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journal: TMH-QPSR
volume: 43
number: 1
year: 2002
pages: 051-056

http://www.speech.kth.se/qpsr
The relationship between residual hearing and speech intelligibility - Is there a measure that could predict a prelingually profoundly deaf child's possibility to develop intelligible speech?

Anne-Marie Öster

Abstract
The relationship between speech intelligibility of eleven prelingually deaf children and their residual hearing capabilities was investigated. Audio recordings were made of the deaf children, ranging from eleven to seventeen years of age, when they read so-called Helen-questions. Tapes containing the Helen-questions were played to inexperienced and experienced normally hearing listeners to measure the intelligibility of each child's speech. The speech intelligibility scores were related to the amount of residual hearing, measured as the better-ear average of pure-tone thresholds at 500, 1000 and 2000 Hz, shape of audiogram and the degree to which the children could use their residual hearing. The purpose was to investigate if any of these measures of residual hearing might be a good predictor of a prelingually deaf child's possibility to develop intelligible speech. The best correlation was found between the children's ability to use their residual hearing for speech perception and the intelligibility of their speech.

Introduction
A new teaching system in the schools of the deaf in Sweden has given rise to the situation that speech now only exists in the speech clinic, and then only for about 40 minutes per week. Sign language is the first language and Swedish is the second language and will mainly be learnt in its written form. This being the case, speech training in a bilingual deaf school nowadays primarily implies that prelingually profoundly deaf children might develop intelligible speech for the purpose of making statements and more seldom for the purpose of communication.

During some years the Hearing Technology Group have been working in a joint project together with the Manilla School in Stockholm. A lot of work has been done on improving and developing efficient and individualized speech training methods and introducing computer-based speech training.

The children attending this school are educated by sign language. Their hearing loss is often in the vicinity of 90 dB HL or more, where the hearing capabilities may rather be vibrotactile than auditory. Their attitudes towards speech training as well as their speech intelligibility often vary from very poor to very good.

Within this project we have been discussing the following questions: How is speech intelligibility related to audiological data? Is there some measure of residual hearing that could predict a prelingually profoundly deaf child's possibility to develop intelligible speech?

Purpose of the study
The main purpose of this study was to investigate the relation between speech intelligibility of eleven prelingually profoundly hearing-impaired children and their residual hearing capabilities. The study contains three parts. In the first part of the study, the relation between the amount of residual hearing, measured as the better-ear average of pure-tone thresholds at 500, 1000 and 2000 Hz, and the intelligibility of their speech is investigated (I).

In the second part, the interrelationship between the quality of residual hearing, defined as the shape of audiogram and the intelligibility of their speech is studied (II).

In the third part, the relation between the degree to which the children could use their residual hearing and the intelligibility of their speech is studied (III).
Methods and Results

Subjects
Eleven children from the deaf school, five boys and six girls, were selected to cover the range from good to poor deaf speakers. They were not chosen according to degree of their hearing loss. All of the subjects were prelingually deaf and educated by sign language. Their pure-tone averages at .5, 1, 2 kHz were between 90-108 dB HL in the better ear. One child was eleven years of age, while the others ranged from fifteen to seventeen years. Age, sex and mean hearing loss are shown in Table I.

Table 1. Age, sex, and hearing loss for the frequencies .5, 1, 2 kHz in the better ear for the eleven children in the study.

<table>
<thead>
<tr>
<th>Child</th>
<th>Age</th>
<th>Sex</th>
<th>PTA dB HL</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>15</td>
<td>F</td>
<td>90</td>
</tr>
<tr>
<td>2</td>
<td>16</td>
<td>F</td>
<td>92</td>
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<td>3</td>
<td>11</td>
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<td>6</td>
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<td>M</td>
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<td>11</td>
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<td>108</td>
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</tbody>
</table>

Intelligibility test
The speech of the children was recorded on audio-tape, when they read some questions. The questions were so called Helen-questions, of the type “what colour is a lemon?”, which can be answered with one word only. Five different questions read by each child were presented via headphones at a comfortable level to two groups of normally hearing persons (experienced and inexperienced in listening to the speech of prelingually deaf children) to objectively evaluate the speech intelligibility. The listeners had the possibility of repetition. The listener's task was to write down, in Swedish orthography, the answer of the question with one word. Only completely correctly understood questions were counted as correct.

