INTERGESTURAL CV TIMING OF HOMOPHONOUS WORDS WITH DIFFERENT MORPHOLOGICAL STRUCTURES: A CASE STUDY OF LIQUID /L/ IN KOREAN

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ABSTRACT

This EMA study investigated whether and how underlying versus resyllabified onset /l/s in Korean may be differentiated, by examining homophonous sequences varying in morphological structures ($C_1V_1\underline{C_2V_2}$ vs. $C_1V_1\underline{C_2{+}V_2}$ where C_2 is /l/). In Korean, /l/ is produced as [l] in the coda, but as [ɾ] in the onset. But in $C_1V_1\underline{C_2{+}V_2}$, /l/ (in C_2) is resyllabified as an onset where it is produced as [ɾ], predicting no surface difference between the underlying and resyllabified onset conditions. Results showed that while /l/ was produced as [ɾ] in both conditions, the structural differences were reflected in temporal dimensions. [ɾ] was longer in the resyllabified versus underlying onset condition. And intergestural CV timing showed less overlap in the resyllabified versus underlying onset condition, indicating greater gestural cohesiveness of CV in the latter case. These differences were further augmented under prosodic prominence, reflecting speakers' deliberate effort to encode and maintain the morphological structure difference.

Keywords: intergestural timing, morphological structure, prosodic structure, Korean liquids, Articulatory Phonology

1. INTRODUCTION

The Korean liquid phoneme 'ㄹ', /l/, is renowned for its wide allophonic variations [1, 2]. The occurrence of an allophone of Korean /l/ is often determined by its position in a syllable. It is produced as a lateral (light /l/) in the coda position, and as a flap in the onset or intervocalic position [19, 20, 28]. Although Korean listeners perceive them as a single phoneme, the allophones are known to have distinct acoustic and articulatory features. Acoustically, a lateral variant is longer in duration than a flap variant [2]. In the articulatory dimension, the realization of /l/ is closely related to the adjacent vocalic gestures [2, 14, 19, 20]; a lateral is realized as a raising of the tongue tip during the preceding vowel while a flap is featured as a ballistic and short tongue tip movement between vowels [17].

The current study investigates whether and how the same allophone of /l/, occurring in different morpho-phonological environments, would be distinguished in its articulatory manifestation. This question is examined by comparing homophonous sequences of the resyllabified intervocalic /l/, which is underlyingly a coda as is produced in isolation (e.g., /pal + i/, where '+' is a morpheme boundary), and the underlying onset intervocalic /l/ (e.g., /pali/). In the former, the underlying lateral coda would be resyllabified in the intervocalic environment created by a morphological concatenation and thus produced as a flap [paɾi] (= a derived flap condition); and in the latter, with /l/ in an underlying onset intervocalic environment, the word would also be produced as a flap as in [paɾi] (= an underlying flap condition). At the surface phonetic level, therefore, in both cases, /l/ is produced as a flap, despite having different syllable structures due to underlying morphophonological compositions as in /pal + i/ and /pali/.

Previous studies allow us to make competing predictions regarding the production of the derived versus underlying flap. On one hand, studies on speech planning have suggested that the spelled-out segments go through the same process in creating the word's syllabified form, and thus the speech output may have little chance to reflect its internal morphophonological or syllable structure [22, 23]. If this is the case, no articulatory differences would be observed between the two homophonous sequences. On the other hand, the theory of Articulatory Phonology [4, 5, 6, 7, 15] assumes that the gestural coordination, specified as phase relations within a syllable, is stored in the lexicon. According to their assumption, the sequence of CV shows an in-phase relationship (i.e., the C and V gestures more or less start synchronously). The underlying flap in our study would show an in-phase relationship specified in the lexicon whereas the resyllabified flap may show a different pattern as their relationship is not specified in the lexicon (as C and V in our study do not belong to the same word). In addition, previous articulatory studies have provided some evidence that the gestures are coordinated differently depending on their underlying structures [10, 18]. Furthermore, some acoustic studies have also demonstrated differences in homophonous sequences [24]. Therefore, these studies allow us to predict some differences between the surface flap in the two different underlying morphological (and syllable) structures, particularly in terms of their gestural coordination.

