XXII. SPEECH COMMUNICATION*

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A. CINERADIOGRAPHIC STUDY OF KOREAN STOPS AND A NOTE ON "ASPIRATION"

There have been speculations among phoneticians about just how the three types of Korean stops (all voiceless) differ from each other in their production mechanism, and what parameters should be used in their classification. An instrumental study on these questions was undertaken by the author,[1] and the reader is referred to it for detailed background arguments, experimental results, and the author's classificatory schema. I shall report here some recent findings from a cineradiographic analysis of Korean stops, and briefly discuss their theoretical implications in defining the term "aspiration."

A cineradiographic film at the speed of 50 frames per second was taken of the subject (the author), both laterally and anteriorly, at St. John's Hospital, Santa Monica, California, under the supervision of Dr. Brummet, Head of the Radiology Department of the Hospital. Barium sulfate was used to increase the opacity of surface areas of the vocal tract, and recordings of both audio and camera pulses were made simultaneously. The subject uttered the 3 types of stops in 3 places of articulation (labial, dental, and velar) in two frames:

A. /#i-ke+___ al-i-ta#/ [ige+___ arida] 'this is a _____'

B. /#nay-ka+___ ay-t-ta#/ [nɛga+___ tt'a] 'I _____ ed'

(# utterance boundary, + word boundary, - morpheme boundary)

The sample words used in frame A are as follows: (/p', t', k'/ denotes tense unaspirated

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stops, /p, t, k/ lax slightly aspirated, and /p^h, t^h, k^h/ tense heavily aspirated. According to the order of the length of voicing lag, I shall refer henceforth to /p'.../ as type I, /p.../ as type II, and /p^h.../ as type III stops):

	labial		dental		velar	
I.	/p'allay/	'laundry'	/t'al/	'a daughter'	/k'ali/	'a villain'
II.	/pal/	'a foot'	/tal/	'the moon'	/kali/	'a stack'
III.	/p^hal/	'an arm'	/t^hal/	'a mask'	/k^hal/	'a knife'

The present report deals with the analysis of anterior views of utterances in frame A only (analysis of lateral views is in progress). Traditionally, cineradiographic studies of speech have dealt only with the lateral view of the tract, mainly because the lateral view is the best for detecting the dynamic movements of the tongue, velum, lips, etc. Furthermore, the x-ray pictures of the larynx taken from the front usually gives an undesirable degree of clarity, as cartilages and ligaments in the larynx are not very opaque to x-rays. But, inevitable as it may seem, the lateral approach has one serious drawback, in that it does not reveal the behavior of the glottis, which is probably the most essential part in speech production but nevertheless is not easily subject to direct observation by other means, especially during a consonantal articulation, as it obstructs the path of, say, a laryngoscope. To remedy this, the so-called stroboscopic laminagraphy has been used by Hollien and others in their studies of the laryngeal behavior (cf. Hollien and Curtis,[2] and Hollien and Moore[3]). It has, however, a limited application, and in this study, a laminagraph has not been used. A simple cineradiography produced remarkably clear pictures of the front view of the larynx. In particular, outlines of pharynx walls, trachea, and vocal folds were measurably visible. Figure XXII-1 is a schematic picture of a typical frame and 3 axes along which measurements were made in this study.

Since stops were the major concern of this study, tracings, on a 35-mm frame-by-frame analyzer (Tage Arnø), were made primarily of the span of 3 segments in each utterance in which the middle segment is a stop (i.e., [+____a] in frame A). The measurements made on these tracings were then reduced to real life size, and it is this last size that is indicated in the following figures.

Measurement 1 (the pharynx width) was made, as is shown in Fig. XXII-1, at a point 3 cm above the bottom line of the body of 4th cervical vertebra. The study of the pharynx width viewed laterally during the occlusion part of English stops has been done by Perkell.[4] Although lateral measurements should give an index of the varying pharynx width, _ceteris paribus_, one difficulty is that the root of the tongue which constitutes the front wall of the pharynx shifts constantly as a function of the movement of the main body of the tongue, and hence the lateral measurements give little indication of the