Listeners
Twenty-four normally hearing persons listened to the speech-material. Sixteen of the listeners belonged to the staff of the department of Speech, Music and Hearing, KTH and were inexperienced in listening to the speech of deaf children. However, most of them were phonetically trained and had some experience of pathological speech. Eight of the listeners were speech therapists of deaf children and hence experienced in listening to this kind of speech.

Speech intelligibility scores of the children
Figure 1 shows the result of the intelligibility test averaged across all 24 normal hearing listeners. The figure shows number of correctly perceived questions in percent (each bar is based on 120 responses).

Three children's speech was unintelligible, as the listeners could only understand 7-34% of their questions. Two children's speech was semi-intelligible, 57-63% of their questions were understood. Six children were assessed to be intelligible as they were able to make as much as 74-98 % of their questions understood by the listeners.

Consequently, these prelingually deaf children with pure-tone averages at .5, 1, and 2 kHz between 90-108 dB HL in the better ear showed vastly varying intelligibility scores. The result indicates that the eleven children covered the range from good to poor speakers, thus confirming the selection of speakers made in this study.
The effect of listeners’ experience

Figure 2 shows the speech intelligibility of each child across experienced and inexperienced listeners. The average result for all questions and all speakers was 60% for all listeners, 54% for inexperienced and 65% for experienced listeners. For the most intelligible speaker, the two groups got the same scores and for the other five speakers with good intelligibility, the difference between experienced and inexperienced listeners was as high as 82%. The differences for the unintelligible and semi-intelligible speakers were both 15%. It is natural that listener experience is more important for speakers with good capability. Speaker 4 differs 31% in intelligibility and speaker 11 only 9%, which implies that individual speaking habits are possible to learn by experience.

I. Relation between amount of residual hearing and speech intelligibility

It is a general opinion that there exists a very close relationship between degree of hearing impairment and speech intelligibility of deaf children. Poor speech accompanies higher hearing loss. Levitt & Geffner (1987) have shown that the intelligibility of a deaf child’s speech was significantly correlated with his or her degree of hearing impairment. On the average, speech intelligibility decreased with increasing hearing loss until a loss of about 90 dB, in their study. Above that, the degree of correlation was reduced.

To investigate if the amount of hearing also is predictive of the speech intelligibility of prelingually profoundly deaf children with PTA averages of 90-108 dB HL, the relation between the amount of residual hearing and the children’s speech intelligibility was studied. The index most commonly used to indicate the amount of hearing of a deaf person, is the better-ear average of pure-tone thresholds at 500, 1000 and 2000 Hz.

II. Relation between shape of audiogram and speech intelligibility

The sort of speech a child develops depends not only on the amount of hearing but also on the quality and the use the child is able to make of his/her residual hearing. It has been discussed whether or not the shape of the audiogram,
rather than the degree of hearing loss as measured by PTA, may be the main factor which affect the intelligibility of deaf speakers. In general, flat audiograms are said to be associated with high speech intelligibility scores and falling audiograms with low speech intelligibility scores.

Markides (1985) investigated the relationship between shape of audiogram and rated speech intelligibility of children with similar average hearing loss of about 50 dB in their better ear. Six groups of children represented different types of audiogram shapes. However, he found no significant correlation between audiogram shape and rated speech intelligibility in that group of hearing-impaired children.

To investigate if the “quality” of residual hearing might be predictive of prelingually profoundly deaf children's speech intelligibility, we used the method of Risberg & Martony to classify the children's audiograms (Figure 4). By this method the audiograms are divided in a low frequency area from 125-1000 Hz and a high frequency area from 2000-8000 Hz. These two areas are then divided in 0-D for low frequencies and 0-6 for high frequencies. Consequently, by a combination of a letter and a digit, coarse information about quality of the residual hearing and shape of the audiogram is given.

