ORAL AIR PRESSURE IN THE PRODUCTION OF SWEDISH STOPS

Anders Löfqvist

Stops and fricatives are normally produced with an increase in oral air pressure. Several studies have been made of this parameter which in part have examined how pressure in the supraglottal cavities is affected by variations in stress and position and in part have used air pressure as a means for investigating other aspects of speech, e.g. speech production under sensory deprivation, Hutchinson and Putnam (1974). Since the pressure build up behind the place of articulation is especially important for voiceless stops and fricatives these sounds are severely impaired in the speech of individuals with cleft lip and palate, Moll (1968), and aerodynamic techniques have been applied to the assessment of the speech of such patients, see Lubker (1970) for a review and further references.

This paper reports some studies of oral air pressure in the production of Swedish voiced and voiceless stops.

Procedure

Oral pressure was sampled through a plastic tube, 20 cm long and with an inner diameter of 1.9 mm. The tube was introduced into the pharynx through the nose and coupled to a differential pressure transducer EMT 33 (Siemens-Elema); the output from the transducer was amplified by an electromanometer EMT 31 and recorded together with the speech signal on a Mingograph at a paper speed of 100 mm/sec. A simultaneous tape recording was made of the speech signal through a Sennheiser MD 421 dynamic microphone on a Studer A 62 tape recorder at a recording speed of 7.5 ips.

The end of the tube sensing oral pressure was open and the plane of the opening was perpendicular to the air flow which could give rise to spurious pressure records due to air impinging on the open end of the tube, cf. Hardy (1965). One might argue, on the other hand, that air flow for the sounds under investigation is minimal except at the release which would make this problem a less serious one.

Before the pressure signal was written out on the Mingograph it was low pass filtered at 80 Hz. In spite of this filtering the fre-

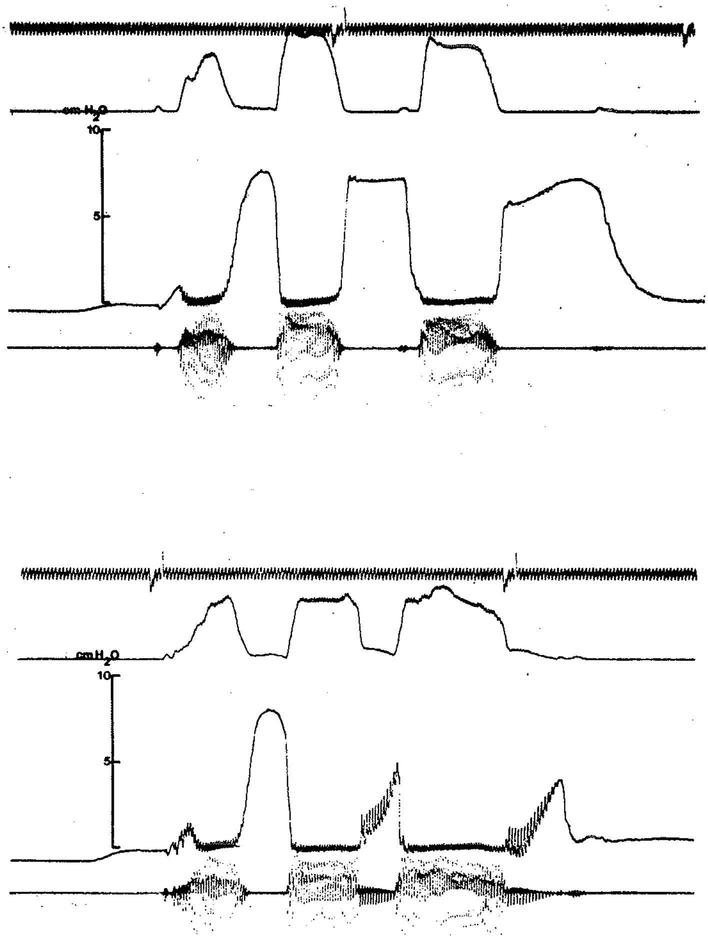

Figure 1 Record of the utterances "Ja sa tat", top, and "Ja sa dad", bottom. The curves represent from top to bottom, time signal, 0.01 sec, intensity, oral air pressure and oscillogram.

quency response of the recording system was judged sufficient for the purpose of the study which was concerned with the rather slow variations in pressure associated with stop production, see further Fry (1960) for a detailed account of technical aspects of pressure recordings.

