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ABSTRACT

In the IEC 29B/WG15 multilanguage test Swedish intelligibility tests and quality ratings were performed.
The Swedish tests showed extremely good repeatability. The word materials showed good balance in sensitivity to noise and reverberation. The correlation between intelligibility test and ratings was high, indicating the possibility of an enlarged use of quality ratings.
The correlation to RASTI was good, especially to the -2 dB corrected RASTI.
The good differentiation of RASTI at high intelligibility scores, might make it useful in room acoustic planning also for the hearing impaired.

This work was supported by the Swedish Telecommunications Administration and the National Swedish Board for Technical Development.
The international test was handled by the Institute for Perception, TNO, Soesterberg, the Netherlands.

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1 INTRODUCTION

Measuring speech intelligibility in room acoustics has always been a time consuming task with several critical parameters. Many test subjects are required to secure statistical significance. The influence of speaker, either he/she is speaking directly or played back over a loudspeaker, is marked. For practical reasons it is desirable to perform the listening tests in a laboratory with headphones. It is very difficult, however, to get an exact reproduction of the original sound in headphones. Attempts to calculate speech intelligibility for example by Articulation Index, AI, have been made. The disadvantage of AI is, however, that it uses stationary signals.

In 1973 Houtgast and Steeneken, Institute for Perception, Soesterberg, the Netherlands, presented a method to measure or predict speech intelligibility in room acoustics. After that the method has been improved to be valid also for electrical speech transmission systems. In this method the natural intensity modulation of speech is the clue. The Modulation Transfer Function, MTF, for different frequency bands and modulation frequencies are measured. From these data a Speech Transmission Index (STI) is calculated.

In the International Electrotechnical Commission (IEC/29B/WG15) it was decided to administrate a test with on one hand MTF-STI and on the other hand intelligibility tests in several languages to study the general relevance of the method.

The report "A multi-language evaluation of the RASTI-method for estimating speech intelligibility in auditoria" by Houtgast and Steeneken (1981) describes the whole international test. The aim of our report is to look more at the specific Swedish aspects.

2 SUMMARY OF THE MTF-STI METHOD

The test signal is a speech spectrum noise divided into seven octave bands. These octave bands are presented with modulation frequencies from 0.63 Hz to 12.5 Hz and with modulation index m=1. See Fig. 1. The modulation frequencies are representative for the natural modulation of speech.
Passing a non-ideal transmisson channel, as for example a reverberant room and/or an electrical system the modulation is degraded to an index $m<1$, because of noise, distortion and reverberation.
After thus establishing a matrix of modulation indices, modulation transfer functions are calculated for each octave band. By applying an empirically deduced frequency weighting a Speech Transmission Index (STI) is calculated.

A simplified version of the method using only two octave bands and only a few modulation frequencies, all presented simultanously, gives the Rapid Speech Transmission Index (RASTI). See Fig. 2.

3 MULTI-LANGUAGE TEST

3.1 Design

Tapes with speech material generally used for intelligibility tests were supplied by 11 laboratories in different countries. Some laboratories sent material for quality rating too. The tapes were played back in an auditorium with various degrees of reverberation and background noise. See Fig. 3 and Table I. New tapes were recorded at different positions in the auditorium. These tapes were sent back to the originators for their own listening tests of the totally 16 conditions. MTF-STI and RASTI were also measured for all conditions.

The Swedish speech material was supplied by the Department of Technical Audiology, Karolinska Institutet, where the intelligibility tests were carried out. The quality ratings were performed by the Swedish Telecommunications Administration.

3.2 Results

The intelligibility scores from different countries were not comparable because of various types of speech material and methods. Therefore Spearman rank order correlations (pseudo ranks) between the STI values, the RASTI values and the results from the laboratories were calculated. The correlations between RASTI and the intelligibility tests ranged between 0.82 and 0.97. Between RASTI and the quality ratings the correlations were 0.89 to 0.94. Since the correlations to the RASTI values were almost as high as to the STI values, only the RASTI values were used in the report.

Results of the RASTI measurements are shown in Table II. This table shows both the orignal RASTI values and -2 dB level corrected RASTI values, which give better correlation to the listening tests. See further the report by Houtgast and Steeneken (1981). At this moment it is not quite clear whether the original RASTI method or a corrected one will be recommended by IEC.

Variations were calculated and a multidimensional scaling was performed. The dimension discriminating between noise interference and reverberation was found to explain 72 % of the discrepancies between the intelligibility tests. The main characters influencing this dimension were carrier phrases, speakers, level defects and possibly also phonemes and languages. The two extremes were the English test without carrier phrase, which was very little affected by reverberation, and a Dutch test with a very particular speaker voice.

4 SWEDISH INTELLIGIBILITY TEST

4.1 Method

4.1.1 Speech material

Two types of phonetically balanced 50-word lists were used, consisting of nonsense syllables and PB-words respectively.

The nonsense syllables, read by a female speaker, are phonetically balanced CVC-combinations without linguistic significance. Each consonant part consists of a single consonant or of a combination of consonants. These syllables are normally used at intelligibility tests in research at our department and at some clinics.

The PB-words, read by a male speaker, are used in speech audiometry by Swedish hearing clinics. The words are chosen to be common and well-known Swedish words. The words are repeated orally by the tested person.

4.1.2 Subjects

Twelve subjects, aged 20-29 years, with Swedish as their mother tongue, took part in the experiment. All of them were normal-hearing subjects (less than 20 dB hearing loss 250-8000/ISO R 389). They were paid for their participation.

4.1.3 Listening conditions

The test subject sat in a sound-insulated booth binaurally listening through head-phones TDH-39 with cushions MX 41 A/R. The test subjects listened two by two to the nonsense syllables in the same booth. They were instructed as follows (from paper and from tape, in Swedish).

Instruction, nonsense syllables:

"We intend to investigate how the intelligibility of speech is influenced by acoustics and noise in large halls. You will be listening to monosyllabic words, more or less affected by reverberation and noise. Most of the words have no linguistic significance. The words consist of one consonant-part, one vowel (long or short), and furthermore another consonant-part. The consonant-parts may each of them consist of one or more consonants. The monosyllabic words are presented in the phrase "Det är.....vi hör" (It is.....we hear).

Do listen carefully to the word and write down your answer on the questionnaire. The tape is running all the time. Write

down your answer immediately in order to be ready for the next word. Should you miss one word, write "-" and continue to the next line on the questionnaire.

We want you to spell as the sounds are pronounced.

.
.
.

Some spelling examples are excluded here.

.
.
.

If you want to ask us any questions, please do that now, then we start some training lists. Naturally we will also help you later when in doubt."

Instruction, PB-words:

"We intend to investigate how the intelligibility of speech is influenced by acoustics and noise in large halls. You will be listening to monosyllabic words, more or less affected by reverberation and noise. The monosyllabic words are presented in the phrase "Nu hör ni...", (Now you hear...).

Do listen carefully to the word and repeat it distinctly for Ann (the tester) to take down. The tape is running all the time. Therefore - be ready to listen to the next word at once."

The test needed six (or five) one-hour sessions with a break in the middle of each session. The listening level was chosen to be as natural as possible. Therefore the calibration signal was set to 70 dB(A) in the head-phones (measured on an IEC 303 coupler). No frequency correction when playing back the tapes was needed.

The test equipment, our permanent psycho-acoustical measuring device including tape recorders, amplifiers, mixers, attenuators etc., was calibrated before the test and checked in the middle of and after the test.

4.1.4 Procedure

The tests with the two kinds of speech materials were handled as two separate tests. Six of the subjects listened to the nonsense syllables first. The other six subjects listened to the PB-words first.

Before starting each type of lists, the subject had some training in order to be familiar with the nature of the speech material and the test situation. For the nonsense syllables the subject had to learn the spelling rules and was not allowed to start the test before spelling at least 96 % of the syllables correctly. (In spite of the training one subject often forgot to mark the long vowels. He had to answer orally, also to the nonsense syllables).

The order of the test lists was randomized with the restriction that all lists should appear approximately equally often among the first lists and the last lists. For a few acoustical conditions where the same lists were used, it was arranged that these appeared at least five lists/conditions apart.

4.1.5 Data treatment

The written answers were put into a computer data base. The percentages of correct answers for each condition and each type of word list were worked out for the whole words, the initial consonants, the vowels and the final consonants. This was made for the individuals and for the whole group. For the nonsense syllables also the means for the initial and the final consonants were calculated. 96 group confusion matrices were computed (16 conditions, 2 speech materials, initial consonant, vowel and final consonant).

