Speech intelligibility in simulated acoustic conditions for normal hearing and hearing-impaired listeners

Iris Arweiler[1], Torben Poulsen[2], and Torsten Dau[1]

[1]*Centre for Applied Hearing Research, Ørsted•DTU, Technical University of Denmark, DK-2800 Lyngby, Denmark*

[2]*Acoustic Technology, Ørsted•DTU, Technical University of Denmark, DK-2800 Lyngby, Denmark*

The possibility to predict speech intelligibility scores for hearing-impaired listeners from the audiogram depends on the variability of these scores among listeners. It is not clear how large this variability is when speech intelligibility is assessed in complex listening environments for groups of hearing-impaired listeners with different hearing loss configurations. Therefore, speech reception thresholds (SRT) were measured in this study for different groups of hearing-impaired listeners in simulated acoustic environments. The variability among hearing-impaired listeners with a mild (group 1) or steeply sloping (group 2) sensorineural hearing loss was small for all configurations whereas hearing-impaired with a moderately sloping (group 3) or flat moderate to severe (group 4) sensorineural hearing loss showed considerable variability of the SRT. Spatial separation of the signal and the interferer increased the variability for the listeners from group 3. An average SRT with a small standard deviation could not be obtained for group 3 and 4 and speech intelligibility prediction from the audiogram is therefore not possible for these groups with the necessary accuracy.

INTRODUCTION

Speech intelligibility depends on many factors, such as the room acoustics, the acoustical properties and location of the signal and the interferer(s), and the ability of the auditory system to process monaural and binaural sounds. The influence of all these factors makes it difficult to predict speech intelligibility in complex environments, particularly for hearing-impaired listeners. Several studies have attempted to correlate audiometric pure tone thresholds to speech intelligibility scores, with limited success (e.g. Plomp, 1986; Yoshioka, 1980). One main reason for this is that there is a large variability of speech intelligibility performance among hearing-impaired listeners even if they have similar audiometric thresholds. Marshall (1981) measured speech intelligibility scores for words in quiet in 774 hearing-impaired listeners whereby listeners with similar audiograms were grouped together resulting in eight different groups of audiogram configurations. He concluded that, due to the large variability in speech recognition scores, it is difficult to determine whether an individual's score is abnormal. Another study (Nabelek, 1974) examined speech recognition performance with the Modified Rhyme Test (MRT) in babble noise and a classroom. Two different reverberation times were realised by altering the absorption of the room. Speech and noise sources were separated by 60°. The five hearing-impaired listeners of that study had

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similar moderate to severe sensorineural hearing losses. Although the purpose was not to reveal interindividual differences the speech recognition scores among listeners varied greatly.

The aim of the present study was to examine the variability of speech intelligibility scores in complex listening conditions for listeners with different types of hearing loss. Former studies typically did not use complex acoustic conditions for the speech intelligibility assessment or they did not differentiate between different hearing loss configurations and only addressed one type of hearing loss. In our study, SRTs were first measured in anechoic conditions with a stationary noise interferer. The effect of reverberation was investigated next. Finally, the influence of spatially separating the speech and noise source on the variability of the SRTs was examined. Four groups of listeners with different types of hearing losses were used.

The results are relevant for advanced binaural speech intelligibility models that attempt to predict speech intelligibility from the audiogram. If the variability among hearing-impaired listeners even with similar audiograms is large such models should have difficulties to predict the correct speech intelligibility scores.

METHODS

Stimuli

A sentence test was applied to measure speech intelligibility. Sentence tests come closer to conversational speech than, e.g., word tests or consonant-vowel-consonant (CVC) tests. The speech intelligibility measures were performed in two different laboratories (Technical University of Denmark and University of Oldenburg) with a Danish and a German sentence test, respectively. The Danish sentence test “Dantale II” (Wagener, 2003) was used with Danish listeners and the German sentence test “Oldenburger Satztest - OlSa” (Wagener, 1999a,b,c) with German listeners. Both tests are based on the Hagerman sentence test (Hagerman 1982). The sentences consist of five words with a fixed syntactical structure (Name-Verb-Numeral-Adjective-Object). They are created from 50 words that are randomly combined according to this structure (e.g. ‘Peter sieht acht grosse Steine’, ‘Anders ejer fem hvide biler’). The redundancy of these sentences is low so that they can be used repeatedly for the same listener. A stationary speech-shaped noise (SSN) was used as interferer, created from the sentence material in the corresponding language (Wagener, 2003 and Wagener, 1999a,b,c).

