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# THE EFFECT OF NON-LINEAR AMPLITUDE DISTORTION, AN INVESTIGATION BY VARIATION OF THE QUADRATIC AND THE CUBIC COMPONENTS

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The performance of a hearing aid is described by its physical data obtained from electro-acoustical measurements. Distortions can be generated at different stages in the amplifiers or by the transducers and can be of different kinds as linear distortion, amplitude distortion, transient and phase distortion. The reproduction quality is influenced by the distortion and the intelligibility for speech can be reduced. Many authors have tried to find correlations between the above mentioned physical data and the score from speech audiometric tests. Investigations have been designed to compare the articulation score with the physical data of different hearing aids.

Conflicting results have been reported partly because hearing aid performance change considerably with the condition of the battery, the temperature etc.

A project has been initiated in order to investigate the influence on quality and intelligibility for speech by the different types of distortion on a broad basis and step by step.

The test series started with measurements of physical data from 6 types of hearing aids. The over all performance of the amplifier, the microphone and the receiver with the proper generator and load impedances

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were investigated. The measurements included frequency response curve, harmonic distortion, intermodulation distortion, input and output impedances.

Amplitude distortion was investigated by measuring the harmonic distortion and the intermodulation distortion. It is not possible to measure the harmonic distortion acoustically at high frequencies for hearing aids since the 2 cc coupler cuts off at about 3000 Hz.

Intermodulation distortion, however, can be measured with good reliability. First order intermodulation, which corresponds to the second harmonic, can be measured at the difference frequency, and the second order intermodulation, corresponding to the third harmonic, at the frequency of $2 f_1 - f_2$, figure 1.

All body worn types showed a high degree of intermodulation at high frequencies when measured in the coupler with acoustical input. Distortions from one hearing aid and its earphone are shown in figures 2 and 3.

This distortion was not generated in the earphone, which was expected, but in the amplifier. One possible reason to this is mismatching between the microphone and the amplifier and between the amplifier and the receiver.

Amplitude distortion measurements using sustained sinusoids give the picture of the distorted sound with stationary, simple signals. Speech, however, being a very complex signal can give rise to another type of amplitude distortion.

A good quality transistor amplifier is peak-clipping high output signals. This overload disappears instantaneously when the input signal is decreased, figure 4.

All hearing aids investigated, however, showed an overload which remained when the high input signal decreased. With an input signal giving an output level of -1 dB relative to the peak-clipping level the transfer function was normal. With just a few dB higher input level, however, a severe distortion appears, figure 5. This will stay for about 100 ms after the moment when the overloading signal is decreased.

It is well known, that many hard of hearing patients use their hearing aids with a gain permitting a certain degree of overload, 10-15 dB has been reported. Speech is always mixed with noise, which at short intervals can overload the hearing aid giving masking effects due to this type of overload.

The effect upon the intelligibility of speech has been investigated using a special test program and trained normal hearing subjects. The test program consisted of speech, nonsense syllables, at a level 1 dB below the overloading level and tone brusts, 8000 Hz, at a repetition rate of 10 Hz and with a pulse length of 1 ms. The tone bursts were set at a level 15 dB above the overloading level, figure 6.

Intelligibility tests have been made with a signal to noise ratio of 15 dB. The speech material has been recorded over the hearing aid in free field and the 2 $cm^3$ coupler IEC. The tone bursts were given to the hearing aid through the telephone pick-up coil.

RESULTS

Results are shown in figure 7, where

- a is a laboratory amplifier with a bandpass filter to give the bandwidth of the hearing aid,
- b is the hearing aid without overloading tone bursts,
- c is the hearing aid with tone bursts but with the total level decreased 20 dB. At that level the tone bursts did not overload the hearing aid.
- d is the hearing aid as in c but with the overloading tone bursts 15 dB above the overloading level.

The ranges are indicated by the vertical lines.

Comparison b to c shows that the pulses themselves have no masking effect.

A comparison c to d shows the very severe effect, the score decreases from 58% to 28%.

The described distortion is common in hearing aids and is probably masking other distortions such as harmonic and intermodulation distortion. The technical reason seemsto be long discharge times of coupling capacitors.

Harmonic and intermodulation distortion

Amplitude distortion is generated in the amplifier, as was described above and can be of two kinds, center distortion or power series distortion, figure 8. These give both rise to intermodulation and harmonic distortion but will have quite different influence on the transmitted sound. Center distortion will affect low level signals, power series distortion high level signals.

Power series distortion can be described by the equation

$$y = \sum_{n=1}^{\infty} a_n x^n$$

where y and x are output and input respectively and $a_n$ distortion coefficients. If no linear distortions are involved there are fixed mathematical relations between harmonic and intermodulation distortions.

The effect on speech intelligibility has been investigated with normal hearing subjects using nonsense syllables which have been recorded through an amplitude distortion synthetizer. Linear distortions and noise were added to form a test program with the physical dimensions very accurately known.

The signal to noise ratios used were 60 and 20 dB, measured before the synthetizer. The noise band was limited to 6000 Hz to fit the bandwidth of the headphones. The distortion introduced by the synthetizer and described by the harmonic content was 40% at the peak levels of the speech material for the quadratic term and 25% for the cubic term.

## RESULTS

Results from intelligibility tests are shown in figures 9 and 10.

The cubic distortion has a negative effect on the intelligibility. Especially with the lower value of the signal to noise ratio the effect is considerable. At the most comfortable level the decrease was found to be from 100% to 80% score, which is of the same order as reported for clipped speech by Licklider et.al.

