inter-noise 2009
innovations in practical noise control
2009 August 23-26
Ottawa, Canada

The effect of room acoustics on the measured speech privacy in two typical European open plan offices

Remy H.C. Wenmaekers[a]
Nicole H.A.M. van Hout[b]
Renz C.J. van Luxemburg[c]
Level Acoustics
De rondom 10
5612 AP Eindhoven, The Netherlands

Constant C.J.M. Hak[d]
Eindhoven University of Technology
PO-box 513
5600 MB Eindhoven, The Netherlands

ABSTRACT

The reverberation time and the background noise level are often used as the most important design parameters in European open plan offices to achieve a comfortable acoustic climate and to control speech intelligibility. Good speech intelligibility is desired for people working together, but bad speech intelligibility is desired between independent working groups. The latter situation is also referred to as speech privacy. To investigate speech privacy, acoustical parameters like STI and the SII can be used. Both parameters rely on the use of two types of weighted signal to noise ratios to determine the speech intelligibility, taking into account the speech level, background noise level and room acoustics. The influence of room acoustics is translated to an apparent signal to noise ratio by the use of the Modulation Transfer Function (SNR1). Besides that, room acoustics influences the received speech level, which together with the background noise results in another signal to noise ratio (SNR2). To investigate the influence of both types of SNR on the speech privacy, the STI was measured of two typical European open plan offices for the situations with and without SNR1 and with and without SNR2. The results show that the difference between the STI with and without SNR1 is within the estimated JND of 0.1 between independent working groups. The difference between with and without SNR2 is far beyond the estimated JND.

[a] Email address: r.h.c.wenmaekers@tue.nl
[b] Email address: n.h.a.m.v.hout@tue.nl
[c] Email address: l.c.j.v.luxemburg@tue.nl
[d] Email address: c.c.j.m.hak@tue.nl

1. INTRODUCTION

Parameters for measuring and predicting the intelligibility of speech have been well established, like the Speech Transmission Index STI[1,2] and the Speech Intelligibility Index SII[3]. Both parameters take into account the effect of reverberation as well as the effect of background noise on the intelligibility of speech. Recently, these parameters are also used to measure or predict the unintelligibility of speech, often referred to as Speech Privacy. A good overview of these developments with references can be found in an article by Virjonen from 2007[4]. Good speech intelligibility is reached with a STI $\geq$ 0.6[2], whereas good speech privacy is reached with a STI $\leq$ 0.17[5]. The Just Noticeable Difference (JND) for the STI is estimated to be 0.1[2]. In most European open plan offices, good speech intelligibility is desired for people working together, but good speech privacy is desired between independent working groups.

The reverberation time and the background noise level are often used as the most important design parameters for open plan offices. However, also reflection paths have to be considered. Typical European open plan offices have sound absorbing ceilings, sound absorbing furniture or screens to control the reverberation and sound attenuation over distance. It is not common to use high cubicles or active sound masking systems, however deliberately noisier air systems are sometimes used as a passive sound masking system. As a result the background noise levels may vary between 35 and 45 dB(A). The vast amount of sound absorbing materials to attenuate the speech over distance often results in low reverberation in these offices. In this research, the effect of room acoustics has been investigated on the measured speech privacy in two typical European open plan offices with a bad speech privacy reputation.

2. TWO TYPICAL OPEN PLAN OFFICES

The open plan offices that were used for the experiments both had a sound absorbing ceiling and floor carpet, a glass façade on one side of the working groups and partly a reflective service core on the other side. Office 1 has an average reverberation time of 0.5 seconds, an average working group distance of 7 meters with high reflective storage cabinets on the sides of the groups and low reflective screens between the desks (see figure 1). Office 2 has an average reverberation time of 0.4 seconds, an average working group distance of 5 meters with low absorptive storage cabinets between the groups and without screens between the desks (see figure 2).

