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Acoustic shortening and gestural reduction in English polysyllabic words by Korean L2 speakers*

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Yun, Gwanhi. 2025. Acoustic shortening and gestural reduction in English polysyllabic words by Korean L2 speakers. *Linguistic Research* 42(2): 303-335. The present study examined the potential implementation of polysyllabic shortening process at the acoustic dimension and its concomitant gestural reduction at the articulatory level by Korean L2 speakers of English. Acoustic data were drawn from stressed syllables in English and articulatory data from the onset consonants of the identical syllables produced by eight Korean learners. Both the parameters were extracted from the preliminary ultrasound recordings. Analyses of the acoustic data included the measurement of the duration of the stressed syllables and their sub-syllabic constituents. Ultrasound data yielded articulatory characteristics, i.e., the placement of the tongue tip or dorsum pertinent to the production of the onset consonants of the stressed syllables contained in monosyllabic, disyllabic and trisyllabic words. First, the polysyllabic shortening effect was evident, primarily between monosyllabic and polysyllabic words. The durations of stressed syllables as well as the onset and nucleus were shorter in longer words. Second, the onset alveolars and velars placed in the identical stressed syllables were produced with the lower tongue tip or blade (for alveolars) and tongue dorsum (for velars) in longer words. This finding indicates that gestural reduction co-occurs with polysyllabic shortening, especially in the onset of stressed syllables, supporting the interaction between temporal weakening and gestural target undershoot. Furthermore, it indicates that Korean L2 speakers seem to be at the developmental stage of producing a key rhythmic pattern in L2 English. **(Daegu University)**

Keywords Polysyllabic shortening, gestural reduction, stress-timing rhythm, stressed syllables, English

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1. Introduction

This study primarily investigates the emergence of polysyllabic shortening, focusing particularly on consonants in the production of Korean L2 English speakers. Polysyllabic shortening (PSS) refers to the process where syllables or feet bearing primary stress are abbreviated when integrated into longer words (White and Turk 2010). This phenomenon incurs phonetic modifications of stressed syllables, notably reduction of onset, nucleus, and coda primarily in terms of duration (Abercrombie 1967; Lehiste 1972). For instance, in comparing the sentences *The ˈfamily has enˈjoyed the vaˈcation and The ˈfamily could have enˈjoyed the vaˈcation*, the duration of the syllable "-joyed" in the word "enjoyed," which bears primary word stress in the latter sentence, is shorter than in the identical syllable in the former.

Each language possesses its unique rhythm, resulting in language-specific rhythmic systems based on stress-timing, syllable-timing, mora-timing, among others (Ladefoged 2006). Polysyllabic shortening is a distinctive feature of stress-timed languages such as English, German, and Russian, characterized by isochrony—a rhythmic pattern where there is nearly equal duration between stressed syllables in sentences (Lehiste 1977; Dauer 1983; Hoequist 1983; Grabe and Low 2002; Gibson and Summers 2018). Gibson and Bernailes (2019) propose that polysyllabic shortening may be a universal aspect of speech, noting its more frequent use by bilingual children in L1 Spanish compared to L2 English. Conversely, languages like Korean, French, Spanish, Chinese, and Indian English are classified as syllable-timed languages, where syllables are pronounced in nearly equal time spans (Pamies 1999).

Given the diverse phonological systems governing rhythm across languages, second language learners may encounter challenges in acquiring a second language whose rhythmic structure differs from their native language (L1). This study explores whether Korean L2 English speakers produce polysyllabic shortening in the acoustic dimension and specifically examines the articulatory performance of onset consonants in primary stressed syllables affected by this rhythmic phenomenon.

2. Theoretical background

2.1 Polysyllabic shortening in languages with isochrony

Polysyllabic shortening is a by-product of isochrony in English, i.e., the pressure to preserve uniform speech timing. A typical characteristic of polysyllabic shortening is the modification of the duration of sub-elements of the stressed syllables. Gimson (1980) showed that stressed syllables in English keep regular rhythmic patterns with an almost equal number of intervals along the temporal dimension regardless of the number of intervening unstressed syllables. It was suggested that such isochrony is fulfilled in conjunction with the frequent reduction or weakening of unstressed syllables. When the number of stressed syllables are equal, the duration of the whole utterance remains constant even though the number of syllables increases in the sentence (Avery and Ehrlich 1992). Lehiste (1972) and Port (1981) showed that the stressed vowels in English words undergo shortening in proportion to the increase in the word length. Port (1981) found that when the tokens, “dib, dibber, dibberly” were embedded and produced in the carrier sentence, “I say __________ again every Monday.” the duration of the stressed syllable was shortened as the number of syllables increased.

However, White and Turk (2010) pointed out that Port and others examined only word-initial stressed syllables and the target syllables were placed in nuclear accented words (Klatt 1973; Nakatani et al. 1981). In contrast, Turk and Shattuck-Hufnagel (2000) conducted a follow-up study where the length of the whole interpolated sentence was equal, phrasal boundary was aligned, and the placement of stressed syllables was divided into two, i.e., word-initial and word-final. This study found the effect of PSS in stressed syllables, with greater magnitude word-initially rather than word-finally. They also found that its effect size was bigger when the target syllables received sentence stress than when they did not.

White and Turk’s (2010) experiment with English native speakers also showed similar results. For example, the duration of [mes] was 16 ms longer in “mace” than in “mason” and the identical syllable was 26 ms longer in “mace” than in “masonry”. Furthermore, when the target words did not receive sentence stress, the extent of shortening was greater in mono- and di-syllabic words, compared to trisyllabic words (e.g., *sense, censor*≫*censorship*). In addition, to investigate which syllable constituents undergo such reduction, the durations of onset, nucleus and coda were measured. Analysis showed that PSS emerged consistently across all three syllabic elements of the sentence-stressed words. In particular, the shortening in onsets arose primarily word-initially rather than word-medially in line with the finding of Cooper (1991) (e.g., *dog-dogma-dogmatist* ≫ *mend-commend-recommend*).

This acoustic preservation effort to keep eurhythmy is also observed in many languages. Lindblom's (1968) study showed that the polysyllabic shortening emerged with respect to stressed syllables when the words containing the target syllables were inserted in the fixed carrier sentence in Swedish. Additionally, this phenomenon was found in Dutch words (Nooteboom 1972). Suomi (2007), however, did not find this rhythm-induced timing control in Finnish. This finding was attributable to the fact that lexical stress in Finnish is fixed word-initially and plays a crucial role as a robust word boundary marker for the listener, blocking radical fluctuations in the magnitude of its duration.

2.2 Polysyllabic shortening in non-native or bilingual speakers

L2 learners whose L1 has a syllable-timed system are expected to face trouble recognizing word boundaries and segmentation in their L2 learning. Furthermore, it is predicted that those like Korean L2 English learners will have difficulty producing isochrony based on stress-timed rhythm even when they become familiarized with their L2 (Yavaş 2006: 195; Bunta and Ingram 2007). This difficulty is commonly attributable to the transfer of the L1 syllable-timed rhythm to the L2 stress-timed pattern (MacWhinney 2005). MacWhinney's (2005) Unified Competition Model posits that phonological representations in L1 and L2 are shared, that two representations compete and that one is selected based on language experience and proficiency. L2 articulatory units, whether phonemes or syllables, and L2 motor plans become more susceptible to L1 motor plans (or more likely to transfer from L1) when L2 speakers have lower proficiency and less exposure to L2 (Kormos 2006; Gibson and Summers 2018).

Lin and Wang (2007) found that Chinese-English bilingual adults with high L2 English proficiency leveraged a syllable-timing pattern to their L1 Chinese speech while using a stress-timing rhythm for L2 English, which is indicative of a lack of L1 transfer.

A similar absence of transfer was observed for Spanish-English bilinguals who were highly proficient in both languages (Carter 2005). Gibson and Summers's (2018) experiment with bilinguals showed that highly proficient English speakers exhibited polysyllabic shortening in English but failed to transfer it to Spanish, to which they were exposed in a limited manner. Furthermore, they showed that balanced Spanish-English bilinguals applied PSS to both languages. These findings were interpreted to suggest that transfer of motor planning in L1 to L2 might be deterred when L2 is acquired early regardless of their L2 proficiency.

