Comparison of five speech masking sounds - a laboratory experiment

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SUMMARY

The purpose of this study was to find out what kind of features should be preferred and avoided when using speech masking sound in open-plan offices. Fifty-four subjects were tested in seven sound conditions: speech, silence and five masked speech conditions. The five masking sounds were filtered pink noise, ventilation noise, instrumental music, vocal music and the sound of spring water. They were superimposed on speech. The masked speech conditions corresponded to an acoustically excellent open-plan office in respect of the Speech Transmission Index (STI 0.38). The speech condition (STI 0.62) corresponded to an STI obtained between nearby workstations in an acoustically poor open-plan office. Silent condition (STI 0.00) corresponded to the STI measured between two nearby private office rooms. In each of the seven sound conditions, the subjects performed a short-term memory task, a proofreading task and a creative thinking task and completed a questionnaire on acoustic comfort. Compared to the silent condition, short-term memory performance deteriorated in speech condition and in most masked speech conditions. Compared to the speech condition, performance improved when speech was masked with spring water sound. Ratings of acoustic satisfaction and subjective workload showed that the masked speech conditions subjectively improved the working conditions compared to the speech condition. Overall, the performance results and subjective perceptions showed that the spring water sound was the most optimal speech masker whereas vocal music produced negative effects similar to those of speech.

INTRODUCTION

Most office workstations are located in open-plan offices although the occupants often suffer from distracting noise and lack of speech privacy (e.g. De Croon et al. 2005; Pejtersen et al. 2006; Haapakangas et al. 2008; Kaarlela-Tuomaala et al. 2009; Bodin Danielsson & Bodin 2009; Jensen et al. 2005). Speech from adjacent workstations is the most distracting type of noise.

The benefits of open-plan offices are numerous and easy to translate into economical terms, e.g. space efficiency, flexibility, and ease of ad hoc communication. An acoustic consultant, who is aware of the disadvantages of open-plan offices, can always suggest the use of private office rooms when the work requires high privacy and concentration. However, the benefits of open-plan offices are so evident that private office rooms are seldom used instead of open-plan offices. The acoustic consultant must, then, take care of proper room acoustic design in the open-plan office.

Recent studies provide means for creating high speech privacy with room acoustic design. These include, in short, high absorption in the ceiling, walls, screens and storage units, high screens between workstations, textile floor coverings, acoustic division between nearby teams, and the use of speech masking sound.

For many decades, speech masking sound has been used in open-plan offices, ships and other places where acoustic division is not possible by walls. Hongisto (2008) has published a field study which shows some benefits of speech masking.

Speech masking is based on the use of sound which covers speech to a sufficient degree so that the speech intelligibility of nearby speech is reduced. The sound pressure level is typically adjusted to 40...45 dB ($L_{A,eq}$) which is a level that does not hamper normal conversations at short distances but still produces efficient speech masking.

In most commercial applications, filtered pink noise, or related non-natural sound is used. Filtered pink noise sounds like ventilation. It is spectrally comfortable and quite easy to habituate to. It is often suggested that alternative masking sounds should be tested since they might be more comfortable in the long run.

The aim of this study was to find out what kind of masking sound is most optimal in terms of cognitive performance and subjective comfort. Psychological research methods were applied in assessing these effects.

This paper is a shortened version of Haapakangas et al. (2011).

MATERIALS AND METHODS

Subjects

Fifty-four university students were recruited for the experiment. Subjects were 19 to 45 years old (mean=26; SD=5).

Comparison of 16 masking sounds - a pre-experiment

The main experiment was preceded by a pre-experiment. Its purpose was to screen a variety of potential sounds and select the most interesting ones to the experiment. The pre-experiment included the following 16 masking sounds: four differently filtered pink noises, three different ventilation sounds, two vocal music samples with slow tempo, two vocal music samples with fast tempo, instrumental music, road traffic noise measured behind a facade in a room, one commercial melodic masking sound, sound of spring water and babble caused by 20 persons talking in a café (non-intelligible multi-speech). The sounds were tested with 11 persons in an office laboratory using three-minute exposure times. Subjective perceptions were measured with the same acoustic satisfaction questionnaire that was used in the main experiment. It was administrated after each masking sound. The most satisfactory sounds were spring water, instrumental music, ventilation, traffic noise and the pink noise spectrum with a slope of - 5 dB/octave, in this order. Vocal music was the least satisfactory, particularly with Finnish (native language) lyrics and fast tempo.

