Effect of sound masking on workers in an open office

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Appropriate masking sound is necessary for reaching acceptable speech privacy in open offices, especially between nearby workstations. Electronic masking systems have not become a common practice although the importance of masking is emphasized in design guidelines worldwide. One reason may be that very few scientific field experiments have been published in this area and the results are contradictory. The aim of this pilot study was to investigate the effects of artificial masking sound on workers in a small department (N=13). Measurements and questionnaires were conducted before and after launching the system. Initial background noise level was 35 dBA. Masking sound 44 dBA was produced using centralized pink noise generator and ceiling loudspeakers. The spectrum reminded ventilation noise having an ascending spectrum of -5 dB per octave. Masking reduced the radius of distraction, r_D, the distance where STI drops below 0.50, from 15 m to 7 m. Thus, acoustic privacy improved significantly. The questionnaire revealed several positive trends attributable to masking. Distraction caused by speech and other office sounds was reduced. Noise-related stress was reduced. Evaluations of acoustic environment, speech privacy and self-rated work efficiency were improved. The results showed no adverse effects of masking on workers.

1 Introduction

Appropriate masking sound is necessary for reaching acceptable speech privacy in open offices, especially between nearby workstations. The necessity of masking was admitted already in the early office design guidelines of Hardy (1957) [1]. Masking was the presupposition of speech privacy also in the concepts of landscaped office (low screen height, low degree of enclosure). Open-plan offices in USA made no exception to this (high screen height, high degree of enclosure). [2]

Masking can be created by either built-in systems or electrically. Built-in systems are, e.g. ventilation, air-conditioning, traffic noise or babble in the room. The sound level and spectrum of built-in masking is difficult or impossible to adjust. However, their acceptability is expected to be higher than that of electronic systems because the masking sound can be believed to belong to the environment.

Electronic production of masking sound was mentioned in the literature already in 1969. [3] Electronic systems are usually based on sound source and loudspeaker. Each workstation can have its own sound source (local system) or the whole office can be managed with a single sound source (centralized system). Centralized systems are most common because of lower price and ease of installation and maintenance. Central sound source drives a net of loudspeakers placed evenly to the workstation area. Centralized system was also used in this study.

Centralized system suffers from the lack of individual adjustment, which is the main benefit of the local system. However, local systems are questionable because neighbour's masking can create a new source of disturbance.

Electronic masking systems have not become a common practice although the importance of masking is emphasized in design guidelines worldwide. One reason may be that very few scientific field experiments have been published in this area and the results are contradictory.

Chanaud (2007) has reviewed very recently the technical progress in sound masking technology. [4]

The optimum spectrum of electronic masking sound, based on pink noise, has been studied in laboratory conditions by Veitch et al. (2002) [5]. They found that optimum spectrum, considering both speech privacy and comfort, is close to sound spectrum, where sound pressure level reduced 5 dB per octave in the frequency range of 100 to 10000 Hz.

Venetjoki et al. (2006) found in a laboratory experiment that masking was experienced significantly less annoying than speech with the same sound pressure level. [6] Therefore, masking does not necessarily increase speech privacy with the immediate cost of reduced comfort.

There are very few field studies where the effects of masking on workers were surveyed. Some of them are reviewed below.

Hegvold (1971) presented a case study conducted in an open office. Workers found the comfort of masking sound acceptable when played at 48 dBA. The results were based on oral feedback and a questionnaire was performed. [7]

Warnock (1973) conducted three experiments with masking sound using a simple feedback form given to the occupants. [8] Workers rejected each combination and preferred the initial background noise level of the ventilation, which was 40 to 45 dBA. Interviews revealed that their work was of such nature that intruding speech sounds did not distract them. Thus, masking systems are not preferable unless high demands for speech privacy exist. Because the setup of the study and questionnaire methods did not fulfil general standards obeyed in work environmental experiments, and the sample size was not reported, concluding remarks could not be made of this interesting study.

Lewis (2003) investigated the effect of masking system on 136 office workers. Masking system significantly reduced subject's self-reported level of distraction and their awareness of sounds. [9] Suggestive evidence was found that performance was improved after the change. Unfortunately, no information of the masking system and sound levels was reported.

Helenius and Hongisto (2004) studied the effect of many-sided noise control project, including masking system, on workers using a questionnaire before and after the noise control. [10] Noise control improved the perceived acoustic conditions. However, the influence of masking cannot be separated from the net results.