For Korean L2 learners of English, it has been revealed that the applicability of transfer of the L1 rhythmic pattern to L2 differs depending on a multitude of factors, including L2 proficiency, type of L2 production tasks, and the part of speech of target words, etc. (Kim and Chung 2011; Seo 2015). As reported, Korean is a syllable-timed language while English has a stress-timed rhythm. Kim and Chung (2011) showed that the L1 rhythmic pattern emerged in read-aloud speech in L2 English, indicative of negative transfer of syllable-timing. Furthermore, in spontaneous L2 speech, the influence of L1 motor plan was trivial. These findings suggests that the utterance type also affects the realization of L2 rhythmic pattern.

2.3 The present study

The present empirical study aims to investigate two issues regarding the realization of polysyllabic shortening, which is common in English. First, we address the question as to whether Korean L2 speakers whose L1 is a syllable-timed language produce the essential property of a stress-timed language like English. To see whether stress-timing is realized in their production, we examine whether/how Korean speakers apply polysyllabic shortening rule in English with reference to the gestural weakening of target consonants. The rationale behind this is as follows: if Korean speakers have learned the mechanism of stress-timing in English, it might be plausible that they apply the PSS rule due to the crucial effect of the preservation of isochrony between sentence-stressed words.

Taking a step further, if the PSS rule is implemented, it is likely to induce reduction of consonants as well as that of vowels of the stressed syllables in terms of temporal dimension. That is, primary stressed vowels are expected to be shortened and onset or coda consonants in the same syllables might also undergo shortening (or weakening) along with gestural reduction. In this study, we attempt to compare the durational properties of consonants in the primary stressed syllables among mono-, di-, and tri-syllabic words to check out the potential performance of polysyllabic shortening (e.g., 'tip-tiptop-tiptopper'). If polysyllabic shortening progressively occurs in di- or tri-syllabic words, compared to mono-syllabic words, onset /t/ in the primary stressed syllable 'tip' is expected to become shortened in the same /t/ in 'tiptop' or 'tiptopper' than in 'tip'. To verify the temporal reduction of the target consonants, the durations of alveolars and velars in the onset (i.e., their closure duration and aspiration) were measured and compared.

Another goal of this study is to examine the impact of PSS on the gestural magnitude of onsets from the articulatory perspective. As far as polysyllabic shortening is concerned, there has been scant attention to its effect in light of articulatory characteristics such as gestural weakening. The scarcity of articulatory investigations allows this study to draw a comprehensive picture of the production of polysyllabic shortening. We assume that PSS influences articulatory dimension in conjunction with acoustic properties. Consequently, it is expected that the primary articulator, such as the tongue dorsum or blade does not fully reach its target along the palate, i.e., alveolar ridge for alveolars or the soft palate for velars-under the polysyllabic condition, compared to monosyllabic words. That is, we presume that gestural reduction might emerge in the form of gestural undershoot for the articulation of the consonants embedded in syllables subject to polysyllabic shortening. For example, it is predicted that if PSS occurs in the production of Korean speakers, the articulation of word-initial /t/ in 'tiptop' or 'tiptopper' would involve less amount of contact in the region of alveolar ridge and thus lower tongue dorsum than in 'tip'. Taking another example, /k/ in 'captive' or 'captainship' would be articulated with less amount of constriction of tongue back against the velum and less movement at the tongue height dimension, compared to the same /k/ in 'cap'. In a nutshell, the pressure for isochrony in English is likely to induce gestural reduction or weakening as well as temporal reduction of the primary stressed syllable encompassing the onset, nucleus and coda.

3. Experiment

3.1 Participants

Eight native Korean learners of L2 English participated in an ultrasound experiment. They were undergraduate students recruited from Daegu University in Korea. Four were females and four males. They were majoring in English education at the time of experimentation. Ages ranged from 21 to 26 (M=5:10, SD: 8 months). A biographical background survey was administered before the experiment. All participants had no experience of staying in English-speaking countries. Their self-evaluation of English proficiency ranged from 3 to 6 on a 10-point scale with mean 5. They can be identified as English L2 learners of intermediate level.

3.2 Stimuli

This experiment used twenty four different test words containing the primary stressed syllables in monosyllabic, disyllabic and trisyllabic words as presented in Table 1. Since word-initial position is perceptually and phonologically prominent, onset consonants are known to undergo lengthening word initially. Hence, to counterbalance this effect, we chose two groups of stimuli words: (1) Left-headed words whose initial syllables contain target consonants /t,d,k,g/ (e.g., ‘típ-típtop-típtopper’) and (2) Right-headed words embedding the target syllables in the second or third syllables (e.g., ‘téem-estéem-misestéem’). Left- and Right-headed words consisted of twelve tokens. Each group of words had four triads and a total of eight triads which consisted of mono-, di- and tri-syllabic words. This pattern of stimuli is basically similar to those adopted in White and Turk (2010).

Unlike White and Turk (2010), this study primarily investigates the effect of PSS due to stress-timing rhythm in English on the gestural reduction of the consonants in the primary stressed syllables. Accordingly, the target syllable initial consonants embedded in the primary stressed syllables were fixed as two alveolars /t, d/ or two velars /k, g/. One acoustic parameter, i.e., duration of these target consonants was measured and compared in each of these eight triads. Additionally, one articulatory property, i.e., the tongue dorsum height was obtained in the ultrasound experiment and compared in each of the triads. This triplet comparison would reveal the potential differences in the degree of how the articulators, i.e., tongue blade of the alveolars and tongue dorsum of the velars approach the constriction regions along the palate.

Table 1. Stimuli

Target consonants	Left-headed words	Right-headed words
/t, d/	tip tiptop tiptopper	teem esteem misesteem
	tape taper tapering	tapped adapt disadapt
/k, g/	cap captive captainship	get forget unforget
	coat coatrack coatcolor	cast recast undercast

The twenty four target words in the format of eight triads were presented to eight participants in the carrier sentences as exemplified in Table 2. These sentences were created in such that they sound meaningful. To elicit the stress-timing rhythmic patterns for each utterance as much as possible, pitch accented words were marked in capital letters and each sentences embedded two pitch accents. The first accented words were placed sentence initially or in the second position and the second accented words were situated sentence finally or in second rightmost position. The target word stimuli were placed sentence medially between these two initial and final accented words. In the left-headed word condition, one syllable was uniformly interpolated between the initial accented words and the target syllable whereas the number of intervening syllables laid out between the target syllables and the nuclear accented syllable in the final accented words remains identical because the number of target syllables vary in the triads. In right-headed word condition, the number of intervening syllables between the target syllables and the nuclear accented syllables in the final accented words was controlled as one or two. However, the number of syllables between the initial accented syllables and the target syllables varied depending on the size of the target words. .

Table 2. Carrier sentences containing test stimuli

Left-headed words	Right-headed words
PICK the tip again TODAY	SUE let her teem it ALL
PICK the tiptoe again TODAY	SUE let her esteem it ALL
PICK the tiptopper again TODAY	SUE let her misesteem it ALL
PUT the tape TOGETHER	LET him tapped TODAY
PUT the taper TOGETHER	LET him adapt TODAY

PUT the tapering TOGETHER	LET him disadapt TODAY
GIVE the cap to JANE again	JOE had to get it AGAIN
GIVE the captive to JANE again	JOE had to forget it AGAIN
GIVE the captainship to JANE again	JOE had to unforget it AGAIN
I SAW the coat TODAY	I SAW him cast it AWAY
I SAW the coatrack TODAY	I SAW him recast it AWAY
I SAW the coatcolor TODAY	I SAW him undercast it AWAY

The sentences containing the monosyllable target words had six to seven words in either left- or right-head words condition. The lengths of the sentences embedding disyllabic and trisyllabic words increased by one or two syllables due to the increase of the size of target words.

All participants were instructed to read each carrier sentence as naturally as possible at normal speaking rate with focusing on the accented words to facilitate stress-timing rhythm and not to deviate from a normal speech. The order of the carrier sentences was randomized in the reading task and each participant was asked to read this list three times. All the sentences were listed in a piece of paper and written in English orthography. Participants were given a short practice before the recording session to assist them to familiarize themselves with the target words. A total of 576 experimental sentences were visually and aurally recorded in the ultrasound machine (24 target words (or sentences) $\times$ 3 repetitions $\times$ 8 participants).

