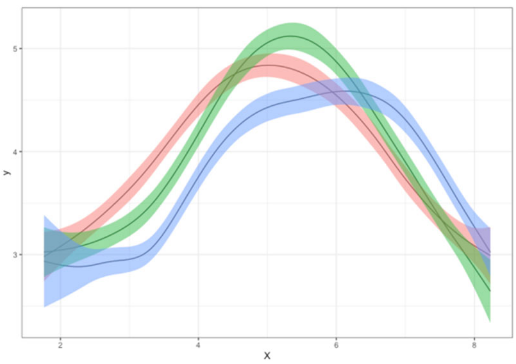
(b) No deletion



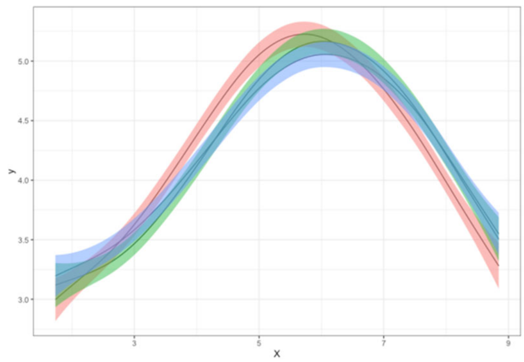
(c) Hyperartculation

Figure 10. (a) SSANOVA tongue contours representing /t/ deletion before a labial, (b) no-deletion anc (c) hyperarticulation (Blue line refers to the tongue contour of /t/ followed by a vowel, and pink line to that of the part corresponding to word-final /t/ before a labial.)

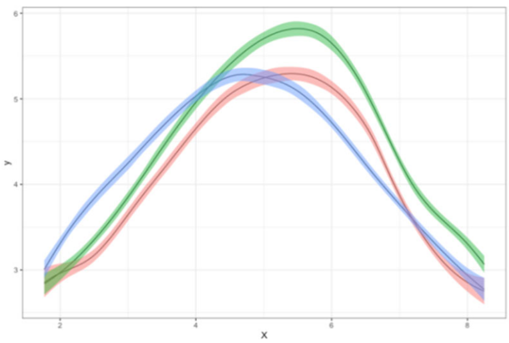
Figure 11 illustrates three types of production variants involved in the articulation of /t/ followed by a velar /k, g/. (Note that for this case, compare blue curve with green curve in view of the frontness of the front part of the tongue.) Fig. 11(a) shows the /t/ deletion variant reflected in the further front positioning of the tongue contour for /t/ placed in the non-deletion context (blue line) than that for /t/ followed by a velar (green line). This deletion variant was observed across many speakers (IS 2, 4, 5, 6, 7, 8). No deletion variants are also found when /t/ is followed by a velar across many speakers (IS 1, 2, 3, 4, 5, 7, 8) as illustrated in Fig. 11(b) where two tongue contours marked by green and blue lines completely overlap with each other. This is confirmed by our finding that the /t/ flanked by /s/ and /k, g/ is positioned exactly in the same region as the /t/ followed by a vowel. Hyperarticulation of the /t/ is found to be more common before a velar than before a labial as is evident from (c). The tongue body contour for the /t/ placed in the deletion context (green line) is placed further front than that for the /t/ followed by a vowel (blue line).



