A PALATOGRAPHIC INVESTIGATION OF PLACE OF ARTICULATION IN KOREAN CORONAL OBSTRUENTS

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Abstract. This study uses static palatography to determine articulatory positions for coronal obstruents, for five native speakers of Seoul Korean in their twenties. For four of the speakers, affricates are consistently articulated slightly further back on the teeth than stops. However, stops, affricates and fricatives all show contact patterns in the denti-alveolar region. These results may reflect a shift in place of articulation of affricates from post-alveolar to denti-alveolar, for younger speakers of Korean. Gender differences are not observed for contact patterns on the palate, but contact patterns on the tongue do vary with gender. Female speakers in this study use laminal articulations, while male speakers use apico-laminal ones. The plain-aspirated-tense distinction does not affect articulatory measures of place of articulation, or amount of tongue-palate contact, implying that the lax-aspirated-tense distinction need not necessarily involve concomitant place distinctions.

1. INTRODUCTION

Korean is known for its intricate consonant contrasts that include the three series of coronal obstruents summarized overleaf (the asterisk marks tenseness):

Stops: /t/, /tʰ/, /t*/
Affricates: /c/, /cʰ/, /c*/
Fricatives: /s/, /s*/

These contrasts differ along a number of acoustic and aerodynamic dimensions. Cho, Jun & Ladefoged (2002) report systematic differences among the three stops and between the two fricatives. In the stops, they find that voice onset time is longest for /tʰ/, intermediate for /t/, and shortest for /t*/. At the same time, aspirated /tʰ/ involves a higher amplitude burst than the other stops. On the other hand, lax /t/ is associated with a lower $f0$ in the following vowel than either of the other stops. In addition, the vowel following /t/ is breathier in voice quality, while that following /t*/ involves pressed voice. In terms of aerodynamic differences, /tʰ/ and /t*/ build up higher pressure behind the constriction during closure, while at release, airflow is highest for /tʰ/, followed by /t/ and then /t*/.

The fricatives /s/ and /s*/ also differ in the relative $f0$ and voice quality of the following vowel; /s/ is associated with lower $f0$ and breathier voice quality than /s*/, while the latter often involves glottalization at the onset of the following vowel. In terms of centroid frequency, /s*/ is higher than /s/.

The findings in Cho et al.'s comprehensive study reflect the field's most current understanding of the salient acoustic and laryngeal characteristics of Korean coronal consonants. However, there is much we still do not understand about Korean coronals. For instance, there is still substantial disagreement over their precise place of articulation. The three affricates are treated as 'dental' by Lukoff (1982:xix) and H. Kim (1999); as 'alveolar' by Martin (1992:24), Chang (1996:14), Lee & Ramsey (2000:24), and H. Kim (2001)[1] and Choo & O'Grady (2003:40); as 'lamino-alveolar' by Park (1991:30); as 'alveo-palatal' by Shin & Hayward (1997); as 'post-alveolar' by Cho (2001); and as 'palatal' by Sohn (1994: 432, 1999:153).

Similar disagreement surrounds the non-affricates. They are classified as 'dental' by Lukoff (1982:xix), Martin (1992:24), Chang (1996:14), and Lee & Ramsey (2000:24); as 'denti-alveolar' by Choo & O'Grady (2003:29-30, 45); as alveo-dental' by Sohn (1999:153); as 'alveolar' by Shin & Hayward (1997)[2] and H. Kim (2001)[3]; as 'lamino-alveolar' by Sohn (1994:432); and as 'apico-alveolar' by Park (1991:3).

To complicate matters further, there are disagreements regarding whether the lax, aspirated and tense members of a given series differ in place of articulation. The assumption implicit in assigning "lax", "aspirated" or "tense" descriptions

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[1] This study focused on lax obstruents. Thus, of the affricates it considered only /c/.
[2] Only the stops were treated in this study.
[3] Again, this study limited itself to lax obstruents, and thus considered only /t/ and /s/.

to members of the stop and affricate series is that laryngeal features alone differentiate them. However, studies such as Shin & Hayward (1997), Cho & Keating (2001), and S. Kim (2001) report differences in place of articulation for members of a given series.

