Working Papers 25 1983
Linguistics-Phonetics
Lund University, 113-137

ACOUSTIC ANALYSIS OF FRICATIVES IN CAIRO ARABIC

Kjell Norlin

1. INTRODUCTION

This article describes the acoustical properties of fricatives in Cairo Arabic (CA). With its eleven fricatives, CA, like all forms of Arabic, belongs to the small group of less than one per cent of the languages of the world with such a large inventory of fricative phonemes (Nartey 1979). Acoustical investigations of these do not abound. On the contrary it is easy to find somewhat fanciful descriptions of many Arabic phonemes in the literature. One author states that /ḍ/ is "un peu comme le 'dang' sonore et prolongé, qui veut imiter le son d'un cloche de cathedral", (Jomier 1964), and that /ḥ/ reminds you of "la respiration d'un chien haletant après une course" (Jomier 1964). Still another one finds that /ʕ/ "is made far back in a tightened throat, and sounds and feels rather like being sick"(Scott 1962), /ɣ/ "is the noise which the camel makes when growling at being loaded" (Scott 1962), /q/ "resembles more than anything else the 'kok-kok-kok' sound made by liquid being poured out of a full bottle". (Scott 1962).

This investigation presents a more data-oriented approach and a method of analyzing fricatives which provides the means of describing the fricative acoustic space of a language. Parameters for characterizing fricative spectra are given and applied to CA fricatives. This method makes comparison possible between different speakers and also between CA and other languages, for example Chinese, which has been investigated by the same method (Svantesson 1983).
This method has made it possible to quantify data and state the difference between pharyngalized fricatives and their non-pharyngalized counterparts.

1.1 The fricatives of CA

f   s z   ṣ ẓ   š   x ɣ   ḥ ʕ   h

2. PROCEDURE

Six informants from Cairo were recorded on a Studer tape-recorder in the studio of the Phonetic Department in Lund. The fricatives were pronounced in real words in a sentence frame, preceded by a# and followed by ā, (a# Cā). The word list was read twice. /s/ and /ṣ/ followed by all long vowel phonemes of CA, /ā/, /ī/, /ū/, /ē/, /ō/, in minimal or near-minimal pairs, were read twice by three speakers.
Analysis was made from the second reading.
Sampling started after the first third of the fricative for 25.6 ms.

Some difficulties were experienced in finding the boundaries of /ɣ/ and /ʕ/ because they more closely resembled approximants than fricatives as revealed by their wave-form on duplex oscillograms.

3. ANALYSIS

1. FFT spectra up to 10 kHz of the middle of the 25 msecs of all the fricatives were made. These spectra were converted to critical band spectra (Schroeder et al. 1979) and analyzed in terms of the spectral center of gravity and dispersion in the manner described by Svantesson (1983).

2. Spectrograms were used to measure and compare formant transitions and vowel formants after /s/ and /ṣ/.

3. Duplex oscillogram along with intensity and F_o curves were used for analyzing non-spectral properties for pharyngalized versus non-pharyngalized fricatives, as well as for the pharyngals.

4. RESULTS FROM CRITICAL BAND SPECTRA

Figure 1:1-22 shows oscillograms of sound waves, FFT spectra in linear scale, spectra in logarithmic units (dB) and critical band spectra of one speaker (speaker 6). /š/ of speaker 4 is missing in the data. The critical band units were in some cases measured twice, the result of the check being practically the same as the first measurement. Table 1 gives the center of gravity of the critical band spectra, measured in critical band units and also given in Hz, the dispersion and the mean intensity level (dB). The mean intensity level are given as deviations from the average for each series of fricatives read on the same occasion. This makes them roughly comparable also between other speakers.

In figure 2 the center of gravity for each fricative is plotted against the dispersion, thus representing the fricative space of CA in a way which enables comparison with other languges. Figure 3 gives the mean values of the six speakers in figure 2. In figure 4 the fricative space is represented in another form. The center of gravity is plotted against the mean intensity level over the critical bands.
Figure 5 gives the mean values of the six speakers in figure 4. In figures 2 and 4 the individual fricatives are rather well kept apart even if the distance between /s/ and /ṣ/ on one hand and /z/ and /ẓ/ on the other is usually small with some outstanding exceptions. There is overlapping, especially between individual speakers and particularly between /s/ and /z/ and their pharyngalized counterparts. One must suppose that perception of fricatives involves normalization between different speakers.

/s/ and /ṣ/ are characterized by a sharp peak in the higher frequency ranges, band 21-23, and an abrupt fall towards the lower ranges. Figure 1:15 shows that the peak of /ṣ/ is somewhat broader than that of /s/ (figure 1:13). This difference is obvious here, but is usually impossible to notice when comparing all the critical band histograms of the informants. This difference is possible to quantify, however, by measuring the center of gravity. Table 1 shows that /ṣ/ has the center of gravity in lower frequency ranges than /s/ with one negligible exception , speaker 1. It also has a greater range of dispersion. The difference is not excessively large, but corresponds well to the slight, but quite noticeable perceptual impression of these sounds.

/z/ and /ẓ/ both have a substantial peak of energy in the bands 3-6 in addition to the high frequency peaks of /s/ and /ṣ/, although the former have lower intensity. The concentration of

energy in both ends of the spectrum, together with a cut in the top frequency range as compared to /s/ and /ṣ/ make their centers of gravity more or less coincide with their voiceless counterparts. There is a strong tendency for /z/ and /ẓ/ to have greater dispersion than /s/ and /ṣ/. For speakers 4 and 5 the relationship between center of gravity and dispersion of /z/ and /ẓ/ is reversed as compared to all others.
The difference between centers of gravity in critical bands has been the only criterion found in this investigation to measure the difference between pharyngalized and non-pharyngalized fricatives. Inspections of intensity and wave-form on mingograms has not revealed any obvious differences between these sounds, nor can anything be seen on spectrograms.

/š/ is characterized by a broader peak than /s/ and /ṣ/, ending in two smaller peaks on top. This is the typical shape of all histograms except one. The fall towards lower frequencies is as sharp as for /s/ and /ṣ/. The top covers the range from bands 16-21, showing lower frequency, but not greater dispersion.

/f/ has a spectrum falling much more slowly from high frequencies than the sibilants and has also much lower mean intensity. Spectra of /f/ have roughly the same centers of gravity as /š/ and is distinguished from the latter by greater dispersion.

/ḥ/ has the center of gravity roughly in the center of the critical band spectrum, with a fairly steep slope in the lower ranges and a more gradual slope in the higher frequencies. The main contour of the spectrum is rather dome-shaped.

/h/ has energy spread over the whole frequency range, giving the contour a roughly flat shape, /h/ and /ḥ/ intermingle in figure 2, showing no absolute contrast in either center of gravity or dispersion. There is a tendency, however, for /h/ to have less dispersion.
For contrasts in wave-form, see below.

/x/ has energy evenly spread from band 7 upwards, with a slowly graded descent towards the lower ranges.

/ɣ/ and /ʕ/ are not sharply divided either in centers of gravity or dispersion, but there is a tendency for /ʕ/ to have its center of gravity in the somewhat lower frequencies. /ʕ/ generally has lower mean intensity (figures 4 and 5).

5. RESULTS FROM SPECTROGRAMS

Measurements on spectrograms of locus and formants of vowels following /s/ and /ṣ/ show great impact on formant transitions after pharyngalization (figure 6:1-5). F2 is particularly affected and locus is drastically lowered for all vowels except /ū/ where locus is raised by 100-150 Hz (figure 6:5). Changes of F1 and F2 are also noticeable, but on a very small scale and of no consistent pattern. The raising of F2 of the vowel /ū/ after /ṣ/ in contrast to the falling of F2 of all other vowels is due to the successive movement backwards of the tongue constriction area as shown in the nomograms by Fant (1968).

