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SOURCE DIRECTIVITY INFLUENCE ON MEASUREMENTS OF SPEECH PRIVACY IN OPEN PLAN AREAS

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ABSTRACT

The objective of this study is to determine to what extent the source directivity affects the result when measuring parameters for speech privacy in open plan areas. The studied parameters are Privacy Index and Reversed Speech Transmission Index. Both parameters are described in standards where a loudspeaker directivity is also specified. The study is done by computer modeling of an open plan office. A discussion considering the loudspeaker specification in the respective standard will follow. Comparison of speech privacy expressed as Privacy Index respectively as Speech Transmission Index actualizes the question of how to describe privacy in the best way.

1 INTRODUCTION

1.1 Speech privacy – concepts

Speech is the main source of disturbance and various methods are used to objectively evaluate privacy in offices. Hongisto (2005) compiles a wide range of occupational studies confirming a significant decrement of performance due to intrusive speech. Objective methods for quantifying speech intrusion and privacy in field conditions origin from a concept of intelligibility, which has been reversed. This applies to both reverse STI (Speech Transmission Index) scale and Privacy Index (reversed Articulation Index Scale).

1.2 Reversed STI

The standard for measurement of STI highlights the importance of the directivity of the source which characteristics should be similar to that of the human head/mouth.
STI is at this date seen as a powerful descriptor of the ability of a room to transmit speech, and is a well known tool to assess speech intelligibility in f.i. educational premises. Based on the assumption that it is not the sound level of speech that determines its distracting power but its intelligibility, attempts have been made to apply STI to privacy situation in open office environments. Finnish Standard SFS 5907 proposes the use of STI in an appendix addressing design of open plan offices.
STI is based on the reduction of the modulation index m_i of a test signal, simulating the speech characteristics of a real talker when sounded in a room. The modulation reduction can be caused by reverberation, echoes, or interfering noise. STI is based on the weighted contribution of a number of frequency bands within the frequency range of speech signals, the contribution being set by the effective signal-to-noise ratio.
Physical size, directivity, position and sound pressure level of the sound source are important. Unfortunately, implementation of the standard does not always take into consideration the directivity characteristics.

1.3 Privacy Index

Hegvold (1974) writes “Articulation Index indicates the amount of sound generated by the spoken word that is perceived above background noise, weighted in such a way as to take into account the contribution of the different frequency bands to the intelligibility of the spoken signal."
Articulation Index is defined in ANSI S3.5 (1969, 1997) as “a standardised method to assess the intelligibility of speech under a wide range of communication situations, such as noise, filtering, transfer through telephony, reverberation, etc.”
It is calculated by:

$$AI = \Sigma W_i \times R_i$$

Where:
AI = Articulation Index
W_i = weighting factor for respective one-third octave band (see Table 2)
R_i = signal to noise ratio for respective one-third octave band [200-5000 Hz]

Privacy Index is a derived form of Articulation Index and is proposed as a more intuitive privacy metric for privacy applications. Privacy Index is defined as: PI = (1 – AI) x 100%

f	200	250	315	400	500	630	800	1k	1.25k	1.6k	2k	2.5k	3.15k	4k	5k
W_i , ANSI S3.5	0,0004	0,001	0,001	0,0014	0,0014	0,002	0,002	0,0024	0,003	0,0037	0,0038	0,0034	0,0034	0,0024	0,002

Table 1: One-third octave band weighting factors to be used for Articulation Index calculation according to ANSI S3.5. The weighting factor curve emphasises sound energy components, typically located in a frequency range of 500 Hz to 5000 Hz.