The aim of this pilot study was to investigate the effects of artificial masking sound on workers in a small department of 15 workers. In this study, both acoustical and psychological perspectives were adopted. Room acoustic measurements and occupant questionnaires were conducted before and after launching the system.

2 Materials and Methods

2.1 Subjects

A total of 15 workers took part in the survey before and 13 after the installation of masking. All subjects were male. 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 about the masking system. The loudspeakers were visible in the room.

No major changes took place in the work community during the experimental period.

2.2 Acoustical measurements

The acoustic measurements aimed at the objective estimation of speech privacy before and after the installation of masking. The measurements included the spatial attenuation of sound pressure level of speech and spatial decay of Speech Transmission Index, STI. Omnidirectional loudspeaker was placed on one workstation. The measurements were made on workstations at a height of 1.20 m.

Closer description of acoustic measurement methods are presented in an associated paper.[11]

2.3 Questionnaire method and analysis

The questionnaire method was essentially the same as in Ref. [12]. The most important findings are reported, including the translations of the original questions.

The analysis was made using SPSS program and Wilcoxon signed rank test.

2.4 Description of the office

The experiment was carried out in a small open office, the telephone exchange of a Finnish bank. The experiment was carried out in Helsinki during 2005-2006.

More than 60 % of working time consisted of connecting the calls of clients to correct quarter in the company.

The room area was approximately 250 m^2. There were 20 permanent workstations in the office. The room height was 3.3 m. The height of the screens was 1.4 m. Workstations were enclosed from two to four sides. Screens were weakly sound absorbing (EN 11654 class E). The whole ceiling was covered with sound absorbing material (class A). Side walls were covered with the same material by 40 % of area. The floor was hard.

2.5 Masking system and setup of the study

The workers had complained about noise. Speech was experienced annoying. The privacy between workstations was experienced insufficient because the phone conversations could be transmitted between workstations.

Because room absorption was initially exceptionally high and higher screens than 140 cm were not permitted, the remaining room acoustic tool was the installation of a masking system. It was justified because the initial background noise level of ventilation was low, $L_{A,eq}$=36 dB.

The sound masking system consisted of central unit (sound generator, filter, amplifier) and 21 loudspeakers that were installed above the electric shelves in the suspended ceiling, Fig. 1. The distance between the loudspeakers was 3 m, Fig. 2.

The background spectra are presented in Fig. 4.

Fig. 1. Left) Central unit consisting of rack mounted signal generator and amplifier. The filters of the signal generator are configured with PC before launching. Right) One of the black loudspeakers installed above electric ceiling shelf.

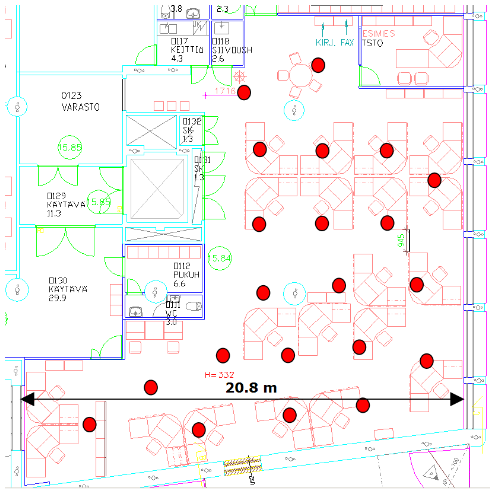


Fig. 2. The layout of the office. The average distance between loudspeakers (balls) was 3 meters.