The goal of the present study is to use the techniques of static palatography to shed light on the articulatory positions of coronal obstruents for a group of native speakers of Standard (Seoul) Korean. We will focus on two questions: (1) Does static palatography reveal differences in place of articulation among the lax, aspirated and tense sounds within each series of coronals?; (2) Does it reveal differences in coronal place of articulation based on manner of articulation (i.e., stop versus affricate versus fricative)?

A brief description of palatographic methods is given in §2. In §3 we report the main articulatory strategies observed for the coronal obstruents, and discuss the effects of such factors as the lax-aspirated-tense contrast, position-in-utterance (initial vs. medial), manner of articulation (stops vs. affricates vs. fricatives), and gender of speaker. Section 4 summarizes our results in light of previous instrumental studies.

2. METHODS

2.1. Speakers and data collection

Three female and two male native speakers of Seoul Korean participated in the study. All were students at the University of Hawai`i at Manoa, and between 20 and 30 years of age.

Direct articulatory data for tongue-palate contact patterns were collected using static palatography, which yields two types of images: palatograms and linguograms. (See Ladefoged 2003, Anderson 2000, and Dart 1998 for detailed descriptions of this methodology.) To obtain a palatogram, a speaker's tongue is painted with a non-toxic marking material. A common material, also used here, is a mixture of olive oil and powdered digestive charcoal (available in pharmacies). The speaker then utters a word containing the coronal of interest, which transfers the marking material from the tongue to the palate. The speaker inserts a mirror into the mouth to reflect the resulting contact area on the palate, which is then videotaped.

To obtain a linguogram, the speaker's palate is painted, which transfers the oil-charcoal mixture to the tongue when the speaker articulates the coronal of interest. The speaker then protrudes the tongue to show the contact pattern.

Figure 1 shows the orientation of the video camera to the speaker's reflected palate. Figure 2 shows, for female speaker F1, sample palatograms (top row) and linguograms (bottom row) of the stops /t/, /tʰ/, and /t*/, respectively.
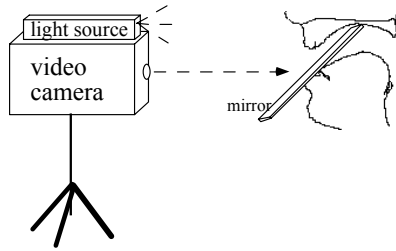

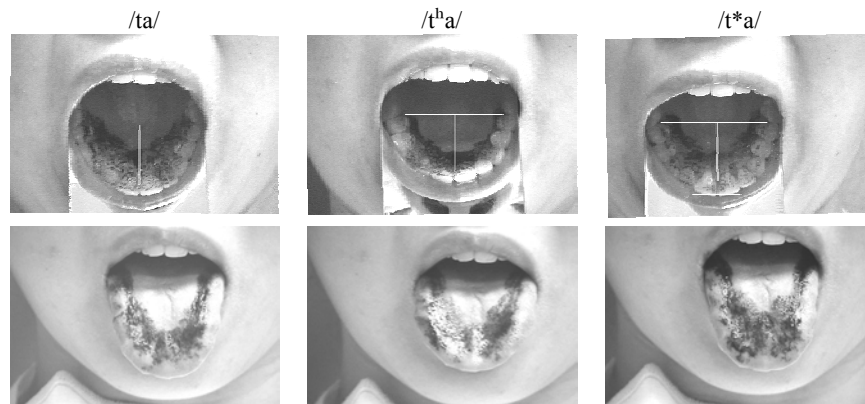*Figure 1: Schematic set–up for static palatography.*

Figure 2: Sample palatograms and linguograms for female speaker F1.

Note that in the palatograms, the speaker's incisors are visible at the top of the photograph, and are reflected at the bottom of the photograph. Horizontal and vertical guidelines have been added to palatograms for correction of angular distortion, as discussed in §2.4.

