SOME OBSERVATIONS ON SUPRAGLOTTAL AIR PRESSURE

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This is a preliminary report of some work in progress on supraglottal air pressure during speech production. It presents data on peak pressure, rise time, pressure decay and duration of oral closure for Swedish stops pronounced under different stress conditions in different positions. Only one speaker has been investigated. The study should be considered explorative and is intended to serve as a base for further research.

METHOD

The air pressure was measured with a differential pressure transducer EMT 33. A plastic tube with an inner diameter of 1,9 mm and 20 cm long was fitted to the transducer and introduced into the oropharynx through the nose and held in the same position during the recordings. This arrangement was chosen because it was felt to minimize interference with articulation and also because it made possible the study of velar sounds. It is possible, however, that the position of the tube with the plane of the opening perpendicular to the air flow might give spurious recordings due to stagnation pressures as pointed out by Hardy (1965). Although one might argue that the air flow for the sounds studied, stops, is minimal except at the release, the possibility should be kept in mind in interpreting the data.

No critical resonances were found in the recording system and the frequency response was judged sufficient for the purpose of the study. For a detailed technical discussion of pressure recordings, see Fry (1960). During the recording sessions it was sometimes necessary to blow air through the tube to expel mucous. By using the same carrier sentence in all the recordings it was possible to check the recording system to ensure that its damping remained the same. The output from the transducer was amplified by an electromanometer EMT 31 and recorded on a Mingograph together with the speech signal; a tape recording was simultaneously made of the speech for acoustic analysis.

The pressure recording system was calibrated with a water manometer and all pressure measurements are given in mm of H_2O. In measuring the pressure for the voiced plosives the pressure trace with the oscillations due to vocal fold activity was bisected and the pressure at the midline was measured.

The following measurements were made:

Peak pressure; this was measured from the peak of the pressure curve to the base line.

Rise time; in the litterature one finds several ways of measuring rise time. In the present study three methods have been used. The first one follows Lisker (1970) and rise time is defined as "the duration of the interval during which pressure builds up to its peak value". In the second case rise time was defined according to Subtelny et al. (1966): "Rise time was defined as the interval between initiation of pressure elevation and the earliest point at which a relatively stable elevated oral pressure was attained." The third measure of rise time was taken from Fischer-Jørgensen (1969) and is the interval during which pressure builds up to 85 % of its peak value.

Pressure decay; this was taken as the interval between the point where the pressure started to fall rapidly and the first point at which supraglottal pressure returned to base pressure.

Duration of oral closure; the duration of the oral closure was taken as the interval between initial pressure elevation and the point at which supraglottal pressure started to fall rapidly. This measure only gives an approximate indication of the duration of the oral closure because the pressure presumably begins to rise before complete closure is attained. More reliable data on the duration of oral closure can be obtained from air flow traces or by special techniques as described by Karlsson and Nord (1970) and Slis (1971).

MATERIAL

The speech material consisted of nonsense words containing different plosives in different positions under different stress conditions. The words were:

1. 'Cɑ:C, where $C_1 = C_2$ = /p, t, k, b, d, g/;
2. Ca'Cɑ:, with the same consonants as above and stress on the last syllable;
3. 'Cɑ́:Cən, with consonants as before and stress on the first syllable; the word had the acute tonal accent or accent 1, in the following denoted by ´;
4. 'Cɑ̀:Cən, with consonants as before and stress on the first syllable; the word had the grave tonal accent or accent 2, in the following denoted by ` .

The words were placed in the carrier phrase "Ja sa ... igen" (I said ... again) except for the words of type 1 which were pronounced in the phrase "Ja sa ... " and thus occured in sentence final position.

A Swedish male speaker - with a dialect of Southwestern Swedish (Västgötska) - pronounced all the words 12 times. The speaker was told to use the same intensity and speech rate during all the utterances. Differences in intensity and speech rate might contribute to variations in the data as they have been shown to affect supraglottal air pressure, cf. Subtelny et al. (1966), Arkebauer et al. (1967).

Earlier investigations of the same parameters for the same class of sounds from other languages do not show a complete agreement in their results. The variations might be due to differences in the composition of the material, differences in intensity and speech rate and also reflect differences between different languages. Even if the same language has been studied there are some variations between different investigations. This is evident from the table below where mean values have been calculated of peak pressure for Am. English stops taken from different investigations. The studies which have been used for the calculations are Subtelny et al. (1966), Arkebauer et al. (1967), Malécot (1968), and Lisker (1970). Values are given in mm of H_2O.

		initial			medial			final	
		ptk	bdg		ptk	bdg		ptk	bdg
Subtelny et al.		75	62		70	53		65	30
Arkebauer et al.		67	30		83	40		63	26
Malécot	C'V	83	69	VC'V	91	65	'VC	57	31
	CV	72	60	'VCV	83	34	VC	57	31
Lisker		57	53	VC'V	68	61		47	15
				'VCV	71	36			

We see that there are not only absolute differences but also differences between the relative values for the two categories of stops in different positions. The tendency seems to be that the voiceless plosives have higher peak pressure than their voiced counterparts. With regard to position the voiceless plosives have the highest pressure in initial position, lower pressure in medial position and the lowest pressure in final position. The voiced plosives tend to have the highest pressure in initial position, lower pressure medially and lowest in final position.

For the three other parameters I will not make any survey of earlier investigations at this point, as they are somewhat difficult to compare. I will make some comparisons and further comments below when I present my own results.

RESULTS AND DISCUSSION

As the material processed as yet is rather limited and explorative in nature data will only be given as frequency distributions and mean values. No further statistical discussion will be presented. Measurements are made in H_2O for pressure and in msec. for duration.

All the examples of the voiced plosives /bdg/ in the study were pronounced with vibrations of the vocal folds as can be seen from the oscillograms. In the following discussion the terms voiced and unvoiced thus refer to two classes of speech sounds differentiated by their respective mode of glottal activity.

Peak pressure

Diagrams of peak pressure variations are presented in Fig. 1–2 and mean values are summarized in Table I.

Table I. Mean peak pressure in mm of H_2O.

	Initial			Medial		Final	
	ptk	bdg		ptk	bdg	ptk	bdg
'CV:	72	47	V'CV:	73	43	59	32
CV	69	48	'V́:CV	73	35		
			'V̀:CV	64	28		

From Table I the following conclusions can be drawn.

Voiceless plosives have higher supraglottal pressure than their voiced counterparts. This is clear in all positions and from Fig. 1 and 2 we see that there is some overlapping between the values for peak pressure for the two sets of plosives only in initial position.

The stress affects supraglottal pressure. The voiceless plosives have higher peak pressure in stressed than in unstressed syllables. The only exception to this is the medial unstressed plosive in words with tonal accent 1 where the pressure is as high as in a stressed syllable.

The voiced plosives show almost the same influence of stress upon peak pressure but in initial position the peak pressure is almost the same irrespective of stress.

If we look at the effects of position upon supraglottal pressure we see in Table I that the voiceless plosives have their highest pressure in medial position and the lowest pressure in final position. The difference between the peak pressure in initial and medial stressed syllable is very small, however, and we can also see that the tonal accent of the word affects the peak pressure of the medial unstressed plosives.

The voiced plosives have highest pressure initially and lowest pressure in medial position. It is, however, difficult to draw any firm conclusions of the effect of position upon peak pressure as it is obviously interconnected with the effects of stress and tonal word accent.

An interesting fact is the difference we find in Table I between the medial plosives in words with tonal accent 1 and the same plosives in words with tonal accent 2: the medial plosive has higher pressure if the word has tonal accent 1 than if it has tonal accent 2. For the initial stops the tonal accent of the word has no influence on peak pressure.

The most obvious difference between the two sets of plosive that could explain the higher supraglottal pressure for the voiceless ones is the glottal activity; vibrations for the voiced set and no vibrations for the unvoiced set. The glottal resistance is higher when the glottis is in a voiced position. The increased glottal resistance for the voiced plosives as compared to the unvoiced reduces the air flow through the glottis and prevents the supraglottal pressure to reach the same level for the two sets of sounds, cf. Fischer-Jørgensen (1963).

Besides the difference in glottal resistance there might also be different articulatory adjustments during the production of voiced and voiceless plosives. If the vocal cords are to vibrate there must exist a pressure drop across the glottis. When the vocal tract is obstructed in the oral cavity as is the case during the production of stops, the pressure drop would tend to diminish and the vocal folds would cease to vibrate. In order to maintain the pressure drop during the closure of a voiced plosive various mechanisms have been proposed, cf. Rothenberg (1968) for a discussion and also Hudgins and Stetson (1935), Perkell (1968), Kent and Moll (1969), Berti (1971).