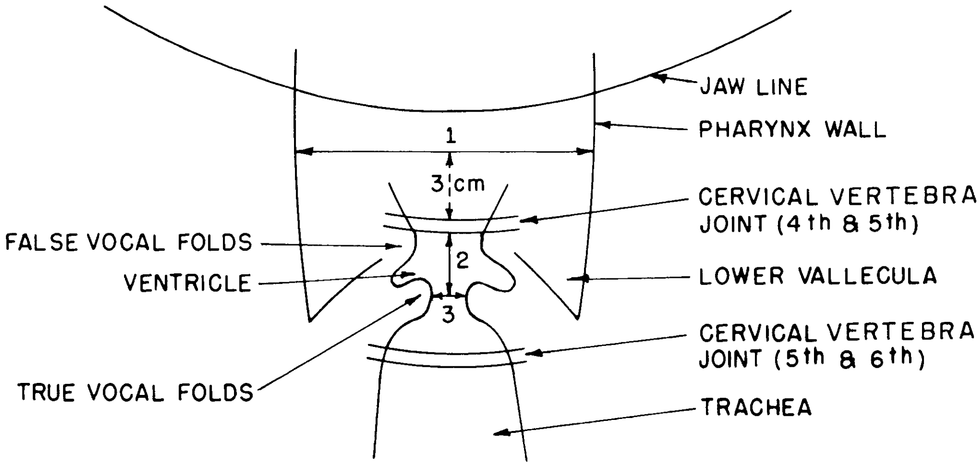

Fig. XXII-1. Tracing of a typical frame. Numbered arrows indicate 3 axes along which measurements were made in this study: (i) the pharynx width, (ii) the relative height of glottis, and (iii) the degree of glottal opening.

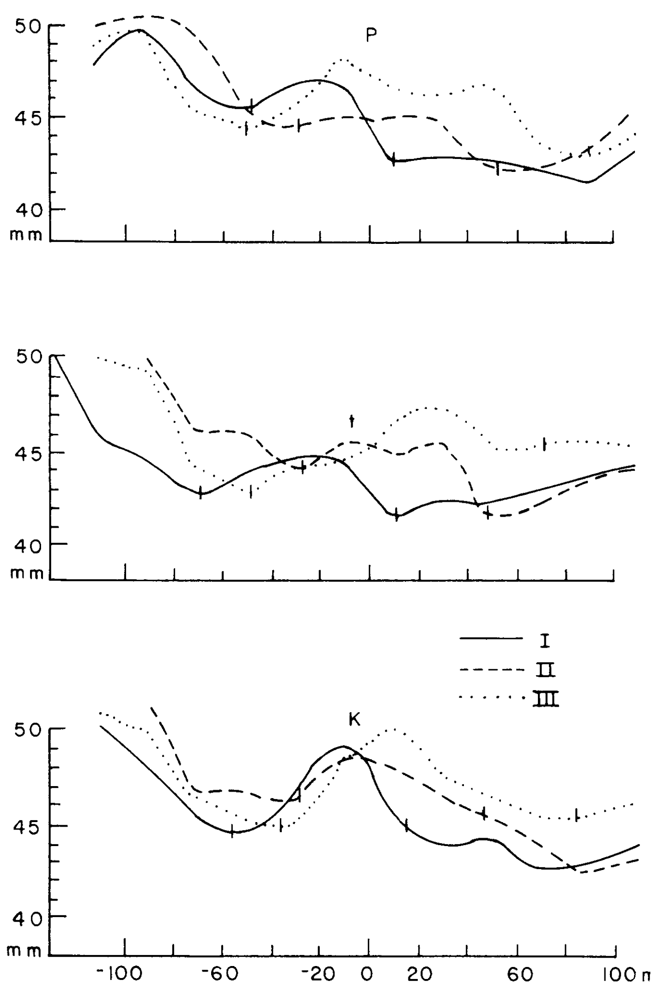

Fig. XXII-2.

Pharynx width measured along axis 1 in Fig. XXII-1. Top graph is for labials; middle, dentals; and the bottom, velars. Solid line indicates type I stop, dashed line type II stop, and dotted line type III stop. All curves are aligned with reference to the time of release as 0. The synchronization error is less than ±10 msec. Vertical bars before 0 indicate the time of oral closure, and those after the release indicate the time of voicing onset.

pharyngeal movement itself independent of the tongue. In this respect, the following study of the pharyngeal behavior viewed from the front is of some interest. Examine now Fig. XXII-2.