6. RESULTS FROM MINGOGRAMS

Inspection of duplex oscillograms along with intensity and F_0 curves revealed no difference between pharyngalized and non-pharyngalized sibilants. Duplex oscillograms of /ɣ/ and /ʕ/ (figure 7:1-2) show that these sounds are phonetically realized as approximants in CA, rather than as fricatives. However, they are always classified as fricatives in phonetic descriptions (eg. Harrell 1957, Abdel-Massih 1975).

/ḥ/ and /h/ differ in two ways. Both sounds stand in intervocalic position in the sentence frame, but /ḥ/ is always voiceless, /h/ is voiced (figure 8:1-2). The vowel following /ḥ/ always has hard onset, after /h/ soft onset.

7. DISCUSSION

The place of each fricative within the fricative space of a language can be defined by the method of making critical band spectra and deriving the suggested parameters from them. The method also makes it possible to compare fricatives of different languages.

Owing to the great number, the fricatives of CA are fairly well spread within the fricative space, defined by the center of gravity and dispersion (figures 2 and 3). The difference between pharyngalized fricatives and their non-pharyngalized counterparts has formerly been investigated on spectrographic evidence (Obrecht 1968).

The critical band method has made it possible to quantify the difference. The pharyngalized fricatives nearly always have a lower center of gravity and greater dispersion. The difference is not necessarily very great. Exceptional cases even show non-pharyngalized fricatives having a lower center of gravity and greater dispersion (/s/, /ṣ/ of speaker 1, /z/, /ẓ/ of speaker 4 and 5). The described difference is therefore neither a sufficient, nor reliable cue to discrimination between these pairs of sibilants. Pharyngalization, or emphasis to use another current term, "never occurs as a feature of a single segment. The minimum range of emphasis is V(:)C or CV(:)" (Harrell 1957). The perceptual cue of importance to discriminate pharyngalization seems to be in the lowering of the locus (slight raising for C̣ū), while the steady-state portion is much less affected, except for C̣ā. Perceptual tests with synthetic speech give ample evidence to the fact that F2 transitions are the most important factors in identification of pharyngalized fricatives (Obrecht 1968).

Since it is generally assumed, however, that the pharyngalization gives another set of fricative phonemes, producing vocalic allophones in the following segments, it is important to quantify the difference between pharyngalized and non-pharyngalized fricatives in terms of their place in the fricative space.

ACKNOWLEDGMENTS

The work reported here is supported by the Swedish council for Research in the Humanities and Social Sciences.

REFERENCES

Abdel-Massih, E. 1975. An introduction to Egyptian Arabic. Ann Arbor: The University of Michigan, pp. 2, 5

Fant, G. 1968. Analysis and synthesis of speech processes. In Bertil Malmberg, ed. Manual of Phonetics. Amsterdam: North-Holland Publishing Company, p. 214

Harrell, R.S. 1957. The phonology of colloquial Egyptian Arabic. New York: American council of learned societies, pp. 25, 78

Jomier, J. 1964. Manuel d'arabe égyptien. Paris: Librairie C. Klinksieck, p. 1

Obrecht, D.H. 1968. Effects on the second formant on the perception of velarization consonants in Arabic. The Hague, Paris: Mouton, p. 41

Schroeder, M.R., B.S. Atal and J.L. Hall. 1979. Objective measure of certain speech signal degradations based on masking properties of human auditory perception. In Björn Lindblom and Sven Öhman, ed. Frontiers of speech communication research, London: Academic Press 1979, pp. 217-229

Scott, G.C. 1962. Practical Arabic. London: Longmans, pp. 2, 6, 7

Svantesson. J-O. 1983. Acoustic analysis of Chinese fricatives and affricates. To be published in Working Papers, Phonetics Laboratory, Lund University

Table 1. Center of gravity, dispersion and mean intensity level of the critical band spectra of fricatives in Cairo Arabic.

	speaker	center of gravity crit.band units	Hz	dispersion crit.band units	mean intensity level, dB
/f/	1	18.42	4179	4.10	-4.54
	2	20.53	5665	3.54	-12.94
	3	17.75	3793	3.76	-8.85
	4	18.44	4191	4.77	-9.90
	5	20.88	5957	2.14	-8.39
	6	22.21	7210	2.16	-7.50
/s/	1	20.55	5681	2.15	4.24
	2	21.18	6219	1.48	7.18
	3	21.53	6540	1.80	4.91
	4	20.83	5914	1.75	13.06
	5	21.83	6827	0.95	7.74
	6	21.98	6976	1.09	6.36
/ṣ/	1	20.59	5714	2.63	2.55
	2	20.90	5974	1.56	1.44
	3	20.99	6052	2.31	1.22
	4	20.71	5813	1.90	13.66
	5	21.39	6410	1.46	7.88
	6	20.80	5889	1.77	6.73
/z/	1	18.36	4143	4.61	-5.84
	2	21.51	6521	1.23	4.50
	3	21.85	6847	1.18	8.80
	4	19.87	5151	2.90	0.70
	5	19.62	4969	5.44	-5.67
	6	21.74	6740	1.62	5.73
/ẓ/	1	15.22	2622	6.49	-2.35
	2	20.52	5656	1.97	2.49
	3	20.66	5771	3.57	-0.71
	4	20.76	5855	2.17	7.84
	5	21.11	6157	1.39	1.60
	6	19.45	4849	5.73	-5.23
/š/	1	18.47	4209	3.16	2.77
	2	18.38	4155	2.43	12.48
	3	16.45	3140	2.02	6.15
	4				
	5	18.85	4447	2.27	7.86
	6	19.21	4684	2.36	9.34
/x/	1	14.05	2205	3.17	0.94
	2	16.02	2948	4.08	1.84
	3	15.83	2868	3.68	0.17
	4	15.95	2918	4.00	2.93
	5	16.15	3005	3.31	0.21
	6	18.51	4234	3.92	2.51

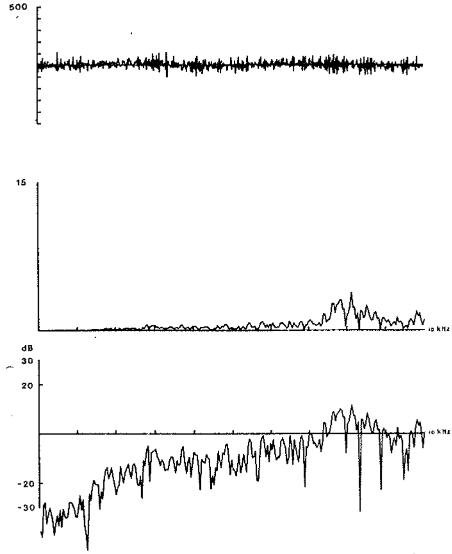
Table 1 cont.