4.2 Results

The intelligibility scores of the Swedish nonsense syllables and of the PB-words are shown in Table III and Table IV, respectively. In Fig. 4 and Fig. 5 the mean word scores are plotted against the $RASTI_{-2dB}$ values. The curves are fitted on a least square basis, with two points fixed: The maximum intelligibility is known to be 95 % for the nonsense syllables and 100 % for the PB-words. The range of RASTI is 0.17 - 0.97. See Houtgast and Steeneken (1981) Table II. The maximum points are therefore chosen to be (0.97, 95.0) in Fig. 4 and (0.97, 100.0) in Fig. 5. The minimum point is chosen to be (0.17, 0.0) in both figures. Condition No. 6 was omitted in the fitting procedure since the corresponding RASTI value is so much displaced from the general trend that it might be an artifact. Fig. 6 shows the relation between the results of the PB-words and the nonsense syllables.

The 96 group confusion matrices are not shown here, but are available upon request. All plottings against $RASTI_{-2dB}$ values are also available for $RASTI_{0dB}$ values.

In Soesterberg the results of our two word materials were not handled separately. The means were taken before calculating rank order. The mean squared difference between the results of two pairs of identical conditions was 0.13 for the Swedish test, 0.83 over all countries. The rank order correlation to RASTI was 0.96. The noise-reverberation sensitivity showed good balance.

5 SWEDISH QUALITY RATING

5.1 Method

5.1.1 Speech material

Two 60 sec long excerpts of running speech were used for rating of quality and listening effort. A male speaker read the fairy tale "Little Red Riding-Hood". A female speaker read "The Sleeping Beauty".

5.1.2 Subjects

Ten subjects rated quality and ten subjects rated listening effort. Four of them participated in both tests. All test subjects were employees at the Swedish Telecommunications Administration. Most of them were experienced in making sound quality ratings.

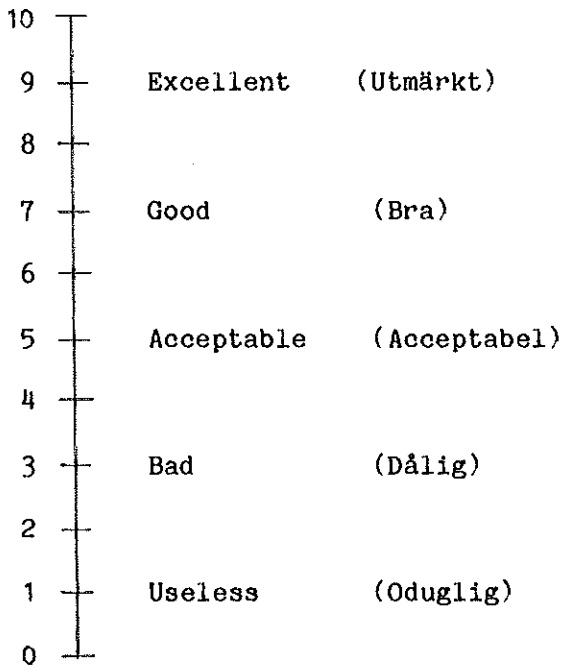
5.1.3 Listening conditions

The subjects were sitting in front of a loudspeaker (Yamaha NS-1000M) in an anechoic chamber. The distance was 5 m. The loudspeaker was driven by a Nakamichi 420 amplifier, connected to a Revox A77 tape recorder. The sound pressure level at the subject was 66 dB(A). Most of the subjects were listening alone. Some of them, however, were listening two at a time. They were told how to do by written instructions for quality ratings in Swedish, but for listening effort in English with translations of the most important words.

Instruction, quality rating:

On the tape you will listen to now, there are recorded 16 versions of an excerpt of the fairy tale "Little Red Riding-Hood" (Rödluvan), read by a male voice. There are also 16 versions of an excerpt of "The Sleeping Beauty" (Törnrosa), read by a female voice. Every part is 60 sec long. In the various versions of the two excerpts the microphone distance, reverberation and noise level are different.

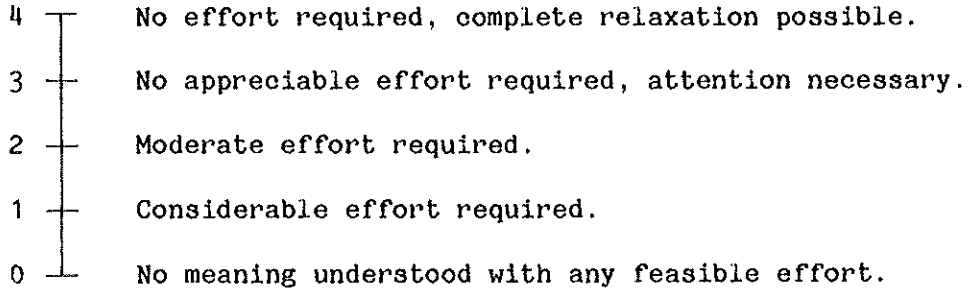
When you listen to these recordings you shall imagine sitting in an auditorium listening to a speaker. Your task is to rate the sound quality for each of the totally 32 parts according to the scale below.



Instruction, listening effort:

On the tape you will listen to now, there are recorded 16 versions of an excerpt of the fairy tale "Little Red Riding-Hood" (Rödluvan), read by a male voice. There are also 16 versions of an excerpt of "The Sleeping Beauty" (Törnrosa), read by a female voice. Every part is 60 sec long. In the various versions of the two excerpts the microphone distance, reverberation and noise level are different.

Your task is to describe the difficulty to follow what is said for each of the totally 32 parts according to the scale below.



Effort: ansträngning
Relaxation: avslappning
Attention: uppmärksamhet
Appreciable: nämnvärd

Moderate: måttlig
Considerable: avsevärd
Feasible: möjlig

5.1.4 Procedure

The 2x16 blocks (conditions) were presented in the same order as on the tape. To avoid accumulating learning effects on certain blocks the tape was started at different blocks for different subjects.

5.2 Results

Mean values and standard deviations for the quality ratings are given in Table V and for the ratings of the listening effort in Table VI. The mean ratings are plotted against the RASTI values in Fig. 7 and Fig. 8 respectively. Fig. 9 shows the relation between the rating of the quality and the rating of the listening effort. Notice here that the quality ratings only use just above half the scale, as contrasted with the ratings of the listening effort.

In Soesterberg the results of the quality ratings and the ratings of the listening effort were not handled separately. The means were taken before calculating rank order. The rank order correlation to RASTI was 0.94. The rank order correlation to the Swedish intelligibility scores was 0.96. The differences between the means in the two duplicated conditions were so small that the replications got the same ranks.

6 DISCUSSION

When relating our results to RASTI, test condition No. 6 is much displaced from the general trend. This is the case for the intelligibility tests and to some extent also for the quality ratings. The reason for this is not clear, but the results of the other countries show the same tendency. As seen in Table I condition No. 6 refers to the far microphone position with artificial reverberation.

The Swedish intelligibility test and quality ratings showed extremely good repeatability. The high correlation between the ratings and the intelligibility test raises expectations of using the less time consuming ratings also for intelligibility assessments, where RASTI is not suitable.

The properties of the two word materials together - carrier phrases, speakers and levels - seems to give a good balance in sensitivity to reverberation and noise. There is nothing indicating that this should not be true for each material separately.

The original RASTI makes a rather good balance between noise and reverberation. The -2 dB corrected RASTI, however, makes the very best summing-up of the multilanguage test. The Swedish intelligibility test

and quality ratings have high correlations to RASTI, but still higher to $RASTI_{-24B}$, in fact the very best of all participating countries. This makes the RASTI method especially interesting from the Swedish point of view.

According to the international test the RASTI method meets the demands for relative measurements. Our analyses of the Swedish tests show that it might be used for absolute measurements as well. The RASTI method shows good differentiation even at high intelligibility values. This fact might make the RASTI method a very valuable tool in room acoustic planning also for hearing impaired people.

7 REFERENCES

Houtgast, T. and Steeneken, H.J.M. A multi-language evaluation of the RASTI-method for estimating speech intelligibility in auditoria. Report from the institute for perception TNO, Soesterberg, The Netherlands (1981).

Steeneken, H.J.M. and Houtgast, T. A physical method for measuring speech-transmission quality. J Acoust Soc Amer 67 (1980), 318.

Houtgast, T. and Steeneken, H.J.M. Predicting speech intelligibility in rooms from the Modulation Transfer Function. I. General room acoustics. Acustica 46 (1980), 60.

Duquesnoy, A.J. and Plomp, R. Effect of reverberation and noise on the intelligibility of sentences in cases of presbyacusis. J Acoust Soc Amer 68 (1980), 537.