We observe that the pharynx width varies considerably during utterances in a rather patterned way; in particular, the pharynx narrows before the closure of a stop, then widens a little during the initial portion of the closure, either maintains this width relatively steadily or expands a little before it narrows again before the point of the voicing onset for [ɑ], and then either levels off or widens again. We may discuss this phenomenon in more detail in terms of 5 stages.

Stage 1: The pharynx narrows before the closure of a stop. There seem to be two possibilities for this to occur. One is that the pharynx narrows in order for it to help the build-up of air pressure needed for the articulation of a stop. We assume that the pressure increase during the stop closure is not the unique function of the pulmonic pressure produced by the contraction of respiratory muscles in the chest, but is aided by the narrowing pharynx. This does not explain why the narrowing occurs to the same degree before type II stops as before type I and III stops, despite the fact that type II, being lax, require much less air pressure during the closure than types I and III stops. Be that as it may, this explanation might have been more feasible than the next one, had the stops under examination occurred word-medially or finally. But the fact that these stops are preceded by a word boundary leads one to speculate whether the pharynx narrowing occurs because of and during this preceding junctural pause. If this assumption is valid at all, it follows that the same phenomenon must occur before the beginning of an utterance, and, in order to verify this, tracings of entire utterances containing labial stops were made and the variation in the pharynx width starting from several frames before the beginning of the utterances were measured. The result is shown in Fig. XXII-3.

Observe that before the beginning of each utterance the pharynx contracts slowly from the wide rest position until the beginning of the first segment of the utterance. Let us regard this phenomenon as the pharynx taking the position for phonation which is different from the position for respiration. That is, we hypothesize that the pharynx contracts in preparation for an utterance so that it may expand as air flows through the glottis. Consider, for example, how room for the air coming through the glottis during the closure of a voiced stop (cf. Perkell[4]) is going to be provided if the phonation started with the pharynx at the maximally expanded position. This phenomenon is perhaps best compared with that of the vocal cords that are also assumed to have the position for phonation to which the cords must move at the beginning of an utterance from the normally wide open position for respiration (cf. Halle and Stevens,[5] and Lieberman[6]).

The fact that this phenomenon of pharyngeal contraction occurs during the word boundary seems to have some theoretical significance, in that it is a physiological

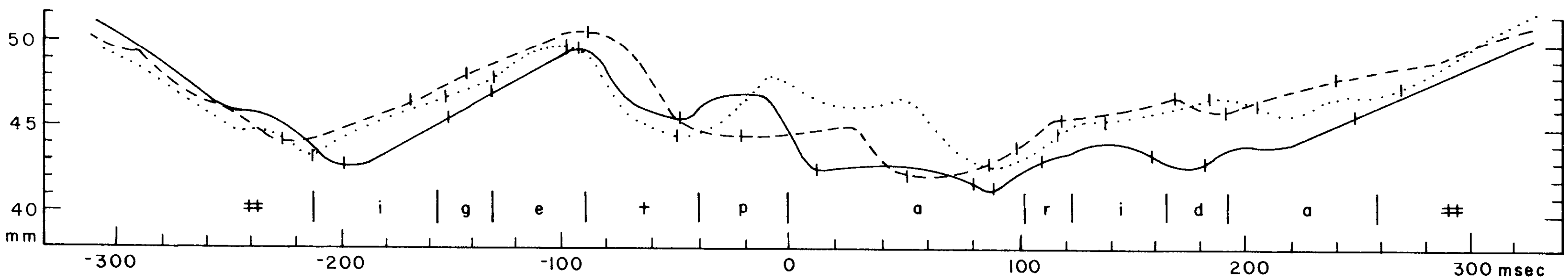

Fig. XXII-3. Variation in pharynx width (measured along axis 1 in Fig. XXII-1) in entire length of utterances involving labial stops. Approximate segmental boundaries for the entire set are indicated with long vertical bars below the curves. The corresponding position in each utterance is indicated with a small bar on the curve in the area above the long bar. Observe that utterances begin and end with the wide open pharynx, and the contraction occurs before the beginning of an utterance, during the word boundary (+), and before [ɑ].