	speaker	center of gravity crit.band units	Hz	dispersion crit.band units	mean intensity level, dB
/ɣ/	1	11.00	1384	4.41	-3.78
	2	11.80	1568	3.30	-1.45
	3	9.97	1173	4.34	-2.48
	4	12.21	1670	3.86	8.47
	5	11.75	1556	6.24	-0.17
	6	9.98	1175	4.79	-4.98
/ḥ/	1	13.22	1947	2.67	-0.79
	2	11.58	1516	3.95	-4.63
	3	13.75	2108	3.37	-0.82
	4	13.22	1947	3.86	-7.00
	5	15.64	2789	2.23	-0.75
	6	11.60	1520	1.83	0.36
/ʕ/	1	10.95	1373	3.96	4.30
	2	9.78	1137	2.90	3.57
	3	8.77	959	3.01	-7.15
	4	9.97	1173	3.74	-15.44
	5	11.91	1595	3.18	-5.76
	6	13.24	1953	4.31	-7.51
/h/	1	12.94	1867	3.35	2.47
	2	10.91	1364	5.07	-10.89
	3	13.81	2127	2.62	-1.20
	4	14.28	2282	3.45	-14.28
	5	15.43	2704	2.84	-4.53
	6	14.70	2428	3.78	-5.78

<u>Mean values</u>

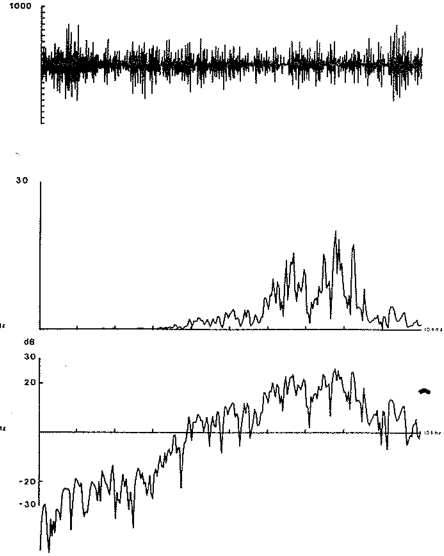
/f/	19.71	5034	3.41	-8.68
/s/	21.32	6345	1.54	7.25
/ṣ/	20.90	5974	1.94	5.58
/z/	20.49	5632	2.83	1.37
/ẓ/	19.62	4969	3.55	0.60
/š/	18.27	4089	2.45	6.43
/x/	16.09	2979	3.69	1.43
/ɣ/	11.14	1415	4.49	-0.73
/ḥ/	13.17	1933	2.99	-2.27
/ʕ/	10.77	1335	3.52	-4.66
/h/	13.68	2087	3.52	-5.70