Sound conditions

Five masking sounds were selected to the main experiment: filtered pink noise, ventilation, vocal music (i.e. instrumental music containing lyrics), instrumental music and spring water sound (Table 1, Figure 1). The first four sounds are typical speech maskers in, for example, offices and health care premises. The fifth represents a natural sound which may be more preferable than artificial sounds.

In the experiment, the masking sound was always played together with speech. The reference sound conditions were silence and speech without masking sound. The total number of experimental conditions was thus seven. STI and sound pressure levels were determined in workstations according to ISO/DIS 3382-3.

Table 1: -weighted sound levels of L_S=speech, L_N=masking, L_{tot}=total level of speech and masking, and L_{SN}=speech-to-noise ratio. STI=Speech Transmission Index

Name of sound condition (abbr.) description	L_S [dB]	L_N [dB]	L_{tot} [dB]	L_{SN} [dB]	STI
silence (silence) speech and masking absent	-	37	37	-¥	0.00
speech (speech) highly intelligible speech, masking absent	48	37	48	10	0.62
filtered pink noise (pink) speech masked with filtered pink noise	45	46	48	-1	0.39
ventilation noise (ventilation) speech masked with ventilation noise	45	45	48	0	0.37
instrumental music (instrumental) speech masked with instrumental music	45	45	48	0	0.35
vocal music (vocal) speech masked music containing lyrics	45	45	48	0	0.36
spring water sound (water) speech masked with spring water sound	45	45	48	0	0.40

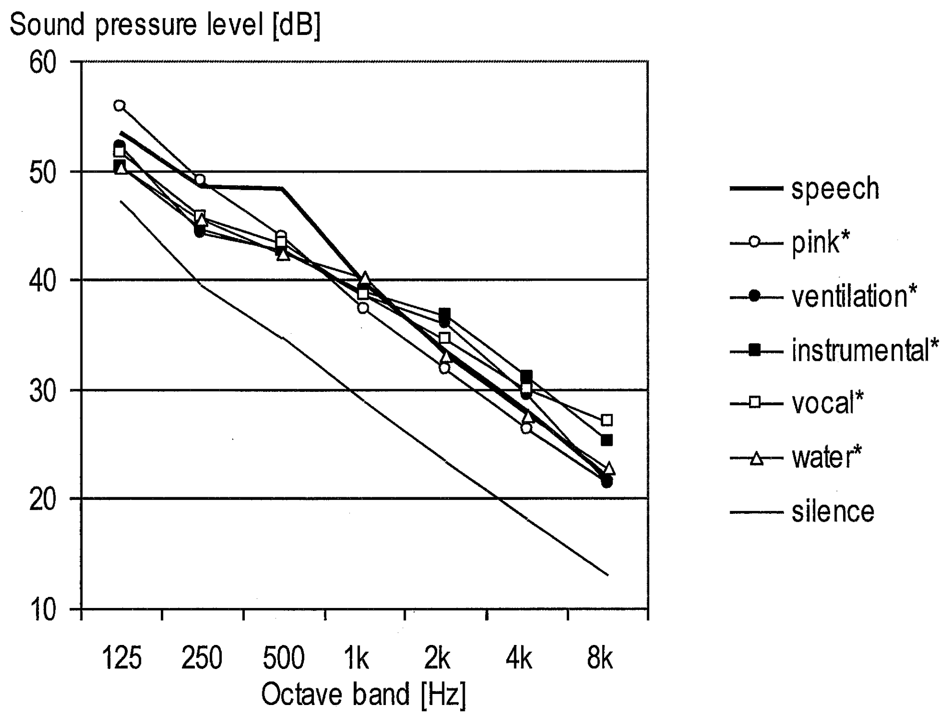

Figure 1: Octave band spectra of the seven sound conditions. The spectra represent equivalent sound pressure levels recorded in the workstations.

Laboratory

The experiment was carried out in a laboratory resembling a normal office room (Figure 2). The speech was produced from loudspeakers in empty workstations (S1-S4). Masking sound was produced from loudspeakers above suspended ceiling (M1-M5).

Questionnaire

Acoustic comfort was measured with a questionnaire that was administered after each sound condition. It included 16 items that measured different subjective aspects of the sound condition. Sum variables were formed for the analysis (acoustic satisfaction 12 items, subjective workload 4 items). The questionnaire also included an assessment of arousal and ratings of disturbance caused by different noise sources.

