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Categorical and gradient effects in segmental deletion: The case study of /w/-deletion in Seoul Korean*

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Kwon, Soohyun. 2024. Categorical and gradient effects in segmental deletion: The case study of /w/-deletion in Seoul Korean. *Linguistic Research* 41(1): 169-189. An increasing body of evidence suggests that phonological processes exhibit both categorical and gradient effects. This study investigates categorical and gradient effects observed in /w/-deletion in Seoul Korean and how the patterns differ by context. Using ultrasound and a side-view camera, midsagittal images of the tongue and lip protrusion of four participants were recorded. The speakers participated in the task of explaining the semantic differences between 18 words of CV and CwV sequence (e.g. *tweji* 'pig' vs. *teji* 'earth'). Optical Flow Analysis was used to quantify the magnitude of lip and tongue movement. Results show that different patterns of categorical and gradient effects of /w/-deletion are observed by context. When /w/ is preceded by a bilabial, /w/ tends to delete categorically, while both categorical deletion and gradient reduction appear to occur when /w/ is preceded by an alveolar or a velar. I argue that the categorical and gradient effects of a related phonological process can be present simultaneously, which can be accounted for by diachronic development of sound patterns. **(Seoul National University)**

Keywords categorical deletion, gradient reduction, glide deletion, Seoul Korean, ultrasound

1. Introduction

An increasing body of evidence from studies in phonetics, phonology, and sociolinguistics suggests that phonological processes often exhibit both categorical and gradient effects. For instance, Turton (2014, 2017) demonstrated that varieties of British English

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(e.g. Received Pronunciation, London, Liverpool, Manchester English) exhibit different patterns of categorical allophony and gradient phonetic effect in terms of /l/-darkening. The tensing of short a in Philadelphia English was shown to consist of a stem-level categorical rule that distinguishes lax /æ/ from tense /æ:/, and a gradient rule through which the precise location of tokens of /æ:/ in F1/F2 space is determined (Labov 1994). The production of /s/ in Spanish was found to exhibit both categorical and gradient outcomes depending on the origins of speakers and whether they recently arrived at or were raised in the city (Erker 2012).

The categorical and gradient patterns of a segmental deletion process have been reported as well. Myers (1995) argued that the /t/-deletion in English undergoes the lexical application of deletion but may also be subject to the postlexical applications of the deletion process that may be gradient (see Bermudez-Otero 2010 for a similar view). Burki and her colleagues demonstrated that, in the schwa deletion in French, both categorical deletion and gradient lenition effects are observed. They further argued that the two are distinct processes by showing that these two processes are conditioned by different sets of constraints (Bürki et al. 2011a, b).

One approach to explaining categorical and gradient effects of related sound patterns is to analyze them mainly based on shifting patterns of gestural structures, with an assumption that phonological alternations result from changes in gestural overlap and magnitude (Browman and Goldstein 1992). In the framework of Articulatory Phonology, it is claimed that a number of phonological processes traditionally assumed to be categorical in nature can be accounted for by gradual phonetic processes. That is, the disappearance of a segment in the speech signal is considered the end point of a gradient phonetic process, by which the segment is obscured by extreme overlap with gestures of adjacent segments. It is further predicted under this approach that a phonetic reduction presents a continuum of realizations ranging from weakly reduced forms with partial acoustic cues to extremely reduced forms with the total disappearance of cues in the acoustic signal.

Meanwhile, a different approach accounting for the coexistence of categorical and gradient effects of the related process lies in how sound patterns evolve diachronically. When viewed in the light of the life cycle of phonological processes (Bermúdez-Otero 2007, 2014), sound patterns follow certain life cycles as they evolve over time and the coexistence of categorical and gradient processes is a natural consequence of how phonological processes evolve. The life cycle of phonological processes begins with

phonologization (Hyman 1976), which occurs when a listener or learner misinterprets the effects of a purely physical or physiological phenomenon as being under the control of speakers' grammar and adjusts her phonetic implementation rules accordingly. This addition of a new cognitively-controlled phonetic rule to the grammar is followed by stabilization (Hayes and Steriade 2004), a stage where a gradient sound pattern becomes categorical. The prediction from the viewpoint of the life cycle of phonological processes is that the categorical effect is expected in the context(s) where the process is more advanced or an old rule is operative. That is, if the process had been operative for a longer period, the process would have had enough time to be fully stabilized. In contrast, the context where both categorical and gradient effects are observed may exemplify an intermediate stage in the life cycle, and the context where only gradient effects are observed can be considered an early stage of the process where the rule has been operative only for a short period (Bermúdez-Otero 2007; Bermúdez-Otero and Trousdale 2012).

