

**FP6–004171 HEARCOM**

## **Hearing in the Communication Society**

**INTEGRATED PROJECT**

**Information Society Technologies**

**D-3-6: First steps towards normative criteria for non-normal hearing listeners in adverse acoustic conditions**

Contractual Date of Delivery:	31 August 2007 (M36) (+45 days)
Actual Date of Submission:	29 October 2007
Editor:	Iris Arweiler, Torben Poulsen
Sub-Project/Work-Package:	SP2 / WP3
Version:	1.2
Total number of pages:	25

<b>Dissemination Level</b>		
PU	Public	X
PP	Restricted to other programme participants (including the Commission Services)	
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## Deliverable D-3-6

<b>VERSION DETAILS</b>
Version: 1.2
Date: 23.10.2007
Status: Final

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<b>DOCUMENT HISTORY</b>			
Version	Date	Responsible	Description
1	03.10.2007	Iris Arweiler	Contributions from DE-UOL, NL-TNO and DK-DTU added together
1.1	17.10.2007	Iris Arweiler	Update according to remarks from reviewers
1.2	23.10.2007	Iris Arweiler	Update from TNO

<b>DELIVERABLE REVIEW</b>			
Version	Date	Reviewed by	Conclusion*
1	15.10.2007	Rainer Huber	Accept with minor modifications
1	15.10.2007	Tammo Houtgast	Accept with corrections/modifications

\* e.g. Accept, Develop, Modify, Rework, Update

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## **Acknowledgement**

Supported by grants from the European Union FP6, Project 004171 HEARCOM. The information in this document is provided as is and no guarantee or warranty is given that the information is fit for any particular purpose. The user thereof uses the information at its sole risk and liability.

## Pre-Amble

The objective of this Deliverable is to look at the speech intelligibility data that was gathered in D-3-5 (to evaluate binaural speech intelligibility models) from a more practical point of view. The present interpretation of the speech intelligibility measures from D-3-5 focuses more on the practical applicability of speech recognition scores for non-normal hearing listeners rather than the theoretical interpretation. Connections are made between measured speech reception thresholds (SRT) for hearing-impaired/non-native listeners and the performance in real life for these two groups.

The Speech Intelligibility Index (SII) and Speech Transmission Index (STI) are helpful tools in linking speech intelligibility to the performance in adverse acoustic conditions. They are used in this Deliverable to reveal the problems that hearing-impaired and non-native listeners might have to face when listening to speech in adverse acoustic conditions.

## 1 Executive Summary

The evaluation of binaural speech intelligibility models was described in D-3-5. Many speech reception threshold (SRT) measurements were carried out for normal hearing, hearing-impaired and non-native listeners. These results are now used to reveal the disadvantages that hearing-impaired and non-native listeners might have in specific acoustic conditions compared to normal hearing listeners.

For hearing-impaired listeners the SII and useful-to-detrimental ratio were considered to identify the disadvantages they have in certain acoustic conditions. Especially in situation where normal hearing listeners can use binaural cues or listen into the dips of a fluctuating masker hearing-impaired people have to face a sometimes very much reduced speech intelligibility compared to normal hearing listeners. For some hearing-impaired listeners a good listening condition cannot be reached in reverberant environments, even without any ambient noise.

Non native listeners generally need a 4-5 dB improvement in signal-to-noise ratio for similar intelligibility as native listeners. The non-native subjects tested in D-3-5 had a moderate foreign language proficiency. A good listening environment for these non native listeners would require an STI of 0.86 – 1.00. However, in certain environments, e.g. the church condition, only an STI value that yields no more than poor intelligibility can be reached.

Recommendations in terms of STI and SII improvements are given in order to achieve similar listening conditions for non-native/hearing impaired listeners as for normal hearing listeners.

## 2 Introduction

First steps towards normative criteria for non-normal hearing listeners have been taken on the basis of the speech intelligibility results from D-3-5. The influence of adverse conditions on speech intelligibility has often been addressed in previous experiments using different characterisations of room acoustics to predict speech intelligibility. But also the nature of the message being transmitted and the hearing abilities or the proficiency of the listener play a crucial role in the process of understanding speech. Unfortunately the acoustic conditions, the speech material and the listener's proficiency can vary greatly. In our experiments these factors were limited to three acoustic conditions (anechoic, classroom, church), one speech material (Hagerman sentences) and some proficiency levels (hearing-impaired with different hearing losses, non-native listeners). The speech intelligibility results are interpreted with respect to the disadvantages that the different groups of non-normal hearing listeners may encounter in these acoustic conditions compared to normal hearing listeners.

This Deliverable is divided into three parts. The first part interprets the results for hearing-impaired listeners on the basis of the Speech Intelligibility Index (SII). The second part interprets the results for non-native listeners on the basis of the Speech Transmission Index (STI). A separate introduction is given at the beginning of these two parts. The third part gives some recommendations to which degree listening conditions have to be improved for non-native and hearing-impaired listeners.

## 3 Towards normative criteria for *hearing-impaired listeners* in adverse acoustic conditions

### 3.1 Introduction

The EC-SII model, which has been described in D-3-3 and D-3-5, was developed to predict speech intelligibility binaurally based on the Speech Intelligibility Index (SII; ANSI 1997). Speech intelligibility measures were performed with normal hearing and hearing-impaired test subjects in specific acoustic conditions and the results compared to the predictions of the model (see D-3-5). A sentence test with Hagerman type sentences was used for the evaluation.

In this part of D-3-6 the results from a selection of these acoustic conditions were taken (anechoic, classroom, church,  $S_0N_0^1$ ,  $S_0N_{105}^2$ , speech shaped noise, ICRA5<sup>3</sup>) and interpreted regarding the disadvantages that hearing-impaired people have to face compared to normal hearing listeners when listening to speech in adverse acoustic conditions. The acoustic conditions chosen to measure the speech intelligibility were quite specific so that no general conclusions can be drawn for speech intelligibility for hearing-impaired in adverse listening conditions. However, the results show – in agreement with other studies – that hearing-impaired people have greater demands regarding room acoustics than normal hearing listeners to achieve good speech intelligibility without high listening effort.