The mechanisms suggested are incomplete velopharyngeal closure, passive expansion of the supraglottal cavities and active expansion of the same cavities. Whether any of these mechanisms is actually used is not completely known at present but they would all affect supraglottal air pressure and tend to reduce it. That supraglottal pressure is higher in stressed than in unstressed syllables can be a result of the increase in subglottal pressure that has been shown to take place in a stressed syllable (Ladefoged 1967).

The relationship between tonal accent and supraglottal air pressure is suitable for further investigations which also should include recordings of subglottal pressure. The problem of the Swedish word accent has not yet been covered in all its aspects. There is a general agreement that variations in the fundamental frequency are important for the accent distinction, cf. Malmberg (1963), Hadding-Koch (1962), Öhman (1968), Gårding (1970), Johansson (1970).

Besides the F_0 variations, which according to Malmberg are the most important perceptual cues, there are also differences of duration and intensity. The pattern of the variations in fundamental frequency differs between various dialects. For the speaker investigated F_0 and intensity curves for the two tonal accents are given in Fig. 3. In the stressed syllable the F_0 shows a fall in words with tonal accent 1 and has a rising-falling pattern in tonal accent 2. The second, unstressed, syllable has a rise in the fundamental frequency for the two tonal accents.

The observed differences in supraglottal pressure to some extent reflect differences in subglottal pressure. During the closure of a voiceless plosive the subglottal and supraglottal pressures are almost equal, cf. Netsell (1969), Scully (1969), Ladefoged (1967, 1968).

We do not find any striking differences between the F_0 and intensity curves for the second, unstressed, vowel in words with tonal accent 1 as compared with the same parameters for the same vowel in words with tonal accent 2. The fundamental frequency shows the same rising pattern. There is a small difference in F_0 at the beginning of the second vowel: here F_0 is approximately 5 Hz higher in words with tonal accent 1 than in words with tonal accent 2. This difference might be caused by the higher pressure but variations in the fundamental frequency depend both upon subglottal pressure and laryngeal adjustments, cf. Ohala (1970).

Further work on this problem should include material from several dialects in order to find out whether the mentioned differences are systematic or accidental and confined to the speaker investigated.

Rise time

Fig. 4 and 5 give some representative examples of supraglottal air pressure curves for unvoiced and voiced plosives. During the production of an unvoiced plosive the air pressure rises quickly until it attains a plateau where it stays more or less stable until the release when it drops rapidly; it is, however, not always the case that the pressure stays at the same level after the plateau has been attained: it might as well continue to rise until the release.

The pressure curve for a voiced plosive most often show a continuous rise during the whole closure period. Sometimes some fluctuations up and down can be seen during the rise, cf. also Fig. 10.

Table II gives mean values of rise time defined as the interval during which pressure builds up to its peak value; frequency distributions for the same measure are given in Fig. 6 and 7.

Table II. Mean duration of the interval during which pressure builds up to its peak value. Msec.

	initial			medial		final	
	ptk	bdg		ptk	bdg	ptk	bdg
'CV:	154	130	V'CV:	74	101	203	155
CV	135	134	'V́:CV	166	101		
			'V̀:CV	196	117		

We see from Table II that rise time is shorter for the voiced than for the unvoiced plosives. The only exception is in medial stressed position.

The effects of stress and position are not quite clear. Rise time is, however, longest in final position, and shortest in medial position.

Rise time for the medial plosives also tend to be shorter if the word has tonal accent 1 than if it has tonal accent 2.

The shorter rise time for the voiced plosives obviously reflects the difference in the shape of the pressure curve and also the shorter duration of the closure for a voiced plosive as compared to a voiceless plosive.

Table III presents mean duration of the interval between the initiation of pressure elevation and the earliest point at which a relatively stable elevated pressure is attained. Only data for the voiceless plosives are given as the voiced plosives do not consistently show any period of stable elevated pressure.

Table III. Mean duration of the interval between the initiation of pressure elevation and the earliest pcint at which a relatively stable elevated pressure is attained. Msec.

	initial		medial	final
	ptk		ptk	ptk
'CV:	50	V'CV:	48	41
CV	50	'V́:CV	46	
		'V̀:CV	46	

Evidently the point of stable elevated pressure is attained in about the same time irrespective of stress and position. This reflects the very quick initial pressure rise for an unvoiced plosive.

Fig. 8 and 9 and Table IV present data on rise time taken as the duration of the interval during which pressure builds up to 85 % of its peak value.

Table IV. Mean duration of the interval during which pressure builds up to 85 % of its peak value. Msec.

	initial			medial		final	
	ptk	bdg		ptk	bdg	ptk	bdg
'CV:	57	112	V'CV:	37	81	65	136
CV	46	119	'V́:CV	39	83		
			'V̀:CV	86	91		

With this measure of rise time we see that the unvoiced plosives have shorter rise time than the voiced ones.

The effects of stress, position and tonal accent interact. The tendency seems to be that rise time is shorter in stressed than in unstressed position. This holds for the voiced plosives but not completely for the unvoiced as in initial position rise time is shorter for the unstressed than for the stressed unvoiced plosive.

In final position we find the longest rise time, in medial position the shortest.

The tonal accent of the word also affects the rise time: it is shorter for the medial plosive if the word has tonal accent 1 than if it has tonal accent 2.

The different measures of rise time give different results and which one that should be preferred depends on the aim of the study. It seems that the last one given gives the intuitively correct result as it takes into account the initial quick pressure rise that occurs for the unvoiced plosives. This is ignored by the first measure of rise time used above.

Two more comments will be made on the shape of the pressure curve. In the material investigated there are some cases of unvoiced plosives where peak pressure is attained immediately after the initial rise and where the supraglottal pressure stays at the peak level during the whole closure. This only occurs for /p/ and /t/, never for /k/. It happens most often in medial stressed syllable where it is the case 11 out of 12 times for /p/ and 10 out of 12 times for /t/.

If we want to explain the differences in the shape of the pressure curve, – cf. Fig. 10 for some more examples of traces for voiced plosives –, we will have to take into account the difference in glottal activity, possible variations in the volume of the supraglottal cavities and subglottal activity.

As to subglottal activity the studies of Ladefoged (1967, 1968) do not permit us to draw any conclusions whether the respiratory system actually increases the subglottal pressure in the production of a voiceless plosive. The rise in supraglottal pressure towards the end of the occlusion for unvoiced plosives could perhaps be explained in this way; see also Rothenberg (1968) for a discussion of this point and Sears and Newsom Davis (1968), Campbell, Agostini and Newsom Davis (1970) for relevant material on the functioning of the respiratory system.

In connection with Fig. 10 it should also be pointed out that the drop in supraglottal pressure that occurs at the beginning of the oral closure for /g/ is very systematic for the speaker investigated and has also been noted for other speakers.

Pressure decay

Mean values of pressure decay are given in Table V and frequency distributions of the data in Fig. 11.

Table V. Mean pressure decay. Msec.

	initial			medial		final	
	ptk	bdg		ptk	bdg	ptk	bdg
'CV:	57	19	V'CV:	63	20	202	29
CV	62	22	'V́:CV	22	21		
			'V̂:CV	23	22		

From Table V we see that the decay is rapid for the voiced plosives irrespective of stress and position.

The voiceless plosives have a rather slow decay in initial position, in medial stressed position, and in final position. In the other positions the decay time for the unvoiced plosives is as rapid as that for a voiced plosive.

The tonal accent of the word has no noticeable influence upon pressure decay.

The results in Table V agree well with those found for English by Lisker (1970).

The measure of pressure decay that has been used is not the same as "aspiration" or the "voicing lag" of Lisker and Abramson (1964) because the vocal folds start to vibrate before the pressure has reached the base pressure. It is, however, of the same dimension as the status of the **glottis** seems to be critical for it. If the glottis is open air can flow up through it and keep the supraglottal air pressure at a high level.

If on the other hand glottis is in a voiced position and the glottal resistance is high the air flow through the glottis will be minimal and the supraglottal pressure will decay at a rapid rate, cf. Fant (1960) p. 272 ff.

Pressure decay might also be influenced by the supraglottal resistance at the place of articulation. During the closure this resistance is infinite and at the release it drops abruptly. The speed with which the supraglottal resistance falls will reflect the speed of the articulators and this might be reflected in the decay of the supraglottal pressure. Keeping other factors constant one might assume that the decay will be proportional to the rate with which the articulatory resistance falls.

In further studies of the interaction of glottal resistance and supraglottal resistance and their effects on pressure decay the findings of Vencov (1968) should be taken into account.

Duration of oral closure

Data on the duration of oral closure are presented in Fig. 12 and 13 and also in Table VI.

Table VI. Mean duration of oral closure. Msec.

	initial			medial		final	
	ptk	bdg		ptk	bdg	ptk	bdg
'CV:	182	137	V'CV:	114	106	283	164
CV	190	141	'V́:CV	191	108		
			'V̀:CV	223	123		

We see that the closure period is longer for the unvoiced than for the voiced plosives.