Different idiolectal strategies for the /n#k/ sandhi discussed in Bermúdez-Otero and Trousdale (2012) provide a clear illustration of how categorical and gradient effects can be observed simultaneously while a sound pattern evolves through phonologization and stabilization. Before the sound change is initiated, almost all members of the community make a full coronal gesture in the /n#k/ sandhi context, with no phonetic coarticulation rule. The sound change starts with some speakers showing the gestural blending of a residual coronal and a dorsal gesture. For these speakers, the coarticulation rule has been phonologized, entering into their phonetic grammar. Over time, some speakers would further show no evidence of a residual coronal gesture, which suggests that the coarticulation rule has entered the stabilization stage of its life cycle. For them, the rule begins to make an impact on phonological categories.

After a sound pattern is stabilized, categorical patterns may further go through phonological restructuring. One instance of such a reanalysis is rule generalization. Oftentimes, sound change starts in a specific context that provides a phonetically favorable condition and then progressively expands to wider contexts. /o/-lowering in Swiss German is an instance of diachronic rule generalization (Kiparsky 1965; Robinson 1976; Bermudez-Otero 2014; Ramsammy 2015). At an earlier stage of the innovation, /o/ lowered to [ɔ:] before /r/ only. At a later stage, an old, pan-dialectal rule of /o/-lowering expanded to be applied before all coronal consonants except /n/ and /l/ in some varieties including the Schaffhausen dialect. Robinson (1976: 155, 159) argues that this innovative rule is added at the very end of the dialect-specific list of ordered rules, which Kaisse (1993:

356-357) interprets as meaning that the innovative rule applies postlexically. From the perspective of synchronic grammar, an old /o/-lowering rule at the stem level coexists with an innovative generalized /o/-lowering rule at the phrase level in the Schaffhausen dialect (Ramsammy 2015). The life cycle theory therefore predicts that both the categorical effect of an old rule of /o/-lowering before /r/ and the gradient effect of an innovative /o/-lowering before coronal consonants will be observed in the Schaffhausen dialect.

Against this backdrop, this study aims to investigate the categorical and gradient effects of /w/-deletion in Seoul Korean with regard to the predictions from the gestural and diachronic approaches that provide different angles looking at the same phenomenon. In Korean, the labiovelar glide /w/ in rising diphthongs is variably deleted primarily after a consonant as in /sa.kwa/ → [sa.ka] 'apple'. Previous studies have shown that a preceding segment is one of the strongest factors conditioning how frequently /w/ is delete. It has been repeatedly found that /w/ after a bilabial consonant deletes most frequently, followed by /w/ after an alveolar, and /w/ after a velar exhibits the lowest deletion rate among the three environments (Silva 1991; Kang 1997; Kwon 2018, 2023). Of note is that the deletion rate in a post-bilabial position was consistently found to be more than twice as high as that in a post-alveolar and velar position in both read and conversational speech. The variable deletion of /w/ in Korean, especially in a post-bilabial position, is considered to have been phonetically motivated. Kang (1997) underscores the perceptual motivation for /w/-deletion, pointing out that the acoustic cues for /w/ are obscured when /w/ is preceded by a bilabial consonant. Because both a bilabial and /w/ provide the same lip rounding cue, listeners would have difficulties in precisely parsing the acoustic cue for /w/. When a nonlabial consonant precedes /w/, in contrast, listeners do not have such difficulties. He argues that this acoustic ambiguity between the 'C_{labial}wV' sequence and the 'C_{labial}V' sequence results in perceptual confusion for listeners, which consequently leads them to attribute the acoustic cue of /w/ to the preceding bilabial consonant. In this vein, /w/-deletion is argued to be an instance of "sound changes by listeners" as proposed by Ohala (1981: 187) where listeners fail to recognize the phonetic environment causing perturbations on a neighboring segment and misinterpret the sequence of sounds.

While the gestural approach predicts that /w/-deletion presents a continuum of realizations ranging from weakly reduced forms with partial acoustic cues to extremely reduced forms with total disappearance of cues in the acoustic signal regardless of the context, it is predicted under the diachronic approach that the results of /w/-deletion

would differ by context or how long the process has been operative. That is, the phonetic reduction of /w/ would have been initiated in a post-bilabial position, based on the perceptual motivation discussed above, and become phonologized and stabilized over time. Given that /w/-deletion largely limited to a post-bilabial position in Seoul Korean has spread to other post-consonantal contexts including the post-alveolar and post-velar positions by rule generalization (Kwon 2018, 2023), the diachronic approach predicts that an innovative generalized /w/-deletion rule after all consonants that applies postlexically and shows gradient effect would coexist with an old /w/-deletion after a bilabial that applies at higher levels (e.g. word or stem, or both) and shows categorical effect in Seoul Korean. More specifically, the categorical pattern is expected to occur in a post-bilabial position because it is the environment where /w/-deletion has had enough time to be fully stabilized. In contrast, it is expected that /w/-deletion process in post-alveolar and post-velar positions is at a relatively less advanced stage not only because these contexts provide weaker phonetic motivation for /w/-deletion but they also show much lower deletion rates compared to a post-bilabial position (Kang 1997; Kwon 2018, 2023). Given that the rate of application often proves to be proportional to the historical "age" of the process (Ramsammy 2015), the process of /w/-deletion in post-alveolar and post-velar contexts is expected to be at an early stage of the life cycle, showing both categorical and gradient effects simultaneously, or gradient effects only.