Test persons

The speech intelligibility was measured for 14 normal hearing and 16 hearing-impaired listeners. Four of the normal hearing listeners were Danish and ten German. From the hearing-impaired listeners, 7 were Danish and 9 were German. The hearing thresholds for the normal hearing listeners were 20 dB HL (re. ISO 389-8) or better for all tested audiometric frequencies.

Group 1	Mild hearing loss (2 listeners)
Group 2	Steeply sloping from 1 kHz (4 listeners)
Group 3	Moderately sloping hearing loss (7 listeners)
Group 4	Flat moderate to severe hearing loss (3 listeners)

Table 1: Audiogram specification of the hearing-impaired listeners.

The hearing-impaired listeners had different kinds of symmetrical sensorineural hearing losses, from mild over steeply sloping to severe. They were grouped into four categories (see Table 1). Figure 1 shows the audiometric thresholds of the 16 hearing-impaired listeners in the different groups. The initials with small letters refer to the listeners from Germany and the initials with capital letters to the listeners from Denmark. The listeners were between 35 and 81 years old, with a median age of 66.5 years. The age of the listeners is shown in the audiograms behind the initials.

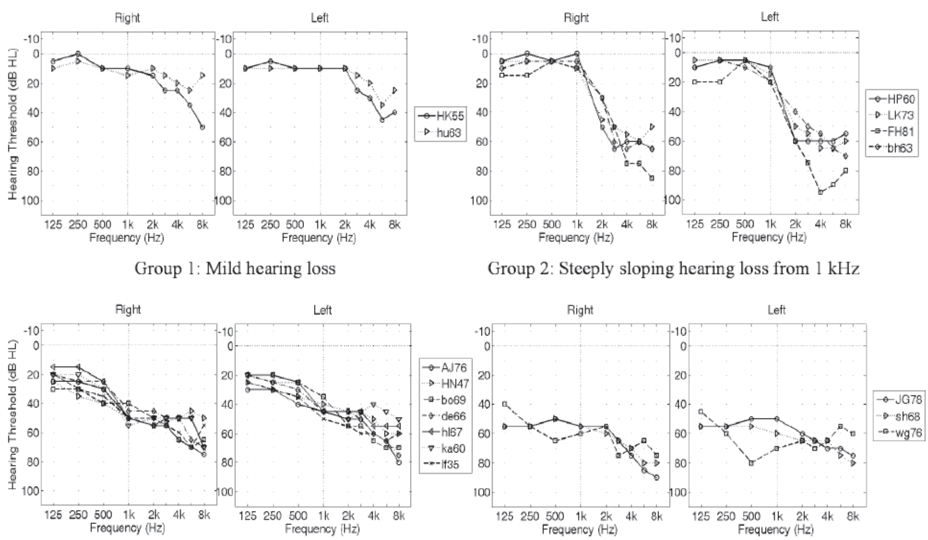

Fig. 1: Audiometric hearing thresholds for right and left ear, Groups 1-4.

Simulated acoustic conditions

Three acoustic environments were simulated with the room acoustic software Odeon (Odeon, 2005): a classroom, a church and an anechoic reference condition. For the anechoic condition, the classroom was selected and the surfaces were covered with 100% absorbing material. The early decay times (EDT - based on the initial 10 dB of the reverse integrated decay curve and averaged over 0.5, 1 and 2 kHz) and dimensions of the rooms are listed in Table 2.

	EDT	Length	Width	Height
Classroom	0.49 s	9.66 m	6.89 m	3.20 m
Church	6.55 s	63.41 m	31.61 m	21.81 m
Anechoic	--	9.66 m	6.89 m	3.20 m

Table 2: Early decay times and dimensions of the simulated rooms considered in this study.

Within these rooms, two different setups of source (target signal and interferer) and receiver (listener) positions were simulated (see Fig. 2):

Setup 1 (S_0N_0): Both target signal and interferer were presented directly from the front of the listener (0° azimuth) at a distance of 3 m.