The recording system was calibrated with a water manometer at regular intervals during the recording sessions to check stability and linearity.

Material

The speech material consisted of voiced and voiceless stops in various positions and under different stress conditions; they occurred in nonsense words of the following types:

1. 'Cɑ:C – where $C_1 = C_2$ = /p, t, k, b, d, g/;
2. Ca'Cɑ: – with the same consonants as before and stress on the second syllable;
3. 'Cɑ́:Cən – with consonants as before and stress on the first syllable; the word carried tonal accent 1;
4. 'Cɑ̀:Cən – as above but the word had tonal accent 2.

The words were embedded in the carrier phrase "Ja sa ... igen" except for those of type 1 which were produced in the frame "Ja sa ..." and thus occurred in utterance final position.

The words were repeated several times in random fashion by the following speakers:

1. male speaker of Southern Swedish;
2. male speaker of Southwestern Swedish;
3. male speaker of Southern Swedish;
4. female speaker of the dialect of the island of Gotland on the Swedish east coast.

During the recordings no attempt was made to strictly control variations in intensity and tempo and each speaker chose the level and rate which seem natural to him/her. All speakers had various degrees of phonetic training.

Inspection of the records revealed that most of the tokens of voiced stops were produced with glottal vibrations during the period of articulatory closure so the terms "voiced" and "unvoiced" in the