The shapes of all audiograms were “falling”, but the qualities of the residual hearing were varying among the children from B3 to C6. Six of the children's audiograms were in the areas C4-6, that means in ranges where sound might be perceived through vibrotactile rather than auditory receptors. However, no clear relation existed between speech intelligibility and quality of their residual hearing. Except for one child (B3 with an intelligibility score of 98%), there was no prediction that a child with a classification of C4-6 should be a poorer speaker than a child with a classification of B4-C3.

### III. Relation between use of residual hearing and speech intelligibility

The functional hearing of a child, that is the degree to which he can use his residual hearing for speech perception and control of his own speech production, depends on his ability to perceive temporal and spectral information in speech, like the ability to perceive gap durations and small differences both in frequency and intensity. Speech processing capabilities are of course more appropriate to measure by means of a speech-test than by pure tones. Since the range of speech reception skills in profoundly deaf children is quite limited and since they are low verbal, speech material can be difficult to use. Sentences might contain words that they do not know or difficult grammatical constructions. Speech-test especially designed for this group must be used. Several researchers have shown (Cramer & Erber, 1974; Erber, 1974) that a simple spondee recognition test can give valuable information about a profoundly deaf child's ability to perceive speech.

To investigate if the use of the residual hearing could predict the intelligibility of a prelingually profoundly deaf child's speech, the functional hearing of each child was measured by means of a speech-test consisting of twelve common spondaic words familiar to the children. Twenty-four words were presented to the children via headphones at a comfortable level. The children answered by pointing to pictures that illustrated the test words. Figure 5 shows the functional hearing of the eleven children. Percentage of correctly perceived spondaic words is shown for each child.
The relation between measured speech intelligibility and functional hearing of the children is shown Figure 6.

A positive correlation was calculated to 0.73 between functional hearing and speech intelligibility measured for all listeners in average. The correlation between functional hearing and speech intelligibility scores for experienced listeners was 0.74 and for inexperienced listeners 0.70.

This indicates that the result of a simple speech test is a moderately good predictor of a prelingually deaf child’s ability to develop intelligible speech.

**Discussion**

In this study, the relation between speech intelligibility of eleven profoundly and prelingually deaf children and different aspects of their residual hearing capabilities was investigated. The purpose was to study if there is a measure of residual hearing that might predict the deaf child's ability to develop intelligible speech. Correlations were made between speech intelligibility scores and (I) amount, (II) “quality” and (III) use of the children's residual hearing.

Several previous studies have shown that there is a positive correlation between amount of residual hearing, as measured by better-ear average of pure-tone hearing threshold levels at 500, 1000 and 2000 Hz and speech intelligibility of hearing-impaired speakers in general. This is, however, not the case for profoundly deaf children. Pure-tone audiograms on the whole were poorly related to the speech intelligibility of the profoundly deaf children. Low correlations were found between pure-tone averages and speech intelligibility and between quality of residual hearing, as classified through the Risberg & Martony audiogram classification method, and speech intelligibility. The result of this study indicates that a profoundly deaf child's speech intelligibility is more related to his functional hearing, in this study measured through the ability to recognize simple speech stimuli.

The degree to which a deaf child can use his residual hearing is of course only one of many factors affecting the speech development in prelingually deaf children. Levitt has shown that there also exists a strong relationship between speech intelligibility and age at onset of deafness, early special education, use of hearing aid and additional handicaps.

Profoundly deaf children are often defined as those, who have pure-tone audiograms in the vibrotactile area where sound might be perceived through vibrotactile rather than auditory receptors (Erber, 1977). Pure-tone audiograms cannot differentiate “vibrotactile” from “auditory” children. Vibrotactile perception is mostly limited to speech-envelope features like duration and intensity. Auditory perception identifies even spectral features like small differences in fundamental frequency and vowel formant patterns. It is possible that those children, who got good results on the spondaic-word-test, were “auditory” children while those who got poor results were “vibrotactile” children.

In a future study, attempts are going to be made to develop a simple speech-test that should discriminate profoundly deaf children's ability to perceive temporal or/spectral information in speech. The speech perception test should
contain easy and familiar word-pairs of minimal contrast, which could be illustrated with pictures. Such a test could be useful to speech therapists for diagnostic purposes.

Acknowledgement

The work has been supported by grants from the Bank of Sweden Tercentenary Foundation.

References