### 3.2 Speech intelligibility and SII

The speech intelligibility index (SII) is a means to predict speech intelligibility from the spectrum levels of a given pair of speech and noise signals. Band importance functions are used to characterise the relative significance of a given frequency band to speech intelligibility. The SII Standard (ANSI S3.5-1997) primarily focuses on how to calculate the SII. Several calculation methods are addressed using different frequency band procedures, i.e. the number and size of frequency bands used in the calculation (e.g. critical frequency bands, octave frequency bands etc.). This monaural SII (a value between 0 and 1) is interpreted as a proportion of the total speech information available to the listener. The speech intelligibility also depends on other factors, such as the message

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<sup>1</sup> Speech and noise both presented from 0° azimuth

<sup>2</sup> Speech presented from 0° azimuth, noise presented from 105° azimuth

<sup>3</sup> Speech modulated noise with male weighted speech spectrum at normal effort

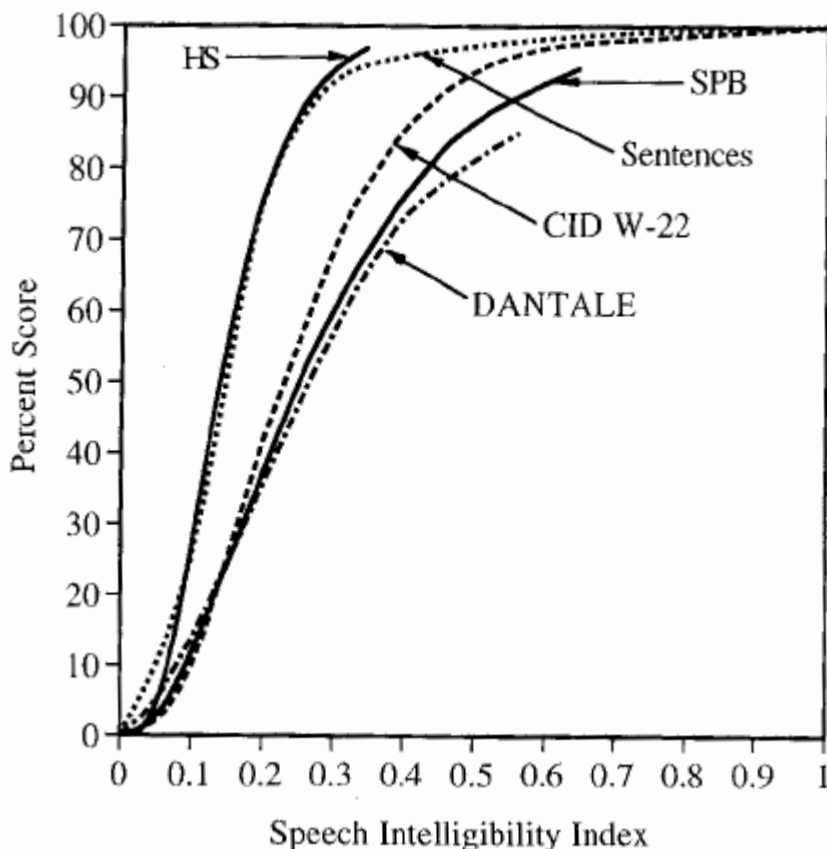
being transmitted and the proficiency of the listener, which can be included in the calculation of the SII.

Annex A of the Standard includes hearing impairment in the calculation of the SII. However, the extension of the SII towards hearing impairment only refers to elevated thresholds and does not include any suprathreshold deficits.

In Annex B the Standard lists band importance functions for various speech tests which can be used to develop the transfer function for the specific speech test, i.e. the relation between the speech intelligibility score of the corresponding test and the SII. A transfer function for the Hagerman sentence test (Hagerman, 1982) has been developed by Magnusson (Magnusson, 1996, see figure 3-1) using a 1/3 octave band procedure, stationary speech-weighted noise and a band importance function of average speech<sup>4</sup>. The transfer function shows that a normal hearing person needs an SII of only 0.14 for 50% recognition. For conditions with an SII of 0.4 a normal hearing person will recognise almost all words of the sentence test.

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<sup>4</sup> This band importance function can be used when the equivalent noise and speech spectrum levels are roughly parallel, cf. ANSI 1997; for the Hagerman sentence test the noise that is used is almost identical to the speech spectrum.



**Figure 3-1: SII transfer function for Hagerman sentences (HS) together with transfer functions for other speech material (from Magnusson, 1996)**

The Hagerman sentence test is a Swedish sentence test. In our evaluation we used the German Oldenburger Satzsets (OISa; Wagener 1999a,b,c) and the Danish Dantale II (Wagener 2003). Both, the OISa and the Dantale II were developed on the basis of the Swedish Hagerman sentence test. The speech reception threshold (SRT – the SNR that yields 50% intelligibility) was determined with both sentence tests in the different acoustic conditions in our experiments.

The SII standard itself gives only a general relation between the intelligibility of received speech and the SII. Approximately, a good communication system has an SII in excess of 0.75 while a poor communication system has an SII below 0.45. Relating these values to the transfer function of the Hagerman sentences we conclude that even under poor acoustic conditions almost 100% of the sentences can be recognised by a normal hearing person. These kinds of sentence tests seem to be very insusceptible to deteriorations in the quality of a speech environment, i.e. only if the quality decreases very much (SII < approx. 0.25) the speech intelligibility rapidly goes down to zero, or put in other words, for  $0.25 < \text{SII} < 1$  the speech intelligibility of Hagerman sentences will be between 90 and 100 %.