Articulation Index concerns the transmission of critical speech frequencies from one point in a room to another. Weighting factors will then emphasize the ability of the fittings to attenuate the propagation of speech elements contributing most to intelligibility. It is underlined in the standard that one of the parameters influencing Articulation Index is the position of the source relatively to the receiver as well as the orientation between them. Literature indicates that speech energy at high frequencies, typically above 1000 Hz, is directive and mostly spread in front of the speaker. Therefore the issue of the directivity of the sound source as specified in ASTM E 1179-87 is interesting.
How do variations within the specified directivity tolerance of the loudspeaker influence the measured Articulation Index and STI? The objective of this paper is therefore to investigate in a computer simulation the contribution of the loudspeaker characteristics in general and its directivity in particular to the predicted Articulation Index and Speech Transmission Index.

2 EVALUATION METHOD

The calculations have been performed in CATT-Acoustic. It is considered to be a very neutral way of comparing directivity of different sound sources as it is sure that no undesired parameters are changed. The office chosen for the model is being built at the moment and all original geometry settings have been kept. The dimensions of the room are 175m x 70m x 3,3m. Four receiving positions and one source position have been chosen as in Figure 1.

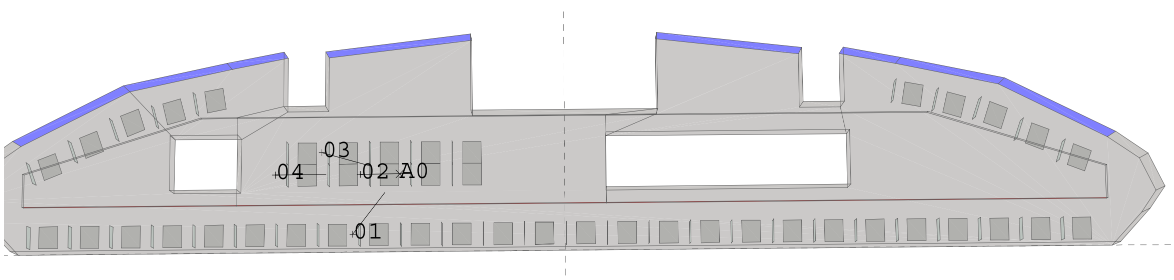


Figure 1: Model of open office with one source position, A0 and four receiver positions, 01-04

2.1 Room conditions

The room is equipped with desks and panels like in Figure 1. Three different room configurations have been defined. The configurations differ by the material of ceiling and walls used.

Material/Absorption coefficient (Hz)	125	250	500	1k	2k	4k
perforated gypsum ceiling, construction height 0,2 m	0,45	0,7	0,75	0,65	0,65	0,6
40 mm glass wool ceiling, construction height 0,2 m	0,45	0,85	0,95	0,9	0,95	0,95
ceiling 0,2 m and walls in 40 mm glass wool	0,2	0,7	0,95	0,95	0,95	0,9

Table 2*: absorption coefficients*

NB: a fourth condition with no absorbing ceiling was also calculated but led to Privacy Index out of the boundary condition of 30 dB and therefore is of no interest for this study.

2.2 Directivity contained in the standards

2.2.1 ASTM E1179, referred to by ASTM E1130 (for measuring Articulation Index)

The sound source shall be a loudspeaker enclosed in a box that has a maximum dimension of 0,3 m on a side. The sound pressure levels within any one-third octave band at any angle up to 25 degrees in any direction from the loudspeaker axis shall differ by 2 dB or less. At angles beyond 25 degrees, the source shall produce lower levels than within the 50 degrees angle.

2.2.2 Directivity of Acculab Open-Office test Loudspeaker

This loud speaker is recommended in ASTM E1179for measuring AI as well as for measuring laboratory performance of acoustical components.