The quadratic distortion shows a different picture. At the higher levels and S/N 60 dB the influence is negligible, but at the lower levels the distortion results in an increase of the score.

At very low levels the fricatives and the stop consonants become nearly inaudible and confusions will arise. With intermodulation of the first order speech sounds will be frequency transposed to the low and middle frequency range and discriminated by trained listeners.

## SUMMARY

The influence of the quadratic and the cubic distortion on the intelligibility for speech has been studied. A severe remaining distortion in hearing aids after overloading short tone bursts has been described and a measure of its effect on normal hearing subjects has been shown. Other types of distortion and their combinated effects on normal hearing listeners as well as on different groups of hearing impaired are subject for further studies.

## References:

Some 200 papers are listed in the report to the Swedish Board for Technical Development, project No. 68-299-f which is available on request.

S11/1970
October 8, 1970

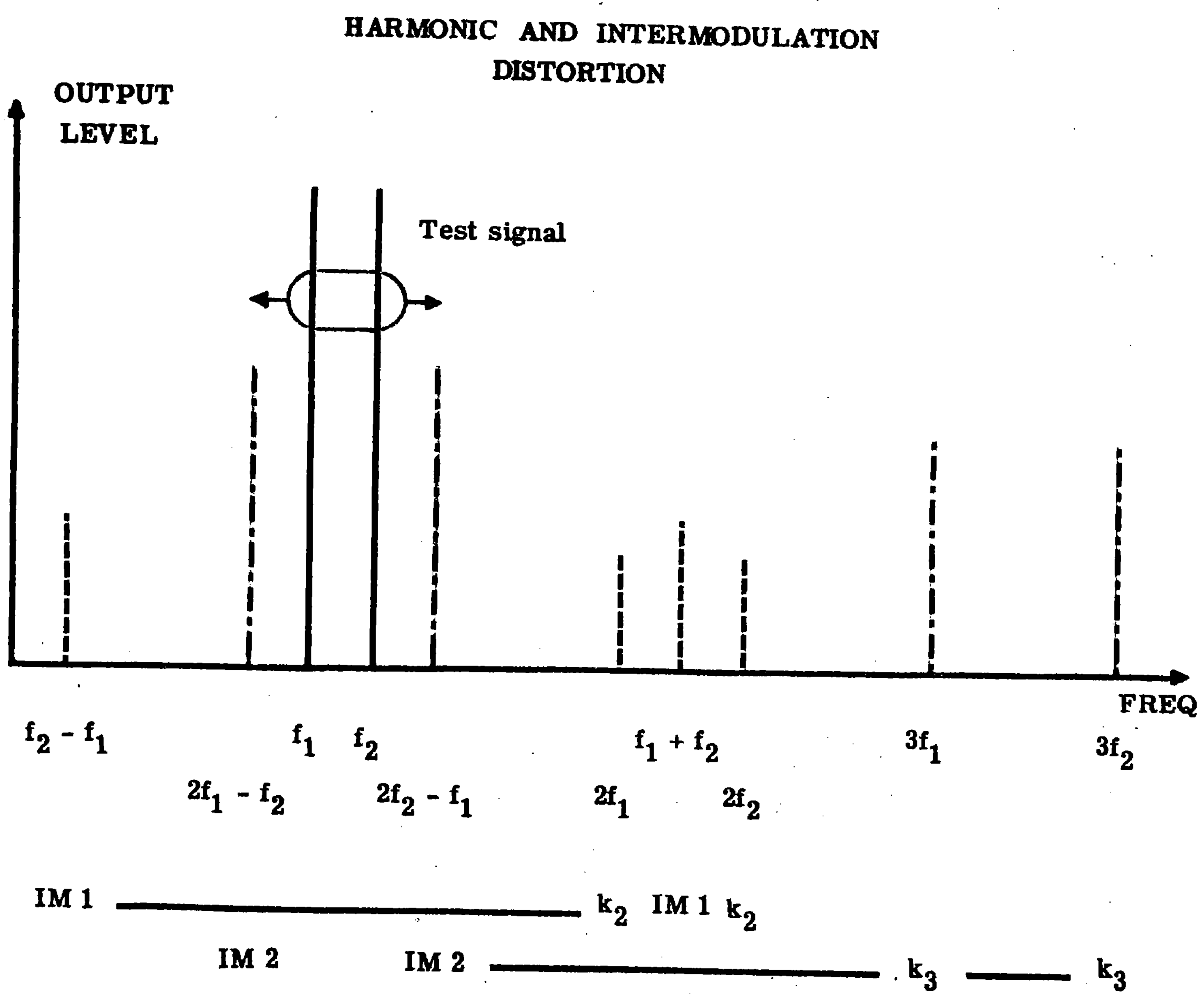

HARMONIC AND INTERMODULATION DISTORTION
OUTPUT LEVEL
Test signal
FREQ
$f_2 - f_1$
$f_1$
$f_2$
$f_1 + f_2$
$3f_1$
$3f_2$
$2f_1 - f_2$
$2f_2 - f_1$
$2f_1$
$2f_2$
IM 1
$k_2$
IM 1
$k_2$
IM 2
IM 2
$k_3$
$k_3$

Fig. 1.