figure I:1



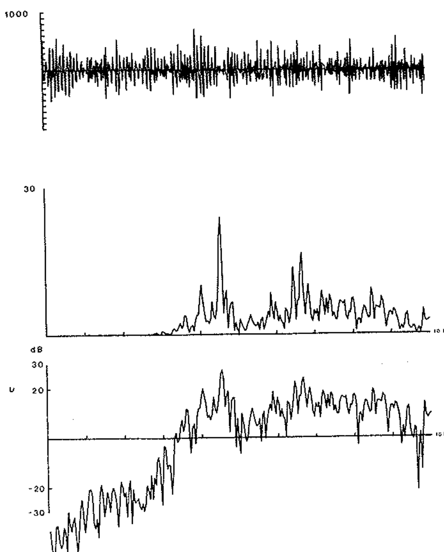
f6

figure I:2



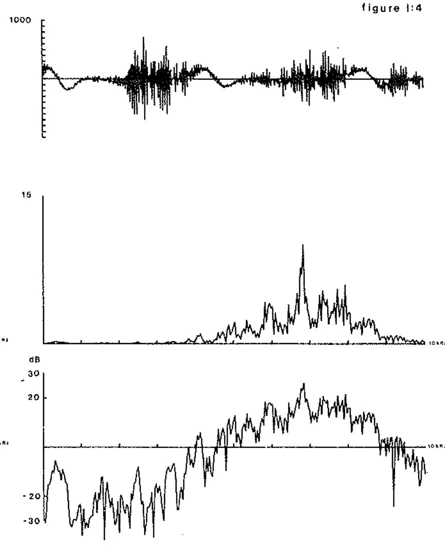
S6

figure I:3



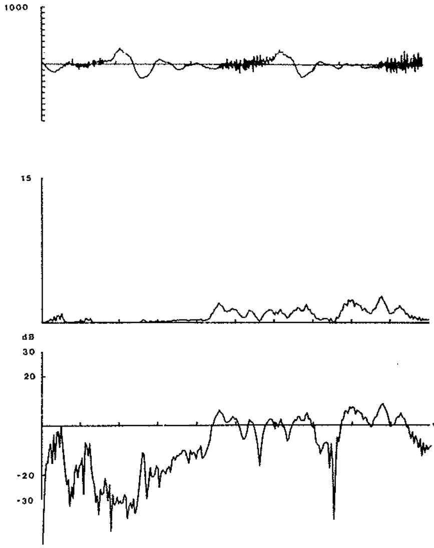
S6

figure I:4



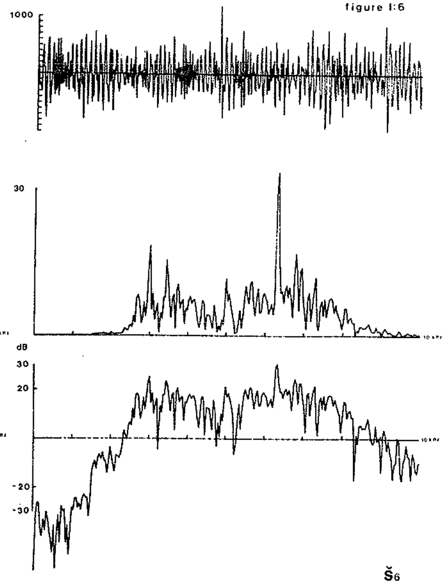
Z6

figure I:5



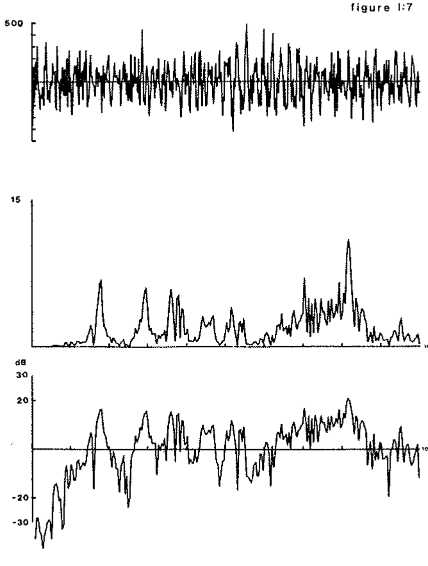
ẓ$_6$

figure I:6



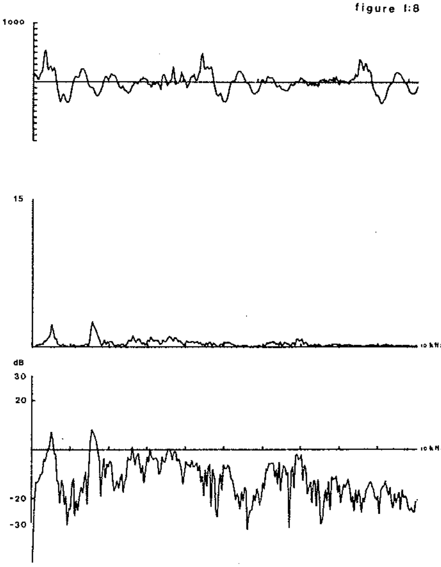
š$_6$

figure I:7



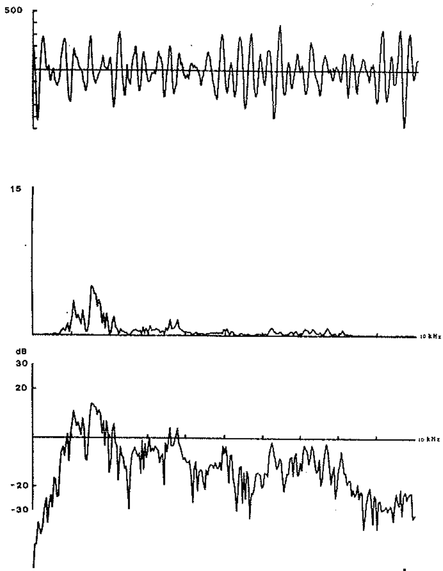
x$_6$

figure I:8