Plomp, R. Dusquesnoy, A.J. Room acoustics for the aged. J Acoust Soc Amer 68 (1980), 1616.

condition	+ noise	+ PA-system	+ AMBIO-system	micr. position
1 and 3	*	(noise mixed electrically)		
2 and 4	*			
5		*		far
6			*	far
7		*	*	far
8	*	*	*	far
9	*	*		far
10				close
11		*		close
12		*	*	close
13	*	*	*	close
14	*	*		close
15	*			close
16			*	close

Table I. Overview of the various aspects involved in the 16 conditions. Conditions 1 to 4 contain no influence of the auditorium.

CONDITION	RASTI	RASTI (-2 dB)
1	0.63	0.56
2	0.46	0.40
3	0.67	0.60
4	0.46	0.40
5	0.67	0.67
6	0.37	0.37
7	0.43	0.43
8	0.31	0.28
9	0.50	0.45
10	0.79	0.79
11	0.72	0.72
12	0.58	0.58
13	0.36	0.31
14	0.60	0.56
15	0.71	0.68
16	0.47	0.47

Table II. Results of the original and the -2 dB corrected RASTI measurements. 16 test conditions with reverberation and noise.

COND.		WORDS	INITIAL	VOWEL	FINAL	CONS.MEAN
1	MEAN	81.00	95.67	94.83	88.83	92.25
	ST.DEV	6.58	1.88	4.13	4.55	2.42
2	MEAN	55.33	85.50	83.33	72.83	79.17
	ST.DEV	6.89	3.83	6.73	5.29	3.90
3	MEAN	81.33	93.67	95.17	91.00	92.33
	ST.DEV	6.17	2.81	5.01	4.22	3.00
4	MEAN	53.83	86.17	88.00	70.33	78.25
	ST.DEV	7.70	3.01	6.15	7.71	4.71
5	MEAN	82.17	96.67	93.50	91.50	94.08
	ST.DEV	6.41	2.46	4.60	3.73	2.43
6	MEAN	17.67	54.17	63.00	42.00	48.08
	ST.DEV	6.87	8.55	10.36	7.03	7.35
7	MEAN	65.17	93.17	85.33	78.83	86.00
	ST.DEV	9.70	2.76	5.74	8.11	4.65
8	MEAN	33.50	70.50	76.83	53.83	62.17
	ST.DEV	6.04	6.33	8.92	6.12	5.11
9	MEAN	58.67	92.17	85.33	73.83	83.00
	ST.DEV	8.46	3.35	7.97	4.39	3.44
10	MEAN	87.00	95.33	94.83	95.50	95.42
	ST.DEV	5.75	2.87	4.93	1.93	1.51
11	MEAN	85.17	97.00	94.50	91.17	94.08
	ST.DEV	5.08	1.81	4.98	3.01	1.51
12	MEAN	72.83	95.83	89.17	84.67	90.25
	ST.DEV	11.07	1.99	7.55	6.89	3.89
13	MEAN	38.67	75.67	82.67	57.67	66.67
	ST.DEV	7.35	5.18	7.79	6.54	4.62
14	MEAN	70.50	93.17	94.17	80.00	86.58
	ST.DEV	6.99	2.62	5.69	5.26	3.00
15	MEAN	85.33	96.00	96.17	92.33	94.17
	ST.DEV	7.00	2.26	5.01	3.60	2.37
16	MEAN	67.17	92.33	90.67	77.00	84.67
	ST.DEV	10.00	3.89	8.19	7.93	5.07

Table III. Results of the intelligibility tests with Swedish nonsense syllables. Means and standard deviations over 12 subjects. 16 test conditions with reverberation and noise.

COND.		WORDS	INITIAL	VOWEL	FINAL	CONS.MEAN
1	MEAN	84.83	94.17	98.67	87.67	90.92
	ST.DEV	4.13	3.46	2.46	3.89	3.00
2	MEAN	48.50	76.83	86.00	53.17	65.00
	ST.DEV	3.09	6.06	8.36	3.35	4.31
3	MEAN	82.50	95.50	99.00	82.67	89.08
	ST.DEV	5.85	2.43	2.89	5.48	3.50
4	MEAN	54.00	76.67	90.00	60.00	68.33
	ST.DEV	6.27	4.77	5.05	7.63	5.79
5	MEAN	92.67	97.83	99.00	94.83	96.33
	ST.DEV	4.12	1.34	1.35	3.66	1.97
6	MEAN	25.17	41.00	83.67	36.50	38.75
	ST.DEV	7.11	10.70	14.16	6.04	8.04
7	MEAN	70.67	89.33	95.50	74.00	81.67
	ST.DEV	6.51	4.21	4.27	5.59	4.54
8	MEAN	43.83	63.17	83.67	53.67	58.42
	ST.DEV	5.36	7.46	11.78	6.81	6.35
9	MEAN	76.83	97.33	96.00	79.17	88.25
	ST.DEV	5.15	1.56	2.09	4.78	2.38
10	MEAN	94.83	98.33	99.67	96.00	97.17
	ST.DEV	4.22	1.67	0.78	3.72	2.37
11	MEAN	93.33	96.83	99.33	95.83	96.33
	ST.DEV	3.34	2.48	1.30	2.76	2.23
12	MEAN	80.67	94.00	96.67	83.17	88.58
	ST.DEV	4.54	3.62	2.15	4.13	3.63
13	MEAN	54.50	78.83	90.17	59.50	69.17
	ST.DEV	10.41	10.94	7.46	8.10	8.66
14	MEAN	86.50	96.33	98.00	87.17	91.75
	ST.DEV	5.54	3.06	1.71	4.93	3.74
15	MEAN	85.00	96.17	99.67	88.00	92.08
	ST.DEV	6.35	1.80	0.78	6.44	3.50
16	MEAN	71.17	89.33	94.50	73.50	81.42
	ST.DEV	6.06	6.11	6.45	5.47	5.02

Table IV. Results of the intelligibility tests with Swedish PB-words. Means and standard deviations over 12 subjects. 16 test conditions with reverberation and noise.

Cond.	Voice	Mean	St.dev	Male + female Mean	Male + female St.dev
1	male	3.4	1.4		
	female	3.2	1.4	3.3	1.4
2	male	2.1	1.2		
	female	1.6	1.3	1.9	1.3
3	male	3.5	1.3		
	female	3.2	1.3	3.3	1.3
4	male	2.0	1.0		
	female	1.4	1.1	1.7	1.0
5	male	5.3	1.6		
	female	5.2	1.9	5.3	1.7
6	male	0.8	0.7		
	female	0.7	0.5	0.8	0.6
7	male	2.8	0.6		
	female	2.6	0.6	2.7	0.6
8	male	0.8	0.9		
	female	0.5	0.7	0.7	0.8
9	male	3.4	0.9		
	female	3.0	1.3	3.2	1.0
10	male	6.1	1.7		
	female	6.0	1.8	6.0	1.7
11	male	4.8	1.6		
	female	4.9	1.7	4.8	1.7
12	male	3.0	1.4		
	female	3.2	1.3	3.1	1.3
13	male	1.4	0.8		
	female	1.1	1.0	1.2	0.9
14	male	3.5	1.3		
	female	3.5	1.1	3.5	1.2
15	male	5.3	0.9		
	female	5.3	1.0	5.3	1.0
16	male	2.0	1.0		
	female	2.4	0.9	2.2	0.9

Table V. Mean values and standard deviations of Swedish quality ratings. 16 test conditions with reverberation and noise. 10 subjects.

Cond.	Voice	Mean	St.dev	Male + female Mean	St.dev
1	male	2.6	1.1		
	female	2.4	0.9	2.5	1.0
2	male	1.3	0.7		
	female	1.0	0.7	1.2	0.7
3	male	2.7	1.0		
	female	2.3	0.9	2.5	0.9
4	male	1.4	0.8		
	female	1.2	0.7	1.3	0.7
5	male	3.5	0.4		
	female	3.3	0.5	3.4	0.4
6	male	0.5	0.6		
	female	0.4	0.4	0.5	0.5
7	male	2.0	0.6		
	female	2.0	0.4	2.0	0.5
8	male	0.4	0.5		
	female	0.3	0.4	0.3	0.4
9	male	2.5	0.7		
	female	2.4	0.7	2.4	0.7
10	male	3.8	0.4		
	female	3.7	0.5	3.7	0.4
11	male	3.7	0.6		
	female	3.7	0.5	3.7	0.6
12	male	2.8	0.6		
	female	2.9	0.8	2.8	0.7
13	male	1.2	0.6		
	female	0.8	0.6	1.0	0.6
14	male	2.6	0.9		
	female	2.4	0.9	2.5	0.9
15	male	3.3	1.0		
	female	3.1	1.0	3.2	1.0
16	male	2.3	0.8		
	female	2.2	0.7	2.2	0.7

Table VI. Mean values and standard deviations of Swedish ratings of listening effort. 16 test conditions with reverberation and noise. 10 subjects.

