Glottal Adjustments for English Obstruents*

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Observation of the larynx for articulation of English consonants in running speech were made by using a coherent fiberoptics bundle. The procedures were as follows:

The fiberoptics bundle was inserted through the nose and positioned in the hypopharynx so as to obtain a good view of the glottis. A 16mm cinecamera was attached to the external end of the optics. The cinecamera was driven by a synchronous motor at sixty frames per second. Simultaneously with the filming, speech signals were recorded on tape together with synchronization time marks.

A list of sentences consisting of from three to fifteen syllables each and containing voiced and voiceless consonants were read aloud by three native American English talkers. Slide 1 shows selected frames of the motion picture for the sentence "Rub Billy's head with this towel." Each frame is correlated with the proper point in the sound spectrogram. A narrow-band trace is displayed above the wide-band pattern to show the voicing during speech. The symbols at the bottom are those of a broad phonetic transcription of the utterance.

In the leftmost frame, we see the larynx in inspiratory position with wide-open glottis before the utterance. The next frame shows the situation immediately before voice onset. The larynx is in phonatory position and the arytenoids are closed, while a narrow spindle-shaped opening is seen along the membranous portion of the glottis. The next frame shows almost the same position of the larynx, in which the blurred edges of the vocal folds indicate vibratory motion. The next frame is for the [b]-closure of "Rub Billy's." Here also, the larynx is in phonatory position with vibrating vocal folds. Its appearance is almost the same as in the next frame for the following vowel.

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*Paper presented at the meeting of New York Speech and Hearing Association, May 1970.

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The sixth frame is for the transition from [z] to [h] of "Billy's head." The glottis is open with separated arytenoids. A sharp definition of the vocal fold edges indicates the cessation of vibration. The last frame shows the glottis just before the release of [t] of "towel." The opening of the glottis is as large as, or a little larger than, during the transition from [z] to [h].

On the films taken for the three subjects, we made a frame-by-frame analysis of the laryngeal state during the articulation of various consonants. In the frame analysis, the following features were examined:

1) opening and closing timing for the arytenoid cartilages
2) interruption and resumption of vocal fold vibration
3) maximum width of glottal aperture
4) width of glottal aperture at the time of oral release of the stop closure.

The corresponding spectrograms were used to fix the times of supraglottal articulatory gestures, as well as those of interruption and resumption of glottal pulses.

Our data revealed that, in voiceless aspirated stops and voiceless fricatives, there was a wide opening of the glottis with separation of the arytenoids, as well as interruption of glottal vibration. On the other hand, findings for the voiceless unaspirated stops and voiced consonants were somewhat complicated.

In Slide 2, the voiced and voiceless unaspirated stops, /b,g/ and /p,k/, are classified in two ways, depending on whether or not the vocal folds ceased to vibrate and whether or not the arytenoids were separated. In the lower right quadrant are the pooled data for three subjects.

In general, the sets /b,g/ and /p,k/ can be described as follows: most /b,g/ tokens show no arytenoid separation and no interruption of glottal vibration. Most cases of /p,k/ show both separation of arytenoids and interruption of vibration. At the same time, we should note that a few cases showed separation of the arytenoids and that some had an interruption of glottal vibration. There are, moreover, a large number (fifteen cases) of /p,k/ tokens in which no separation of the arytenoids was observable, while a few showed no interruption of glottal vibration.

Looking at the behavior of individual subjects, we can recognize certain differences between them, although the number of observations is perhaps too small to draw firm conclusions. For example, subject C has a considerable number of [p]'s without separation of the arytenoids, while subject A has all the [b]'s with separation of the arytenoids and a fair number of the [p]'s without arytenoid separation.

In distinguishing between voiced and voiceless categories, subjects C and L have no difficulty. In the case of subject A, there seems to be some overlap

Arytenoid Separation and Interruption of Glottal Vibration for English Voiced and Voiceless Unaspirated Stops

subject C

		b	p	g	k
Aryt. Sep.	+	0	11	0	15
	–	9	6	3	2
I.G.V.	+	0	16	0	17
	–	9	1	3	0

subject A

		b	p	g	k
Aryt. Sep.	+	4	8	0	13
	–	10	4	3	1
I.G.V.	+	5	9	0	14
	–	9	3	3	0

subject L

		b	p	g	k
Aryt. Sep.	+	0	9	0	15
	–	8	1	5	1
I.G.V.	+	0	10	0	15
	–	8	0	5	1

Pooled Data

		b	p	g	k
A.S.	+	4	28	0	43
	–	27	11	11	4
I.G.V.	+	5	35	0	46
	–	26	4	11	1

SLIDE 2

Arytenoid Separation and Interruption of Glottal Vibration for English Voiced Fricatives and Affricates

subject C

		z	ð	v	ǰ
Aryt. Sep.	+	8	0	0	2
	–	3	10	6	1
I.G.V.	+	0	0	0	0
	–	11	10	6	3

subject A

		z	ð	v	ǰ
Aryt. Sep.	+	10	--	0	4
	–	1	--	5	0
I.G.V.	+	3	--	0	3
	–	8	--	5	1

subject L

		z	ð	v	ǰ
Aryt. Sep.	+	1	0	0	0
	–	8	6	3	2
I.G.V.	+	0	0	0	0
	–	9	6	3	2

Pooled Data

		z	ð	v	ǰ
A.S.	+	19	0	0	6
	–	12	16	14	3
I.G.V.	+	3	0	0	3
	–	28	16	14	6

SLIDE 3

between /p/ and /b/, but the overlap disappears if the items are separated according to context.