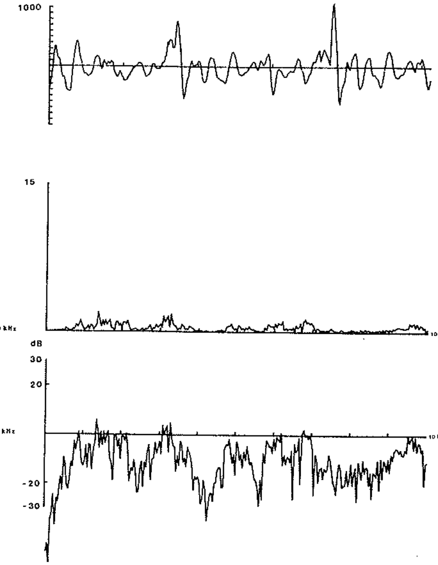
ɣ$_6$

figure I:9



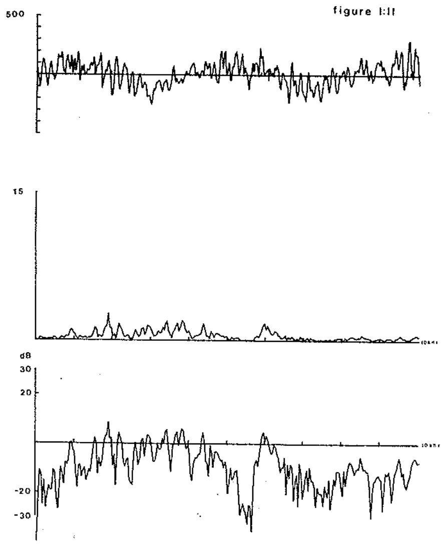
ḥ6

figure I:10



ʕ6

figure I:11



h6

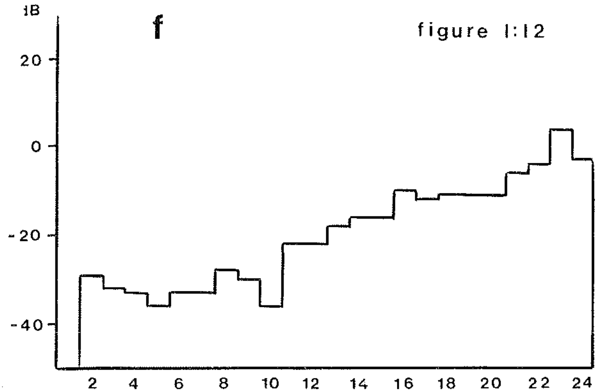


figure I:12

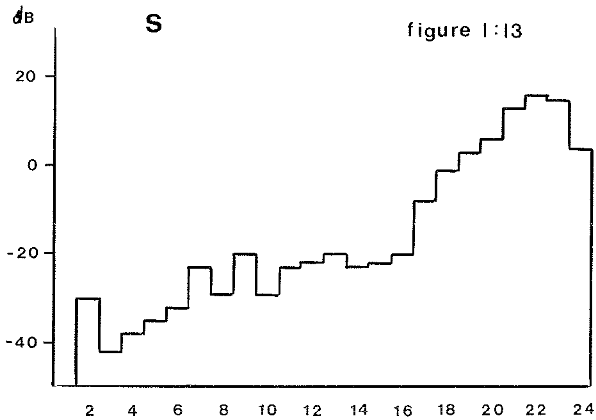


figure I:13

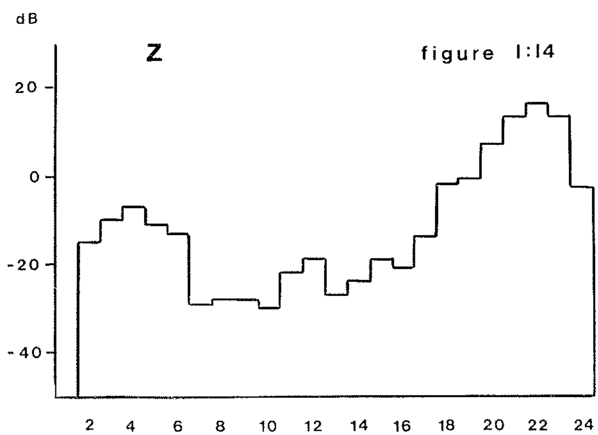
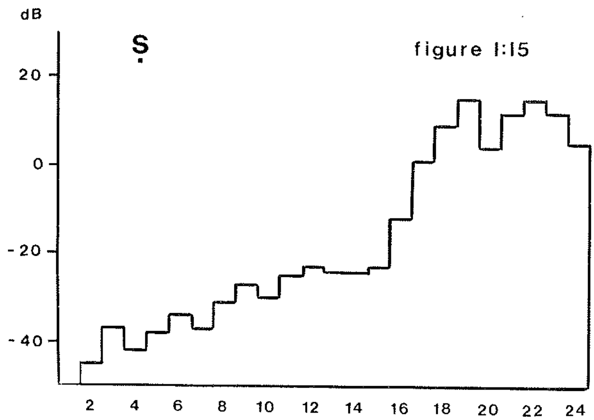
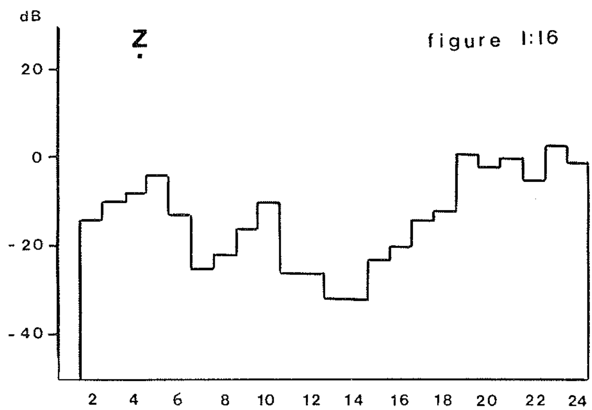
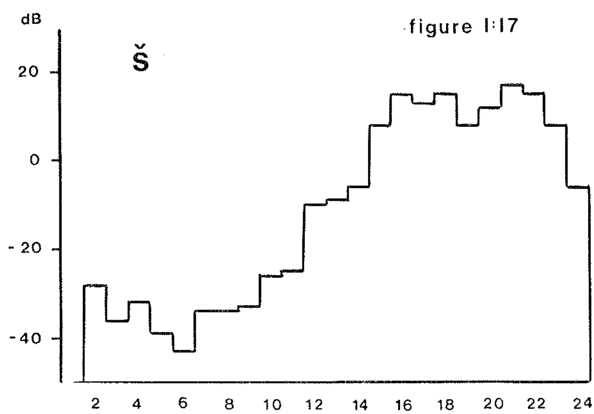