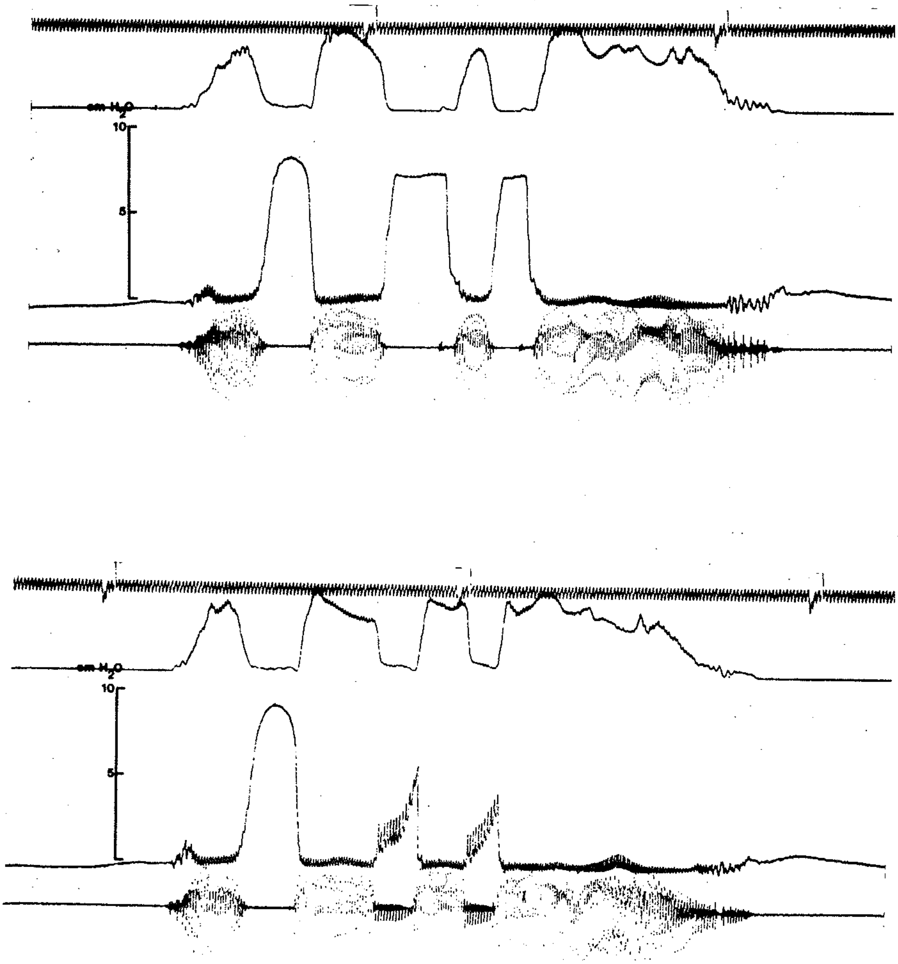

Figure 2 Record of the utterances "Ja sa ta'ta igen", top, and "Ja sa da'da igen", bottom.

following refer to two classes of sounds differentiated inter alia by their respective modes of glottal activity.

Measurements

From the mingographic records the following measurements were made:

1. peak oral pressure;
2. the interval from pressure rise to peak pressure;
3. the interval from pressure rise to the point where oral pressure had reached 85 % of its peak value;
4. the interval from pressure rise to the point where a level of stable elevated pressure occurred; this measurement was only made for the voiceless stops since no corresponding point can be found in pressure curves for voiced stops, cf. Figs. 1-3.

The measurements 2, 3 and 4 all refer to what has usually been called "rise time". This measure has, however, been defined in different ways in various investigations which sometimes makes comparisons difficult. It was thus decided to incorporate various possible ways of measuring rise time to see if and how they relate to each other. Measurement no 2 is essentially the same as the one chosen by Lisker (1970); no 3 is taken from Fischer-Jørgensen (1968) and no 4 follows Subtelny et al. (1966).

All pressure measurements are given in mm of water; whenever voicing occurred the pressure trace was bisected and pressure measured at the midline. The temporal measurements are given in milliseconds.

Results

Before we turn to the presentation of the results a few points should be noted. The absolute values for the various measurements differed for the different speakers but the relations between stops in various positions and between voiced and voiceless stops remained almost the same irrespective of these variations; thus, the pooled results for all speakers will be given below. The variations in absolute values can presumably be explained by differences in speech level and tempo since these factors were not strictly controlled and they have been shown to influence oral pressure, Subtelny et al. (1966), Arkebauer et al. (1967).

