Measurements of frequency-discrimination ability of severely and profoundly hearing-impaired children

Risberg, A. and Agelfors, E. and Boberg, G.

journal: STL-QPSR
volume: 16
number: 2-3
year: 1975
pages: 040-048

http://www.speech.kth.se/qpsr
B. MEASUREMENTS OF FREQUENCY-DISCRIMINATION ABILITY OF SEVERELY AND PROFOUNDLY HEARING-IMPAIRED CHILDREN

A. Risberg, E. Agelfors, and G. Boberg

Abstract

The pure-tone audiogram gives a limited information about the residual hearing of hearing-impaired subjects. This is especially the case when the hearing loss is severe or profound. In these cases often wide variations are obtained in results on speech-discrimination tests for the same degree of hearing loss. In some cases it is likely that the pure-tone audiogram only shows tactile sensations in the ear. One possibility to improve the diagnosis of a hearing impairment might be to measure the frequency-discrimination ability of the impaired ear.

Measurements have been made on two groups of severely and profoundly hearing-impaired subjects. The total number of measured ears is 58. Measurements have also been made in the palm of the hand on a group of normal-hearing subjects. The results show that the audiogram area can be divided into three parts. In the first part normal or almost normal frequency-discrimination ability is found. In the second part frequency discrimination varies very much for the same degree of hearing loss and in the last part frequency-discrimination ability is the same as in the palm of the hand.

Measurements of speech discrimination by means of a spondee test show that the results are good for subjects with a frequency-discrimination ability, better than 7 % at 1000 Hz, but very poor for subjects with a discrimination ability that is worse than 7 %.
Introduction

Measurements of frequency-discrimination ability (difference limen) of hearing-impaired subjects have been published by several investigators (Butler and Albrite 1956; Di Carlo 1962; Gengel 1969 and 1973; König 1961; Mártony 1968 and 1974a; Meurmann 1954; Pickett and Mártony 1970; and Schubert 1951). Most of the reported measurements have been made on subjects with a mild to moderate hearing loss. Measurements on severely and profoundly hard of hearing children are reported on by Di Carlo (1962) and Gengel (1969 and 1973) for sinusoidal signals and for vowel formants by Pickett and Mártony (1970). The results of these later measurements show that these groups of subjects in some cases have frequency-discrimination abilities that are far below what is found in normal-hearing subjects or subjects with a mild or moderate hearing loss. A significant negative correlation between frequency-discrimination ability and speech-discrimination ability is also found (Di Carlo 1962). In some cases frequency-discrimination ability is found in the ear that is comparable to what is found when a vibrator is used in the palm of the hand. The fact that the same frequency-discrimination ability is found in the ear and in the palm of the hand might indicate a total loss of hearing. In these cases the pure-tone audiogram only shows reactions to vibratory sensation in the ear and a measurement of frequency-discrimination ability might then be used as a part of a diagnosis of a total loss of hearing.

The measurements of frequency discrimination might also provide valuable help in selecting the best type of technical aid for the subject. This might be especially important when different types of auditory recoding strategies are considered as e. g. frequency transposition (Gabrielsson et al 1975; Johansson 1961; Ling 1968; and Pimonow 1963).

The results reported here are a part of a project to develop technical aids that should be used in combination with lipreading. In these aids, certain parts of the information in the acoustic speech signal that are important for the lipreader are extracted and presented either as new auditory signals or as tactual or visual signals (Mártony 1974b; Miller et al 1975; Pickett et al 1975; Traunmüller 1975; and Upton 1968). It is hoped that the frequency-discrimination measurements can be used to select the optimum modality for information transmission in an individual case.
At present measurements are only made with sinusoidal signals but it is likely that more speech-like signals can give more information about the usefulness of a small amount of residual hearing.