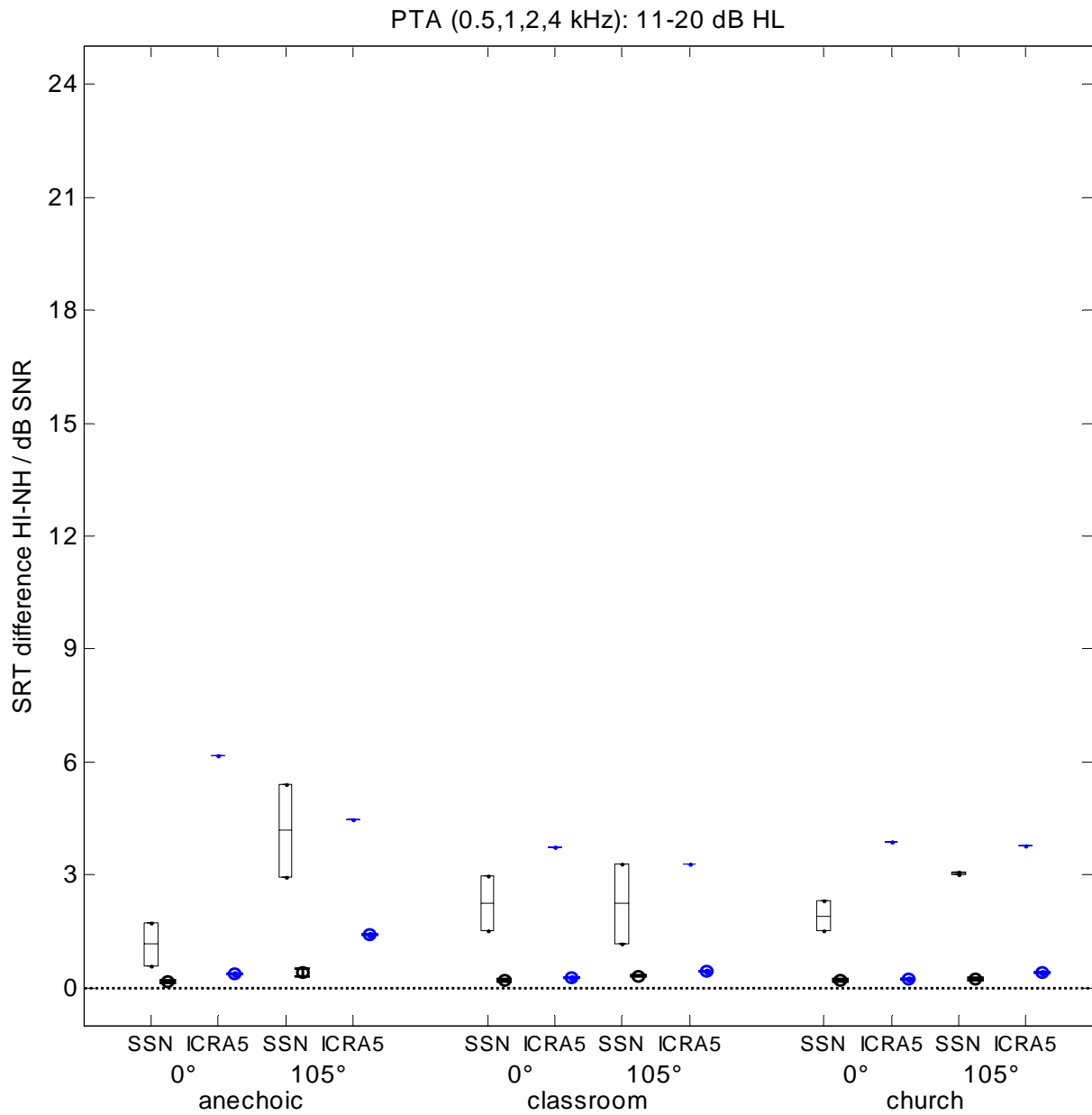
### 3.3 Reduced speech intelligibility in hearing-impaired listeners and consequences

The normal hearing listeners whose speech intelligibility was measured in D-3-5 showed indeed little variation in SRT between the different rooms in monaural conditions ( $S_0N_0$ ). The hearing-impaired listeners showed a considerable decrease in speech intelligibility (higher SRTs) compared to normal hearing listeners. Furthermore the variability between hearing-impaired test subjects was large. This increase in SRT compared to normal hearing listeners and the variability among hearing-impaired listeners for the selected acoustic conditions is shown in the following box and whisker plots (figures 3-2 through 3-5). For a complete description of the specific conditions see D-3-5. The 25 hearing-impaired test subjects were grouped according to their hearing losses. All subjects had a symmetrical hearing loss. The pure tone average (PTA) is often used as a means of describing the hearing loss. We used the average of the pure tone hearing threshold at 0.5, 1, 2 and 4 kHz (averaged across left and right ear) to group the test subjects in four different categories of PTA (0.5, 1, 2, 4 kHz):

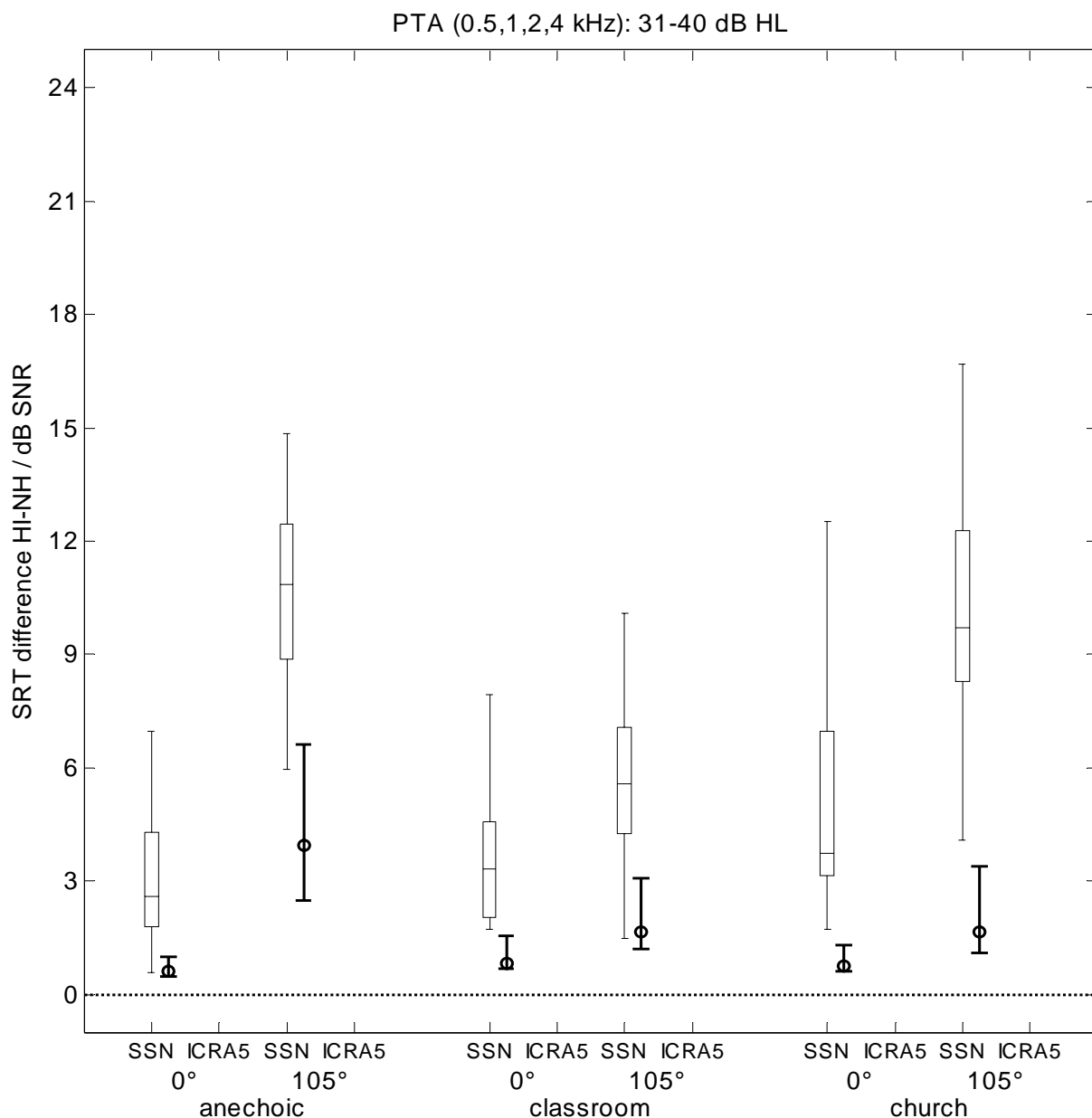
- 11-20 dB HL (SSN: 2 subjects, ICRA5: 1 subject)
- 31-40 dB HL (SSN: 5 subjects, ICRA5: 0 subjects)
- 41-50 dB HL (SSN: 10 subjects, ICRA5: 6 subjects)
- 51-60 dB HL (SSN: 8 subjects, ICRA5: 3 subjects)