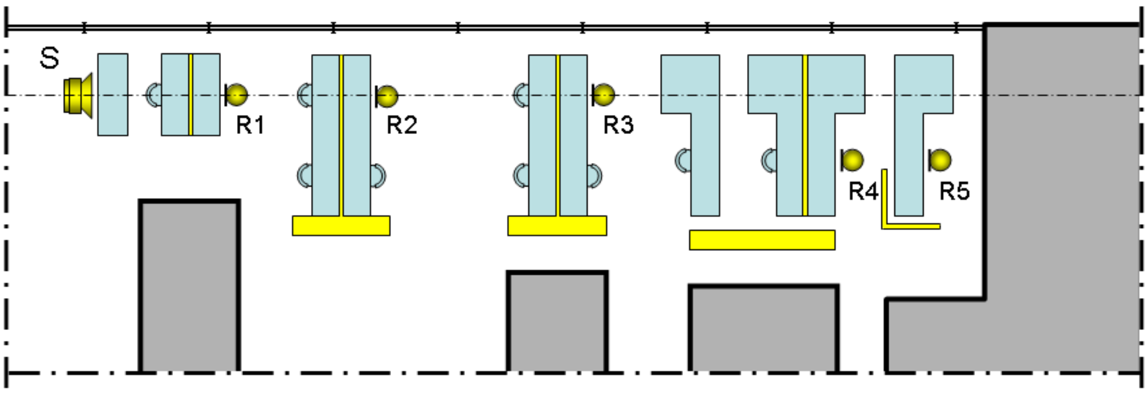

Figure 1: Schematic floor plan of Office 1 with source and receiver positions.

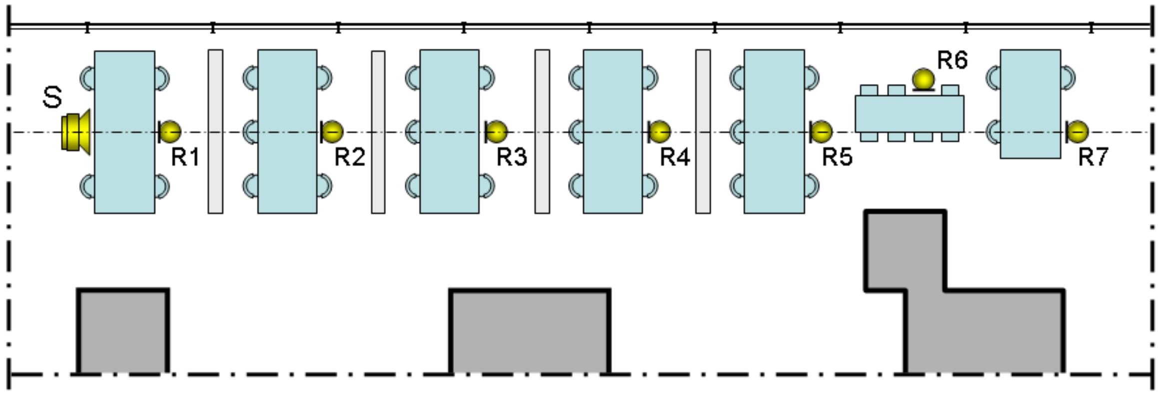

Figure 2: Schematic floor plan of Office 2 with source and receiver positions.

3. METHOD

The STI relies on the use of two types of weighted signal to noise ratios to determine the speech intelligibility, taking into account the speech level, background noise level and room acoustics. The influence of room acoustics is translated to an apparent signal to noise ratio by the use of the Modulation Transfer Function (SNR1). Besides that, room acoustics influences the received speech level, which together with the background noise results in another signal to noise ratio (SNR2). To investigate the influence of both types of SNR on the speech privacy, the STI was measured of both open plan offices for the combinations with and without SNR1 and with and without SNR2 for two different levels of background noise (BGN).