Therefore, this study aims to test the following questions in order to test the predictions of the two different approaches that have attempted to account for how both categorical and gradient effects can be observed for the same sound pattern.

Research question I: Does the magnitude of articulator movement for Korean /w/ show a continuous distribution ranging from weakly reduced forms to extremely reduced forms that implicates the gradient reduction effect, or two discrete modes that implicates categorical deletion?

The first question examines whether the variable deletion of /w/ in Seoul Korean exhibits the categorical effect or not, by testing whether the current data are consistent with the gestural approach which predicts that a phonetic reduction presents a single continuum of realizations or the diachronic approach which predicts two discrete categories in certain contexts. Note, however, that a single peak may still indicate a possibility that the magnitude of lip or tongue movement is completely reduced obligatorily.

Research question II: Are the patterns of categorical and gradient effects uniform across contexts or differ by context?

The second question examines the predictions from the diachronic approach (Bermúdez-Otero 2007; Bermúdez-Otero and Trousdale 2012), by testing whether the categorical and gradient effects pattern differently based on how long the process has been operative in different segmental contexts. Specifically, it tests whether categorical effects are observed in a context where the process had a long time to be fully stabilized, a post-bilabial position in this case, whereas gradient effects, sometimes along with the categorical effect, would be observed in contexts where the process is considered to be at a relatively less advanced stage, post-alveolar and post-velar positions in this case.

We begin by describing the details of the ultrasound methodology and Optical Flow Analysis (OFA) that enable us to test our hypotheses with articulatory data (Section 2). In Section 3, we provide the results from the ultrasound experiment that reveal that both the categorical and gradient effects of /w/-deletion are observed and the patterns differ by context. In Section 4, the main findings of the study are discussed in view of the diachronic development of sound patterns.

2. Methods

2.1 Participants and ultrasound recordings

Four native female speakers of Seoul Korean participated in the study and were compensated for their time. Ultrasound, acoustic, and video recordings were made simultaneously inside a quiet room. During the production of target words, midsagittal images of the tongue from the speakers were recorded using an EchoB portable ultrasound machine with a 5-8 MHz convex-curved transducer that produces up to 87 scans per second across a 70-degrees field of view. The focal depth was set at 70mm. The aluminum headset, designed by Articulate Instruments, was used to stabilize each speaker's head. This lightweight and portable headset fixes the transducer midsagitally under each speaker's chin, which ensures that there is little lateral movement of the probe and no probe rotation. A lavalier microphone was attached to the headset and the side-view of each participant's face was video-recorded to capture their lip rounding. The

audio signal from a microphone was synchronized with the incoming video signals from the ultrasound machine and side-view camera, using a SyncBrightUp unit (Articulate Instruments Ltd 2010). Before the recording session began, each speaker was recorded while swallowing water which allowed the imaging of the hard palate illustrated in a green line in Figure 1. The stimuli were presented to the speaker using Articulate Assistant Advanced (AAA) software which records participants' ultrasound images as well as acoustic data.

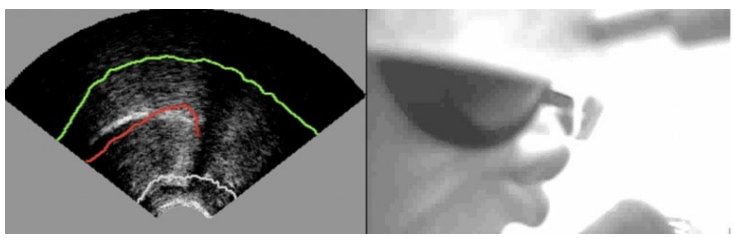

Figure 1. Sample image of a tongue surface (left) and lip shape (right) for /w/. In the ultrasound image, the right side is the tongue tip and the left side is the tongue root. The green line is the palate trace, the highest possible point of the tongue; the red line indicates the position of the tongue at rest.; the gray line indicates the bottom possible point.