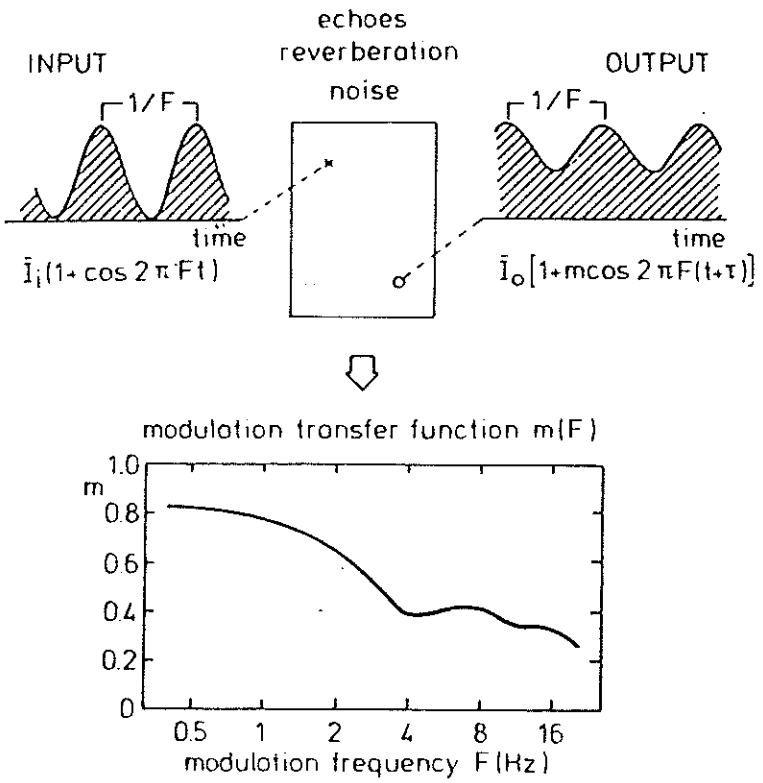


Figure 1. The Modulation Transfer Function m(F) quantifies the degradation of the modulation index when a signal is passed through an enclosure. The test signal is speech-shaped noise with 100% intensity modulation, with the modulation frequency F as parameter.
(Figure 1 in Houtgast & Steeneken, 1981)

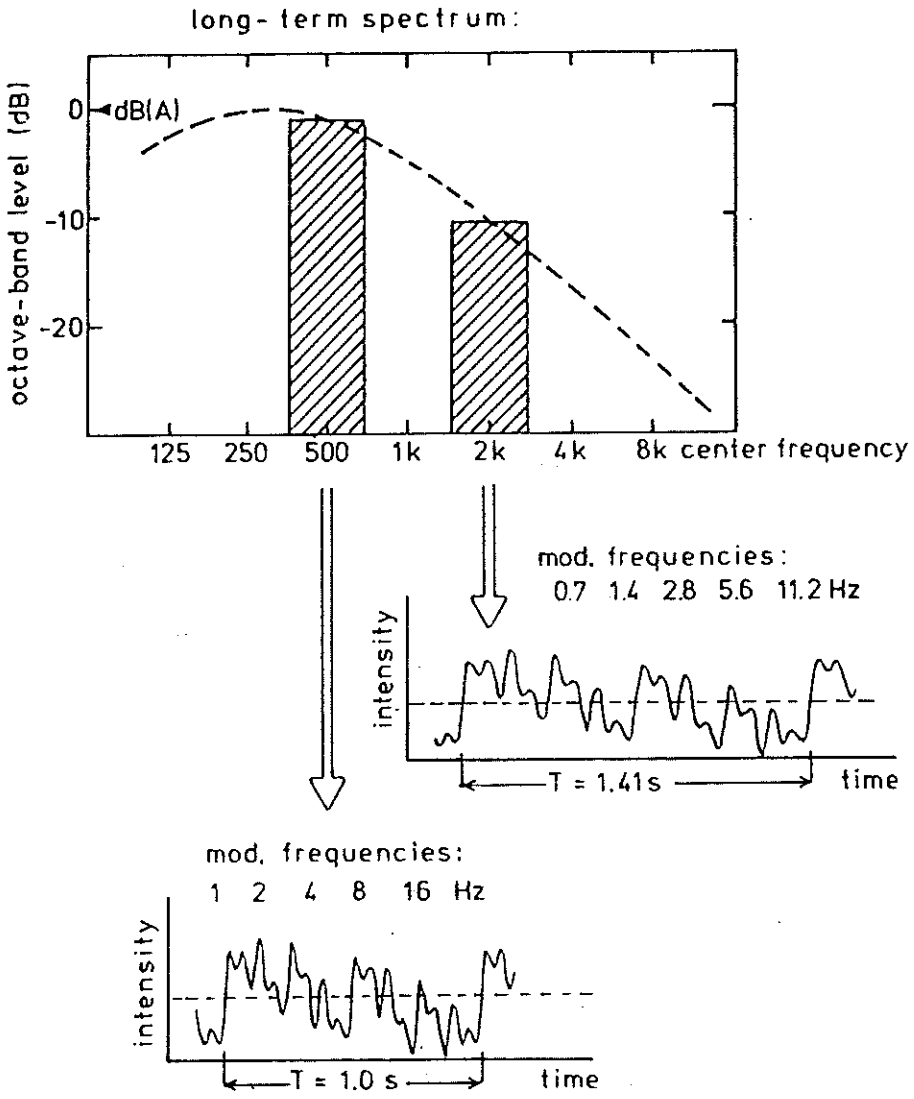


Figure 2. Illustration of the RASTI test signal. Two octave bands of noise are presented simultaneously, each with an intensity-envelope comprising five simultaneous modulation frequencies, each with a modulation index of 0.32.
(Figure 3 in Houtgast & Steeneken, 1981)

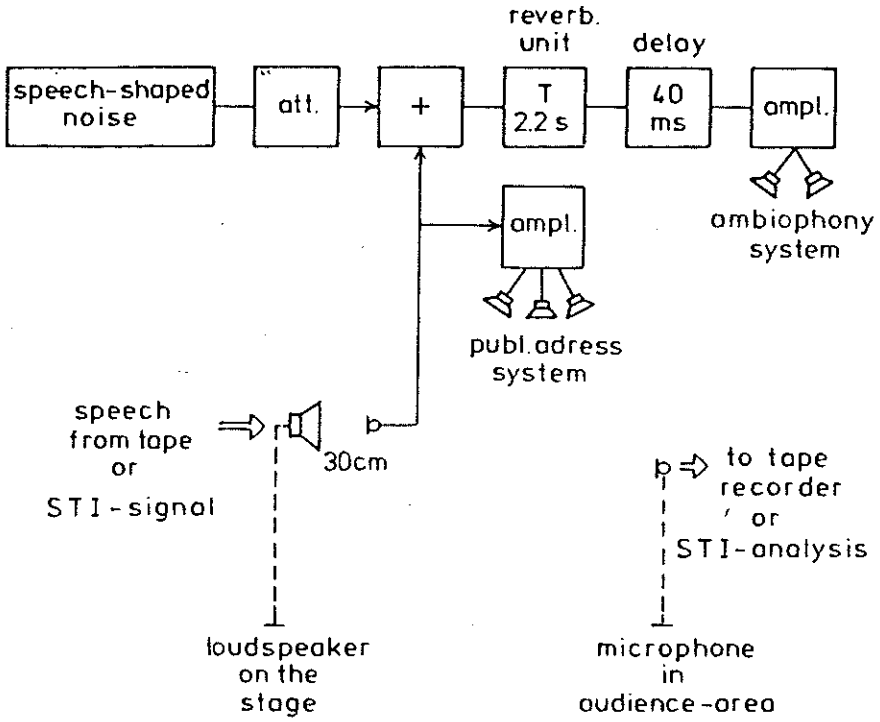


Figure 3. Schematic representation of the various aspects involved in the loudspeaker-microphone transmission paths in the auditorium. Parameters were (1) the microphone position, (2) the use of a PA system and (3) the application of interfering noise.
(Figure 5 in Houtgast & Steeneken, 1981)