It should be noted that static palatography has drawbacks when compared with electropalatography (EPG), another common technique used to investigate articulatory patterns.[4] In particular, static palatography may yield overly careful, hyperarticulated speech, which, as an anonymous reviewer has pointed out, can lead to ceiling effects in the resultant data.

In contrast, EPG does not produce information about the position of the tongue during articulations, and because of its high cost, seldom involves more than one or two speakers.

2.2. Dental impressions

It is important to collect three-dimensional information about the shape and size of speakers' palates, in order to be able to correct distortions in the reflected palatograms, and relate palatographic and linguographic patterns to an articulation as a whole. In order to create a permanent three-dimensional reference against which palatograms could be compared, a dental impression was taken of each speaker's palate, and was used to make a cast of the speaker's palate in hard plaster.
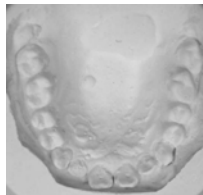

Figure 3: Hard plaster cast taken from alginate dental impression.

2.3. Palatography word list

Static palatography provides a cumulative record of tongue–palate contact during an utterance. Thus, it is important to choose utterances containing no coronal or dorsal segments except the segment under investigation, to avoid confounding effects of other tongue-palate contacts. High vowels often involve

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[4] For EPG, a speaker wears a fitted pseudo-palate that records contact when the tongue touches it.

tongue contact with the upper molars, and should also be avoided. Words selected with these criteria in mind are shown in Table 1. For each speaker, two palatograms and two linguograms of each word were recorded. In total, 160 palatograms and 160 linguograms were collected (16 words x 5 speakers x 2 repetitions of each word.)

Table 1. Static Palatography wordlist: Korean coronals.

Initial position			Intervocalic position		
다	타	따	배다	배타	배따
ta	tʰa	t*a	pɛta	pɛtʰa	pɛt*a
'all'	'It's burning.'	'Pick it (fruit).'	'to conceive'	'exclusivity'	'Cut open the belly (of a fish).'
재	채	�째	배재	배채	배쩨
cɛ	cʰɛ	c*ɛ	pɛcɛ	pɛcʰɛ	pɛc*ɛ
'ash'	'shredded vegetable'	'Cut it open.'	'Paejae (Seoul High School)'	'shredded pear'	'I don't care.'
서		써	어서		어써
sʌ		s*ʌ	ʌsʌ		ʌs*ʌ
'Stop!'		'It's bitter.'	'without hesitation'		'Oh, bitter!'

2.4. Palatograms: image processing.

For each token, the relevant video clip was digitized into a computer file from which a high-quality still frame was chosen for analysis. Measurements of palatograms were taken using tools in Adobe Photoshop. As mentioned above, slight differences in the angle at which the mirror is placed in the mouth relative to the occlusal plane (angle x, in Figure 4) cause the reflected image to be potentially lengthened or shortened, in both the vertical direction and, to a lesser extent, the horizontal direction. (As shown in Figures 5a-b, 'vertical' and 'horizontal' refer to 'front-to-back' and 'side-to-side' articulatory dimensions, respectively.) For each still frame, measurements along vertical and horizontal axes were independently corrected for angular distortion by referring to actual millimeter measurements taken from the lifesize plaster casts of speakers' palates.
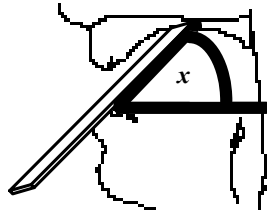
Figure 4. Angle of mirror with respect to occlusal plane.

To obtain the horizontal correction factor for a given palatogram, a horizontal calibration measure was taken at a line between the inner surfaces of the teeth on each side, just forward of the upper first molars on the still frame (line **'h'** in Figure 5a). The same measure was taken on the lifesize cast of the speaker's palate with calipers, to obtain actual millimeter values. The ratio of apparent-to-actual size was then used as a correction factor for horizontal measurements on this still frame.