Method

Different psychophysical methods have been used to obtain the difference limen for frequency. The methods used influence the size of the difference limen and it has been discussed which method gives the true value. In the present experiment the main demand on the method of measurement is that it can be used on subjects with a profound hearing loss where frequency discrimination might be poor and where it is difficult to describe the task due to the poor language of the subjects. For these reasons a method is used where the response alternatives are "same" or "different". In the test, two stimuli are presented after each other in the order AB, AA, BA, or BB where A always has a lower frequency than B. The subject answers on two pushbuttons and is told by two lamps if the answer is correct. The frequency difference between the two signals is, from the beginning, as large as 30-50%. A block of 12 pairs is presented with a random selection between the four alternatives. If the subject obtains at least nine correct answers the frequency difference between the A and B stimuli is made less and a new block of 12 pairs is presented. In this way the minimum frequency difference that the subjects can discriminate at least 75% of the time is obtained and this value is taken as the frequency-discrimination ability of the subject.

The A-signal can be 125, 250, 500, 1000, 2000, and 4000 Hz. The results show that the frequency region between 500 and 2000 Hz is very important and the frequencies 750 and 1500 will also be included in later measurements. The difference between the A- and the B-signal can be 1, 2, 3, 5, 7, 10, 15, 20, 25, 30, 40, and 50%. The duration of the two signals is 500 ms and the separation between them is 250 ms. Rise and decay time is 50 ms. The test equipment can give a maximum sound pressure level in the TDH 39 earphones with MX-41/AR cushions of 135 dB SPL. The distortion components at maximum sound pressure level are at least 35 dB below the fundamental except at 4000 Hz, where they are 25 dB lower. *

The measurement is started by establishing the detection threshold for the A-stimulus. Frequency-discrimination ability is then measured

* The test equipment will be manufactured by Special Instruments, Pob 270 66, S-102 51 Stockholm, Sweden
at the intensity that the subject considers to be a comfortable listening
level. This is as a rule 20-40 dB above the detection threshold. If pos-
sible, the measurements are made at all test frequencies. As learning
influences the result (Gengel 1969) it is necessary to repeat the measure-
ments 3-5 times on each frequency.

Results

Measurements have been made on one group of adult normal-hearing
subjects in the palm of the hand and on one group of twelve hearing-im-
paired children from the School for the deaf in Stockholm (Manillaskolan)
and a group of 28 subjects from a school in Örebro (Risbergska skolan).
The ages of the hearing-impaired children were 10-12 years and 18-20
years, respectively. Measurements are reported from 58 ears. All
subjects were auditory trained and used hearing aids at least during
school hours.

The aim of the measurements on the normal-hearing subjects in the
palm of the hand was to establish values on tactile discrimination with the
TDH 39 earphone and the test method used. The earphone was held a-
gainst the palm of the hand with the help of a rubber band with enough
pressure to avoid leakage. Frequency discrimination was measured
20 dB above the detection threshold at the frequencies 125, 250, and
500 Hz. The results are shown in Fig. II-B-1. In this figure, results
are also shown from tactile measurements by Knudsen (1928) on two
subjects and by Goff (1967) and the results from auditory-frequency discrimi-
nation were published by Harris (1952). As no attempt was made in our
measurement to force the subject to respond only to changes in frequen-
cy it is likely that they responded to a combination of frequency and inten-
sity cues. In the measurements of Goff intensity differences were
balanced out by first establishing values of equal subjective intensity as
a function of frequency and then to present signals with difference in fre-
quency but with the same perceived intensity.

Based on the results shown in Fig. II-B-1 an area of "Tactile DL-
threshold" was defined. This area is shown in the following figures. In
the audiograms the area where tactile thresholds have been found is also
marked (Boothroyd and Cawkwell 1970; Norber 1967 and 1970; and Rös-
ler 1957).
Fig. II-B-1. Results from measurements of frequency-discrimination ability in the palm of the hand. Results are also shown from measurements on the fingertip by Goff (1967) and Knudsen (1928). In the measurements of Goff the influence of intensity variations is balanced out. The measurements by Harris (1952) are in the ear of normal-hearing subjects.
In Fig. II-B-2 the audiograms and test results are shown for three typical cases. In the audiograms the area of tactile thresholds has been marked and in the DL-measurements the area where DL-values in the palm of the hand were obtained for normal-hearing subjects. In the audiogram the threshold of discomfort is shown by squares.