correlate of the unit "phonological boundary" which defines the domain of application of phonological rules and across which different phonetic phenomena appear. In English, for example, there are several phonetic differences between such pairs of phonemically identical strings as <u>my train</u> – <u>might rain</u>, a <u>grey tie</u> – <u>a great eye</u>, etc., e.g., /t/ of <u>train</u> and <u>tie</u> has a stronger aspiration than /t/ of <u>might</u> and <u>great</u>, respectively; /t/ of <u>train</u> is retroflexed but /t/ of <u>might</u> is not; /ay/ of <u>eye</u> may be preceded by a glottal stop [?] while /ay/ of <u>tie</u> may not, etc. These differences have been ascribed to "junctures" being in different places, and some phoneticians (Jones, Joos) explain them as being a "fresh attack" on /t/ of <u>train</u> but not in that of <u>might</u>, etc. Note what this "fresh attack" means. It means that, to phonate the segment at issue, that is, the segment immediately following a phonological boundary, the articulators assume the same position as they would for phonation of a corresponding utterance-initial segment. It is clear that this fresh articulatory effort would prevent any tendency for extreme coarticulation, assimilation, slurring, etc., and this explains, physiologically, why such rules as velar softening, stress shift, /g/-deletion, nasal assimilation, etc. do not apply in English across what is called a "formative boundary."

At this point, it may be mentioned that in Korean there is a voicing assimilation rule that makes a type II (lax) stop voiced when it falls between two voiced segments, but this voicing assimilation does not occur when the stop is preceded by a word boundary, even though it is otherwise surrounded by vowels. For example, in frame A utterances, a type II stop is preceded by [e] (discounting a word boundary) and is followed by [ɑ], but it nevertheless remains voiceless. Compare this with /t/ of /-i-ta/ which become voiced [-ida] (see Fig. XXII-3). This is probably because the pharyngeal contraction preceding the stop closure allows no room for the air to come through the glottis, and thereby suppresses any tendency to "voice through" this lax stop.

To conclude, we argue that, no matter how abstract such phonological units as word boundary, stress, etc. may be at the deepest phonological level (i.e., the systematic phonemic level in the current format of Chomsky-Hallian generative phonology), and no matter how mentalistic the character of speech perception may be claimed to be, there are physiological correlates for each of these units. Unless one accepts this argument, one cannot explain why such rules as palatalization, voicing assimilation, nasal assimilation, etc. do not in general apply across a certain phonological boundary.

<u>Stage 2</u>: The pharynx widens a little during the initial period of the stop closure. I assume that this is so because the pulmonic pressure increases after the closure has been made, thereby expanding the pharynx a little. Note that the rate of this expansion is smallest in type II stops (there is practically no increase in /p/), but that it is significantly greater in type I and III stops. This may be taken as an indication of differences in the relative degree of pulmonic or subglottal pressure, i.e., pulmonic pressure is considerably greater in I and III than in II. The tense/lax distinction

seems to appear in this respect, too.

Stage 3: The pharynx width is relatively steady or expands a little during the latter part of the stop closure and until 10-20 msec before the point of the voicing onset. Note that the duration of this steady or expanding period before the next narrowing stage is rather proportional to that of aspiration (or voicing lag), i.e., it is the shortest for I, longer for II, and the longest for III. Although why this should be so is not altogether clear at the present moment, I venture the following explanation. Once the oral pressure is built up to the degree that is necessary and sufficient for the stop phonation, this pressure will be maintained steadily until the release of the closure (measurements of oral air pressures show that this is true, see Kim[1]). Now the release of the oral occlusion should also release the tension of the pharynx which was somewhat built up during the stop closure. From this release, one should expect the pharynx to relax at least momentarily and move toward the neutral rest position. This means that the pharynx will expand, and this is what seems to be happening in type III stops (although it is not clear in /p^h/, whose long period of voicing lag allows the pharynx to relax (or widen) momentarily just after the release before it contracts again for the configuration of the following vowel [ɑ]). For both type I and type II stops, this momentary relaxation of the pharynx does not seem to happen, probably for different reasons. In II it does not happen, probably because the pharynx did not contract in the first place, i.e., it remained lax throughout the closure; in I the relaxation does not happen simply because there is no time to, i.e., the pharynx must position itself for the ideal configuration of the following vowel [ɑ] during the closure (i.e., before the release), as the voicing must start immediately after the release of the oral occlusion.