INTERMODULATION

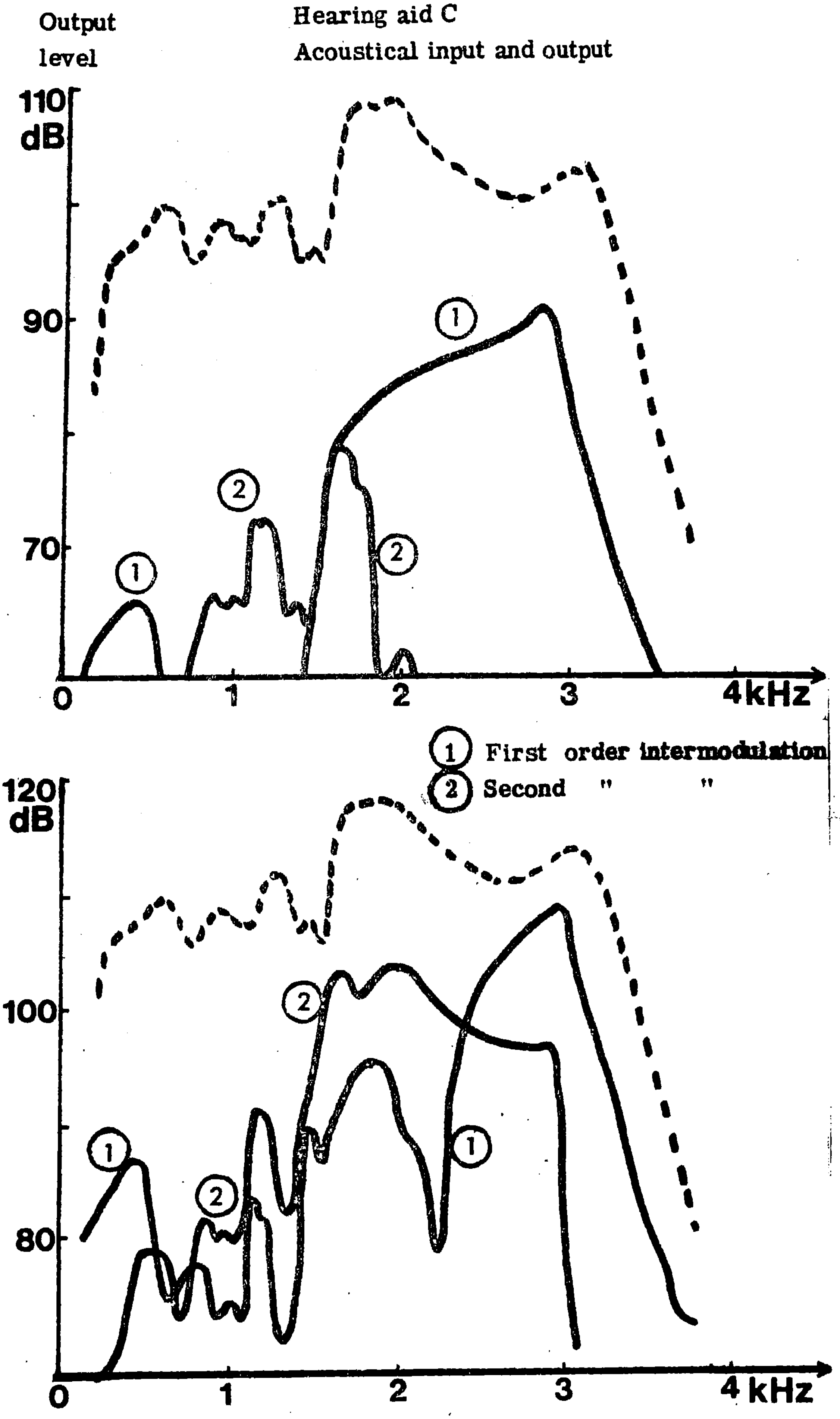



Fig. 2.