(a) /t/ deletion



(b) No deletion

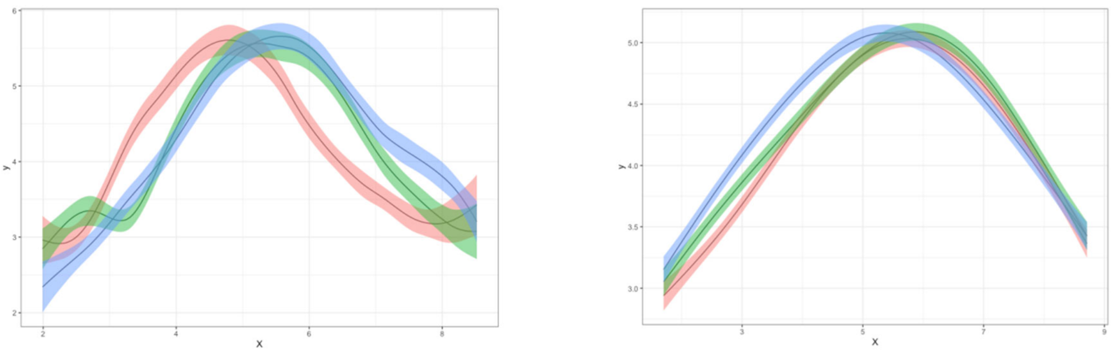


(c) Hyperarticulation

Figure 11. (a) SSANOVA tongue contours representing /t/ deletion before a velar, (b) no-deletion anc (c) hyperarticulation (Blue curve refers to the tongue contour of /t/ followed by a vowel, pink curve to that of the part corresponding to word-final /t/ before a labial, and green curve to that of /t/ before a velar.)

We observed that the word-final alveolar /t/ is deleted, not deleted or hyperarticulated whether it is followed by a labial or velar. The occurrences of these production variants, however, differ according to whether the following vowel is a labial or velar. Furthermore, we found that most IS exhibit more than two of these production variants.

Finally, it was observed that word-final /t/ showed variation between a labial condition and a velar condition (Figure 12 (a)) or no variation (Figure 12 (b)). As seen in Fig. 12(a), the tongue contour for the /t/ before a labial does not overlap with that for the /t/ before a velar. On the other hand, the tongue contours for the /t/s in both conditions are in complete overlapping relations with each other, exhibiting no variation regardless of the following consonant as can be seen in Fig. 12(b). Six speakers (IS 1, 2, 3, 4, 6, 7) showed these two types whereas two speakers (IS 5, IS 8) showed only one type, i.e., either variation or no variation. This result suggests that English alveolar deletion is gradient rather than categorical for IS.



(a) Variation between /t/s in a labial and velar condition (b) No variation

Figure 12. (a) SSANOVA tongue contours representing variations of /t/ deletion in a labial and a velar condition and (b) no variation of /t/ deletion (Blue curve refers to the tongue contour of /t/ followed by a vowel, pink curve to that of the part corresponding to word-final /t/ before a labial, and green curve to that of /t/ before a velar.)

4. Discussion

This study examined EFL and ESL speakers' phonological variation of their target languages, addressing three research questions: (1) Do EFL or ESL speakers exhibit phonological variation? (2) Do the spectrum of phonological variation differ in their magnitude according to individual rules? (3) Do EFL speakers show different patterns of phonological variation from ESL speakers?

Ultrasound tongue contours from this study show that both Korean EFL and Indian ESL speakers produce a spectrum of phonological variation in their target language English. First, both KS and IS realized the word-final alveolars /t, d, s, z/ placed in a palatalization context as two variants, i.e., (1) palatoalveolar affricates [ʧ, ʤ] and (2) a canonical form (i.e., underlying alveolars). KS did not palatalize the targets at 74% and palatalized variants constituted only 26%. Likewise, for IS, canonical variants were dominant at 80% and palatalization forms were less common at 20%. Both speaker groups seem to have applied English palatalization optionally, not obligatorily. As previously mentioned, our results show that the likelihood of palatalization is quite low and it is not affected by string frequency, target consonant type or preceding vowel for both groups. These results for KS and IS are not in agreement with those for native English speakers (Bush 2001, Cooper and Paccia-Cooper 1980, Kreidler 1989). For example, palatalization occurred in low string frequency phrase such as "mad you" (with frequency 0) whereas high string frequency sequence like "need you" (with frequency 2113) did not induce palatalization.

This rarity of palatalization might be interpreted in such that KS and IS might not have acquired the mode and context where the rule is applied. In Tamil, palatalization is known to apply optionally in spoken colloquial style, and Korean palatalization is obligatorily applied across morpheme boundary (Schiffman 1999, Sohn 2001). Accordingly, they might have focused on orthography and hyperarticulated the word-final target alveolars, blinding themselves to a multitude of lexical and phonological factors such string frequency or target type.