Stage 4: The pharynx contracts again before the voicing onset of the following vowel [ɑ]. We may assume that this contraction occurs in order for the pharynx to help the vocal tract assume the ideal tract configuration for the vowel [ɑ], which has the so-called point of constriction in the back of the oral cavity and requires a wide front cavity and a narrow back cavity to produce the desired acoustic output of [ɑ] (high F1, low F2, etc.). Although this narrowing of the back cavity is primarily made by the main body of the tongue retracting toward the back wall of the pharynx, there is no reason why the side pharynx walls should not contract to decrease the size of the pharyngeal cavity. Since what is important here is not the degree of constriction per se defined from a lateral point of view, as it is in most consonants, but the decreasing of the back cavity as a whole, it would be only natural if the pharynx contracted, in addition to the tongue retraction, for [ɑ]. Note that the same phenomenon occurs, though to a lesser degree, before the utterance-final [ɑ] (see Fig. XXII-3).

Stage 5: The pharynx width either levels off or gradually widens after the onset of the vowel [ɑ]. This is probably an indication that, in the former case, the pharynx maintains its position for [ɑ], and that, in the latter case, it either already anticipates

[i] in the following syllable or it has started its slowly relaxing movement toward the end of an utterance. At the present time, it is an open question.

Measurement 2 was made to see if there is any difference in the relative heights of the glottis during the phonation of the three types of Korean stops. Figure XXII-4 shows that, in general, the glottis is raised a little in I, and that it is lowest in II, III being between the two. Although the difference is not great (the observed maximum difference

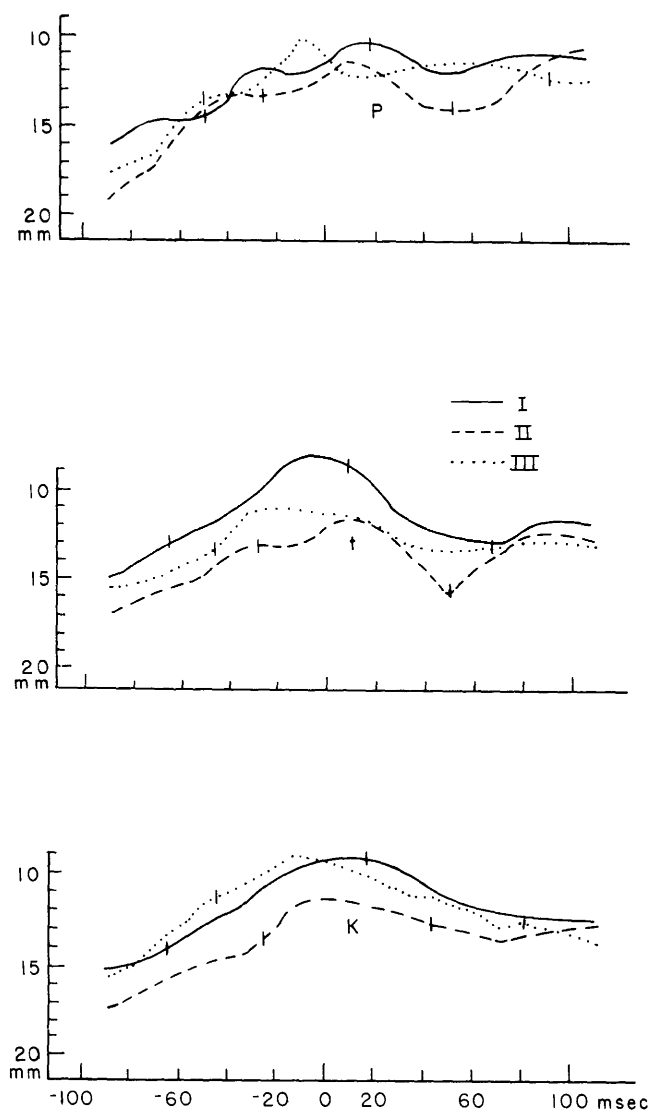

Fig. XXII-4. The relative height of the glottis measured along axis 2 in Fig. XXII-1 (from the top of the 5th cervical vertebra to the top of the glottis). Thus, the smaller this distance, the higher the glottis. For explanations of graphical conventions, see the legend of Fig. XXII-2.

between I and II just before the release is ~5 mm), it must be an indication of differences in pulmonic pressures, since according to Boyle's Law, a 4-mm difference in the glottal height is equivalent to approximately 3 cm H_2O difference in the air pressure. And if we consider the fact that in English the subglottal difference between the stressed and unstressed segment is ~5-~6 cm H_2O (cf. Lieberman[6]), the figure above is not insignificant, and may well account for a well-known phenomenon in Korean phonology in which the "intensified" counterpart of a word (usually descriptive adjectives or adverbs) is formed by replacing type II consonants in the word with the corresponding type I or type III consonants, e.g., kəmɨn 'black', k'əmɨn 'pitch black'; pəlləŋ 'gently waving (flag, etc.)', pʰəlləŋ 'fluttering'. In any case the raising of the glottis in I (and to a degree in III) seems to be due to the greater subglottal pressure.