INTERMODULATION

Hearing aid C, earphone

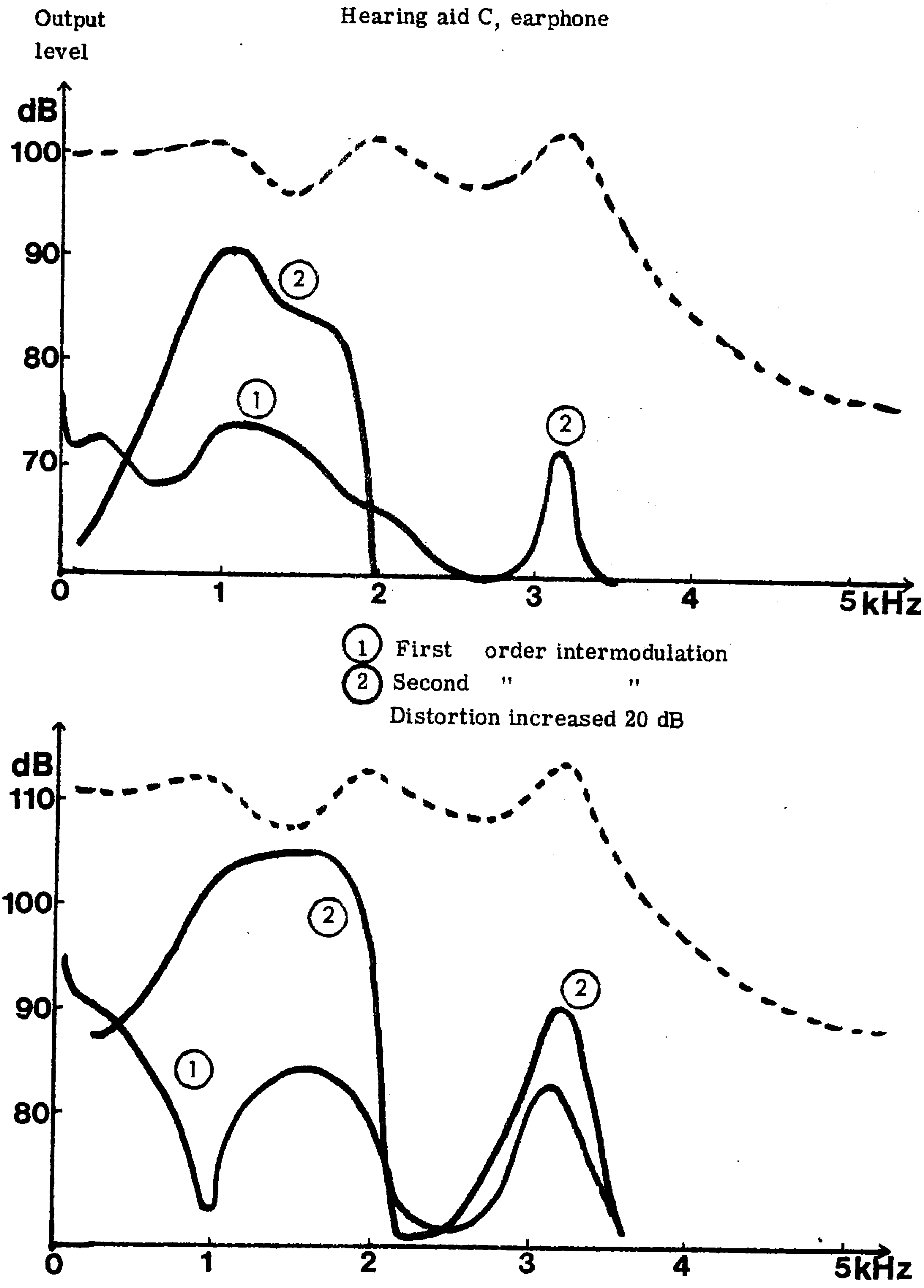



Fig.3.

TRANSFER FUNCTION
Transistor amplifier