Behind the categories the numbers of test subjects that had been tested for the two different noises are given. (SSN: stationary speech shaped noise, ICRA5: speech-modulated noise).

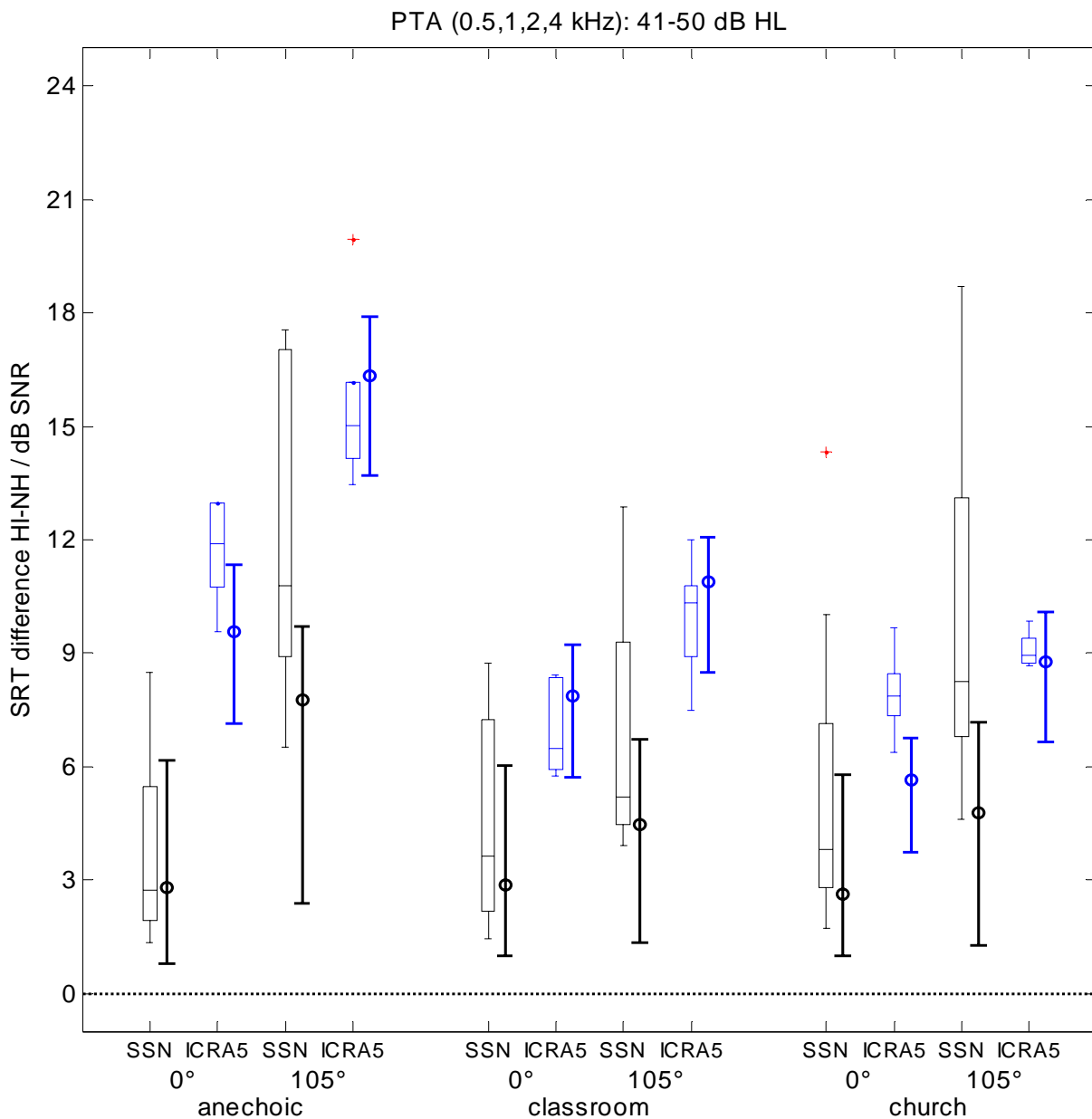
The boxplots show medians, upper and lower quartiles, and minimum and maximum values of SRT differences for the corresponding group of hearing-impaired test subjects. Also included are the predictions of the EC-SII model showing the medians and minimum and maximum values for the corresponding groups of hearing losses and conditions. In that way the increase in SRT for hearing-impaired vs. normal hearing listeners can be compared to the model predictions. If the model predictions agree with the measured data, the model can be used to extend the predictions for other acoustic environments and hearing losses and thus be a helpful tool in establishing normative criteria for speech intelligibility in complex acoustic conditions.