In Figs. II-B-3-II-B-5 frequency difference limen is plotted relative to hearing loss for the frequencies 125, 250, 500, 1000, 2000, and 4000 Hz for each of the measured ears. In the older group some of the subjects had an acquired hearing loss. These are indicated by squares.

For some of the subjects in the older group the speech-discrimination ability was measured by means of a spondee test (Erber 1974). The test consisted of 12 well-known nouns with spondaic stress pattern. The 12 test words were known to the subject and when they heard a test word that was presented by means of a tape recorder they selected the test word they thought was the correct one. The test was presented through the hearing aids by means of the magnetic loop system the subjects used daily in their ordinary classroom. The numbers at each point show the mean hearing loss for the frequencies 500, 1000, and 2000 Hz. Filled circles show subjects that always used hearing aids and open circles show subjects that only used hearing aids during school hours, Fig. II-B-6.

Discussion

The results presented must be considered preliminary. For the group of children at the school in Stockholm, two to five measurements were as a rule made for each frequency. Figs. II-B-3-II-B-5 show the mean value for the last two measurements. For the older group only one measurement was made at each frequency.

There was no problem in getting the children to cooperate in the test. They immediately understood the task and a reliable answer could as a rule be obtained from the first measurements. Experiments are now going on with children around 8 years of age and in these cases the problem of getting the children to cooperate is considerable, especially for children with very poor hearing.

As the response alternatives were "same" and "different" it is not possible to tell if the children reacted to intensity differences or frequency differences of the signal. In some cases it was quite clear that the
Fig. II-B-2. Results from three typical cases. The marked area in the audiogram is the area where tactile thresholds have been obtained. The squares show the threshold of discomfort. The marked area in the frequency-discrimination measurements is the area where DL-values in the palm of the hand were obtained, see Fig. II-B-1. Relative DL values for repeated measurements are shown.
Measurement no. 1 O, no. 2 X, no. 3 □, no. 4 +, no. 5 Δ.
Fig. II-B-3. Frequency-discrimination 'ability of the two groups of subjects for 125 Hz and 250 Hz.

- ○ from the school in Stockholm.
- X from the school in Örebro.
- ★ from the school in Örebro, acquired hearing loss.

HEARING LOSS AT 125 Hz, dB

HEARING LOSS AT 250 Hz, dB
Fig. II-B-4. Frequency-discrimination ability of the two groups of subjects for 500 Hz and 1000 Hz.

- from the school in Stockholm.
- from the school in Orebro.
 from the school in Orebro, acquired hearing loss.
 from Gengel (1973).
Fig. II-B-5. Frequency-discrimination ability of the two groups of subjects for 2000 Hz and 4000 Hz.

○ from the school in Stockholm.
× from the school in Örebro.
★ from the school in Örebro, acquired hearing loss.
children responded to intensity differences, especially for the frequencies 1000 Hz and above where they often could not detect the presence of the B-signal. Typical for these cases is that they, for large differences, 30-50%, said that they could only perceive one signal. When the difference was made smaller, 20% or less, they could not detect the difference between the two signals. One possibility to get more reliable results should be to introduce a small random change in the amplitudes of the two signals. This should force the subjects to concentrate on the frequency difference between the two signals.