figure I:14


dB
ṣ
figure I:15
20
0
-20
-40
2
4
6
8
10
12
14
16
18
20
22
24


dB
ẓ
figure I:16
20
0
-20
-40
2
4
6
8
10
12
14
16
18
20
22
24


dB
figure I:17
š
20
0
-20
-40
2
4
6
8
10
12
14
16
18
20
22
24

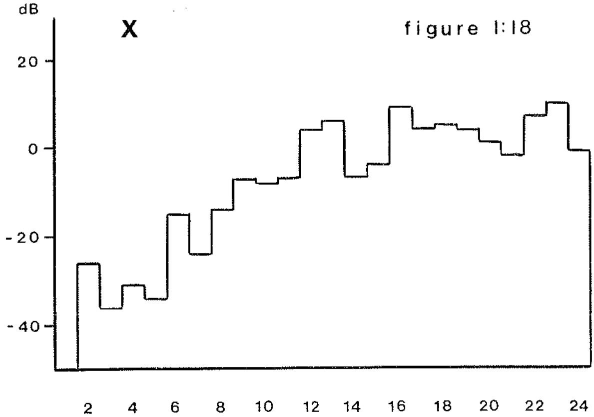


figure I:18

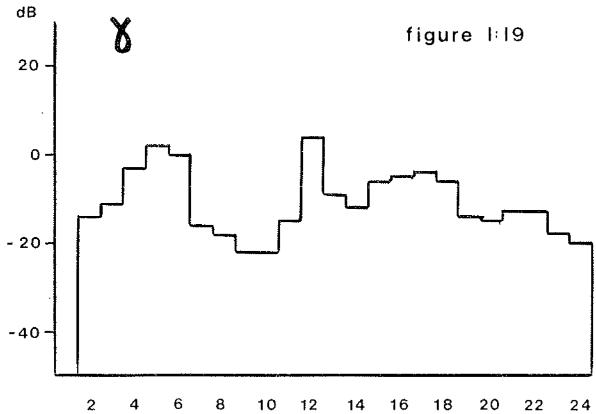


figure I:19

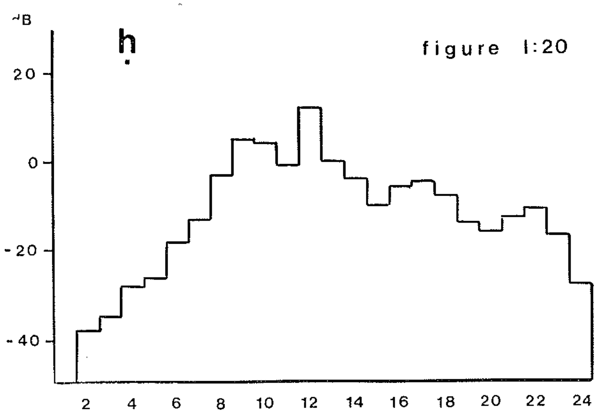


figure I:20

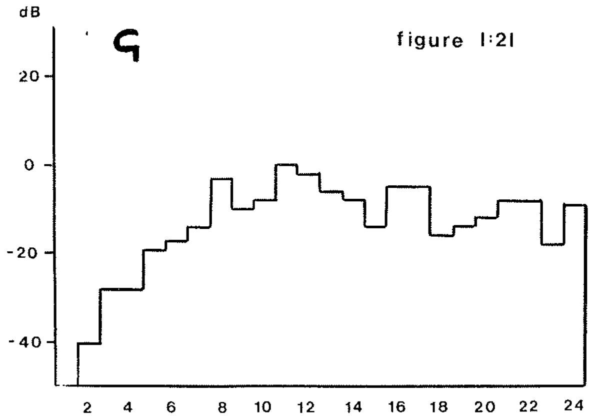


figure I:21

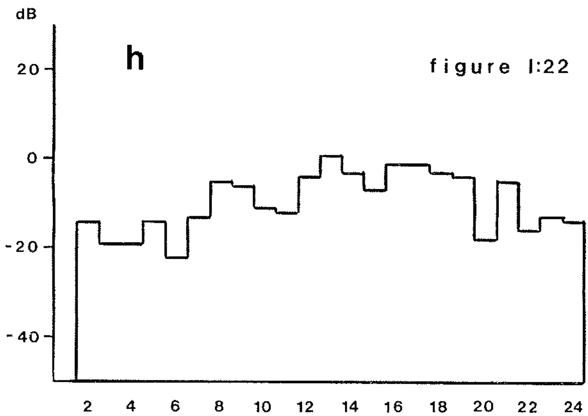


figure I:22

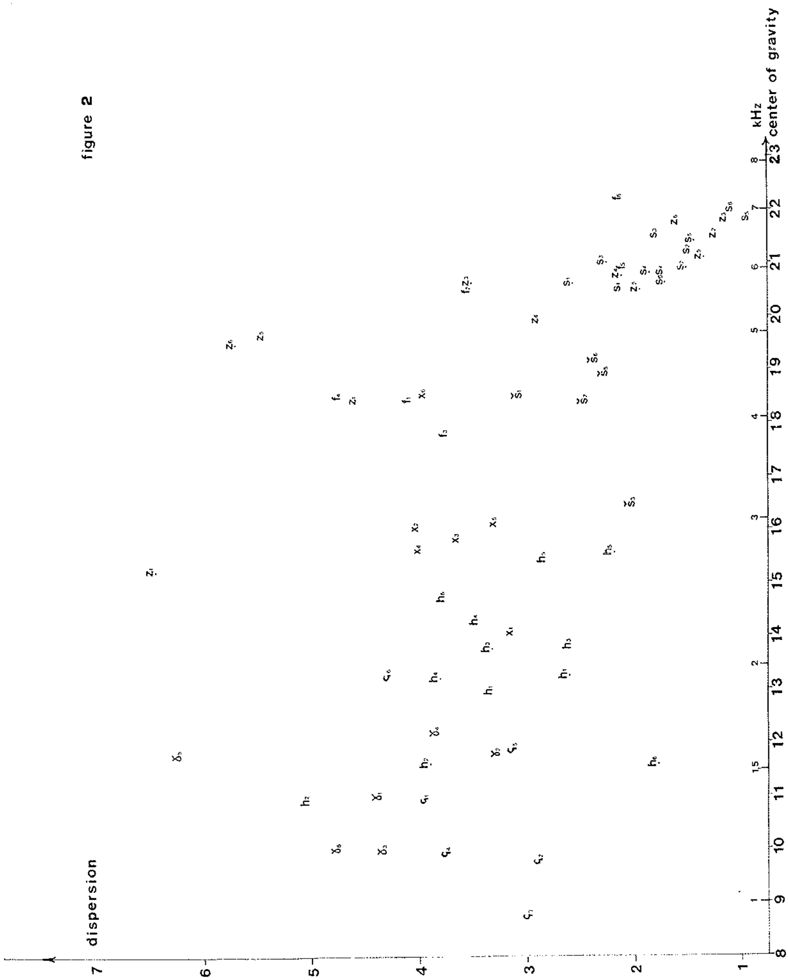
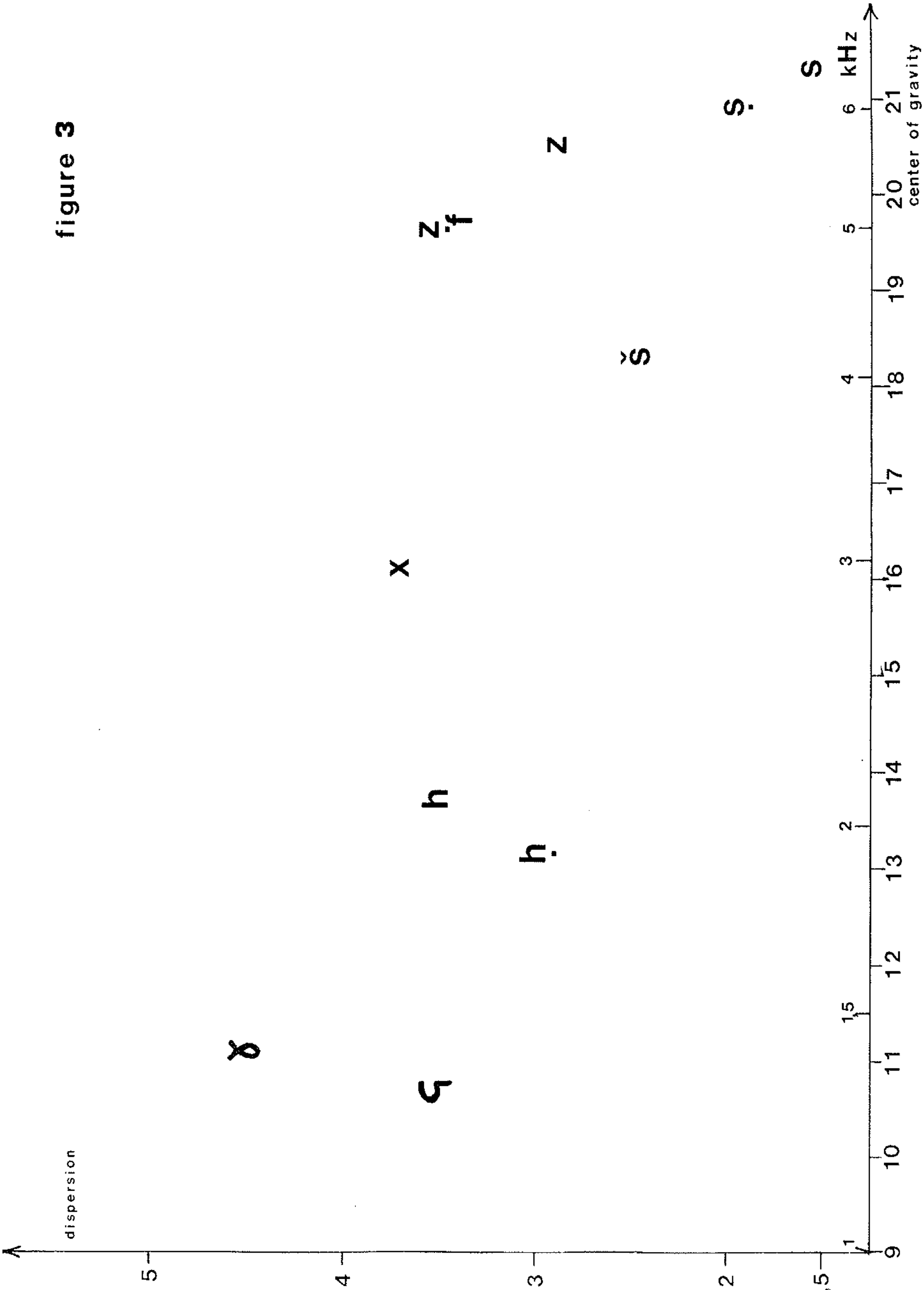