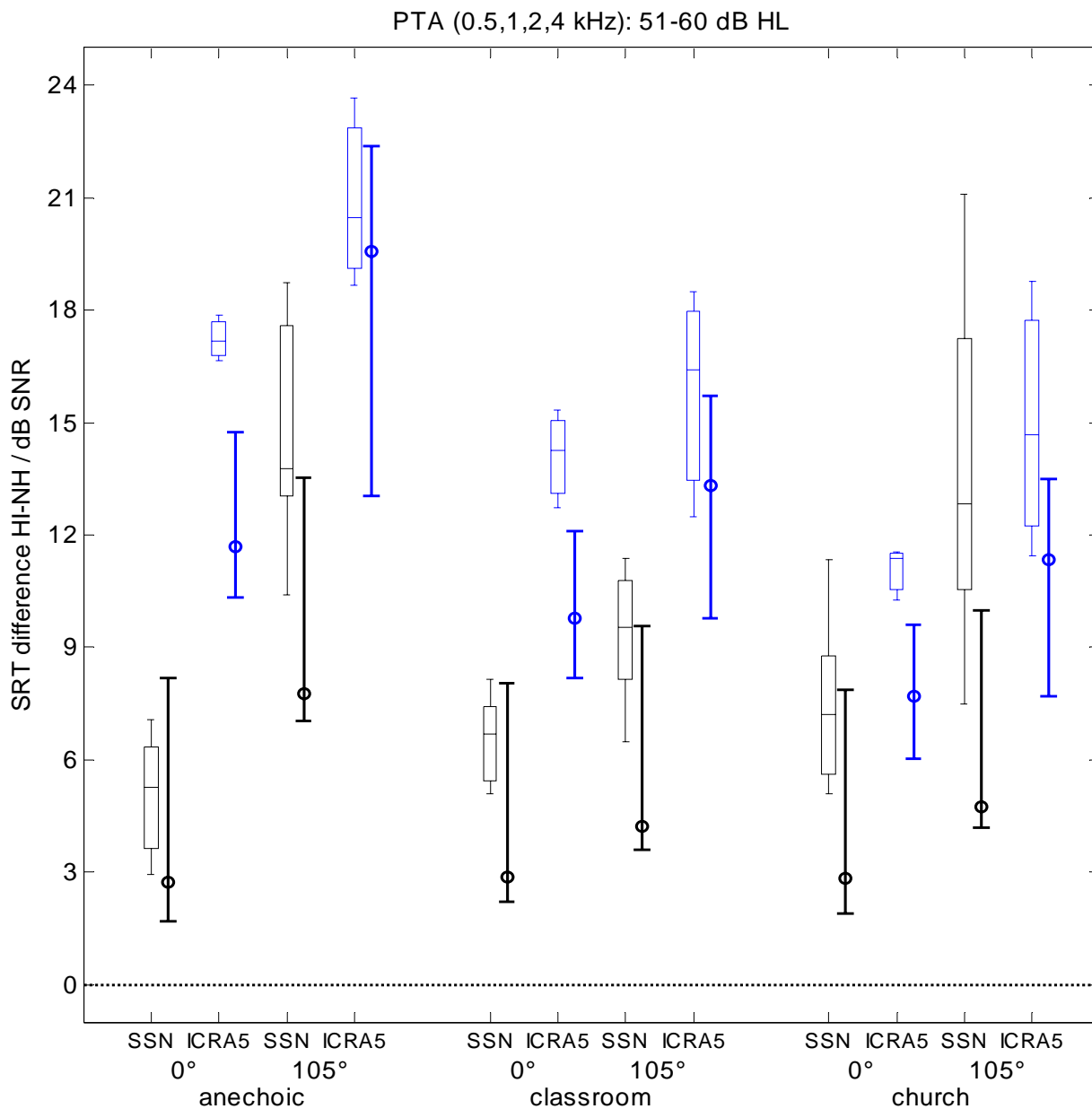
**Figure 3-2: Differences in SRT between normal hearing listeners and hearing-impaired listeners for different acoustic conditions. PTA (0.5, 1, 2, 4 kHz) = 11-20 dB HL. Black: SSN = stationary speech shaped noise. Blue: ICRA5 = speech modulated noise. Boxplots: measured results (median, quartiles, minimum and maximum values). Circles and thick lines: Predicted results with median, min and max value. (Only 1 subject for ICRA5)**



**Figure 3-3: Differences in SRT between normal hearing listeners and hearing-impaired listeners for different acoustic conditions. PTA (0.5, 1, 2, 4 kHz) = 31-40 dB HL. Black: SSN = stationary speech shaped noise. Blue: ICRA5 = speech modulated noise. Boxplots: measured results (median, quartiles, minimum and maximum values). Circles and thick lines: Predicted results with median, min and max value. (No subject for ICRA5)**



**Figure 3-4: Differences in SRT between normal hearing listeners and hearing-impaired listeners for different acoustic conditions. PTA (0.5, 1, 2, 4 kHz) = 41-50 dB HL. Black: SSN = stationary speech shaped noise. Blue: ICRA5 = speech modulated noise. Boxplots: measured results (median, quartiles, minimum and maximum values). Circles and thick lines: Predicted results with median, min and max value. Red crosses mark outliers (more than 1.5 times the upper or lower quartile).**



**Figure 3-5: Differences in SRT between normal hearing listeners and hearing-impaired listeners for different acoustic conditions. PTA (0.5, 1, 2, 4 kHz) = 51-60 dB HL. Black: SSN = stationary speech shaped noise. Blue: ICRA5 = speech modulated noise. Boxplots: measured results (median, quartiles, minimum and maximum values). Circles and thick lines: Predicted results with median, min and max value.**

The following general observations can be made from the medians in figure 3-2 through 3-5:

- Differences between normal hearing and hearing-impaired test subjects become larger the more severe the hearing loss, i.e. the higher the PTA
- Differences are greater for  $S_0N_{105}$  than for  $S_0N_0$  conditions
- Differences are greater for the fluctuating ICRA5 noise than for the stationary speech-shaped noise
- Differences are greater in the anechoic condition than in the reverberant conditions when the noise is fluctuating (ICRA5) and/or when speech and noise are spatially separated ( $S_0N_{105}$ )
- Differences are greatest for the anechoic  $S_0N_{105}$  condition with ICRA5 noise
- Model predictions hardly correlate with the measured data

Comparing the performance for speech intelligibility in complex acoustic conditions between hearing-impaired and normal hearing listeners reveals that the differences between these two groups are greatest in situations where the normal hearing have access to cues that enhance speech intelligibility whereas the hearing-impaired cannot make use of these cues to the same degree. Such cues are for example listening into the dips of a fluctuating interferer to hear the speech signal or profiting from binaural processing when speech and noise are spatially separated. In the anechoic condition these cues are fully available without being affected by reverberation. That's why normal hearing listeners perform very well in the anechoic condition where speech and noise are separated and ICRA5 is the interferer. Hence, that's why the greatest difference between normal hearing and hearing-impaired listeners appears for this condition for all groups of hearing-impaired listeners.

The variability among the hearing-impaired subjects within one group is to some extent large. Even though the PTA (0.5, 1, 2, 4 kHz) does not differ by more than 10 dB within one group the differences in speech reception threshold (SRT) compared to normal hearing listeners differ by up to 14 dB SNR (PTA 41-50 dB HL, church, SSN,  $S_0N_{105}$ ). The EC-SII model often can predict the large variability but the median values are only predicted correctly for a few conditions. Therefore the model in its current form cannot be used to provide normative criteria for hearing impaired listeners in adverse acoustic conditions.

### 3.4 Reduced speech intelligibility related to room acoustic measures

A measure to relate speech intelligibility to room acoustics is the useful-to-detrimental ratio U/D. The useful sound is defined as the early arriving speech energy ( $E_e$ ) and the detrimental sound as the sum of the later-arriving speech energy ( $E_l$ ) and the ambient noise ( $E_n$ ):

$$\frac{U}{D} = 10\log\left(\frac{E_e}{E_l + E_n}\right)dB \tag{1}$$

Bradley (1986) found that a time limit of 80 ms for the early arriving speech energy gave the strongest correlation with speech intelligibility. The useful-to-detrimental ratio with this early time limit is referred to as  $U_{80}$ .

Latham (1979) suggested that speech intelligibility scores for words should be 97% for a very good listening condition. In Bradley’s (1986) experiments this would require a  $U_{80}$  value at 1 kHz of +4 dB.

The room simulations we used were made with the room acoustic software Odeon (2005). Odeon does not give  $U_{80}$  values but instead it calculates  $C_{80}$  which is the clarity. It is calculated as the ratio of the early (0-80 ms) to late (80-∞ ms) energy ratio of the sound:

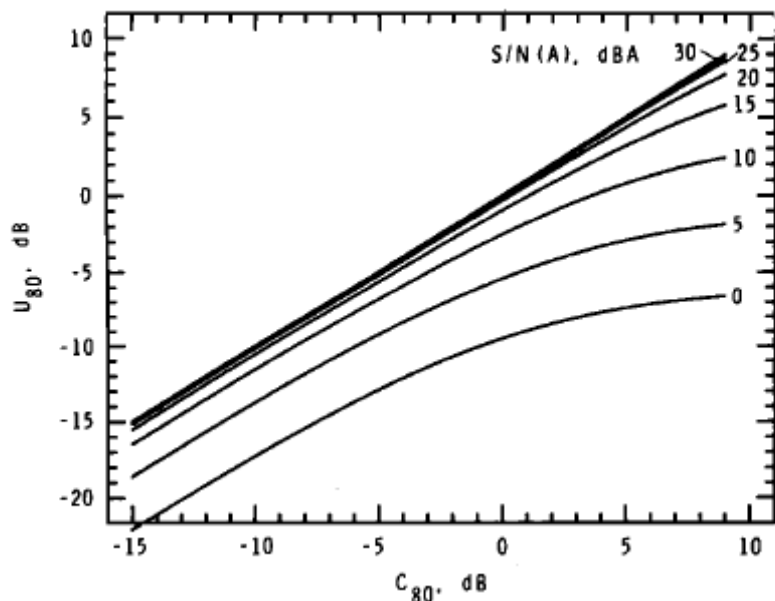
$$C_{80} = 10\log\left(\frac{E_{(0-80)}}{E_{(80-\infty)}}\right), dB \tag{2}$$

$C_{80}$  values for the classroom and the church for the different frequency bands as derived from Odeon are given in table 1.

Octave band in Hz	63	125	250	500	1000	2000	4000	8000
Classroom	6.7	9.1	8.8	9.9	9.3	9.9	11.2	15.8
Church	-1.2	-1.4	-0.8	1.5	-0.6	3.1	7.2	14.6

Table 1:  $C_{80}$  values (dB) in classroom and church

When background noise levels are very low, the  $C_{80}$  will be equal to the  $U_{80}$ . However, if there is non-negligible background noise, the SNR determines the relation between  $C_{80}$  and  $U_{80}$ . Bradley (1986) established such a relationship (see figure 3-6).



**Figure 3-6: Calculated  $U_{80}$  vs  $C_{80}$  at 1 kHz for overall signal-to-noise ratios of 0, 5, 10, 15, 20, 25, and 30 dBA. Taken from Bradley (1985).**

The calculated  $C_{80}$  value in Odeon at the 1 kHz octave band for the classroom is 9.3 dB and for the church -0.6 dB. If we want a  $U_{80}$  of +4 dB to achieve a very good listening condition we would need an SNR of approx. 12.5 dB in the classroom (see figure 3-6). In church,  $U_{80} = +4$  dB could not be reached with any SNR. This is for normal hearing listeners.