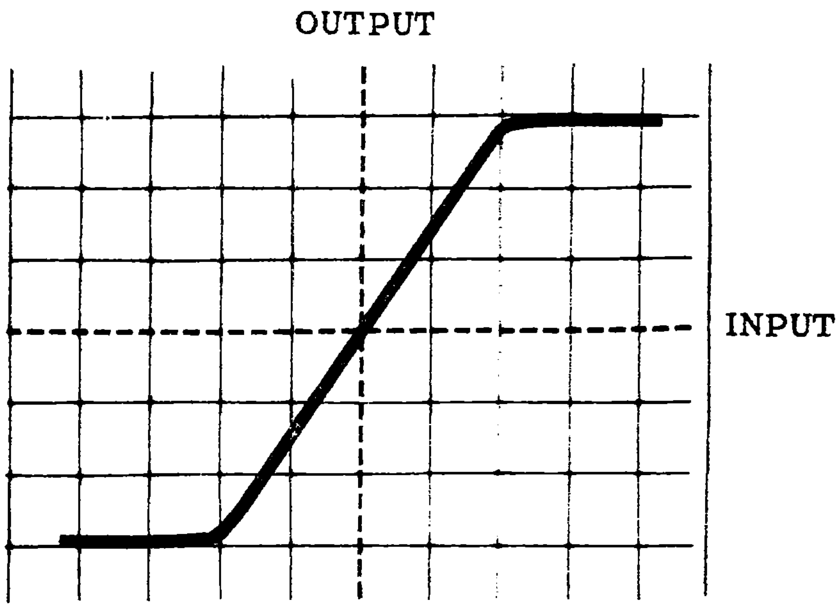
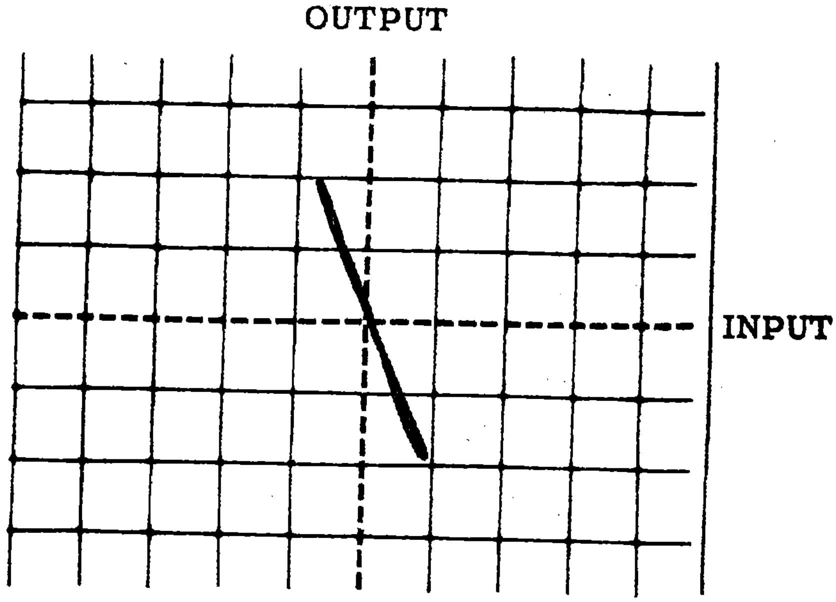
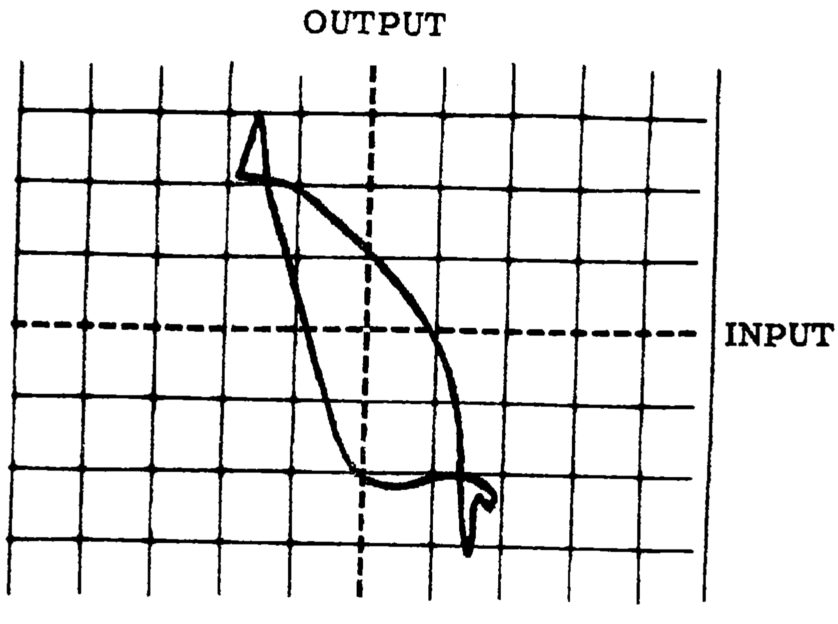