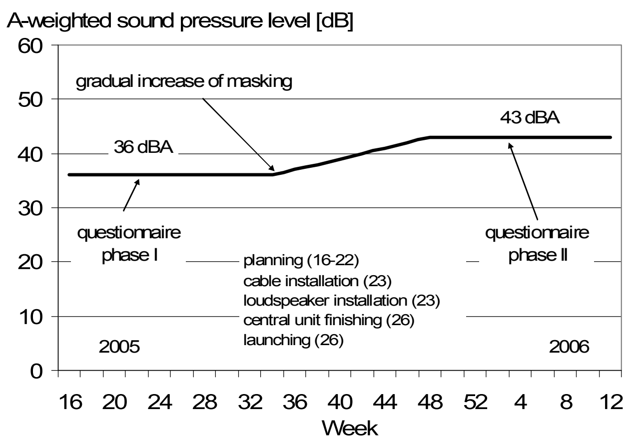
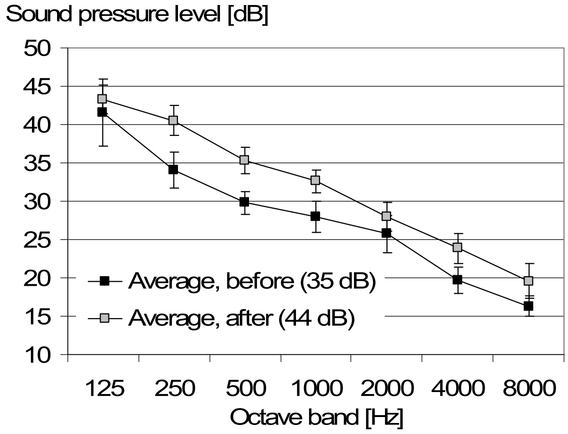


Fig. 3. Time schedule of the experiment.



Fix. 4. 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.

3 Results

3.1 Effect on room acoustics

The spatial attenuation of SPL of speech and spatial attenuation of STI are presented in Figure 5.

The measurement results are presented in Table 1. Because the acoustic change concerned the background noise level, only two parameters out of five were changed. The other parameters describe the attenuation of speech.

	$L_{p,S,4m}$ [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

Table 1. Room acoustic results. A-weighted SPL of speech at 4 m from the speaker, $L_{p,S,4m}$, spatial attenuation rate of A-weighted SPL of speech, DL_2, radius of distraction, r_D, (distance where STI falls below 0.50), A-weighted background noise level, Lp,B, and average reverberation time, T_{20}, in the frequency range 125-8000 Hz.

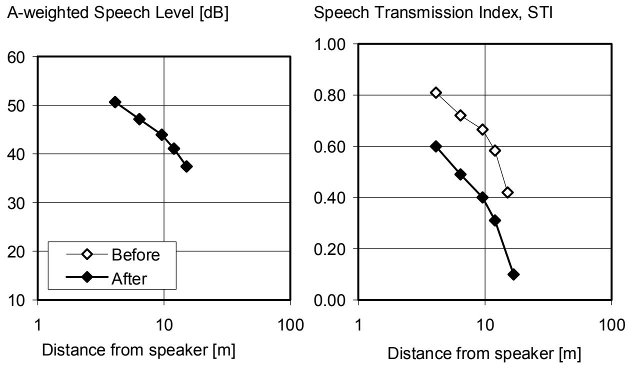


Fig. 5. Spatial attenuation of the SPL of speech and STI.

3.2 Questionnaire results

Satisfaction with work environment as a whole or with acoustic environment did not change significantly.

Noise and thermal conditions were the most disturbing indoor environment factors in the office, Figure 6. After the installation of 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.

Speech and human-borne sounds were the most disturbing sound sources, Figure 7. The distraction from speech and laughter was reduced almost 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 8. 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, Table 2, reduced significantly ($p<.05$). After the masking, the behavioral effects of noise were on a very low level.

The self-rated waste of working time due to noise reduced. The change was not statistically significant, Table 3.

Difficulties with concentration did not change significantly.

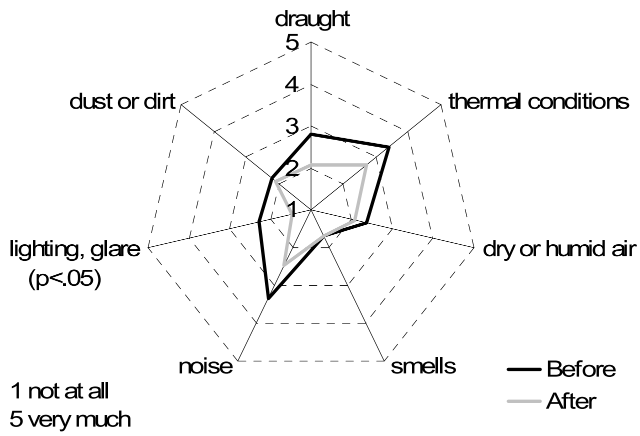


Figure 6. "How much have the following indoor environmental factors disturbed you at your work station during the last month?" Mean values.

