

Cinegraphic Observations of the Larynx During Voiced and Voiceless Stops\*

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At the last meeting of the Society (J. Acoust. Soc. Am. 47, 105 (A), 1970), we reported certain observations of laryngeal activity associated with the production of English stop and fricative consonants in running speech. The method involved introducing a coherent fiberoptics bundle into the pharynx via the nose and coupling its external end to a cinecamera set to operate at 60 frames per second. From data on a single talker, it appeared that certain classes of sounds may be distinguished by whether or not the arytenoid cartilages move apart during their production. Thus, the voiceless fricatives /s,ʃ,f/ regularly show separation of the arytenoids, while the voiced stops do not. But some consonant classes show a degree of variability in this respect, in particular those variants of the voiceless stops described as unaspirated, which are found before unstressed vowels. Tokens of the set /b,g/ are sometimes produced without voicing during buccal closure, and of these, some are produced with separation of the arytenoids. Because these two consonant classes, the set /b,g/ with frequent lack of voicing during articulatory closure and the unaspirated set /p,k/, seemed to offer the most difficulty to the view that English stops can be neatly partitioned on the basis of whether or not the arytenoids execute an opening gesture, we chose to pay them special attention.

The present findings are derived from recordings of three native Americans, who read a list of sentences consisting of from three to fifteen syllables each. The sentences were designed to include a good selection of stops and fricatives in a variety of contexts. In conjunction with the filming, use was made of both a conventional and a throat microphone. Timing pulses enabled us to synchronize the photographic and acoustic recordings. An illustration is pro-

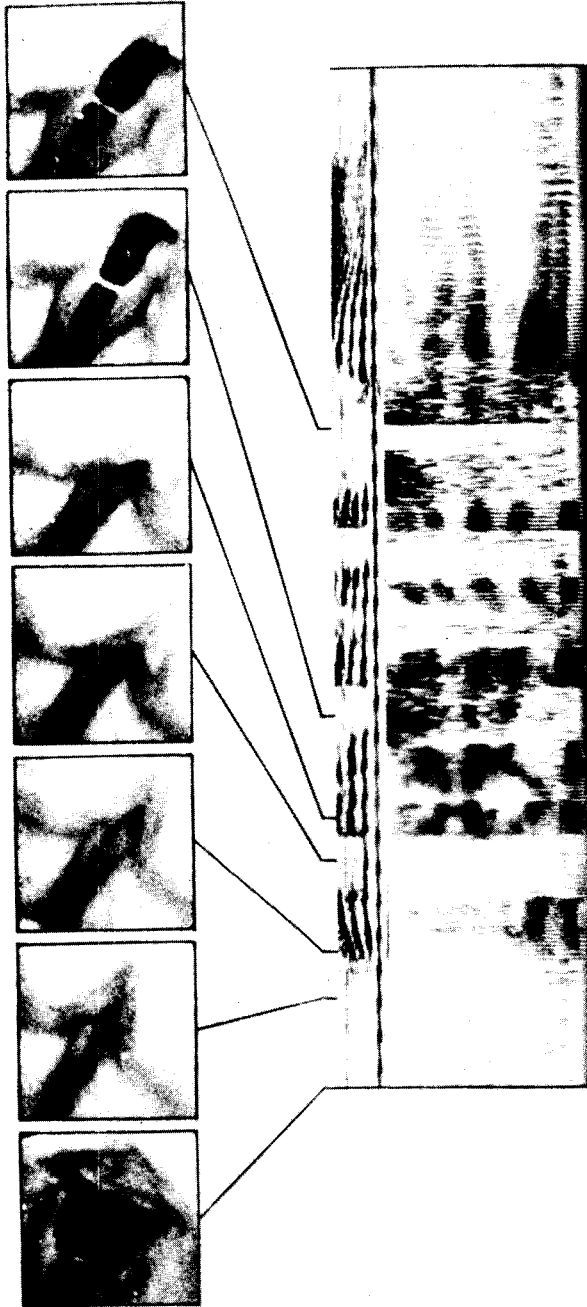
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r a b b i l i z h e d w i t h s t a w i

SLIDE I

vided by Slide 1, in which selected frames are matched with locations in the spectrogram of the utterance Rub Billy's head with this towel. The seven frames are a sample of the range of glottal states observed in our study. Appropriate frame-sequences for the stop consonants in the utterances recorded were examined for the following features:

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

The corresponding spectrograms were used primarily to fix the times of the stop-closure and release.

