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Korean /l/-flapping in an /i/-/i/ context

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ABSTRACT

In this study, we aim to describe kinematic characteristics of Korean /l/-flapping in two speech rates (fast vs. comfortable). Production data was collected from seven native speakers of Seoul Korean (four females and three males) using electromagnetic midsagittal articulometry (EMMA), which provided two dimensional data on the x-y plane. We examined kinematic properties of the vertical/horizontal tongue tip gesture, the vertical/horizontal (rear) tongue body gesture, and the jaw gesture in an /i/-/i/ context. Gestural landmarks of the vertical tongue tip gesture are directly measured. This serves as the actual anchoring time points to which relevant measures of other trajectories referred. The study focuses on velocity profiles, closing/opening spatiotemporal properties, constriction duration, and constriction minima were analyzed. The results are summarized as follows. First, gradiently distributed spatiotemporal values of the vertical tongue tip gesture were on a continuum. This shows more of a reduction in fast speech rate, but no single instance of categorical reduction (deletion). Second, Korean /l/-flapping predominantly exhibited a backward sliding tongue tip movement, in 83% of production, which is apparently distinguished from forward sliding movement in English. Lastly, there was an indication of vocalic reduction in fast rate, truncating spatial displacement of the jaw and the tongue body, although we did not observe positional variations with speech rate. The present study shows that Korean /l/-flapping is characterized by mixed articulatory properties with respect to flapping sounds of other languages such as English and Xiangxiang Chinese. Korean /l/ flapping demonstrates a language-universal property, such as the gradient nature of its flapping sounds that is compatible with other languages. On the other hand, Korean /l/-flapping also shows a language-particular property, particularly distinguished from English, in that a backward gliding movement occurs during the tongue tip closing movement. Although, there was no vocalic reduction in V2 observed in terms of jaw and tongue body height, spatial displacement of these articulators still suggests truncation in fast speech rate.

Keywords: Korean /l/-flapping, flap, kinematic, gradient, reduction, backward

1. Introduction

A flap serves as the phoneme /ɾ/ in Spanish while it is an allophonic variant of underlying alveolar consonants, such as /d/, /t/, and /l/, in English, German, and Korean (/d/-flap, /t/-flap, /l/-flap for input representation and [ɾ] for output representation). Traditionally, an intervocalic alveolar voiced/voiceless stop /d, t/ becomes an alveolar flap [ɾ] as a target segment undergoes a phonological rule (Kahn, 1980, Hayes, 1995). In Australian English, an alveolar flap is derived through a transformation rule from a voiceless alveolar stop /t/ (e.g., /VtV/ → [VɾV] (Kahn, 1980; Selkirk, 1982). An alveolar flap can also be derived from underlying voiced (/d/) as well as voiceless (/t/) alveolar stops, which are observed in German dialects (Northern Low Saxon) (Ladfoged and Maddieson, 1996). Similarly, an aspirated voiceless alveolar stop /t^h/becomes a flap in Xiangxiang Chinese (e.g., /VdV/ or /Vt^hV/ → [VɾV] in Ting (2007)). For English, a flapping rule is known to further satisfy lexical or prosodic conditioning for its rule application. This takes place when an alveolar stop occurs in an unstressed syllable (e.g., unstressed V in 'ladder' (/'lædɚ/ → ['læɾɚ]) in (Zue & Laferriere, 1979), ‘obesity’ (/oʊ'bisətɪ/ → [oʊ'bisəɾɪ]) in Kahn (1980), ‘winter’ (/'wɪntɚ/ → ['wĩɾɹ]), 'revolting' (/rɪ'voʊltɪŋ/ → [rɪ'voʊɫɾɪŋ]),

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'parting' (/'paɹtɪη/ → ['paɹɾɪη]) in Banner-Inouye, 1989) or even across a word boundary as long as it is produced as a single prosodic rhythm (a clitic in ‘He beat him’ (/hɪ'bɪtɪm/ hɪ'bɪɾəm]) in Monnot & Freeman (1972)). A flap is also described in the autosegmental representation such that a single contour segment is comprised in the order [-cons][-cont][-cons] under a single timing unit (Banner-Inouye,1989). Flapping is part of a weakening process, an allophonic variation relevant to ‘stronger’ input consonants (Kirchner, 1998), and it involves not so much categorical changes as it does gradient changes (Browman and Goldstein, 1992).

Phonetically, an alveolar flap is articulatorily implemented with a short contact of the tongue tip against the alveolar ridge followed by an immediate release and belongs to the rhotic group (Ladefoged & Maddieson, 1996). In terms of articulation, a flapping sound is hypothesized to be a single unit with a triadic sequence (in the order open-close-open) with maneuvering from aerodynamic mechanisms (i.e., the Bernoulli effects) (Banner-Inouye, 1989). It comes along with a short contact of the tongue tip against alveolar ridge or even with a "near" contact (Banner-Inouye, 1989: 68).

Many a study has proposed that a derived flapping sound shows substantial variation in terms of occlusion, release burst, jaw position (Umeda, 1977; Zue & Laferriere, 1979; Stone & Hamlet, 1982; Turk, 1992) - /d/-flaps can occur along a continuum where /d/ is produced with a complete articulation on one extreme and a tapping articulation on the other (Haugen, 1938). Highly variable acoustic realizations of /d/-flaps and /t/-flaps have been observed with inter-speaker variability and task-dependent variability in the measurements of pre-flap vowel duration, F1, fundamental frequency, and degree of an intensity dip (Braver, 2010). Ting (2007) conducted an acoustic-aerodynamic study on flapping of /d/ and /th/ in Xiangxiang Chinese. Acoustically, her data demonstrated intra-speaker variation in the phonetic realization of /d/-flaps and /t/-flaps, which rendered several variants. In her study, derived flapping sounds fell along a continuum with different degrees of acoustic occlusion duration, release burst, and voicing variation, where longer closure duration with a strong release burst with/without voicing occurred at one extreme, a vowel-like approximant at the other extreme, and a typical tap with a short occlusion with/without voicing fell in between.