2.2 Stimuli and task

The speakers participated in a revised version of the semantic differential task (Labov 2001) of explaining the difference in meaning between nine pairs of words of CV and CwV sequence (see Table 1). In each stimuli word, /w/ is preceded by a bilabial, alveolar, or velar stop and followed by a front vowel /ɛ/ or /e/, the first of which has been merged into the latter in contemporary Seoul Korean (Hong 1988).

Table 1. Stimuli list

Preceding consonant	CV		CwV	
bilabial	pe.ta	'to be cut'	pwe.ta	'to greet (honorific)'
	sʌn.pe.ta	'to be a senior'	sʌn.pwe.ta	'to display'
	me.caŋ	'burial'	mwet.ca.li	'a burial site'
alveolar	te.ke	'usually'	twe.ke	'very'
	te.ta	'to put, approach'	twe.ta	'to become'

	te.d͡ʒi 'ground'	twe.d͡ʒi 'pig'
velar	ke.sʌŋ 'personality' ke.njʌm 'concept' ke.to.kuk 'a developing country'	kwe.sʌŋ 'eerie shriek' kwe. njʌm 'concern' kwe.to 'orbit'

The semantic differential task is a widely used method in sociolinguistic research in which participants are asked to explain the difference in meaning between two words to elicit the careful articulation of minimal or near-minimal pairs. This study employed the revised version of this task by asking the speakers to provide many example sentences using the target words after explaining the semantic differences. For example, the participants were first asked to explain the difference in meaning between /te.d͡ʒi/ 'ground' and /twe. d͡ʒi/ 'pig' and then provide as many sentences including the target words as possible. One advantage of this method is that we can elicit many tokens of the target words in a short period of time. Another advantage is that we can collect multiple repetitions of the target words ranging from very careful articulation when they intend to differentiate one word from another word to casual production where they occasionally delete /w/ when they cite examples to explain the meaning of the word. Although the number of tokens or repetitions, therefore, varies from participant to participant and from target word to target word, each participant produced five tokens for each target word, on average. This yielded the final dataset including 806 tokens: 401 tokens for lips and 405 tokens for tongue. Four tokens of lip movement were excluded because lip movement was not properly captured.

2.3 Segmentation and duration measurement

Acoustic segmentation was made mainly through the Korean Forced Aligner (Yoon and Kang 2013), but TextGrid files were manually inspected and, if necessary, corrected in Praat. The duration of the entire syllable (CV, CwV) was extracted in milliseconds using a Praat script and log-transformed from the original raw values to reduce the influence of atypical outliers. The entire syllable (CwV or CV) was used as a unit of analysis instead of /w/ itself not only because finding the boundary between /w/ and the following vowel was not always straightforward but also because /w/ tends to coarticulate with surrounding segments, which should be reflected in measuring the magnitude of articulator movement.

2.4 Quantitative analysis of articulator movement: Optical Flow Analysis (OFA)

For the quantitative analysis of articulator movement involved in the production of /w/, the FlowAnalyzer software (Barbosa 2017) was employed for Optical Flow Analysis (OFA; Horn and Schunck 1981; Fleet and Weiss 2006). OFA is a video-based motion analysis tool that measures the apparent magnitude of movement (MM) of objects in a video (Barbosa et al. 2008). The optical flow algorithm compares the difference in brightness of individual pixels from frame to frame in the defined regions of interest in the image. This results in frame-by-frame measures of Magnitudes of Movements (MMs) and the sum of the magnitudes of all pixels inside each region of interest can be calculated.

The method's utility has been demonstrated for the data from a number of languages including Plains Cree, English, and Shona (Barbosa et al. 2008). Recent articulatory studies have introduced OFA as a relatively easy but powerful tool for extracting articulatory information from ultrasound video. Hall et al. (2015, 2017) show that the magnitude of tongue movement determined by OFA of ultrasound videos is greater for English tense vowels in closed syllables compared to those in open syllables. In their multimodal speech and gesture research, Danner et al. (2018) demonstrate that OFA is an effective technique for quantitatively analyzing coordination and kinematics, using video, audio, and electromagnetic articulatography (EMA) data. In studying lateral bracing cross-linguistically using ultrasound, Tong et al. (2018) tracked and measured the magnitude of vertical tongue movement using Flow Analyzer for optical flow analysis.

OFA is a particularly appropriate analysis method for the current study for the following reasons. First, OFA is capable of extracting reliable kinematics in any type of video. For the current articulatory study of the production of /w/ involving two articulators, lips and tongue, OFA can calculate the movement of the tongue in the ultrasound videos and that of lips in the side-view videos in the same fashion. This enables the unified measurement of the motions of tongue and lips, which allows the comparison between two articulators in terms of the magnitude of movement. Second, OFA extracts the data from all frames, rather than single frames as is common with static postural analyses widely used in the ultrasound analysis (Barbosa and Vatikiotis-Bateson 2014; Moisik et al. 2014; Hall et al. 2015). Extracting the movement of articulators from a series of time sequences can be more advantageous in seizing the global movements of

articulators before and after the production of /w/.