Likewise, to obtain the vertical correction factor for a given palatogram, a calibration measure was taken at a line drawn from the front edge of the front incisors backward to the horizontal calibration line (line **'v'**, Figure 5b). Again, this measure was made on the lifesize cast, to determine actual length of the line in millimeters. The ratio of apparent to actual size was used as a correction factor for vertical measurements on the frame in question.
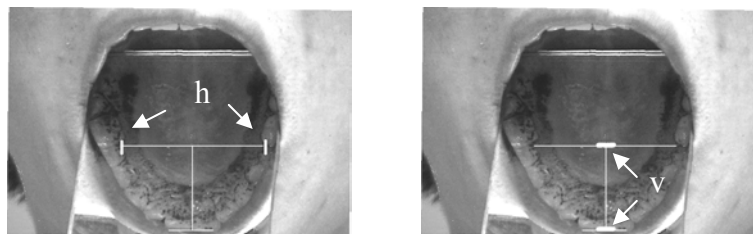

Figure 5a (left). Horizontal calibration measure bounded by inside surfaces of teeth.
*Figure 5b (right). Vertical calibration measure bounded by front edge of front incisors and line **'h'**.*

2.5. Palatograms: Absolute and relative measurements

Measurements of palatograms were taken in pixels, and converted to both absolute dimensions (millimeters) and relative dimensions (percent). For example, the point of frontmost contact, shown as distance back from the base of the teeth to the beginning of the black contact pattern, (measure **'a'** in Figure 6) was converted to millimeters via its correction factor, and then to a percentage of its calibration measure, in this case line **'v' (%=[a/v]*100).** Since speakers' mouths vary in size and shape, relative measurements were used when comparing articulations across speakers.
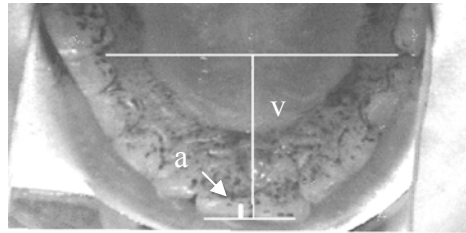

*Figure 6. 'Frontmost contact' ('**a**') as a percentage of '**v**' (line '**v**' taken to be 100%.)*

Three measurements were taken for palatograms of stops and affricates: **a**) point of frontmost contact, as in Figure 6; **b**) contact length in the midsagittal (vertical) plane, as in Figure 7; and **c**) contact length in the coronal (horizontal) plane, at the point just forward of the upper first molars, as in Figure 8.
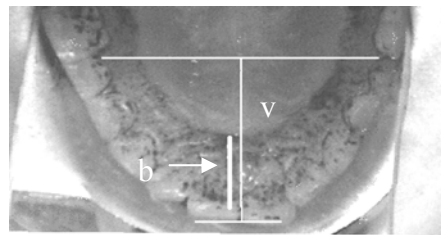

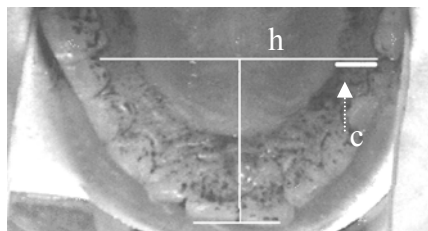*Figure 7. 'Midsagittal contact length' ('**b**') as a percentage of '**v**' (line '**v**' taken to be 100%.)*

*Figure 8. 'Side contact length' ('**c**') as a percentage of '**h**' (**half of line '**h**' taken to be 100%.)*

For fricatives, 'a' and 'b' could not be reliably measured, because fricatives often involve a gap in the midline. To give some quantification of the articulatory target on the palate, point of rearmost midsagittal contact was recorded where possible. This is shown as measure **'d'** in Figure 9. Gap width (measure **'e'**, Figure 9) was also reported, as a percentage of line **'h'**.
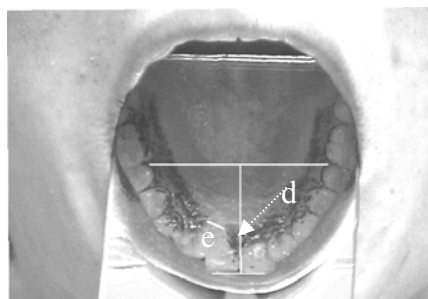