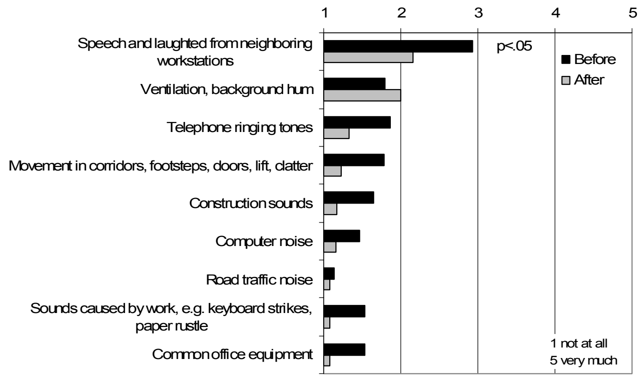


Figure 7. "How much do the following sounds disturb your concentration on your work at your work station?" Mean values.

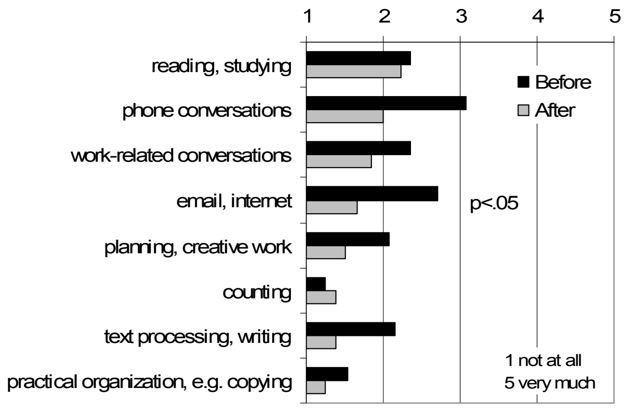


Figure 8. "How much do the sounds disturb the following types of work?" Mean values.

	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 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.

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

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."

4 Discussion

The acoustic measurements indicated a remarkable improvement in speech privacy after the installation of masking system. The distance where STI falls below 0.50 (radius of distraction) reduced from 13 meters to 6 meters.

The spatial attenuation rate of speech, DL_2 was initially low because of low screen height. The value of DL_2 can exceed 12 dB in well designed open offices. [11] Therefore, the acoustic conditions after the installation of masking did not represent the best possible situation.

The need for additional acoustic improvements is quite low because the questionnaire did not reveal major acoustic problems after the installation of masking. The remaining minor discomfort could be reduced by improving the spatial attenuation.

According to the questionnaire, no adverse effects of masking on workers were found. The result represents the opinions of this workplace because of high response rate.

The results showed several positive trends. Some of them were statistically almost significant ($p<.05$). However, statistically significant change could not be found in many points because of very small sample size. With a larger sample, many of positive trends would have reached the statistical significance.

The results cannot be generalized because of following reasons.

- The study was carried out in a small department doing a specific job, here, phone switch center. Different results might have observed in different kind of work.
- The background noise level was initially very low. Therefore, the change in acoustic privacy was reasonably large. If the change is smaller, the subjective responses would have been weaker as well.
- The loudspeakers were visible because there was no place to hide them. Therefore, the localization is easier and, correspondingly, the annoyance can be larger. It is suggested that better results are obtained with hidden loudspeakers. Also slightly larger sound pressure levels could be used.
- The spectrum of masking was not optimal considering comfort. The slope was -4 dB per octave while -5 dB per octave gives better comfort without major reduction in masking performance.

The results agreed well with Helenius and Hongisto (2004) although their study involved also some other acoustic improvements than masking.

It seems that the questionnaire method is appropriate for this kind of experimental field studies.

This study gives suggestive evidence that masking could be recommended in open offices when acoustic complaints exist and initial background noise levels are low.

The need of future research is evident both in field and laboratory conditions. Field experiments should include different types of office work, larger number of respondents and the use of technically most appropriate masking sound systems. Large-scale experiments are significantly more difficult to carry out because of several practical reasons.

However, they are necessary to reach scientific evidence about the benefits of masking.

5 Conclusions

The effect of masking was experimented in a small open office of 15 respondents. This pilot study gives suggestive evidence that masking can be recommended in open offices where major part of work consists of phone conversations and workers are dissatisfied with acoustic environment. Technical presuppositions for positive results are that the initial background noise level is low. The current study was inadequate because of specific type of office work and small sample size. Future field experiments should include different types of office work and larger number of respondents.

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