This study also examines how the articulatory realization of the resyllabified and the underlying flap are further modulated by prosodic structure reflected in prosodic boundary strength and prominence. Prosodic strengthening via prominence or prosodic position is well known to maximize lexical contrast or to enhance the gestural bonding relationship [9, 11, 12, 13]. The prosodic modulation on the articulation of the allophone, therefore, will further shed light on whether and how speakers encode the underlying structural differences of the surface identical allophones.

2. METHOD

2.1. Participants

Twelve native speakers of Seoul Korean (6F, 6M in their 20s) participated in the experiment and were paid for their participation. In this paper, a subset of the collected articulatory data was analyzed first (4F, 3M) and the remaining data is still under analysis.

2.2. Speech materials and procedures

Two monomorphemic CVC-CVCV word pairs were used as target words, in which /l/ is placed in the coda or in the intervocalic onset position as in /pal/ 'foot' - /pali/ 'bowl' and /mal/ 'horse' - /mali/ 'Mari, *a proper name*'. They were followed by a grammatical particle /(i)lago/, of which the function is to directly cite the preceding word(s). Note that /i/ in the particle is inserted only when it follows a closed syllable. The combination of a target word and the particle yielded two sets of identical segmental strings with different underlying syllable structures: /pal+ilago/-/pali+lago/ and /mal+ilago/-/mali+lago/ where '+' refers to a morpheme boundary, and the underlines (i.e., $C_1V_1C_2$+V_2 and $C_1V_1.C_2V_2$) indicate the target sequences.

As shown in Table 1, target words were inserted in carrier sentences where two prosodic factors, Boundary and Focus were manipulated. The Intonational Phrase initial (IP-initial) condition and the IP-internal word initial (Wd-initial) condition were distinguished by the presence or absence of a prosodic phrasal juncture (including a pause) between the target and the preceding word. For the focus condition, target words were contrasted in a carrier sentence (e.g., "Did you write **/pali/** or **/pal/**?"). For the unfocused condition, non-target words were contrasted (e.g., "Did **you** write /pal/ or did **that person** write /pal/?).

Participants were asked to read out each written sentence presented as a written text on a computer screen. To induce each intended prosodic context, typographical cues were employed. A comma and a space were used at the IP boundary. The Wd boundary condition employed the pronoun /wuli/, which establishes a possessive relationship with the following noun. The targets were presented immediately after the pronoun without any space in between (e.g., /wulipal/ 'ourFoot'). The focused words were highlighted in red and bold.

During the recording sessions, two trained Korean ToBI transcribers checked whether each token was produced as the intended prosodic rendition or not. 240 sentences were produced per participant (4-target * 2-boundary * 2-focus * 15-repetition). In total, 1680 tokens were collected from 7 speakers, and by excluding 45 tokens with unintended prosodic renditions, 1635 tokens (97.3%) were analyzed.

Articulatory data were collected using EMA (AG501, Carstens Electronics), and acoustic data were recorded using a Tascam US 4*4 audio interface and a SHURE VP88 microphone simultaneously with the articulatory data. Five sensors were attached to the primary articulators: tongue tip (TT), tongue body (TB), upper lip (UL), lower lip (LL), and the middle of the lower gumline (LG). In this paper, kinematic data from TT (for the consonantal /l/ gesture) and TB (for the vocalic gesture) movements were analyzed.

Table 1: Examples of the test sentences. Targets are underlined, and contrasted words are marked in bold. '#' and '+' refer to phrase boundary and morphological boundary, respectively.