Not measured here, but nevertheless to be noted, is the shape of the vocal folds during the closure and at the time of its release in different types of stops. A typical shape at the time of the release for each type is shown in Fig. XXII-5. It can be seen that in I, the vocal folds are thinner and the ligamental edges point upward, while in II, the folds are thicker and stay even. In III, the vocal folds are wide open and the lower parts blend into the trachea. As would be expected, these thin tense vocal folds in I raise the fundamental frequency of the following vowel at the beginning (cf. Kim[1] and Hollien[7]).

Measurement 3 is concerned with the degree of the glottal opening in the three types of Korean stops (see Fig. XXII-6). It is clearly seen that the glottis is narrow (but not closed) in I, moderately open in II, and wide open in III. The fact that the glottis is never completely closed in type I stops should dispel any further speculation about whether or not they are (pre)glottalized stops. What we normally call "glottalized" (or ejective) stops have a different phonation mechanism. (One might argue that the glottal opening in I is within the range of the open phase of the vocal vibration. But since we know by other means that throughout the closure a type I stop is voiceless, we may safely assume that the glottis maintains its narrow opening during the entire closure without ever closing it between some two successive frames.)

Another thing to be noted is that there seems to be a direct correlation between the degree of the glottal opening at the time of release and the degree of aspiration, that is, between the time it takes for the glottis to close for the vibration of the following vowel and the length of aspiration or voicing lag. This is only logical. Lieberman[6] showed that it takes approximately 100-150 msec for the open glottis to come together for the initiation of phonation. And my own examination of the present film shows that it takes 100-120 msec for my glottis to close, just before the beginning of each utterance, for [i] (the first segment) from a respiratory position. Although it is not known at this time whether the rate (speed) of closing of the glottis would be faster utterance-medially than utterance-initially, it is safe to say now that aspiration is nothing but a function of the

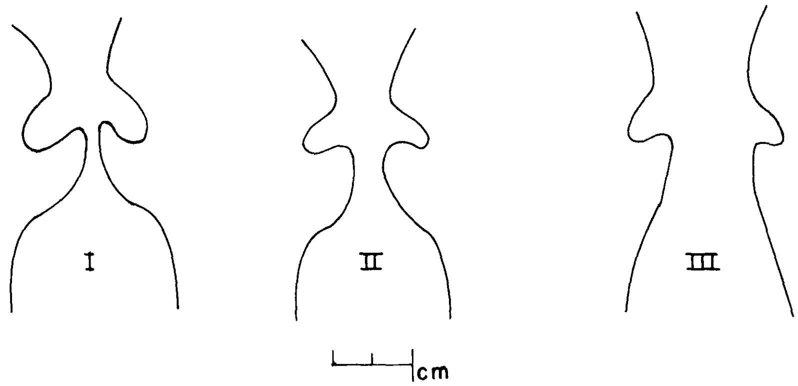

Fig. XXII-5. Tracings of a typical vocal fold shape of each type of stop at the time of release.