Fig. 4.

TRANSFER FUNCTION
Hearing aid: H




1000 Hz, not overloaded




1000 Hz, overloaded

Fig. 5.

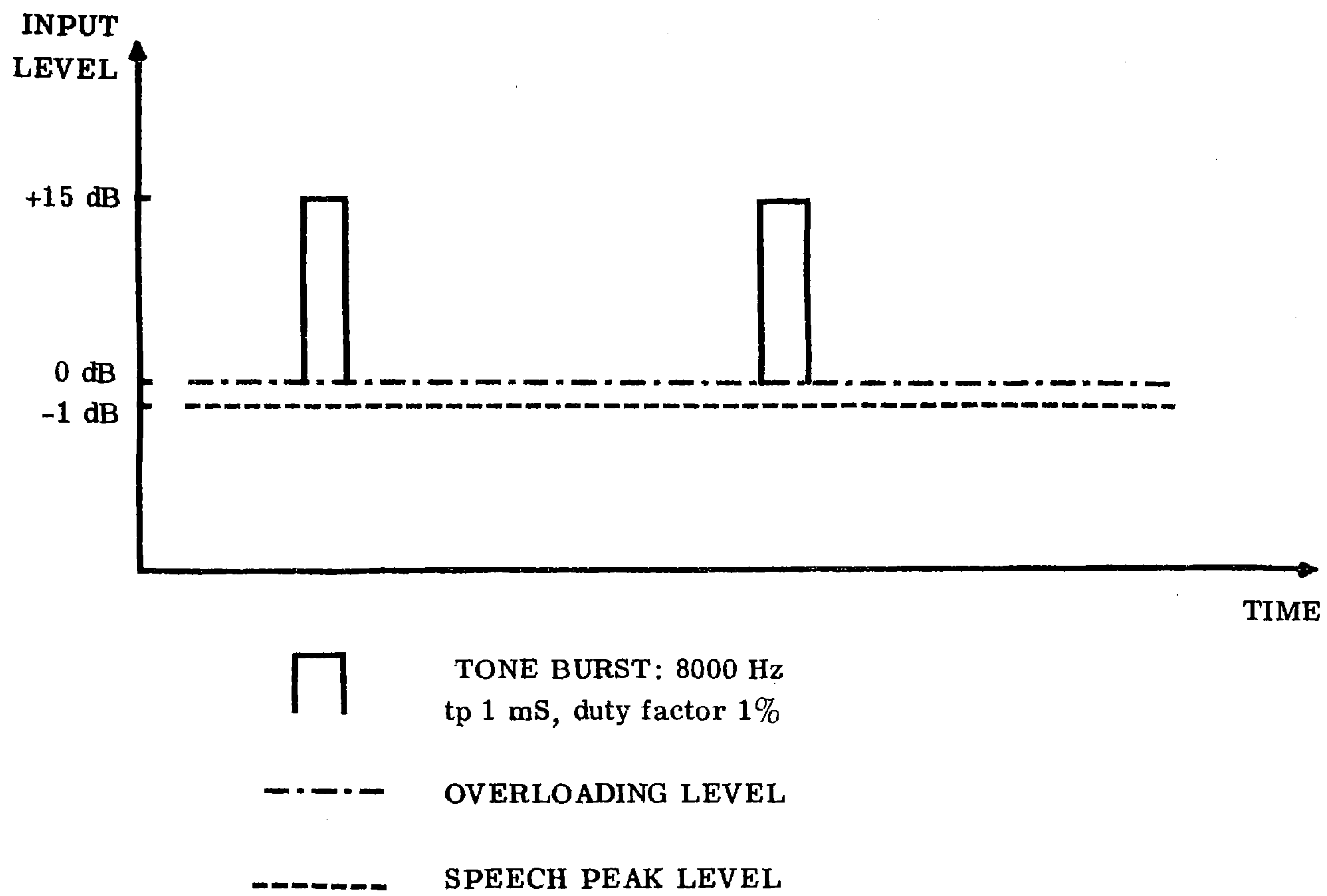

INPUT LEVEL
+15 dB
0 dB
-1 dB
TIME
TONE BURST: 8000 Hz
tp 1 mS, duty factor 1%
OVERLOADING LEVEL
SPEECH PEAK LEVEL

Fig. 6.