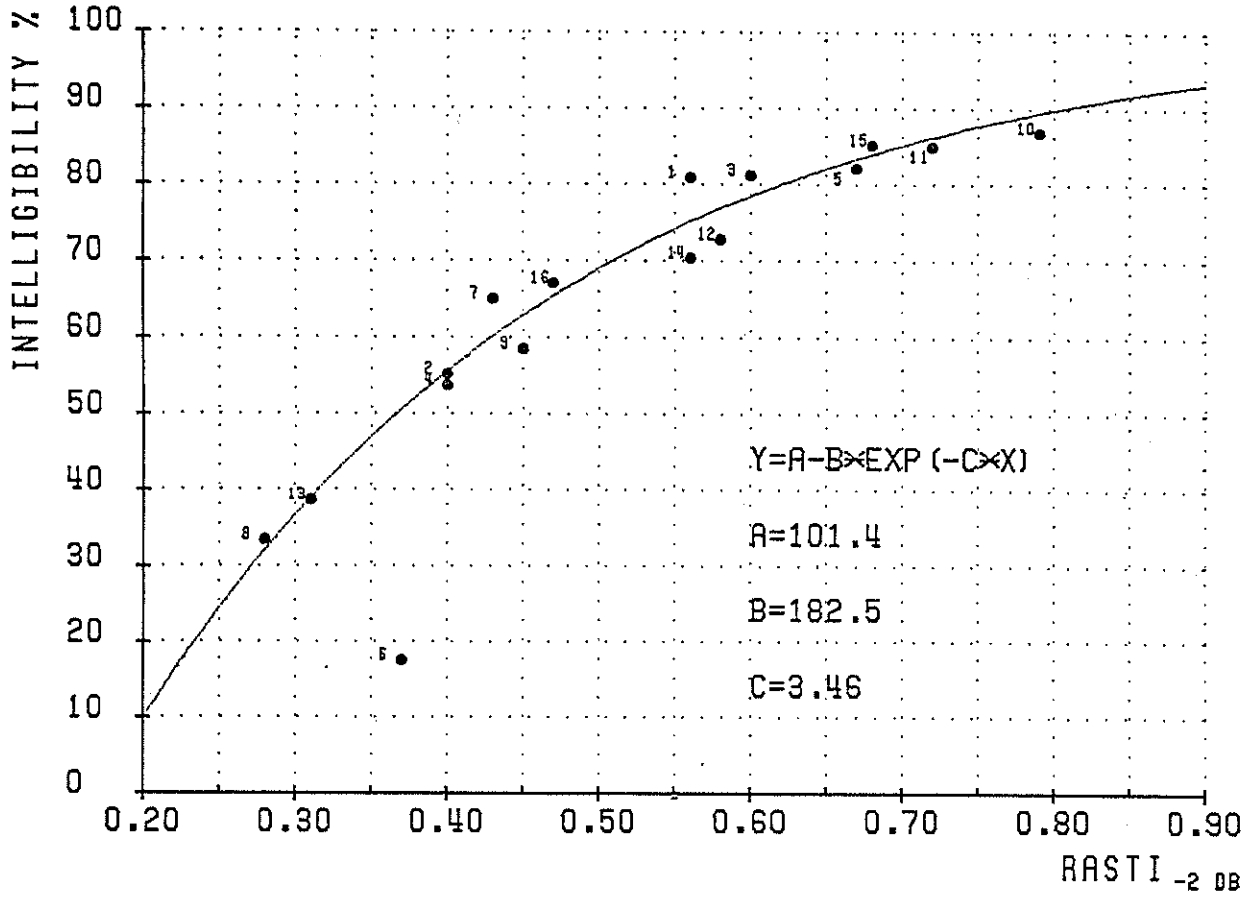


Figure 4. Swedish nonsense syllables. Mean word scores plotted against $RASTI_{-2\ dB}$. 16 test conditions with reverberation and noise. Further information about fitting procedure in text.

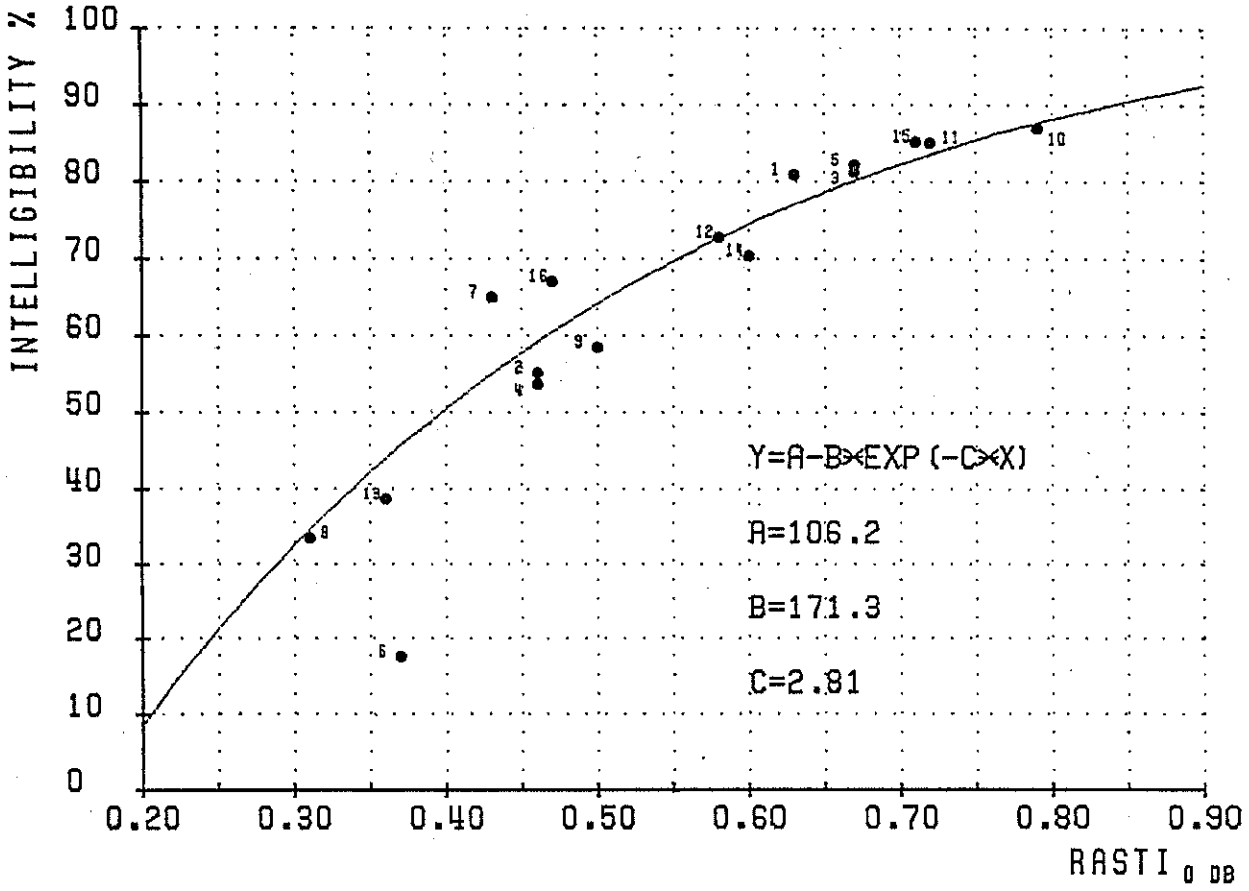


Figure 4b. Swedish nonsense syllables. Mean word scores plotted against RASTI $_{0\ dB}$.

16 test conditions with reverberation and noise. Further information about fitting procedure in text.