Acculab Open-Office test Loudspeaker Azimuth frequency response, dB re 20 uPa.															
1/3 Octave sound levels wen driven by pink noise. (Note Speaker driver frequency response may differ for different specimens).															
Frequency	**200**	**250**	**315**	**400**	**500**	**630**	**800**	**1000**	**1250**	**1600**	**2000**	**2500**	**3150**	**4000**	**5000**
Azimuth, Degrees															
0 N*	69.5	68.2	70.4	69.5	68.6	68.5	67.6	68.5	68.2	68	67.2	69.4	69.9	69.1	69.1
45	68.9	67	68.7	68	67.2	66.9	65.7	65.4	65	65.3	65.7	69.1	68.9	65.3	65.7
90 E	67.7	66	66.7	65.8	63.4	62.9	62.3	61.8	59.5	58.8	58.9	61.1	61	55.9	56
135	67.8	65.6	65.1	66.4	62.3	61.2	58.9	57.5	55.3	56.3	57.3	57.9	55.9	53.4	47.7
180 S	67.5	66.4	6y.6	66.3	63	63.1	61.9	61.4	59.1	57.7	57.3	59.3	57.6	52.9	48
225	67.7	66	65.3	65.5	61.7	61.4	58.7	58.7	55.4	55.9	55.6	57.3	58	52.2	47.1
270 W	67.7	66.6	66.6	66.4	63.6	64.2	63	62.5	60.1	59.6	60.4	62.1	61.3	58.9	57.4
315	69	67.6	69.1	68.4	67.3	67.1	66.1	65.9	65.6	65.7	65.6	69.4	68.9	66.4	66.1
*0 degrees = along the axis of the speaker aperture						Note: Elevation response not known, but will be similar. March 31, 2006, AJC.									

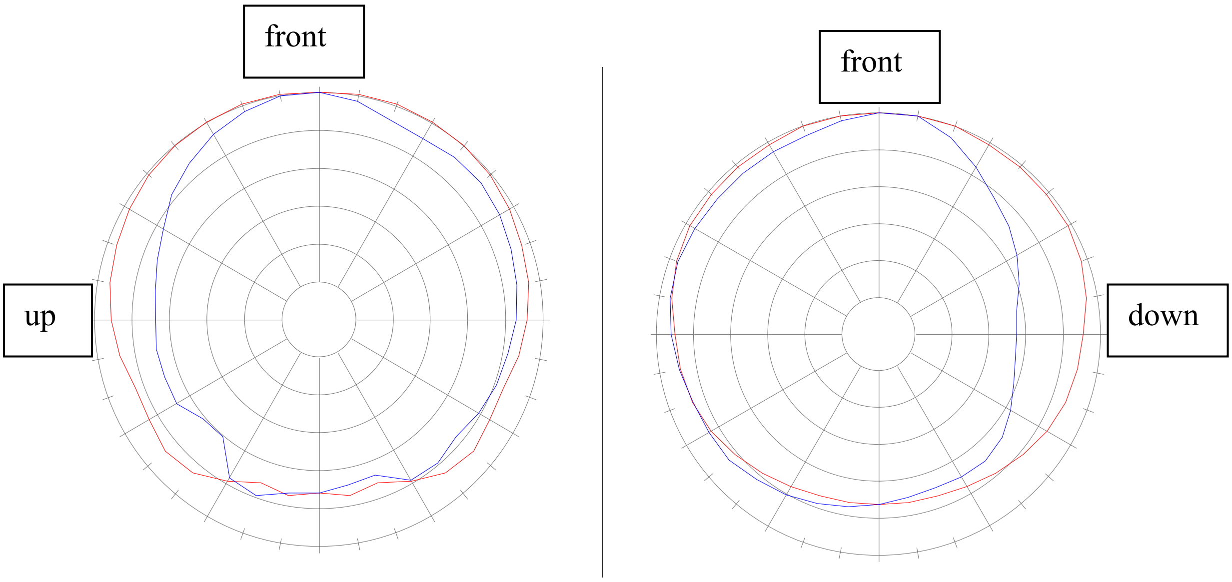
Table 3*: Directivity for loudspeaker recommended by ASTM E1179*

2.2.3 EN IEC 60268-16:2003 (standard for measuring STI)

A mouth simulator having similar characteristics to those of the human mouth should be used.

