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SIMILARITY RATINGS AND DIMENSION ANALYSES OF PERCEIVED SOUND QUALITY OF HEARING AIDS

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ABSTRACT

Twenty-five normal hearing subjects rated the similarity between eight hearing aid systems as regards their reproduction (recorded over a 2 cc coupler) of three different programs (music, speech). They also made "free verbal descriptions" concerning the reproduction of the systems. The systems included a variety of hearing aids with widely differing characteristics. The similarity ratings were analyzed according to a model for individual differences in multidimensional scaling (INDSCAL). The results point to perceptual dimensions as "brightness-darkness", "fullness" ("volume"), "loudness", "clearness/distinctness", various "room characteristics", and a dimension related to certain resonance characteristics of the systems.

INTRODUCTION

This paper enters into a series of studies on the perceived sound quality of hearing aids. The background and the general purposes of the work were described in an earlier report (Gabrielsson & Sjögren, 1974). Hearing aids are usually primarily designed to give good intelligibility of speech. However, it is not sure that a hearing aid designed for good intelligibility is also a good one as regards the perceived sound quality in general. Although there are frequent complaints from hard-of-hearing people concerning the perceived sound quality of their hearing aids, this point has often been neglected in earlier research and technology.

To get a basis for improvements it is necessary to increase our scarce knowledge about the various dimensions in perceived sound quality and to relate them to physical parameters of the hearing aids. Multivariate techniques like factor analysis and multidimensional scaling (MDS) may be useful tools to attack these problems. In the above mentioned report we used a variant of the "semantic differential" (ratings on various "adjective scales" followed by factor analysis) to get a dimensional description of the perceived sound quality of five selected hearing aids. In the present experiment an MDS technique was tried. The subjects made similarity ratings concerning the reproduction of eight different hearing aids and the ratings were then analyzed according to a special model for MDS. A similar technique was successfully applied to judgments of loudspeaker reproductions (Gabrielsson *et al* , 1974).

METHOD

Stimuli and listening conditions

The stimuli were constituted by three different programs as presented over each of eight different reproduction systems. Both the programs and the systems were selected to represent widely differing characteristics.

Listening levels were set by the experimenters to correspond to a natural level for the respective program sections (see below in the description of the programs). The difference in average level between the different systems reproducing a given program was less than ± 3 dB.

The programs were:

Program 1 (P1) : Oscar Peterson's jazz trio (piano, bass, drums). Recorded in a gramophone studio. Level: about 70 dB SPL. Gramophone record: "Verve 2304 062". Sample from the tune "Something's coming". Time: 1'50" - 2'05".

Program 2 (P2) : Excerpt from Gustav Mahler: Symphony No. 5. Recorded in the Concert Hall of Stockholm, Stockholm Philharmonic Orchestra (full orchestra in fortissimo). Level: about 80 dB SPL. Gramophone record: "Lyssna" 4. Sample from the 5th movement. Time: 15'10" - 15'31".

Program 3 (P3) : Recording from a coffee break in the laboratory. Some fifteen persons chatting. Level: about 70 dB SPL.

Each program section lasted 15-21 seconds and was selected so as to represent fairly homogeneous excerpts from the music or speech in question.

The systems for reproductions were:

System 1 (S1) : Broad-band system. Copy of the respective master tape, bandwidth 100-15000 Hz ± 3 dB, distortion less than 1 %.

System 2 (S2) : Body-worn hearing aid, type A.

System 3 (S3) : Body-worn hearing aid, type B.

System 4 (S4) : Body-worn hearing aid, type C with tone-control setting "N" ("normal").

System 5 (S5) : Body-worn hearing aid, type C with tone-control setting "L" ("low").

System 6 (S6) : Body-worn hearing aid, type C with tone-control setting "H" ("high") together with an extra tube 80 mm length between earphone and coupler.

System 7 (S7) : Body-worn hearing aid, type D.

System 8 (S8) : Body-worn hearing aid, type E.

Frequency curves and distortions for systems S2-S8 are given in Figure 1 and Table I, respectively.

These systems were recorded in an anechoic chamber using the 2 cc coupler IEC and a loudspeaker which is flat ± 5 dB 100--5000 Hz, see Figure 2. Note that the 2 cc coupler can be used for measurements only up to about 2000 Hz. Therefore it gives an unwanted "coloring" of the sound for higher frequencies. The reader should keep this in mind when reading the results and discussions. In later experiments we intend to use the same hearing aids fitted in individual earmoulds to see whether the results will be compatible or not with those given in this paper.

During the experiment the stimuli were presented binaurally over headphones TDH39, cushion MX41AR. The subjects were sitting three at a time in an audiometric booth.

Tape copies of all stimulus material are available on request.

Figures 1 - 2 about here

Subjects

There were 25 male subjects, 20-32 years old, all but one with normal hearing ($\leq$ 20 dB hearing loss 125-4000 Hz). One subject (subject 24) had 25-30 dB loss 125-500 Hz for his left ear. At most seven or eight subjects could be said to have experience of high fidelity sound reproduction. Some few subjects performed music as amateurs. All subjects were paid.

Procedure

The eight reproduction systems were arranged in all possible pairwise combinations, that is, (8 x 7)/2=28 combinations, within each program. Since there were three programs, there were in all 84 (3 x 28) combinations. These 84 pairs were recorded on tape in a randomized order and subdivided into twelve blocks of each seven pairs. The order of these twelve blocks was then independently randomized for each new experimental session. The silent interval within each pair was about one second and the interval between pairs about six seconds.

For each of the 84 pairs the subjects rated the perceived similarity between the respecitve reproductions according to the following instruction:

"In this experiment you will listen to two sections of music, one with jazz music and one with symphony music. There is also a section with people chatting during a coffee break. These sections have been recorded as they sound in different hearing aids. Each section is played two times in immediate succession, the first time as it sounds in one of the hearing aids, the second time as it sounds in another one. For each such case you shall judge the similarity between the two reproductions - how similar you think the two reproductions are between themselves. The judgment shall be made on a scale from 0 to 100. The number 100 denotes perfect similarity (you cannot hear any difference, it sounds like the same reproduction both times). The less similarity the lower number - down to the number 0, which denotes 'minimum similarity'. Use any number from 0 to 100 which you think is the most appropriate for describing the similarity according to this scale.... Notice that your judgments shall not refer to evaluations of the reproductions. Your judgments shall refer solely to the perceived similarity between the reproductions, regardless of what you think about their quality."