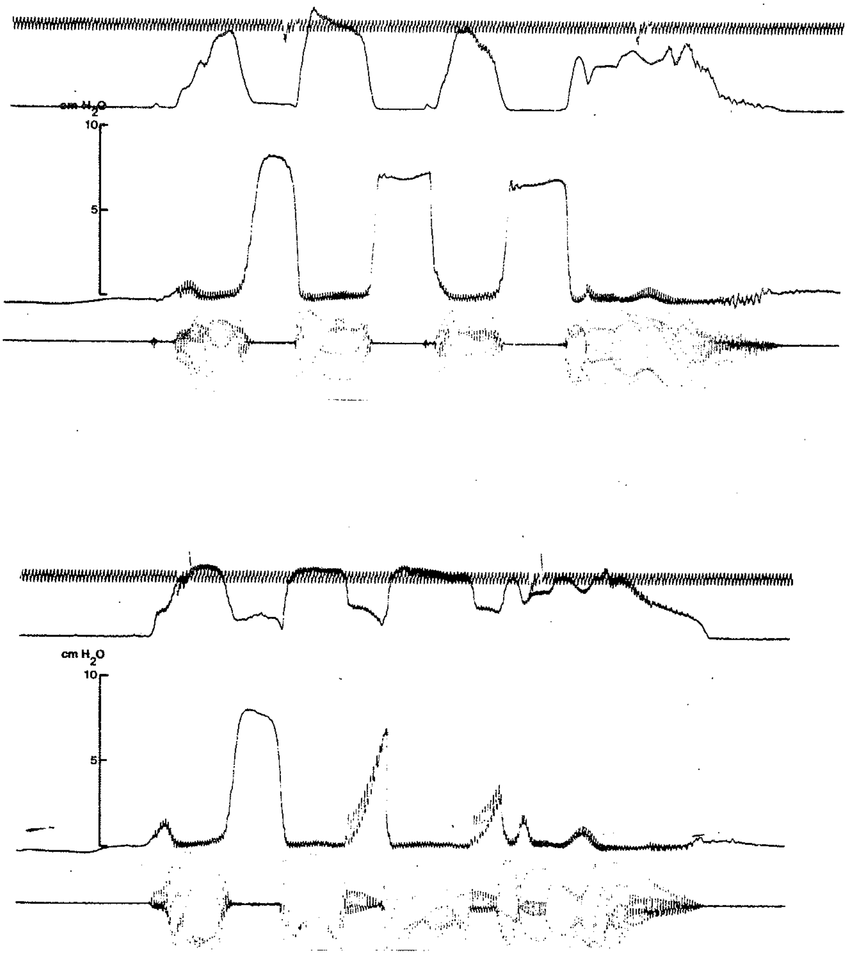

Figure 3 Record of the utterances "Ja sa táten igen", top, and "Ja sa dáden igen", bottom.

One phenomenon could, however, not be explained in this way, the influence of the tonal accent of the testword on the pressure for the medial stops in words of types 3 and 4. Here, the speaker's dialect appeared to be involved as well as the way the accent distinction is manifested. The pooled results for these positions thus do not give the whole picture in that they reflect the tendency found for three of the speakers, no 1, 3 and 4, whereas speaker 3 had the opposite pattern to the one showed in the Tables below as far as the relations between the medial stops in words with different tonal accents are concerned. These facts have been discussed in detail in Löfqvist (1974) where also some studies of subglottal pressure are reported; in the present context it is sufficient to note that the variations due to tonal accent seem to reflect different respiratory activity and can be related to the F_o variations associated with the particular manifestation of the accents.

If the tonal accents thus were found to influence oral pressure for the medial consonants in the words of types 3 and 4 no such influence could be found for the initial stops in the same words which in their turn proved not to be different from the initial stops in words of type 1; the results for stops in these three positions have thus been pooled.

Peak oral pressure

The measurements of peak oral pressure are summarized for stops with different places of articulation in Table I and for voiced and voiceless stops in different positions in Table II.

From Table I it appears that labials tend to have lower oral pressure than dentals and velars; for the latter two the order is not clear and the difference rather small. The differences within the voiceless set are, however, not statistically significant - $F = 3.526$, $P > 2.5$ - whereas the differences among the voiced stops are - $F = 17.417$, $P < 0.05$.

In Table II we see that stress is an important determinator of oral pressure, as could be expected; pressure is higher in prestress than in poststress position.

There is a significant difference in oral pressure between the voiced and voiceless stops in all positions - $P < 0.001$, two-tailed test.

Table I Peak oral pressure for different stops in # 'CV: position, n = 144.

	p	t	k	b	d	g
$\bar{x}$	85.4	89.6	87.5	62.6	72.6	73.5
s	13.0	13.7	14.2	15.2	17.5	19.6

Table II Peak oral pressure for voiced and unvoiced stops in different positions, n = 144 except for # 'CV: position where n = 432.

Position / Sound		# 'CV:	# CV	V'CV:	'V́:CV	'V̀:CV	V:C#
ptk	$\bar{x}$	87.5	84.8	90.1	72.8	77.2	64.4
	s	13.8	13.9	14.6	8.6	12.8	7.9
bdg	$\bar{x}$	69.6	66.5	73.2	42.4	51.2	45.8
	s	18.2	19.2	23.6	16.2	20.9	16.2

Table III The interval from pressure rise to peak oral pressure for different stops in # 'CV: position, n = 144.

	p	t	k	b	d	g
$\bar{x}$	117	127	128	116	117	122
s	46.0	42.4	45.5	21.3	23.6	21.7

Table IV The interval from pressure rise to peak oral pressure for voiced and unvoiced stops in different positions, n = 144 except for # 'CV: where n = 432.