Table 1: 5 different combinations of SNR1 and SNR2

Combination	SNR1	SNR2
1	with SNR1	without SNR2
2	with SNR1	with SNR2, 37 dB(A) BGN
3	without SNR1	with SNR2, 37 dB(A) BGN
4	with SNR1	with SNR2, 45 dB(A) BGN
5	without SNR1	with SNR2, 45 dB(A) BGN

The sound level spectra for the background noise level of 37 dB(A) and 45 dB(A) are derived from the Noise Rating Curves 25 and 35 dB in accordance with ISO 226[6] and approximate the common range of background noise levels in open plan offices. The STI for each case is determined at all receiver positions as indicated in figure 1 and 2.

The STI is derived from measured impulse responses using a directional loudspeaker (head simulator according to IEC 60268-16[7]), an omni directional microphone (RION NL21) and room acoustical software (DIRAC 4.1[8]). In the combinations 2 to 5, the SNR2 is calculated afterwards for all receiver positions for both background noise levels and inserted in the STI calculation in DIRAC. To be able to do so, all measured impulse responses had a decay range (INR[9]) of at least 15 dB. In the combinations 3 and 5 without SNR1, only measured receiving speech levels and background noise levels are considered.

The used speech level is the spectrum of a male voice with a normal speaking level of 60 dB(A) at 1 meter distance in accordance with IEC 60268-16. Higher signal levels have been used during the measurements; the sound levels at the receiver positions are corrected afterwards by using the sound level at 1 meter distance from the sound source as a reference.

4. RESULTS

The results for the measured STI for 5 different combinations of SNR1 and SNR2 are presented in table 2 and figure 3 for Office 1 and in table 3 and figure 4 for Office 2. In general, for both offices the results show that a good speech privacy of STI $\leq$ 0.17 is only achieved at a distance more than approximately 15 meters from the sound source and only in the situation with a background noise level of 45 dB(A).

Also in the tables, the absolute differences are given between combinations:

- 1 – 2 = "Δ with/without SNR2 for 37 dB(A) with SNR1";
- 2 – 3 = "Δ with/without SNR2 for 37 dB(A)";
- 4 – 5 = "Δ with/without SNR2 for 45 dB(A)".

The difference values exceeding the estimated JND of 0.1 are indicated in grey. The results show that for both offices:

- in most cases the difference in STI between situations with and without SNR2 exceeds the JND;
- for receiver positions close to the sound source and with a low background noise level of 37 dB(A) the differences in STI between situations with and without SNR1 exceed the JND. For Office 1 this is within a distance of approx. 18 meters, for Office 2 this is within a distance of approx. 10 meters;
- at receiver positions with a STI < 0,40 without SNR1, the differences in STI between situations with and without SNR1 are less than the JND.