REMOTE DISTORTION

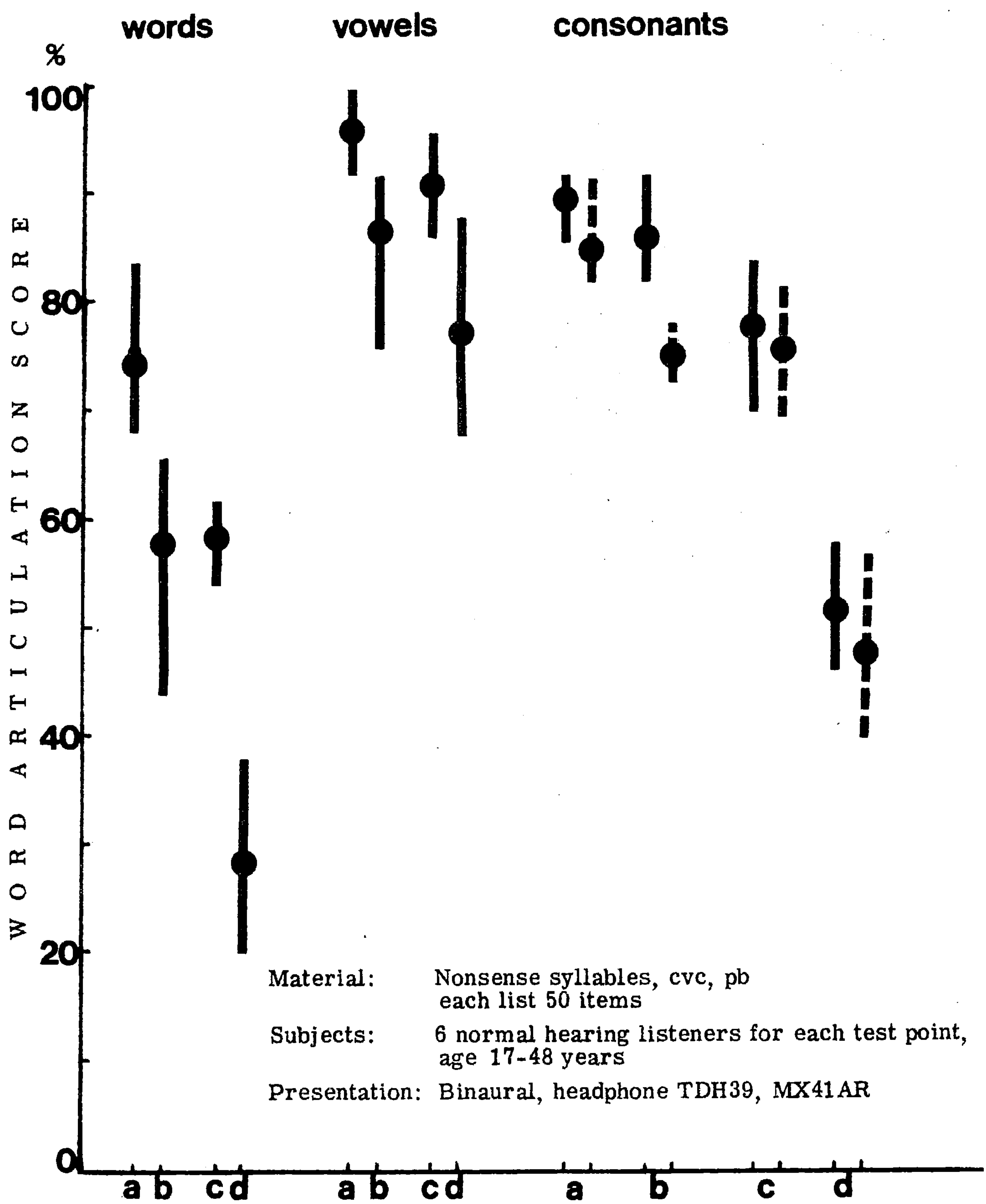
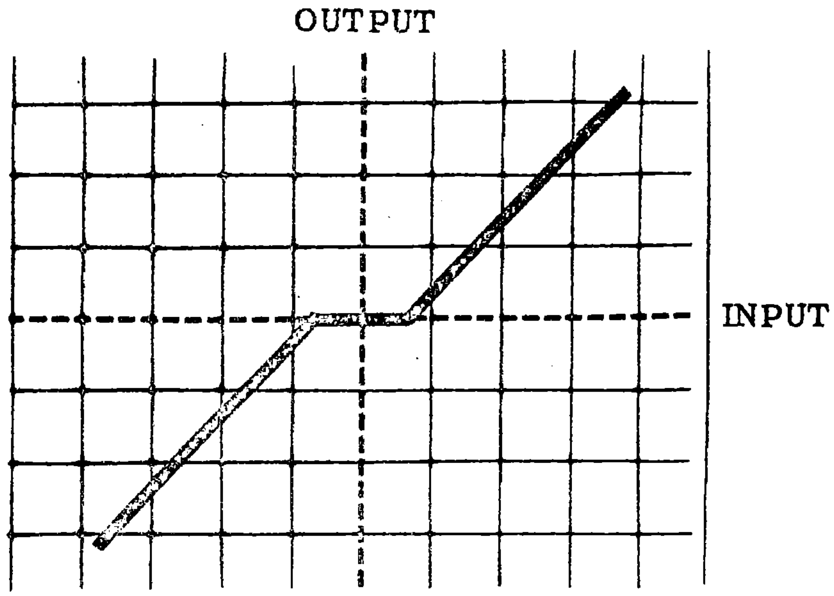
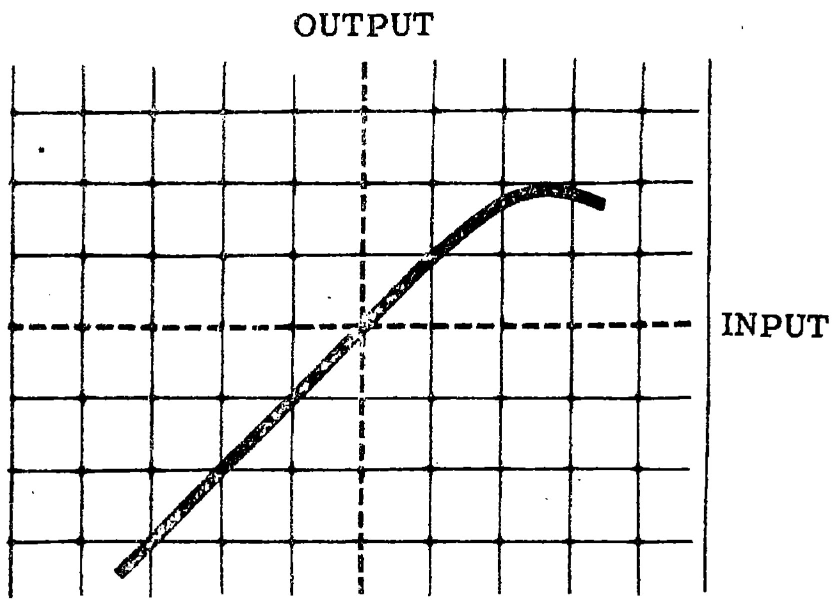