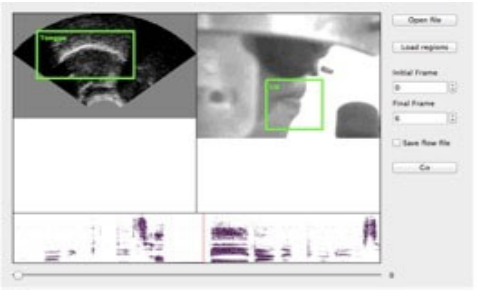

Figure 2. Defining regions of interest in the optical flow domain

The data acquisition and processing procedures for OFA were as follows. First, the ultrasound and side-view videos of CV and CwV sequences were exported from AAA and saved in avi files. Using the FlowAnalyzer software (Barbosa 2017), which results in frame-by-frame measures of the apparent magnitude of movement (MM) of objects in a video, the regions of interest were first selected as in Figure 2, one demarcating the areas for tongue movement and the other one demarcating the areas occupied by the lips. To ensure consistency across videos, the four edges of the regions were marked on the computer screen, and the same size of the region of interest was drawn for every token. Then, the total magnitude of lip or tongue movement for each token was calculated by adding up all frame-by-frame measures (i.e. the sum across frames). For the comparison across speakers, MMs for each speaker were normalized to zero mean and unit variance within the speaker to eliminate gestural variation due to physiological differences among speakers.

2.5 Diagnostics for categorical and gradient effects

One critical issue to the exploration we undertake here is how categorical and gradient effects are defined and how they can be diagnosed empirically. In line with the insight provided in the literature (Myers 2000; Strycharczuk 2012; Turton 2014), the categorical effect of a deletion process is defined in this study as follows: tokens of CwV comprise two modes along the continuum of the magnitude of lip or tongue movement, forming two discrete categories. The examination of a statistical distribution of physical

parameters is a frequently employed method to diagnose whether there is more than one phonological category. In contrast, the gradient effect of a related phonological process can be understood to arise from a continuous reduction in the magnitude of articulator (lip or tongue) movement: CwV tokens form an unbroken continuum of a single categor y.[1] Figure 3 illustrates an example of a bimodal distribution showing two bumps (dashed line) for distinct light and dark categories of /l/ in RP and a unimodal distribution with only one bump (dashed line) for a single dark category of /l/ in Manchester English (Turton 2014).

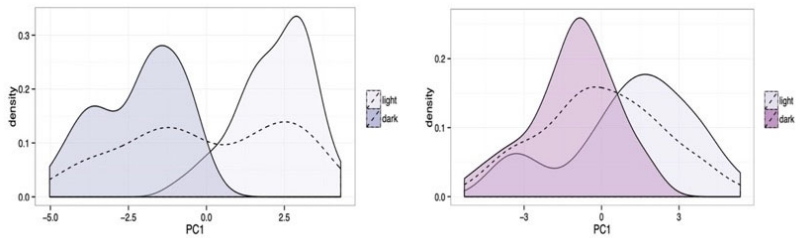

Figure 3. Density plot showing (a) the bimodal distribution of light and dark /l/ for an RP speaker and (b) the unimodal distribution of dark /l/ for a Manchester English speaker. Separate distributions (determined by phonological environment) are indicated by solid lines and overall distribution indicated by dashed lines
(Adapted from Turton 2014)

In order to test the patterns of the distribution statistically, Hartigan's dip test (Hartigan and Hartigan 1985) was used. Hartigan's dip test is a nonparametric statistical test used to test the null hypothesis that a given dataset has a unimodal distribution. The test measures the degree of departure from unimodality, with larger values of the test statistic, D (dip) statistic, indicating a greater degree of bimodality or multimodality in the data. The dip test also offers a p-value showing the statistical significance that the null hypothesis of unimodality can be rejected. Using R's diptest package (Maechler 2013), the dip test was conducted on the magnitude of lip and tongue movement, respectively. The test results are presented with a density plot that shows the overall distribution of the magnitude of lip or tongue movement for CwV tokens. A density plot

1 One of the reviewers raised the question as to how to deal with the tokens that are perceptually ambiguous to determine whether /w/ is deleted or not. The gestural approach would predict that such tokens would be located in the mid-part of the distribution. These tokens, therefore, are included in the analysis.

for CV tokens is presented along with that of CwV tokens for comparison.