After the instruction there were fifteen training trials constituting a representative selection from the 84 cases. Then the 84 combinations were presented in the actual randomized order. The same procedure was repeated (with fewer training trials) in a second session so that each subject made two judgments per each of the 84 pairs. Each session lasted about 1 3/4 hour with two five minutes' breaks and short relaxation pauses between the blocks. At the end of the second session the subjects were instructed to write down in their own words whether they had used any special principles for doing their similarity judgments.

In a third session the subject listened to fifteen of the 84 pairs and was instructed to "write down in your own words how you perceive the similarity or dissimilarity between the two reproductions within each pair". These descriptions will be referred to as "verbal descriptions" in the following. Finally he listened to all reproductions of each program, now however to one reproduction at a time (in all 24 cases = 8 reproductions x 3 programs) and with the task to judge "how true to nature the reproduction is". This judgment was made on a scale from 0 to 10, where 10 denoted "perfectly true to nature (sounds like the original sound)" and 0 "practically no fidelity at all". The 24 cases were recorded in a randomized order and divided into three blocks of eight cases each, the order of the blocks independently randomized for each new session. Eight training trials were made.

Data treatment

Inter- and intra-rater reliabilities were estimated by an analysis of variance technique described in earlier reports (Gabrielsson et al, 1971; Gabrielsson, 1973). The inter-rater reliabilities of the similarity ratings were 0.90 or higher at each of the three programs. The intra-rater reliabilities varied between 0.41 and 0.86, their median being 0.72.

After taking the mean of the two judgments made per each of the pairwise combinations the twenty-five individual similarity matrices were used as input to the INDSCAL program developed by Carroll & Chang (1970), see also Carroll (1972). This model is designed to deal with individual differences in multidimensional scaling (MDS) on the assumption that different individuals may give different weights to different dimensions. It results in a representation of the stimuli (here the reproduction systems) as points in a Euclidean space with fixed axes (no rotation of axes). Furthermore the subjects are represented as points in a "subject space" presenting information about the different subjects' weightings of the actual dimensions. For a short description and examples see Gabrielsson (1973). This model was successfully applied in a re-analysis of data from an earlier report on perceived sound-reproduction (Gabrielsson 1974).

The analysis was made separetely for each of the three programs. The individual similarity matrices cannot be given here. However, the group data matrices are seen in Table II.

For each analysis (at least) three different solutions were compared. In two of them the iterative procedure started from different initial configurations. As a control a solution was also obtained for a reduced group of nineteen subjects, eliminating those six subjects who had an intra-rater reliability less than 0.60. In general there was a good agreement between these different solutions for the case of three dimensions. For the case of four or five dimensions, however, there were more discrepancies. Accordingly the three-dimensional solutions were studied in the first hand. The interpretation was made utilizing the information about the physical characteristics of the systems given in Figure 1 and the "verbal descriptions" given by the subjects (as related also to the weights of the various dimensions for different subjects according to the INDSCAL solution).

RESULTS

The three-dimensional INDSCAL solutions are seen in Figures 3-5 and Table III. The corresponding subject spaces are not given in figures but the weights appear in Table IV. In most cases the interpretation of the dimensions is about the same for all three programs and so the description is made dimension for dimension rather than program for program. Three dimensions accounted for 65.7 % of the variance in the data for program 1, and for 69.2 % and 72.5 % of the variance in the data from program 2 and 3, respectively.

Tables III and IV and Figures 3-5 about here

In dimension I (abbreviated D I) the ranking of the systems is almost identical for all three programs. S8 and S3 are to the left, followed by S7 and S6, S2 is somewhere in the middle and the remaining three systems S1, S4, and S5 lie more or less together to the right.

This ranking has a rather close correspondence in the frequency curves of the different systems, see Figure 1. S3 and S8 are narrow-band systems with peaks in the region about 1000-3300 Hz and a rapid fall on both sides of this region. S6 behaves in a similar manner, however, also with a (less pronounced) peak around 500 Hz. S7, too, has peaks in the 1000-3000 Hz region but falls off much slower towards the bass region (down to 250 Hz). This is also true for S2, which is, however, somewhat flatter than S7 and also falls off slower towards higher frequencies (from 3000 Hz upwards). S1 is flat over a greater frequency range than in any other system. S4 is flat within ± 4 dB 150-3500 Hz, including a rounded peak in the region 200-300 Hz. In S5, finally, there is a trend to a rising frequency response towards the bass region with a peak in the 200-300 Hz region. In summary, one may see a trend from narrow-band systems with peaks at high frequencies (S3, S8) towards flatter broad-band systems, even with a certain emphasis on the bass region (S5). (It may be noted that the peak appearing in the vicinity of 1000 Hz for S2 - S8 is mainly an effect of the loudspeaker used for the recording, compare Figure 2.)

Most subjects have their highest weights in D I (see Table IV). Studying their "verbal descriptions" and answers concerning judgment principles definitely gives the impression that the perceptual differences between the reproductions are mainly connected with the bass versus treble content in the respective reproductions. Therefore, D I may be mainly interpreted as a "brightness-darkness" dimension (possibly with a strain of "hardness-softness") in accordance with results from earlier experiments (see, for instance, Gabrielsson et al, 1971,1973, 1974). A physical correlate of this dimension is found in the form of the frequency curve as described above. Thus S4 and S5, which extend into lower frequencies and with a bass boost in S5, sound "darker" than the narrow-band systems which fall off more or less steeply towards the bass region. S1 is less "dark" than S4 and S5 since it extends into higher frequencies and has a flatter response curve than those two systems. From an evaluative point of view a good reproduction should neither be too "dark" (as S5, which emphasizes the counter-bass or other low-pitched instruments too much and does not make justice to the high-pitched cymbals in the jazz program or the trumpets in the excerpt from Mahler's symphony), nor too "bright" (as S3, S8 and others) in which the bass instruments more or less disappear and in which the drum beats in the jazz section lose their "substance").