Closure duration also seems to be shorter in a stressed than in an unstressed syllable.

For the voiced plosives we find that the closure is shortest in medial position; it is a little longer in initial position and longest in final position.

The voiceless plosives have the longest closure duration in final position but it is hard to draw any conclusions for medial and initial position because other factors also play a role.

The closure duration of the medial unstressed plosives is markedly influenced by the tonal accent of the word in which they occur. They have longer closure in words with tonal accent 2 than in words with tonal accent 1.

The difference in closure duration between voiced and unvoiced plosives corresponds to that found by Karlsson and Nord (1970) for Swedish. For Dutch the same kind of variations has been noted by Slis (1970, 1971) whereas Kent and Moll (1969) did not find any difference in closure duration due to difference in voicing for American English stops.

The fact that closure duration is shorter in a stressed than in an unstressed syllable is not in agreement with the findings of Slis (1971) for Dutch. Karlsson and Nord (1970), who studied Swedish, state that an unvoiced plosive after a stressed vowel is lengthened as compared to the same plosive before a stressed vowel. They found the shortest closure durations for stops between two unstressed vowels.

As matters seem to be rather complicated it seems unwise to draw any firm conclusions on the basis of the present material.

One further point appears from the present data: there seems to be an inverse relationship between closure duration and pressure decay: when closure duration is short, as in a stressed syllable, pressure decay is slow and the other way round.

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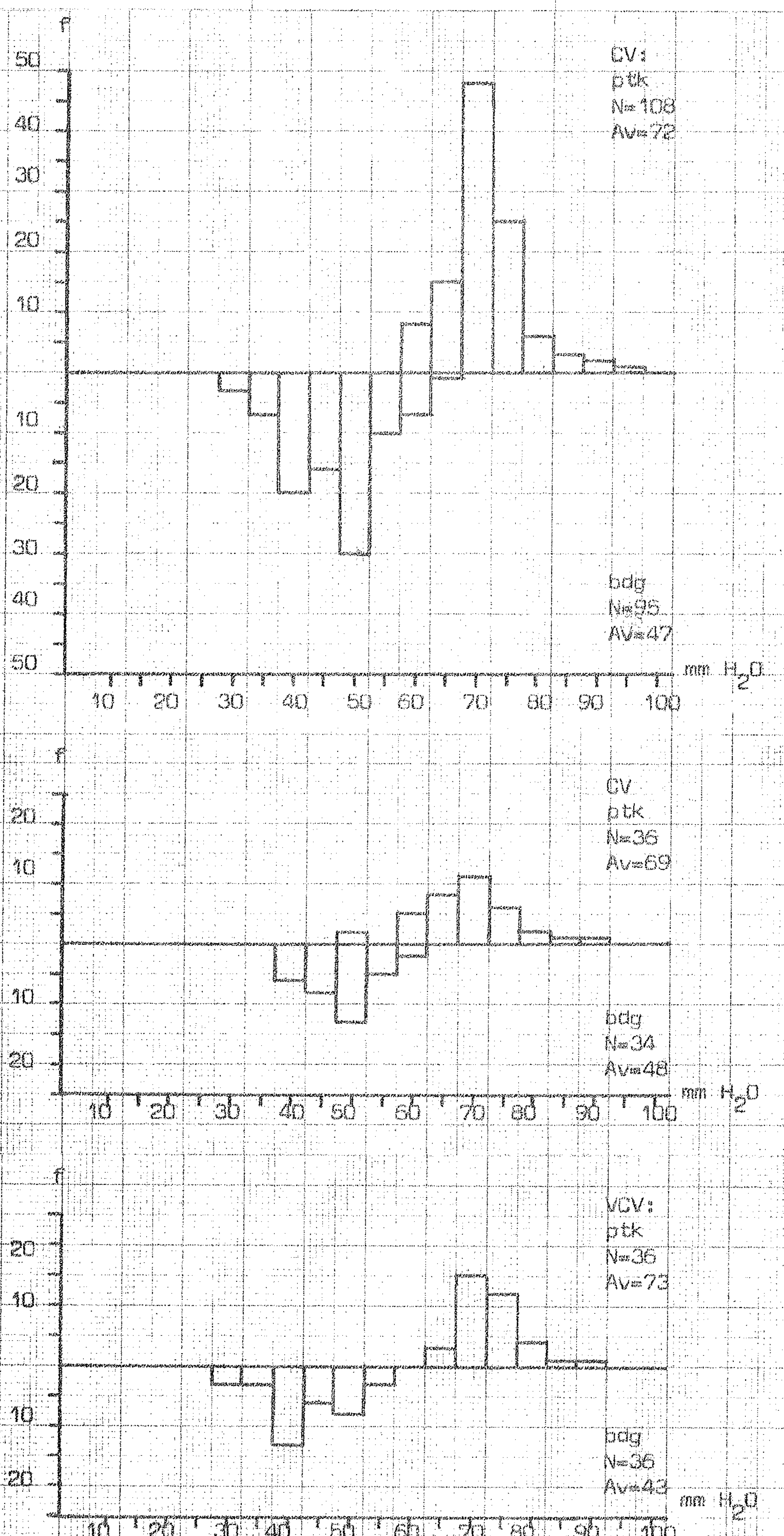


Fig. 1. Frequency distributions for peak pressure values.

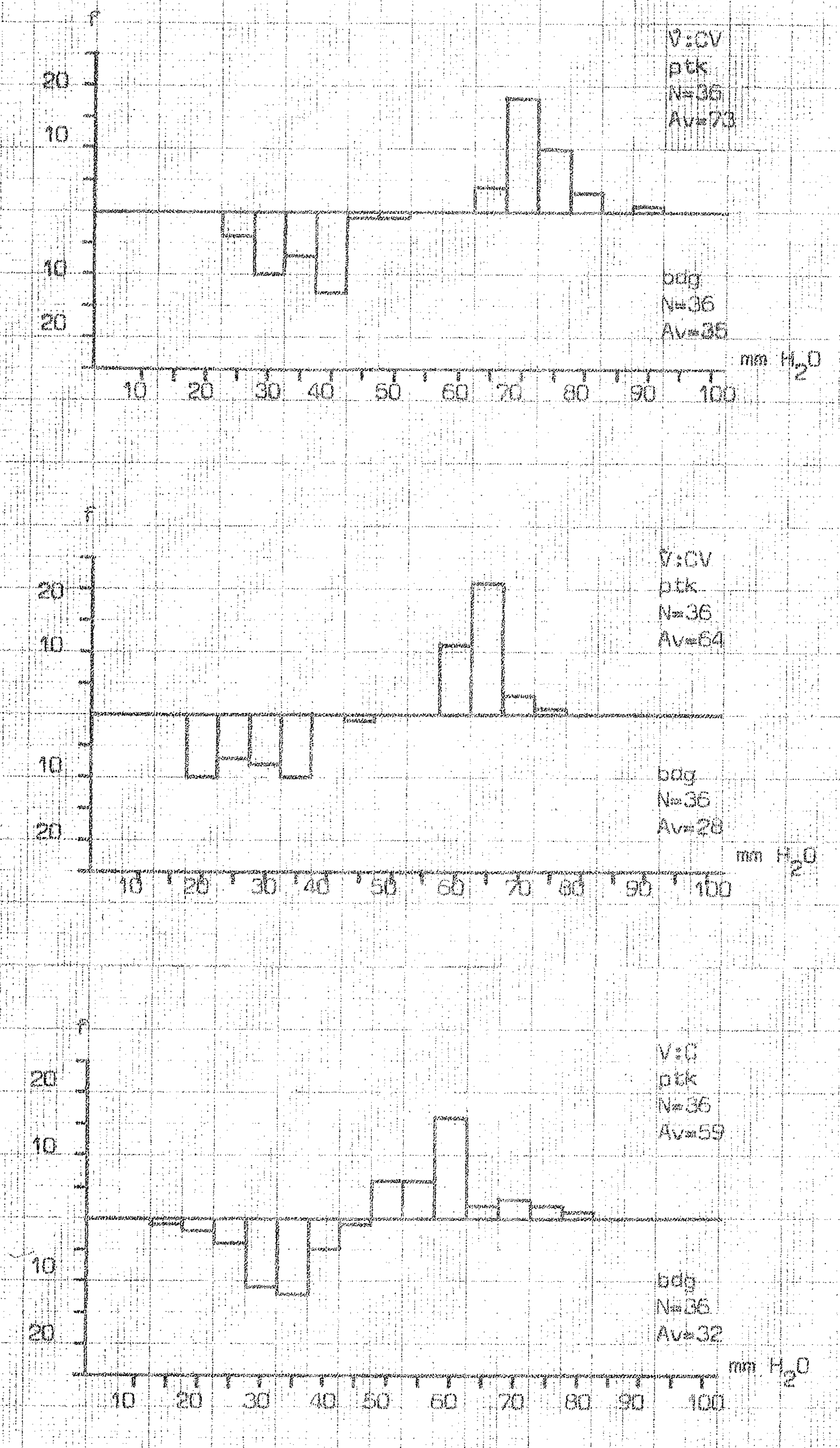


Fig. 2. Frequency distributions for peak pressure values.

