Periodic-nonperiodic test of hearing capacity

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journal: STL-QPSR
volume: 9
number: 2-3
year: 1968
pages: 019-028

http://www.speech.kth.se/qpsr
III. COMMUNICATION WITH AUDITORY HANDICAPPED

A. PERIODIC-NONPERIODIC* TEST OF HEARING CAPACITY**

A. Risberg

There is at present a great deal of interest in attempting to make the maximum use of the residual hearing of severely hard of hearing subjects. One result of this interest is the development of the so-called "speech analyzing hearing aids" (12). In these aids the speech signal is analyzed and some important elements extracted that the hard of hearing subject is unable to perceive. The extracted signals are then transmitted in a new frequency range and perhaps also by the use of a different signal type, e.g. a periodic signal may be used instead of a nonperiodic signal.

An example of this type of aid is the fricative transposing hearing aid. In this case the purpose is to make the high-frequency fricatives audible to a subject who has residual hearing only in the low-frequency range. Different solutions have been suggested and tested. The systems developed by Johansson (6), Pimonow (16), Kringebohn (7), and Guttman and Nelson (4) transform the high-frequency fricatives to low-frequency noise sounds whereas the systems developed by Lafon and Isaac (8) and Ling and Druz (9) transform the fricatives to low-frequency tones.

Many other investigators seem to have worked on this problem without publishing any description of equipment or test results. Principally, the same system has been tried by IBM (Hopner and Andrews) (5) to increase the intelligibility on a telephone line.

The application of the speech analyzing technique in hearing aids makes it necessary to have tests that can show that a subject can use this new information. For this purpose Pimonow (15) and Mazéas (10) have tried to measure the hearing capacity of an impaired ear by measuring time, frequency, and amplitude discrimination and then calculate the channel capacity of the system in bits/sec. Other investigators have concentrated on one aspect of auditory perception. Pickett has measured the frequency discrimination for low-pass filtered noise signals, Pickett and Martin, (13) and recently also frequency discrimination for synthetic vowels (14). These last-mentioned measurements have been made in cooperation with Mártony at this laboratory.

* PNP-test
** A summary of the research reported here was presented at the 6th ICA in Tokyo, 1968 (17).
These different tests work on a discrimination level of perception which can be seen as a higher level than the detection task used in taking a pure-tone audiogram. The test described in this article works on a still higher level: identification, and as identification of different elements in a signal is necessary for speech perception it is hoped that the result from the test can be used, for example, to predict if it is possible for the subject to use a fricative transposing hearing aid.

By comparing the result when a finger is stimulated by a vibrator and results from stimulation at the ear by headphone it is hoped that the test also can be used to answer the question if a subject has residual hearing or if the sensation at the ear is due to sensation of vibration.

This assumption is based on a model for perception that includes three stages; a sensory element that transforms the mechanic energy to signals in the nervous system, a second stage where the signal is processed in some way and then made available to the third stage which is a central decision making unit. It is assumed that this last stage is the same both for the vibratory signals to the finger tip and the acoustic signals to the ear. The test result will then show if there is any difference in the two previous stages at the two test points (finger and ear).

**Test equipment**

A periodic signal composed of a train of short pulses with a repetition frequency of 100-300 pulses/sec and with white noise is used as test signals. The frequency spectrum of both signals is flat up to 4 kHz. The duration of the signal is varied in the test and the shortest duration is established that allows the subject to identify which of the two signals was presented to him.

Fig. III-A-1 shows a block diagram of the test equipment. To the left are the two signal sources. The wanted signal type can be selected by the switch. The signal is passed through a filter. In the experiments reported on here, three different filters have been used, 100-4000 Hz, 300-800 Hz, and 2400-3400 Hz. The first filter is called WIDE BAND and the other LOW FREQUENCY (LF) and HIGH FREQUENCY (HF).
Fig. III-A-1. Block diagram of test equipment. All attenuators can be varied in 1 dB steps.
After having passed the filter the signal is passed through a gate with a rise- and decay-time of 1 msec. The on-time of the gate is controlled by the time-generator. In the block diagram are also shown 3 attenuators, a power amplifier, and a switch that can pass the signal either to a vibrator or to headphones.

**Test procedure**

The test starts with the establishment of the threshold for the periodic signal by means of the attenuator "C". Signal duration 1000 msec and periodicity usually 200 pulses/sec. The next step is to establish the threshold for the nonperiodic signal (noise) by means of attenuator "A" and the same duration. The test level is set 15 dB above the thresholds by means of the attenuator "C".