3. Results

3.1 Overall distribution

Figure 4 illustrates a density plot of the overall distribution of the magnitude of lip movement for CwV and CV tokens. The magnitude of lip movement for CwV tokens forms two peaks, which suggests the categorical nature of /w/-deletion: the magnitude of lip movement when /w/ is deleted forms a separate category from the magnitude of lip movement when /w/ is retained. The results from Hartigan's dip test confirm that the significant bimodality dip is evidenced in terms of the magnitude of lip movement for CwV tokens ($D = .04$; $p < .01$). The magnitude of lip movement for CV tokens, in contrast, forms a single peak ($D = .02$; $p = .93$).

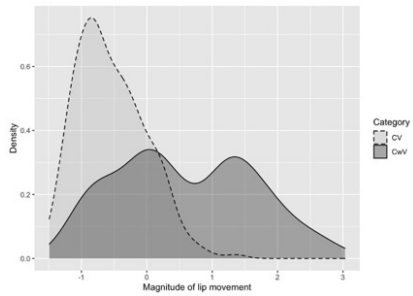

Figure 4. Density plot for the magnitude of lip movement for CV and CwV tokens across contexts

A density plot in Figure 5 shows a bimodal distribution in the magnitude of tongue movement for CwV tokens, which is confirmed by the dip test providing a significant figure of $D = .04$ ($p < .05$). Interestingly, the bump in the higher range is much smaller than that in the lower range. This suggests that a majority of CwV tokens exhibit a reduced amount of tongue movement almost equivalent to CV tokens that show a unimodal distribution ($D = .02$; $p = .83$). The overall pattern suggests that the tongue movement tends to be categorically reduced.

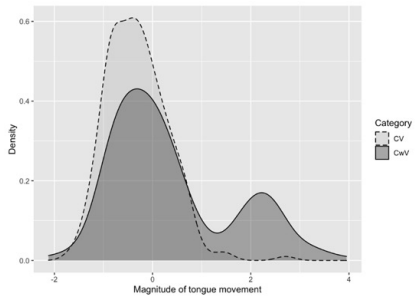

Figure 5. Density plot for the magnitude of tongue movement for CV and CwV tokens across contexts

3.2 The distribution by segmental context

Let us look into the data more closely by examining the distribution of the magnitude of articulator movement in three different segmental contexts.

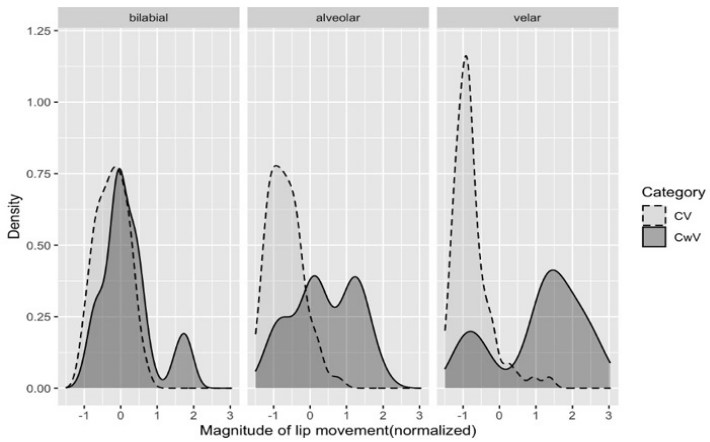

Figure 6. Density plot for the magnitude of lip movement CV and CwV tokens when C is a bilabial, alveolar, or velar stop

Figure 6 displays the distribution of the magnitude of lip movement when an onset consonant, C, in the syllable CV or CwV is a bilabial, an alveolar, and a velar. When C is a bilabial, the magnitude of lip movement for CwV apparently forms two peaks: a smaller peak in the higher range and a larger peak in the lower range. This indicates

that a majority of CwV tokens when /w/ is preceded by a bilabial show a substantial reduction in the magnitude of lip movement and exhibit a similar amount of lip movement with CV tokens. Since the dip is relatively shallow, the D statistic reveals that the distribution is unimodal for CwV tokens, with D = .04, and a non-significant p-value (p = .89). The lack of bimodality for the lip movement for CwV tokens, however, should not be interpreted as the lack of categorical deletion in this context. Rather, it can be interpreted as the lip movement being usually completely reduced or overlapped with the labial gesture of a preceding labial in this context. When C is an alveolar, the magnitude of lip movement for CwV tokens forms two clear bumps. The D statistic confirms its bimodality, with a significant figure of D = .08 ($p < .01$). This suggests the categorical nature of /w/-deletion in this context. The same bimodal pattern is not confirmed for CwV tokens when C is a velar stop. Although C_{velar}-wV tokens appear to show two bumps, the dip is very shallow and the D statistic thus reveals that the distribution is unimodal (D = .06, p = .07).