It is possible, however, that "brightness-darkness" does not cover all aspects of D I. It is noted, for instance, that the positions of S1, S4, and S5 are somewhat different for the Mahler program (P2) than for the other programs. For the Mahler program S1 lies utmost on one side instead of S5 as for the jazz program and the speech program. However, S1 can hardly be said to sound "darker" than S5 for the Mahler program. It was also noted in the verbal descriptions that the systems S1, S4, and S5 were frequently characterized as having more "fullness" than the narrow-band systems, furthermore sounding "louder" and sometimes "nearer to the listener" than the narrow-band systems. These characteristics were especially emphasized for the S1 system (quite naturally). It may be, therefore, that D I rather reflects a composite of "brightness-darkness", "fullness", "loudness", and (perceived) "distance" with their relative prominence somewhat varying between the three programs. It is possible, for instance, that the "fullness" and/or "loudness" aspects become relatively more important at the Mahler program, which is played in fortissimo and extends into both higher and lower frequency regions than the other programs. These questions are treated further in the Discussion.

In dimension II (D II) S1 lies utmost on one side of the continuum, followed by S2. In P1, the jazz program, the extreme position of S1 is very conspicuous. Unlike the situation in D I the broad-band systems S4 and S5 do not appear together with S1 but lie on the other side of D II. A frequently mentioned characteristic of S1 (besides those mentioned in connection with D I) is its "clearness" or "distinctness" as compared to other systems. The different instruments or voices stand out more clearly than in the other systems. An interpretation in terms of "clearness/distinctness" seems natural and is in line with results from earlier experiments (references above). The physical correlates of this dimension are probably the frequency range and the amount of distortion. S1 has a broader frequency range than any of the other systems, permitting a good reproduction of even very low-pitched and high-pitched instruments and making more justice to the "timbre" of instruments and voices by not suppressing their higher frequency components. Furthermore, the amount of distortion produced in S1 is considerably less than in the other systems which ought to contribute to its "clearness".

The fact that S4 and especially S5 appear on the "poor" side of this dimension may depend on the circumstances that they do not reach so high in frequency as S1, that they introduce more distortion than S1, and because of the bass boost in S5. The relative dominance of the bass region make voices sound "dull", "diffuse", "blurred" and the like and gives relatively more emphasis to the low-pitched accompanying instruments in the music sections.

Although the remaining systems have narrower frequency range and in general introduce more distortion they may appear "clearer" than S4/S5 in certain respects. For instance, voices may appear more distinct by suppressing the bass region. In certain hearing aids the frequency curve is deliberately given a 6 dB/octave rise towards higher frequencies to give good intelligibility of speech. As regards the music sections the suppression of the bass region may contribute to an increased "clearness" in the sense that much of the accompanying instruments are suppressed and the melody-leading instruments stand out more clearly (this is perhaps most evident for the relatively complex symphony section, P2).

The fact that S1 stands out from the other systems much more at the jazz program (P1) than at the others may be dependent on the relative "clearness" of the programs themselves. In the jazz section there are few instruments, and the piano is quite dominating. In the section with symphony music there is a full symphony orchestra playing a "dense" and "complex" section in fortissimo. And in the speech section there is a lot of people talking at the same time so that distinct voices appear only here and there.

The common feature of dimension III (D III) for all three programs is that S6 lies in one end of the continuum and S3 in the other end. The order of the other systems between these extremes is somewhat varying for the different programs. It is noted, however, that S8 comes near to S6 for programs 1 and 2, and that S7 comes near to S3 for programs 2 and 3. It seems that this dimension is related to the relative prominence of the various resonance peaks in the frequency curves of the systems. In S3 the peak slightly below 2000 Hz strongly dominates over two other peaks around 1000 and 3000 Hz, respectively. And the situation is in fact very much the same for S7. In S6, on the other hand, there are three peaks at about the same frequencies as in S3, however, all of them reaching the same level. There is also a less pronounced peak around 500 Hz.

The situation is rather similar for S8 (except for the peak at 500 Hz).

While S3 as well as S6 both certainly sound very bad, there is a marked difference between them in their "colouring" of the reproduced sound. The reasons are probably found in the facts mentioned above. The perceptual interpretation of this dimension is more difficult than for the earlier dimensions, and we presently refrain from such an interpretation awaiting results from further research.

It seems probable that the perceived sound quality of the different systems is most dependent on their respective frequency responses. Concentrating on the way the systems differ in their frequency response one may also discuss dimensions I - III in the following way, see also Figure 6.

Figure 6 about here

In D I there is a "gradual" transition from narrow-band systems with peaks at high frequencies (S3, S8) to broader systems still falling towards the bass region (S7, S2), further to a broad-band system with flat response (S1), finally to broad-band systems more or less rising towards the bass region (S4, S5). It seems rather natural that this continuum would perceptually reflect a gradual transition from "bright" and "thin" to "dark" and "full-toned".

In D II there is a transition from the broad-band system with flat response (S1) to a relatively broad system falling towards the bass region (S2), further to narrow-band systems emphasizing higher frequencies (S3, except at P1, S8, S6, S7) and finally to broad-band systems with a certain bass emphasis (S4, S5). This may perceptually be reflected as "clearness/distinctness", possibly with a certain emphasis on "clearness" in the middle- and high-frequency region.

In D III (the perceptual interpretation of which is presently left open) there are narrow-band systems at both ends of the continuum, however, differing in the prominence of their resonance peaks: S3 with a dominating peak at about 2000 Hz, S6 with three peaks equalized in level. S3 and S6 are followed by other narrow-band systems, S7 and S8, respectively (with some exceptions), and the broad-band systems lie more or less in the middle of the continuum.