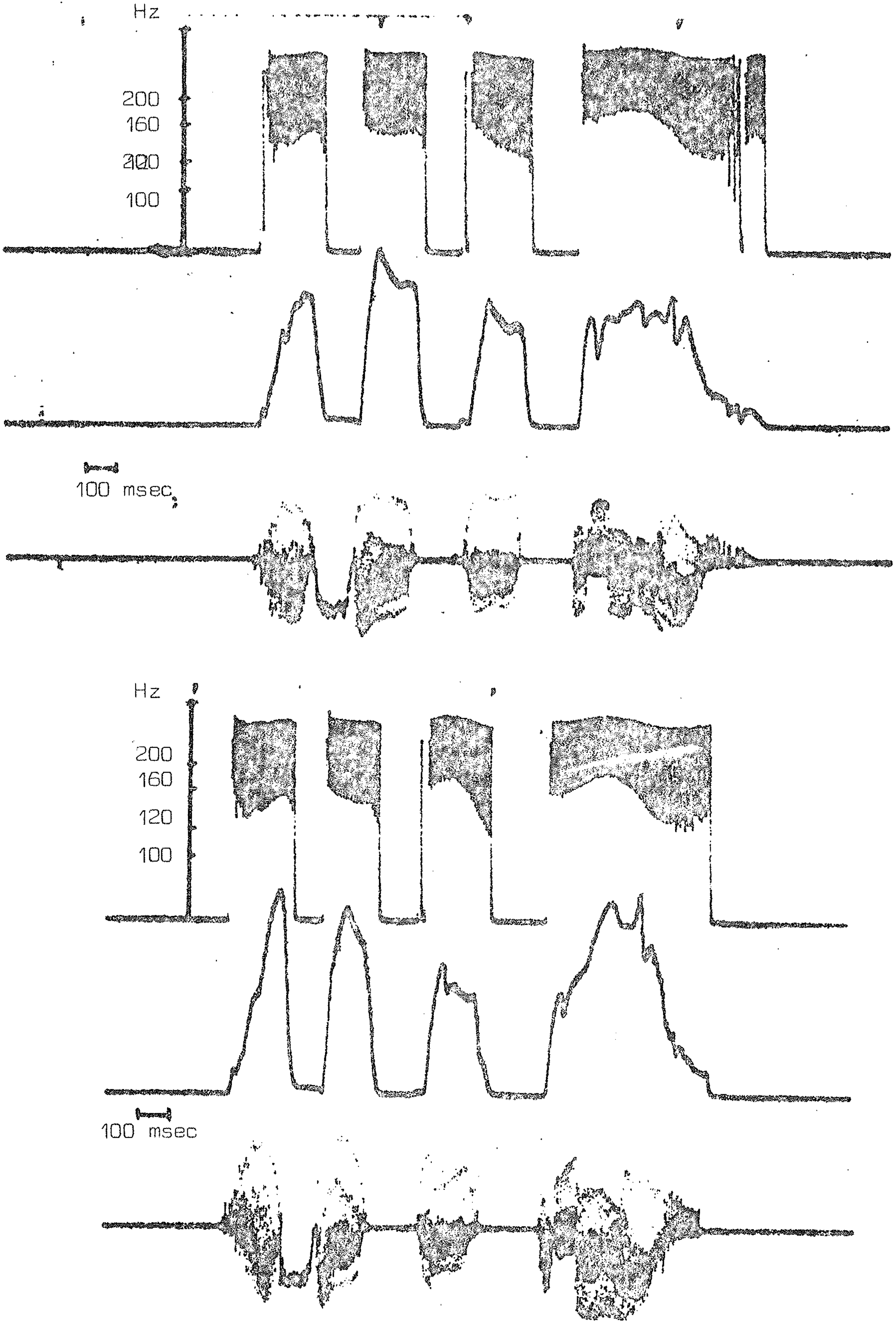


Fig. 3. F_0 curve, intensity curve and duplex oscillogram for the utterances "Ja sa pápen igen" (above) and "Ja sa pàpen igen" (below).

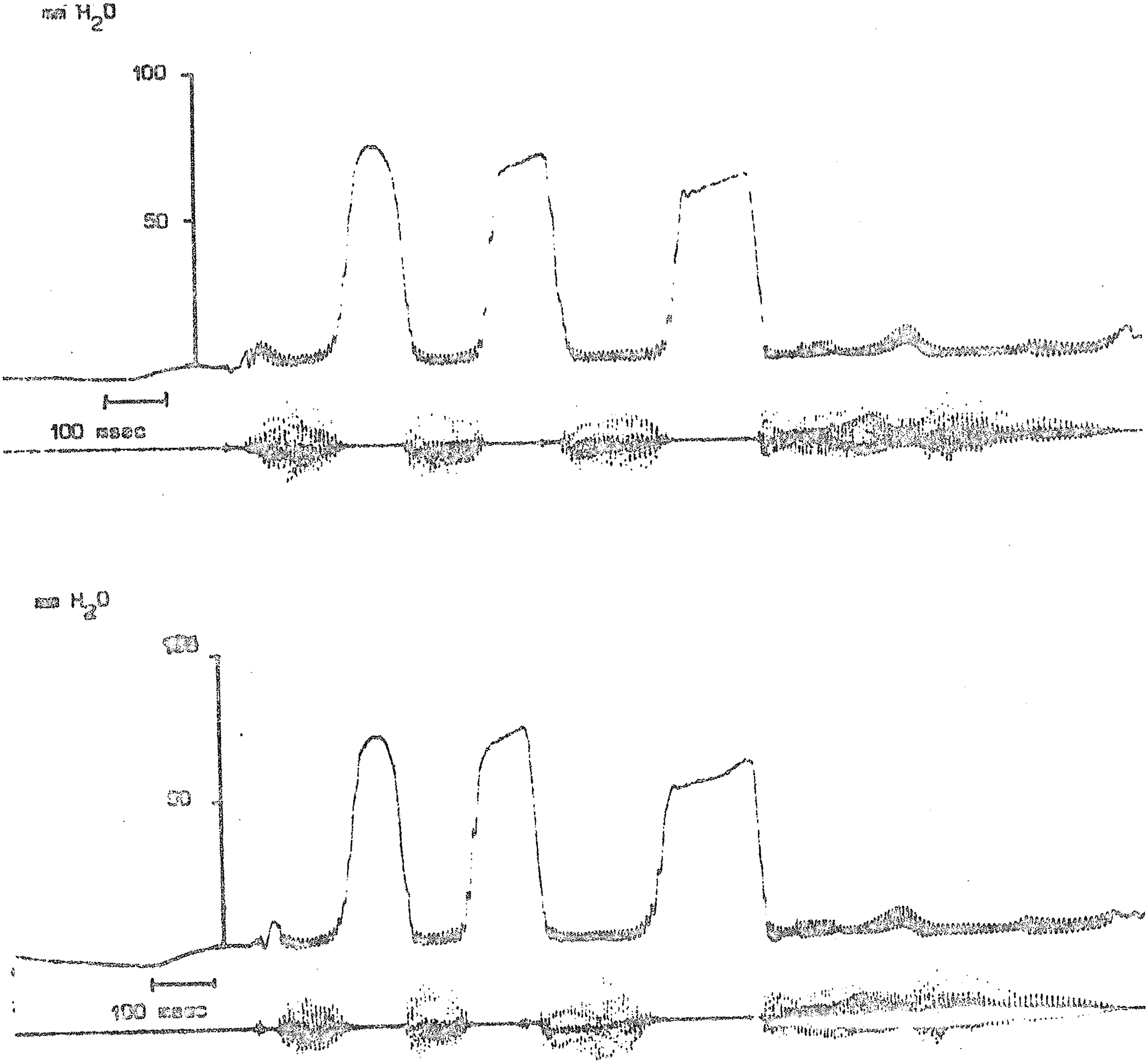


Fig. 4. Supraglottal air pressure during the utterances "Ja sa kǻken igen" (above) and "Ja sa kå̀ken igen" (below).