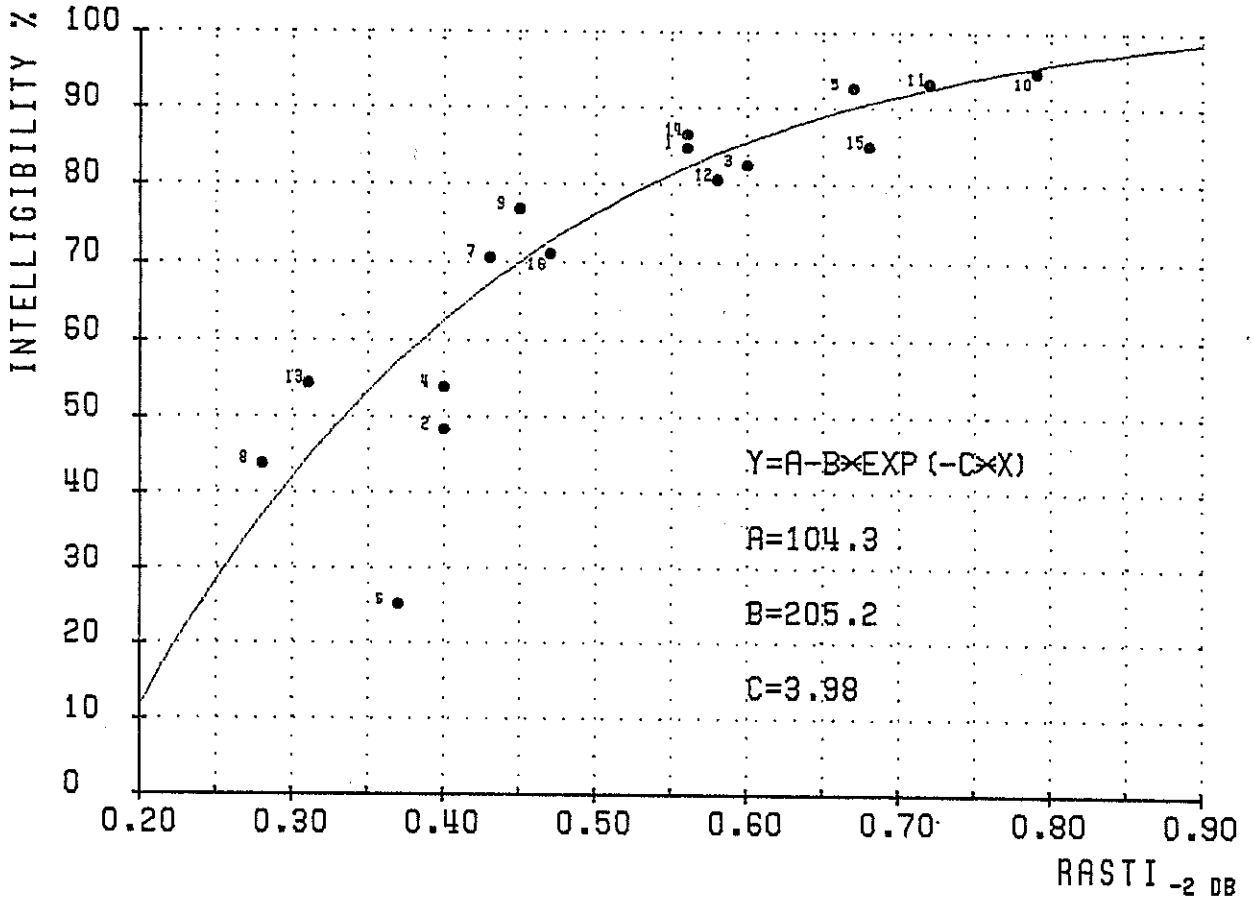


Figure 5. Swedish PB-words. Mean word scores plotted against $RASTI_{-2\ dB}$. 16 test conditions with reverberation and noise. Further information about fitting procedure in text.

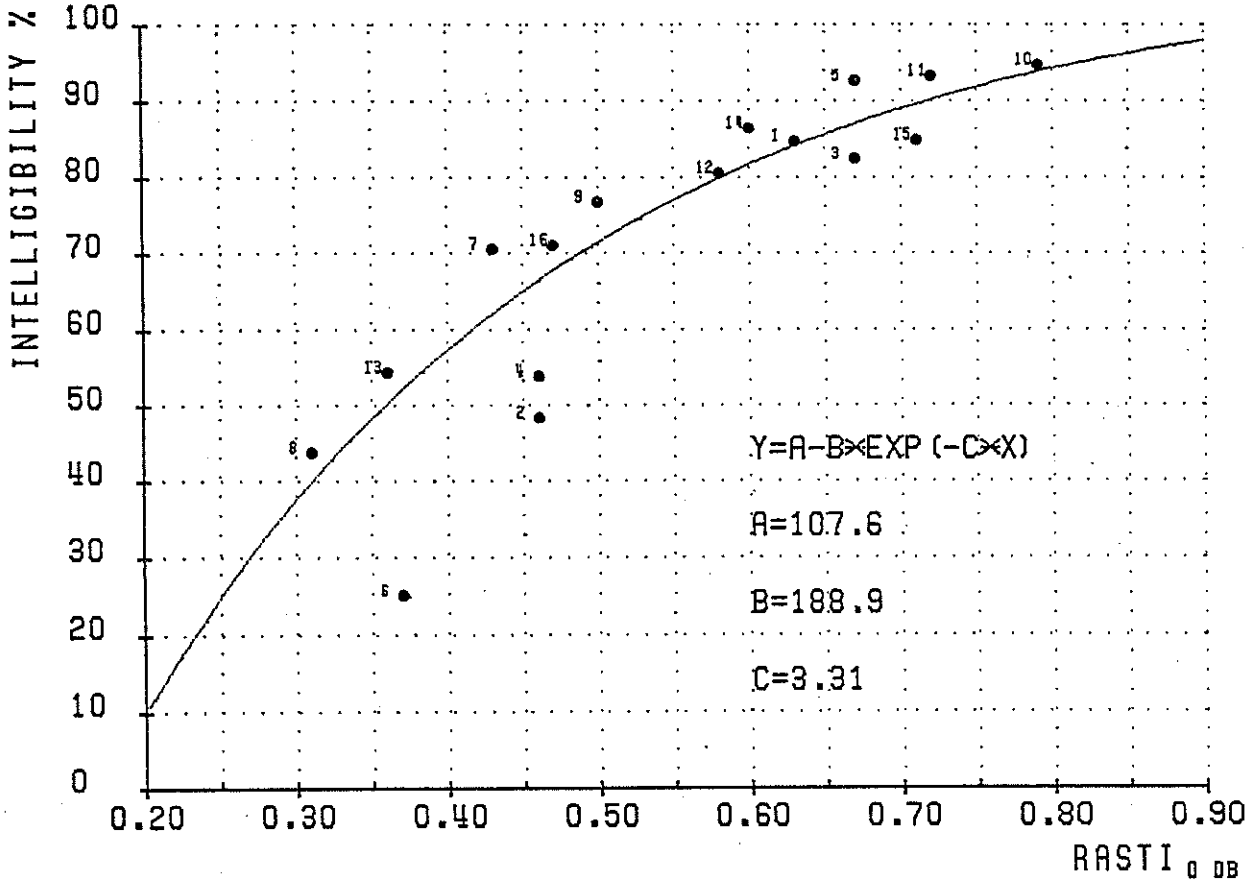


Figure 5b. Swedish PB-words. Mean word scores plotted against RASTI $_{0\ dB}$. 16 test conditions with reverberation and noise. Further information about fitting procedure in text.

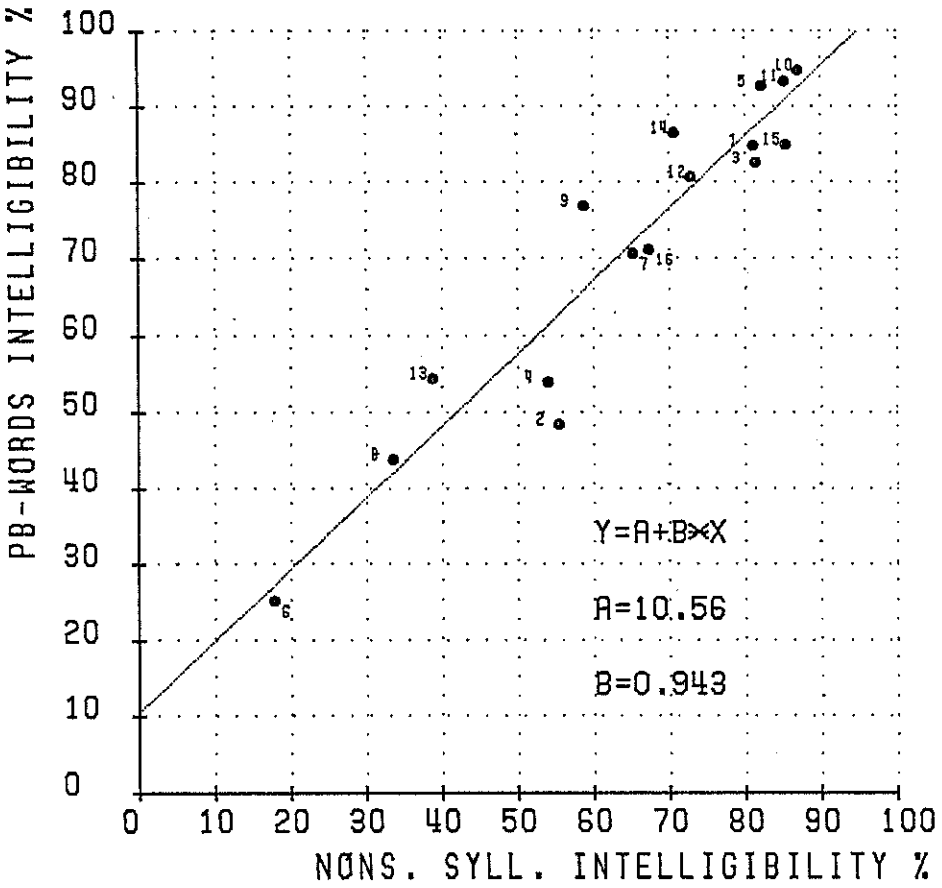


Figure 6. Relation between mean word scores of Swedish PB-words and nonsense syllables. 16 test conditions with reverberation and noise. Regression line.