Slide 3 shows a similar display for voiced fricatives and affricates. In the pooled data, we see that all the /ð/ and /v/ tokens were produced with closed arytenoids and continuation of glottal vibration, while the situation is complicated in /z/ and /ǰ/. Looking at data for individual subjects, we again see certain differences among them. In subject L, almost all the /z/ and /ǰ/ tokens show neither separation of the arytenoids nor interruption of glottal vibration. For subjects C and A, most of the /z/ and /ǰ/ tokens were produced with arytenoid separation. Furthermore, subject A has all the tokens which showed interruption of vibration.

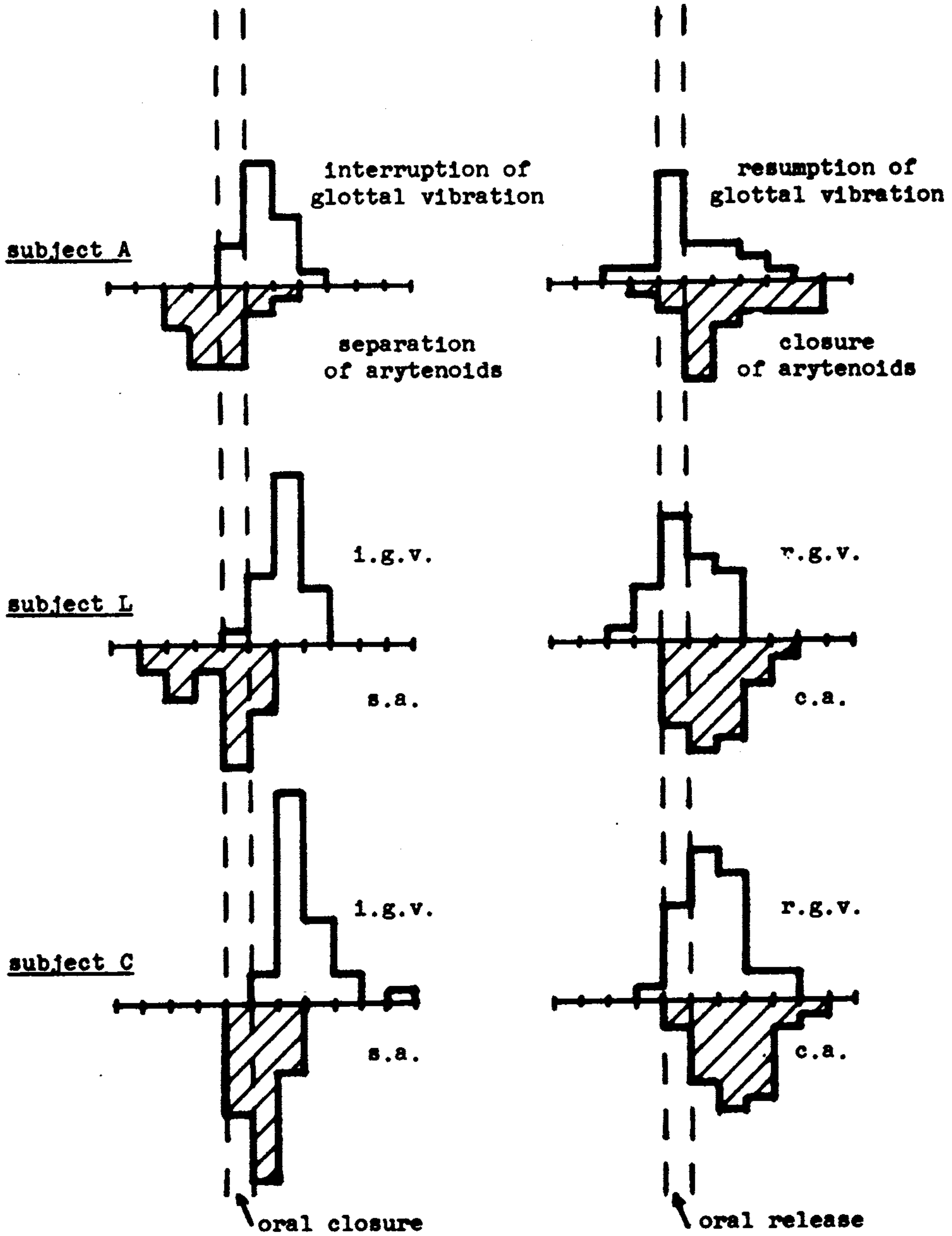
Now let us focus attention on the time relations between laryngeal and supraglottal articulatory gestures for voiceless consonants.