2.3 Directivities used in this study

Simulations were made with three different directivity characteristics. Omni, speaker, and a Peavey Impulse 6T, which corresponds to ASTM E1179. The loudspeaker Acculab recommended in ASTM E1179 couldn't be used as there is no complete directivity data measured yet but the directivity of Acculab correspond well with the chosen Peavey directivity for verifiable frequencies.



Peavey Impulse 6T according to E1179 Speaker

Figure 2:*Directivity at 2000 Hz, Red line is for the horizontal axis, blue line is for the vertical axis*

3 RESULTS FROM MODELING

The source was directed towards each receiver. The background noise was 33,5 dBA, the spectrum was registered from a real office.

3.1 Privacy Index derived from 1-AI

The calculation was done according to ASTM E 1130, normal male speech spectrum was used.

material	directivity	Position 1	Position 2	Position 3	Position 4
perforated gypsum ceiling	E1179	13	15	32	39
perforated gypsum ceiling	speaker	11	12	27	34
perforated gypsum ceiling	omni	2	1	18	25
40 mm glass wool ceiling	E1179	20	30	43	54
40 mm glass wool ceiling	speaker	18	25	40	51
40 mm glass wool ceiling	omni	11	14	30	39
40 mm glass wool ceiling + wall panel	E1179	20	32	48	67
40 mm glass wool ceiling + wall panel	speaker	18	18	44	58
40 mm glass wool ceiling + wall panel	omni	11	20	36	52

Table 4: *Privacy Index with three different directivities*

3.2 Reversed STI, Speech privacy derived from 1-STI

The calculation was done according to EN IEC 60268-16.

material	directivity	Position1	Position2	Position3	Position4
perforated gypsum ceiling	E1179	36	31	38	41
perforated gypsum ceiling	speaker	37	32	38	44
perforated gypsum ceiling	omni	39	42	50	57
40 mm glass wool ceiling	E1179	20	47	39	76*
40 mm glass wool ceiling	speaker	22	50	39	77*
40 mm glass wool ceiling	omni	40	46	52	73*
40 mm glass wool ceiling + wall panel	E1179	16	33	35	51
40 mm glass wool ceiling + wall panel	speaker	19	33	36	51
40 mm glass wool ceiling + wall panel	omni	37	44	51	81*

Table 5*: Reversed STI with three different directivities, *RASTI-value is used, the level of STI is too low compared to the background level to be calculated by CATT-A.*

3.3 PI- ; Reversed STI- differences between source E1179 and OMNI

material	Position1	Position2	Position3	Position4
perforated gypsum ceiling	11;3	14;11	14;12	14;16
40 mm glasswool ceiling	9;21	16;1	13;13	15;4
40 mm glasswool ceiling + wall panel	9;21	12;11	12;15	15;30

Table 6*: Differences between OMNI source and source according to ASTM E1179 for PI and RSTI*

The directivity according to E1179 always gives higher values for PI than the OMNI source does. The differences are around 15 (PI ranges from 0 to 100). The amount of difference is almost the same for all cases and doesn't vary with different room absorption, neither with distance from the source. The differences for STI vary from 0 to 20 (STI ranges from 0 to 100) but the variations has no correlation with the room condition or the measured position.

3.4 PI- ; Reversed STI- differences for two similar directivities, source according to ASTM E1179 and Speaker

material	Position 1	Position 2	Position 3	Position 4
perforated gypsum ceiling	2;1	3;2	5;0	5;4
40 mm glasswool ceiling	2;3	5;3	3;0	3;1
40 mm glasswool ceiling + wall panel	2;3	14;0	4;1	9;0

Table 7*: Differences between speaker source and source according to ASTM E1179 for PI and RSTI*

The conclusion from comparing two similar directivities, Speaker and source according to ASTM E1179 indicates differences around 5 for PI and up to 3 for Reversed STI, the variations has no correlation with the room condition or the measured position.

4 PI, RESULTS FROM A REAL MEASUREMENT

A measurement with an OMNI loudspeaker and an ACLAN GDB 95 was recently done in Paris in two open offices. The directivity spectrum of the ACLAN loudspeaker is unknown, the dimensions are 0,5 m, which is bigger than the size according to the standard (0,3m). The results are presented in Table 8. The differences are up to 30 which is the double compared to the differences from the computer modeled PI.