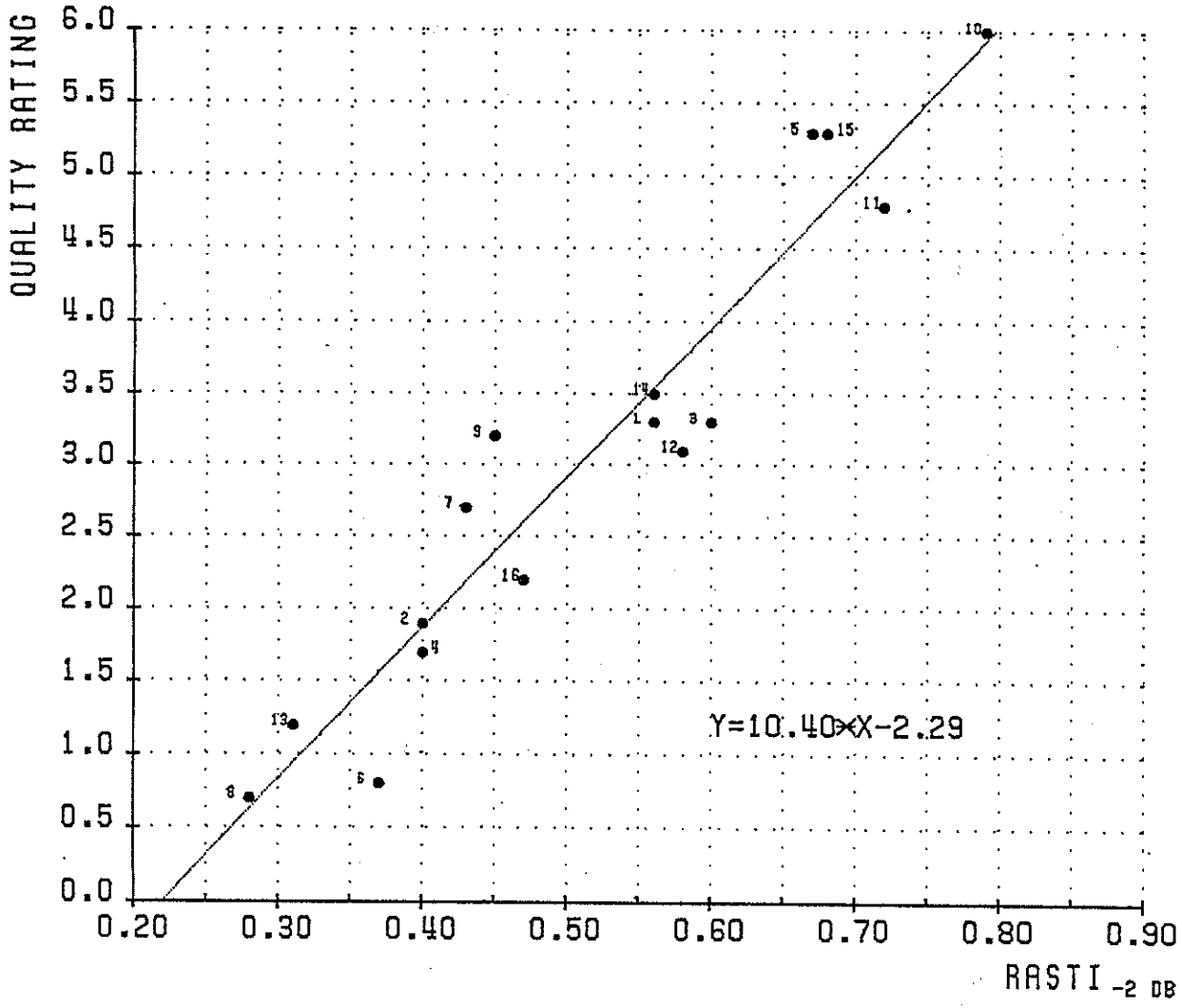


Figure 7. Quality ratings. Means of Swedish ratings plotted against $RASTI_{-2\ dB}$. 16 test conditions with reverberation and noise. Regression line.

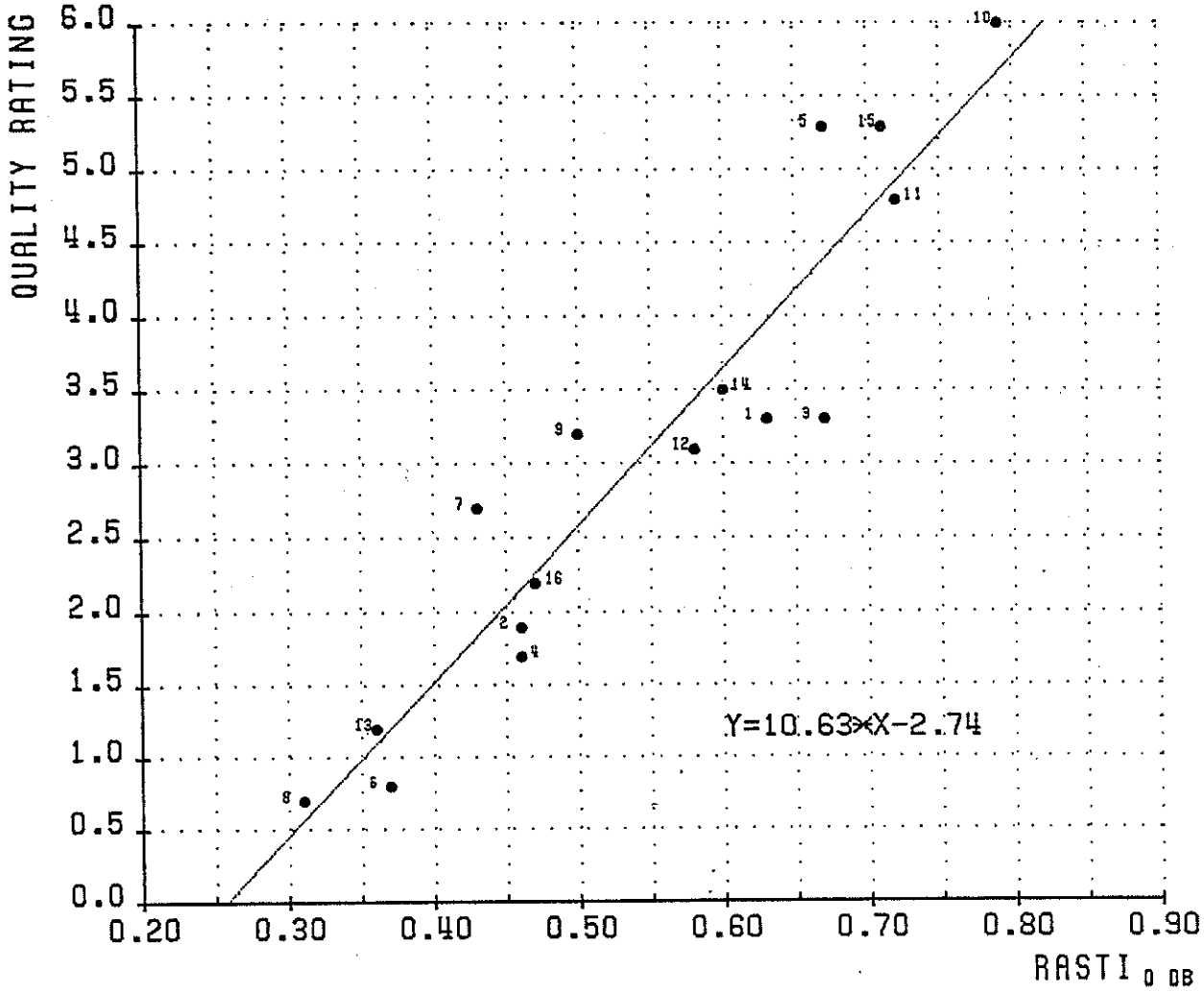


Figure 7b. Quality ratings. Means of Swedish ratings plotted against RASTI $_{0\ dB}$. 16 test conditions with reverberation and noise. Regression line.