3.3 Procedure

Regarding the elicitation of the articulatory data, the researcher recorded each participant's production using Articulate Assistant Advanced (AAA), which is a software designed to record and analyze speech production data from instruments. When recording, a participant was asked to read three randomized sets of stimuli aloud. All participants wore a Ultrafit headset to stabilize the probe and minimize head movement during the recordings, to elicit the reliable tongue images.

3.4 Data collection and analysis

To participate in the experiment, all the participants were invited into a quiet phonetics room. To produce midsagittal ultrasound videos, we used a MicrUS EXT-1H ultrasound machine with Articulate Assistant Advanced (AAA). Recordings of articulatory and acoustic stimuli were conducted, and both data were obtained simultaneously. Each participant was seated before a computer running AAA software. The computer was connected to a MicrUS EXT-1H ultrasound machine (Articulate Instruments Ltd. 2012). The machine had a transducer, which took 82 frames per second across a 92° field of view. The transducer was fixed to the chin by being attached to the headset (Spreafico et al. 2018). A microphone was connected with an external pre-amplifier at the sampling rate of 22,050 Hz.

Figure 1 shows a representative SSANOVA comparison of the /t/s based on the ultrasound images. To consistently compare the tongue front and tongue dorsum region, tongue body line was divided into three parts. Tongue dorsum was designated from 45° leftward of center to the point of 25° rightward of center (Allen et al. 2013: 192). The rightmost part represents the tongue front region, i.e., tongue blade and tip. The main focus of this study is tongue dorsum for velars and tongue blade and tip for alveolars.

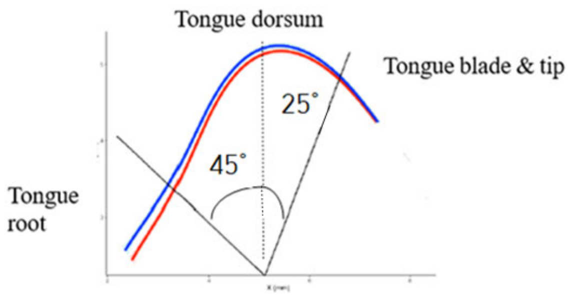


Figure 1. A sample SSANOVA for the comparisons of /t/s

To quantify the data of the tongue configuration, the extracted images were overlaid with the tongue contours by drawing the tongue body lines in AAA. We manually traced all midsagittal tongue contours by connecting 36 points along the tongue body line with a mouse of the computer. Then, the tongue contours were again extracted in a series of 36 (x-y) coordinates. The x axis represents tongue anteriority and the y axis refers to tongue height. The tongue splines were exported based on 36 fan line overlaid on the images, resulting in 36 x-y coordinates. The adjusted tongue contours were subjected to a smoothing Spline Analysis of Variance (henceforth, SSANOVA) for the statistical analyses.

Since it has been pointed out that Cartesian coordinate-based SSANOVA is inappropriate especially for tongue tip or root data collection due to the limitation of warping of the region and wider confidence interval, Cartesian coordinates were converted to polar coordinates with angular coordinate θ and radian coordinate r and transformed back to Cartesian coordinates for visualization, following a polar GAMM model (Mielke 2015; Hussain and Mielke 2021). Based on the (x-y) coordinate plots of the average tongue contours from each speaker, the contour sets are calculated as significantly different when the confidence intervals (95%) from the set of contours do not overlap, equivalent to $p < .05$. In this study, English alveolar and velar stops were compared to examine any significant differences in tongue dorsum height in three contexts, i.e., in mono-, di- and tri-syllabic words.

Additionally, to ascertain whether PSS, the target context for gestural reduction in this study arose with respect to temporal parameters, audio files were extracted from the ultrasound videos of five speakers out of eight. The acoustic data from three speakers were excluded due to technical issues and the quality of sounds in the audio files. Thus, a total of 360 target words were extracted and analyzed for acoustic measurement (24 target words × 3 repetitions × 5 participants). As evidence for PSS, four acoustic parameters were adopted and measured, following White and Turk (2010): (1) duration of target stressed syllables, (2) duration of the onset of stressed syllables, (3) duration of the nucleus of stressed syllables, and (4) duration of coda of stressed syllables. The gradual shortening of the whole duration of the stressed syllables and their components contained in longer words is deemed as the supportive evidence for PSS (Turk and Shattuck-Hufnagel 2000).

3.5 Acoustic results for polysyllabic shortening

To examine whether PSS occurs in Korean L2 speakers' production and whether PSS is a potential context affecting the gestural reduction, the target was placed on the stressed syllables, i.e., th potential targets of PSS with reference to their temporal dimension, i.e., duration. A one-way repeated-measures ANOVA was performed with duration of the syllables as dependent variable and the number of syllables as independent variable. All the data were analyzed by SPSS Statistics Version 27. Analysis revealed that the effect of PSS in stressed syllables emerged when headedness of the target syllables was collapsed ($F[2,8]=9.41$, $p=.01$). The duration of stressed syllables was shorter in longer words (Mono:Di:Tri=314 ms:282 ms:278 ms). A post-hoc LSD test exhibited that the difference between monosyllabic and disyllabic conditions was marginally significant ($p=.05$) and stressed syllables were significantly longer in monosyllabic words than in disyllabic words ($p<.01$). The difference between disyllabic and trisyllabic conditions did not reach significance ($p>.05$). This finding evidently indicates that PSS arose in a partial fashion, especially between monosyllabic and disyllabic words.

Figure 2 shows durational differences of stressed syllables by word length and headedness. To assess the effects of word length (i.e., the number of the syllables) on the duration of the primary stressed syllables, we run a one-way repeated-measures ANOVA with duration of the primary stressed syllables as dependent variable and word length as independent variable. For the duration of the stressed target syllables in left-headed words, stressed syllables were longer in shorter words (e.g., *tape* » *taper* » *tapering* 303 ms:294 ms:280 ms). These differences in mean duration, however, were not statistically significant ($F[2,8]=.61$, $p>.05$). On the contrary, there were marginally significant effects of word length on the duration of stressed syllables in right-headed words (e.g., *teem-esteem-misesteem*, 306 ms:271 ms:274 ms, $F[2,8]=3.84$, $p=.06$). Post-hoc LSD test showed that the difference between mono- and di-syllabic conditions was marginally significant ($p=.09$). These findings suggest that the magnitude of PSS is contingent on the headedness of the stressed syllables, in favor of being greater in right-headed words. This asymmetry in the effect size of PSS in L2 speakers is incongruent with the finding obtained for native English speakers. To be specific, the effect of PSS was greater in left-headed words than in right-headed words for L1 English speakers (Beckman and Edwards 1990; Turk and Shattuck-Hufnagel 2000). Overall, it is indicated that, compared to L1 English speakers' production, L2 English speakers whose L1 is a syllable-timed language, have more difficulty producing PSS conceivably due to the negative transfer of divergent L1 rhythmic units in Korean.

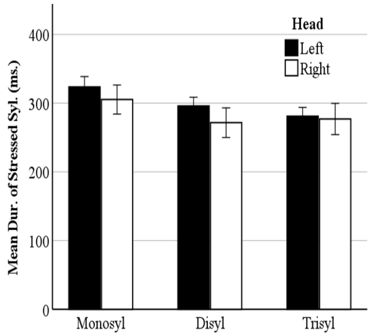


Figure 2. Mean duration of the stressed syllables by word length and headedness

We examined whether PSS occurs consistently across individual L2 speakers. Table 3 shows mean duration of stressed syllables, i.e., the target for PSS by word length and speakers. As is illustrated, the tendency of PSS exhibited a slight degree of interspeaker variation. Among five L2 speakers, three speakers (K3, K4 and K5) produced stressed syllables in the longer words with shorter duration. Such a pattern was not observed in two speakers (K1 and K2). For K3 and K5, post-hoc LSD test revealed that significant differences were found between monosyllabic and disyllabic words and between monosyllabic and trisyllabic words ($p<.05$), but there were no significant differences between disyllabic and trisyllabic conditions ($p>.05$). For K4, the stressed syllables tended to become shorter for longer words in the average duration, but the difference did not reach significance.