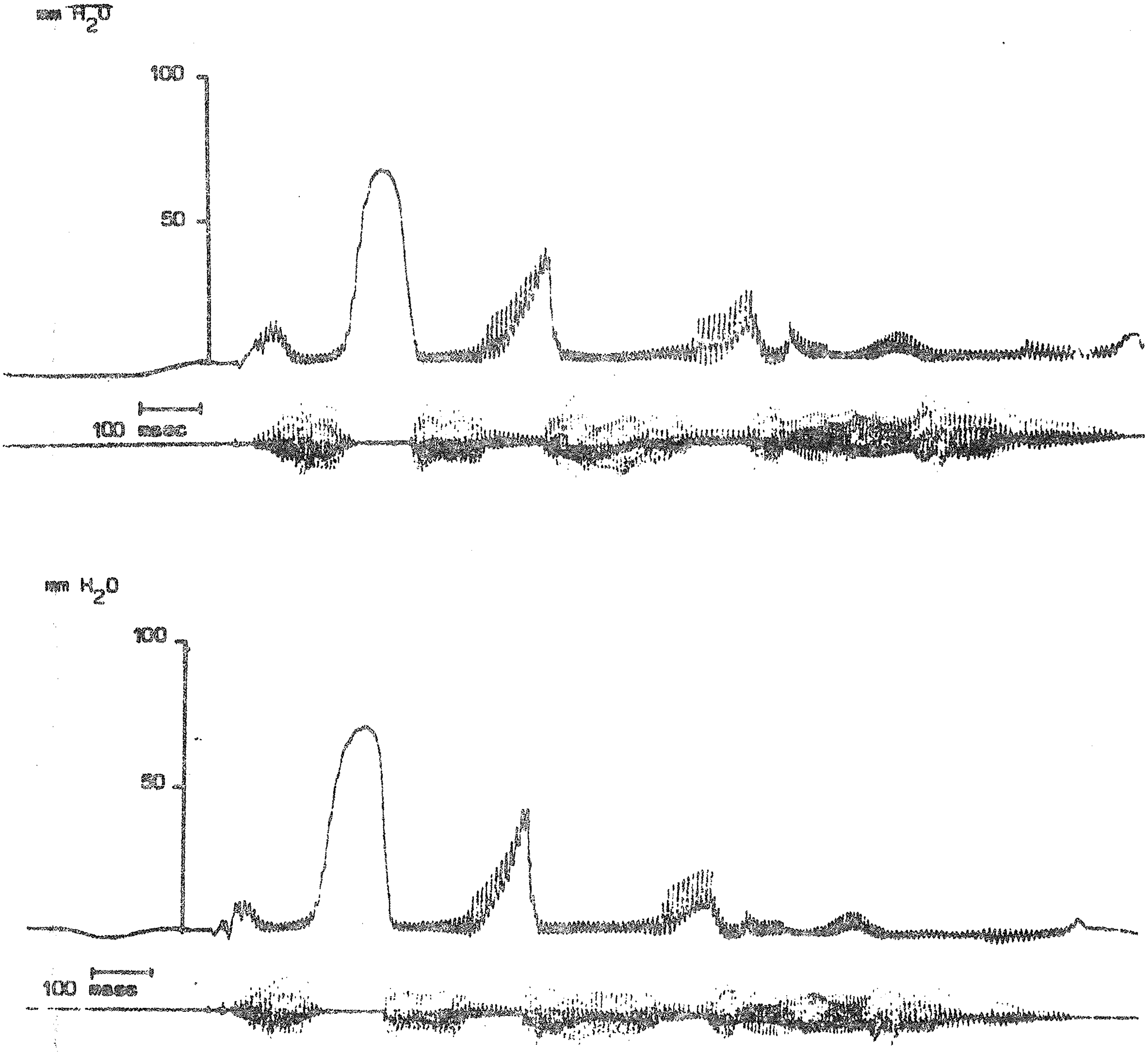


Fig. 5. Supraglottal air pressure during the utterances "Ja sa gágen igen" (above) and "Ja sa gàgen igen" (below).

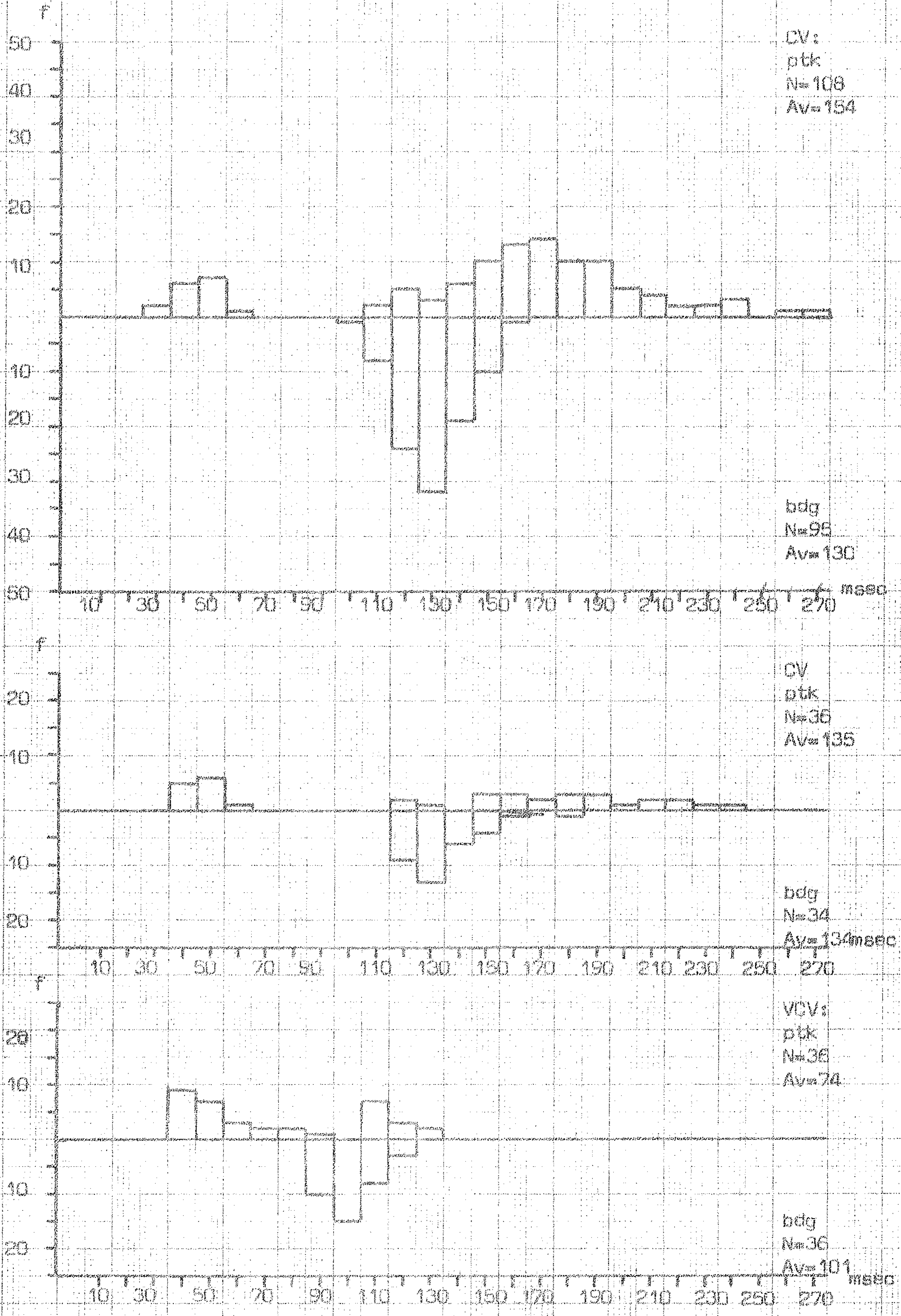


Fig. 6. Frequency distributions for the duration of the interval during which pressure builds up to its peak value.