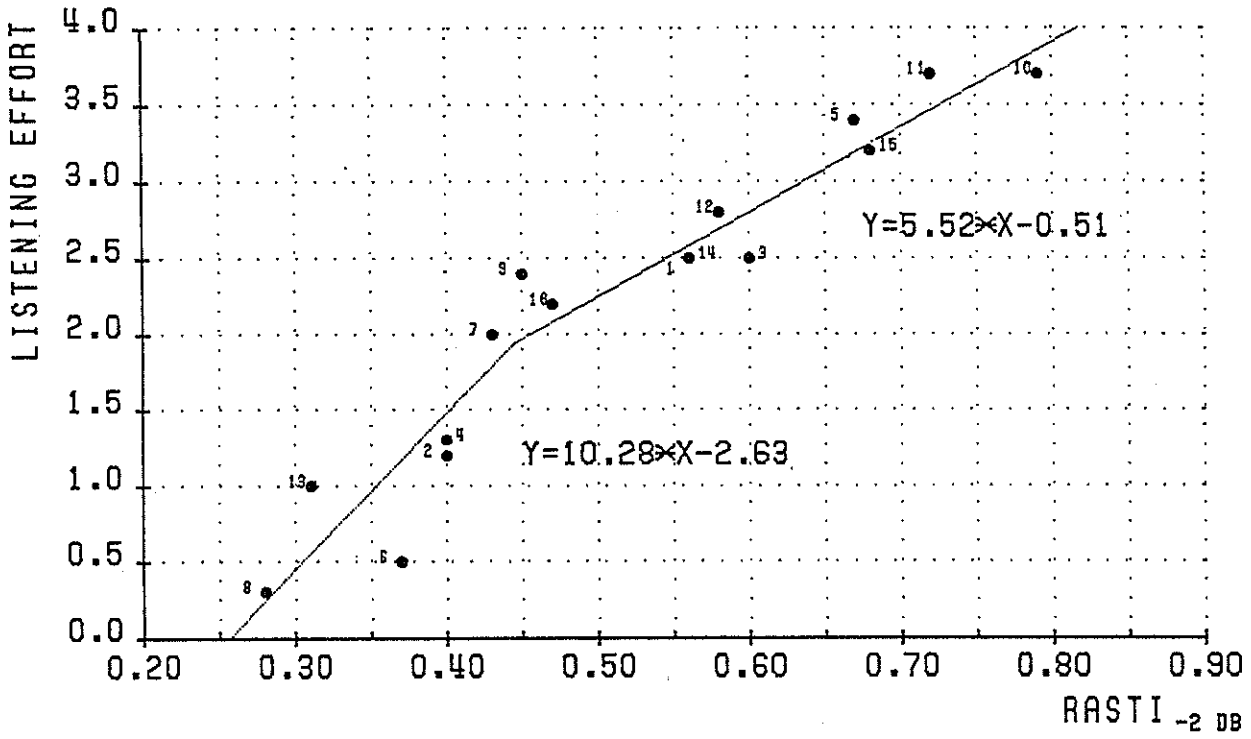


Figure 8. Listening effort. Means of Swedish ratings plotted against $RASTI_{-2\ dB}$. 16 test conditions with reverberation and noise. Two regression lines.

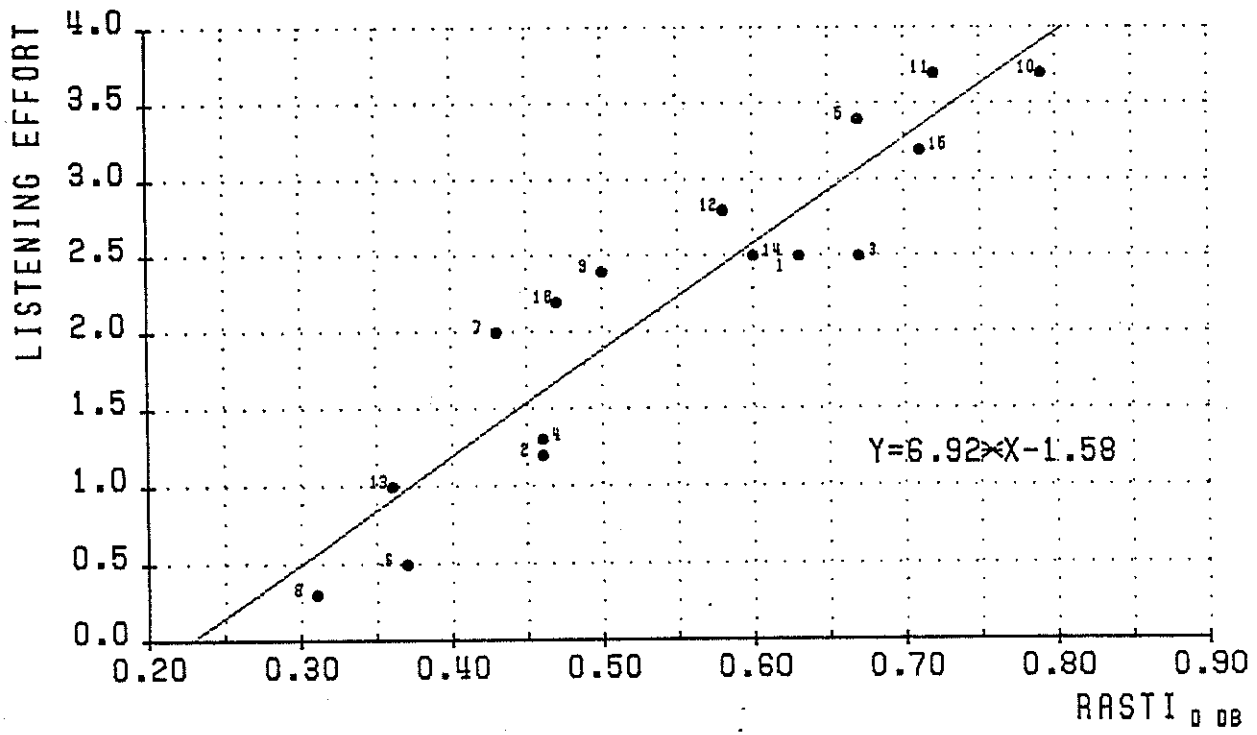


Figure 8b. Listening effort. Means of Swedish ratings plotted against RASTI $_{0\ dB}$. 16 test conditions with reverberation and noise. Two regression lines.

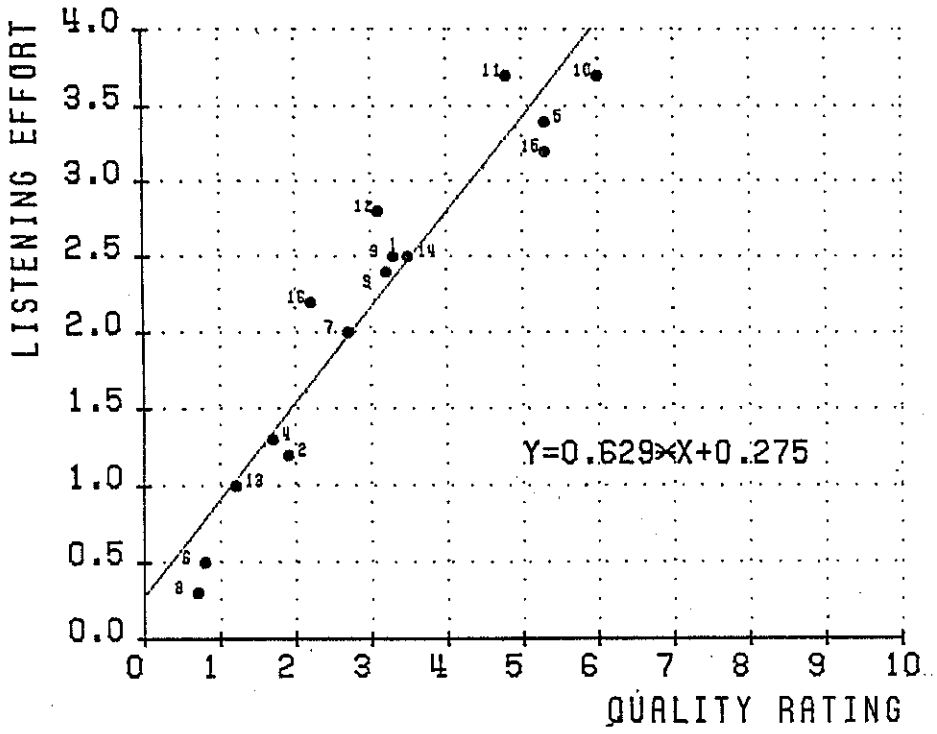


Figure 9. Relation between ratings of listening effort and quality ratings. 16 test conditions with reverberation and noise. Regression line.