Table 3. Duration (ms.) of stressed syllables by word length and speakers

Spkrs	Head	Monosyl	Disyl	Trisyl	F-values	p-values
K1	L	309	307	272	$F[2,67]=0.59$	$p>.05$
	R	330	333	332		
K2	L	351	343	312	$F[2,69]=1.08$	$p>.05$
	R	298	292	283		
K3	L	319	282	290	$F[2,68]=4.72$	$p<.05$
	R	310	233	256		
K4	L	353	288	280	$F[2,64]=2.67$	$p=.07$
	R	298	271	291		
K5	L	286	254	246	$F[2,64]=6.69$	$p<.05$
	R	293	226	212		

To examine whether the effect of PSS is manifest at sub-syllabic constituents, we conducted a one-way repeated-measures ANOVA with duration of onsets of the stressed syllables as dependent variable and word length as independent variable. Analysis showed that the duration of the onset of the stressed syllables was affected by word length ($F[2,8]=9.5$, $p<.01$). Onsets of the stressed syllables contained in longer words were shorter than those in shorter words (Monosyl:Disyl:Trisyl=120 ms:106 ms:102 ms). This trend is consistent with the duration of the whole stressed syllables.

As Figure 3 shows, there was marginally significant interaction between Word Length and Headedness ([F2,8]=3.76, $p=.07$). Additionally, there was a main effect of Word Length ($F[2,8]=8.58$, $p<.05$) and main effect of Headedness also approached significance ($F[1,4]=7.91$, $p<.05$). To be specific, the duration of the onset was longer in shorter words than in longer words and the onset was produced with shorter duration in right-headed words (e.g., 95 ms, *teem-esteem-misesteem*) than in left-headed words (e.g., 124 ms, *tip-tiptoe-tiptopper*). For the left-headed words, the duration of the onset of the stressed syllables was marginally influenced by Word Length (127 ms:125 ms:119 ms, $F[2,8]=3.94$, $p=.06$). On the other hand, the effect of polysyllabic shortening on the duration of onset emerged to a greater extent in right-headed words than in left-headed words as is clearly depicted in Figure 4 (113 ms:87 ms:86 ms, $F[2,8]=6.42$, $p<.05$). These findings indicate that the effect of PSS was evident on the duration of onset of the stressed syllables for left-headed and right-headed words.

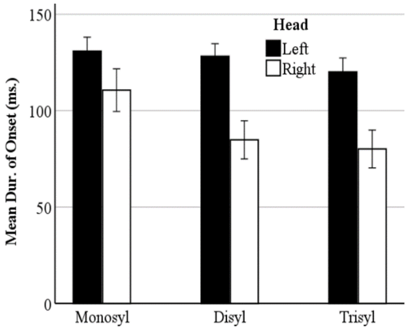


Figure 3. Mean duration of the onsets by word length and headedness

There was a main effect of Word Length ($F[2,8]=8.7$, $p=.01$) but no main effect of Headedness was found ($F[1,4]=3.77$, $p>.05$). Interaction between these two did not approach significance ($F[2,8]=2.01$, $p>.05$). Left-headed series (e.g., *cap-captive-captainship*) manifested the polysyllabic shortening effect in the duration of nucleus (F[2,8]=16.81, p<.01, 118 ms:105 ms:99 ms) whereas no such effect arose in right-headed words (e.g., *get-forget-unforget*) as is evident in Figure 4 (122 ms:119: ms:118 ms, F[2,8]=.24, p>.05).

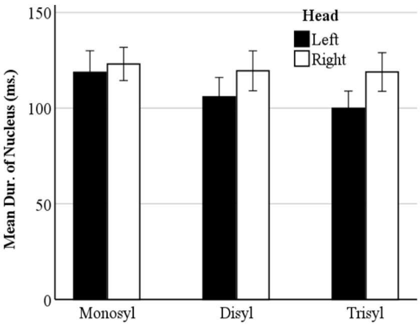


Figure 4. Mean duration of the nucleus by word length and headedness

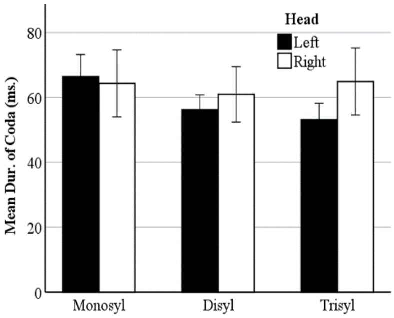


Figure 5. Mean duration of the codas by word length and headedness

Finally, we examined the effect of PSS on the duration of the codas of the stressed syllables. Figure 5 shows the mean duration of the codas in the stressed syllables by word length and headedness. Although the mean duration of the codas varied, it was not affected by word length (Mono:Di:Tri=65 ms:59 ms:56 ms, F[2,8]=1.92, p>.05). Post-hoc LSD analysis also exhibited that no significant differences emerged between two conditions (p>.05). Furthermore, there were no main effects of Word Length on the duration of the codas (F[2,8]=2.87, p>.05) and of Headedness (F[1,4]=.04, p>.05). Interaction between these two factors witnessed no significance (F[2,8]=.44, p>.05). Left-headed series, however, reveal a marginally significant effect of PSS (68 ms:59 ms:55 ms, $F[12,8]=3.83$, $p=.06$) whereas no significant effect was found for right-headed words (64 ms:56 ms:57 ms, $F[2,8]=.74$, $p>.05$). This finding suggests that the effect of polysyllabic shortening did not emerge in the duration of the codas in the stressed syllables regardless of whether the containing words are left- or right-headed.

In summary, for Korean L2 English speakers, the effect of PSS emerged on the duration of the stressed syllables as well as on the sub-syllabic constituents like onsets and nucleus, not codas. Furthermore, unlike native English L1 speakers, this effect was manifested, primarily between monosyllabic and disyllabic words or between monosyllabic and trisyllabic words. It was not observed between di- and tri-syllabic words.

3.6 Articulatory results

3.6.1 Gestural reduction with PSS

To see whether onsets in the stressed syllables undergo gestural reduction with reference to tongue dorsum height probably accompanied by or due to PSS, tongue contours for alveolars or velars embedded in the triplets were compared. Eight triplets were obtained per speaker and a total of 64 triplets were subject to polar GAMM SSANOVA. Gestural reduction is referred to as the process whereby tongue blade or tip for alveolars is lowered or tongue dorsum or back is lowered or retracted for velars. Comparative tongue configuration patterns for triples were classified into four categories: Type 1, Type 2, Type 3 and No GR. Type 1 to 3 are designated as the cases of gestural reduction in longer words whereas No GR is the pattern where gestural reduction is not observed in polysyllabic words. Type 1 refers to the case where target consonants in the disyllables or trisyllables exhibit gestural reduction, compared to the identical consonants in monosyllabic words, indicative of incomplete reduction. Type 2 is another case of incomplete reduction where tongue blade or dorsum shows target undershoot in trisyllables, compared to those in disyllables. Type 3 is the typical case of gestural reduction in the triplets where greater reduction occurs in trisyllables than in disyllables showing greater reduction than in monosyllables.