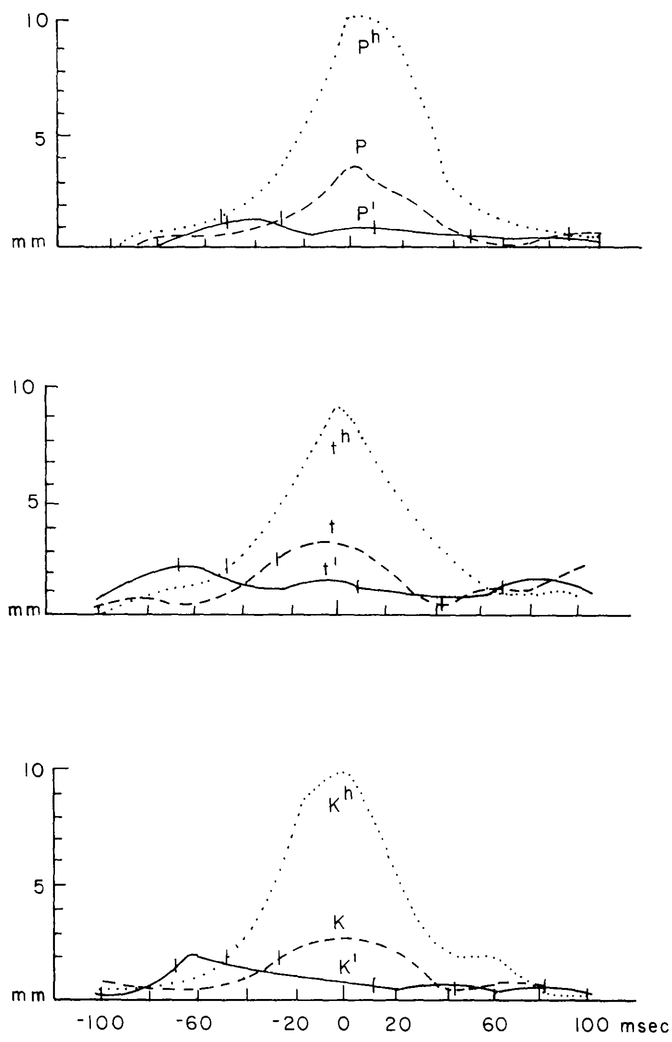

Fig. XXII-6. Distance of glottal opening at the narrowest point along axis 3 in Fig. XXII-1. For explanations of graphical conventions, see the legend of Fig. XXII-2.

glottal opening at the time of the release. This is to say that if a stop is 'n' degree aspirated, it must have an 'n' degree glottal opening at the time of the release of the closure. From this it follows that no stop is aspirated if it has a small glottal opening, and a stop cannot be unaspirated if it has a large glottal opening at the time of the release. The century-old speculation whether the voiceless stops of Romance languages are glottalized or not can now be deductively answered, i.e., since these stops are unaspirated the glottal opening at the time of release must be narrow (but not closed, as normally there is a voicing lag of ~5-20 msec, cf. Lisker and Abramson[8]). They are "glottalized" only if we use the term "glottalized" loosely to include narrow glottis, as well as closed glottis (during the occlusion). Otherwise, they are not.

As far as I know, "aspiration" has never been explained in this way. Traditionally "aspiration" has been defined as a glottal friction. That this definition is completely misleading is obvious, since the more aspiration, the more the glottis is open, and if a "glottal frictión" presupposes some sort of glottal friction, then it simply is not there. One might ask then how and where a turbulence that accompanies the [h] articulation is created if [h] is a glottal sound (so classified in every phonetic table) and yet there is no glottal constriction, as is claimed here. I contend that the turbulence is created not at the glottis but at the point of constriction, for the following vowel whose configuration is formed, through coarticulation, during [h]. One can actually hear an acoustic difference in two [h]'s of /hi/ and /hɑ/. The fact that /hi/ is allophonically [çi] in many languages supports this contention.

Another frequently met definition of aspiration is in terms of "puff of air." Heffner,[9] for instance, states

> "If the release is impulsive and sudden, the rush of air out of the stopped cavity may be vigorous and puff-like. Stops which have this puff are called aspirated stops.... Evidently the degree of energy displayed by these puffs depends on the degree of compression achieved during the occlusion."

Heffner's last sentence is mistaken, since the degree of aspiration has no relation to the degree of compression of the air or the subglottal pressure. The type I stops of Korean have a much stronger air pressure during the occlusion than type II stops. Yet the former is unaspirated, while the latter is moderately aspirated. Thus the notion is false that the heightened subglottal pressure blows the closed or narrowed glottis wide apart and the time that it takes for them to come together again for voicing is aspiration. (One might ask why there is a voicing lag in ejectives which have a completely closed glottis both during the closure and at the time of the release. Note that in ejectives the closed glottis is raised to increase the pressure of the air between the point of the oral closure and the closed glottis, and that here the glottis is <u>not</u> pushed up by the heightened subglottal pressure, but the whole larynx is raised by the laryngeal muscles. This act will increase the lung volume and will <u>lower</u> the subglottal pressure, and the voicing will not start until the glottis comes down and the pulmonic pressure is built up, at least great enough to cause the Bernoulli effect.)