*Figure 9. 'Rearmost sagittal contact' ('**d**') as a percentage of '**v**'; 'gap width ('**e**') as a percentage of '**h**' (line '**h**' taken to be 100%.)*

2.6. Qualitative analysis of linguograms

Unlike palatograms, linguograms are not amenable to measurement. Even when images are corrected to reflect lifesize proportions, the tongue's apparent size and shape can vary greatly because of its flexibility. For this reason, quantitative analysis was limited to palatograms, while linguograms were studied to determine the general areas of the tongue participating in the articulation (e.g., tip or blade).

2.7. Statistical analysis of palatographic measurements

Relative (percent) palatographic measurements were submitted to statistical Analysis of Variance (ANOVA). Max & Onghena (1999) call attention to the risks of overestimating statistical significance when analyzing the variance of individual repetitions of speech data, especially when the group of speakers is small. To counter this possible Type I error, we followed a procedure similar to that of Cho & Keating (2001) and S. Kim (2001), and performed factorial analysis of variance of dependent measures 'a' through 'e'. Factors were speaker, value for lax-aspirated-tense, and manner (stop, affricate, or fricative). Each datapoint was the average of both repetitions, to reduce degrees of freedom in the F-ratio. Moreover, we set the significance level at $p \leq .01$ rather than the more usual $p \leq .05$.

3. RESULTS AND DISCUSSION

Recall that the first goal of this study was to determine the place of articulation of Korean coronals and whether differences in place of articulation would be observed among the lax, aspirated and tense sounds within a given series. We will discuss results for each series in turn.

3.1. Stops

The lax, aspirated and tense coronal stops observed here were all articulated with the tongue making contact with an area that begins at the biting surfaces of the upper teeth, and extends back to the alveolar ridge; i.e., the passive articulator is the denti-alveolar region as implied by Cho & Keating (2001:166). The active articulator (i.e., the tongue) was found to involve a gender difference, as will be discussed further in §3.4. Figure 10 shows palatograms and linguograms of initial stops for (male) speaker M1, while Figure 11[5] shows a midsagittal diagram depicting M1's apico-laminal[6] denti-alveolar articulation of the stops.

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[5] The midsagittal sections in this paper were drawn with the "Draw Vocal Tracts" phonetic software developed by Peter Ladefoged at UCLA.

[6] The term 'apical' refers to the tongue tip; laminal refers to the tongue blade. By 'apico-laminal', we mean that both the tongue tip and blade are involved in the articulation.
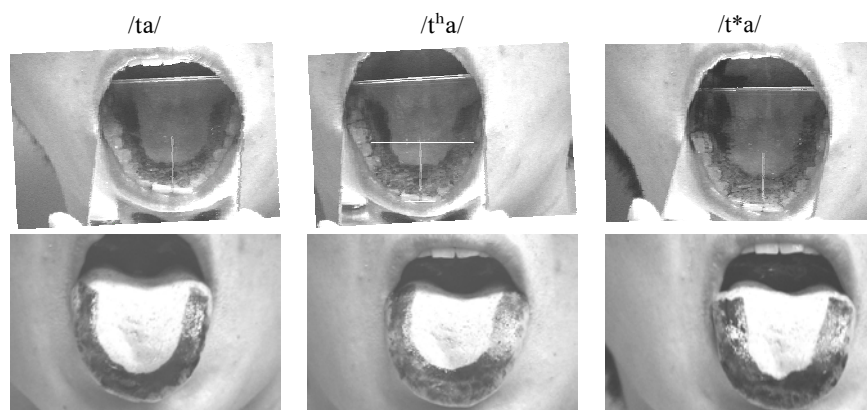
/ta/   /tʰa/   /t*a/