The results from the evaluative ratings regarding how "true to nature" the systems succeeded in reproducing the different programs are given in Table V. The results are as expected. S1 is outstanding, of course, and gets about the same high rating value for all three programs. Among the remaining systems those with a broader frequency range (S4, S5, S2) get higher ratings than systems with narrower frequency response. Most systems are rated higher for the speech program (P3) than for the music programs. A notable exception, however, occurs for S5. Its relatively low value for the speech program (compared to its values for the music programs and compared to the other systems as regards the speech program) is probably due to the bass boost of S5.

It would be interesting to apply a dimension analysis to the data of Table V. Presently, however, there seems to be no quite satisfactory method for dimension analysis of preference data (Carroll, 1972).

Table V about here

DISCUSSION

It seems that similarity ratings concerning the sound reproduction of hearing aid systems can be made with high or fairly high reliability even by subjects who have no special experience of judging sound reproduction systems. The inter-rater reliabilities were very high and the intra-rater reliabilities satisfactory in most cases. With more than two judgments per case (as here) the intra-rater reliabilities will certainly be still higher.

The model for analysis of the similarity ratings (INDSCAL) resulted in three interpretable dimensions without further rotation of the reference axes. The main principle of this model - that different subjects give different weights to different dimensions - in general seems very plausible and is often suggested from comparisons of the "verbal descriptions" given by different subjects.

Supplementary information in the form of free "verbal descriptions" and the like is highly valuable when interpreting the dimensions (compare Gabrielsson, 1973). The capability and willingness of writing such "verbal descriptions" certainly varies very much with individuals and so, too, do their wordings. Combining these two information sources - the results from a dimension analysis and the "verbal descriptions" - gives a more safe basis for interpretation of the results than does either procedure alone.

The dimensions described under Results agree (with exception for dimension III) with dimensions found in our earlier experiments on perceived sound quality of various sound-reproducing systems (Gabrielsson et al, 1971, 1973, 1974). It always has to be pointed out that the resulting dimensions may be highly dependent on the specific context of systems, programs, subjects, analysis methods, etc. The present experiment is no exception. The suggested problems are highlighted in connection with the interpretation of dimension I.

As seen under Results, D I was actually interpreted as a blending of certain dimensions: "brightness - darkness", "fullness" (full-toned versus thin), and possibly "loudness" and "distance". This does not mean that these dimensions could not be psychologically separated from each other. Rather the probable explanation is that the specific systems used here co-vary in some of these dimensions and thus do not allow the different dimensions to fall out separately in the analysis of the similarity ratings. Thus S1, S4, and S5 (and to a certain extent S2) are all perceived as more "full-toned" as well as "darker" and "louder" than the other systems, which in their turn all are relatively "thinner", "brighter" and of somewhat less loudness than S1, S4, and S5.

Although the specific stimulus context thus may have made it hard for dimensions as "fullness" ("volume"), "brightness", and "loudness" to appear as separate dimensions in the multidimensional analysis, it is quite clear from the subjects' own descriptions that these dimensions were noted as separate perceptual aspects. And in earlier experiments with other stimulus contexts (see our earlier reports) dimensions as these indeed appeared as separate entities in the analyses according to various multivariate techniques.

(It is often said that the existence of a certain perceptual dimension is demonstrated by showing that it has a unique relation to one or more stimulus variables. This criterion seems unsatisfactory in situations where, for reasons of stimulus selections, such a unique relation cannot appear. It seems that a more adequate criterion must lie on a psychological level, that is, whether it can be demonstrated that the subjects agree in observing a certain perceptual dimension, even though its underlying psychophysical relation cannot be said to be unique in the actual situation.)

The fact that the configurations of the systems are somewhat different for different programs is quite in line with the frequently occurring interactions between systems and programs (see the earlier reports). The details are, however, extremely complicated to explain due to the big difficulties of adequately describing the programs in physical terms as well as the phenomena appearing when they are reproduced by various systems.

The appearance of about the same dimensions here as in earlier reports points forward to a rather limited set of dimensions to be selected for validation studies. Further comments on these questions will be given in a forth-coming paper.

We finally remind the reader of two important limitations: the reproduction of the systems was recorded over the 2 cc coupler and normal-hearing subjects were used. The results, however, provide a good reference basis for judging the results from experiments (now in progress) with hearing aids used directly by hard-of-hearing people.

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TABLE I. Harmonic distortion in % for systems S1 - S8.

Second harmonic

	S1	S2	S3	S4	S5	S6	S7	S8
125 Hz	<1	3		<1	<1	<1		
250	<1	0.5	<6	<1	<1	<1	3	6
500	<1	1	6	<1	<1	<1	3	10
1000	<1	1	3	<1	<1	<1	2	4

Third harmonic

	S1	S2	S3	S4	S5	S6	S7	S8
125 Hz	<1	3		<1	<1	<1		
250	<1	3	1	<1	<1	<1	<1	3
500	<1	3	3	1	1	1	2	1.5
1000	<1	3	2	1	1	1	2	1

TABLE II. Similarity ratings averaged over 25 subjects for pairs of systems at three programs.

Systems		S1	S2	S3	S4	S5	S6	S7	Program
	S2	39							PROGRAM 1
	S3	27	41						
	S4	41	42	44					
	S5	35	40	23	74				
	S6	26	41	48	35	42			
	S7	36	52	59	47	44	52		
	S8	29	43	51	32	37	64	57	
	S2	49							PROGRAM 2
	S3	31	48						
	S4	53	58	47					
	S5	45	46	21	64				
	S6	32	56	41	59	47			
	S7	39	62	71	65	43	58		
	S8	24	52	56	41	42	78	57	
	S2	50							PROGRAM 3
	S3	32	49						
	S4	48	52	34					
	S5	43	34	25	85				
	S6	31	42	41	39	36			
	S7	43	51	66	56	37	40		
	S8	24	46	49	33	25	62	75	

TABLE III. Co-ordinate values for eight systems in the three-dimensional INDSCAL solution.