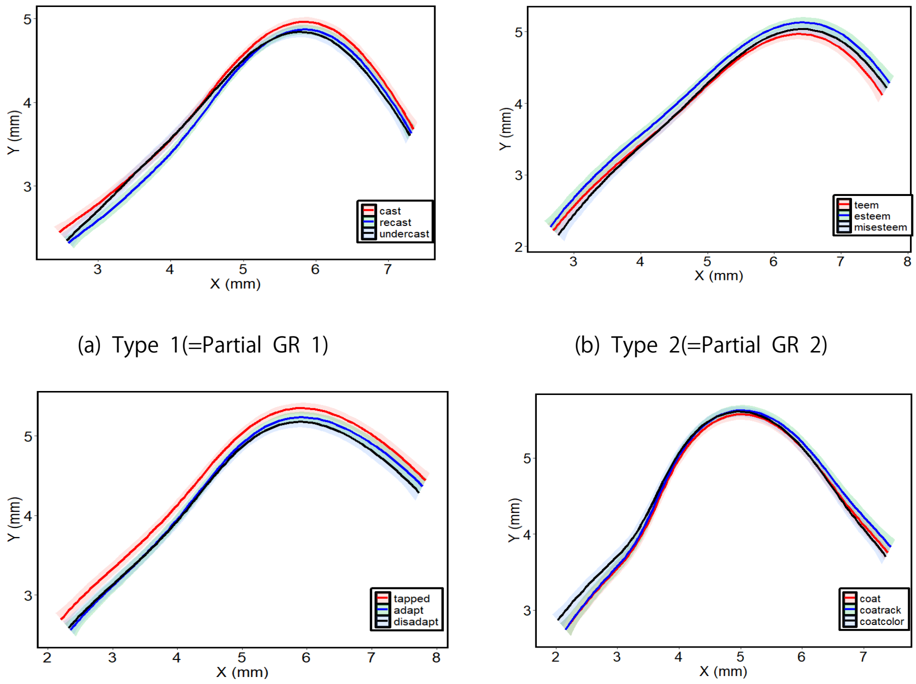
Table 4 shows the number and mean rates (%) of triplets by Type. Rates of each type of triplets were calculated by dividing the total number of obtained tokens (64) by the number of each type. As seen, gestural reduction was observed substantially more frequently than No GR (58% vs. 42%), exhibiting greater degrees of gestural reduction in longer words ($t(3)=3.29$, $p<.05$). Type 1 was found more frequently than Type 2 and Type 3 was most rare. To be specific, gestures of tongue blade or dorsum tend to undergo reduction more commonly for onset consonants embedded in primary stressed syllables in disyllabic or trisyllabic words, compared to those in monosyllabic words (28%). Additionally, Korean L2 speakers exhibited the typical effect of gestural undershoot mainly associated with PSS, showing the consistently gradual gestural reduction in longer words (16%). This finding suggests that there is comparatively higher tendency for gestural reduction for onset consonants in the stressed syllables belonging to longer words which are targets for PSS, compared to the non-gestural reduction.

Table 4. Number and rates (%) of triplets containing at least one pair of target reduction

Gestural reduction (=GR)			No GR
Type 1	Type 2	Type 3	
1σ 》 2σ ,3σ	2σ 》 3σ	1σ 》 2σ 》 3σ	
18 (28)	16 (25)	10 (16)	20
37 (58)			20 (42)

Figure 6 illustrates the example polar SSANOVA comparisons for Korean speakers, comparing onset consonants (alveolars /t,d/ or velars /k,g/) embedded in monosyllables (red curves), disyllables (blue curves), and trisyllables (black curves). Figure (6a) shows an example of Type 1 where the identical onset /k/ in disyllables or trisyllables is articulated lower than that in monosyllables with reference to tongue dorsum height, indicative of reduction of tongue dorsum gesture in polysyllabic words (e.g., *c̲ast*≫ *rec̲ast, underc̲ast*). An example of Type 2, i.e., Partial GR is shown in Figure (6b) where the tongue blade or tip involved in /t/ in trisyllables is positioned lower than that in /t/ in disyllables (e.g., *est̲eem* ≫ *misest̲eem*). Put differently, /t/ in ‘misesteem’ seems to have undergone target undershoot, compared to /t/ in ‘esteem’ in the sense that the tongue blade or tip for the former does not reach the alveolar ridge as high as that in the latter. Figure (6c) displays the typical case of polysyllabic reduction where /d/ in disyllables (e.g., ‘adapted’) is articulated with lower tongue blade than /t/ in monosyllables (e.g., ‘tapped’) and is produced with higher tongue blade than

/d/ in trisyllables (e.g., ‘disadapt’). This suggests that onsets embedded in the context of PSS in temporal dimension undergo gestural reduction or target undershoot in polysyllabic words with reference to the magnitude of gestural movement, i.e., tongue dorsum kinematics. Finally, Figure (6d) exemplifies the case of No-GR where gestural reduction involved in the tongue dorsum raising for /k/ is not realized in longer words with disyllables or trisyllables, i.e., ‘coatrack’ or ‘coatcolor’). Overall, there is a clear polysyllabic gestural reduction effect from the magnitude of tongue kinematics which might stem from PSS in the temporal dimension (Turk and White 1999; White and Turk 2010).



(a) Type 1(=Partial GR 1)

(b) Type 2(=Partial GR 2)

(c) Type 3(=Full GR)

(d) No GR

Figure 6. Polar SSANOVA of tongue contours for onsets (alveolar or velars) embedded in triplets: monosyllables (red curves), disyllables (blue curves) and trisyllables (black curves) (The left side represent tongue back and the front part of the tongue is on the right)

Figure 7 shows mean rates of triplets obtained from eight Korean speakers by Type (polysyllabic gestural reduction vs. No gestural reduction) and Subject. All eight speakers showed polysyllabic gestural reduction, varying in its rates and types. Its rates varied significantly by speakers (t(7)=5.1, p<.001, Mean 58, SD 31.9). Specifically, two speakers, K2 and K8 showed polysyllabic gestural reduction with 100%, exhibiting Type 1 and 3. Additionally, gestural reduction occurred for onsets for three speakers (K1, K4, and K7), ranging from 50% to 70%. The other three speakers (K3, K5, and K6) witnessed polysyllabic target undershoot approximately at 25%, which was comparatively lower than the rest of speakers.

For the ranges of types of gestural reduction, more than two types (Type 1, 2 or 3) emerged across all speakers. Of interest is the finding that a typical case of higher likelihood of gestural reduction in longer words, i.e., Type 3 was observed for six out of eight speakers. This evident effect of polysyllabic gestural weakening indicates that participants in this study apply polysyllabic gestural reduction in the context of English PSS, albeit less than native speakers of English.

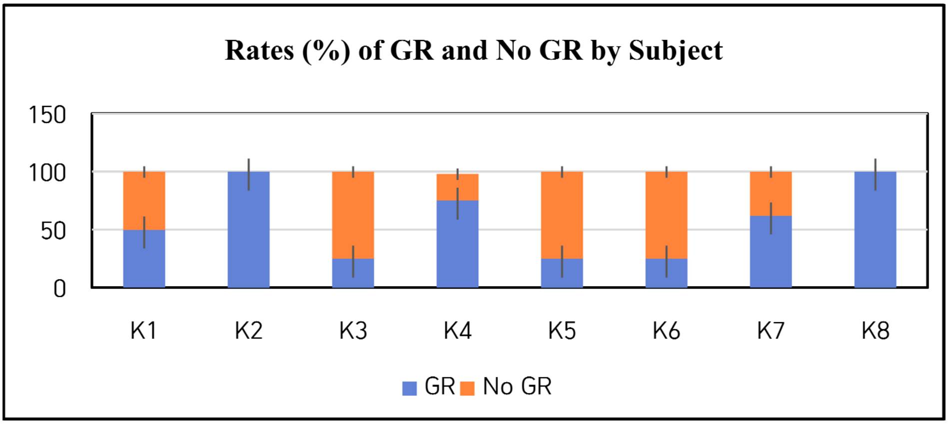


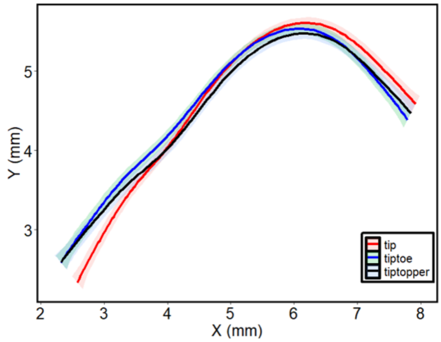
Figure 7. Rates (%) of polysyllabic gestural reduction and no gestural reduction by subjects

Table 5 shows the number of the word triplets which manifest polysyllabic gestural reduction where onsets (alveolars or velars) are produced with the decreasing magnitude in the raising movement of the main articulators, i.e., tongue blade (tip) or tongue dorsum as the number of syllables in the words increases. The total number of compared triplets was sixty four comparisons obtained from eight speakers. Out of the eight word series, the triplets of ‘teem’, ‘tapped’ and ‘cast’ manifest relatively the greater polysyllabic gestural reduction effect for onset consonants embedded in the PSS context. To be specific, ‘teem’ series exhibits gestural reduction with 100%. Three series, e.g., ‘tip’, ‘coat’ and ‘get’ witness gestural weakening with more than 50%. Only one series of triplet, i.e., ‘tap-taper-tapering’ does not undergo gestural reduction, compared to the rest of series. The overall results indicate that polysyllabic gestural reduction for the target onsets is evident for most of the triplet word series examined in the present study. It seems clear that right-headed word series do manifest relatively greater gestural weakening effect, compared to left-headed word triplet series (42% vs. 28%). This tendency of asymmetry in applicability of polysyllabic gestural reduction in sub-phonemic level seems to be associated with word-initial strengthening phenomena observed in marked position of left-headed words.