Performance tests

Three tasks were used. In the serial recall task, subjects had to recall visually presented digits from 1 to 9 in the order of presentation. The task contained 10 sequences. The percentage of digits not recalled in their correct positions was calculated for each sequence. The average score from all 10 sequences (mean error rate) was analysed. This task is a classic task for studying cognitive effects of noise.

In the creative thinking task, the subjects were instructed to write down as many alternative uses for a given object as possible in 5 minutes. They were presented with one name of an object (e.g. 'potato') on a paper and the common use of the object was given. Two dependent variables were formed for the analysis: ideational fluency and ideational originality.

In the proofreading task, subjects marked mistakes in a text containing 60 errors. Half of the errors were spelling errors and the other half contextual errors. The time limit was 10 minutes. The total number of correctly found errors was analyzed.

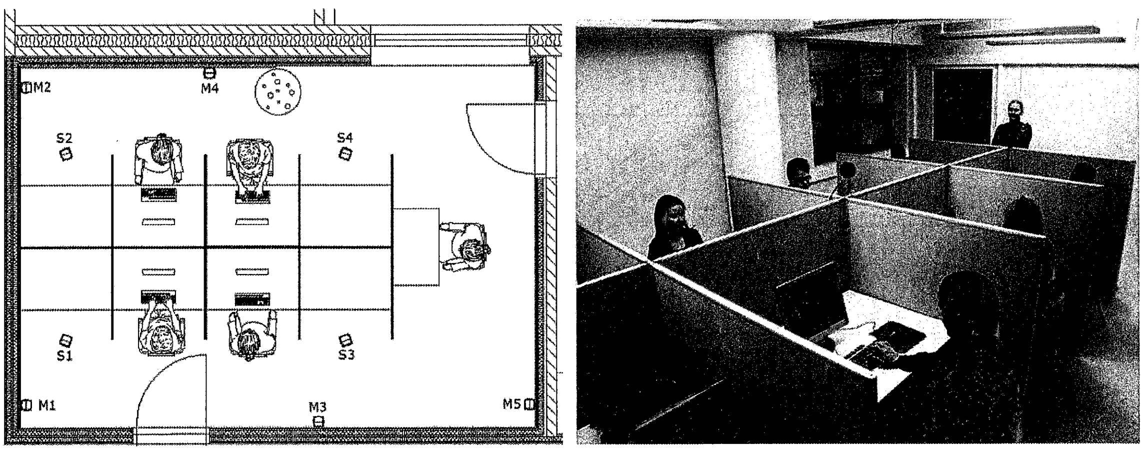

Figure 2: Layout and photograph of the laboratory.

Experimental design

The study was a repeated measures design, i.e. all subjects took part in all seven sound conditions, thus acting as their own control. Three to four subjects were tested at a time (altogether 14 test groups). The sound conditions were presented in a quasi-random order for the test groups. In each sound condition, subjects performed the three above-mentioned tests. The task performance and the subjective perceptions of the sound conditions were the dependent variables.

Procedure

The experiments were conducted in May 2008. The experiment lasted 4½ hours. Half of the subjects were tested from 8 a.m. to 12.30 p.m. and the other half from 1 p.m. to 5.30 p.m. Before the experiment started, subjects were informed that the study dealt with performance in an office-like environment. Subjects filled in the questionnaire gathering background information. This was followed by a 30-minute practice session of the tasks in silence. Before the actual experiment started, subjects were instructed to ignore the sounds and concentrate on the tasks. The experimenter switched on the masking and speech sounds, and then said which task the subjects should start. After the tasks had been completed, the experimenter turned off the sounds. Each sound condition lasted approximately 25 minutes, and was followed by the questionnaire (5 min) before the next sound condition began. A ten-minute break was given after the 1st condition and again after the 4th sound condition. Subjects were informed in detail about the aim of the study after the experiment.