In Slide 2, the voiced and voiceless unaspirated stops are classified in two ways, depending on whether or not the arytenoids were seen to separate and on whether or not the vocal folds ceased to vibrate. In the lower right quadrant are the pooled data for the 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, while most instances of /p,k/ have both separation of the cartilages and interruption of glottal vibration. At the same time, we should note that a few cases of [b] showed separation of the arytenoids and that some had an interruption of vibration. There are, in addition, some fifteen cases of /p,k/ tokens in which no separation of the arytenoids was detected, while a few, moreover, showed no interruption of glottal vibration.

Certain differences were observed among individual subjects, but the number of observations is perhaps too small for us to draw very firm conclusions. Subject C, for example, contributed most of the [p]'s without arytenoid separation, while subject A contributed all the [b]'s with arytenoid separation, all the [b]'s with interruption of vibration, and a fair number of the [p]'s without arytenoid separation. In distinguishing between voiced and voiceless categories, subjects C and L offer no difficulty. In the case of subject A, there seems to be some overlap between /b/ and /p/, but even there, this largely disappears if items are separated according to context.

Turning away from the question of distinguishing the two linguistic categories, we can learn something of the time relations between laryngeal and supraglottal articulatory gestures from our data. Slide 3 shows such time relations for the voiceless unaspirated stops. The three plots on the left indicate when interruption of glottal vibration occurred relative to the stop

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

subject C

	b	p	g	k
+	0	11	0	15
-	9	6	3	2
+	0	16	0	17
-	9	1	3	0

Aryt. Sep.

I.G.V.

subject A

	b	p	g	k
+	4	8	0	13
-	10	4	3	1
+	5	9	0	14
-	9	3	3	0

Aryt. Sep.

I.G.V.

subject L

	b	p	g	k
+	0	9	0	15
-	8	1	5	1
+	0	10	0	15
-	8	0	5	1

Aryt. Sep.

I.G.V.

Pooled Data

	b	p	g	k
+	4	28	0	43
-	27	11	11	4
+	5	35	0	46
-	26	4	11	1

A.S.