Articulatory and perceptual aspects of flaps [ɾ] also has been examined in previous literature using different methodologies with/without acoustic analysis. In terms of articulation, a flapping sound is a sound in which an active articulator contacts briefly either the dental, alveolar, or post-alveolar area of the roof of the mouth. According to Ladefoged and Maddieson (1996: 231), this apical sound is pronounced by "moving the active articulator tangentially to the site of the contact, so that it strikes the upper surface of the vocal tract in passing." In an X-ray study on rhotics, Monnot and Freeman (1972) showed that the tongue tip positioned *backward* right before hitting the alveolar ridge for an American-English alveolar flap [ɾ] while the tongue tip goes straight forward to the alveolar ridge for a Spanish dental tap. More recently, an X-ray microbeam study on English has been conducted with alveolar stops /d/ in ‘toad’ and /t/ in ‘tote’ embedded in the carrier phrase ‘Put the ____ on the table.’ Using the flesh-point tracking system, sounds perceptually categorized as a flap [ɾ] demonstrated a *forward tangential* movement of the tongue tip for a flapping contact (de Jong, 1998: 284). Electropalatography (EPG) studies on the Catalan alveolar tap [ɾ] showed context-sensitive articulatory variation, resulting in devoicing (e.g., /pɾa/, /pɾo/, /eɾi/) and in undershoot of the tongue tip contact (e.g., /gɾu/) (Recasens and Espinosa, 2007).

Compared to flapping sounds explored in other languages, relatively little is known about Korean with respect to gradience and articulation. The flap [ɾ] is derived in Korean from an underlying voiced alveolar lateral approximant /l/ with/without a morphological boundary that has a following vowel (Lee, 2001). Being a post-lexical process, this is sensitive to prosodic structure, e.g., within-accentual phrase boundary (Jun, 1993). Specifically, /l/-flaps can occur intervocalically as shown in (1a), between a preceding vowel and a following semi-vowel as shown in (1b), but not so in the word-final position (1c) or with a following homorganic/heterorganic consonant (1d & 1e).

(1) Korean flapping
a. /ki+lin/ → [kiɾin] ‘giraffe’
b. /mi+lje/ → [miɾje] ‘future’
But,
c. /kil/ → [kil], not *[kiɾ] ‘road’
d. /pilli+m/ → [pillim], not *[piɾlim] ‘borrowing’
e. /mal+ki/ → [malgi], not *[maɾgi] ‘not doing’

In Sung (2007), Korean flapping sounds were examined in an acoustic study. There was an average of 20 ms of occlusion duration across speakers, voicing during occlusion duration in 95% of production, and release burst in 42% of production.

Based on results from previous articulatory studies (e.g., Monnot and Freeman, 1972; de Jong, 1998; Recasens and Espinosa, 2007), it is plausible to assume that Korean /l/-flaps are another instance of temporal and spatial reduction. Under this premise, /l/-flaps can also be phonetically realized in a gradient manner as a reduced tongue tip constriction gesture is preceded by *ballistic* closing gesture in the temporal and spatial domains. In the present study, we are interested in learning several things which bear on articulatory characteristics of Korean flapping sounds in general as well as two speech rate effects (fast and comfortable). In order to develop this line of inquiry, we are specifically concerned with the following research questions.

Our first interest is to learn whether derived flapping sounds in Korean are understood as distributed along a continuum and whether reduction occurs as speech rate varies. In particular, fast rate has been a condition for phonological and phonetic variations (e.g., lenition including flapping (Kirchner, 1998); place assimilation (Jun, 1996, Son, 2008); speech production errors (Mowrey & MacKay, 1990; Pouplier & Goldstein, 2010); we are interested in examining the possibility for reduction of a flapping sound demonstrating rate sensitivity. To meet this goal, we made use of three kinematic events of the tongue tip gesture (i.e., the tongue tip closing movement gesture, constriction duration including constriction minima, and opening gesture).

Secondly, we wish to learn whether, and if so, how, there is ballistic forward tangential contact in Korean /l/-flaps as observed in American-English alveolar flaps. Monnot and Freeman's (1972) X-ray study showed a flap is articulated with a brief tongue tip retraction followed immediately by striking of the tongue tip against the alveolar ridge. De Jong (1998) also reported a forward movement of the tongue blade. Since nothing substantial is known about directionality of the tongue tip closing movement of the Korean /l/-flap, to the best of our knowledge, we estimate directionality of movement of horizontal tongue tip position with reference to a set of two kinematic time points – tongue tip movement onset (beginning position) and tongue tip constriction minima (ending position).

Lastly, the articulator model designed by de Jong, Beckman, and Edwards (1993) proposed that unstressed syllables with a flap-vowel sequence (e.g., ‘ ′toa**d** **o**n’) show more intergestural overlap between the consonantal gesture (C) and the vocalic gesture (V), the latter of which exhibits a lower jaw and lower/retracted tongue body gesture, which in turn results in a reduced tongue tip gesture of C that is characterized by more reduction and retraction of the tongue tip gesture. Since the articulator model suggests that the vowel interacting with a weaker consonant, i.e., a preceding flap sound in this case, be less articulatorily adjusted (therefore, a more antagonistic vocalic gesture). Hence, we examine whether, and if so, how, the second vowel (V2) preceded by a /l/-flap demonstrates a more antagonistic vocalic gesture in fast rate. With respect to speech rate-dependent coarticulatory resistance between V2 and a preceding Korean /l/-flap in the /i+li/ sequence, we are interested in learning whether greater reduction applies to fast rate compared to comfortable rate in the jaw and tongue body gestures in Korean /l/-flaps.

2. Methods

2.1 Data collection and subjects

The Perkell-system electromagnetic midsagittal articulometer system (EMMA) at Haskins Laboratories (Perkell et al., 1992) was used to collect kinematic data of the tongue tip, the tongue body, and the jaw. Serving as head reference points, one transducer was attached at each of the following, for a total of three: the maxillary and mandibular central incisors and the nose ridge. Four transducers were attached on the tongue at approximately equal distances (i.e., on the tongue tip, anterior tongue body, posterior tongue body, and tongue dorsum) when subjects stretched their tongues out. Two transducers were attached, one on the upper lip and the other on the lower lip. They were arranged in a straight line with each subject's vocal tract in the midsagittal plane. The speech signal was sampled at 20 kHz and we conducted post-processing procedures (see Son (e.g., 2011a, 2011b) for detailed description). Acoustic data were collected with a Sennheiser shotgun microphone positioned approximately 30 cm away from each subject's mouth at the time of acquiring articulatory data.

Stimuli containing target words with tongue tip constriction gesture are part of another experiment (Son, 2008). One vocalic context was used (i.e., /i+Ci/), which appeared within a natural sentence as shown in (2). During elicitation, seven speakers (four female; three male) were asked to read at two speech rates, in the order comfortable and fast, as they read stimuli presented in Korean on a computer screen. Each speaker was asked to produce a set of four repetitions of the target sequence, which was followed by stimulus fillers which comprised another group of four repetitions. This procedure of stimulus elicitation from each speaker was repeated twice, rendering sixteen repetitions. A total of 112 tokens were collected and used for further analysis.