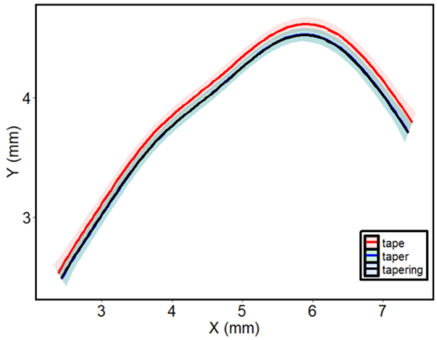
Table 5. No. of word triplet series showing polysyllabic gestural reduction

Triplet series	GR (=Type 1+2+3)	Ex. of Types	No GR
tip-tiptoe-tiptopper	5	Type 1, 2	3
tap-taper-tapering	2	Type 1	6
cap-captive-captainship	6	Type 1, 2, 3	2
coat-coatrack-coatcolor	5	Type 1, 2, 3	3
teem-esteem-misesteem	8	Type 1, 2, 3	0
tapped-adapt-disadapt	7	Type 1, 2, 3	1
get-forget-unforget	4	Type 1, 2	4
cast-recast-undercast	7	Type 1, 2, 3	1

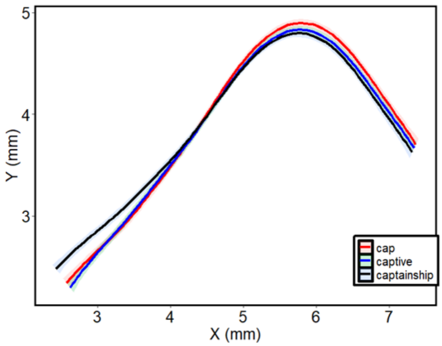
Figure 8 depicts the example polar SSANOVA comparisons of each word triplet series for Korean speakers, comparing onset consonants (alveolars /t,d/ or velars /k,g/) embedded in monosyllables (red curves), disyllables (blue curves), and trisyllables (black curves). Figure (8a) shows the comparison of ‘tip’ series where /t/ in ‘tiptoe’ or ‘tiptopper’ is produced with lowered tongue blade or tip than in ‘tip’, which is observed for K4 as an example of Type 1 as stated above. ‘tip’ word series exhibits Type 1 and 2, excluding Type 3. As illustrated in Figure (8b), ‘tape’ series manifests only Type 1 where /t/ involves lowering tongue blade and dorsum in ‘taper’ or ‘tapering’, compared to that in ‘tape’. The series of words ‘cap’, ‘coat’, ‘teem’, ‘tapped’ show the similar pattern in the sense that it results in a wider variety of types (Type 1, 2 and 3). Figure (8c, d, e, f) show the example of Type 3 where alveolars or velars in the target onsets are articulated with lower tongue blade or dorsum for trisyllables than for disyllables. Furthermore, the onsets in disyllables are articulated with lower raising of tongue blade or dorsum, compared to that in monosyllables (e.g., ‘cap’, 'coat', 'teem', 'tapped'). The 'get' word series shows the two types of gestural reduction (e.g., Type 1 and 2) and Figure (8g) shows the example of Type 1 from K8 who articulates /g/ with lowered tongue dorsum in 'forget' or 'unforget', compared to that in 'get'. The 'cast' series of words also exhibits gestural reduction in disyllable 'recast' or trisyllable 'undercast', compared to monosyllable 'cast', showing Type 1, 2 and 3. Figure (8h) illustrates the case of Type 3 from K8 where /k/ is articulated with lower tongue dorsum in the order of 'undercast', 'recast' and 'cast' as the word becomes longer.



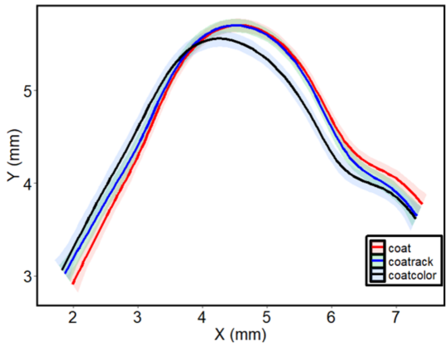
(a) tip » tiptoe, tiptopper (K4:Type 1)



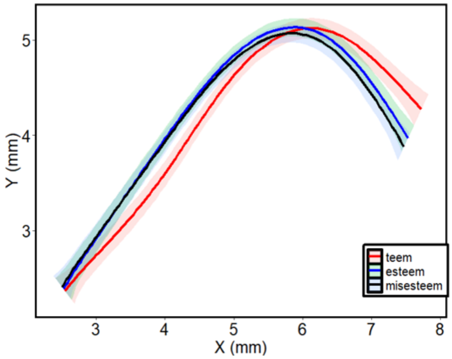
(b) tape » taper, tapering (K2:Type 1)



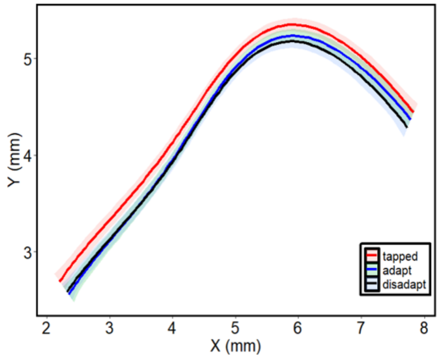
(c) cap » captive » captainship (K2:Type 3)



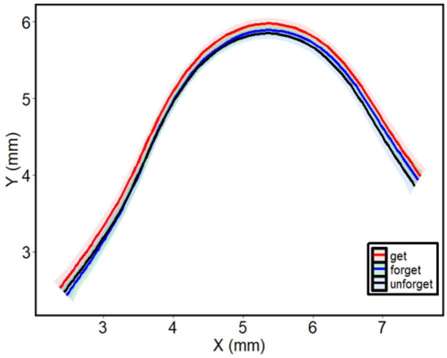
(d) coat » coatrack » coatcolor (K7:Type 3)



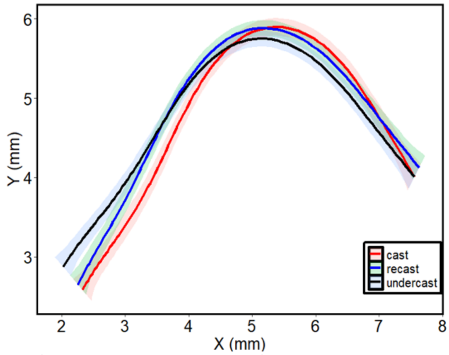
(e) teem »esteem » misesteem (K3:Type 3)



(f) tapped » adapt » disadapt (K1:Type 3)



(g) get » forget, unforget (K8:Type 1)



(h) cast » recast » undercast (K8:Type 3)

Figure 8. Polar SSANOVA of tongue contours for onsets (alveolar or velars) embedded in triplets: monosyllables (red curves), disyllables (blue curves) and trisyllables (black curves) (The left side represent tongue back and the front part of the tongue is on the right.)