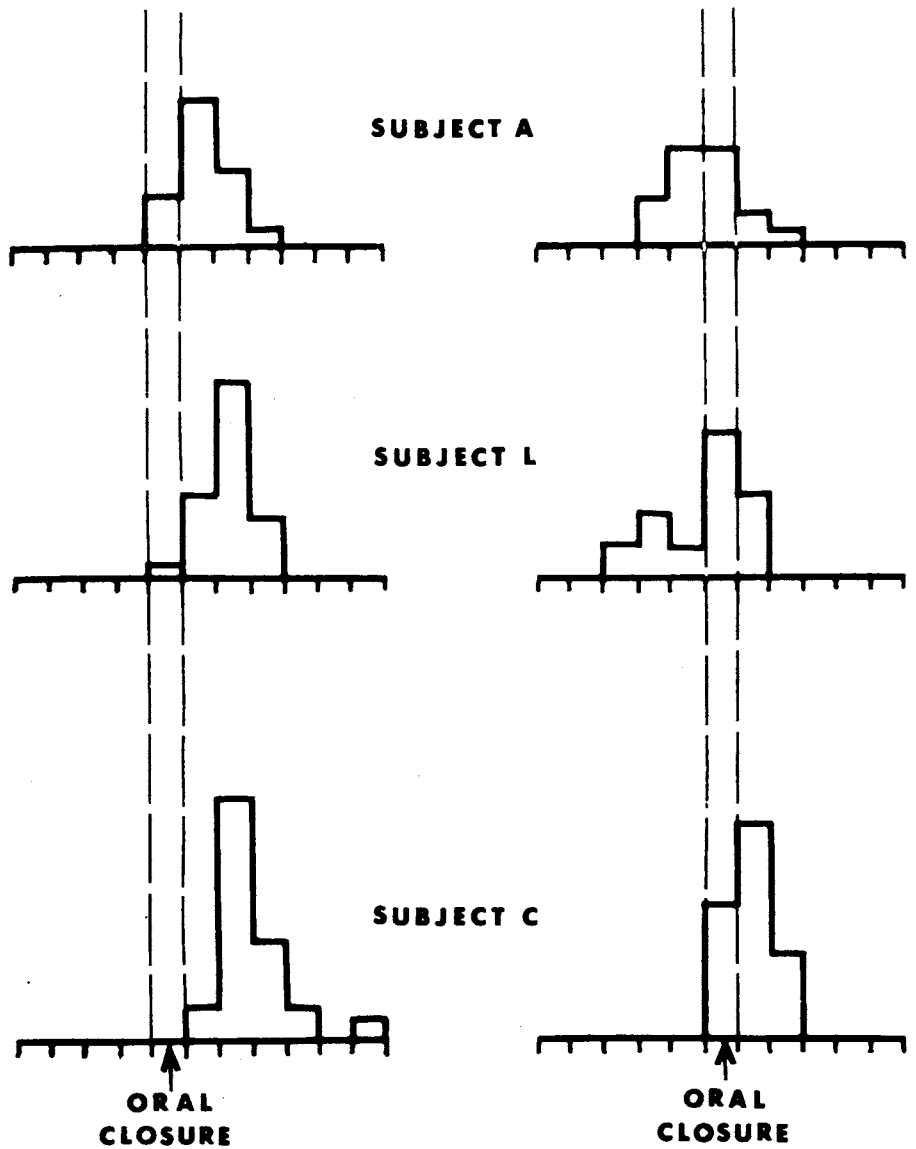
I.G.V.

SLIDE 2

# VOICELESS UNASPIRATED STOPS

INTERRUPTION  
OF GLOTTAL VIBRATION

SEPARATION  
OF ARYTENOIDS



SLIDE 3

occlusion. The abscissa is marked off in intervals representing the film frames in sequence. The ordinate indicates the distribution of values along the abscissa. On the right, the timing relation between the beginning of arytenoid separation and stop occlusion is shown in the same way. We see here that the interruption of glottal vibration usually occurs one or two frames after the beginning of the occlusion. The separation of the arytenoids shows a relative timing that varies considerably, occurring both before and after oral closure with some intersubject differences. Although not apparent from this display, separation of the arytenoids never begins after the interruption of vibration.

Slide 4 presents similar displays for the resumption of glottal vibration and the return of the arytenoids to closed position. In most cases, our films show resumption of vibration just at or immediately following stop release, while a closed state of the arytenoids is achieved, in most cases, just after release. There seems to be a tendency for arytenoid closure to be completed shortly after resumption of glottal vibration.

Because there were in our sample only five tokens of /b/ for which an interruption of glottal vibration was observed and four for which the arytenoids separated, we cannot say much about timing differences between voiced and voiceless unaspirated categories. The five /b/'s with interruption of vibration showed persistence of vibration for several frames into the interval of stop occlusion. Moreover, since for those stops vibration resumed directly upon release, the interval over which the vocal folds appeared to be still was very brief, usually a single frame. For the four /b/'s with arytenoid separation, this took place just at the beginning of oral occlusion, and the arytenoids were back together by the end of the occlusion.