Conditions		Test sentences
#=IP	Foc	/ʧikɨmjʌki, # **pali**+lago s*ʌnni, # **pal+i**lago s*ʌnni/ Right here, did you write a **bowl** or a **foot**?
	Unf	/ʧikɨmjʌki, # pal+ilago **ni**ka s*ʌnni, # pal+ilago **ʧje**ka s* ʌnni/ Right here, did **you** write a foot or did **that person** write a foot?
#=Wd	Foc	/ʧikɨmjʌki, wuli#**pali**+lago s*ʌnni, wuli#**pal+i**lago s*ʌnni/ Right here, did you write our **bowl** or our **foot**?
	Unf	/ʧikɨmjʌki, wuli#pal+ilago **ni**ka s*ʌnni, wuli#pal+ilago **ʧje**ka s* ʌnni/ Right here, did **you** write our foot or did **that person** write our foot?

2.3. Measurements and statistical analyses

A matlab-based software, MVIEW [30] was used to define kinematic landmarks such as the onset and target of each movement. The articulatory landmarks were determined on the basis of changes in the velocity profiles of the articulatory movements by using a 20% threshold criterion. [25, 27].

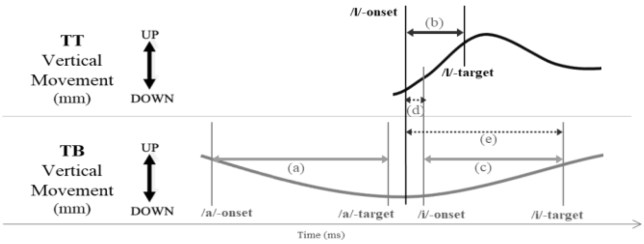

Figure 1: Schematized illustration of the tongue tip and tongue body vertical movements and the kinematic measurements: (a) V_1 duration, (b) C_2 duration, (c) V_2 duration, (d) time interval between C_2 and V_2 onsets, and (e) C_2V_2 duration

The duration of V_1, C_2, and V_2 was measured from the onset to the target of the gestural movement (Fig.1a~c). C_2V_2 duration (Fig. 1e) and the intergestural interval between the onset of C_2 /l/ and the onset of /i/ (Fig.1d) were also measured. For the intergestural time interval, a positive value indicates that the C_2 starts earlier than V_2 (hereafter "Earlier C_2") while a negative value shows that the C_2 starts later than V_2 (hereafter "Later C_2"). Since the actual degree of proximity between the onsets of C_2 and V_2 may reflect how much the two gestures occur synchronously, the absolute time intervals, as well as the Earlier C_2 and Later C_2 values, were analyzed.

A series of linear mixed-effects models were run separately for each measure with the lme4 package [13] in R. Fixed effects were Syllable Structure (CVC+V *vs.* CVCV), Focus (Focused *vs.* Unfocused), Boundary (IP-initial *vs.* Wd-initial), and all their 2-way and 3-way interactions. All the factors were contrast-coded and the reference level of each factor is underlined above. The random structure included by-subject intercepts and slopes for all the fixed factors and their interactions. Nearly maximal models were fitted for each measurement as long as the model converged. When there was a case of non-convergence, a slope with the smallest variance was removed. When there were interactions, post-hoc pairwise comparisons were conducted with the emmeans package [21].

3. RESULTS

In what follows, only the results relevant to the research questions are reported (i.e., the main effects of Syllable Structure and its interaction with Focus and Boundary).

3.1. Durational analyses on individual gestures

There was a significant main effect of Syllable Structure on V_1 duration (β=6.28, t=2.06, *p*=.04; Fig.2a), and some marginal effect on C_2 duration (β=2.27, t=2.32, *p*=.059). Both V_1 and C_2 were longer in the underlying coda condition ($C_1V_1C_2+V_2$) than in the underlying onset condition ($C_1V_1.C_2V_2$). In other words, the vowel /a/ and the consonant /l/ gesture in the underlying $C_1\underline{V_1C_2}$ words were longer than the same phonemes in the $C_1\underline{V_1.C_2}V_2$ words. For V_2 that follows /l/, there was no main effect of Syllable Structure.

