Effects of sound masking on workers - a case study in a landscaped office

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INTRODUCTION

Noise is the most disturbing factor of indoor environment in open offices (Haapakangas et al. 2008a). Several independent laboratory experiments have shown that noise, especially speech, reduces task performance of cognitively demanding tasks. According to the model of Hongisto et al. (2008), task performance reduces with increasing speech intelligibility. The room acoustic design of open offices should, therefore, aim at the reduction of speech intelligibility between workstations. This can be achieved by mainly by three factors: increasing room absorption, increasing screen height and increasing masking sound level.

Appropriate masking is necessary to reach acceptable speech privacy between two neighboring workstations. Masking means that the stable background noise of the office is raised controllably to minimize the intelligibility of nearby speech without creating a new source of distraction. In Finland, the recommended level of masking is 40 to 45 dBA (SFS 2004). Optimum masking sound is smooth and unnoticeable, e.g. ventilation noise. Sound pressure level and spectrum need to be considered to obtain a balance between acoustic comfort and efficient masking performance. In many cases, ventilation creates an appropriate masking. In large and high open offices, constant occupant activities and babble can create an appropriate masking. But in many cases, the creation of optimum masking requires an electronic audio system.

Masking was mentioned already in the early open office design guidelines (Hardy 1957). Masking was the presupposition of speech privacy also in the original concepts of landscaped and open-plan offices in 1960's (Boje 1971). However, the use of electronic masking has not become a common practice although the importance of masking is emphasized in the acoustic design guidelines worldwide. One reason may be that very few scientific experiments have been published in this area and the results have been contradictory. Some studies are reviewed below.

Warnock (1973) conducted experiments with electronic masking sound levels 45 to 51 dBA. Occupants responded to simple feedback forms. The sample size was not reported. They rejected each masking condition and preferred the situation without electronic masking. Interviews revealed that their work was not distracted by intruding speech sounds indicating no need to improve speech privacy. In addition, the original sound level of ventilation was already at a recommended masking level, 40 to 45 dBA, producing nearly sufficient speech privacy and additional need for masking was questionable on the whole. Although the setup of the study was interesting, the methodological weaknesses of the experiment are obvious.

Keighley and Parkin (1979) tested different masking sounds, sound levels and spectra. The experiment was carried out in a landscaped office of 40 workers. Altogether 15 different masking conditions, with sound levels from 37 to 46 dBA, were tested, 3 weeks each. Questions about conversation difficulties, overall acoustic satisfaction and acceptability were presented. None of the conditions were found successful. Unfortunately, no masking sound was produced at and above 4 kHz and very little also at 2 kHz. Therefore, the efficiency of masking in the consonants area did not occur. Acoustic attenuation performance of the room was not described so that the objective speech privacy remained unknown. The measurement of perceived concentration difficulties, acoustic distraction and speech privacy could have been very informative as well. The study has antiquated because typewriters, which produced natural masking itself, are no longer used.

Lewis et al. (2003) investigated the effect of masking system on 136 office workers. Masking system reduced significantly subject's self-reported level of distraction and their awareness of sounds. Suggestive evidence was found that performance was improved after the change. Unfortunately, technical information of the masking system, room acoustics and sound levels was not reported.

Helenius and Hongisto (2004) studied the effect of noise control on workers in an open office. Noise control included the installation of masking system, added ceiling absorption and some phone conversation rooms. Noise control improved the perceived acoustic conditions. However, the influence of masking cannot be separated.

Laboratory experiments have shown the benefits of masking for both acoustic comfort and task performance, e.g. Venetjoki et al. (2006) and Haapakangas et al. (2008b).

None of previous field studies have been able to combine room acoustic and environmental psychological expertise to a robust longitudinal workplace experiment. The aim of this pilot study was to investigate the effects of artificial masking sound at 44 dBA on workers in a small department of 15 workers. Room acoustic measurements and occupant questionnaires were conducted before and after launching the system.

MATERIALS AND METHODS

The experiment was carried out in the telephone exchange of an international Finnish bank in Helsinki. More than 60 % of working time consisted of connecting the calls of clients to the correct person in the company. The workers had complained about acoustic distractions from nearby speech and lack of confidential privacy during phone conversations. The company was aware of the expected benefits of masking and wanted to test the technology in this small department.