Slide 4 shows such time relations for the voiceless unaspirated stops. In the left column, three graphs indicate when interruption of glottal vibration and separation of the arytenoids occurred relative to the stop occlusion. The abscissa is marked off in time intervals representing the film frames in sequence. The ordinate indicates the frequency of occurrence along the abscissa. Blank graphs above the abscissae are distribution patterns for the interruption of glottal vibration, and shaded graphs below the abscissae are for the separation of the arytenoids. In the right column, a similar display is shown for the timing of resumption of glottal vibration and the closure of the arytenoids, relative to the stop release.

In the left graphs, we see that, in most cases, interruption of glottal vibration occurs one or two frames after the beginning of the closure. Separation of the arytenoids shows a relative timing that varies considerably, occurring both before and after oral closure, with some intersubject difference. There is a clear tendency for arytenoid separation to begin earlier than interruption of vibration, although there is some overlap in distribution patterns. Examination of the time relation for each token showed that, in sixty-three tokens out of sixty-six, interruption of vibration took place after arytenoid separation and that there was only one case in which the time relation was reversed.

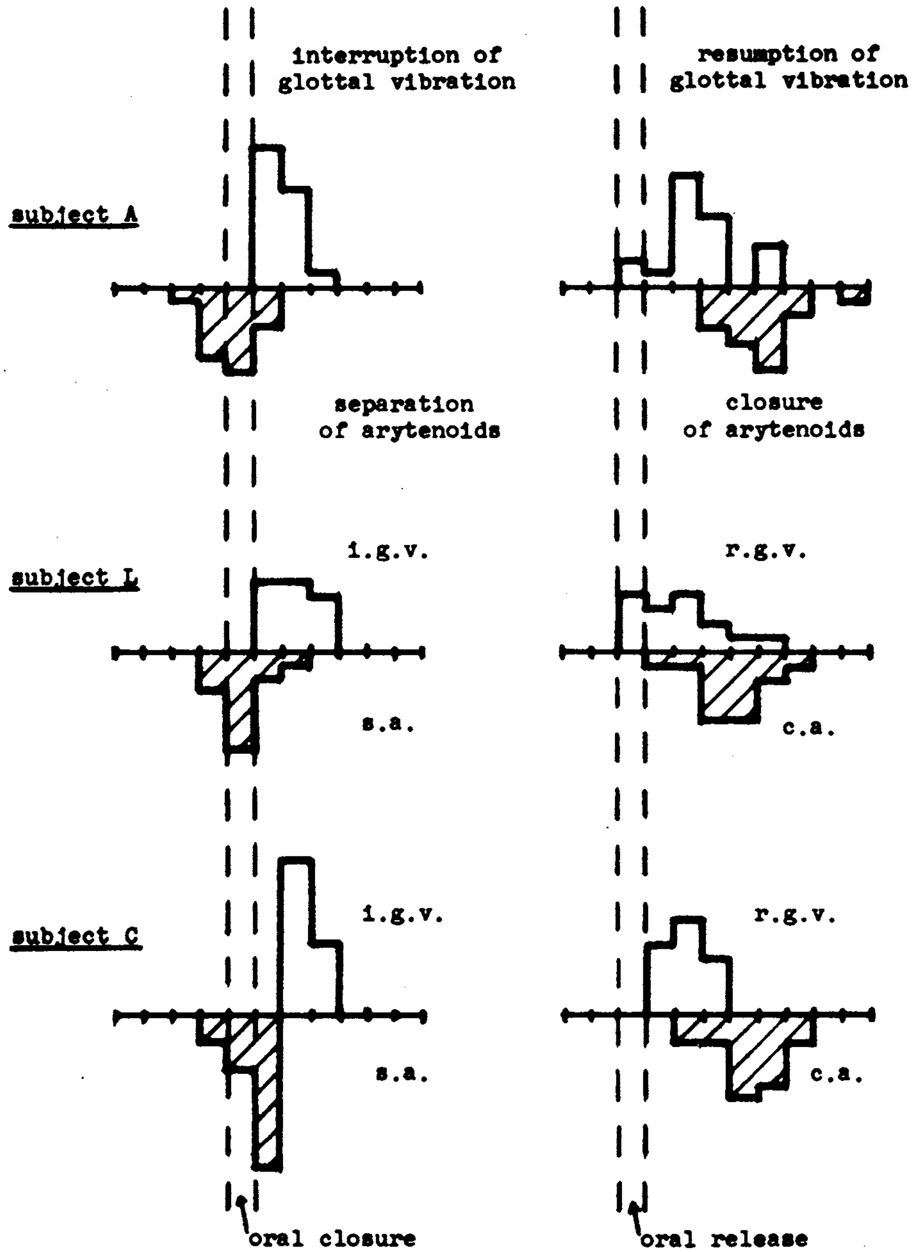
In the graphs on the right, we see that the resumption of vibration takes place, in most cases, just at or immediately after stop release, while arytenoid closure is achieved following the release. There seems to be a tendency for arytenoid closure to be completed shortly after resumption of glottal vibration.