Statistical methods

SPSS 16.0 (SPSS Inc., Chicago, Il, USA) was used for the statistical analysis. A repeated measures ANOVA and t-tests were used for variables that were normally distributed. In the serial recall, only data from 26 subjects is reported here (a complete analysis of the data is reported by Haapakangas et al. 2011)

RESULTS

Serial recall task was significantly affected by the sound conditions (Figure 3a, $F_{6,150}$=4.42, p<0.001). Comparisons of the five masked speech conditions indicated that spring water sound improved performance in comparison to vocal music (t(25)=3.3, p=0.021, two-tailed) and ventilation noise (t(25)=2.7, p=0.039, two-tailed). Spring water was the only masking sound that produced a statistically significant improvement in comparison to unmasked speech (t(25)=2.5, p=0.035, one-tailed). All conditions were also compared to silence, revealing that performance was better in silence than in unmasked speech (t(25)=2.8, p=0.02, one-tailed) and in three masked speech conditions, namely the conditions with vocal music, ventilation noise and filtered pink noise (p<0.05). Spring water sound and instrumental music performed well as speech maskers as they did not differ significantly from silence.

In the creative thinking task, a marginal effect of sound condition was observed for the subjects' ideational originality ($F_{6,306}$=1.93, p=0.075, Figure 3b), with slightly increased performance observed in the spring water sound condition. Proofreading performance was not affected by the sound conditions (p=0.17).

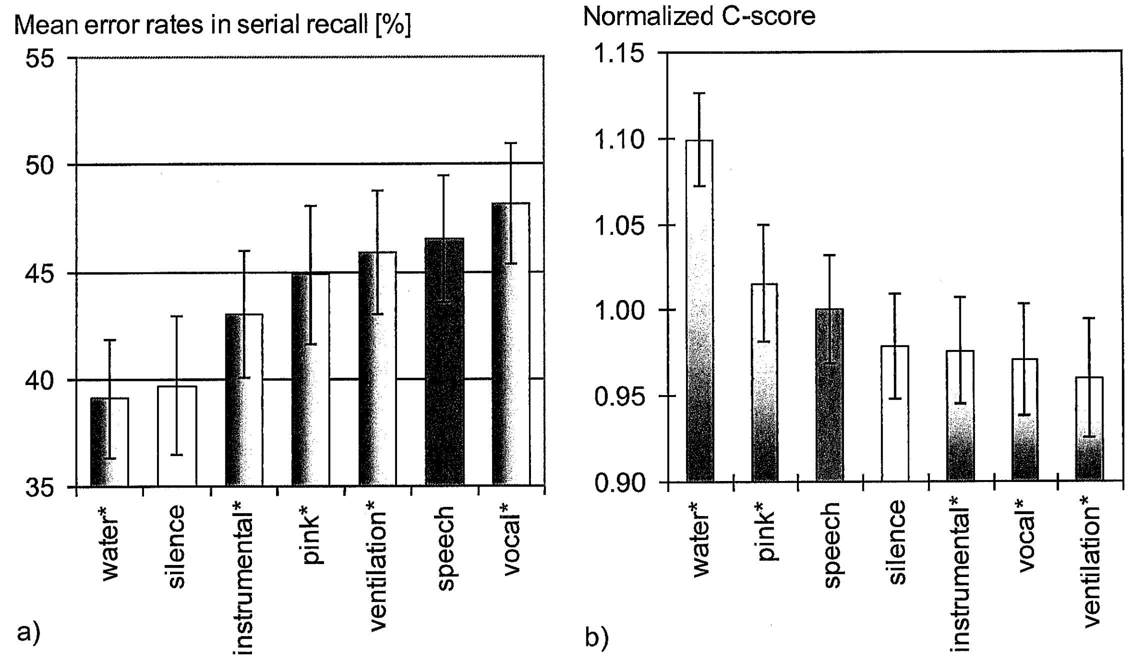

Figure 3: a) Error rates in serial recall task in seven sound conditions. b) Ideational originality of creative thinking task in seven sound conditions. Values above C=1.00 represent higher than average creativity. Lines represent standard errors.
Sounds with an asterisk (*) were played together with speech.