Position / Sound		# 'CV:	# CV	V'CV:	'V́:CV	'V̀:CV	V:C#
ptk	$\bar{x}$	124	103	101	136	149	132
	s	44.7	48.6	25.9	43.7	49.6	68.3
bdg	$\bar{x}$	118	103	105	88	95	120
	s	22.3	27.8	15.1	12.8	19.1	27.1

Table V The interval from pressure rise to the point where oral pressure had reached 85 % of its peak value for different stops in # 'CV: position, n = 144.

	p	t	k	b	d	g
$\bar{x}$	56	47	54	87	99	105
s	31.5	27.6	30.3	19.3	22.0	20.7

Table VI The interval from pressure rise to the point where oral pressure had reached 85 % of its peak value for voiced and unvoiced stops in different positions, n = 144 except for # 'CV: position where n = 432.

Position / Sound		# 'CV:	# CV	V'CV:	'V́:CV	'V̀:CV	V:C#
ptk	$\bar{x}$	53	43	41	49	64	48
	s	30.1	17.6	9.3	16.5	26.9	19.8
bdg	$\bar{x}$	97	86	86	70	71	103
	s	21.9	27.1	14.5	14.1	20.4	28.4

Oral pressure for the voiceless set is generally more than 1.5 cm of water higher than that for the voiced set.

The interval from pressure rise to peak oral pressure

The results for this parameter are given in Tables III and IV. For the different places of articulation the differences are very small, especially for the voiced stops, and labials tend to have shorter rise time than dentals and velars. These small differences are not significant, however - F = 1.130 and 2.810 for the voiceless and voiced sets respectively.

Again, stress is one determining factor in that this interval is shorter in prestress than in poststress position for the voiceless stops whereas the opposite seems to be the case for the voiced set. This interval does not show any significant difference for voiced and voiceless stops except in medial unstressed position where the values for the voiced stops are significantly shorter than those associated with their voiceless cognates.

The interval from pressure rise to the point where oral pressure had reached 85 % of its peak value

Tables V and VI present the relevant measurements. Among the voiceless plosives dentals have a quicker rise than labials and velars but the difference is not significant - F = 3.515. For the voiced set there is an increase in rise time as the place of articulation moves backwards from the lips and the difference is, moreover, significant, F = 27.181.

The effects of stress and position are not quite clear, Table VI. For both voiced and voiceless stops long rise times are found for the stressed initial stops in the prestressed category; at the same time the two other members of the prestressed group show lower values. Short rise times are also found in the poststressed group except that the medial voiceless stops have rather long rise time, at least in words with tonal accent 2. Large interspeaker variations preclude any definite conclusions.

Voiceless stops have shorter rise time than their voiced cognates and the difference is significant in all positions except 'V:CV.

Table VII The interval from pressure rise to the point where a level of stable elevated pressure occurred for different voiceless stops in # 'CV: position, n = 144.

	p	t	k
$\bar{x}$	55	48	57
s	9.1	7.1	24.6

Table VIII The interval from pressure rise to the point where a level of stable elevated pressure occurred for voiceless stops in different positions, n = 144, except for # 'CV: position where n = 432.

Position	# 'CV:	# CV	V'CV:	'V́:CV	'V̀:CV	V:C#
$\bar{x}$	53	52	51	60	64	56
s	16.2	8.4	7.0	14.0	15.9	12.2

The interval from pressure rise to the point where a level of stable elevated pressure occurred

This measurement was only made for the voiceless category since no corresponding point is found for the voiced stops, cf. Figs. 1–3, and the results are given in Tables VII and VIII.

Dentals show a faster rise time in this respect than either labials or velars and the difference is significant, F = 14.173.

Stress and position do not appear to affect this measure to any greater extent and the only notable trend is that the medial unstressed stops occurring after a stressed vowel have a somewhat longer rise time than stops in other positions.

Discussion

The results of the present investigation are generally in agreement with other studies of the same parameter and for comparable speech material: voiceless stops are characterized by higher oral pressure and quicker pressure rise than their voiced cognates and stress is an important determinator of oral pressure, cf. the works listed among the references.