All subjects, naive to the purpose of the EMMA experiments, spent their first twenty-three years mainly in Seoul. They all identified themselves as speaking the Seoul-Korean dialect and did not have any speech-hearing deficits.

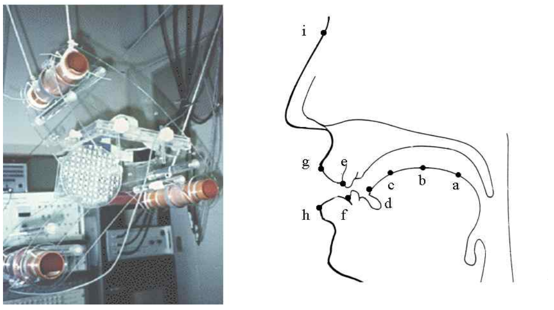

Figure 1. Representative transducer locations superimposed on an image of the midsagittal plane of the human vocal tract image (right panel) (borrowed from Son, 2011: 29): (a) the tongue dorsum; (b) the posterior tongue body; (c) the anterior tongue body; (d) the tongue tip; (e) the upper central incisors; (f) the lower central incisors (serving as jaw position); (g)-(h) the upper and lower lips; and (i) the nose ridge. Two transducers, (e) and (i), serve as reference points The left panel showing the Perkell system was borrowed from the website of Haskins Laboratories (www.haskins.yale.edu).

(2) Stimuli

a. Target sequence /ili/.
/pi+li+ka/ 'fraud' + NOM

b. Natural short sentence including the target sequence.
Target /cən+ip pi+li+ka simha+kun/
‘Fraudulent moving in is fierce.’

2.2 Measurements

Spatial and temporal properties of gestures are measured with respect to the tongue tip, the jaw, and the posterior tongue body (henceforth, the tongue body interchangeably) using MVIEW (Tiede, 2005). For measurements of the tongue tip gesture, the jaw, and the tongue body gesture, vertical and horizontal position of transducers on the x-y plane was measured (Figure 1.c’ and 1.d’). Two functions in MVIEW, *lp_Snapex* and *lp_Findgest*, are used to evaluate spatiotemporal properties. *lp_Findgest* allows us to obtain the times of gestural onset, (closing) peak velocity, target attainment, release onset, (opening) peak velocity, and opening target. In order to locate the spatially maximal constriction degree for the tongue tip (during /ɾ/), *lp_Snapex* is employed, which finds the nearest position minima. For analyzing data, a 20% threshold is used (see Son (2013a, 2013b) for detailed description of how to define gestural landmarks and constriction minima).

For the visual representation of the articulation of a flap, Figure 2 shows schematized kinematic measures relevant to vertical tongue tip movement trajectory that is used as a base for further analysis. Itemized descriptions of gestural landmarks are by and large adopted from Son et al., (2012: 96) and Son (2013a: 113-114) and only bear on the vertical tongue tip gesture in (3). Also illustrated in Figure 2 are schematized movement trajectory of the horizontal tongue tip gesture, the vertical tongue body gesture, the horizontal tongue body gesture, and the vertical jaw gesture, all of which are aligned with several time points of the vertical tongue tip gesture and provide kinematic measures at second hand. Detailed Explicit descriptions of these kinematic gestural events can be seen in (3)

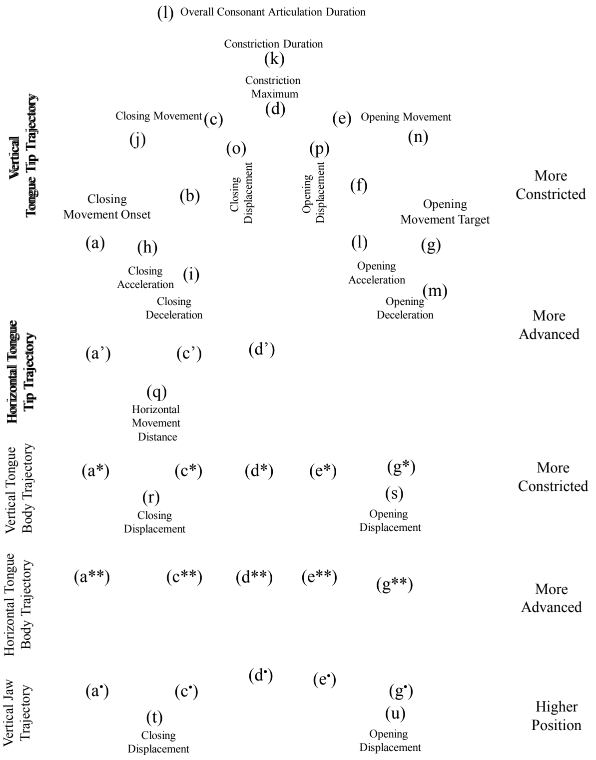

Figure 2. A schematized movement trajectory of the vertical tongue tip gesture with pertinent measures. Explicit descriptions of the gestural landmarks were adopted from Son et al. (2011: 36-37; 2012: 96) and Son (2013a: 113-114). Also shown are four related movement trajectories selected, each of which was aligned with relevant gestural landmarks of the vertical tongue tip gesture. The symbols (', *, **, •) indicate a corresponding time point aligned with a relevant measure of the vertical tongue tip gesture. Greater values represent higher position for the vertical articulators' movement, more advanced position for the horizontal articulators' movement, longer duration for the temporal domain, and greater displacement for the spatial domain.

(3) Fuller descriptions of articulatory gestures shown in (2) (see similar kinematic measurements in Son et al. (2012) and Son (2013b) among others).

<u>I. Vertical tongue tip gesture</u>
(a) Movement onset of the vertical tongue tip movement (Fig. 2a).
(b) Peak velocity of the vertical tongue tip closing movement (Fig. 2b).
(c) Target achievement of the vertical tongue tip gesture (Fig. 2c).
(d) Constriction minima of the vertical tongue tip gesture (Fig. 2d).
(e) Release onset the vertical tongue tip gesture (Fig. 2e).
(f) Peak velocity of the vertical tongue tip opening movement (Fig. 2f).
(g) Opening target of the vertical tongue tip opening movement (Fig. 2g).
(h) Closing acceleration duration of the vertical tongue tip gesture (Fig. 2h).
(i) Closing deceleration duration of the vertical tongue tip gesture (Fig. 2i).
(j) Closing movement duration of the vertical tongue tip gesture (Fig. 2j).
(k) Constriction duration of the vertical tongue tip gesture (Fig. 2k).
(l) Opening acceleration duration of the vertical tongue tip gesture (Fig. 2l).
(m) Opening deceleration duration of the vertical tongue tip gesture (Fig. 2m).
(n) Opening movement duration of the vertical tongue tip gesture (Fig. 2n).
(o) Closing displacement of the vertical tongue tip gesture (Fig. 2o).
(p) Opening displacement of the vertical tongue tip gesture (Fig. 2o).