Taking into account now that hearing-impaired listeners need an SNR that is up to 23.66 dB (maximum SRT difference; reached for PTA 51-60 dB HL, anechoic, ICRA5,  $S_0N_{105}$ ) better than for normal hearing listeners to achieve the same SRT as a normal hearing person, we would need an SNR that is very difficult to realise in a classroom and not realisable in a church to provide them with a very good listening condition. Instead of improving the SNR the room acoustics and  $C_{80}$  respectively could be improved. However,  $C_{80}=9.3$  dB is already a good value for classroom acoustics in regard to speech intelligibility.

In a comprehensive work by Bormann et al. (2005) several studies measuring speech intelligibility in noise and/or reverberation were compared and it was found that persons with a hearing loss need a noise level that is 5-20 dB lower to be able to communicate like normal hearing people, i.e. they need a 5-20 dB better SNR than normal hearing people. This is in good agreement with our results, even though some hearing-impaired people will not reach the same communication ability as a normal hearing person due to restrictions in room acoustical improvements regarding reduced background noise levels and reduced reverberation.

## 4 Towards normative criteria for *non-native listeners* in adverse acoustic conditions

### 4.1 Introduction

The Speech Transmission Index (STI) is a well-accepted and standardised method for objective prediction of speech intelligibility in a wide range of environments and applications (IEC, 2003). A binaural version of the STI (bin-STI) was developed within HearCom, based on interaural cross correlograms, which shows a considerably improved correspondence with subjective intelligibility in dichotic listening conditions. A detailed description of the bin-STI was given in HearCom deliverables D-3-1 and D-3-3. Evaluation of the model with sentence material (measuring the speech reception threshold, SRT) was done in various simulated acoustical environments for normal-hearing native and non-native listeners and for hearing-impaired listeners.

Results of the SRT experiments and predictions by the bin-STI model are described in deliverable D-3-5. In summary, for a limited number of simulated environments (noise, reverberation), the bin-STI model showed generally good predictions for normal-hearing listeners, both native and non-native. For hearing-impaired listeners, however, no reliable predictions could be given.

In this section we will consider normative criteria for speech transmission quality for a wide variety of room acoustic and environmental conditions. Needs for non-native listeners and, if data permit, hearing-impaired listeners will be given special attention.

### 4.2 Basic qualification of intelligibility and STI

#### 4.2.1 Native normal-hearing listeners

A qualification of the intelligibility and the relation between the objective STI and the subjective intelligibility (as measured with speakers and listeners) is given in Table I. For the subjective intelligibility the CVC-word score (% correct) is used. This test is based on monosyllabic nonsense words with equally balanced phoneme distribution (Consonant-Vowel-Consonant, CVC). For the sentence score, the reference is a list of simple everyday sentences.

In general, for a communication channel to deserve the qualification "good" a minimum STI value of 0.60 is required. In worst case situations (e.g. maximum level of disturbance noise) STI=0.35 is the lowest acceptable value for normal-hearing native listeners. This is roughly the threshold for 50% intelligibility of simple everyday sentences in noise (diotic listening). In practical situations, however, this is too low. The

general safe limit, requiring normal listening effort, is considered to be  $STI=0.45$ . Note that a change of 0.1 in STI corresponds to a change of 3 dB in speech-to-noise ratio.

<i>Qualification</i>	<i>STI</i>	<i>Sentence score (%)</i>	<i>CVC word score (%)</i>
Excellent	>0,75	100	>81
Good	0,60-0,75	100	70-81
Fair	0,45-0,60	100	53-70
Poor	0,30-0,45	50-70	31-53
Bad	<0,30	<50	<31

**Table 1: Qualification and relation between STI and CVC word score**

#### 4.2.2 Non-native normal-hearing listeners

Van Wijngaarden (2001) and Van Wijngaarden et al. (2002) have investigated the effect of non-native listeners. Generally, they require a 4-5 dB improvement of the speech-to-noise ratio for similar intelligibility as obtained with native listeners (ISO 9921, 2003).

NPR 3438 (2007) gives a more detailed correction of the qualification table (Table I) for non-native listeners. The approach is an adaptation of the translation of the STI to intelligibility qualifications. There is no change in the STI-computation itself, only a change in interpretation. Depending on the level of proficiency a choice can be made of three categories, as given in Table III. For each category in Table II, an adapted version of Table I applies. This adapted version is shown in Table III.

<b>Proficiency level</b>	<b># years experience with language</b>	<b>Age at which language was learnt</b>	<b>Intensity of language use</b>
Level 1	>5 years	<13 years	Daily
Level 2	1- 5 years	>13 years	Weekly
Level 3	<1 year	As an adult	Monthly - yearly

**Table 2: Indicative classification of levels of non-native proficiency**

STI qualification	Proficiency level		
	Level 1	Level 2	Level 3
Excellent	0.86 – 1.00	Unrealisable	Unrealisable
Good	0.68 – 0.86	0.86 – 1.00	Unrealisable
Fair	0.50 – 0.68	0.60 – 0.86	0.74 – 1.00
Poor	0.33 – 0.50	0.38 – 0.60	0.44 – 0.74
Bad	0.00 – 0.33	0.00 – 0.38	0.00 – 0.44

**Table 3: Adapted intelligibility qualification for non-native listeners**

The non-native listeners used in our experiments (cf. D-3-5) were pupils from a Dutch secondary school with 4-5 years of (limited) experience with German. According to Table II, they would have proficiency level 2.

The average SRT-difference between natives and non-natives in an anechoic room with speech and noise coming from the front ( $S_0N_0$ ) is 2.6 dB speech-to-noise ratio (see D-3-5, Table 4-2). This corresponds to 0.09 STI-units, in good agreement with the shift between level 2 proficiency (Table III) and basic (native) qualification (Table I).

Non-natives do benefit from spatial separation between speech and noise ( $S_0N_{105}$ ). The decrease in SRT in an anechoic room is 8 dB for non-natives (10 dB for natives).

#### 4.2.3 Hearing-impaired listeners

For listeners with hearing impairment the situation is more complex. The STI-method cannot give a reliable prediction for all hearing impairments (cf. Festen and Plomp, 2002). Only in cases of a 'simple' loss (threshold shift) an approximation of a corrected STI-value can be computed. These cases include some types of presbycusis and conductive losses.