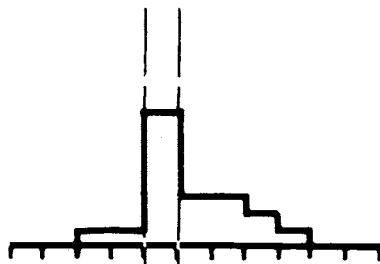
The timing relations observed for the unaspirated stops may be compared with those for the voiceless aspirates, which are shown in Slide 5. The movement of the vocal folds is brought to a halt only after oral closure has been established, particularly in the case of subject C, who showed a similar tendency in his productions of voiceless inaspirates. Arytenoid separation occurs in close synchrony with oral closure. Here too, subject C lags behind. Slide 5 does not show that the magnitude of separation is decidedly greater for these stops than for both classes of inaspirates.

Slide 6 represents timing relations at the termination of occlusion for the voiceless aspirates. The resumption of vibration is somewhat later here than for the voiceless inaspirates, as we might expect. At the same time, we

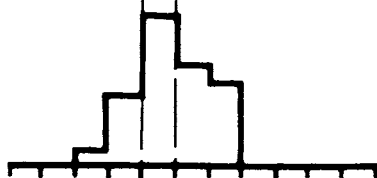
# VOICELESS UNASPIRATED STOPS

RESUMPTION  
OF GLOTTAL VIBRATION

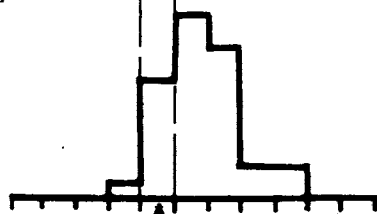
CLOSURE  
OF ARYTENOIDS



SUBJECT A

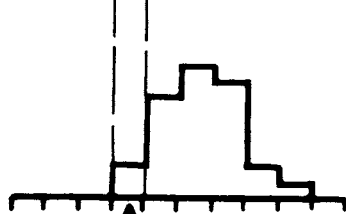
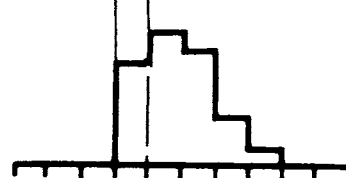
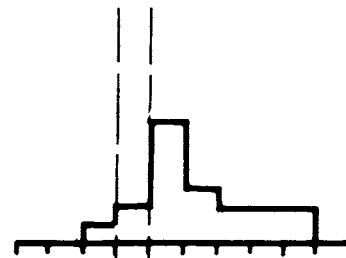