PROGRAM 1

		I	II	III
System	1	.24	-.79	.37
	2	-.01	-.21	.21
	3	-.42	.37	.40
	4	.47	.34	.22
	5	.55	.20	-.35
	6	-.25	-.01	-.56
	7	-.20	.18	.11
	8	-.37	-.07	-.41

PROGRAM 2

		I	II	III
System	1	.56	-.53	.12
	2	.02	-.47	-.25
	3	-.41	-.23	.59
	4	.25	.26	.23
	5	.43	.55	-.21
	6	-.22	.19	-.48
	7	-.20	.04	.35
	8	-.43	.18	-.34

PROGRAM 3

		I	II	III
System	1	.37	-.56	-.29
	2	.04	-.41	-.07
	3	-.27	-.23	.49
	4	.41	.33	.07
	5	.47	.53	-.09
	6	-.34	.21	-.65
	7	-.17	-.04	.49
	8	-.50	.16	.05

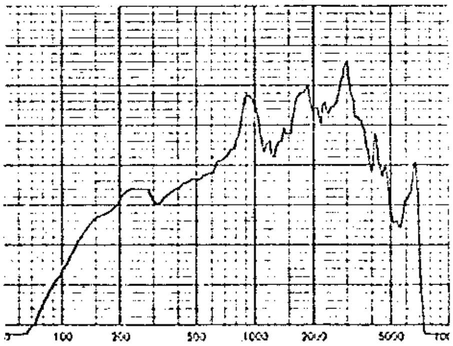
TABLE IV. Weights for individual subjects in different dimensions.

Subject	P1 Dimension			P2 Dimension			P3 Dimension		
	I	II	III	I	II	III	I	II	III
1	.74	.29	.15	.72	.24	.39	.75	.36	.34
2	.64	.46	.25	.67	.23	.44	.59	.47	.17
3	.47	.50	.35	.26	.66	.16	.50	.64	.19
4	.78	.14	.25	.63	.50	.31	.68	.28	.06
5	.32	.45	.49	.70	.12	.54	.35	.52	.41
6	.60	.17	.51	.56	.25	.61	.71	.19	.23
7	.73	.00	.34	.76	.29	.23	.79	.27	.23
8	.56	.50	.22	.77	.17	.24	.55	.50	.44
9	.59	.49	.43	.70	.16	.17	.60	.49	.39
10	.52	.60	.21	.58	.24	.31	.55	.43	.47
11	.57	.52	.36	.79	.35	.07	.72	.45	.41
12	.48	.51	.20	.67	.29	.30	.59	.28	.55
13	.21	.59	.21	.43	.45	.46	.65	.44	.33
14	.25	.46	.69	.36	.60	.40	.64	.30	.45
15	.80	.18	.36	.67	.26	.43	.79	.20	.36
16	.63	.23	.44	.64	.47	.15	.68	.44	.29
17	.72	.38	.32	.70	.21	.33	.83	.30	.18
18	.65	.21	.36	.52	.20	.51	.65	.43	.42
19	.45	.49	.25	.44	.65	.38	.59	.25	.25
20	.74	.23	.32	.85	.16	.14	.85	.21	.20
21	.52	.42	.44	.35	.65	.36	.61	.37	.46
22	.80	.34	.22	.64	.14	.47	.82	.26	.26
23	.66	.16	.34	.75	.32	.23	.48	.50	.33
24	.40	.26	.61	.31	.35	.65	.62	.40	.33
25	.57	.44	.20	.26	.57	.57	.62	.59	.23

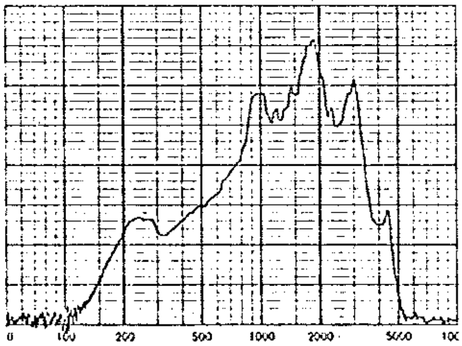
TABLE V. Mean ratings over 25 subjects for different systems on an "true-to-nature" scale.

	Systems							
	S1	S2	S3	S4	S5	S6	S7	S8
Program 1	7.7	5.3	3.1	6.5	6.1	2.7	4.9	2.8
" 2	7.6	4.8	2.4	6.2	6.5	4.6	3.4	3.4
" 3	7.7	6.9	5.7	6.9	4.4	2.9	5.2	3.9

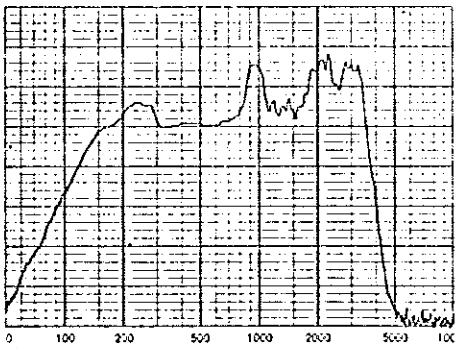
Figure 1. Frequency characteristics for systems 2-8. The frequency curves represent the combination of the respective hearing aid and the loudspeaker shown in Figure 2.