dispersion
kHz
center of gravity
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23

figure 2

figure 3


dispersion
center of gravity
kHz
ɣ
ʕ
h
ḥ
x
š
ẓ
f
z
ṣ
s
5
4
3
2
1,5
1
1,5
2
3
4
5
6
9
10
11
12
13
14
15
16
17
18
19
20
21

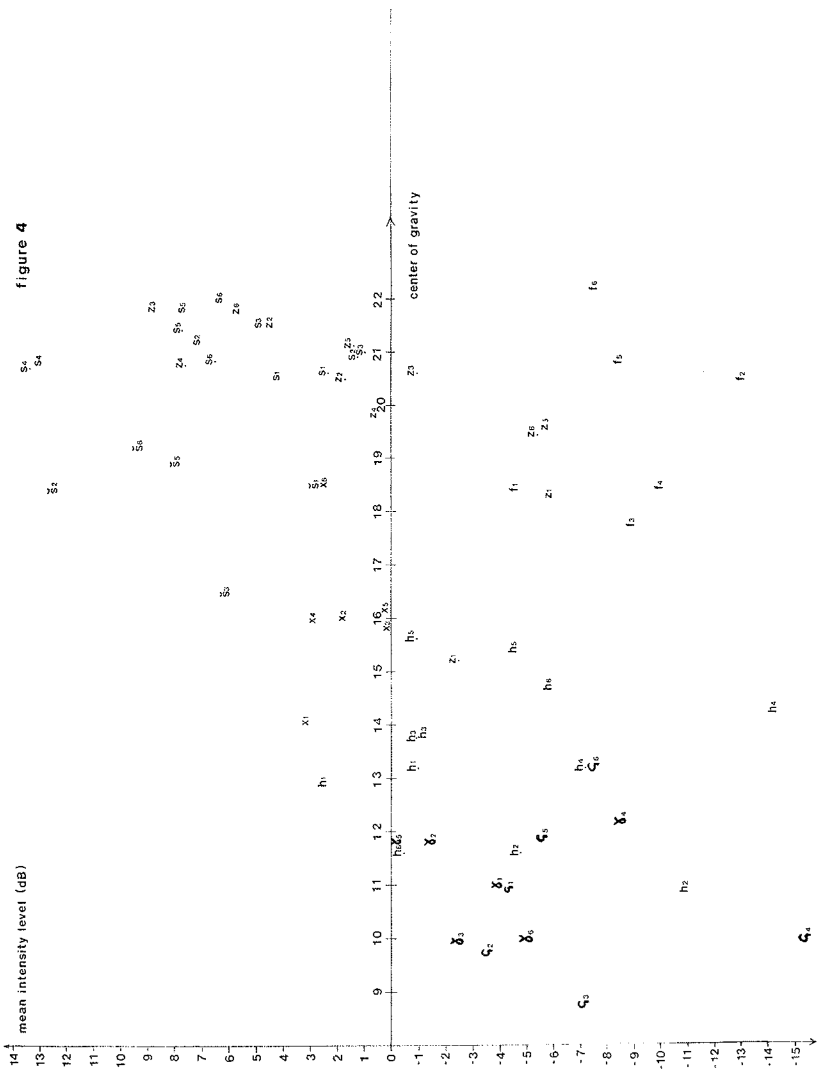


figure 4

figure 5

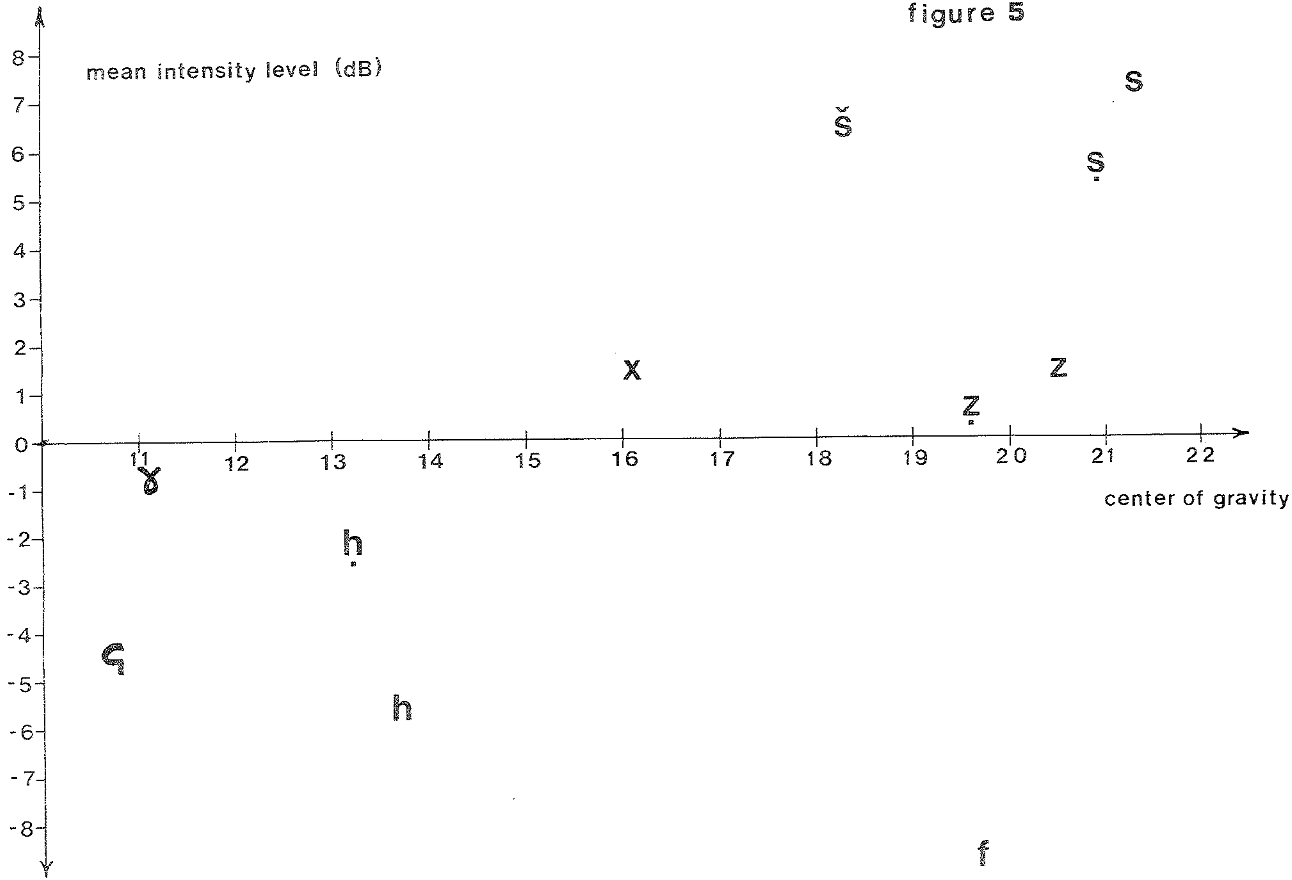
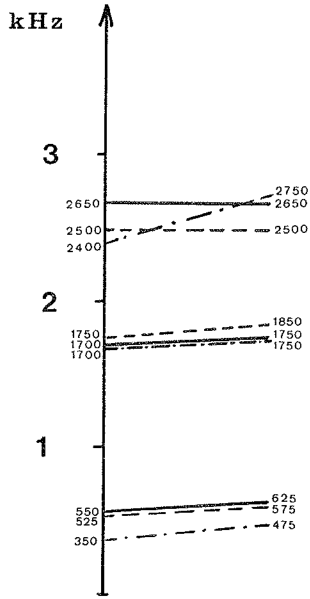
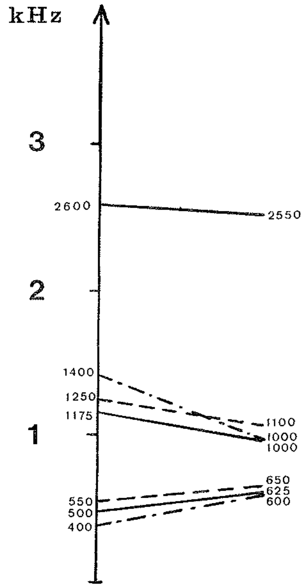

mean intensity level (dB)
8
7
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
-7
-8
11
12
13
14
15
16
17
18
19
20
21
22
center of gravity
s
š
ṣ
x
z
ẓ
ɣ
ḥ
ʕ
h
f

figure 6:1

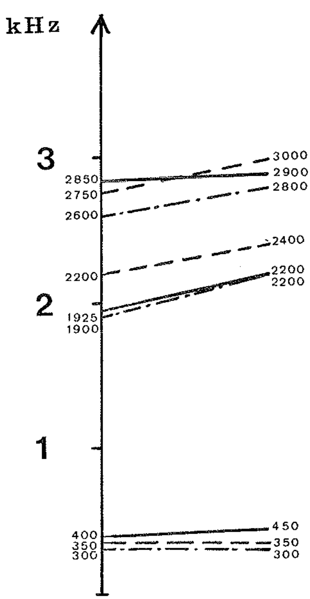


(s)ā(d i s)

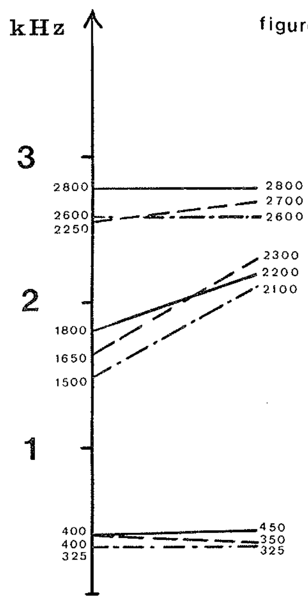


(ṣ)ā(d i ʔ)

figure 6:2

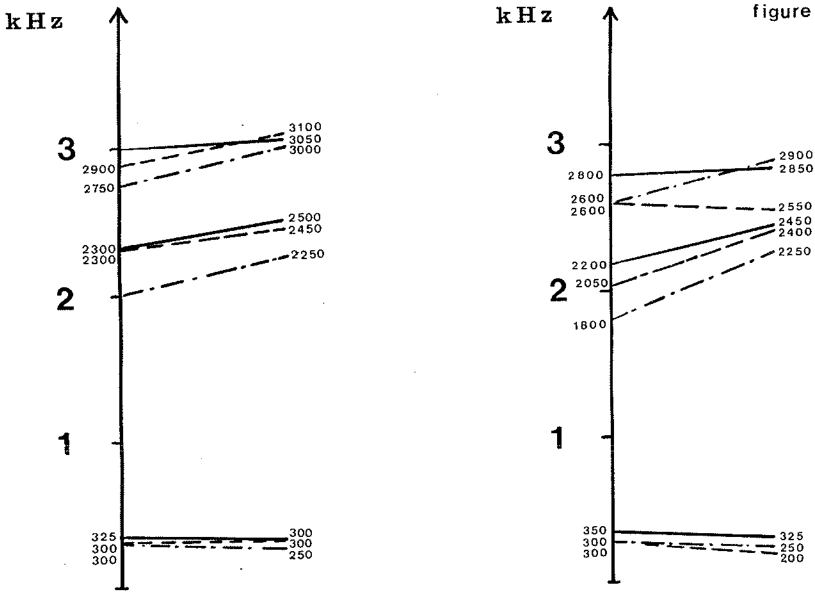


(s) ē (f)



