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Perceived Speech Privacy in Computer Simulated Open-plan Offices

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Abstract In open plan offices the lack of speech privacy between the workstations is one of the major acoustic problems. Improving the speech privacy in an open plan design is therefore the main concern for a successful open plan environment. The project described in this paper aimed to investigate the relationships between the judged speech privacy and the objective acoustic parameters.

Acoustic measurements were carried out in an open plan office, followed by data analysis at the Acoustic Department, DTU. A computer model of the actual office was developed using the ODEON room acoustic software and this allowed a systematic investigation of the possible influence of various acoustic conditions on the speech privacy. Four different versions of acoustic treatment of the office were used and three different distances from the speech source. Listening tests were performed with the sound files obtained from the simulations, in all cases including a masking noise from a ventilation system. It was found that the Speech Transmission Index (STI) is a good descriptor of perceived speech privacy and that values below STI=0.30 are required in order to obtain a “moderately good” speech privacy condition.

1. INTRODUCTION

While a large amount of information is available in the literature concerning the objective acoustic parameters and ways to improve the acoustics of an open plan office, less is known about the relationships between subjective judgments of speech privacy and objective parameters.

Recently, results of subjective tests have been published [1], [2], showing that perceived speech privacy can be related to the Articulation Index (AI) and its newer replacement Speech Intelligibility Index (SII). The study obtained subjective ratings of a range of simulated open office conditions and described the significance of speech privacy regarding SII and AI. The results suggested that the criteria of SII equal to 0.20 or AI equal to 0.15 are the maximum values for the design of open offices that can be related to “acceptable” speech privacy.

The purpose of the present work was to relate the same kind of ratings to the Speech Transmission Index (STI) and eventually to other acoustic parameters used by the ODEON room acoustic software ,namely Definition (D50), Reverberation time (T30) and Spatial decay rate per distance doubling (DL_2) [3].

2. PROCEDURE

A computer model based on measured acoustic parameters of a real open plan office was created using the ODEON room acoustic software and the various acoustic parameters describing the sound field in the office were adjusted. The sound files obtained from the simulation were used for auralization in listening tests and the results of the subjective tests were discussed.

2.1 Real office measurements

In-situ measurements were carried out in an open-plan office in order to compare the real room characteristics with the ones of the computer-simulated room. The office chosen for the simulation is located in Tåstrup, 20 kilometers away from the centre of Copenhagen, Denmark. The office accommodates large personnel in a busy environment, is H shaped and consists of two wings. Figure 1 shows the ground plan of the studied case.

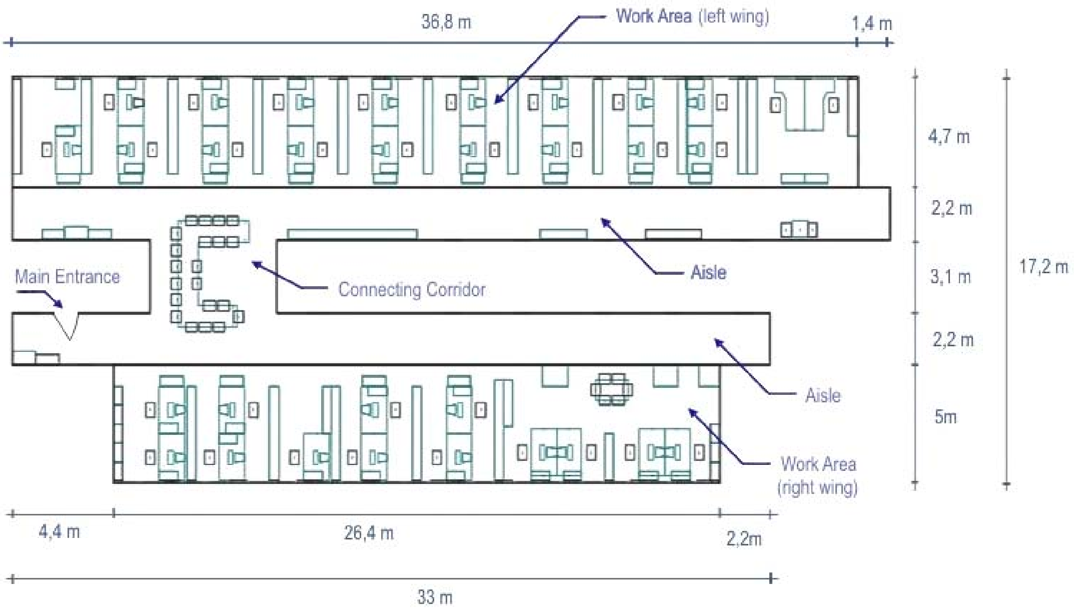

Figure 1: Top view of the open-plan office.