Fig. 7.

TRANSFER FUNCTION




CENTER DISTORTION




QUADRATIC POWER SERIES DISTORTION

Fig. 8.

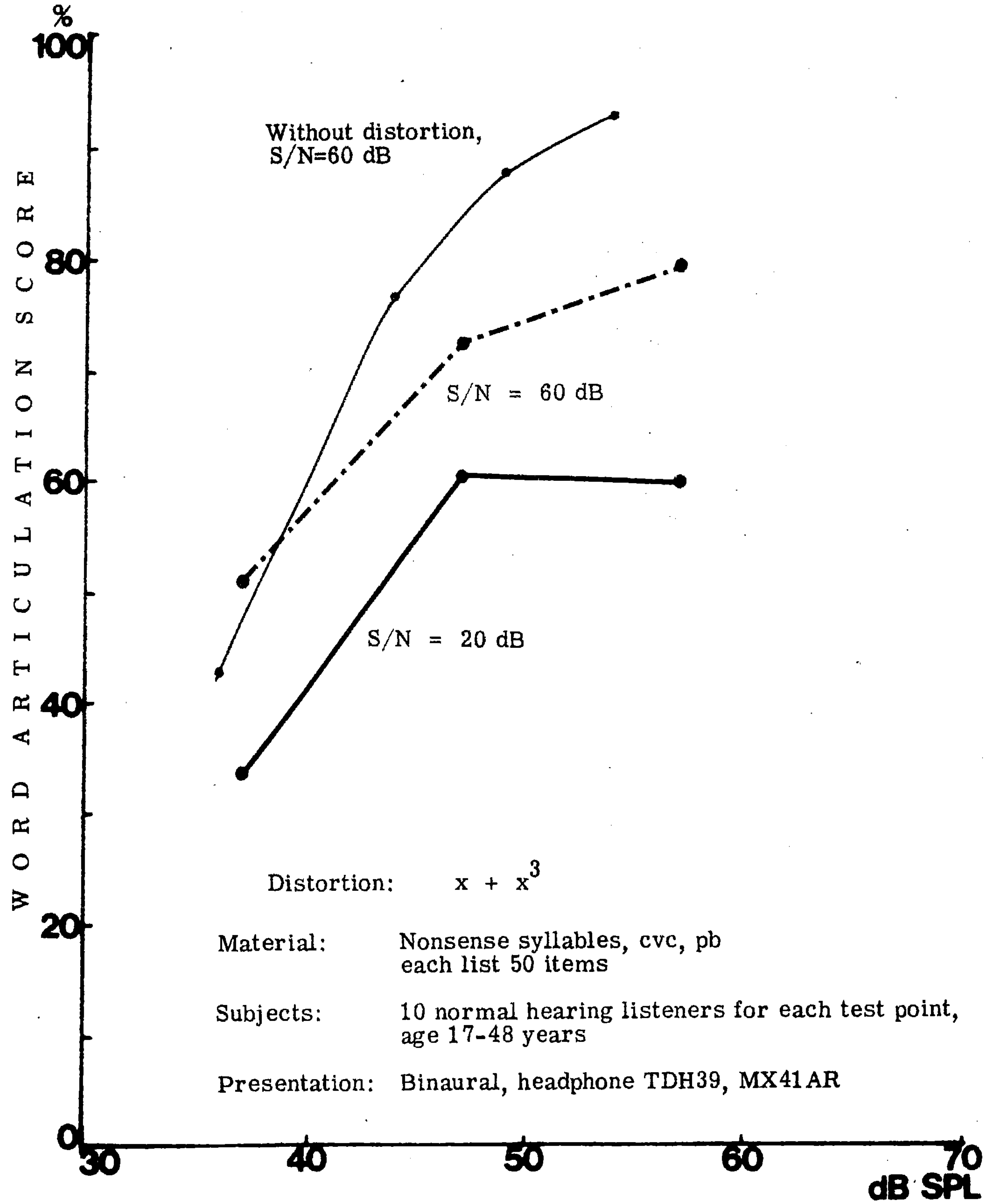

%
100
80
60
40
20
0
30
40
50
60
70
dB SPL
WORD ARTICULATION SCORE
Without distortion,
S/N=60 dB
S/N = 60 dB
S/N = 20 dB
Distortion: x + x3
Material: Nonsense syllables, cvc, pb
each list 50 items
Subjects: 10 normal hearing listeners for each test point,
age 17-48 years
Presentation: Binaural, headphone TDH39, MX41 AR

Fig. 9.

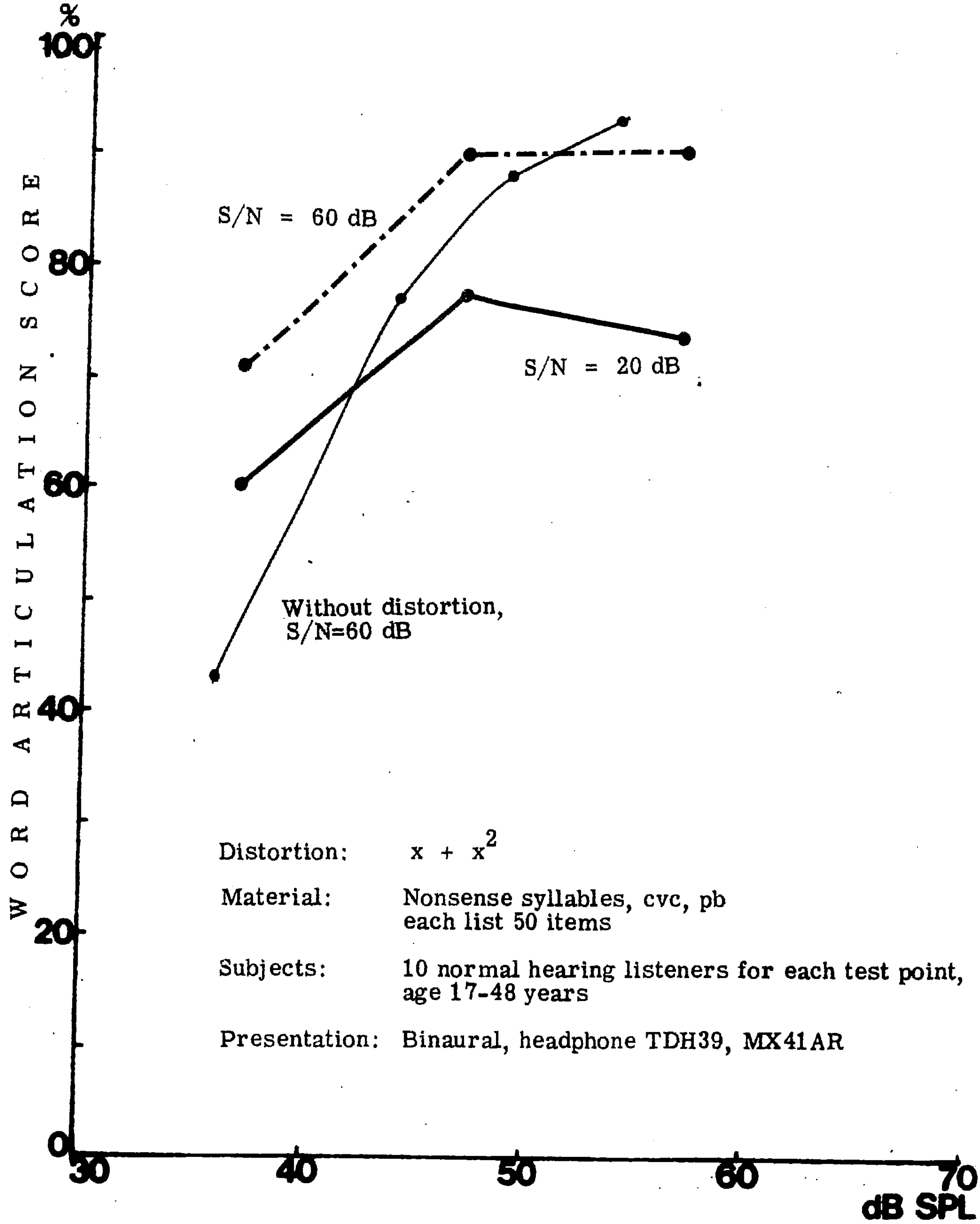

%
100
80
60
40
20
0
WORD ARTICULATION SCORE
30
40
50
60
70
dB SPL
S/N = 60 dB
S/N = 20 dB
Without distortion,
S/N=60 dB
Distortion: x + x2
Material: Nonsense syllables, cvc, pb
each list 50 items
Subjects: 10 normal hearing listeners for each test point,
age 17-48 years
Presentation: Binaural, headphone TDH39, MX41AR

**Fig. 10.**