<u>II. Horizontal tongue tip gesture</u>
(d') Horizontal tongue tip position aligned with the constriction minima of the vertical tongue tip gesture (Fig. 2d').
(q) Movement distance of the horizontal tongue tip gesture between the movement onset of the vertical tongue tip gesture and the target achievement (Fig. 2q).

<u>III. Vertical tongue body gesture</u>
(a*) Vertical tongue body position aligned with the movement onset of the vertical tongue tip movement (Fig. 2a*).
(c*) Vertical tongue body position aligned with the target achievement of the vertical tongue tip gesture (Fig. 2c*).
(d*) Vertical tongue body position aligned with the constriction minima of the vertical tongue tip gesture (Fig. 2d*).
(e*) Vertical tongue body position aligned with the release onset the vertical tongue tip gesture (Fig. 2e*).
(g*) Vertical tongue body position aligned with the opening target of the vertical tongue tip opening movement (Fig. 2g*).
(r) Closing displacement of the tongue body gesture during the vertical tongue tip closing duration (Fig. 2r).
(s) Opening displacement of the tongue body gesture during the vertical tongue tip opening duration (Fig. 2s).

<u>IV. Horizontal tongue body gesture</u>
(a**) Horizontal tongue body position aligned with the movement onset of the vertical tongue tip movement (Fig. 2a**).
(c**) Horizontal tongue body position aligned with the target achievement of the vertical tongue tip gesture (Fig. 2c**).
(d**) Horizontal tongue body position aligned with the constriction minima of the vertical tongue tip gesture (Fig. 2d**).
(e**) Horizontal tongue body position aligned with the release onset the vertical tongue tip gesture (Fig. 2e**).
(g**) Horizontal tongue body position aligned with the opening target of the vertical tongue tip opening movement (Fig. 2g**).

<u>V. Vertical jaw gesture</u>
(d•) Vertical jaw position aligned with the constriction minima of the vertical tongue tip gesture (Fig. 2d•).
(t) Closing displacement of the jaw gesture during the vertical tongue tip closing duration (Fig. 2t).
(u) Opening displacement of the jaw gesture during the vertical tongue tip opening duration (Fig. 2u).

2.3 Statistical analysis

We ran repeated measures analyses of variance (RM ANOVA) on statistical product and service solutions (SPSS) version 18 with data pooled across subjects (Max & Onghena, 1999). In this statistical analysis, each subject provided one data point per condition to RM ANOVA since each subject is used as the experimental unit in the analysis. We tested data for different speech rates (fast vs. comfortable). As we referred to Huynh-Feldt-corrected degrees of freedom and error terms ($p<0.05$), we reported observed F-raitos, p-values, and partial eta squared (η^2) (Huynh & Feldt, 1970). We conducted linear regression coefficients in order to resolve the probability of relationship between independent variables.

3. Results

3.1 Tongue tip gesture

In this section, we look at the consonantal gesture of the flapping sound in the sequence [iɾi] with reference to the tongue tip movement.

3.1.1 Vertical tongue tip gesture

The results showed that the vertical tongue tip gesture showed the ballistic tangential movement of the tongue tip closing movement which was manifested in different speech rates. Using data pooled across subjects, the velocity profiles of the tongue tip closing gesture at three gestural landmarks - movement onset, peak velocity, and target attainment - constantly demonstrated greater velocities in fast rate (fast>comfortable) ($F[1,6]=6.5$, $\eta^2=0.52$; $F[1,6]=7.88$, $\eta^2=0.57$; $F[1,6]=12.83$, $\eta^2=0.68$, all at $p<0.05$) <Figure 3a>. With respect to temporal closing duration, there was a main effect of Speech rate on the tongue tip acceleration duration and on the tongue tip closing duration, consistently demonstrating shorter duration in fast speech rate (fast<comfortable) ($F[1,6]=12.65$, $\eta^2=0.68$; $F[1,6]=23.58$, $\eta^2=0.80$, all at $p<0.05$). However, deceleration duration did not vary with Speech rate (fast=comfortable) ($F[1,6]=3.42$, $\eta^2=0.36$, $p>0.05$) <Figure 3b>. Looking at spatial displacement during the tongue tip closing movement, it did not vary with Speech rate (fast=comfortable) ($F[1,6]=0.89$, $\eta^2=0.13$, $p>0.05$) <Figure 3c>. We examined whether there was a relationship between peak velocity of the tongue tip closing movement and any of the temporal measurements in an analysis of linear regression, finding that it accounted for a significant proportion of the tongue tip acceleration duration, which indicated that higher peak

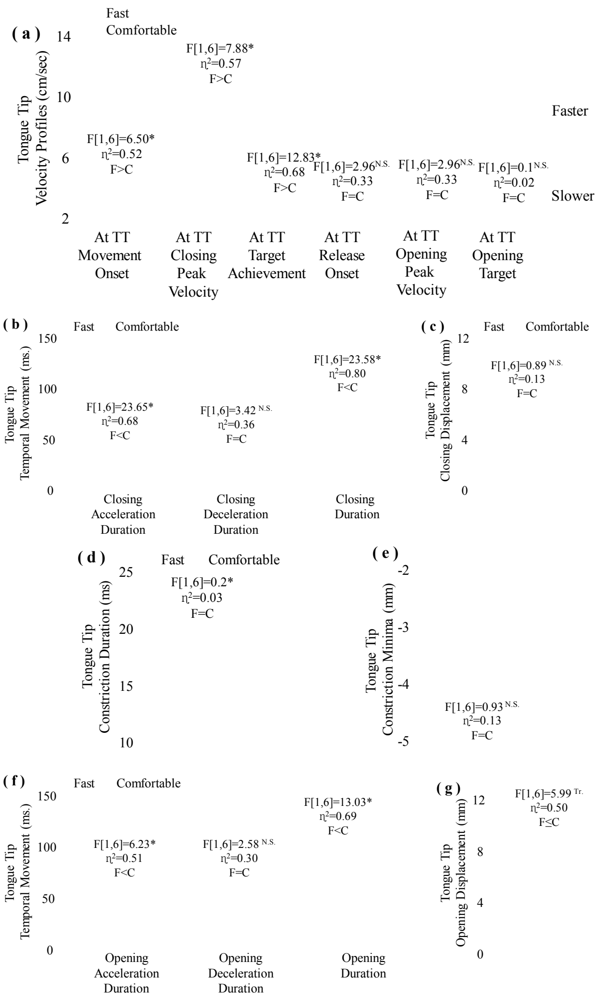

Figure 3. Vertical tongue tip (a) peak velocity values at six gestural landmarks, (b) temporal closing duration (acceleration, deceleration, closing durations), (c) closing spatial displacement, (d) constriction duration, (e) constriction minima, (f) temporal opening duration (acceleration, deceleration, opening durations), and (g) opening spatial displacement. (The symbol '=' is for no statistical difference; '*' is for p<0.05.)

velocity was correlated with shorter acceleration duration in the tongue tip closing gesture (R^2=0.08, F[1, 111]=9.09, p<0.005). In an analysis of linear regression there was a relationship between the tongue tip closing duration and tongue tip spatial displacement, exhibiting greater spatial displacement with more time permitted (R^2=0.34, F[1,110]=57.45, p<0.0001).