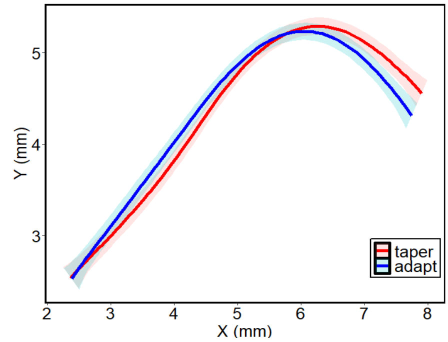
3.6.2 Gestural reduction by headedness

We examined the effect of headedness of the stimuli on the magnitude of gestural reduction in polysyllabic words. To this end, the onset consonants were compared between left-headed and right-headed words, the number of syllables being equal (e.g., *tiptoe* vs. *esteem*, *tiptopper* vs. *misesteem*). Polar SSANOVA of tongue contours were conducted to see whether there is any significant difference in both types of headedness. Table 6 shows mean rates of three patterns regarding the gestural reduction for onsets. The first pattern is the case of comparative gestural reduction for right-headed words over left-headed words whether in disyllables or trisyllables (L ≫ R, *captive* ≫ *forget*). To be specific, under this pattern, the tongue blade or tip in target alveolars or tongue dorsum for velars is positioned lower for right-headed words, compared to left-headed words. The second pattern is defined as the opposite case where tongue blade is lowered or tongue dorsum is retracted or lowered for left-headed condition than for right-headed condition (L ≪ R, *tiptoe* ≪ *esteem*). The last pattern refers to the pair where target onsets of left- and right-headed words show no different positions in the oral cavity with respect to the height or backness of the tongue blade or dorsum (L = R). The rates of each pattern were calculated by dividing the number of the total pairs consisting of two tongue contours for alveolar or velar extracted from left- and right-headed words by the number of pairs exhibiting each pair. As seen in Table 6, gestural reduction occurred more dominantly in right-headed words over left-headed words (66%) over the opposite pattern (23%) (e.g., *tiptoe* ≫ *esteem*). This stronger tendency for Pattern 1 over Pattern 2 shows that right-headed words manifest gestural reduction for the identical onset consonants, compared to left-headed words. Put differently, onsets contained in left-headed words exhibit greater resistance to gestural reduction. This might be contributable to the prominence of word-initial position in left-headed words, which has been revealed mainly in psychological as well as phonological studies. Onsets placed in the weaker position, i.e., word-medially in right-headed words seem to undergo gestural undershoot more frequently than in left-headed words by being more influenced by PSS in English.

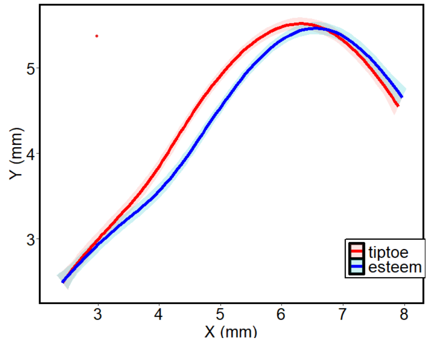
Table 6. Mean rates (%) of patterns of tongue blade fronting or tongue dorsum raising by headedness

Patterns	Pattern 1: L 》 R		Pattern 2: L 《 R		Pattern 3: L ≈ R	
Word size	2σ	3σ	2σ	3σ	2σ	3σ
	21	21	8	7	3	4
	42/64 (=66%)		15/64 (=23%)		7/64 (=11%)	

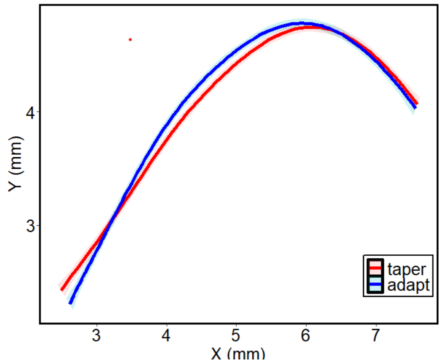
Figure 9 shows illustrative examples of each pattern regarding the gestural reduction of left- (red curves) or right-headed condition (blue curves). Figure (9a) illustrates the dominant case, i.e., Pattern 1 where alveolar /d/ is produced with tongue blade lowering and retraction in the right-headed words (e.g., in ‘adapt’), compared to the identical /t/ in left-headed words (e.g.,‘taper’). This case shows the gestural reduction in light of two dimensions of tongue configurations, i.e., tongue blade lowering and tongue dorsum retraction. The emergence of this pattern is observed with equal rates for disyllables and trisyllables conditions (21% vs. 21%). The opposite tendency, i.e., the example of Pattern 2 is presented in Figure (9b) where the articulation of alveolar involves greater retraction of tongue dorsum and lower raising of tongue blade in left-headed words (e.g., tiptoe) than in right-headed words (e.g., esteem). As stated above, Pattern 2 was observed substantially less frequent than Pattern 1 (23% vs. 66%). Finally, Figure (9c) shows no difference in the placement of tongue blade, the main articulatory gesture for alveolar /t,d/ between left- and right-headedness words (e.g., *taper* vs. *adapt*). This pattern was most rare of all the patterns (11%). In a nutshell, the preference for gestural reduction for right-headed words is strikingly more frequently observed over the opposite pattern.



(a) Left-H » Right-H (taper»adapt)



(b) Left-H « Right-H (tiptoe«esteem)



(c) Left-H = Right-H (taper≈adapt)

Figure 9. Polar SSANOVA of tongue contours for onsets (alveolar or velars) in left-headed words (red curves) and right-headed words (blue curves) (The left side represent tongue back and the front part of the tongue is on the right.)

Furthermore, we examined the trend for gestural weakening for onsets in right-headed words across speakers. The preference for gestural reduction in right- over left-headed words was dominant consistently across speakers. For a majority of speakers, six out of eight speakers (K2, K4, K5, K6, K7, and K8), Pattern 1, i.e., L≫R was realized more than double than Pattern 2 (L≪R). Three speakers (K3, K4, and K8) exhibited either pattern without Pattern 3 (L=R). Both Pattern 1 and Pattern 2 showed speaker-dependent variation (Pattern 1: $t(7)=16.8$, $p=.000$, Pattern 2: L≪R $t(7)=5.39$, $p=.001$). Overall, Korean speakers tend to produce onsets in the right-headed words with greater gestural weakening, compared to those in the left-headed words in English.

4. Discussion

4.1 Polysyllabic shortening effect in Korean L2 speakers' production

To see whether gestural reduction occurs in the onset consonants of the stressed syllables placed in the PSS context, we examined whether the effect of PSS is evident in the English stressed syllables in the temporal dimension. First, the acoustic results showed that English stressed syllables were longer in the words of monosyllables than those of disyllables for Korean speakers of L2 English (e.g., *tip* vs. *tiptoe*). Of interest is the finding that this tendency is in line with the previous findings for English L1 speakers (White and Turk 2010). The differences between monosyllables and disyllables were very similar in two groups of speakers (L1 English: L2 English=35 ms:34 ms). However, this inverse relation between word length and the duration of stressed syllables did not emerge in the condition of disyllables and trisyllables. Their difference (5ms) did not approach significance, which is not case for the production by English native speakers (22 ms). One plausible account is that this absence of the PSS effect is due to the presence of word boundary in the tokens such as 'coatcolor, coatrack' and difficulty keep isochrony. In any case, the effect of polysyllabic shortening is quite restricted for L2 speakers in the sense that it is manifested solely in the onsets primarily between monosyllables and disyllables (e.g., *tip* » *tiptoe* ~ *tiptopper*). On the contrary, polysyllabic shortening effect was observed for a triplet series of words for English L1 speakers (e.g., *tip* » *tiptoe* » *tiptopper*, White and Turk 2010). This result indicates that Korean L2 speakers are at the developmental stage of becoming native-like production of PSS, particularly evident from the acoustic and articulatory properties of onsets of the stressed syllables.

Furthermore, the pattern of the PSS effect varied according to the headedness of the words. To be specific, the effect of shortening on the onsets was small and insignificant between monosyllables and disyllables in left-headed words (e.g., 9 ms, *cap-captive*). However, the durational difference between monosyllables and disyllables was greater for right-headed words (e.g., 35 ms, *tapped-adapt*). One possible account is that the absence of the durational difference, or shortening effect might be attributed to the hyperarticulation of the word-initial syllables. That is, since word-initial position or phrase-final position is known to be a boundary marker from the view of perception and segmentation, it is more prominent than the other positions and tends to be produced with longer duration (Cooper 1991; Mattys et al. 2005; Langus et al. 2012; Ordin et al. 2017). This universal lengthening potentially applied in word-initial syllables might have overshadowed the PSS effect in left-headed word series. However, as mentioned previously, this finding was not observed for English native speakers (Beckman and Edwards 1990; Turk and Shattuck-Hufnagel 2000). Rather, the PSS effect was consistent for both left-headed and right-headed words and furthermore, the effect was greater for the former than for the latter. This can be interpreted to suggest that the PSS effect is compatible with the word-initial lengthening effect for L1 speakers. Nevertheless, it is still not clear and should await further investigation why Korean L2 production patterns deviate from those of L1 English speakers.