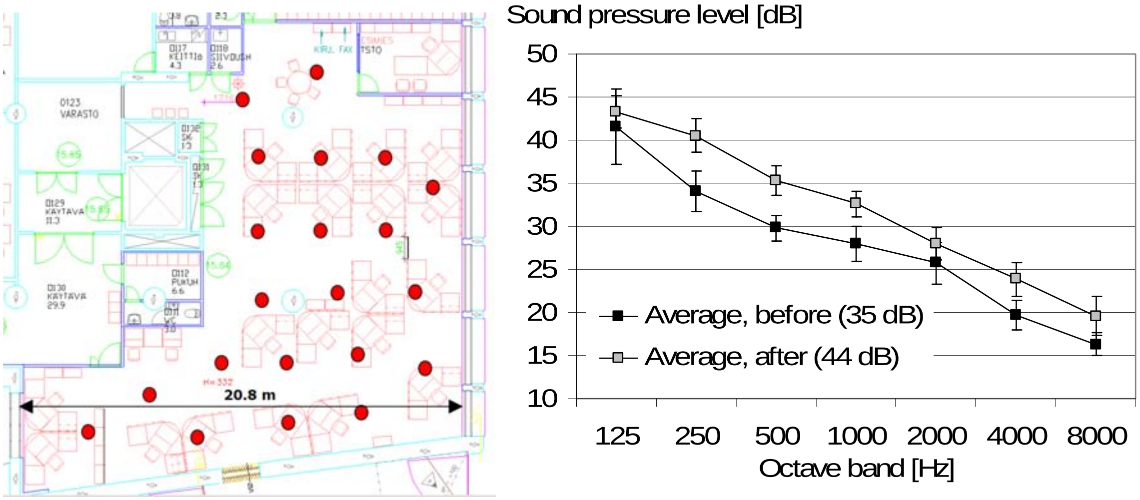
A total of 15 workers took part in the survey before and 13 after the installation of masking. All subjects were female. 13 workers responded both before and after the masking and the statistical analysis was made with these respondents. The response rate was above 80 % both before and after the survey. Subjects were informed that the masking system will be installed to reduce acoustic distractions. No organizational changes took place during the test period.

The acoustic measurements were made to evaluate the objective speech privacy. The measurements included the spatial attenuation of sound pressure level, SPL, of normal effort speech and spatial decay of Speech Transmission Index, STI, which decribes well the speech intelligibility, or inversely, speech privacy. Measurement method is described by Hongisto et al. (2007).

The questionnaire method is described by Haapakangas et al. (2008a). Here, only the most important findings were reported. The analysis was made using SPSS software and Wilcoxon signed rank test.

The floor area of the office was approximately 250 m^2 (Figure 1a) including 20 permanent workstations. The room height was 3.3 m. The height of the screens was 1.4 m. Workstations were enclosed from 2 to 4 sides. Screens were weakly sound absorbing (EN 11654 class E). The whole ceiling was covered with sound absorbing material (class A). Three walls out of six were covered with the same material by 40 % of area. The floor was not sound-absorbing. Because room absorption was initially exceptionally high and higher screens were not permitted, the remaining room acoustic means was the installation of a masking system. It was recommended by the research group because of low background noise level of ventilation, $L_{A,eq}$=35 dB.

The sound masking system consisted of a central unit (sound generator, filter, amplifier) and 21 loudspeakers, Figure 2. The spectrum of noises is presented in Figure 1b. The spectrum was a compromise between the suggestions of Veitch et al. (2002) and the original spectrum of ventilation noise. The masking level was raised from 35 dB to 44 dB slowly to avoid complaints about sudden change, Figure 3.



(a) (b)

Figure 1: (a) The layout of the office. The average distance between loudspeakers (balls) was 3 meters; (b) Spectrum of the background noise of ventilation (before) and masking system (after). The average A-weighted sound pressure levels were 35 and 44 dB, respectively.

(a) (b)

Figure 2: (a) Central unit of masking system consisting of rack mounted signal generator and amplifier. The filters of the signal generator were configured with PC; (b) One of the masking loudspeakers installed above electric ceiling shelf. The cone is directed towards the ceiling to have smoother spatial distribution of sound and to make aural localization of the loudspeaker more difficult.