Figure 10. Representative palatograms and linguograms of initial coronal stops for male speaker M1.
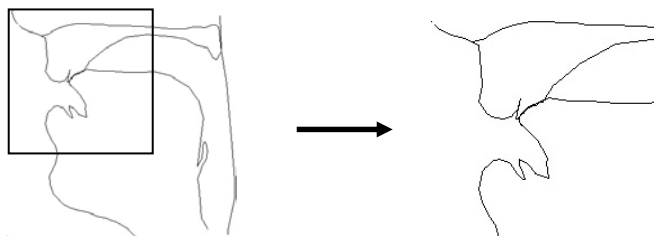

Figure 11. Midsagittal diagram showing M1's articulation of Korean plain, aspirated and tense stops.

In a one-way ANOVA for stops, no main effect of the lax-aspirated-tense distinction was found on any of the three measures **'a', 'b', or 'c'.** (For 'a': F[2,25] = .398, p = .6759. For 'b': F[2,25] = 1.256, p = .302. For 'c': F[2,25] = .561, p = .5779.) Neither was any effect found in a one-way ANOVA for initial versus medial position. (For 'a': F[1, 26] = 1.528, p = .2274. For 'b': F[1, 26] = .908, p = .3493. For 'c': F[1, 26] = 3520, p = .0719.) In brief, regardless of their phonological value for the lax-aspirated-tense distinction, and regardless of their (initial or medial) position in a word, the stops showed no significant

differences in position on the palate. For comparison, Figure 12 shows palatograms and linguograms of medial stops for (male) speaker M1.
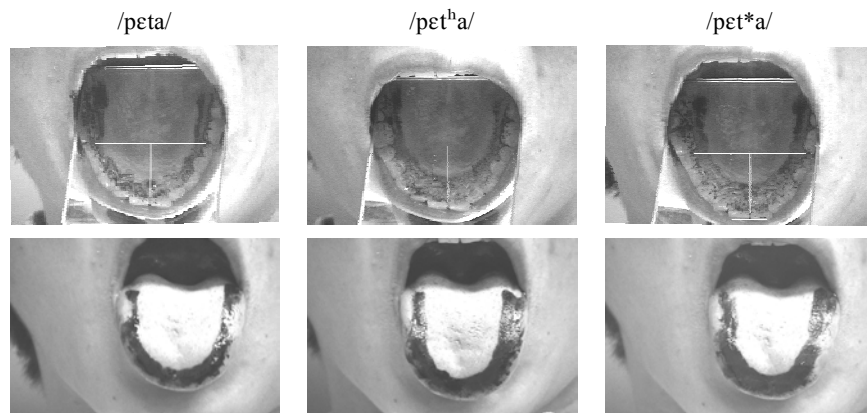
/pɛta/   /pɛtʰa/   /pɛt*a/

Figure 12: Representative palatograms and linguograms of medial coronal stops for male speaker M1.

3.2. Affricates

Like the stops, the affricates are (apico-)laminal (denti-)alveolar, as also reported by H. Kim (1999, 2001). It is important to note, however, that our findings differ from those of Pandeli (1993), Shin (1996), Shin & Hayward (1997), and Cho (2001), all of whom report a postalveolar or even palatoalveolar place of articulation for Korean affricates based on electropalatography studies. We will return to this matter in our general discussion.

The coronal affricate series behaves similarly to the stop series, in that /c/, /cʰ/, and /c*/ do not differ significantly from each other on any of the articulatory measures used here. (For measure a: $F[2,27] = .378$, $p = .6889$. For 'b': $F[2, 27] = .249$, $p = .7814$. For 'c': $F[2,24] = .085$, $p = .9191$.) Moreover, position-in-word has no main effect on any of the measures. (Measure 'a': $F[1,28] = .019$, $p = .8918$; 'b': $F[1,28] = 2.177$, $p = .1512$; 'c': $F[1,25] = .337$, $p = .5670$.) Again, for the sake of comparison, palatograms and linguograms of medial affricates for (male) speaker M1 are shown in Figure 15.