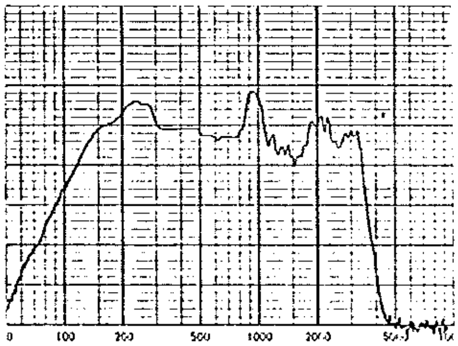
System 2



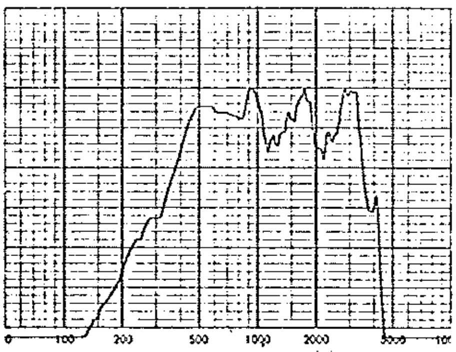
System 3



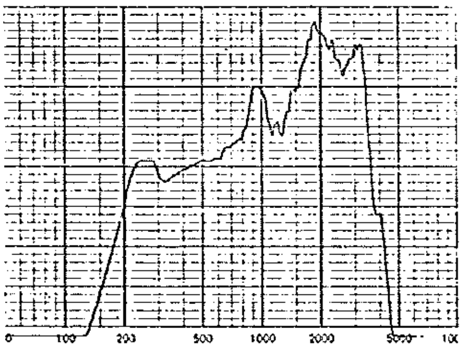
System 4



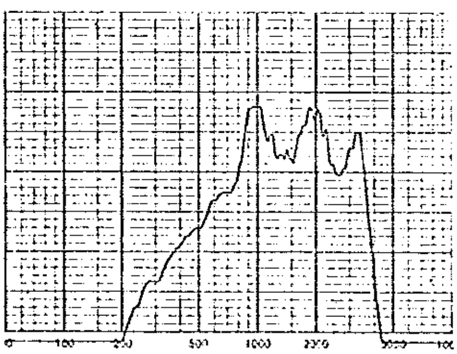
System 5



System .6

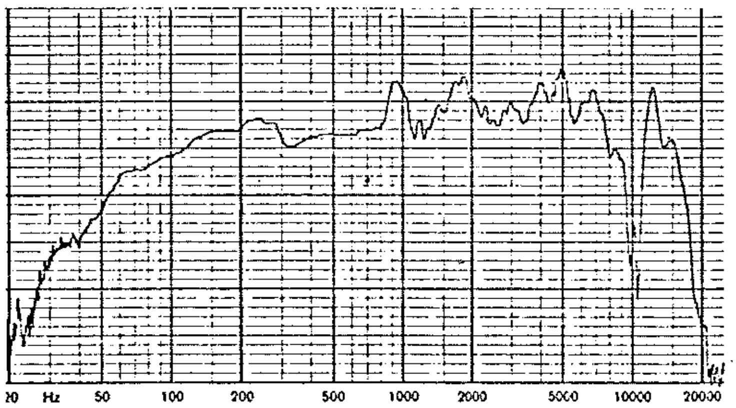


System 7



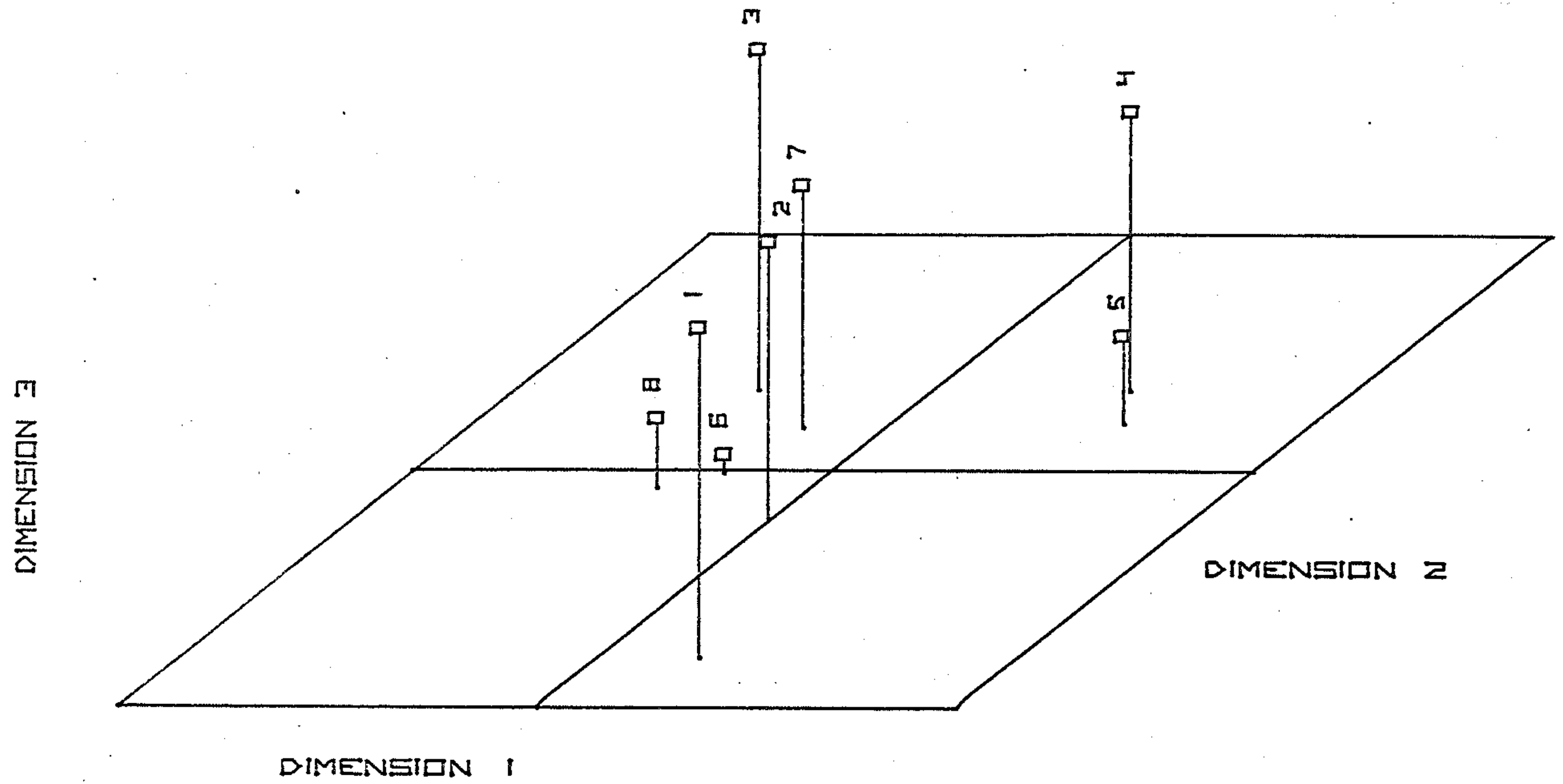
System 8

Figure 2. Frequency characteristic of loudspeaker used for the recording of program sections.