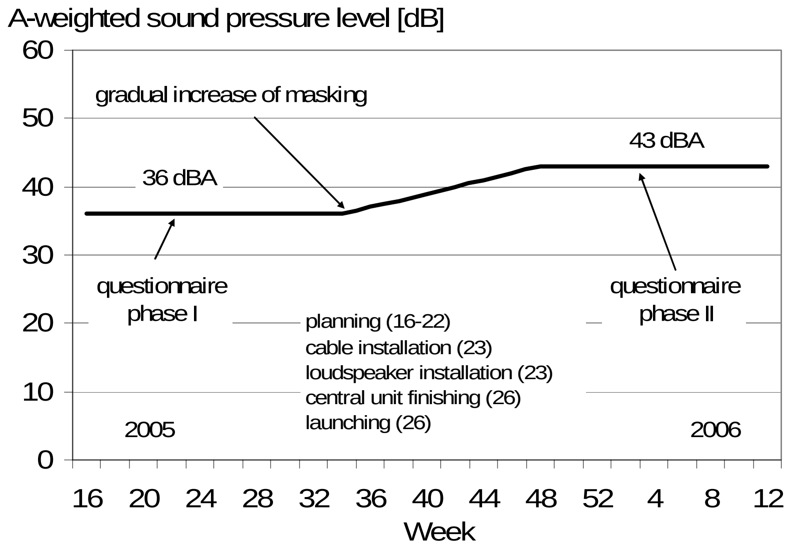


Figure 3: Time schedule of the experiment

RESULTS

The results of room acoustic measurements are summarized in Table 1. The spatial attenuation of the SPL of speech and spatial attenuation of STI are presented in Figure 4. DL_2 expresses the reduction of SPL of speech per distance doubling. It did not change because attenuation was not changed. Radius of distraction, r_d, is the distance where STI falls below 0.50. A significant improvement in objective speech privacy occurred after the installation of masking system. The radius of distraction reduced from 13 to 6 meters.

Noise and thermal conditions were the most disturbing indoor environment factors in the office, Figure 5. After the installation of the masking system, noise disturbance declined but the change was not statistically significant. Other indoor environmental factors were also rated better. The change in thermal conditions and draught could be explained by seasonal changes. Disturbance caused by lighting was reduced significantly ($p < .05$). The reason for the unexpected change is unknown but it may reflect general satisfaction to the improvement. However, satisfaction with work environment as a whole and satisfaction with acoustic environment did not change significantly.

Speech and human-borne sounds were the most disturbing sound sources, Figure 6. The distraction of most sound sources reduced but only the distraction of speech and laughter was reduced significantly ($p < .05$). Disturbance caused by ventilation and background hum, including masking, increased slightly but not significantly. It seems that masking sound was noticed by some people but the loudness was not too high to create a new source of distraction for most workers.

Before the masking, noises disturbed phone conversations, the primary task, the most, Figure 7. After the change, all types of work were less distracted by noise. The change in the task "email, internet" was statistically significant ($p < .05$).

The use of coping methods altogether reduced significantly ($p < .05$, Table 2). After the masking, these negative behavioural effects of noise were on a very low level.

The self-rated waste of working time due to noise halved after the installation of masking. The change was not statistically significant, Table 3.

Noise-related symptoms were also inquired. Concentration difficulties did not change.

Table 1: Summary of the room acoustic measurements. A-weighted SPL of speech at 4 m from the speaker, $L_{p,S,4m}$, spatial attenuation rate of A-weighted SPL of speech per distance doubling, DL_2, radius of distraction, r_D, A-weighted background noise level, $L_{p,B}$, and average reverberation time, T_{20}, in the range 125-8000 Hz.

	$L_{p,S,4m}$ [dBA]	DL_2 [dB]	r_D [m)	$L_{p,B}$ [dBA]	T_{20} [s]
Before	51	6.0	13.2	35	0.3
After	51	6.0	6.2	44	0.3