The work area shown in the top of the drawing (left wing) has a length of 36.8 m and a width of 4.7 m. The part shown at the bottom of the drawing (right wing) is 26.4 m long and 5 m wide. On both sides of the open plan office there is a 2.2 m wide aisle beside the work area, as shown on the right side of Figure 2.

Figure 2: Office layout in the right wing.

An acoustic ceiling is suspended from the structural ceiling. At the time of the measurements, there were no sound screens installed between the work stations. However, screens were installed at a later date and it would have been interesting to perform a new set of measurements with screens in place. Storage cabinets are placed between the workstations and on the sides of the desks. The aisles and the corridor are covered with a thin carpet layer while on the work area there is only a linoleum layer covering the concrete slabs.

In order to obtain the room's acoustical parameters, the measurements were performed in the open plan office using the Dirac computer program. A diagram of the measurement set-up is shown in Figure 3.

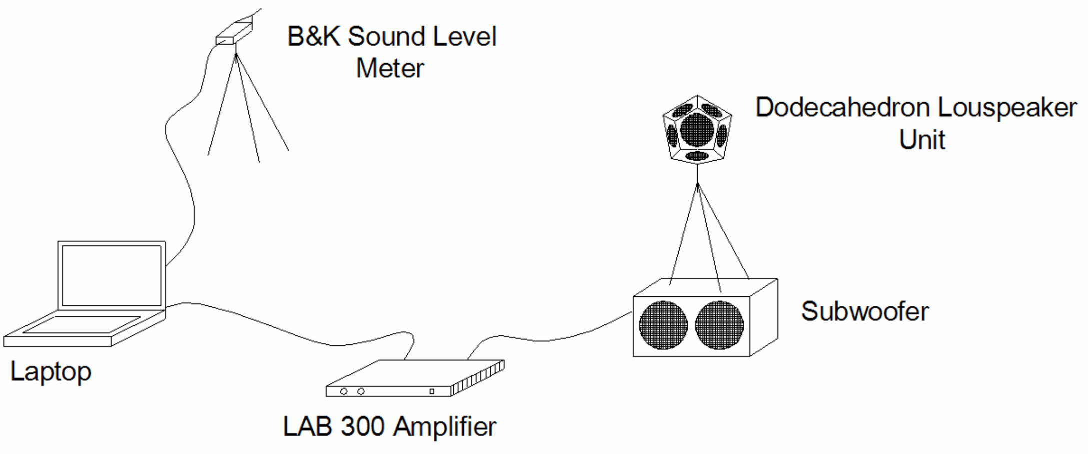

Figure 3: Impulse response measurement set-up.

The Dirac software running on a Toshiba laptop was used to generate the MLS and Sine sweep excitation. The signal was fed to a LAB GRUPPEN LAB 300 power amplifier. A dodecahedral omnidirectional loudspeaker system and a subwoofer unit were used as sound sources. The recordings were made with the microphone of the B&K type 2231 sound level meter and the impulse response data was stored on the hard disk of the computer.

2.2 Computer modelling

Four ODEON computer models with different acoustical properties were developed. The initial computer model was developed based on the parameters obtained by the in-situ measurements and was a fairly detailed and accurate replica of the real office. Figure 4 shows a screenshot from the original model.

Figure 4: The computer-simulated open-plan office (version with no screens).

The second version was a model with a longer reverberation time than the actual office, so as to provide a possibly wider range of subjective ratings from the listening tests. To achieve this goal the absorption coefficient of the ceiling was strongly reduced thus making the ceiling very reflective. The geometry of this version was identical to the one of the original simulation.

The third version shared the same absorption characteristics for the materials as the initial one. The internal geometry of the office was slightly modified by adding sound baffles perpendicular to the ceiling.

The fourth version of the computer model for the open plan office had the same features as the previous one except that sound screens were introduced between desks.

2.3 Listening tests

The purpose of the listening experiments was to relate the perceived speech privacy and degree of distraction due to speech to objective measures. The test persons were asked to rate the perceived degree of speech privacy and how distracting they found each condition presented to them. One source for a speaking person was used together with a large number of sources in the ceiling to simulate the background noise from the air-conditioning. In each of the four room versions, three different listening positions were used: 2.4 m, 8.3 m and 14.9 m from the speech source. Thus 12 different sound files were created with the ODEON simulations, each of them 3 minutes and 20 seconds long. The methodology of the listening tests has been adapted from [2]. The test subjects were asked to perform two simple tasks during the listening tests in order to better simulate a real open-plan environment. Asking the listeners to spell check a text and perform simple mathematical calculations helped them to be not especially focused on the sound files presented to them. Figure 5 shows the set-up used for the listening tests.