A block of ten stimuli is presented to the subject with random variation on attenuator "B". The starting duration is 1000 msec and the subject reports his answers by means of two pushbuttons and is immediately informed if he is correct or not. The test continues until the duration $T_1$ is found where he cannot identify the two signals with at least 80% probability. The attenuator "B" is used to make it difficult for the subject to use loudness as a clue in the identification.

The duration $T_1$ is measured both for tactual stimulation on a finger tip by means of the vibrator (Goodman V 47) and for stimulation in the ear by the headphones (Telphonic TDH 39). The contactor area of the vibrator is $0.3 \text{ cm}^2$.

**Results**

Fig. III-A-2 shows the identification times for normal hearing subjects as a function of test level. Wide-band signal. For auditory signals it is in this case not possible to identify the periodic signal as periodic. The test results instead show how long a noise signal must be in order to make it distinguishable from a short click. Note the great difference in identification times.

For band-pass filtered signals an auditory identification time of about 20 msec is obtained when a low-frequency band, 300-800 Hz, is used and around 10 msec when a high-frequency band, 2400-3400 Hz, is used. For tactual stimulation the identification time for the low-frequency signal varies between 40 and 80 msec.

* and also random variation between periodic and nonperiodic.
SUBJECT P.J.

<table>
<thead>
<tr>
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<td>A</td>
<td>T</td>
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<td>A</td>
</tr>
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<td>1000/2</td>
<td>1000/0</td>
<td>500/2</td>
<td>1000/0</td>
</tr>
<tr>
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<td>800/0</td>
<td>500/2</td>
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<td>100/1</td>
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<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

T = TACTUAL STIM.  A = AUDITORY STIM.

1000/2 = SIGNAL DURATION 1000 ms., 2 ERRORS.

Table III-A-1. Test results for a severely hard of hearing subject (audiogram, see Fig. III-A-4). For each duration a block of 10 stimuli is given and if the subject achieves 80% correct or better the duration of the test signal is decreased.
Fig. III-A-2. Test results for normal hearing subjects, wide-band signal. Repetition frequency of pulse generator is 120 pulses/sec. Values for auditory stimulation shows in this case how long a short burst of noise must be to make it distinguishable from a click.
Fig. III-A-3. Audiograms (ISO) and test results on the PNP-test for two groups of children from the school for hearing impaired at Stockholm (Manillaskolan). Identification times are given for band-pass filtered signal (see text) and repetition frequency 200 pulses/sec. In the audiogram the "limit for hearing" is indicated by the dotted line.
SUBJECT: M.E.  
\[ T_{LF} = 60 \text{ms} \]
\[ A_{LF} = 40 \text{ms} \]
\[ A_{HF} = - \]

SUBJECT: P.J.  
\[ T_{LF} = 30 \text{ms} \]
\[ A_{LF} = 20 \text{ms} \]
\[ A_{HF} = 10 \text{ms} \]

Fig. III-A-4.
SUBJECT: R.A.

TLF = 80 ms
ALF = 20 ms
AHF = 20 ms

Fig. III-A-5.
Fig. III-A.6.
Fig. III-A-7. Detailed test results for two subjects with similar audiograms, see Fig. III-A-5.
Table III-A-1 shows the test results for a severely hard of hearing boy, 13 years old, with congenital perceptive hearing loss, wide-band signal. As the subject is not used to perceive signals of this type, it is necessary to repeat the test several days to obtain final values. As can be seen from Table III-A-1 shorter identification times are obtained for stimulation at the ear which indicates a functioning hearing mechanism.

Figs. III-A-3 to III-A-6 show audiograms and test results for 11 severely hard of hearing children, 13-15 years old. A factor can be obtained by dividing the tactual identification time with the auditory value. If this factor is considerably above unity this might indicate a functioning hearing mechanism. If the factor is around unity it is probable that the response in the pure-tone audiogram is due to sensation of vibration.

In the audiograms on Figs. III-A-3 to III-A-6 a "limit for hearing" has also been indicated. This curve (dashed) is taken from the work of Barr (1) and Rösl er (18) and is the audiogram for subjects that have shown no reactions to sound (Barr) and the audiogram for subjects where the diagnosis of total deafness is possible by other means than only audiogram measurements. It is clear that this limit is an average value and that considerable individual deviation can occur.

In addition, Rösl er measured the threshold of detectability for vibratory stimuli at the finger tip with a bone conduction transducer and compared these values with measurements at the mastoid. He also measured the threshold when a headphone was held in the palm of the hand and when it was placed over the ear. The results show that these four thresholds for a totally deaf subject are parallel. By comparing the measurements Rösl er tries to find a method that can give an indication of total deafness but the large individual variations in the "limit for hearing" makes this in many cases difficult. In Table III-A-2 the conclusion that can be drawn from the audiogram about residual hearing when this "limit for hearing" is used has been indicated under "RESIDUAL HEARING". The same conclusion drawn from the PNP-measurements is also indicated.