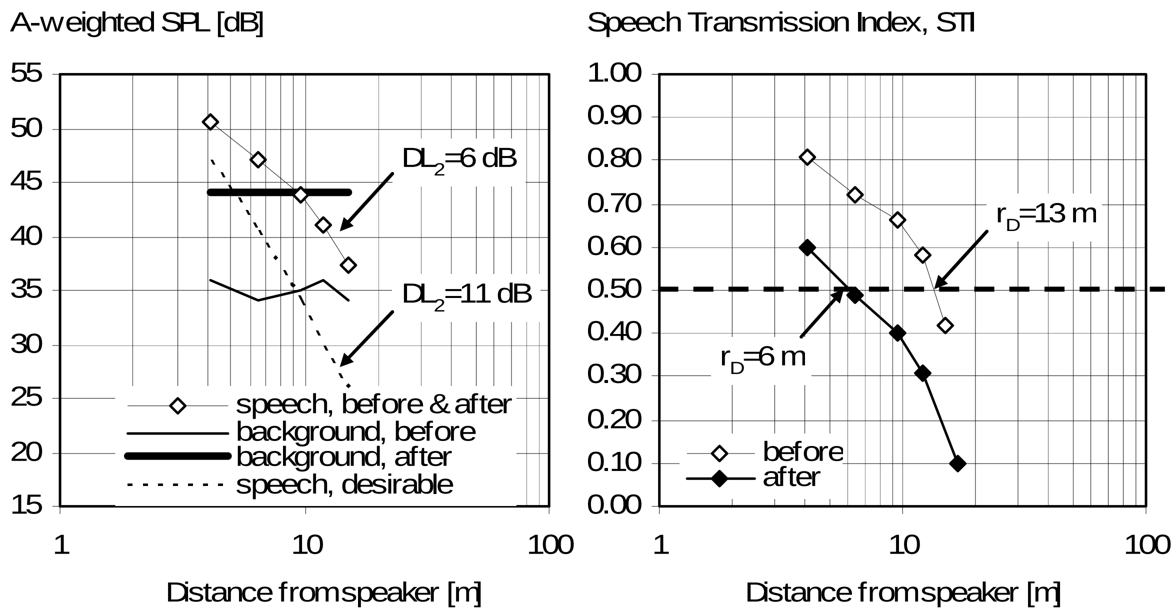


Figure 4: (a) Spatial attenuation of the A-weighted SPL of speech; (b) Spatial reduction of STI

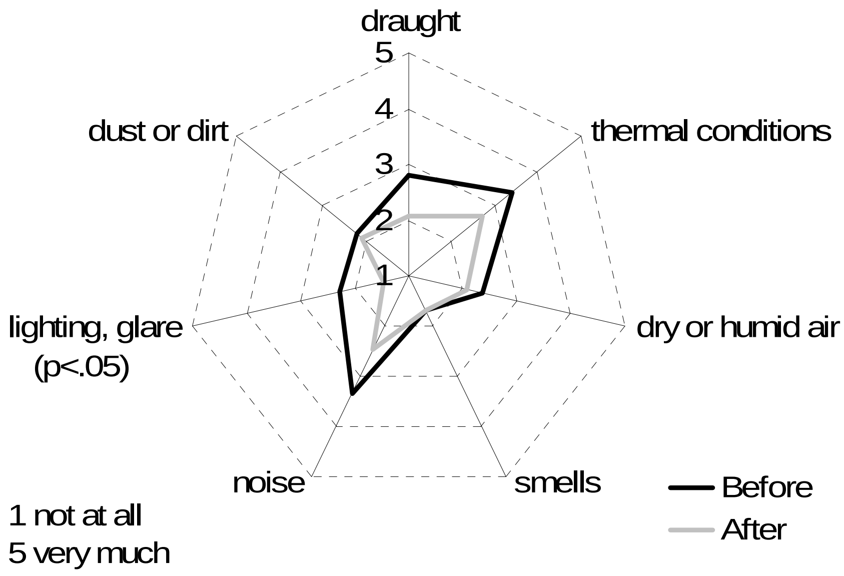


Figure 5: "How much have the following indoor environmental factors disturbed you at your work station during the last month?" Mean values