There was a significant interaction between Syllable Structure and Focus on both C_2 (β=3.08, t=4, *p*<.001) and V_2 duration (β=2.67, t=2.47, *p*=.014). As can be seen in Fig.2b and Fig.2c, the interactions stem from the fact that the Syllable Structure effect (i.e., longer C_2 and V_2 in $C_1V_1\underline{C_2+V_2}$ than in $C_1V_1.\underline{C_2V_2}$) was significant only under focus (C_2: β=3.81, t=3.629, *p*=.028; V_2: β=2.06, t=2.58, *p*=.019). The emergence of the difference is mainly due to the fact that the consonantal and vocalic gestures temporally expanded more for $C_1V_1\underline{C_2+V_2}$ in the Focus condition as illustrated in Fig.2b and 2c. No other significant interactions were observed.

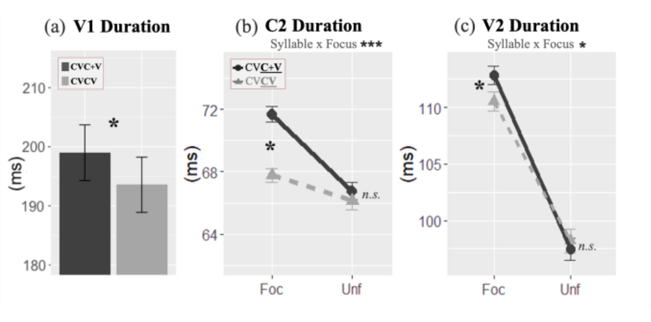

Figure 2: (a) Main effect of Syllable Structure on V_1 duration; (b) Syllable x Focus interaction on C_2 duration, (c) Syllable x Focus interaction on V_2 duration. Error bars represent standard errors. ('*' refers to *p*<.05, and '***' to *p*<.001)

3.2. Intergestural analyses

As for the intergestural time intervals between C_2 and V_2 onsets, there was a significant main effect of Syllable Structure on the absolute values and on the later C_2 values (Absolute, β=1.98, t=2.17, *p*=.031; Later C_2, β=-15.1, t=-2.59, *p*=.014). The intergestural intervals were longer for the resyllabified flap ($C_1V_1\underline{C_2+V_2}$) than for the underlying flap ($C_1V_1.\underline{C_2V_2}$). That is, the consonantal and the following vocalic gestures were farther apart in the heteromorphemic than in the monomorphemic conditions.

There was no significant Syllable Structure by Focus interaction, but a marginal interaction was observed in the absolute time interval values (Absolute, β=3.43, t=1.87, *p*=.062). As shown in Fig 3a, this is presumably due to the fact that the temporal interval difference in terms of syllable structure was significant only in the focused condition, with longer interval in $C_1V_1\underline{C_2+V_2}$ than in $C_1V_1.\underline{C_2V_2}$ (β=3.7, t=2.88, *p*=.009).

There were significant interactions between Syllable Structure and Boundary in Absolute and Later C_2 (Absolute, β=-4.22, t=-2.3, *p*=.022; Later C_2, β=29.48, t=2.87, *p*=.005). As can be seen in Fig.3b, the interactions seem to have come from the fact that the significant difference between the two syllable structures were observed only in Wd condition: Intergestural interval between C_2 and V_2 gestures were longer in $C_1V_1\underline{C_2+V_2}$ than in $C_1V_1.\underline{C_2V_2}$ (Absolute, β=-4.09, t=3.1, *p*=.02; Later C_2, β=-29.84, t=-2.72, *p*=.04).