In Fig. III-A-7 test results from two subjects with very similar audiograms, see Fig. III-A-7, Y. J. and L. J., are shown. As can be seen a marked difference is obtained for the two subjects in the PNP-
measurements. Subject Y. J. obtains the same identification times with stimulation at a finger tip and at the ear, but subject L. J. obtains shorter identification times with stimulation at the ear. The result then indicates that Y. J. has no residual hearing but that L. J. has residual hearing at both low and high frequencies. These two cases then show that the PNP-measurement can give valuable supplementary information to the pure-tone audiogram.

Relation to speech perception

To study the relation between the pure tone audiogram, result on the PNP-test and speech perception, six of the subjects went through a short training experiment with three different speech materials. In all the tests the stimuli were presented through the group amplifier in the classroom and the subjects adjusted the amplification on their control units to the listening level they were used to. The training was achieved by means of the group teaching machine described in this issue of QPSR by Spens and Risberg (19). The following training material was used:

Test 1. Low-frequency discrimination

The training material consisted of rhyming word pairs where the words in the pair were selected so that the difference between them consisted of the vowel pairs /uː - oː/ and /oː - aː/, e.g. /fuːr - foːr/. In order to identify which word was presented it is necessary that the subject can perceive the difference in the location of \(F_1\) and \(F_2\), which are both below 1000 Hz for these vowels. The test is then a test of formant frequency discrimination in the frequency range below 1000 Hz. Per cent correct after eight presentations, and a total training time of about 80 minutes, is given in Table III-A-2.

Test 2. High-frequency discrimination

This test uses the same technique. The words in the pair differed in a high-frequency region between 1500-4000 Hz as the selected vowels were /uː, iː, yː/, e.g. /fuːl-fiːl/, /siːl-syːl/ /dʒiːkə-duːka/. The result in Table III-A-2 is obtained after three training sessions.
Table III-A-2. Summary of data for the subjects and result on the speech perception tests.

<table>
<thead>
<tr>
<th>Subject</th>
<th>Cause of deafness</th>
<th>Age</th>
<th>PNP-test</th>
<th>Residual hearing *</th>
<th>Speech perception, percent correct</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>$T_{LF}$</td>
<td>$A_{LF}$</td>
<td>$A_{HF}$</td>
</tr>
<tr>
<td>T.B.</td>
<td>meningitis</td>
<td>12</td>
<td>30</td>
<td>30</td>
<td>-</td>
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<tr>
<td>Y.J.</td>
<td>unknown</td>
<td>12</td>
<td>80</td>
<td>100</td>
<td>-</td>
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<tr>
<td>L.J.</td>
<td>hereditary</td>
<td>12</td>
<td>50</td>
<td>20</td>
<td>10</td>
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<tr>
<td>M.E.</td>
<td>unknown</td>
<td>12</td>
<td>60</td>
<td>40</td>
<td>-</td>
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<tr>
<td>P.J.</td>
<td>unknown</td>
<td>12</td>
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<td>14</td>
<td>80</td>
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<tr>
<td>T.H.</td>
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<td>E.K.</td>
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<td>40</td>
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<td>-</td>
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<tr>
<td>S.A.</td>
<td>hereditary</td>
<td>14</td>
<td>30</td>
<td>30</td>
<td>-</td>
</tr>
</tbody>
</table>

* see text
Test 3. Fricative transposing test

To test if the PNP-test could be used to predict results from training with a fricative transposing equipment a test was made with word pairs containing the phonemes /v-s/ and /l-s/. The fricative transposing equipment used is shown in Fig. III-A-8. The speech signal is divided into two channels. In the first channel the signal goes directly to the output mixer and in the other the signal is passed through a band-pass filter 4-7 kHz, a rectifier, a low-pass filter, and then to a modulator fed by a noise generator. The output from the modulator is passed through a band-pass filter 0.3-1 kHz and then to the mixer. The result is that the high-frequency sounds are transformed to low-frequency noise sounds. A hard of hearing subject can identify the words used in the test if he can identify a low-frequency sound as being periodic, /l/ or /v/, or nonperiodic, /s/. In order to restrict the information to the low-frequency part the signal was passed through a steep low-pass filter at 1000 Hz before presentation to the subjects. The results shown in Table III-A-2 are obtained after four training sessions, total training time was one hour.