Voiceless Unaspirated Stops



SLIDE 4

Voiceless Aspirated Stops



SLIDE 5

Examination of each token revealed that, in most cases, resumption of glottal vibration preceded the arytenoid closure, although there was a considerable number of tokens, particularly for subjects L and C, in which the two occurred at the same time.

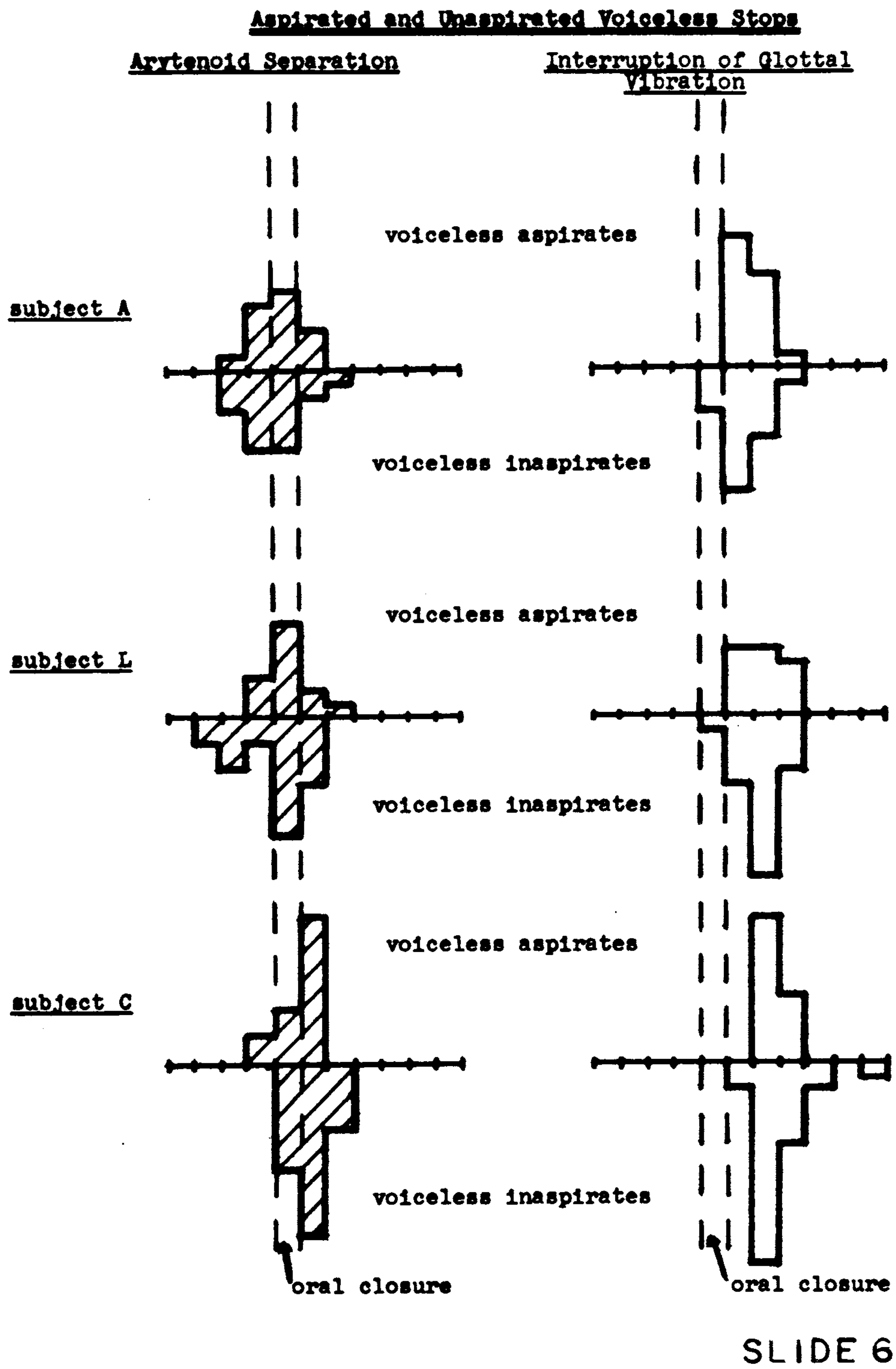
Slide 5 shows the same display for voiceless aspirated stops. The timing of the interruption of vibration and arytenoid separation relative to the stop closure, shown on the left, is quite similar to the situation for the voiceless inaspirates. Here also, separation of the arytenoids regularly precedes interruption of vibration for every token. On the right, we see that the arytenoid closure is achieved long after the stop release. Examination of the relative timing between arytenoid closure and resumption of vibration revealed that, in almost all tokens, the arytenoids were closed after resumption of vibration.