For the production of English place assimilation, articulatory results found for both KS and IS show a similar spectrum of variants, e.g., assimilation form, non-assimilation form (i.e., canonical forms) and hyperarticulation variants as is seen in Table 8. Coronal-to-labial assimilation induced only two variants (e.g., assimilation forms and non-assimilation forms) whereas coronal-to-velar assimilation led to three variants (e.g., assimilation, non-assimilation and hyperarticulation) as is summarized in Table 5. Interestingly, overall, the likelihood pattern of place assimilation for KS parallel that for IS. Assimilation variants were dominant, non-assimilation forms were quite common and hyperarticulation variants were least common. However, the likelihood of assimilation differed according to the word-initial trigger consonants. To be specific, coronal-to-labial assimilation occurred more frequently for IS than for KS (81% vs. 63%). However, coronal-to-velar assimilation rule seems to be applied slighlty more often for KS than for IS, in view of average rates of occurrences (38% vs. 31%). As a result, half of the tokens did not undergo coronal-to-velar assimilation for IS as is evident from 50%. It is not clear why this asymmetry or bias in the likelihood of assimilation is attested between these types for both groups.

Table 5. Mean Rates (%) of Variants of Targets Placed in an Assimilation Context for KS and IS

Variants	KS			IS		
	Word-initial Consonants			Word-initial Consonants		
	Lab	Vel	Total	Lab	Vel	Total
Assim	63	38	50	81	31	56
Non-assim	37	24	31	19	50	34
Hyperartic	0	38	19	0	19	10

What is worth mentioning is the finding that non-assimilation forms are quite common with respect to coronal-to-labial assimilation for KS (37%) and are dominant regarding coronal-to-velar assimilation for IS. This is a striking finding in the sense that a great bulk of production variants seem to have undergone place assimilation from the auditory judgment but in fact, are not assimilated from the articulatory perspective. Crucially, the ultrasound imaging technique used in this study revealed that in a multitude of tokens, tongue contours of the target alveolars are placed in the region of alveolar ridge in an assimilation context as those of the alveolars embedded in a non-assimilation context. This case might fall into the category of perceptual illusion as illustrated and repeated in Figure 12. This perceptual place assimilation was also found in Japanese moraic nasal /n/ produced by English L2 Japanese learners (Mizoguchi et al. 2019). Their ultrasound study found that moraic nasal [n] in “anga” is not involved in the contact with the soft palate like [n] in “anata” but does not overlap with the tongue contour of a velar [g] in “hagata”. Articulatorily, the nasal is positioned similar to the non-moraic /n/ but it sounds like the assimilated [ŋ]. Perceptually illusory assimilation is commonly interpreted to arise due to gestural overlap between the tongue tip closure of the word-final alveolar and lip closure of the following labial or tongue dorsum contact with the soft palate (Browman and Goldstein 1995, Byrd 1995). Figure 13 demonstrates that tongue contours of the tongue front part of /t/ completely overlap among /t/ in coronal-to-labial assimilation, coronal-to-velar assimilation and non-assimilation contexts, suggesting that despite the application of auditory assimilation, articulatory assimilation has not occurred.

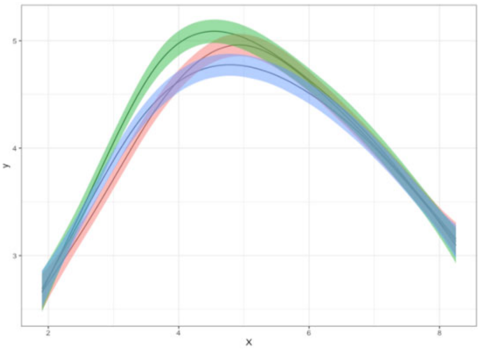


Figure 13. Tongue contours of [t] in "cat boy" (pink curve), [t] in "pot girl" (green curve) and [t] in "pet toad" (blue curve)

For native English speakers, it was found that the likelihood of regressive place assimilation differed according to the word-final target consonants (Dilley and Pitt 2007). Their Buckeye Corpus study showed that word-final /n/ was assimilated most, then /d/ and then /t/ (73% vs. 51% vs. 25%). Furthermore, more frequent words such as function words produced a wider spectrum of variant forms (e.g., assimilation, deletion, glottalization, etc.) than less frequent ones. Conversely, the results in the current study do not pattern with these previous findings. It suggests that KS and IS might not have been exposed to the distributional pattern of the exemplars like native English speakers.