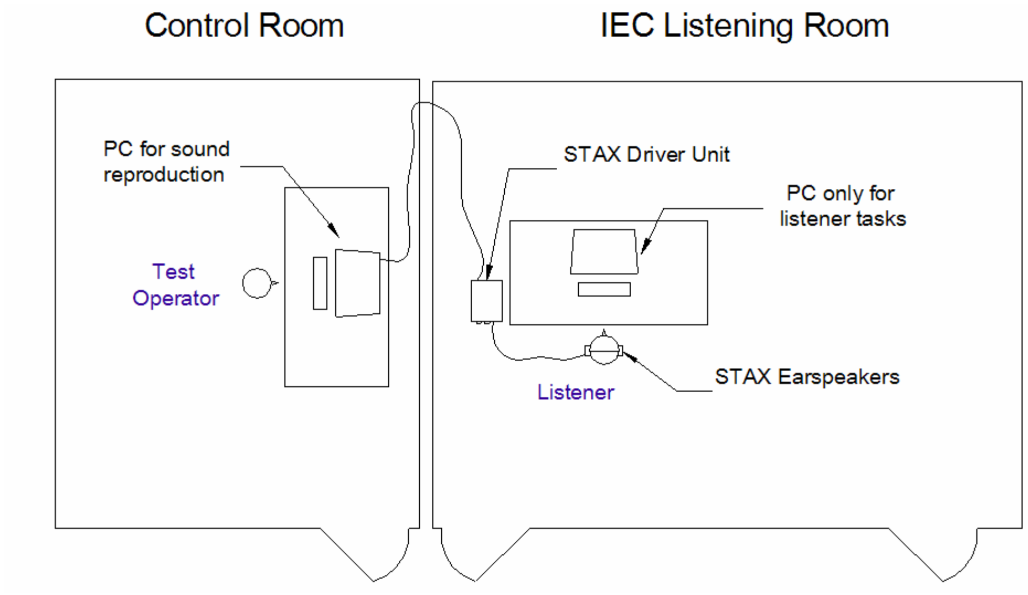

Figure 5: Listening tests arrangement.

The audio files were played from the computer located in the control room using a commercially available audio software - Real Player v.10. The signal was amplified through the STAX SRM – T1 driver unit for Earspeakers. The signal was presented to the listeners through STAX SR Lambda Professional Earspeakers with vacuum tube output.

In order to make sure that the sound levels from ODEON are the ones that the test subjects are going to experience through the headphones, the speech and background noise levels were measured using the Brüel & Kjær Head and Torso Simulator (HATS) – Type 4128. The HATS was connected to the B&K Digital Signal Analyzer Type 2031 which made possible the spectral analysis of the simulated background noise and speech signals.

All the subjects, except one, were students or staff at the Department of Acoustic Technology at the Technical University of Denmark. They had all been given a hearing threshold test in the last 2 years during various experiments or following the completion of an audiology course. They were all reported with normal hearing. A total number of 15 subjects made the listening experiment.

3. RESULTS

Figure 6 plots the speech privacy mean ratings of the 15 subjects for the 12 evaluated conditions versus STI. The mean scores after the math task and the text editing task are shown separately, as well as their average.