Discussion

In Table III-A-2 the results from the different tests have been summarized. All the subjects have normal or above normal intelligence and show no signs of secondary handicap. Their ages are 12-14 years. In the column "Residual hearing" an attempt has been made to indicate the information derivable from the pure-tone audiograms if it is assumed that an audiogram that coincides or is below the "limit for hearing" represents vibration sensation. In the high-frequency region it is difficult to say from the audiogram if useful residual hearing exists. A value of around 120 dB has tentatively been used as the limit. For the PNP-test a quotient of around unity between the value for tactual stimulation and auditory stimulation has been taken as an identification of total deafness.

There is a general agreement between these two measurements. Exceptions are the subject Y. J., see also Fig. III-A-7, where the PNP-test indicates no hearing, and the subjects L. J. and P. J., where the audiogram only indicates hearing at high frequencies but the PNP-test also indicates hearing at low frequencies.
MIXER

BP FILTER 4-7 kHz

LP FILTER 40 Hz

MODULATOR

BP FILTER 0.3-1 kHz

NOISE GENERATOR

FRICATIVE TRANSPOSING HEARING AID

Fig. III-A-8. Block diagram of the fricative transposing hearing aid used in the experiment.
For the lower group in Table III-A-2 the first three subjects have very similar audiograms, see Fig. III-A-5, and show also about the same results on the PNP-test and the speech perception tests. All obtained good results on the fricative transposing test and on the low-frequency test. The result on the high-frequency speech test is not significantly different from guessing. Of the three subjects V. L. has the poorest hearing (audiogram) for low frequencies but this does not seem to show up in the measurements if not the short identification time for tactual stimulation is taken as an indication of this. Note the subjects T. B., P. J., A. W., and S. A. who all show this short identification time for tactual stimulation and all have audiograms below the "limit for hearing".

The last three subjects have also about the same audiogram, see Fig. III-A-6. They react in the same way on the PNP-test and also on the test with transposed fricatives where none of them achieves results no better than guessing. Subject S. A. achieves a very good result on the low-frequency test in spite of an audiogram below the "limit for hearing" and a bad PNP-value for low frequencies. There can be many explanations to this. One is that the identification of the vowels is based on high-frequency components as the audiogram is relatively good for higher frequencies and the speech signal for this test was not low-pass filtered as in the fricative transposing test. This interpretation is in agreement with the relatively good result on the high-frequency test. Another rather hypothetical explanation is that this subject can make frequency discriminations in spite of the poor audiogram but not time-domain identifications which were required by the PNP-test. Further tests with this subject will probably resolve this question.

Conclusions

The data presented here must be considered as preliminary as we do not know how much training is needed before final values can be obtained on both the PNP-test and the speech perception tests. It must, however, be noted that all the subjects had been trained in perceiving speech through the group amplifier and hearing aids from a very early age. The test results from the PNP-test tended to stabilize after three to four measurements both for tactual and auditory stimulation.
As was shown in Fig. III-A-7 and Table III-A-2 the PNP-test can give valuable information that supplements the information obtained by the pure-tone audiogram. The results show also that the test predicts the effect of training with a fricative transposing equipment but this does not necessarily mean that the subject will benefit from using such an equipment as only one aspect of perception was investigated, the differentiation of a fricative from a periodic sound. It is possible that the transposing equipment introduces some unwanted effects that will give a negative net effect. This problem will be studied further.

Table III-A-2 shows great variations in the values for actual stimulation between the subjects, from 30 to 80 msec. It is not clear if this has any diagnostic value. The definition of total deafness from the audiogram and from the PNP-measurements needs a very thorough validation against education progress, results from various speech tests, and so on.

In the work on the PNP-test a very pragmatic approach has been taken. It is clear that many details in the test procedure need to be studied, for example the shift of loudness for periodic and noise signals when the duration is decreased. This is especially important as the test procedure relies on the assumption that the two signals have about the same loudness. To some extent the effect of a slight unbalance in loudness is counteracted by the random variation on attenuator "B" in Fig. III-A-1. When the test time is very short this is not enough as the periodic signal then is reduced to a click. Tests where the subject's task is to identify a signal as a click or a tone has been tried\(^{(2)}\).

The work on the PNP-test will be continued. More data from both normal hearing and hard of hearing subjects will be collected and further comparisons between speech perception scores on different speech materials and the identification time will be made. It is of special interest to try the test on preschool children.

Acknowledgments

The research reported here has been supported by the Swedish Council for Applied Research. All the measurements have been made by Miss E. Agelfors. The children are from the school for the hearing impaired in Stockholm (Manillaskolan) and I am very grateful for all
assistance from the teachers of the deaf, C. B. Flodell and M. Ohlsson. 
Dipl.ing. J. Mártony has taken a very active part in the development 
of the test method.

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