Room 1									
directivity	pos A	pos B	pos C	pos D	pos E	pos F	pos G	pos H	pos I
GDB 95	87	79	98	96	66	75	-	100	82
OMNI	58	45	67	67	35	56	54	82	72
Difference, OMNI-GDB 95	29	34	31	29	31	19	-	18	10
Room 2									
GDB 95	69	43	89	100	100	70	81		
OMNI	44	19	56	75	78	51	61		
Difference, OMNI-GDB 95	25	24	33	25	22	19	20		

Table 8: *Measured Privacy Index with two different directivities*

5 COMPARISON OF SPEECH PRIVACY CALCULATED AS, 1-AI ;1-STI

material	directivity	Position 1	Position 2	Position 3	Position 4
perforated gypsum ceiling	E1179	13;36	15;31	32;38	39;40
perforated gypsum ceiling	speaker	11;37	12;32	27;38	34;44
perforated gypsum ceiling	omni	2;39	0;42	18;50	25;57
40 mm glasswool ceiling	E1179	20;20	30;47	43;39	54;76*
40 mm glasswool ceiling	speaker	18;22	25;50	40;39	51;77*
40 mm glasswool ceiling	omni	11;40	14;46	30;52	39;73*
40 mm glasswool ceiling + wall panel	E1179	20;16	32;33	48;35	67;51
40 mm glasswool ceiling + wall panel	speaker	18;19	18;33	44;36	58;51
40 mm glasswool ceiling + wall panel	omni	11;37	20;44	36;51	52;81*

Table 9: *PI ; Reversed STI, Privacy Index derived from Articulation Index and from Speech Transmission Index. *calculated from RASTI values*

6 CONCLUSIONS

The modeling and the measurements with an OMNI- and two directive sources show that the choice of loudspeaker is crucial for the result when performing objective measurements of speech privacy.

6.1 Privacy Index, PI

Differences for PI turn out to be around 15% from modeling and 30% from the real measurement referred to in this study. The directive loudspeaker in this measurement was not according to standard E1179 but nevertheless this example shows the importance of the loudspeaker. A directive loudspeaker always gives higher values for PI than an OMNI source does. Differences between two loudspeakers are almost the same for all conditions, they don't vary with different room absorption, nor with distance from the source. When comparing two similar directivities, Speaker and source according to ASTM E1179, differences are small, around 5%, which seems reasonable when comparing their directivity spectrums, see Figure 2. This means that the loudspeaker Acculab in Table 3, recommended by the standard, is very similar to a speaker's spectrum and shows small differences. Note that it would have been possible to use a completely different spectrum (no energy on the back of the horizontal axis) and still follow the ASTM E1179.

6.2 Reversed STI

The modelling with an OMNI- and two directive sources show how the differences for STI vary from 0 to 20%, the variations having no correlation with the room condition or the measured position. With two sources with similar directivity, see Figure 2, the difference for STI can be neglected.

6.3 Loudspeaker standard

The presented results indicate that the directivity in the two main standards used for speech privacy measurements needs to be more closely specified. For measuring AI, there needs to be stated what the directivity is supposed to be outside the specified range of 50 degrees. For measuring STI, a reference directivity spectrum for comparison would be useful. The use of an OMNI source gives a completely different result than the purpose, according to the methods in the standards.

6.4 Speech privacy

These findings raise the question of which is the most appropriate method to describe speech privacy: Privacy Index , 1-AI or Reversed STI , 1-STI? This study doesn't give the answer to this but it shows that the speech privacy turns out completely differently for the two methods and they also show reversed tendencies depending on the amount of absorption in the room, see table 9. "1-STI" decreases with more absorption while "1-AI" increases. Both parameters increase with bigger distance, the increasing rate depending on the room conditions.

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