Setup 2 (S_0N_{105}): The target signal was presented from the front direction (0° azimuth) at a distance of 3 m. The interferer was presented from 105° azimuth at a distance of 2 m.

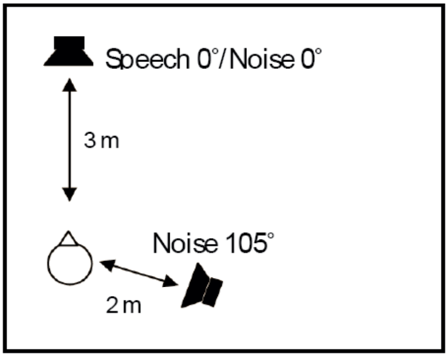

Fig. 2: Setups for target and interferer.

The listener and the interferer had a height of 1.20 m, representing a person of medium height sitting on a chair. The target signal was uttered at a height of 1.75 m. All sources had a directivity pattern resembling that of a human speaker talking with normal vocal effort.

Procedure

Binaural room impulse responses (BRIRs) were created within the Odeon programme from each source-receiver position in each setup, using head related transfer functions (HRTF). The HRTFs were taken from a public database (CIPIC) and had been recorded on Kemar. All speech and interferer signals were convolved with the BRIRs. The filtered speech and interferers were mixed according to the respective setup, and presented over Sennheiser HDA 200 headphones which were free-field equalized according to ISO 389-8 (ISO, 2004). For the calibration, an IEC 60318 (IEC, 1970 and 1996) artificial ear, connected to a Brüel & Kjær 2636 measuring amplifier, was used. All sounds were calibrated to dB SPL.

The SRT for the sentences was measured to determine the speech intelligibility. The listeners' task was to listen to the sentences and repeat the words they could understand. The instructor marked the correctly repeated words on a computer screen. The SRT for each condition was determined with 20 sentences. Word scoring was used, i.e., the level of the sentences changed adaptively depending on how many words were repeated correctly. Before the actual start of the measurement, a training session with at least 2 x 20 sentences was undertaken by the test person.

The interferer level was kept constant at 65 dB SPL for the normal hearing listeners. For the hearing-impaired listeners, the interferer level was kept constant at a level that was clearly audible but not uncomfortably loud. Table 3 indicates the interferer levels used for each group of hearing-impaired listeners. The interferer was gated; it started 500 ms before and ended 500 ms after the sentence and was chosen as a random part of the whole noise signal. All measurements were performed in random order.

	Group 1	Group 2	Group 3	Group 4
Interferer level (dB SPL)	70	75	75	80

Table 3: Interferer levels, in dB SPL, used for hearing-impaired listeners in the different groups.

RESULTS

Normal hearing listeners

The results of the SRT measurements for the normal hearing listeners are shown in Fig. 3. The standard deviations are small in all conditions for both sentence tests.

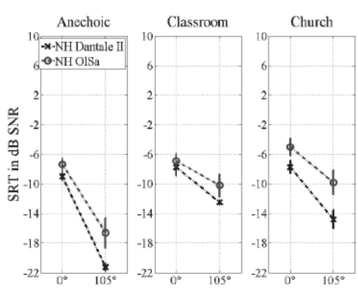

Fig. 3: Measured SRTs with Dantale II and OlSa for normal hearing listeners in six acoustic conditions.

The Dantale II and OlSa have different reference SRTs. The reference SRT for normal hearing listeners is -8.4 dB SNR for Dantale II (Wagener, 2003) and -7.3 dB SNR for OlSA (Wagener, 1999a,b,c). This difference is also reflected in the results of the anechoic S_0N_0 condition in this study (Fig. 3) where the average SRT of the normal hearing listeners is -8.98 dB SNR for Dantale II and -7.34 dB SNR for OlSa. The results of the hearing-impaired listeners were corrected to compensate for these language or test differences in order to pool the data of the Dantale II and the OlSa.