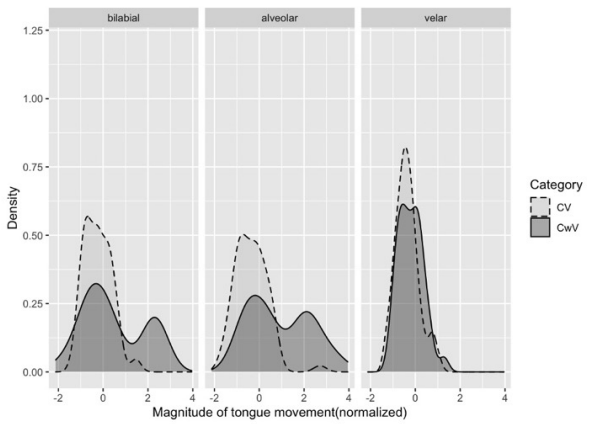

Figure 7. Density plot for the magnitude of tongue movement CV and CwV tokens when C is a bilabial, alveolar, or velar

Let us turn to the tongue movement. Figure 7 displays the distribution of the magnitude of tongue movement when C is a bilabial, an alveolar, and a velar stop. When C is a bilabial, the magnitude of tongue movement for CwV shows two bumps, a larger peak in the lower range and a smaller peak in the higher range. This indicates that a multitude of CwV tokens is leaned toward a larger peak in the lower range while the

rest of the CwV tokens are clustered around a smaller peak in terms of the magnitude of tongue movement. The dip test provides statistical confirmation for the bimodal distribution ($D = .08$; $p < 0.01$). This suggests that /w/-deletion shows a categorical effect when it comes to tongue movement in a post-bilabial position. Similarly, when C is an alveolar, the distribution of the magnitude of tongue movement for CwV tokens shows two clear bumps. The D statistic confirms this bimodality ($D = .07$; $p < .05$). When C is a velar stop, the distribution for CwV tokens shows only one peak ($D = .04$; $p = .69$) and its distribution almost completely overlaps with that of CV tokens, as in the case of the lip movement when C is a bilabial. This strongly suggests that the tongue gestures for /w/ substantially overlap with those for a preceding velar. Thus, the lack of bimodality here also indicates the complete deletion of tongue movement for /w/ when preceded by a velar.

4. Discussion

This study built on previous findings that a number of phonological processes show both categorical and gradient effects and tested whether /w/-deletion in Seoul Korean exhibits patterns of categorical deletion and gradient reduction as well. It was further tested whether the patterns differ according to how advanced the process is in different phonological contexts along its life cycle. The results showed that when /w/ is preceded by a bilabial stop, the lip movement for /w/ appears to be almost completely reduced or overlapped with the lip movement for a preceding bilabial, which suggests that /w/-deletion shows a categorical effect in terms of lip movement. The tongue movement for /w/ is shown to be categorically deleted in a post-bilabial position as well. When /w/ is preceded by an alveolar, the distribution of lip and tongue movement for CwV tokens shows a clear bimodal distribution which suggests the categorical effect of /w/-deletion in this position. When /w/ is preceded by a velar, the distribution of lip movement for CwV tokens failed to show a bimodal distribution: /w/-deletion appears to show only a gradient component for lip movement. The tongue movement for /w/, however, appears to be completely reduced or overlapped with the tongue movement for a preceding velar most of the time.

One may attempt to explain these patterns based on how our synchronic grammar is designed. Such proposals have been made by researchers working within the framework

of Articulatory Phonology (Browman and Goldstein 1992). It has been claimed that a number of phonological processes assumed to be categorical in nature can be accounted for by gestural overlap. For example, Zsiga (1995) demonstrated that the output form of /s/+/j/ coarticulation across word boundary exhibits different gestural and durational properties from those of a lexical /ʃ/ and argues that /s/+/j/ coarticulation occurring across a word boundary can be explained by an overlap of an alveolar and a palatal gesture tongue rather than categorical feature delinking and spreading.

Studies under this tradition have improved our understanding of the gradient effects of the related phonological processes that have been largely overlooked. However, certain limitations remain in that not all phenomena can readily be accounted for as the result of gestural overlap only. Holst and Nolan (1995), for instance, provided the acoustic evidence that four different idiolectal strategies are found in /s/ to /ʃ/ assimilation in English: no assimilation, two distinct types of partial assimilation, and categorical assimilation. Contrary to the prediction of gestural models that categorical assimilation is a case of gestural blending that produces the output differentiated from that of lexical /s/ and /ʃ/, some speakers realized complete assimilation that cannot be distinguished from /ʃ/. Accumulating acoustic and articulatory evidence of the speakers who do not make intermediate realizations has been provided, suggesting that there are cases of categorical alternations (Nolan et al. 1996; Ellis and Hardcastle 2002; Ladd and Scobbie 2003). Based on the current study's findings that evidently show individual speakers who rarely make intermediate realizations, /w/-deletion in Seoul Korean is not adequately accounted for by gestural overlap, either.