With respect to temporal constriction duration and spatial magnitude of the tongue tip gesture, we observed no rate effects on constriction duration and constriction minima with similar temporal and spatial properties between two speech rates (fast=comfortable) (F[1,6]=0.2, η^2=0.03; [F[1,6]=0.93, η^2=0.13, all at p>0.05) <Figure 3d and Figure 3e>.

Turning to the velocity profiles of the tongue tip opening movement, the three velocity profiles of the tongue tip opening gesture did not show any rate effects on three measures (fast=comfortable) (F[1,6]=2.96, η^2=0.33 for release onset; F[1,6]=2.96, η^2=0.33 for peak velocity; F[1,6]=0.1, η^2=0.02 for opening target) <Figure 3a>. Patterning with the temporal tongue tip closing measurements, a main effect of Speech rate was observed in tongue tip opening acceleration duration and tongue tip opening duration, indicating shorter duration in fast rate (fast<comfortable) (F[1,6]=6.23, η^2=0.51; F[1,6]=13.03, η^2=0.69, all at p<0.05), not in tongue tip opening deceleration duration (F[1,6]=2.58, η^2=0.30, p>0.05) <Figure 3f>. For the spatial displacement during the temporal tongue tip opening movement, there was a tendency that greater displacement was observed in comfortable rate (fast≤comfortable) (F[1,6]=5.99, η^2=0.50, p=0.05) <Figure 3g>. We also tested the possibility for a relationship between peak velocity of the tongue tip opening movement and any of the temporal measurements in an analysis of linear regression. The greater spatial displacement of the tongue tip opening movement also occurred with more tongue tip opening time permitted (R^2=0.48, F[1,110]=100.28, p<0.0001).

3.1.2 Horizontal tongue tip gesture

One time point aligned with vertical tongue tip constriction minima was measured so as to evaluate the horizontal tongue tip location at the maximal contact. There was no main effect of Speech rate on the horizontal tongue tip position, which indicated that both rates showed similar tongue position at the time point of tongue tip vertical constriction minima (fast=comfortable) (F[1,6]=1.33, η^2=0.18, p>0.05) <Figure 4a>. A pair of two separate time points aligned with tongue tip movement onset and tongue tip constriction minima was measured in order to estimate how far the tongue tip advances

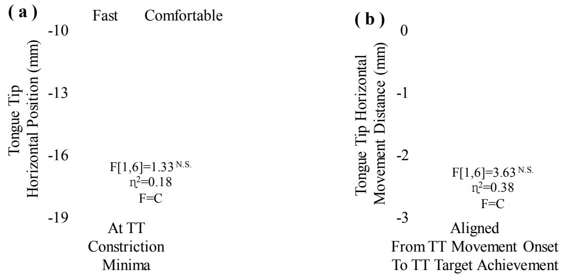

Figure 4. Horizontal tongue tip (a) position at the time of the TT constriction minima, and (b) movement distance measured from the TT movement onset to the TT target achievement. (The symbol '=' stands for no statistical difference; '*' is for p<0.05.)

or retreat. Speech rate effects on travel distance were not observed (fast=comfortable) (F[1,6]=2.39, η^2=0.28, p>0.05) <Figure 4b>.

Examining each data point from a total of 112 tokens, we confirmed its direction during tongue tip closing movement. Backward gliding tongue tip movement (expressed in negative values) was observed in the majority of tokens, i.e., 83%, while static movement (zero values) and forward gliding tongue tip movement (positive values) were relatively rarer at 3% and 14%, respectively <Figure 5>.

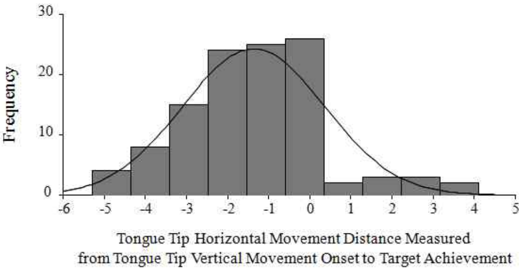

Figure 5. Density estimated with the bin size of 1 for horizontal tongue tip movement distance. Negative values indicate backward directionality and positive values forward directionality.

Lastly, we tested the possibility for tongue tip stretching or shrinking using the relationship between two independent variables, tongue tip constriction minima and tongue tip horizontal position at the time of the corresponding vertical gestural event. An analysis of linear regression revealed that (R^2=0.21, F[1,110]=28.66, p<0.0001) <Figure 6>, which indicates that the more constricted tongue tip constriction minima is, the less advanced tongue tip horizontal position is. This is interpreted such that tongue tip stretching did not occur diagonally.

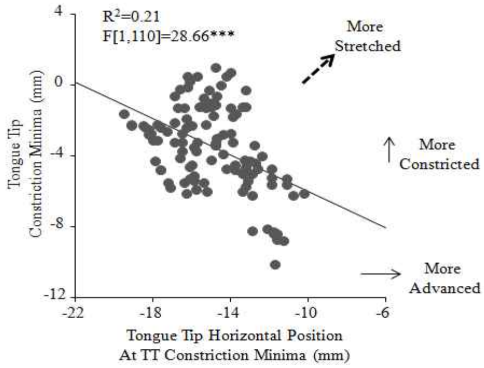

Figure 6. Tongue tip constriction minima plotted against tongue tip horizontal position aligned at the tongue tip constriction minima. Greater values indicate more advanced on the x-axis and more constricted on the y-axis. (The symbol '***' indicates p<0.0001.)