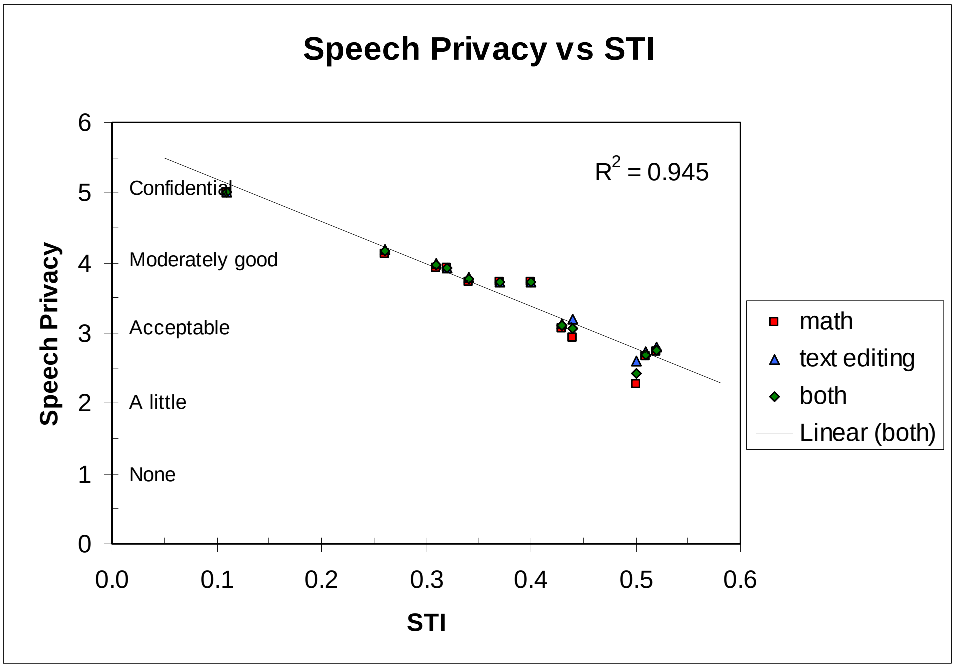

Figure 6: Subjective rating of speech privacy versus Speech Transmission Index (STI).

The two sets of ratings follow closely each other and, except for two cases where the scores for the math and the text differ with small amounts, the ratings are almost identical. The correlation of the STI with the perceived speech privacy is very strong (R^2=0.945).

Figure 7 shows the subjective ratings of the speech privacy versus the rate of spatial decay per distance doubling.

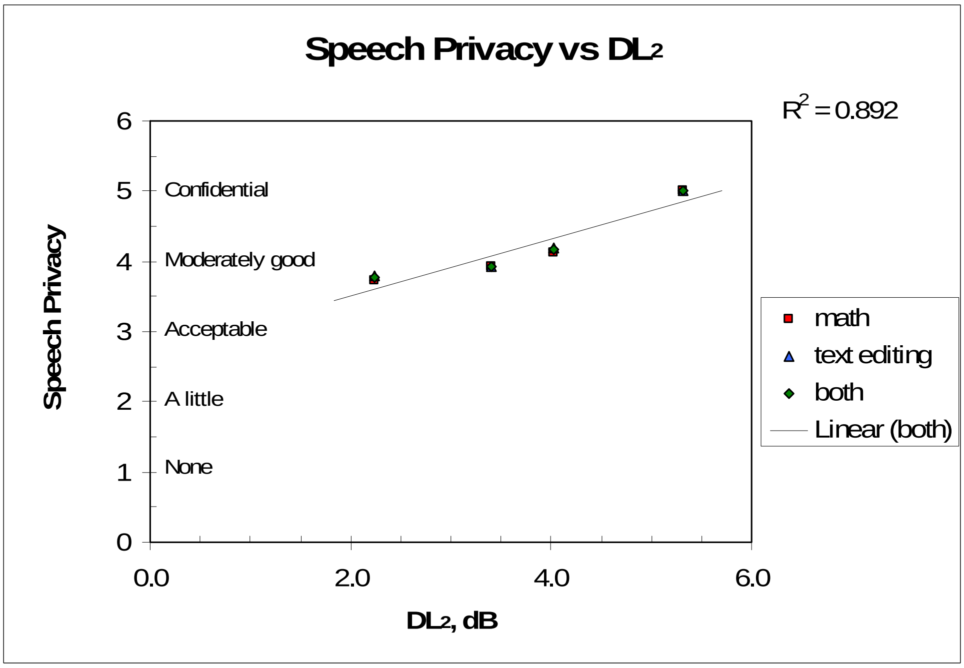

Figure 7: Subjective rating of speech privacy at a distance of 15 m versus the rate of spatial decay per distance doubling (DL_2).

As opposed to the STI, which was plotted for specific positions in the four room versions, the DL_2 parameter characterizes the acoustic properties of the room. The DL_2 is strongly related to the speech privacy (R^2= 0.892). A room with higher rate of spatial decay yields higher speech privacy.

When a room is large and flat (as the open-plan office) the spatial decay rate is recommended to describe the acoustic conditions instead of the reverberation time, see ISO 11690:1 [4]. For a workroom a value of DL_2 greater than 3 to 4 dB is recommended. From the present work it seems that DL_2 should be greater than 4 dB in order to achieve good speech privacy in distances that are not too close to the source.

4. CONCLUSIONS

According to these subjective scores, in order to achieve better speech privacy conditions in open plan offices, STI values below approximately 0.45 would be required. A condition rated as “moderately good” would correspond to approximately 0.3 for the STI, while a condition possibly rated with “confidential” would correspond to an STI value of approximately 0.15.

The speech privacy was found to relate well to the DL_2 parameter (R^2= 0.892) for the four rooms. From the rate of the spatial decay it is possible to asses the acoustical quality of the room and, therefore, the effectiveness of a surface treatment. The acoustic quality of the room is high if the DL_2 is high. A DL_2 value greater than 4 dB seems to be a reasonable criterion for a room to reach the goal of good speech privacy.

ACKNOWLEDGEMENTS

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