II

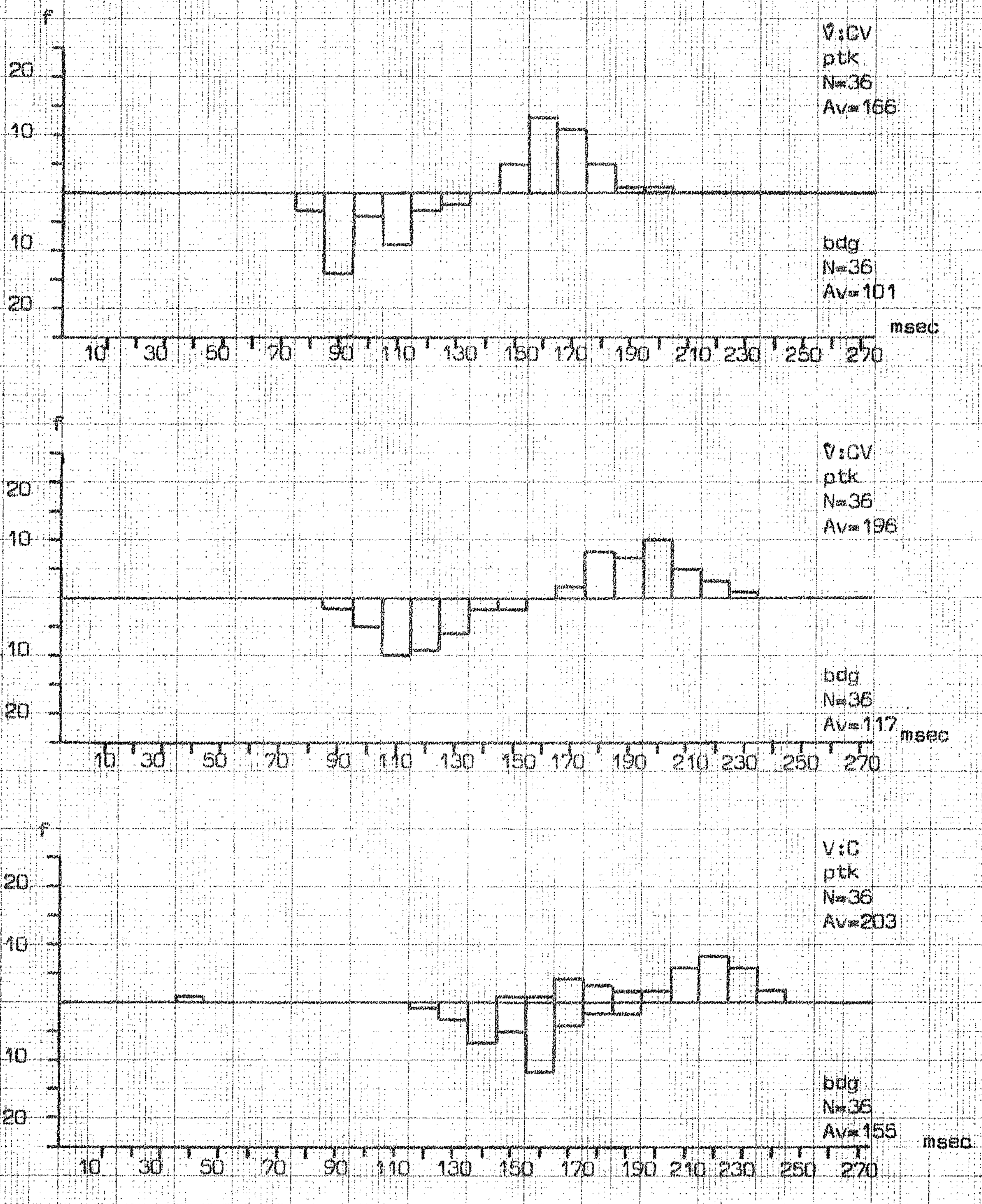


Fig. 7. Frequency distributions for the duration of the interval during which pressure builds up to its peak value.

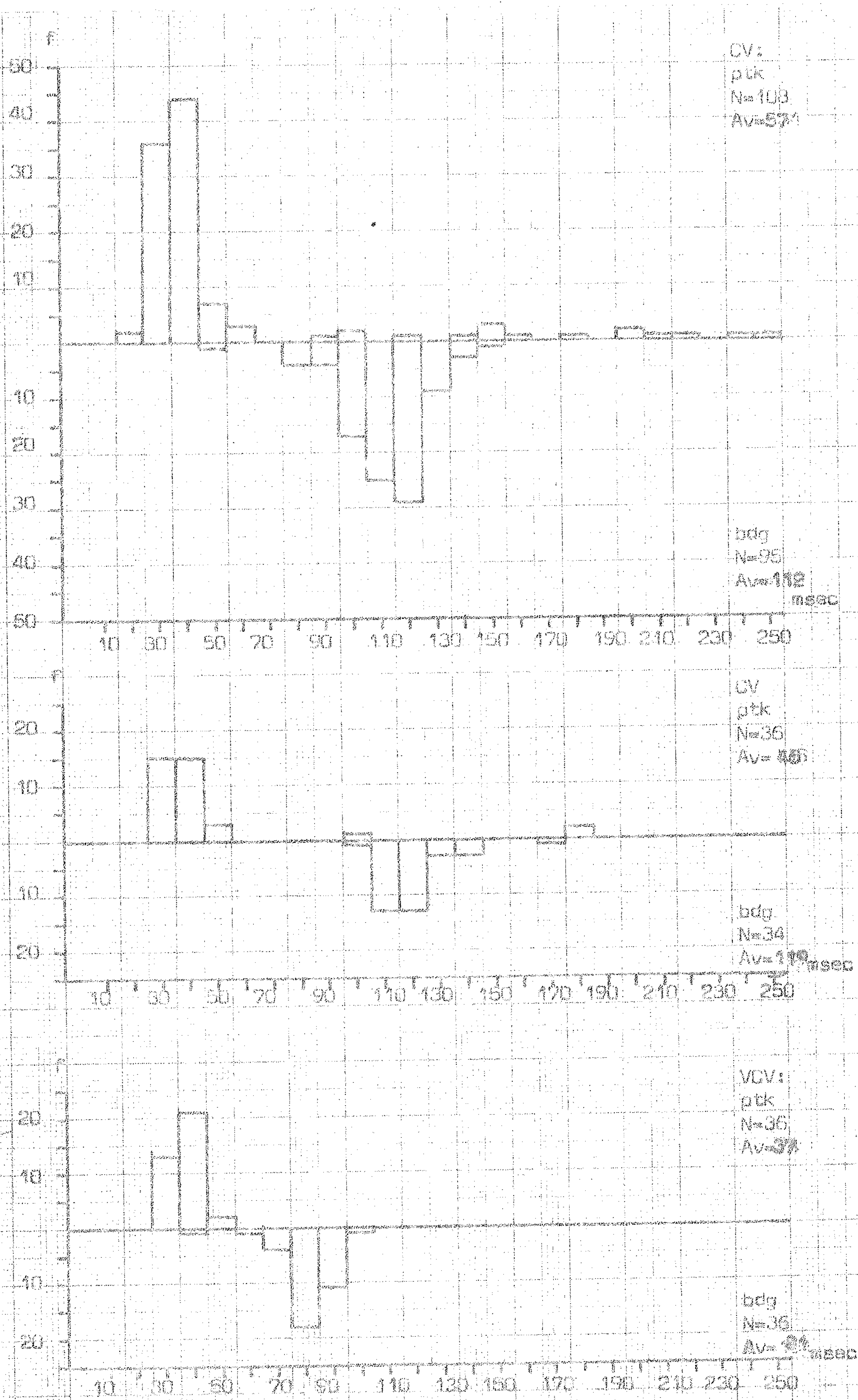


Fig. 8. Frequency distributions for the duration of the interval during which pressure builds up to 85% of its peak value.