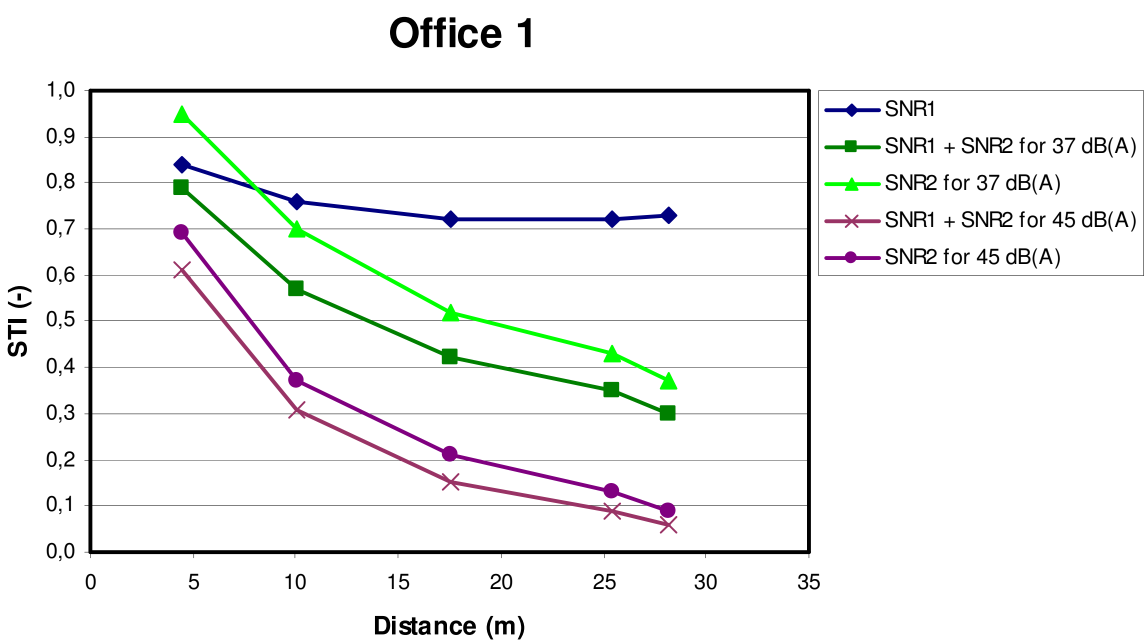

Figure 3: Graph of STI in Office 1 for 5 combinations of SNR1 and SNR2.

Table 2: STI values in Office 1 for 5 combinations of SNR1 and SNR2.

	Receiver Position	R1	R2	R3	R4	R5
	Distance from sound source in meters	4.5	10.1	17.5	25.4	28.2
1	SNR1	0,84	0,76	0,72	0,72	0,73
2	SNR1 + SNR2 for 37 dB(A)	0,79	0,57	0,42	0,35	0,30
3	SNR2 for 37 dB(A)	0,95	0,70	0,52	0,43	0,37
4	SNR1 + SNR2 for 45 dB(A)	0,61	0,31	0,15	0,09	0,06
5	SNR2 for 45 dB(A)	0,69	0,37	0,21	0,13	0,09
1-2	diff with/without SNR2, 35 dB(A) BGN	0,05	0,19	0,30	0,37	0,43
2-3	diff with/without SNR1, 35 dB(A) BGN	0,16	0,13	0,10	0,08	0,07
4-5	diff with/without SNR1, 45 dB(A) BGN	0,08	0,06	0,06	0,04	0,03