3.2 Tongue body gesture

In this section, we looked at the vocalic gesture of the flanking vowels (V1 and V2) in the sequence [iɾi] while referring to the tongue body movement. There was no main effect of Speech rate on any measures of vertical tongue body position, either vertical or horizontal, aligned with five gestural landmarks of the vertical tongue tip gesture (i.e., TT movement onset, TT target attainment, TT constriction minima, TT release onset, and TT opening target) for [ɾ] (fast=comfortable) (for vertical tongue body position, F[1,6]=0.7, η^2=0.01; F[1,6]=0.4, η^2=0.01; F[1,6]=0.3, η^2=0.01; F[1,6]=0.32, η^2=0.05; F[1,6]=2, η^2=0.25, all at p>0.05; for horizontal tongue body position, F[1,6]=0.74, η^2=0.11; F[1,6]=0.1, η^2=0.02; F[1,6]=0.28, η^2=0.05; F[1,6]=0.75, η^2=0.11; F[1,6]=0.6, η^2=0.01, all at p>0.05) <Figure 7a and 7b>.

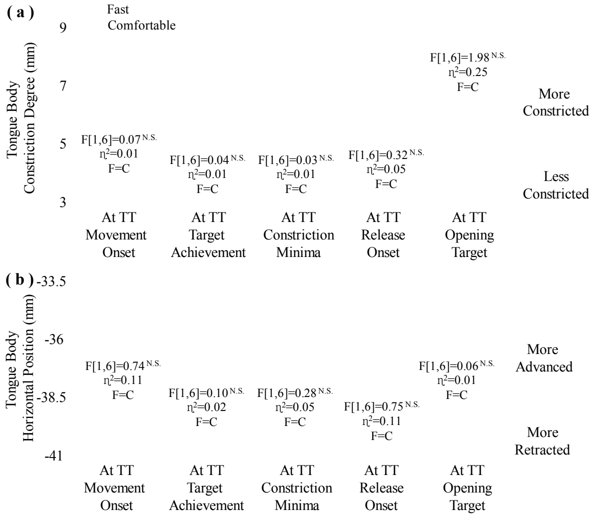

Figure 7. Tongue body (a) vertical position and (b) horizontal position aligned with five gestural landmarks of the vertical tongue tip gesture (TT movement onset, TT target achievement, TT constriction minima, TT release onset, and TT opening target). (The symbol '=' stands for no statistical difference.)

Referring to two pairs of two separate time points aligned with the vertical tongue tip gesture, we tested the possibility of speech rate effects on spatial tongue body displacement. Tongue body closing displacement did not vary with different speech rates (fast=comfortable) (F[1,6]=1.67, η^2=0.22, p>0.05) <Figure 8a>. However, greater opening displacement of the tongue body was observed at comfortable speech rate; a main effect of Speech rate on tongue body opening displacement in the time between tongue tip release onset to tongue tip opening target was observed (fast<comfortable) (F[1,6]=10.27, η^2=0.63, p<0.05) <Figure 8b>. An analysis of linear regression revealed that longer tongue tip opening duration accounted for a significant proportion of greater tongue body displacement (R^2=0.31, F[1,110]=61.03, p<0.0001) <Figure 8c>. This indicates that the tongue body moves farther as elapsed time increases.

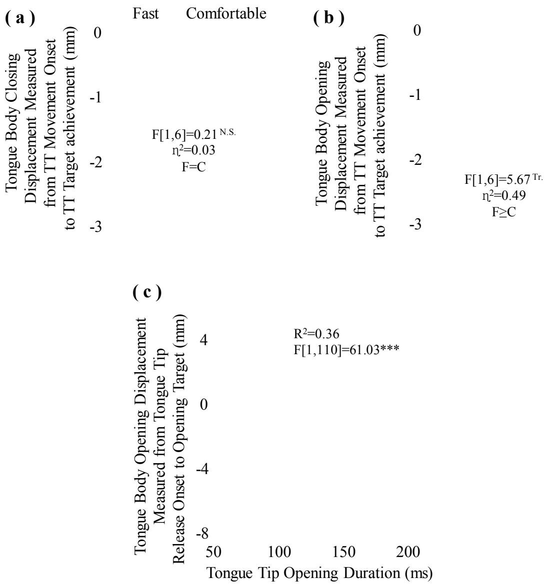

Figure 8. Vertical tongue body (a) closing displacement during the vertical tongue tip closing movement (TT movement onset to TT target achievement), (b) opening displacement during the vertical tongue tip opening movement (TT release onset to TT opening target), and (c) opening displacement plotted against vertical tongue tip opening duration. Greater values indicate longer duration on the x-axis and greater displacement on the y-axis. (The symbol '=' stands for no statistical difference.)

3.3 Jaw gesture

Jaw position at two speech rates did not differ at each time point aligned with five gestural landmarks of the vertical tongue tip gesture (i.e., TT movement onset, TT target attainment, TT constriction minima, TT release onset, and TT opening target) for [ɾ] (fast=comfortable) (F[1,6]=0.09, η^2=0.02; F[1,6]=0.01, η^2=0.002; F[1,6]=0.3, η^2=0.004; F[1,6]=0.03, η^2=0.005; F[1,6]=1.74, η^2=0.23, all at p>0.05) <Figure 9a>. As with the tongue body gesture, we also referred to two pairs of two separate time points aligned with the vertical tongue tip gesture, testing speech rate effects on spatial displacement of the jaw gesture. Displacement of the jaw gesture, like the tongue body gesture, varied with different speech rates. A main effect of Speech rate on tongue body opening displacement was detected, indicating greater jaw displacement measured from tongue tip release onset to tongue tip opening target for comfortable speech rate (fast<comfortable) (F[1,6]=18.09, η^2=0.75, p<0.05) <Figure 9c>, but not jaw closing displacement (fast=comfortable) (F[1,6]=0.21, η^2=0.3, p>0.05) <Figure 9b>. An analysis of linear regression revealed that longer tongue tip opening duration accounted for a significant proportion of jaw opening displacement (R^2=0.12, F[1,110]=14.53, p<0.0001) <Figure 9d>.