Rather, the results from this study receive a principled explanation from the diachronic approach. Under this approach, /w/-deletion is presumed to have started as a gradient reduction process with a strong phonetic grounding in a post-bilabial position, as discussed in Section 1. Over time, this phonetic reduction process would have stabilized as a categorical deletion while extending to wider contexts at a different pace. Since the rule has been active for the longest time in a post-bilabial position, it might have had enough time to stabilize into a categorical rule. The highest rate of deletion in this position suggests that the process has been operative for a long time, given that the rate of application often proves to be proportional to how old the process is (Ramsammy 2015). Another piece of evidence supporting that the rule has been operative in this context for a long time is that there are words with a bilabial+/w/ sequence that have lexicalized forms without /w/. For example, /mwʌ/ 'what' is very often

produced as [mʌ] and /pwɑ/ 'try' [pa]. An important prediction regarding the end point of the life cycle is that sound patterns often cease to be phonologically controlled, with a phonological rule replaced by a morphological operation or lexicalization (Bermudez-Otero 2007, 2014; Anderson 2015).

For the /w/-deletion process operative in a post-alveolar position, the diachronic approach would predict that it is less advanced than that in a post-bilabial position considering the two facts: first, this position has weaker phonetic motivation for /w/-deletion compared to the post-bilabial context thus, the rule has been extended from a post-bilabial position as discussed in Section 1; second, the deletion rate in a post-alveolar context is much lower than that in a post-bilabial context, although its deletion rate is higher than that in a post-velar context. The results have shown that /w/-deletion in a post-alveolar context shows both categorical and gradient effects, as the diachronic approach predicts. A post-velar context which had a less strong phonetic motivation and a much lower deletion rate than a post-bilabial context turned out to show only a gradient effect with regard to lip movement and a categorical, and obligatory, reduction for tongue movement, which is also consistent with the prediction of the diachronic approach.

While it has been widely attested that categorical and gradient effects of the related phonological processes can coexist in different grammatical levels (Labov 1994; Myers 1995), the coexistence of the categorical and gradient effects in different phonological contexts has rarely been reported. Given the process of diachronic evolution of sound patterns discussed thus far, it is conceivable phonological rules in different phonological contexts may be at different stages of their life cycle, especially when the rule is initiated in a certain environment and spread to broader contexts. The findings of this study thus lend further support to the diachronic explanation of how both categorical and gradient effects are observed for many phonological processes across languages.

In linguistic research, synchronic and diachronic explanations can complement each other by providing vital clues for unaccounted parts of the explanation (Bermudez-Otero 2014). Since many synchronic phenomena emerge diachronically, understanding diachronic developments of linguistic processes will often help us ease the burden of explaining unresolved mysteries only from the synchronic perspective.

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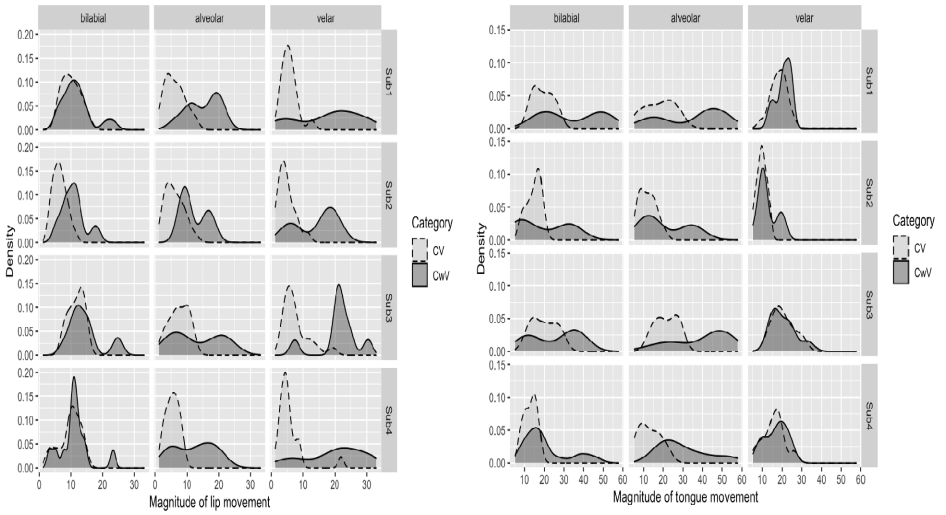
Appendix

Density plots for the magnitude of lip and tongue movement for CV and CwV tokens

by subject (Sub1-4) and context (when C is a bilabial, alveolar, or velar stop).



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