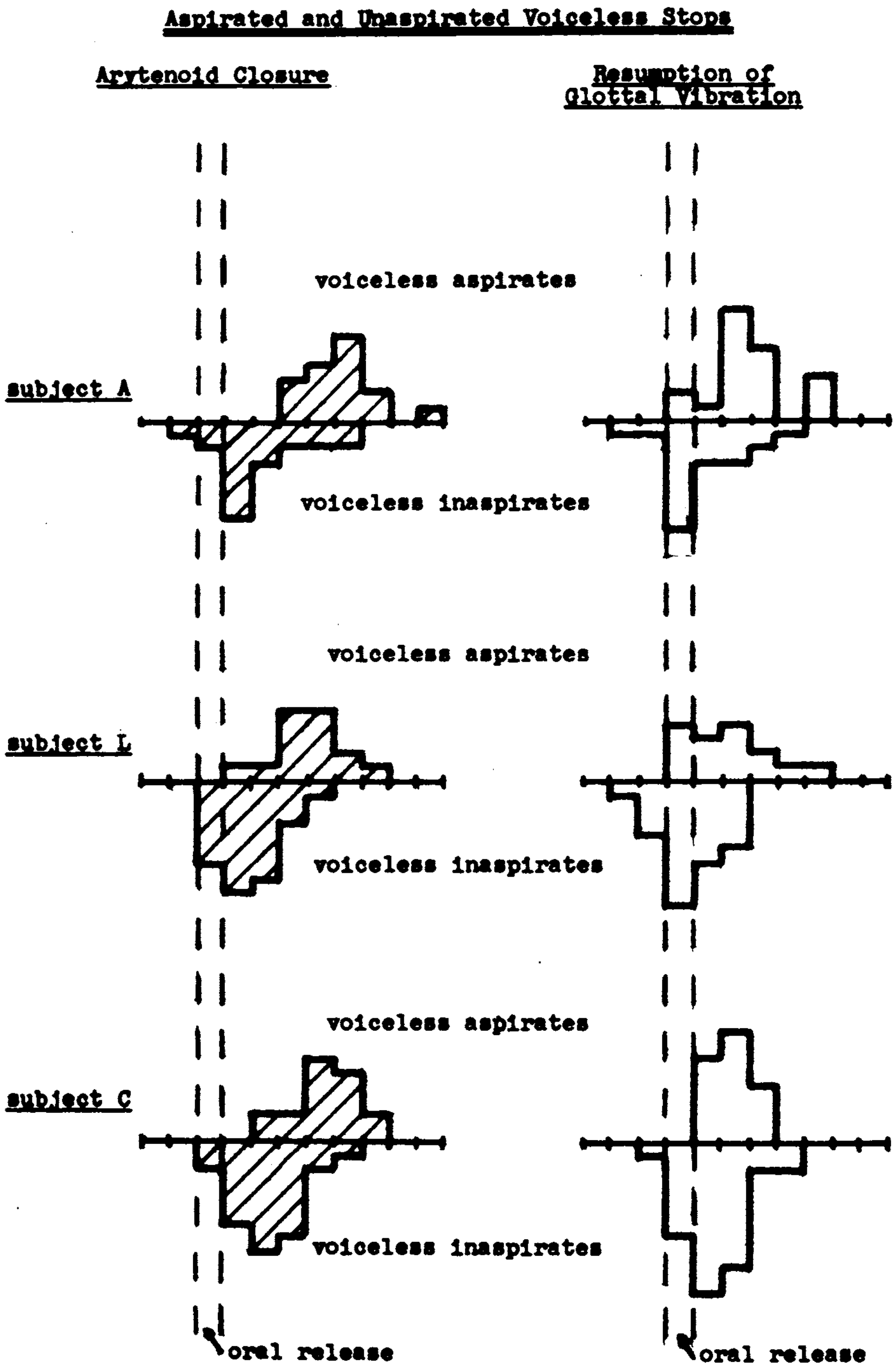
Slide 6 shows the timing of the laryngeal gesture at the beginning of voiceless aspirated stops in comparison with that of voiceless inaspirates. Graphs below the abscissae are those for the inaspirates. Shaded graphs on the left are for arytenoid separation, and blank ones on the right are for interruption of glottal vibration. Distribution patterns for the aspirates are well matched to those of the inaspirates. The display indicates that there is no difference in timing of laryngeal gestures between aspirates and inaspirates at the beginning of stop closure.