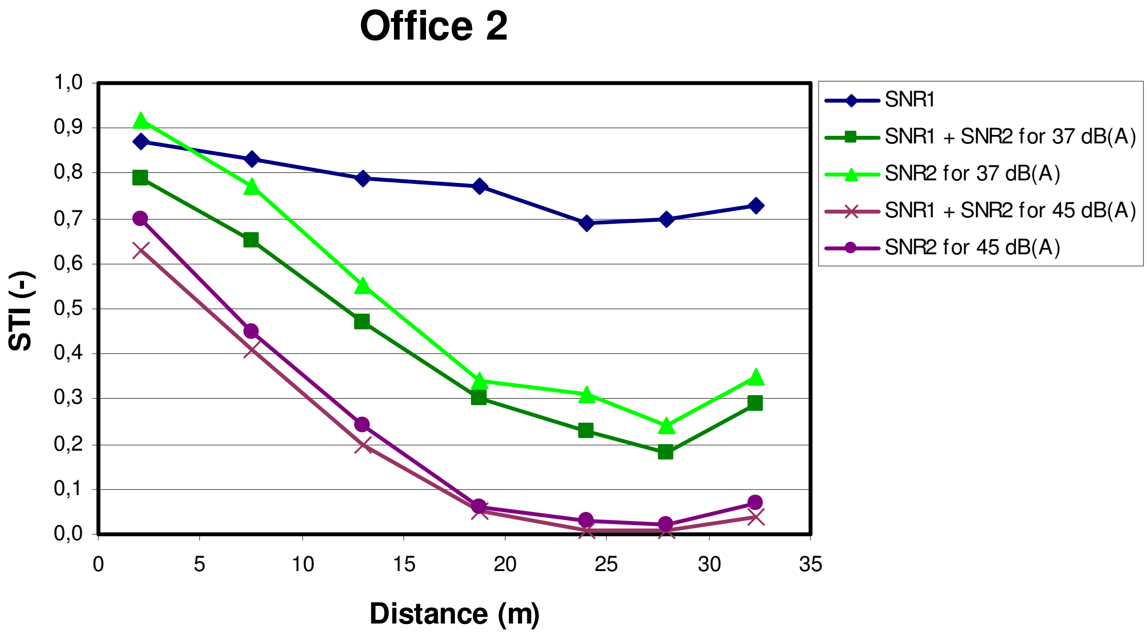

Figure 4: Graph of STI in Office 2 for 5 combinations of SNR1 and SNR2.

Table 3: STI values in Office 2 for 5 combinations of SNR1 and SNR2.

	Receiver Position	R1	R2	R3	R4	R5	R6	R7
	Distance from sound source in meters	2.1	7.6	13	18.7	24	27.9	32.3
1	SNR1	0,87	0,83	0,79	0,77	0,69	0,70	0,73
2	SNR1 + SNR2 for 37 dB(A)	0,79	0,65	0,47	0,30	0,23	0,18	0,29
3	SNR2 for 37 dB(A)	0,92	0,77	0,55	0,34	0,31	0,24	0,35
4	SNR1 + SNR2 for 45 dB(A)	0,63	0,41	0,20	0,05	0,01	0,01	0,04
5	SNR2 for 45 dB(A)	0,70	0,45	0,24	0,06	0,03	0,02	0,07
1-2	diff with/without SNR2, 35 dB(A) BGN	0,08	0,18	0,32	0,47	0,46	0,52	0,44
2-3	diff with/without SNR1, 35 dB(A) BGN	0,13	0,12	0,08	0,04	0,08	0,06	0,06
4-5	diff with/without SNR1, 45 dB(A) BGN	0,07	0,04	0,04	0,01	0,02	0,01	0,03

5. CONCLUSIONS

From the measured speech privacy STI in two typical European open plan offices, with and without SNR1 and with and without SNR2, it can be concluded that:

- in all cases it is necessary to take into account the background noise level to accurately calculate the speech privacy by the use of the STI;
- in cases when the STI is fairly low (<0.4), the typical range where speech privacy occurs, it is sufficient to consider receiving speech levels and background noise levels to predict the speech privacy STI with a accuracy less than the JND.

REFERENCES

[1] M.R. Schroeder, "Modulation transfer functions: definition and measurement," *Acustica **49*** (1981) 179-182

[2] T. Houtgast and H.J.M. Steeneken, "The modulation transfer function in room acoustics as a predictor of speech intelligibility," *Acustica **28*** (1973) 66-73

[3] American National Standard ANSI S 3.5, 1997, American National Standards Institute, New York, USA

[4] P. Virjonen et all. "Speech Privacy Between Neighboring Workstations in an Open Office - A Laboratory Study," *Acta Acustica united with Acustica Vol. 93* (2007) 771 – 782

[5] Bradley, J.S. "Measuring and predicting speech privacy in open-plan spaces," IRC NRCC report 50075

[6] ISO 226:2003 Acoustics -- Normal equal-loudness-level contours

[7] IEC 60268-16:2003 Sound system equipment - Objective rating of speech intelligibility by speech transmission index

[8] DIRAC 4.1 software, B&K 7841 / Acoustics Engineering

[9] C.C.J.M. Hak, J.P.M. Hak, R.H.C. Wenmaekers, "INR as an Estimator for the Decay Range of Room Acoustic Impulse Responses," AES Convention Amsterdam (2008)

[10] ISO 18233:2006 Acoustics - Application of new measurement methods in building and room acoustics