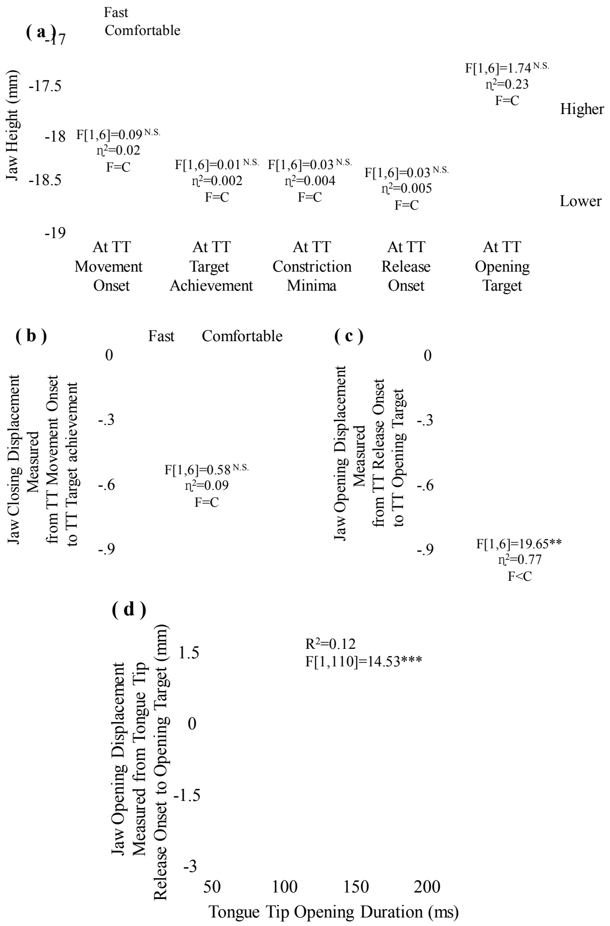

Figure 9. Vertical jaw (a) position aligned with five gestural landmarks of the vertical tongue tip gesture (TT movement onset, TT target achievement, TT constriction minima, TT release onset, and TT opening target), (b) closing displacement during the vertical tongue tip closing movement (TT movement onset to TT target achievement), (c) opening displacement during the vertical tongue tip opening movement (TT release onset to TT opening target), and (d) opening displacement plotted against vertical tongue tip opening duration. Higher numerical values indicate longer duration on the x-axis and higher numerical values greater displacement on the y-axis. (The symbol '=' stands for no statistical difference.)

4. Summary and Discussion

4.1 Summary

In the present study we examined kinematic aspects of Korean flapping sounds which are known to be the allophonic variation of an underlying alveolar lateral approximant /l/. Based on the results, we observed lateral reduction in various kinematic measurements discussed in section 3, without detecting even a single deleted token.

The summary of the tongue tip gesture is as follows. First, three velocity profiles of the tongue tip closing movement (gestural onset, peak velocity, and target attainment) consistently exhibited speech rate effects (Fast>Comfortable) but stop being contrastive in the tongue tip opening movement (Fast=Comfortable). Second, temporal tongue tip closing acceleration duration showed a negative correlation with peak velocity: the faster the peak velocity, the shorter the tongue tip closing acceleration duration. This held true for two measurements of the tongue tip opening movement – acceleration duration and deceleration duration. Third, spatial displacement of the tongue tip opening gesture showed a positive relationship in that longer tongue tip opening movement duration was associated with greater tongue tip opening displacement. Fourth, tongue tip stretching did not occur diagonally during tongue tip closing movement but rather showed retraction in 86.6% of a total of 112 tokens. Also was observed higher tongue tip position with more retracted tongue tip and lower tongue tip position with more advanced tongue tip.

The tongue body gesture and the jaw are summarized as follows. Vertical as well as horizontal positional difference of the tongue body did not exist with two speech rates. However, the tongue body tends to move farther as more time elapses. Likewise, the jaw gesture showed similarity in that jaw lowering is more far-reaching as time elapses during tongue tip opening movement.

4.2 Discussion

4.2.1 Korean /l/-flaps on a continuum of gestural reduction

In this study, we found that fast speech rate showed shorter temporal duration in some kinematic measurements – tongue tip closing acceleration duration, tongue tip closing duration, tongue tip opening acceleration duration, and tongue tip opening duration. This is compatible with other studies in that gestural weakening occurs more frequently in fast speech rate (see lenition in Kirchner (1998); place assimilation (Jun, 1996, Son, 2008); speech production errors (Mowrey & MacKay, 1990; Pouplier & Goldstein, 2010). However, neither constriction duration nor maximal contact (both vertically and horizontally) varied with different speech rates. What could possibly be a reason for the discrepancy between tongue tip closing/opening gestures and temporal/spatial constriction duration? The answer may be found in the ballistic nature of a flapping sound. In the definition of a flap articulation, the gestural event of constriction duration (temporal as well as spatial) can be interpreted to occur on the way between paired hitting and releasing events. Given that, speakers might not have controlled constriction duration (temporal as well as spatial) *per se*, which in turn might result in the absence of rate effect on constriction duration (temporal as well as spatial).

As we look at the tongue tip gesture, spatiotemporal data points measured with kinematic parameters were distributed in a gradient manner. Previous studies also found that gradiently distributed flapping sounds were on a continuum of which one extreme end was not quite distinguished from adjacent vowels (de Jong, 1998; Warner et al., 2009, Tucker, 2011). Despite gradient variation of perceptual stimuli in these studies, listeners showed categorical perception. The results support the hypothesis of articulatory phonology in that phonetic forms can occur anywhere on a quantitative continuum of gestural reduction (Browman & Goldstein, 1992). Under this hypothesis, phonological and allophonic changes are ascribed to "processes occurring during the physical act of talking" (Browman & Goldstein, 1992: 171). Our articulatory data of Korean /l/-flaps is indeed in line with gradient variation, not categorical variation. Notice that Warner et al.'s (2009) acoustic-perceptual study showed that listeners even detected flapping sounds in over 90% of American-English /d/-flapping and /t/-flapping stimuli which could have listeners confused due to the absence of acoustic occlusion and near absence of intensity dip in the particular stimuli used in that study. They attributed the listeners' good perceptual performance to skilled evaluation of variability along the acoustic correlates of reduction in a flap. Similarly, acoustic-aerodynamic study of /t^h/-flaps and /d/-flaps in Xiangxiang Chinese showed that there was no oral airflow change (i.e., no fluctuation) that corresponded with the absence of acoustic occlusion, release burst, and strong magnitude of formants. However, we did not find evidence for absolute tongue tip reduction to the extent that the tongue tip gesture was categorically deleted; not a single token of categorical reduction of the Korean /l/-flap was observed in the present study.

Although still in the initial stage of research, we suspect that acoustically defined (near) categorical reduction of flapping sounds may not really be as such when we refer to the results of our articulatory-acoustic-perception study (in progress). Scrutinizing data from individual speakers, five tokens (out of a total of 112) clearly showed formant structures undistinguished from those of adjacent vowels. Notice that we could detect reduced but apparent articulatory gestures for these acoustically ambiguous tokens. Still open is the possibility that English listeners might have perceived or become attuned to obvious tongue tip closing and opening gestures no matter how much they had been reduced. As we leave this issue of articulatory-acoustic-perceptual correlation, if there is any for Korean /l/-flaps, which needs to be more systematically examined for future study, we temporarily conclude that categorical reduction of flapping sounds is not so much a cross-linguistic difference but rather an experimental methodological difference.