This view of aspiration seems to provide a more plausible and natural explanation for some well-known phonetic phenomena involving aspiration. I shall examine a few here.

1. Why does the abutting of /p/ (unaspirated) and an independent phoneme /h/ give [p^h] in Korean and many other languages? In anticipation of /h/ whose articulation requires a wide opening of the glottis, the glottis will open during the closure period of /p/ (a simple case of coarticulation). The result is, of course, [p^h]. The answer seems to be straightforward, but if one holds the view that aspiration is 'a puff of air' resulting from a heightened pulmonic pressure, it cannot explain why there should be an extra heightening of pressure for the stop before /h/.

2. Why are English stops after /s/ unaspirated? The usual explanation has been in terms of phonological redundancy, i.e., they may be unaspirated, since in that position they do not contrast with voiced (unaspirated) stops. But this is not a phonetic explanation, and does not even raise (not to mention, answer) the question why English never developed a system in which voiceless and voiced (or aspirated and unaspirated) stops contrast after /s/.

It has been hypothesized by Kozhevnikov and Chistovich[10] that the minimal unit of motor commands is a syllable, not a phoneme, and, accordingly, that segments within a syllable receive a simultaneous package of instructions (cf. it was found that in the syllables of the type stu, ntu, dnu, etc. of Russian, the lip protrusion began practically simultaneously with the beginning of the first consonant). (What makes the string realized in a serial order, nevertheless, is, they hypothesize, not a separate and direct instruction for each segment from the speech center, but a proprioceptic impulsation occurring upon the movements of articulators during the articulation of the preceding segment.) If we accept this hypothesis, it follows that the effector organs already possess information concerning the second consonant in, say, /sp/ at the same time the articulation of the first consonant /s/ is being accomplished. And if we further assume that in the coordination of the articulations of the segments within a syllable, there is no requirement to delay a certain movement of the second segment until a certain movement of the first segment has been completed, as long as the two movements are not simultaneously incompatible because of some inherent physiological constraints, then it follows that the glottal movement for /p/ in /sp/ will start during /s/, i.e., the glottis will begin to widen. This means that, if the glottis is instructed to open to the same degree and for the same period for /p/ of /sp/ as it would for initial /p/, the glottis will begin to close by the time the closure for /p/ is made, and, consequently, by the time /p/ is released, the glottis will already have become so narrow that the voicing for the following vowel will immediately follow, and thus we have an unaspirated /p/ after /s/. Note that the notion of simultaneous compatibility is crucial here, i.e., since /s/ is voiceless and does not require the closing of the glottis, the opening of the glottis does not have to wait for the completion of /s/ but can proceed simultaneously with the oral articulation of /s/. All this is still speculative, of course, but I believe that it is a reasonable explanation for the absence of aspiration in English stops after /s/.

3. Why would a neutralization occur utterance-finally and before another consonant among /p'/, /p/, and /p^h/ in Korean?

The duration of the voicing lag has been defined as the time between the release of a stop closure and the voicing onset of the following vowel, and if one or both of these two reference points are lost, the length would, by definition, become unmeasurable. In the perception of Korean stops, the voicing lag differences apparently play a significant role (perhaps more than is implied in Kim[1]), to such an extent that when these differences are not manifest a neutralization occurs. Recall that all 3 types of Korean stops are voiceless. This means that "voicing" cannot come to help prevent the neutralization, as it does in English and French where the final stops are differentiated by the presence or absence of the voicing during the closure, not by that of aspiration. Note that in initial position, the situation is reversed in English, i.e., there it is the presence or absence of aspiration, not voicing, that identifies a stop as voiceless or voiced, respectively, as the voicing does not start until the time of release in many English speakers. In French, however, voicing during the closure of a voiced stop must be kept, as voiceless stops are unaspirated and the voicing follows immediately after the release. In German where the voicing of a voiced final stop ceases well in advance (probably in anticipation of the pause), the neutralization between voiced and voiceless stops is inevitable. Note that if aspiration is defined in terms of "strong puff of air," there is no reason why the two types of German stops should not be still differentiated word-finally because even if the devoicing of the voiced stops occurred, they would not be followed by a "puff of air," while the voiceless stops would be.

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C.-W. Kim

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