Finally, as for C_2V_2 duration, there was a significant Syllable Structure (longer in $C_1V_1\underline{C_2+V_2}$ than in $C_1V_1.\underline{C_2V_2}$; β=1.96, t=2.21, *p*=.05), and this effect further interacted with Focus (β=5.8, t=3.94, *p*<.001). As shown in Fig 3c, the interaction stems from the fact that Syllable Structure difference was significant only under focus (β=18.21, t=4.18, *p*=.021).

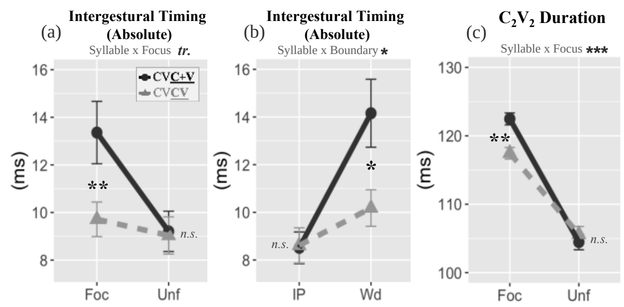

Figure 3: (a) Syllable x Boundary interaction on the intergestural timing for the Absolute condition; (b) Syllable x Boundary interaction on the intergestural timing for the Later C_2 condition; (c) Syllable x Focus interaction on C_2V_2 duration. Error bars represent standard errors ('*' refers to *p*<.05, '**' to *p*<.01, and '***' to *p*<.0001).

4. DISCUSSION

The present study examined kinematic characteristics related to the Korean /l/ in order to understand whether and how its allophone [ɾ], occurring in two different morphophonological environments, is articulatorily manifested and further modulated by higher order prosodic structure. Comparisons were made between the resyllabified flap derived from the underlying coda from a heteromorphemic environment as in /pal + i/ and the underlying intervocalic flap from a monomorphemic environment in /pali/, both of which are produced as [paɾi] on the surface. The articulatory durations of the consonantal (i.e., /l/) and the surrounding vocalic gestures (i.e., /a/ and /i/) were measured and the intergestural time interval between the flap and the following vowel /i/ was calculated.

One of the basic findings was that the articulatory duration of the tongue body movement for /a/ was longer in the underlying heteromorphemic $C_1\underline{\mathbf{V_1}}C_2$+$V_2$ structure than in the underlying $C_1\underline{\mathbf{V_1}}C_2V_2$ monomorphemic environment, and this difference was not further modulated by prominence or neighbouring boundary strength. The result suggests that the intrinsic temporal difference between the monosyllabic and disyllabic words, which must be encoded in the lexicon, arises on the surface in the articulatory dimension.

Moreover, the tongue tip gesture for the target liquid showed a subtle but significant temporal difference as a function of morphophonological structure, but only under focus. That is, the derived vs the underlying flap did not differ from each other at least in the temporal dimension when they were produced in the unfocused environment, yet the morphophonological difference emerged articulatorily when the two structures were contrasted under focus. Note that the same kind of focus-induced modulation was observed in the tongue body gesture for the following /i/ vowel, and in the intergestural duration measured from the onset of the tongue tip gesture to the offset of the tongue body gesture. All these temporal adjustments were mainly manifested by more lengthening in the heteromorphemic sequence under focus. The results therefore seem to suggest that speakers engage in a deliberate effort to make a distinction between the two homophonous sequences, referring to the underlying structures, when the contrast is called for by the information structure. The results therefore support the views, in line with previous studies, that the lexical contrast is maximized in a fine-phonetic detail under prominence [cf. 9, 11, 12, 13], and that the gestures are coordinated differently depending on their underlying structures [10, 18, 29].