4.2.2. Gestural overlap effects on the horizontal tongue tip movement in the Korean /l/-flap

In a flap articulation, two articulatory events have come to be considered important, ballistic tongue tip closing movement and short constriction duration (Monnot & Freeman, 1972; Ladefoged & Maddison, 1996; de Jong, 1998). Using the flesh-point tracking system, the present study tested the Korean /l/-flap in terms of closing movement and constriction duration (e.g., comparable to acoustic occlusal duration), as well as opening movement. At every stage of gestural landmarks along the tongue tip closing movement (movement onset, peak velocity, target achievement), we consistently observed higher velocity in fast rate and shorter closing duration (acceleration duration and closing duration) manifested accordingly.

Using the flesh-point tracking system, the present study tested the Korean /l/-flap for directionality of the tongue tip onto the target attainment and showed a backward gliding movement in the majority of cases, i.e., in 83% of production. For American-English /t/-flaps and /d/-flaps, previous articulatory studies have consistently shown a *forward tangential* movement (Monnot & Freeman, 1972; de Jong, 1998). Although forward gliding movement was present in this study, it was somewhat limited in its occurrence, at 14%, compared to backward gliding movement. Moreover, no horizontal movement was detected at all in several tokens, at 3%, and this was not ascribed to a specific speaker or speech rate. Our question is why we end up with the directional discrepancy between Korean the /l/-flap and English alveolar flap.

Note that a retracting motion of the tongue tip, being though extremely brief however, before a tongue tip contact was also tracked in Monnot & Freeman (1972). From the perspective of gestural overlap on casual speech production (Browman & Goldstein, 1992), we conjecture that it could have occurred in passing from gestural events of inter-dental/dental [ɵ] to the flapping gesture of [ɾ]. An excessive tongue tip retraction could have occurred to secure space where the tongue tip hit the alveolar ridge, not moving smoothly along the surface of the teeth and alveolar ridge. Unlike English data from Monnot and Freeman (1972), the retraction of the tongue tip gesture occurred all along way to the contact.

Under the hypothesis of articulatory phonology (1990b, 1992), gestural overlap exists inherently between consonantal gestures and vocalic gestures within a syllable (e.g., C-V and V-C). The anticipatory effect of CV2 (not only V2 but also the intervening C) on the preceding V1 in V1CV2 sequences was also observed (Cole, Linebaugh, Munson, & McMurray, 2010). Besides, vocalic effects on the consonantal gesture are also found in Greek and English where VCV sequences have shown an invariant consonantal gesture, but more retracted tongue tip or tongue body position with flanking back vowels, compared to front vowels ([idi]<[ada] in Saltzman & Muhnall (1989); [ki] <[ka] in (Arbisi-Kelm, Beckman, Kong, & Edwards (2009)). Based on the coarticulation hypothesis, the tongue tip gesture in Korean /l/-flaps, biomechanically entrenched with the tongue body as well as tongue dorsum, could have receded on its way to contact (Kühnert, Hoole, & Mooshammer, 2006). Notice that in this study, stimuli we presented to speakers during elicitation included [ɾiga] (C1V1C2V2) from a /pi+li+ka/ sequence (‘fraud' + NOM). To put it roughly, retracted tongue dorsum position for C2V2 ([ga]) could have influenced the tongue body gesture in C1 ([i]), which, in turn, could have pulled back C1 at the later time point (TT target achievement (flap [ɾ]) in this case) as compared to the earlier time point (TT movement onset (flap [ɾ]) in this case). From the perspective of anticipatory coarticulation, the Korean /l/-flap could have been not so much different from English alveolar flapping (e.g., in terms of backward motion vs. forward motion) but rather a mere articulatory byproduct of biomechanical constraints and intergestural coarticulation. In order to confirm this possibility, however, both languages should be coherently tested in future study so that a better balanced cross-linguistic comparison can be conducted using more controlled stimuli from both languages.

4.2.3 Vocalic reduction in V2 in an /i/-/i/ context

We examined whether rate effects are reflected on the vocalic gesture, extending to the jaw and the tongue body in this case. The jaw height and constriction degrees of the vertical/horizontal tongue body aligned with the vertical tongue tip gesture were not modulated as a function of speech rate (fast=comfortable, all at p>0.05). Notice that Macchi (1985) proposed that jaw position, other things being equal, be relatively lowest for an intervening consonant in V1-C-V2 contexts with an unstressed V2. Under this account, English alveolar flapping is a byproduct in a prosodic context which induces consonantal weakening. Another flip side of this account also involves vocalic weakening in that jaw position of the flanking vowels in the unstressed condition is relatively higher for a low vowel /a/, compared to stressed condition. In the present study, we observed neither jaw weakening in a consonantal gesture (e.g., jaw position at the TT constriction minima) nor jaw weakening in the vocalic gesture of V2 (e.g., jaw position at the TT opening target) as a function of speech rate. One possible reason that Korean /l/-flapping did not show more reduction of the jaw and the tongue body gestures (e.g., an indication of antagonistic vocalic gesture) in fast speech rate may be due to high front vowel contexts. In the present study, we used /i/-/i/ context with an intervening /l/; therefore, greater reduction of the vocalic gesture (e.g., higher jaw position) could have resulted in facilitating the articulation of a semi-consonantal /j/, which may violate the upper limit of vocalic gesture. With respect to consonantal reduction, it is plausible to assume that the jaw gesture and the tongue body gesture could have been already too reduced in comfortable speech rate to further weaken the jaw gesture in fast speech rate.

Nevertheless, we found evidence for speech rate-dependent vocalic reduction during tongue tip opening gesture. Spatial movement of the jaw gesture measured at two time points of the vertical tongue tip gesture (the TT release onset and the TT opening target) was truncated in fast rate (fast<comfortable). In line with this, there was a tendency that the tongue body gesture was truncated in fast speech rate, demonstrating a smaller displacement (fast≤comfortable). If positional values and displacement values are taken together, we may conclude that rate effect may not be obviously signified in the vocalic gesture, but is still engraved in the spatial displacement magnitude. Note that the present study is somewhat limited to uncover vocalic reduction as a function of speech rate since we did not include various vocalic contexts such as a low vowel /a/-/a/ context. Our interpretation on vocalic reduction needs to be more structurally tested in future study, reinforcing analytical shortcomings.

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