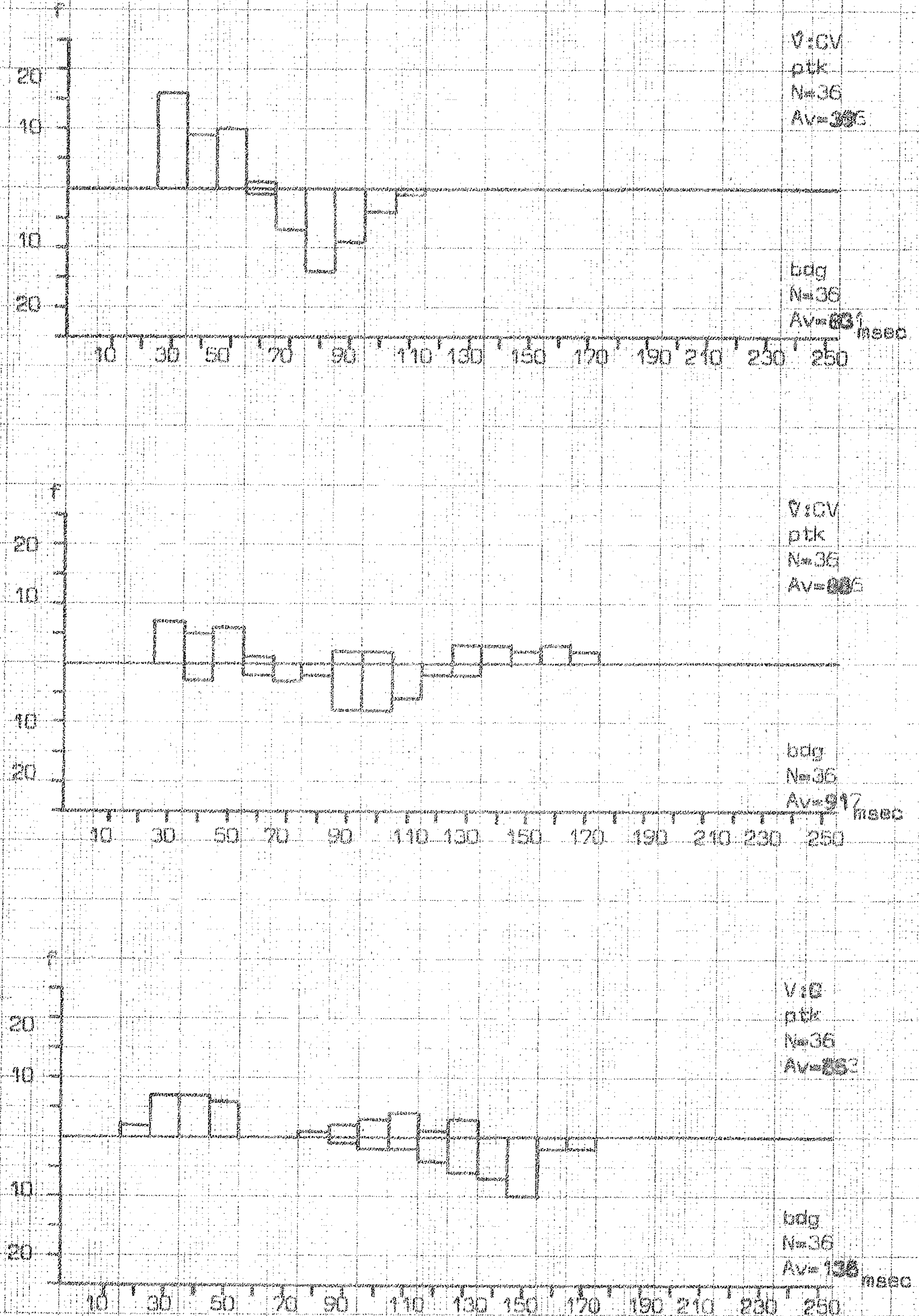
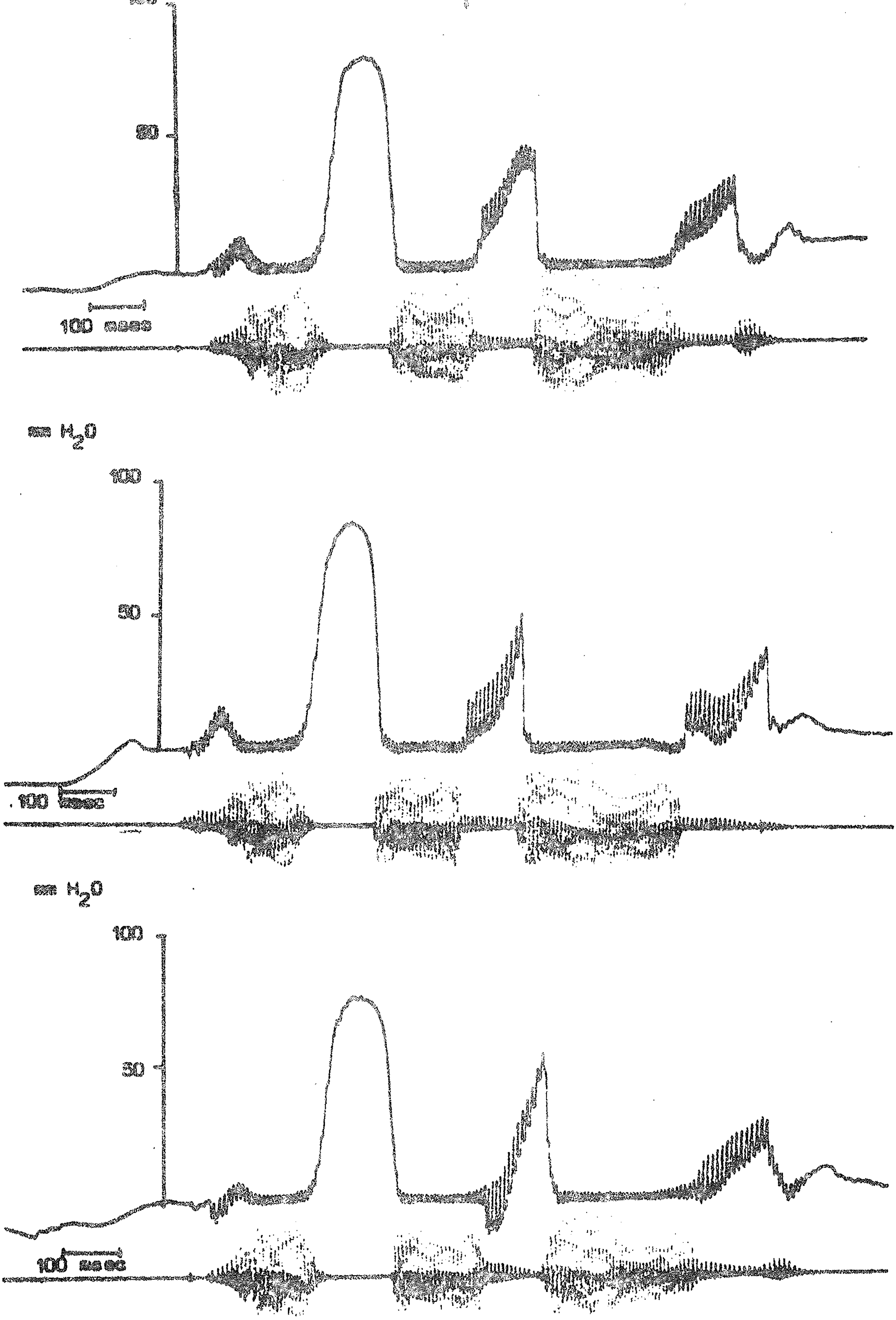


Fig. 9. Frequency distributions for the duration of the interval during which pressure builds up to 85% of its peak value.



- Fig. 10. Supraglottal air pressure during the utterances "Ja se bab" (top), "Ja se ded" (middle) and "Ja se gag" (bottom).

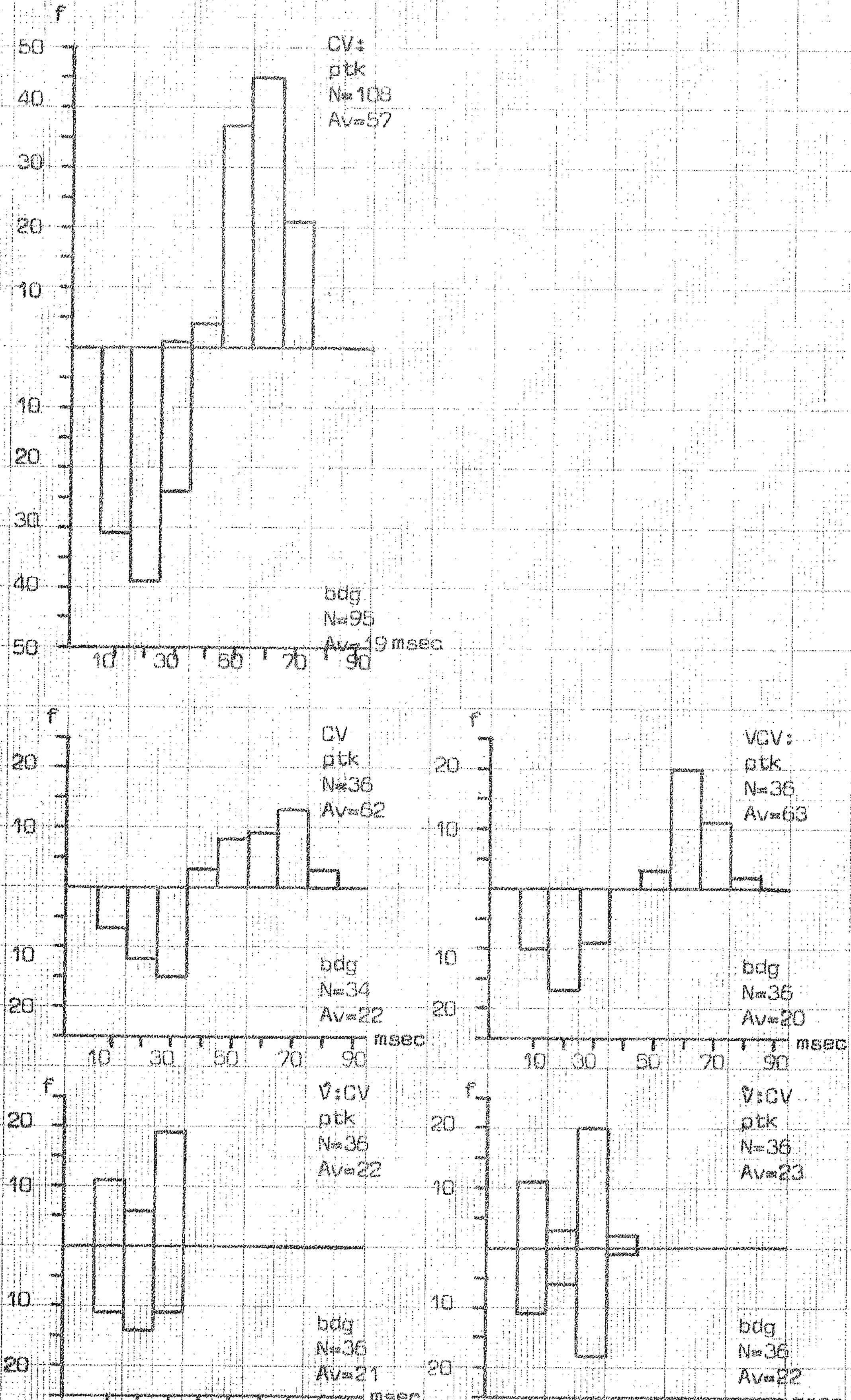


Fig. 11. Frequency distributions for pressure decay.