On the other hand, the difference in the timing of the laryngeal gesture for release of stop closure is clearly seen in Slide 7. On the left, we see that the arytenoid closure is achieved later in the aspirates than in the inaspirates. A similar tendency is observable for resumption of vibration, as shown on the right half of the slide, although there is more overlapping in the distribution patterns.

Slide 8 shows the time relation between laryngeal and upper articulatory gestures for voiceless fricatives. The graphs show patterns similar to those for voiceless unaspirated stops. For every token, the arytenoids begin to separate before interruption of glottal vibration.

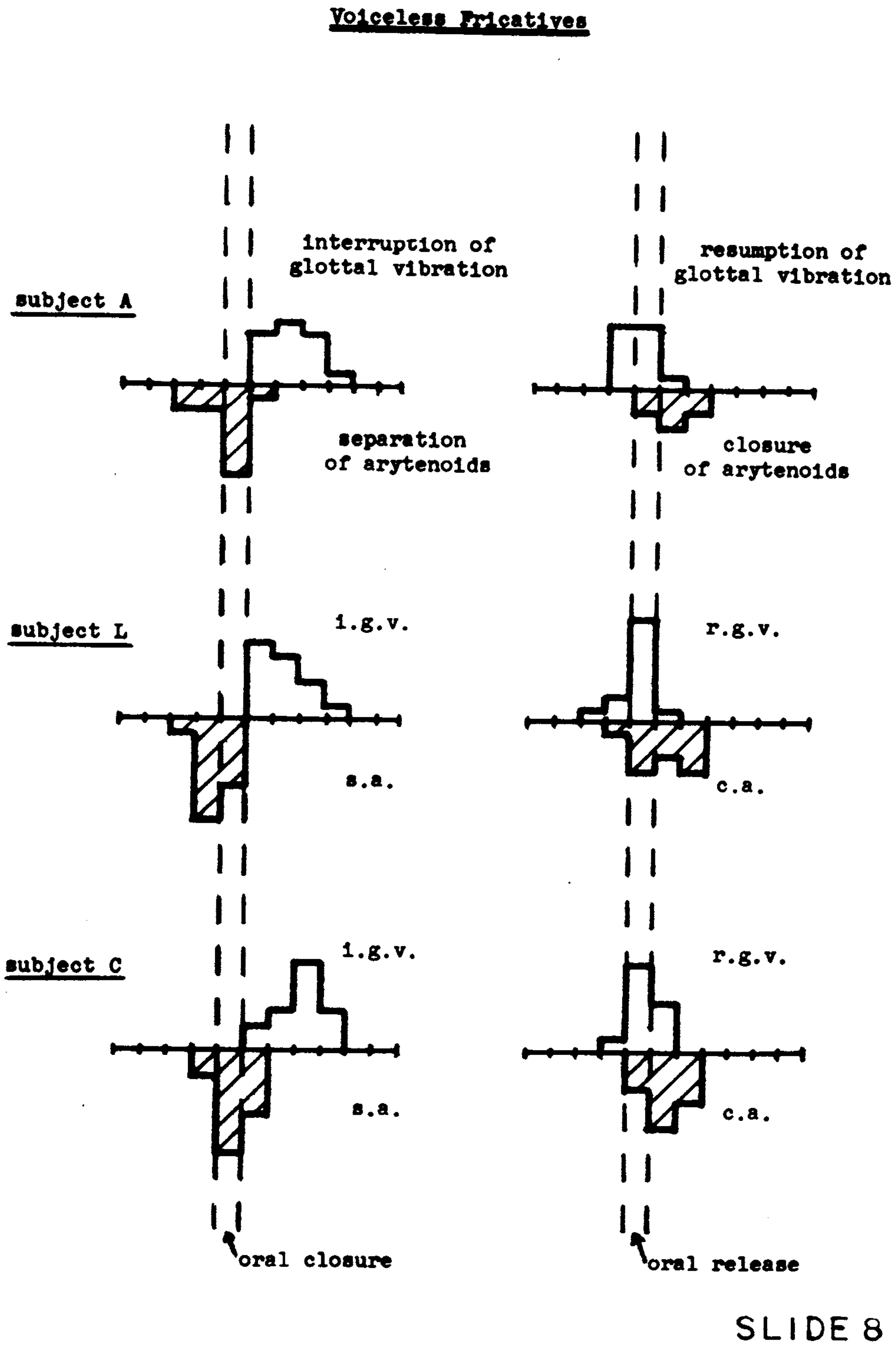
For estimating width of glottal opening, we measured the distance between the vocal fold edges on magnified traces of the films. Slide 9 shows the maximum opening of the glottis during the articulation of voiceless consonants. We classified the width of the opening in 5mm steps as indicated on the abscissa. It should be noted that the values on the abscissa do not indicate the absolute values of the actual glottal opening. The ordinate indicates numbers of cases along the abscissa. The glottal aperture is smaller in inaspirates than in