Hearing-impaired listeners

The SRTs determined for the different groups of hearing-impaired listeners in the six conditions are shown in Fig. 4. The two listeners of group 1 had very similar SRTs in all conditions. The maximum difference was 2.46 dB SNR for the S_0N_{105} setup in the anechoic condition. The SRTs in group 2 varied only slightly for three listeners; however, listener FH81 revealed much higher SRTs in all conditions. This might be due to the increased hearing loss at high frequencies compared to the hearing loss of the other listeners in this group. Group 3 showed a large variability of SRTs in all conditions. In particular, when the target and the interferer were spatially separated, the differences in SRT between the individual listeners increased up to 10.8 dB SNR (Anechoic S_0N_{105}). The variability was also large for group 4. Despite their similar audiograms, the hearing-impaired listeners of this group did not show similar SRTs but differences of up to 6.8 dB SNR (Anechoic S_0N_0).

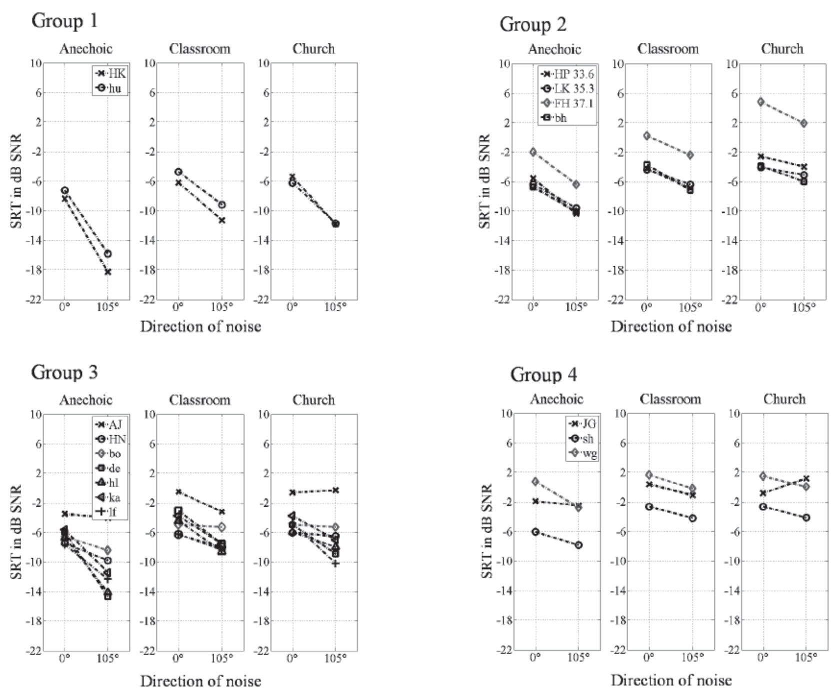

Fig. 4: Measured SRTs for Group 1-4 in six acoustic conditions.

DISCUSSION

The results show that there can be considerable differences in speech intelligibility for different groups of hearing-impaired listeners with similar audiograms. Group 3 (moderately sloping hearing loss) showed a larger variability of SRTs when target and interferer were spatially separated than when they were presented from the same direction. The increase of reverberation itself did not affect the variability of the SRT. These listeners differ therefore more in their speech intelligibility when listening involves binaural processing of the sounds. This is in contrast to group 4 (flat moderate to severe hearing loss) where the difference between the listeners is large in essentially all conditions, i.e. the variability between hearing-impaired listeners is large in an anechoic S_0N_0 condition and remains large in an S_0N_{105} and reverberant condition.

Group 1 (mild hearing loss) showed clearly more homogenous results. As one would expect these listeners showed results similar to normal hearing listeners and therefore show small variability. It is somewhat surprising that all of the listeners of group 2 with a steeply sloping hearing loss (excluding the test person with a more severe hearing loss at the high frequencies) showed very homogenous results in all conditions. More listeners are needed to ensure this result.

Speech intelligibility models can predict speech intelligibility correctly from the audiogram only if the variability between listeners with similar audiograms is small. From the results of the present study this seems possible for hearing-impaired listeners with a mild hearing loss or listeners with a steeply sloping hearing loss from 1 kHz. The prediction does not seem possible for hearing-impaired listeners with a moderately sloping or a flat moderate to severe hearing loss since an average SRT with a small standard deviation cannot be determined. Here, additional information about the individual listener's auditory profile is required in order to account for the data.

ACKNOWLEDGEMENT

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