Figs. II-B-3-II-B-5 show very large variations of the frequency-discrimination ability for the same degree of hearing loss. For the frequencies below 1000 Hz it seems possible to divide the audiogram area into three parts. One part where the frequency discrimination is normal or almost normal, one part that shows large individual variations, and one part where, in most cases, values are obtained that are about the same as those that are obtained in the palm of the hand. In Fig. II-B-7 these three areas are indicated. For 1000 Hz tactual frequency discrimination could not be measured and the value 7% has then been taken as the critical value. This is based on the results shown in Fig. II-B-6. As the measurements in this experiment were made on profoundly deaf and severely hard of hearing children very few results are obtained in the area of normal or almost normal frequency-discrimination ability. The limits shown in Fig. II-B-7 are, however, supported by measurements made by Di Carlo and by Gengel (Di Carlo 1962; Gengel 1969 and 1973). The area of tactile DL corresponds closely to the area in which tactile thresholds have been reported (Boothroyd and Cawkwell 1970; Norber 1967 and 1970; and Rösler 1957). Until more data are available it is suggested that the separation in Fig. II-B-7 is used mainly for planning further experiments. Of special interest would be to study children with audiograms in the area of large individual variations. As an example of such studies the results for children with an acquired hearing loss (between 4 and 10 years of age) are shown in Figs. II-B-3-II-B-5. The DL-values tend, in these cases, to be lower than for the group as a whole. Attempts were also made to relate DL-values to intensive early auditory training but the available data were too limited to show any tendency.

The results from the speech-discrimination test in Fig. II-B-6 are very tentative as results from very few cases could be obtained due to lack
Fig. II-B-6. Result on speech-perception test with spondee words. The numbers indicate the mean hearing loss for 500, 1000, and 2000 Hz. Filled circles are from subjects that always use hearing aids and open circles from subjects that use hearing aids only during school hours.

Fig. II-B-7. Summary of results from frequency-discrimination measurements. As the measurements were made on severely and profoundly hearing-impaired subjects few results were obtained in the area with normal or almost normal relative difference limen.
of time. The spondee test is mainly a test of vowel perception and the results show a rapid degradation when frequency discrimination is worse than 5-7 % at 1000 Hz. When the results are plotted against DL at other frequencies, this clear tendency is not obtained. The results agree with the results published by Di Carlo (1962). He measured speech discrimination for PB-words and found a significant negative correlation between speech perception and frequency DL for 500 and 1000 Hz but not for 2000 Hz. Closer study of his data also shows that speech discrimination is very poor when frequency DL approaches 7 %.

The explanation for the significant correlation between DL at 1000 Hz and speech perception is that the frequency region around 1000 Hz is very important for speech perception, especially the perception of vowels. It therefore is important to concentrate effort on the measuring of frequency discrimination in the range 500 to 1500 Hz. The frequencies 750 and 1500 Hz were not included in our test equipment but a modification is under way.

Conclusions

The results of this study show that the ability to discriminate small differences in frequency can be measured on profoundly deaf children at least from the age of 10 years. The results can give valuable information about the residual hearing of the children that can be used in hearing-aid fitting and auditory training. Based on the results it seems possible to divide the audiogram area into three parts, see Fig. II-B-7. A subject with an audiogram in the first part will probably show normal or almost normal frequency-discrimination ability. In the second part of the audiogram area large individual variations can be found and in the last part in most cases values that are the same as those obtained by tactile stimulation are obtained.

Audiograms in this last area are, in most cases, probably a result of tactile stimulation in the ear. A definite answer about the presence of some residual hearing or total loss of hearing cannot be based on the pure-tone audiogram or frequency-discrimination measurements. By combining results from several types of measurements it might, however, be possible to arrive at a reliable answer.

A frequency-discrimination ability better than 5-7 % for frequencies around 1000 Hz seems to be necessary for the perception of speech sounds.
Further studies are needed of the relation between frequency discrimination and speech perception.

Many profoundly deaf children show a frequency-discrimination ability that in most frequencies is worse than 10% (e.g. subject 2 in Fig. II-B-2). It is possible that in these cases a recoding technique can be used that fits some elements in the speech signal to the available residual hearing in a better way than the original amplified speech signal. This type of aid should be developed as a lipreading aid.

Acknowledgments

This research is supported by the Swedish National Board for Technical Development, Contract No. 75-3723A and 3723B. The measurements have been made at the School for the deaf in Stockholm (Manilla-skolan) and Risbergska skolan in Örebro. We wish to thank the staff of these two schools for their kind cooperation.

References