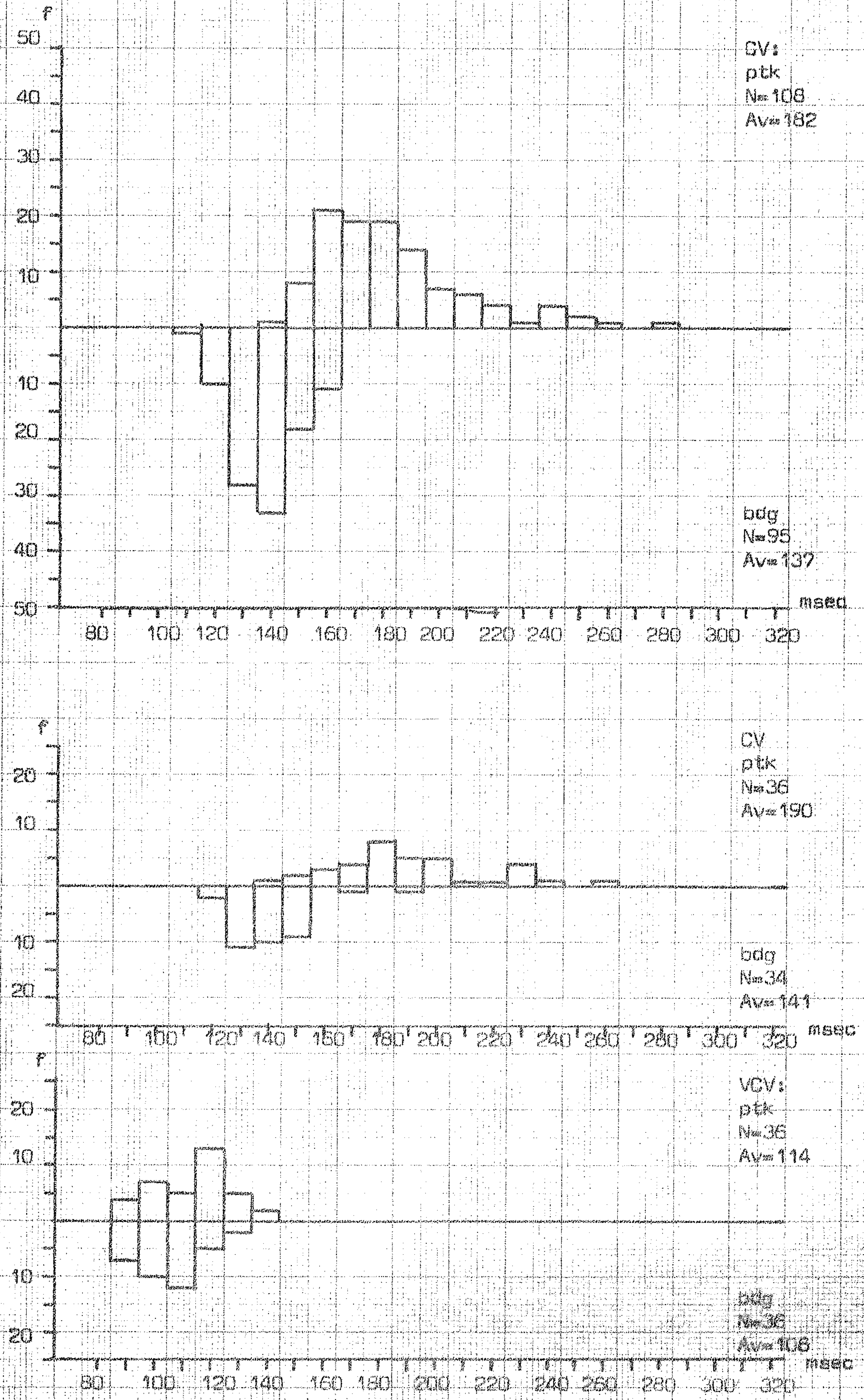


Fig. 12. Frequency distributions for duration.

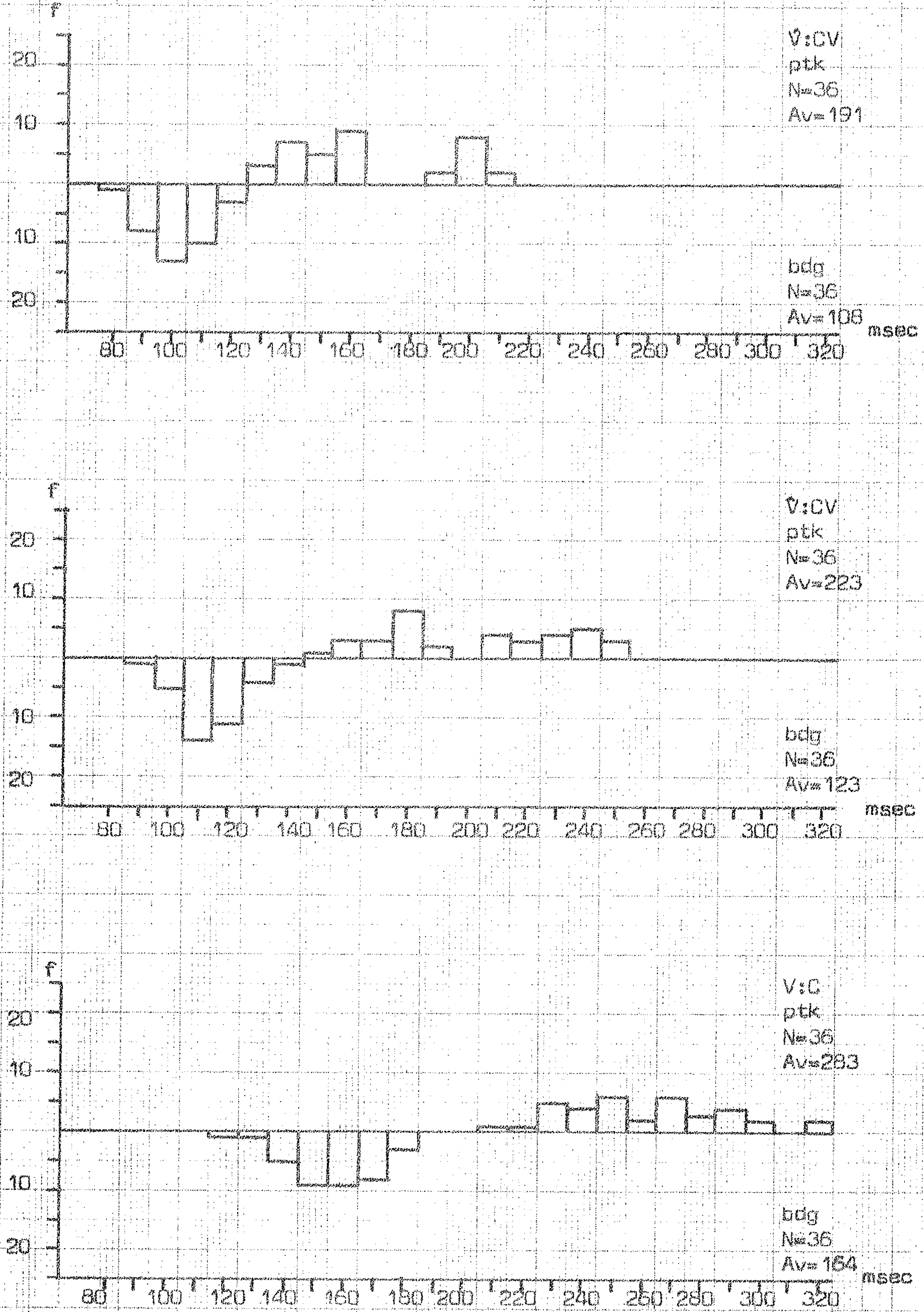


Fig. 13. Frequency distributions for duration.