SUBJECT L



SUBJECT C

↑  
ORAL  
OPENING



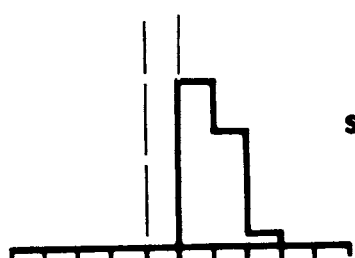
↑  
ORAL  
OPENING

SLIDE 4

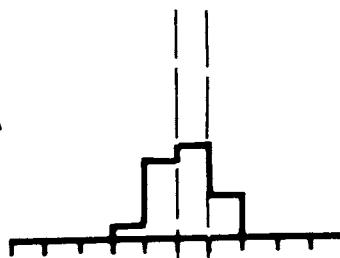
# VOICELESS ASPIRATED STOPS

INTERRUPTION  
OF GLOTTAL VIBRATION

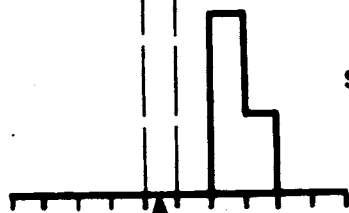
SEPARATION  
OF ARYTENOIDS



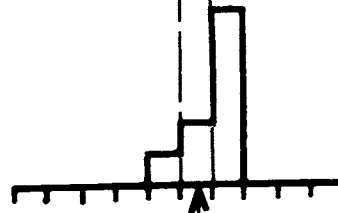
SUBJECT A



SUBJECT L



SUBJECT C



ORAL  
CLOSURE

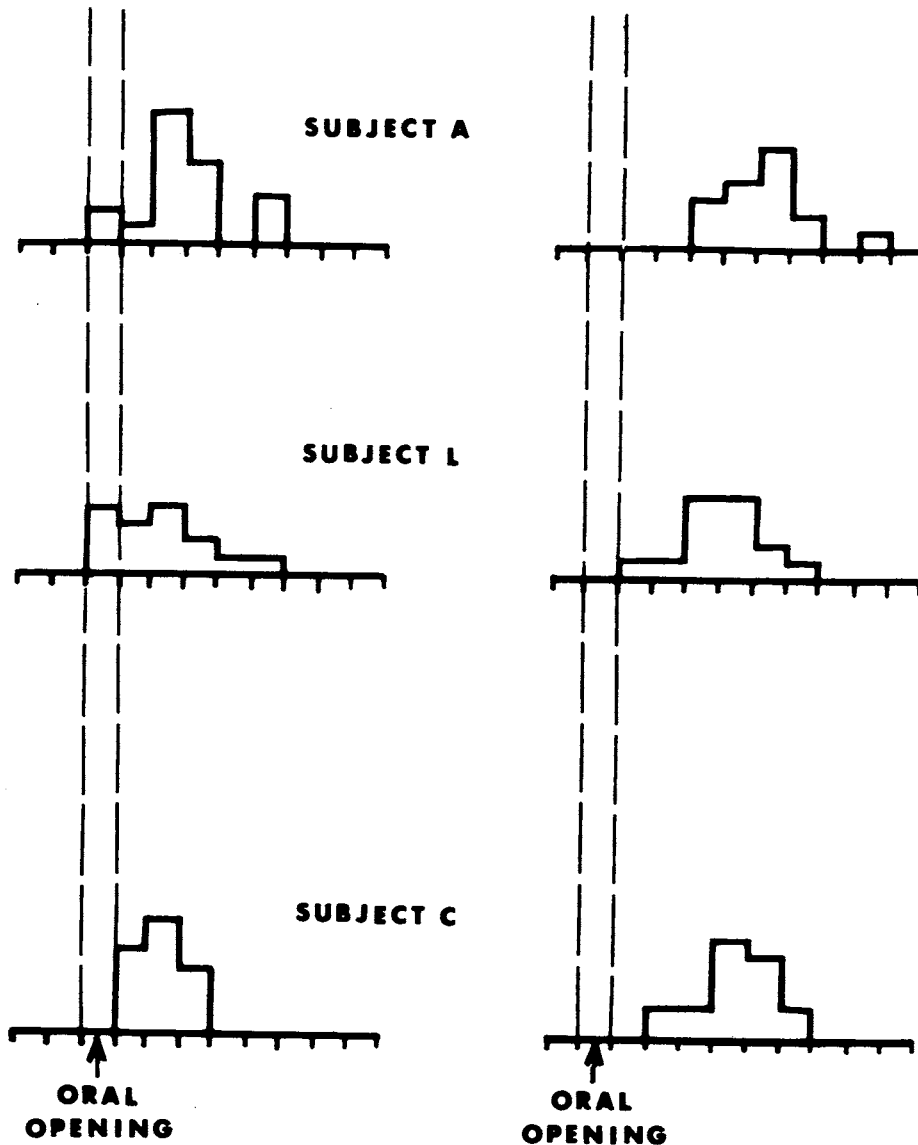
ORAL  
CLOSURE

SLIDE 5

# VOICELESS ASPIRATED STOPS

RESUMPTION  
OF GLOTTAL VIBRATION

CLOSURE  
OF ARYTENOIDS



SLIDE 6

should note that, particularly for subject L, a number of items show resumption of vibration co-occurring with oral release. The arytenoids resume a closed position well after oral release, on the average after the onset of vibration.

Allowing for a certain amount of noise in our observations, which we will not go into here, it appears that the classes of phonetic events we have been considering are produced with rather different laryngeal gestures, in respect both to magnitude of opening and to timing relative to supraglottal events.