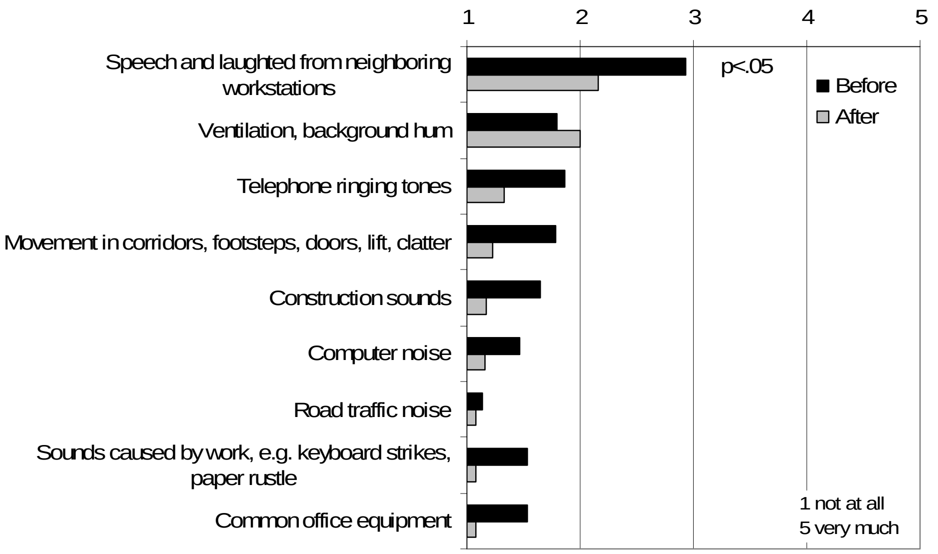


Figure 6: "How much do the following sounds disturb your concentration on your work at your work station?" Mean values

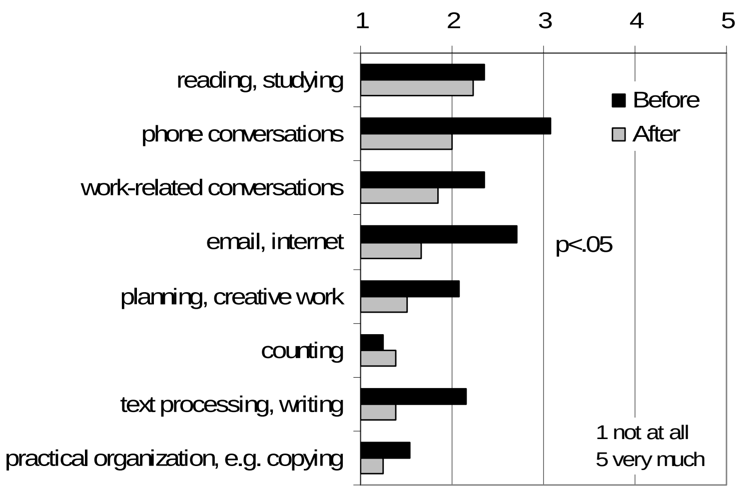


Figure 7. "How much do the sounds disturb the following types of work?" Mean values

Table 2: "How often do you act in the following way to cope with your work because of the sounds in your work environment?" Mean values. Scale: 1=never 5: very often

	Before	After
discussed the noise problem with colleagues	3.4	2.5
made an even greater effort	3.1	2.5
tried to be quieter in the hope that others would do the same	2.9	2.2
used a sign so that your colleagues avoid disturbing you temporarily	2.4	2.2
made a proposal to the management to improve the acoustic conditions	3.3	2.1
slowed down the pace to maintain concentration and quality of work	2.5	2.1
interrupted your work or left your desk	1.7	1.8

Table 3: "When you think about the effects of the sounds in your work environment, how many minutes are wasted per day? Mean values and the corresponding percentage of daily working time

	[min]	[%]
Before	14	3.2
After	6	1.4

GENERAL DISCUSSION

The need for further acoustic improvements became negligible because major acoustic problems no longer existed after the installation of masking.

However, it is expected that even higher acoustic satisfaction would have been obtained if the spatial attenuation had been increased together with masking so much that DL_2=11 dB would be reached (see dotted line in Figure 4). Now, DL_2 was very low because of low screen height. Therefore, the acoustic conditions after the installation of masking did not represent the best possible room acoustic situation.

No adverse effects of masking were reported by the workers. This contradicts with previous studies, e.g. Warnock (1973) and Keighley and Parkin (1979) but agrees with Helenius and Hongisto (2004) and Lewis et al. (2003).

The results showed several positive trends. Some of them were statistically almost significant ($p < .05$). With a larger sample, many of positive trends found in this study would have reached the statistical significance.

The study was carried out in a small department doing a specific job. Different results might have observed in different kind of work. Regarding the noise sensitivity of job types, this study agrees with the cross-sectional survey of Haapakangas et al. (2008a), according to which verbal tasks and conversations are most distracted by speech while routine work is not.