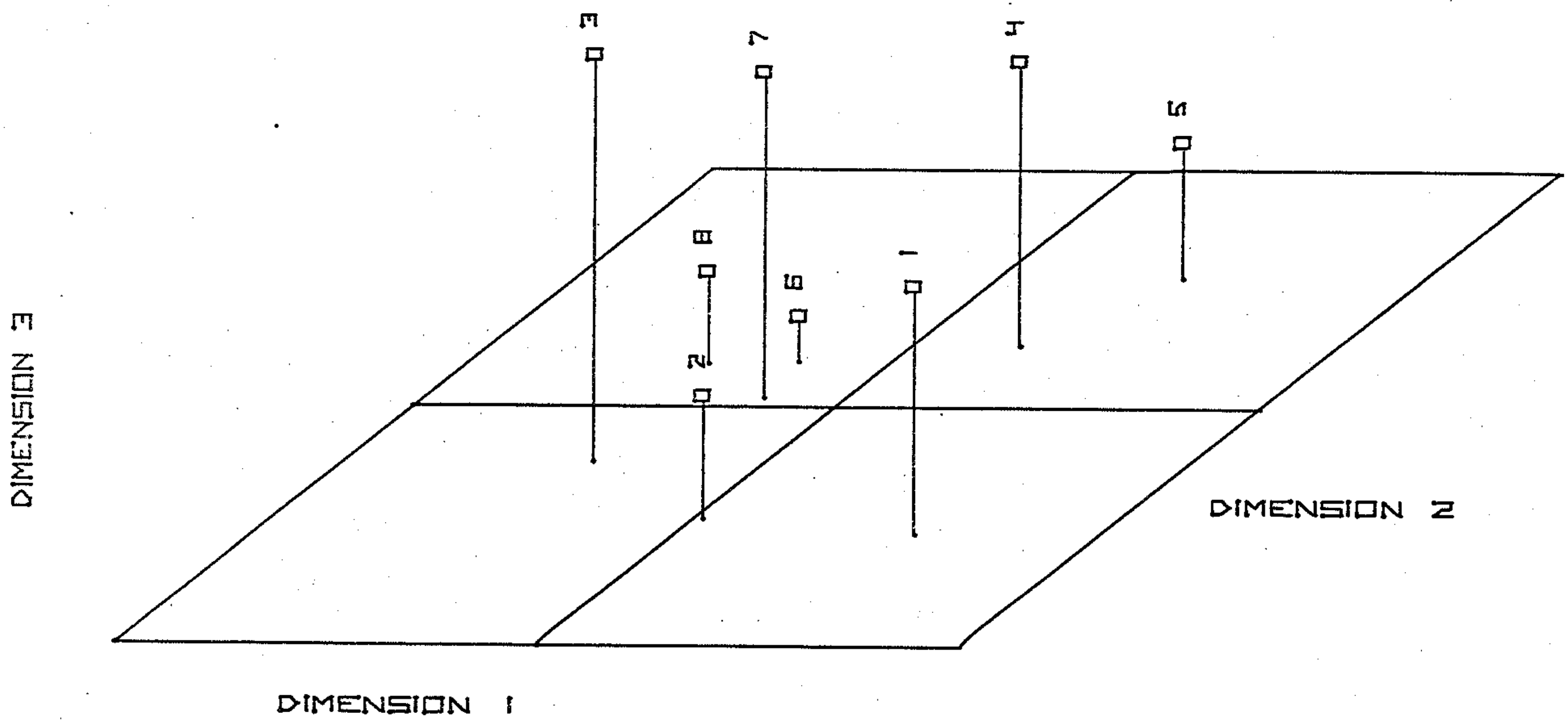
PROGRAM 1

Figure 3. Position of eight systems in the three-dimensional INDSCAL solution for program 1. (Co-ordinate values given in Table III. Dimension 3 is transformed to make the lowest co-ordinate value in this dimension appear slightly above the plane of dimensions 1 - 2.)