In addition, our results found that production of word-final /t/ placed in a deletion context engendered variations for KS and IS. As is repeated in Table 6 below, KS and IS exhibited three types of variants in a /t/ deletion context: (i) deletion, (ii) non-deletion (e.g., a canonical form), and (iii) hyperarticulation. But these groups showed a slightly different pattern of the spectrum of variants. For KS, canonical forms were more dominant than deletion variants whereas IS elicited deletion variants more frequently than non-deletion forms. This suggests that more proficient IS tend to apply final [t] deletion more than less proficient KS.

Moreover, as can be seen in Table 6 below, the width of the spectrum of variants and the likelihood of the /t/ deletion also differ across speaker groups as well as phonological context. First, for KS, final /t/s were realized as canonical (underlying) forms more frequently than deletion variants when the following consonant was a labial (57% vs. 43%). However, when the target /t/ was followed by a velar, hyperarticulation variants were dominant (e.g., *mus[t] cap*). Also the spectrum of the /t/ variants were wider for a velar condition than for a labial condition. This suggests that KS make more efforts to maintain the final, underlying /t/ before a velar than before a labial, suggesting stronger resistance to /t/ deletion. Second, regarding the IS' production, deletion variants were dominant, compared to non-deletion forms when the following consonant was a labial, which is in marked contrast with KS' pattern. Additionally, word-final /t/ did not undergo deletion most often before a velar. Similarly to KS, IS also hyperarticulated final /t/ quite frequently.

Table 6. Mean Rates (%) of Variants of Targets Placed in a Deletion Context for KS and IS

Variants	KS			IS		
	Word-initial Consonants			Word-initial Consonants		
	Lab (e.g. *must pad*)	Vel (e.g., *must cat*)	Total	Lab (e.g., *last ball*)	Vel (e.g., *last cot*)	Total
Deletion	43	29	36	50	25	38
Non-del	57	29	43	31	41	36
Hyperartic	0	42	21	19	34	28

Unlike previous studies on English corpus data by Jurafsky et al. (2009), our results for KS and IS did not confirm the effect of lexical frequency on the likelihood of /t/ deletion. The corpus-based analysis showed that probability of /t,d/ deletion word finally is affected by word frequency, i.e., high-frequency words (e.g., *want, just*) are more likely to delete /t/ than low-frequency words (e.g., *closed, draft*). However, due to a very limited number of token words in this study, this frequency effect was not tested.

5. Conclusion

The articulatory results based on ultrasound imaging indicate that EFL and ESL speakers show phonological variation in their target language with reference to three rules such as palatalization, coronal place assimilation, and word-final /t/ deletion. The results are crucial in the sense that EFL and ESL learners produce a wide spectrum of pronunciation variants as native speakers would do. It may imply that the application of phonological rules are inherently gradient rather than categorical. This universal feature of phonological variation makes it possible to interpret the results such that Korean EFL learners and Indian ESL speakers who participated in this study might be on the right trajectory to their L2 learning. It is also shown that the extent of the spectrum of production variants differs according to individual phonological rules or context. Finally, it is observed that the likelihood of each phonological variant varies according to whether the speaker group is EFL or ESL learners or depending on phonological environment.

Future articulatory investigation on the effects of lexical frequency and other phonological contexts will accrue the knowledge of phonological variations in view of tongue root advancement or the degree of constriction of the tongue body against the roof of the mouth in the oral cavity. Also the examination of the ESL speakers with different proficiency will lead us to a better understanding of language learners' phonological rule application.

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Examples in: English
Applicable Languages: English
Applicable Level: Tertiary