### 4.3 Required qualification for various activities

Which qualification of intelligibility is required depends on the application. Activities where accurate and quick information exchange is essential require optimal intelligibility. Complexity of messages, urgency of speech communication and frequency of communication are important

parameters. ISO 9921 (2003) mentions a number of examples. An extended survey is given in guideline NPR 3438 (2007). Table IV below is adapted from the latter.

		Frequency		
		Low	Mid	High
Urgency, Complexity, Importance	High	GOOD <b>Command Warning</b>	GOOD/EXCELLENT <b>112 emergency</b>	EXCELLENT <b>Medical instruction Emergencies Lecture Long instruction Classroom</b>
	Mid	FAIR/GOOD <b>Reception Hotel lobby Restaurant Kitchen</b>	GOOD <b>Incident room Short instruction Daycare center Sports Phone conversation Church</b>	GOOD/EXCELLENT <b>Meeting Group discussion</b>
	Low	POOR <b>Café/Bar Simple instruction</b>	FAIR/GOOD <b>Shops Surveillance Acquisition Social interaction</b>	GOOD <b>Check in (airport)</b>

**Table 4: Minimal required intelligibility qualification for various types of activities**

### 4.4 Effects of binaural listening, noise, and reverberation

In all cases we investigated, spatial separation of speech and noise source ( $S_0N_{105}$  vs.  $S_0N_0$ ) gives better intelligibility for natives and non-natives. Non-natives do not benefit as much as natives, though. The binaural benefit reduces slightly with increasing reverberation.

Early decay times (EDT) for classroom and church are 0.49 s and 6.55 s, respectively.  $STI=0.60$  is the minimum desired value, which yields fair/good intelligibility for natives and fair intelligibility for non-natives (proficiency levels 1 and 2). For anechoic and classroom the speech-to-noise ratios will have to be 3 dB and 7 dB, respectively. For the church  $STI=0.60$  cannot be reached (NPR 3438, 2007). Again, binaural benefits will allow for lower speech-to-noise ratios (about 4-5 dB less in practical situations), but yield no more than poor intelligibility in the church.

## 5 Recommendations

Two groups of non-normal hearing listeners are addressed in this Deliverable – non-native and hearing-impaired listeners. In a complex listening situation like a classroom or church with speech shaped noise as an interferer they would need a better STI or SII value in order to reach the same speech intelligibility as normal hearing listeners. Non-native listeners need a better SNR of approx. 3 dB in a situation where speech and noise are presented from front and 4.5 dB in a situation where the sound sources are spatially separated compared to normal hearing listeners. This corresponds to an increase in STI or SII of 0.1 and 0.15 respectively (see table 1). Taking the median results for the hearing-impaired a similar increase in STI/SII as for non-native listeners is necessary for the  $S_0N_0$  conditions, except for hearing impaired with the highest PTA who need an increase of 0.2. For the  $S_0N_{105}$  condition a better STI/SII is needed for the more reverberant condition (church) for hearing impaired with moderate to severe hearing losses (PTA 31-60 dB HL).

The following table gives a summary on the increase in STI or SII value that is needed for non-native and hearing-impaired listeners in order to achieve the same speech intelligibility in a certain condition as a normal hearing person.

		Non-native (level 2)	PTA 11- 20 dB HL	PTA 31- 40 dB HL	PTA 41- 50 dB HL	PTA 51- 60 dB HL
$S_0N_0$ SSN	Classroom	0.1	0.07	0.1	0.1	0.2
	Church					
$S_0N_{105}$ SSN	Classroom	0.15	0.1	0.17	0.17	0.3
	Church			0.3	0.3	0.43

**Table 1 Increase in STI/SII values that non-normal hearing listeners need to achieve the same speech intelligibility as normal hearing listeners in specific adverse conditions**

It should be noted that the necessary increase in STI/SII for  $S_0N_0$  is due to the hearing loss/non-nativeness whereas for the  $S_0N_{105}$  condition a reduced benefit from spatial release from masking (in addition to the hearing loss/non-nativeness) accounts for the additional increase in STI/SII.

A good listening condition for a normal hearing person is achieved with an STI of at least 0.6 (monaural). Depending on the listening situation

however, architects and acousticians have to take into account that different groups of non-normal hearing listeners have different needs for a better STI/SII to find themselves in a good listening condition.

The data presented is limited to very specific acoustic conditions; therefore it is difficult to give concrete practical advice for architects or acousticians in how to design a room. But the above listed necessity for a better STI/SII can be a first indication on how to include non-native and hearing-impaired listeners in considerations about good listening conditions.

## 6 Dissemination and Exploitation

The work presented in this Deliverable has not been published in any way but it will be useful when the speech intelligibility models that are described in D-3-3 and D-3-5 will be implemented in a room acoustic software. The results from D-3-6 are based on data from D-3-5. Please refer to the dissemination and exploitation section in D-3-5.

### 6.1 Ethical issues

No ethical issues.

## 7 Conclusions

The disadvantages that hearing-impaired people have to face in speech intelligibility become most obvious in situations where normal hearing people have access to cues that facilitate speech intelligibility in certain conditions. The impaired auditory system of people with a hearing loss hinders the binaural and temporal processing of speech; therefore they have the biggest disadvantages compared to normal hearing when speech and noise are spatially separated and/or when the interferer is fluctuating over time. The disadvantages increase with increasing hearing impairment.

Using room acoustical measures to define a good listening environment for hearing-impaired people we have to be aware of that for some hearing-impaired people neither improving the signal-to-noise ratio nor the reverberation patterns nor both together (within realisable limits) in a room would be sufficient to give them access to good speech intelligibility. For some hearing-impaired, however, increasing the signal-to-noise ratio or improving the room acoustics will help to improve their speech intelligibility.

Non-native listeners have disadvantages compared to native listeners depending on their proficiency level. A higher STI value is needed to achieve the same intelligibility. For some conditions, e.g. the church, the

required STI is not realisable and therefore no more than poor intelligibility is reached for non-native listeners. But in many cases this can be achieved by using a well designed loudspeaker system.

With the data presented it is difficult to give concrete practical advice for architects or acousticians on how to design rooms for non-normal hearing listeners as only very specific conditions were addressed. However an attempt was made to point out the disadvantages non-native and hearing impaired listeners have compared to normal hearing listeners and to which degree a listening condition has to be improved in terms of STI or SII values.

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