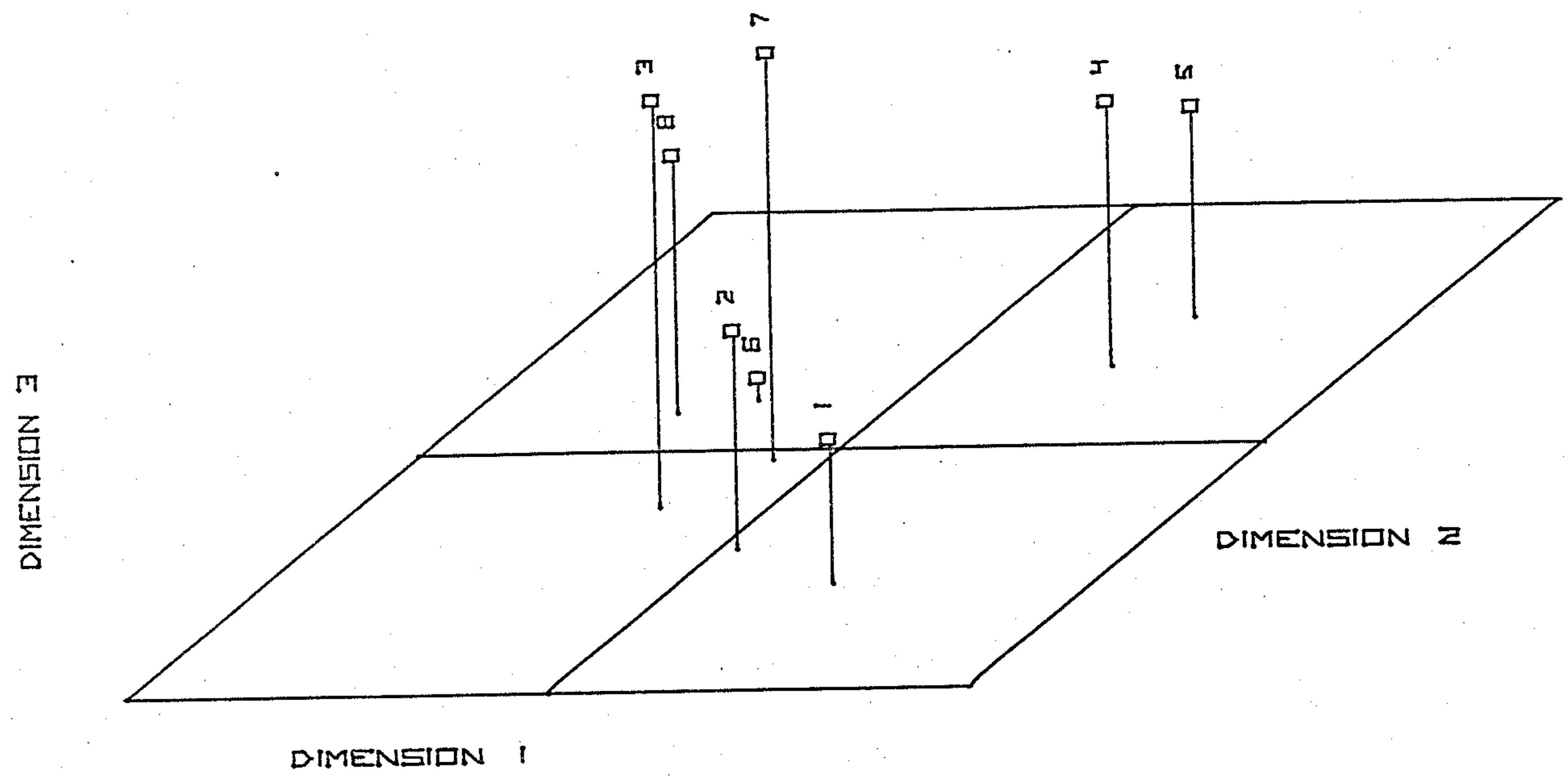
PROGRAM 2

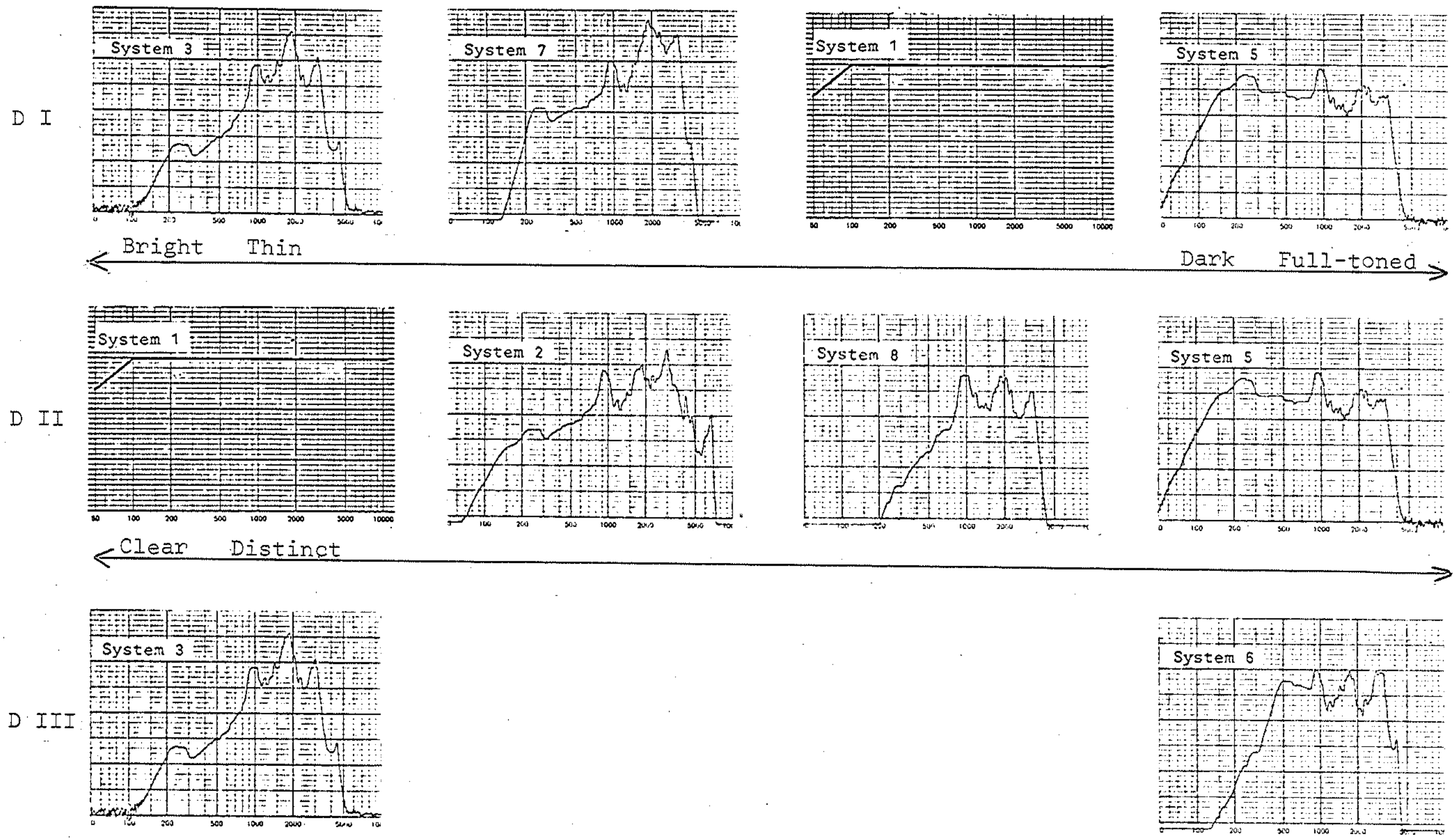
Figure 4. Position of eight systems in the three-dimensional INDSCAL solution for program 2.



PROGRAM 3

Figure 5. Position of eight systems in the three-dimensional INDSCAL solution for program 3.





<u>Figure 6</u>. Interpretation of dimensions I-III in terms of the frequency characteristics of the systems.