Reviews of comparable studies of oral pressure in stop production, cf. Subtelny et al. (1966), Arkebauer et al. (1967), Löfqvist (1971), show considerable variations in the results as far as position is concerned. If, however, the prime role of stress is taken into account much of this variation is resolved and the remaining part would seem to be accounted for by differences in the composition of the test material – specifically the use of a carrier phrase or not – and variations in speech level and tempo.

The relationship between the various measurements used in the present study is generally the following: voiceless stops having higher peak pressure also have shorter rise time; the voiced stops with higher peak pressure, on the other hand, usually have longer rise time.

The higher peak pressure in the voiceless set depends mainly on the lower glottal resistance during their production – the glottis is open – in comparison with the voiced category which was normally produced with glottal vibrations; a close correlation between voicing and oral pressure has been reported by Fischer-Jørgensen (1963). The same explanation also takes care of the shorter rise time in the voiceless set, provided rise time is taken as the interval from pressure rise to the point where oral pressure had reached 85 % of its peak value. Another factor which could play a role is a possible expansion of the supraglottal cavities in the production of voiced stops to maintain a transglottal pressure drop and thus facilitate voicing during the occlusion, see Rothenberg (1968), Minifie et al. (1974), Bell-Berti (1975).

The interval from pressure rise to peak oral pressure is not significantly different for the two sets of stops except in medial unstressed position. This is presumably related to the continous rise in oral pressure that occurs during voiced stops, cf. Figs. 1-3; in this case one would expect that this interval is related to the duration of the oral closure and in the position noted above the voiced stops have very short closure durations, Löfqvist (1976).

Another, more obscure, phenomenon involved here is the behavior of oral pressure for the voiceless stops when a level of stable elevated pressure has occurred. After this oral pressure may either stay at about the same level or rise a little. The latter is the more common case. The mechanisms governing the oral pressure for the voiceless category in these instances are difficult to pin down since no definite trends could be found and there are, moreover, speaker specific tendencies. On the whole, this particular measure of rise time seems to be the least revealing one to judge from the present results.

Labials tend to have lower peak oral pressure than velars and dentals; this is presumably related to differences in the volume of the supraglottal cavities for the three places of articulation and one would expect these variations to show up most clearly among the voiced stops due to the lower transglottal air flow in their case. Studies of both oral and subglottal pressure for voiced stops show the same difference as the one reported here for oral pressure but none that could be related to place of articulation for subglottal pressure, Löfqvist (1975).

For the voiced stops rise time becomes longer as the place of articulation moves backwards from the lips and this is presumably related to the differences in peak pressure noted above. Among the voiceless stops dentals show a quicker rise time than labials and velars, the difference between the latter two being insignificant. The reason for this is unclear, perhaps the greater mobility of the tongue tip is involved, if its greater mobility can be said to be an established fact.

Oral pressure has sometimes been taken as a reflection of the difference between tense and lax stops, the lax ones usually being voiceless and thus having higher oral pressure, cf. Malécot (1955, 1970). The higher oral pressure would, however, seem to depend more on these stops being unvoiced than lax and oral pressure is now not regarded as a correlate of tenseness and laxness, Fischer-Jørgensen (1968).

References

Arkebauer, H.J., Hixon, T.J. and Hardy, J.C. 1967. Peak intraoral air pressures during speech. J. Speech and Hear. Res. 10:196-208

Bell-Berti, F. 1975. Control of pharyngeal cavity size for English voiced and voiceless stops. J. Acoust. Soc. Amer. 57:456-461

Black, J.W. 1950. The pressure component in the production of consonants. J. Speech Dis. 15:207-210

Brown, W.S. and McGlone, R.E. 1969. Relation of intraoral air pressure to oral cavity size. Folia Phoniat. 21:321-331

Brown, W.S. and McGlone, R.E. 1969. Constancy of intraoral air pressure. Folia Phoniat. 21:332-339