Another important finding of the present study is that the morphophonological structural difference between the two homophonous sequences is clearly reflected in the intergestural timing between the consonantal and the following vocalic gesture. The fact that the absolute distance between the two gestures were shorter for the monomorphemic $C_1V_1.C_2V_2$ than for the heteromorphemic $C_1V_1C_2$+V_2 suggests that the gestural cohesiveness is stronger when the two gestures belong to the same syllable/morpheme underlyingly. Note also that such a structure-sensitive temporal difference in the absolute term was found significant only under focus. This can be accounted for within the Articulatory Phonology, which views that the gestural coordination is specified within the lexicon [4, 5, 6, 7]. C_2 and V_2 in the $C_1V_1.C_2V_2$ belong to the same word and form an underlying CV syllable. The smaller temporal interval between the onsets of C_2 and V_2 can be deemed as revealing a stronger in-phase relationship specified in the lexicon. In contrast, C_2 and V_2 in the $C_1V_1.C_{2+}V_2$ do not belong to the same word, and hence their timing relationship is not intrinsically specified in the lexicon. The farther distance between the two gestures under focus therefore appears to reflect a relatively loose relationship in their gestural timing as the two gestures do not belong to the same word. Their yet enhanced distance under focus seems to provide another piece of evidence for the speakers' effort to maximize the structural difference when on demand.

The present study also found that the intergestural timing difference due to the syllable structure (stemming from morphological structure) was further modulated by the strength of prosodic boundary at which the target-bearing word occurs. The aforementioned intergestural timing difference between the resyllabified and the underlying CV structure (i.e., longer in the former than in the latter) was found significant only in the phrase-medial (Word) condition, not in the IP-initial condition. That is, at the IP-initial position, despite the fact that C_2V_2 were not strictly at the edge of the prosodic phrase (forming the second syllable of the IP-initial word), they showed smaller intergestural timing. This indicates a strong bonding relationship between C_2 and V_2 in the IP-initial position, regardless of whether the flap is derived or underlying. On the other hand, the gestural bonding appears to be loose in the medial condition. This result is in line with the previous studies showing a strong gestural bonding at a larger boundary, possibly reflecting domain-initial strengthening [8, 12].

In conclusion, the current study showed that the flap allophone of Korean /l/ occurring in homophonous surface sequences from two different underlying structures (i.e., a resyllabified flap and an underlying flap), can be articulatorily distinguished and their difference particularly shows up under focus. The results take the support away from the studies arguing that the underlying representations (e.g., morphological differences) are dimmed through the resyllabification process (i.e., during the phonological encoding stage) by making the adjacent words spelled-out segments "on the fly" (i.e., phonological syllable) [22, 23]. Rather, the present study provides evidence that speakers fine-tune the articulatory realization of gestures and their coordination depending on the underlying morphological structure and a higher-order prosodic structural demand.