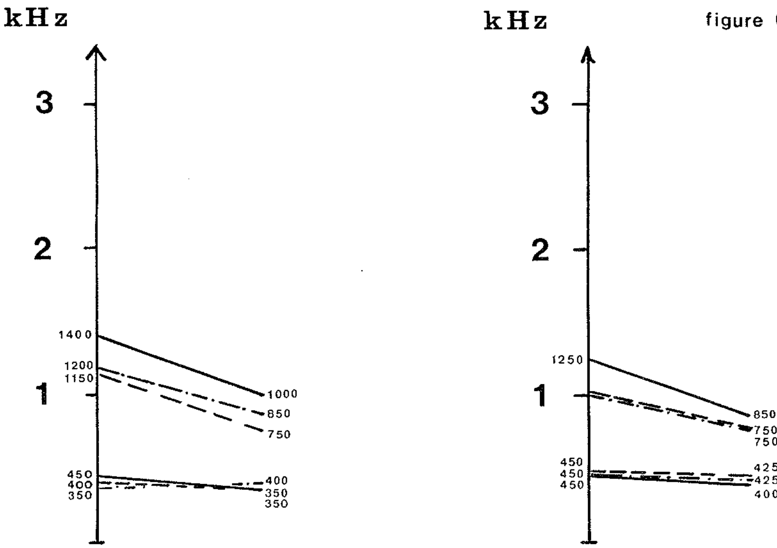
(ṣ) ē (f)

figure 6:3



(s)ī(di) (ṣ)ī(ni)

figure 6:4



(s)ō(da) (ṣ)ō(t)

figure 6:5

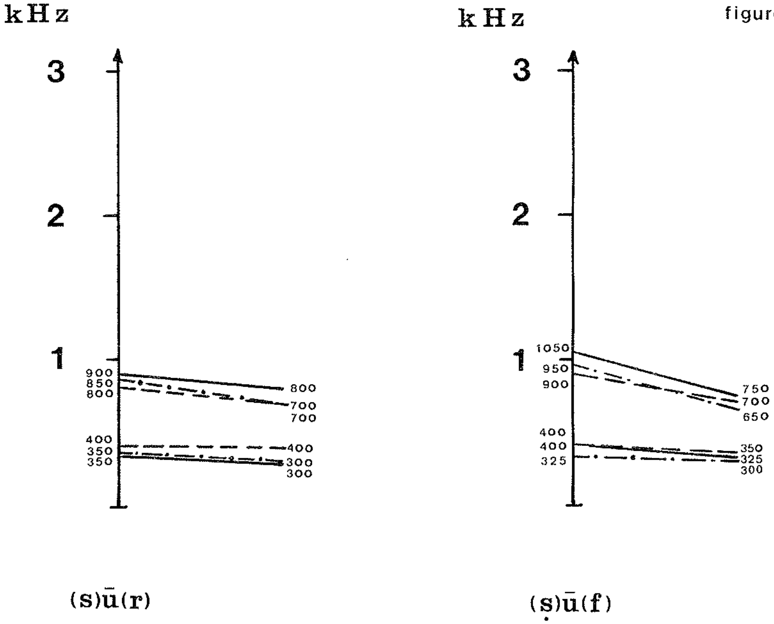

kHz
3
2
1
900
850
800
400
350
350
800
700
700
400
300
300
(s)ū(r)
kHz
3
2
1
1050
950
900
400
400
325
750
700
650
350
325
300
(ṣ)ū(f)

figure 7:1

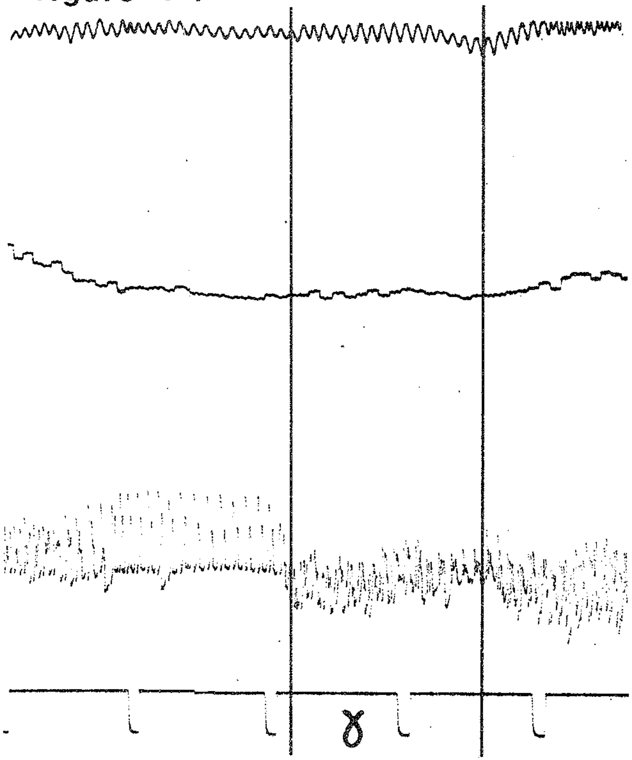


figure 7:2

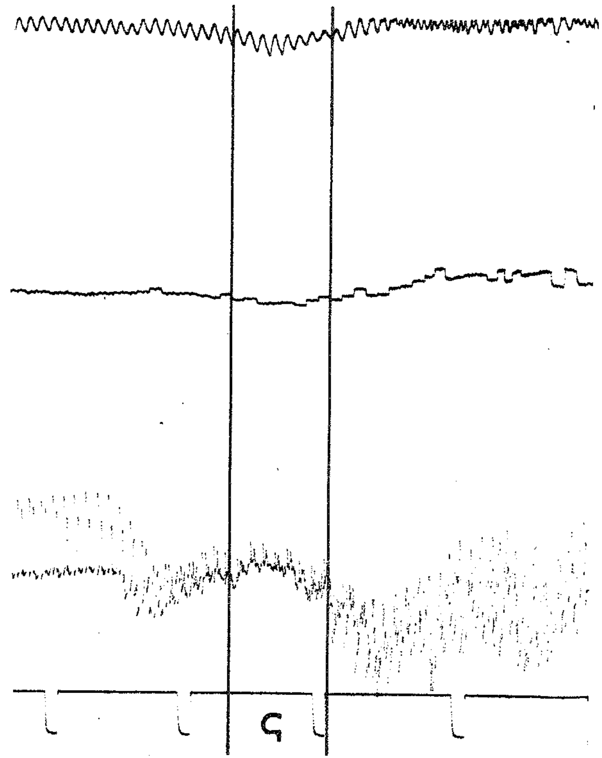


figure 8:2

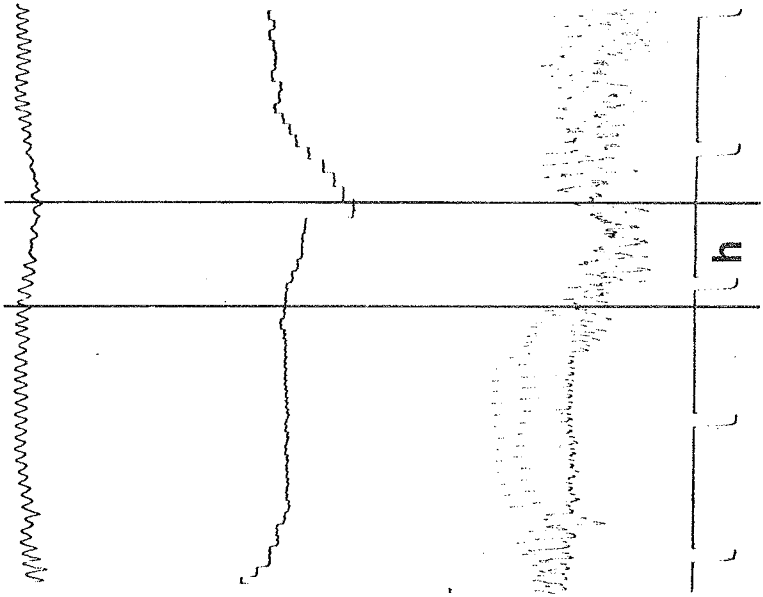


figure 8:l