Additionally, the durational effect appeared consistently at sub-syllabic constituents like onsets and nuclei of the stressed syllables except for coda position. First, the duration of the onsets was shorter in longer words than in shorter words both for the left-headed (127 ms » 125 ms » 119 ms) and right-headed words (113 ms » 87 ms » 86 ms). The shortening effect between monosyllables and disyllables was greater for right-headed word series than for left-headed series. One plausible account for this asymmetry in the effect size for the onsets is that the constant situation of the onset in word-initial position for left-headed series invokes word-initial strengthening effect due to phonological markedness and accordingly is likely to reduce the PSS effect, compared to right-headed series. In any case, this inverse relation between word length and onset duration was the same as the finding for English L1 speakers (e.g., Left-headed, 128 ms » 120 ms » 117 ms; Right-headed, 129 ms » 98 ms » 85 ms, White and Turk 2010). This finding indicates that the PSS trends span the whole syllables, affecting the phonological constituents of the stressed syllables for L2 speakers as well as L1 speakers.

Furthermore, the PSS effect was evident for the duration of nucleus of the stressed syllables for left-headed words (118 ms » 105 ms » 99 ms), but not for right-headed words (122 ms »119 ms » 118 ms). Additionally, the shortening effect size was greater between monosyllables and disyllables than between disyllables and trisyllables. Also the durational differences in the nucleus between monosyllables and disyllables were smaller than those in the onset of the stressed syllables (e.g., 8 ms vs. 14 ms). However, this temporal shortening effect on the duration of nucleus emerged both for left- and right-headed words for English L1 speakers (White and Turk 2010). This comparatively smaller effect of PSS for L2 speakers, compared to L1 speakers, indicates that Korean speakers do not efficiently implement rhythmic patterns for longer English words, especially trisyllabic words in the current study.

Finally, we observed that the durational shortening effect did not arise for the codas either for the left-headed or right-headed words. The duration of the codas in the stressed syllables did not vary depending on the length of the words where they belong. This finding can be interpreted to suggest that the temporal properties of the codas are not affected by the PSS for L2 speakers' production. This result is not consistent with findings for L1 speakers. Codas in the stressed syllables were shorter in longer English words, i.e., in the order of monosyllables, disyllables and trisyllables (e.g., *cap-captive-captainship*). That is, PSS is evident in sub-syllabic constituents like the onset or nucleus, but not in the coda.

In brief, along the temporal dimension, the PSS patterns appeared in the duration of the whole stressed syllables. Furthermore, such effect is evident at onset as well as at nucleus with the greater effect size in onset over nucleus.

4.2 Gestural reduction in a context of polysyllabic shortening

Acoustic data analysis in previous section showed that the PSS effect is evident for the duration of stressed syllables as well as the onset and nucleus of the same syllables in Korean L2 speakers' production. Another important goal of the present study was to explore whether gestural reduction or weakening also is implemented along temporal decrease in the phonological context of PSS rule in English. Focus paid on the present study, it is expected that the onsets placed in the environment of PSS behaviors are susceptible to target undershoot or gestural reduction as the onset has undergone reduction in its duration in the phonological context. This speculation is based on the rationale that temporal reduction is likely to lead to or be accompanied by the weakening of the articulatory gestures involved in the production of the onset.

Interestingly, the ultrasound investigation of the onset alveolars or velars embedded in the PSS context demonstrated that gestural reduction occurs more than chance level (58%) as seen in Table 4. Target undershoot seems to have arisen, especially to the onsets in double pair comparisons (e.g., *tip* » *tiptoe*) more frequently in triplets (e.g., *tip* » *tiptoe* » *tiptopper*) (53% vs. 16%). To be specific, tongue tip or blade of the onset consonants was articulated in the lower position for longer words (i.e., di- or tri-syllabic words), compared to monosyllabic words. Additionally, tongue dorsum was raised toward the velar in a lesser degree in longer words than in shorter words. This shows that articulatory targets involved in the onset production, i.e., alveolar ridge or velum were approached comparatively farther away for longer words.

One plausible explanation might stem from the interaction of kinematics of the tongue and faster utterance of speech. That is, the reduction of the primary articulatory movement of the tongue seems to be related to the shortened amount of time involved in the production of the onset consonants due to the application of PSS. It might be the case that Korean L2 speakers utter the onset as well as the whole stressed syllable to keep rhythmic patterns, i.e., isochrony in English. Consequently, the articulatory targets of the onsets are not fully reached from the perspective of tongue kinematics. The present study is significant in the sense that the PSS-induced target undershoot emerged in the movement of articulatory gestures. A majority of previous studies showed that segments or subsegments undergo reduction in casual, conversational reduced speech (Johnson 2004; Ernestus and Warner 2011; Warner and Tucker 2011). These acoustic studies demonstrated that VOT or duration of the segments become shortened or the whole segments are deleted in faster speech. Building on these results, the present study revealed that the temporal reduction in the segments induces the shrinkage in their gestural movement.

While previous studies accentuate the main role of the pragmatic factor like speech styles in the durational shortening of the segments, the present research indicates that gestural reduction is deemed triggered by the effort to keep the rhythmic unit.

That is, this study offers the empirical evidence for isochrony-induced gestural weakening, i.e., reduction in the temporal magnitude engenders target undershoot. Such incomplete articulatory contact of tongue blade or dorsum against the palate has been indirectly reflected in acoustic parameters like shorter VOT or smaller intensity in previous studies (Warner and Tucker 2011). This reduction process has been documented primarily in rapid, spontaneous speech. Of course, anecdotal experiences seem to indicate that faster speech rates do not necessarily to give rise to temporal shortening or target undershoot. Some individual speakers tend to articulate utterances clearly even at high speech rate. However, the present study shows the concomitant reduction in both articulatory and acoustic parameters. That is, the shorter the onset in longer words, the greater the gestural reduction in the PSS context.

Similar to acoustic findings, the articulatory data also showed that gestural reduction involved in the production of onset alveolars or velars is evident in dual pairs, i.e., between monosyllabic and disyllabic or trisyllabic words (28%) and between disyllabic and trisyllabic words (25%). The gradual gestural reduction in the triplet series also was observed, albeit with small portion (16%). As previously mentioned, this pattern is not congruent with acoustic findings for English L1 speakers that the durations of the stressed syllables including the onset, nucleus and coda were shorter in the order of trisyllabic, disyllabic and monosyllabic words (Beckman and Edward 1990; Turk and Shattuck-Hufnagel 2000; White and Turk 2010). In sum, although not like the English target speakers, Korean L2 speakers seem to apply PSS and simultaneously be at the development stage of the gradual target undershooting for the onsets placed in the PSS environment. Given the interaction between temporal reduction and gestural weakening in the PSS context, Korean L2 learners whose L1 is a syllable-timed language attempted to keep rhythmic isochrony which is an essential characteristic of stressed-timed languages like English.

4.3 Limitations of the present study

The present study is a preliminary investigation of the effect of PSS on the articulatory characteristics of the onsets of primary stressed syllables as well as acoustic properties of these syllables and so is without limitations. First, the acoustic results were obtained from a limited number of L2 learners, and may not be generalizable to L2 speakers with various levels of English proficiency. Second, the focus of this study is restricted to the articulatory weakening of onset consonants of the primary stressed syllables. Since the temporal reduction effects of PSS rule span the whole stressed syllables as reported in this study, further articulatory studies are awaited to reveal the gestural aspects of the nucleus and codas to provide a comprehensive picture of the correlation between temporal and gestural dimensions.

5. Conclusion

This study examined acoustic and articulatory properties of stressed syllables and/or their subsyllabic constituents in L2 English by Korean learners whose L1 belongs to syllable-timed languages. Our findings show that Korean learners of English implemented polysyllabic shortening process primarily between monosyllabic and disyllabic words or between monosyllabic and trisyllabic words at the level of duration of stressed syllables as well as onset and nucleus. Furthermore, gestural reduction was performed for the articulation of the onset consonants, especially alveolars and velars contained in the disyllabic or trisyllabic words, compared to those in monosyllabic words. These findings suggest that Korean L2 speakers of English seem to adapt to the isochrony, a key characteristic of stress-timed languages like English and as a result, to apply PSS in longer words along with gestural reduction pertaining to the articulation of onset consonants. To confirm this interesting pattern in both duration and magnitude of gestural movements, future research need more L2 data and a wider variety of speakers of different L2 proficiency to track the implementation of polysyllabic shortening and their development stages.

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