5. ACKNOWLEDGMENT

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6. REFERENCES

[1] Ahn, S. W. (2002). The electropalatographic evidence of the Korean flap: An intervocalic Korean liquid sound. Speech Sciences, 9(3), 155-168.
[2] Ahn, S. W. (2006). An Electropalatographic Study of English 1, r, Flap and the Korean Liquid ㄹ. Korean Journal of English Language and Linguistics, 6(1), 113-133.
[3] Bates, D., Mächler, M., Bolker, B., & Walker, S. (2014). Fitting linear mixed-effects models using lme4. arXiv preprint arXiv:1406.5823.
[4] Browman, C.P., & Goldstein, L. (1988). Some notes on syllable structure in Articulatory Phonology. Phonetica, 45, 140–155.
[5] Browman, C. P., & Goldstein, L. (1990). Tiers in articulatory phonology, with some implications for casual speech. Papers in laboratory phonology I: Between the grammar and physics of speech, 341-376.
[6] Browman, C. P., & Goldstein, L. (1992). Articulatory phonology: An overview. Phonetica, 49(3-4), 155-180.
[7] Browman, C. P., & Goldstein, L. (1995). Gestural syllable position effects in American English. Producing speech: Contemporary issues, 19-33.
[8] Cho, T., & Keating, P. A. (2001). Articulatory and acoustic studies on domain-initial strengthening in Korean. Journal of phonetics, 29(2), 155-190..
[9] Cho, T., Lee, Y., & Kim, S. (2011). Communicatively driven versus prosodically driven hyper-articulation in Korean. Journal of Phonetics, 39(3), 344-361.
[10] Cho, T. (2001). Effects of morpheme boundaries on intergestural timing: Evidence from Korean. Phonetica, 58(3), 129-162.
[11] Cho, T. (2005) Prosodic strengthening and featural enhancement: Evidence from acoustic and articulatory realizations of /a,i/ in English. Journal of the Acoustical Society of America
[12] Cho, T., Yoon, Y., & Kim, S. (2014). Effects of prosodic boundary and syllable structure on the temporal realization of CV gestures. Journal of Phonetics, 44, 96-109.
[13] de Jong, K. J. (1995). The supraglottal articulation of prominence in English: Linguistic stress as localized hyperarticulation. The journal of the acoustical society of America, 97(1), 491-504.
[14] Hwang, Y., Lulich, S. M., & De Jong, K. J. (2019). Articulatory and acoustic characteristics of the Korean and English word-final laterals produced by Korean female learners of American English. The Journal of the Acoustical Society of America, 146(5), EL444-EL450.
[15] Iskarous, K., & Pouplier, M. (2022). Advancements of phonetics in the 21st century: A critical appraisal of time and space in Articulatory Phonology. Journal of Phonetics, 95, 101195.
[16] Krakow, R. A. (1999). Physiological organization of syllables: a review. Journal of Phonetics, 27(1), 23-54.
[17] Ladefoged, P. & Maddieson, I. (1996). The sounds of the world's languages. Malden, MA (USA): Blackwell Publishing.
[18] Lee, J., Kim, S., & Cho, T. (2019). Effects of morphological structure on intergestural timing in different prosodic-structural contexts in Korean. In Proceedings of the 19th International Congress of Phonetic Sciences, Melbourne, Australia.
[19] Lee, S. & Kang, S. (2003). Acoustic and phonological properties of Korean liquids. Journal of Language Sciences, 10(2), 77-92.
[20] Lee, Y. J., Goldstein, L., & Narayanan, S. S. (2015). Systematic variation in the articulation of the Korean liquid across prosodic positions. In ICPhS.
[21] Lenth, R. V. (2022). Emmeans: Estimated Marginal Means, aka Least-Squares Means, Version 1.8. 1-1.
[22] Levelt, W. J., Roelofs, A., & Meyer, A. S. (1999). A theory of lexical access in speech production. Behavioral and brain sciences, 22(1), 1-38.
[23] Levelt, W. J. (1993). Speaking: From intention to articulation. MIT press.
[24] Plag, I., Homann, J., & Kunter, G. (2017). Homophony and morphology: The acoustics of word-final S in English1. Journal of Linguistics, 53(1), 181-216.
[25] Pouplier, M., & Goldstein, L. (2010). Intention in articulation: Articulatory timing in alternating consonant sequences and its implications for models of speech production. Language and Cognitive Processes, 25(5), 616-649.
[26] Shattuck-Hufnagel, S., & Turk, A. E. (1996). A prosody tutorial for investigators of auditory sentence processing. Journal of psycholinguistic research, 25(2), 193-247.
[27] Shaw, J., Gafos, A. I., Hoole, P., & Zeroual, C. (2009). Syllabification in Moroccan Arabic: evidence from patterns of temporal stability in articulation. Phonology, 26(1), 187-215.
[28] Shin, J. (2015). The sounds of Korean. In Brown, L., & Yeon, J. (Eds.). The handbook of Korean linguistics (Chapter 4). John Wiley & Sons.
[29] Son, M. (2011). The Projection of Syllable Structure: A Case Study of Intervocalic/k/ in Korean. The Korean Journal of Linguistics, 36(2), 395-414.
[30] Tiede, M. (2010). MVIEW: Multi-channel visualization application for displaying dynamic sensor movements. development.