The background noise level was initially quite low. Therefore, the change in acoustic privacy was reasonably large. If the change in background noise level would have been smaller, the subjective responses would have been weaker as well. In general, masking can be suggested only when the initial level is low, much below 40 dBA.

This study gives suggestive evidence that masking could be recommended in open offices when acoustic complaints exist and initial background noise levels are low. It is still expected that masking technology can be easily rejected because of emotional grounds: everybody knows that noise is detrimental to health and comfort. The increase of noise level is against this basic assumption and investment on additional noise is not reasonable.

However, it must be emphasized that the SPL of recommended office masking is very low, 42 to 45 dBA. This does not increase the average noise level during the working day because the average noise levels in open offices are above 50 to 55 dBA because of speech and activities. Negative health effects are not expected to take place because noise energy does not increase. On the contrary, this study gives evidence that distractions reduce which imply that noise-related stress would reduce, indicating positive rather than negative changes in well-being.

The need of future research is evident both in field and laboratory conditions. Experiments in offices should include both team and individual office work, larger number of respondents, different office sizes and different masking technologies. Large-scale experiments are very difficult to carry out because of several practical reasons. However, they are necessary to achieve scientific evidence about the benefits and restrictions of masking. The methodology presented in this study seems to work well in such interventions.

CONCLUSIONS

The effect of masking was experimented in a small open office of 13 respondents. This pilot study gives suggestive evidence that masking can be recommended in open offices when workers are dissatisfied with acoustic environment and the initial background noise level is low. The current study is restricted because of specific office work and small sample size. Future experiments should include different types of offices, job types, masking technologies and larger number of respondents.

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REFERENCES

Boje A (1971). Open-plan offices. Ed. Walley BH, London: Business Books.

Haapakangas A, Helenius R, Keskinen E, Hongisto V (2008a). Perceived acoustic environment, work performance and well-being - survey results from Finnish offices. In: 9th International Congress on Noise as a Public Health Problem (ICBEN) 2008, July 21-25, Mashantucket, Connecticut, USA.

Haapakangas A, Haka M, Keskinen E, Hongisto V (2008b). Effect of speech intelligibility on task performance - an experimental laboratory study. In: 9th International Congress on Noise as a Public Health Problem (ICBEN) 2008, July 21-25, Mashantucket, Connecticut, USA.

Hardy HC (1957). A guide to office acoustics. Architect Rec 121: 235-240.

Helenius R, Hongisto V (2004). The effect of acoustical improvement of an open-plan office on workers. In: Proceedings of Inter-Noise 2004, paper 674, Aug 21-25, Prague, Czech Republik.

Hongisto V, Virjonen P, Keränen J (2007). Determination of acoustic conditions in open offices and suggestions for acoustic classification. In: 19th International Congress on Acoustics, Madrid, Spain, Sept 2-7, 2007.

Hongisto V, Haapakangas A, Haka M (2008). Task performance and speech intelligibility - a model to promote noise control actions in open offices. In: 9th International Congress on Noise as a Public Health Problem (ICBEN) 2008, July 21-25, Mashantucket, Connecticut, USA.

Keighley EC, Parkin PH (1979). Subjective response to sound conditioning in a landscaped office. J Sound Vibr 64: 313-323.

Lewis E, Sykes D, Lemieux P (2003). Using a web-based test to measure the impact of noise on knowledge workers' productivity. In: Proceedings of the Human Factors and Ergonomics Society, HFES 47th Annual Meeting, Denver, CO. 10/2003.

SFS (2004). SFS 5907; en. Acoustic classification of spaces in buildings. Helsinki, Finland: Finnish Standards Association.

Veitch JA, Bradley JS, Legault LM, Norcross S, Svec JM (2002). Masking speech in open-plan offices with simulated ventilation noise: noise level and spectral composition effects on acoustic satisfaction. Institute for Research in Construction, Internal Report IRC-IR-846, April, Canada.

Venetjoki N, Kaarlela-Tuomaala A, Keskinen E, Hongisto V (2006). The effect of speech and speech intelligibility on task performance. Ergonomics 49: 1068–1091.

Warnock ACC (1973). Acoustical privacy in the landscaped office. J Acoust Soc Am 53: 535-1543.