Brown, W.S. and McGlone, R.E. 1974. Aerodynamic and acoustic study of stress in sentence production. J. Acoust. Soc. Amer. 56:971-974

Brown, W.S., McGlone, R.E. and Proffit, W.R. 1973. Relationship of lingual and intraoral air pressure during syllable production. J. Speech and Hear. Res. 16:141-151

Brown, W.S., McGlone, R.E., Tarlow, A. and Shipp, T. 1970. Intraoral air pressures associated with specific phonetic positions. Phonetica 22:202-212

Brown, W.S. and Shearer, W.M. 1970. Constancy of intraoral air pressure related to integrated pressure-time measurements. Folia Phoniat. 22:49-57

Fischer-Jørgensen, E. 1963. Beobachtungen über den Zusammenhang zwischen Stimmhaftigkeit und intraoralem Luftdruck. Zeitschrift f. Phonetik, Sprachwiss. und Kommunikationsforschung 16:19-36

Fischer-Jørgensen, E. 1968. Voicing, tenseness and aspiration in stop consonants with special reference to French and Danish. Ann. Report, Inst. of Phonetics, University of Copenhagen 3:63-114

Fry, D.L. 1960. Physiologic recording by modern instruments with particular reference to pressure recording. Physiol. Rev. 40:753-787

Hardy, J.C. 1965. Air flow and air pressure studies. ASHA Reports 1:151-152

Hutchinson, J.M. and Putnam, A.H.B. 1974. Aerodynamic aspect of sensory deprived speech. J. Acoust. Soc. Amer. 56:1612-1617

Lisker, L. 1970. Supraglottal air pressure in the production of English stops. Language and Speech 13:215-231

Lubker, J.F. 1970. Aerodynamic and ultrasonic assessment techniques in speech-dentofacial research. ASHA Reports 5:207-223

Lubker, J.F. and Parris, P.J. 1970. Simultaneous measurements of intraoral pressure, force of labial contact, and labial electromyographic activity during production of the stop consonant cognates p and b. J. Acoust. Soc. Amer. 47:625-633

Löfqvist, A. 1971. Some observations on supraglottal air pressure. Working Papers, Phonetics Lab., Lund University 5:27-44

Löfqvist, A. 1974. Subglottalt tryck och tonaccenter. In C. Platzack (ed.) Förhandlingar vid Sammankomst för att Dryfta Frågor Rörande Svenskans Beskrivning 8, Lund

Löfqvist, A. 1975. A study of subglottal pressure during the production of Swedish stops. J. Phonetics 3:175-189

Löfqvist, A. 1976. Closure duration and aspiration for Swedish stops. Working Papers, Phonetics Lab., Dept. of General Linguistics, Lund University 13:1-39

Malécot, A. 1955. An experimental study of force of articulation. Studia Linguistica IX:35-44

Malécot, A. 1966. The effectiveness of intraoral air-pressure-pulse parameters in distinguishing between stop cognates. Phonetica 14:65-81

Malécot, A. 1968. The force of articulation of American stops and fricatives as a function of position. Phonetica 18:95-102

Malécot, A. 1970. The lenis-fortis opposition: Its physiological parameters. J. Acoust. Soc. Amer. 47:1588-1592

Minifie, F.D., Abbs, J.H., Tarlow, A. and Kwaterski, M. 1974. EMG activity in the pharynx during speech production. J. Speech and Hear. Res. 17:497-504

Moll, K.L. 1968. Speech characteristics of individuals with cleft lip and palate. In D.C. Spriestersbach and D. Sherman (eds.) Cleft Lip and Communication. New York and London: Academic Press

Rothenberg, M. 1968. The Breath-Stream Dynamics of Simple-Released-Plosive Production. Bibl. Phonetica, vol. 6. Basel: Karger

Subtelny, J.D., Worth, J.H. and Sakuda, M. 1966. Intraoral pressure and rate of flow during speech. J. Speech and Hear. Res. 9:498-518

Warren, D.W. and Hall, D.J. 1973. Glottal activity and intraoral pressure during stop consonant productions. Folia Phoniat. 25: 121-129