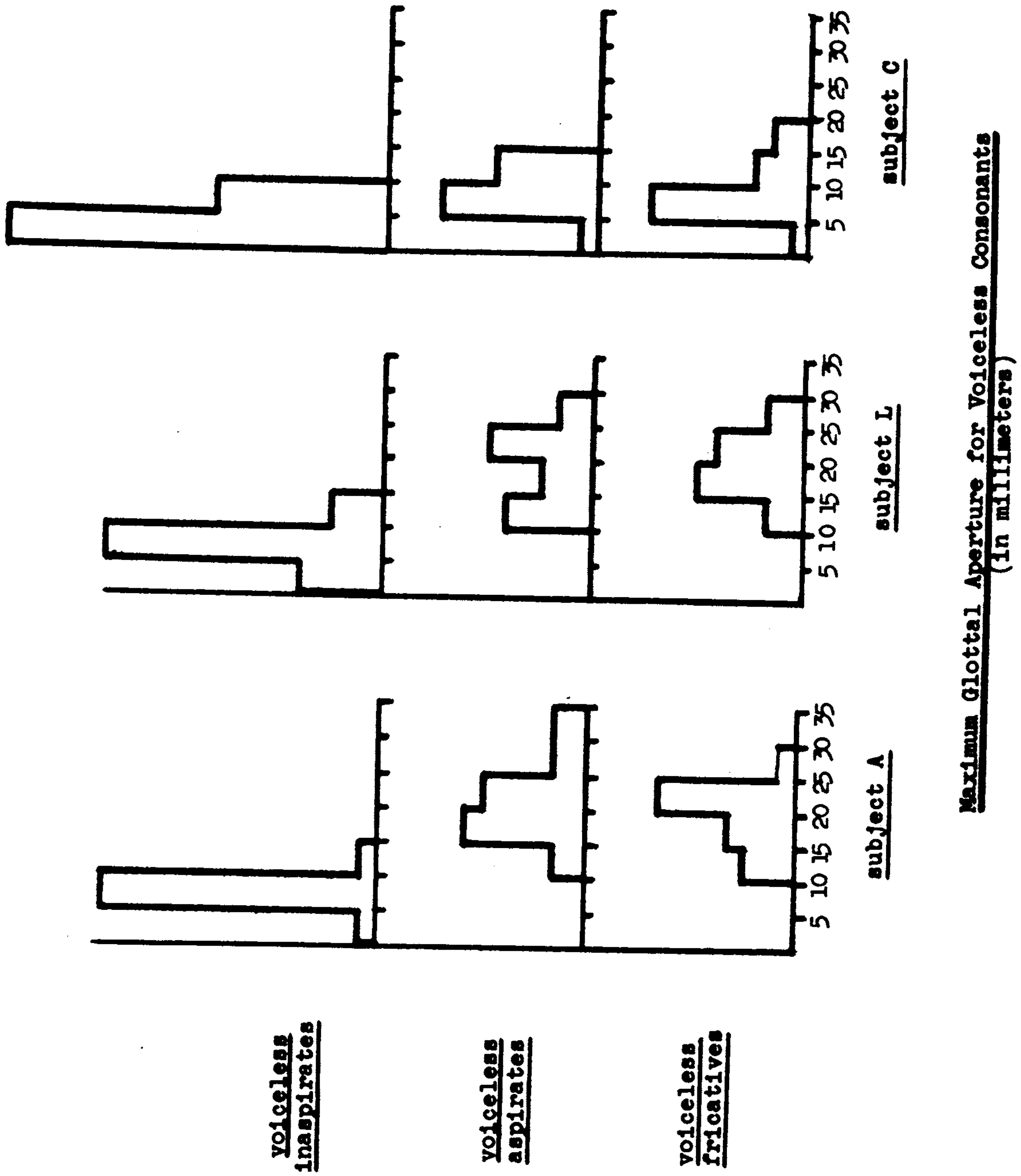

Aspirated and Unaspirated Voiceless Stops
Arytenoid Separation
Interruption of Glottal Vibration
voiceless aspirates
subject A
voiceless inaspirates
voiceless aspirates
subject L
voiceless inaspirates
voiceless aspirates
subject C
voiceless inaspirates
oral closure
oral closure
SLIDE 6