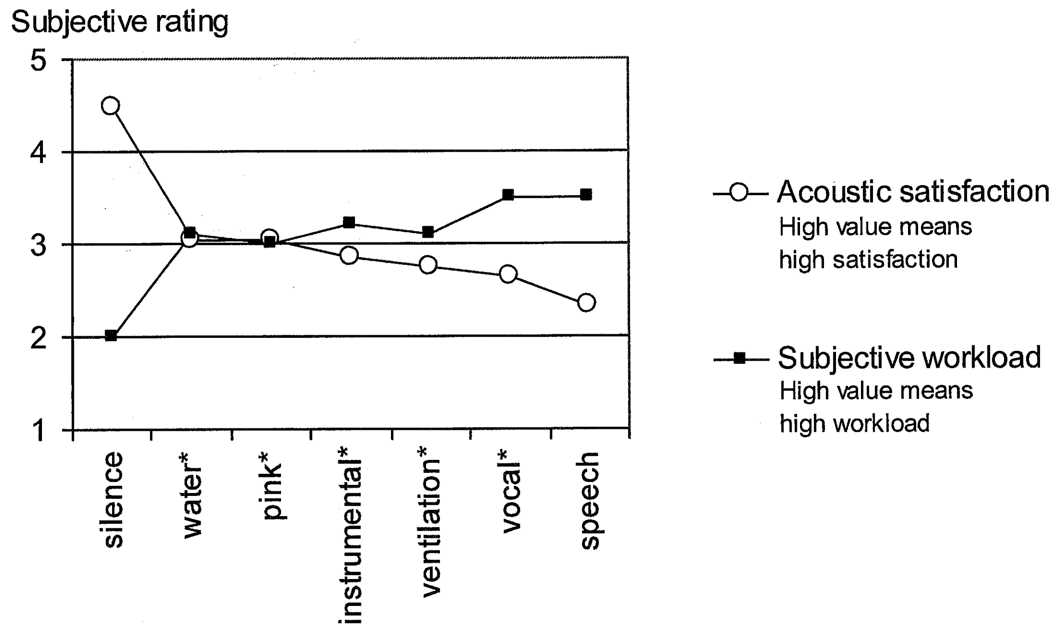

Figure 4: Acoustic satisfaction and subjective workload in the seven sound conditions.
Sounds with an asterisk (*) were played together with speech.

Acoustic satisfaction was significantly affected by the sound conditions ($F_{6,318}$=55, p<0.001, Figure 4). Silence was experienced as the most optimal condition, differing from all other conditions (p<0.001 for all, one-tailed). Masked speech conditions, however, produced higher ratings of acoustic satisfaction than unmasked speech

($p \leq .008$ for all, one-tailed). The following differences were observed between different masked speech conditions: spring water sound was better than vocal music ($t(53)=3.8$, $p<0.001$, two-tailed) and filtered pink noise was better than either of the musical conditions, namely vocal music ($t(53)=3.5$, $p=0.002$, two-tailed) and instrumental music ($t(53)= 2.3$, $p=0.042$, two-tailed).

Subjective workload was also affected by sound conditions ($F_{6,318}=41$, $p<0.001$) and had a very similar pattern as acoustic satisfaction. Subjective workload was lowest in silence ($p<0.001$ for all comparisons to silence, one-tailed). Compared to speech, subjective workload was decreased with all other masking sounds except vocal music ($p<0.05$). This indicates that even though the condition with vocal music was experienced as more pleasant than speech, it was not experienced as an easier environment for performing tasks. Comparisons of masked speech conditions with each other further emphasized the negative experience of vocal music as it differed significantly from all other masked speech conditions ($p \leq .015$, two-tailed). The use of instrumental music also resulted in higher subjective workload than the use of filtered pink noise ($p=0.026$, two-tailed).

The summary of statistically significant findings is presented in Table 2.

Table 2: A summary of findings and overall ranking of masking sounds. A "+" sign indicates that statistically significant improvements were observed in comparison to speech or some of the other masking sounds. A "-" sign indicates statistically significant decrements. Empty cell indicates that statistically significant differences were not found.

	Type of speech masking sound				
	water	pink	ventilation	instrumental	vocal
Comparison to speech					
Performance in serial recall task	+				
Acoustic satisfaction	+	+	+	+	+
Subjective work load	+	+	+	+	
Comparisons between masking sounds					
Performance in serial recall task	+		-		-
Acoustic satisfaction	+	+		-	-
Subjective work load	+	+	+	-	-
OVERALL RANKING ORDER	1	2	3	4	5

CONCLUSIONS

Carefully designed speech masking can reduce the negative effects of irrelevant speech on cognitive work performance and acoustic satisfaction. Vocal or instrumental music are not recommended to be used as a speech masking sound. The most common masking sounds, filtered pink noise and ventilation, are acceptable and also very practical alternatives. More advanced alternatives could be wide-band natural sounds, like the spring water sound, which was the most beneficial masking sound in this experiment. However, field experiments are required before natural sounds, such as spring water sound, can be widely recommended.

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