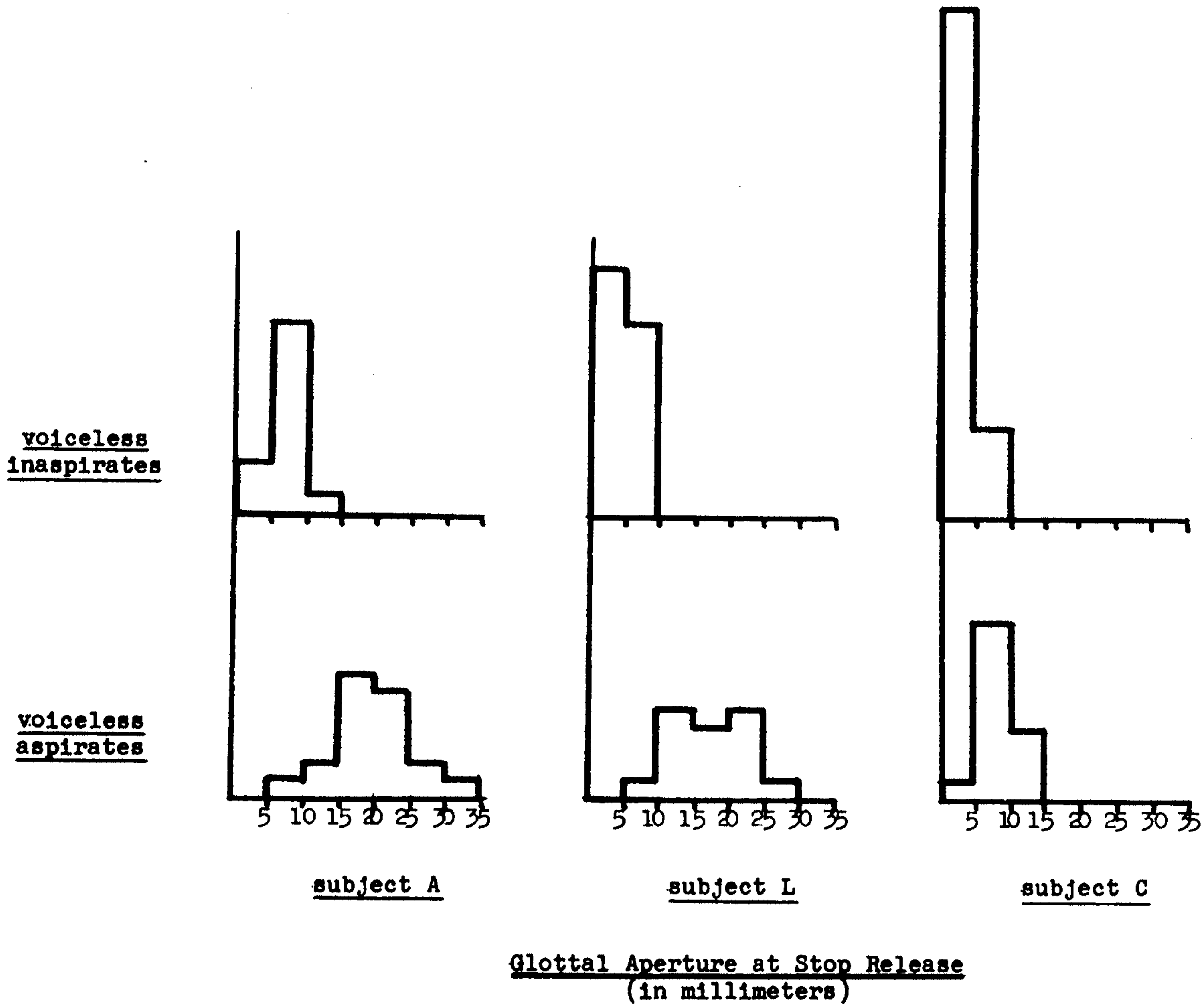
Aspirated and Unaspirated Voiceless Stops
Arytenoid Closure
Resumption of
Glottal Vibration
voiceless aspirates
subject A
voiceless inaspirates
voiceless aspirates
subject L
voiceless inaspirates
voiceless aspirates
subject C
voiceless inaspirates
oral release
oral release

SLIDE 7


Voiceless Fricatives
interruption of
glottal vibration
resumption of
glottal vibration
subject A
separation
of arytenoids
closure
of arytenoids
subject L
i.g.v.
r.g.v.
s.a.
c.a.
subject C
i.g.v.
r.g.v.
s.a.
c.a.
oral closure
oral release
SLIDE 8


voiceless inaspirates
voiceless aspirates
voiceless fricatives
subject A
subject L
subject C
5 10 15 20 25 30 35
Maximum Glottal Aperture for Voiceless Consonants
(in millimeters)

SLIDE 9


voiceless
inaspirates
voiceless
aspirates
5 10 15 20 25 30 35
5 10 15 20 25 30 35
5 10 15 20 25 30 35
subject A
subject L
subject C
Glottal Aperture at Stop Release
(in millimeters)

SLIDE 10

aspirates and fricatives. There seems to be no difference between the aspirates and fricatives.

Slide 10 shows the glottal opening at stop release. The opening in voiceless unaspirated stops is definitely smaller than that in voiceless aspirated stops. The data are consistent with those for the difference in timing of laryngeal gestures at stop release.

Findings presented here concern some basic features of laryngeal gestures. mainly for intervocalic consonants. In further studies, we plan to examine variations in these basic features for various consonant clusters and to extend these studies to include cross-language observations.