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WATER-BASED SOUND MASKING: AN EXPERIMENTAL STUDY IN AN OPEN-PLAN OFFICE

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ABSTRACT

In Finland, the new governmental regulations require that Speech Transmission Index shall be less than 0.50 in open-plan offices. It requires both large amount of absorption materials and artificial sound masking due to low ventilation noise levels. Commercial sound masking systems use often filtered pseudorandom noise as a sound signal. A laboratory experiment reported that water sound was experienced more pleasant than pseudorandom noise when performing cognitive tasks. Our purpose was to determine how different water-based masking sounds are perceived in an office workplace compared to pseudorandom noise. The study was conducted in an open-plan office, where sound masking based on pseudorandom noise had been used for 2 years at 44 dB L_{Aeq}. Our experiment included six conditions: original pseudorandom noise (P1a), four different water-based sounds (N1–N4), and return to original pseudorandom noise (P1b). Each condition lasted for 3 weeks and were presented at 44 dB L_{Aeq}. The employees were asked to respond to a questionnaire after each condition. Eighteen employees responded to all six questionnaires and their responses were analyzed. Water-based sounds appeared to be more disadvantageous than pseudorandom noise for almost all subjective measures. Due to some methodological weaknesses, more research is justified in this field.

Keywords: Sound masking, open-plan offices, room acoustics

1. INTRODUCTION

Haapakangas *et al*. (1) found in an extensive field study that noise annoyance was larger in such open-plan offices where the distraction distance was larger. Distraction distance, r_D, is the central single-number quantity of the standard ISO 3382-3 which describes the methods to objectively measure the room acoustic quality in open-plan offices. The value of r_D indicates the distance from a speaker, when the Speech Transmission Index, STI, falls below 0.50 (2). STI can obtain values between 0.0 and 1.0. STI reflects pretty well the subjective speech intelligibility. When STI falls under 0.50, it has been found (3, 4) that the adverse effects of background speech on cognitive performance begin to reduce. When STI is under 0.20, performance decrement is usually negligible due to speech.

The value of r_D can be reduced by proper room acoustic design which aims at smaller signal-to-noise ratio of speech, SNR. The conventional room acoustic methods for reaching lower SNR are:

A. the use of sound-absorbing materials in walls, ceiling, and furniture;
B. the use of high sound-insulating screens between workstations;
C. the use of artificial sound masking system if the background noise is under 40 dB L_{Aeq}.

The separate and mutual effects of methods A–C have been studied both in laboratory (5,6) and field (7). They prove that methods A–C shall be used simultaneously to obtain a small SNR.

The most usual and the cheapest way to implement Method C is to install a loudspeaker system to the ceiling. Typical density is one loudspeaker per 10 m^2. The spectrum should resemble the spectrum of speech to obtain a good balance between speech masking and acoustic satisfaction towards the masking sound itself (8). The recommended level is 42–45 dB L_{Aeq}. Sound masking is usually produced using small loudspeakers and pseudorandom noise within 200–5000 Hz. The spectrum has

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usually a slope of -5 to -7 dB per octave doubling (REF in Figure 1).

Haapakangas *et al*. (9) found in a psychological laboratory experiment that water-based sound masking (a spring water sound, or water stream) led to higher acoustic satisfaction and cognitive performance than sound masking based on pseudorandom noise, ventilation sound, music with vocals, or instrumental music. They suggested that the finding should be confirmed with a field study.

Our purpose was to determine how different water-based masking sounds are perceived in an office workplace compared to pseudorandom noise while the sound level is constant, 4 dB L_{Aeq}, and the differences in overall spectrum are not drastic.

2. MATERIALS AND METHODS

General design. We conducted an experiment in an open-plan office. We studied various subjective responses (dependent variables) among the office employees six times after exposing them to six *masking conditions* (***MC***s, independent variable). The exposure time for each *MC* was three weeks. The employees were invited to respond to a questionnaire after eight working days from the start of the exposure. Employees were informed about the research and it's purpose in advance but they were not involved with the design of the experiment nor with the selection of masking sounds.

Office. The office as well as the original sound masking (*MC* P1a) had been used for 2 years. The masking sound signal was filtered pseudorandom wide-band noise (see P1a in Figure 1). The office (19x50 m, height 2.4 m, 930 m^2) involved 54 workstations and various kinds of teams (administration, IT, quality, sales, marketing). Partition walls existed only around meeting rooms. The office was occupied by 77 employees. Most of the employees had fixed workstations but there were also a lot of elements of activity-based office (sofa groups, meeting pods, working pods, drop-by workstations) to be occasionally used by traveling occupants who did not need a permanent workstation.

Masking conditions. The *masking conditions* (*MC*s) are described in Figure 1. *MC*s P1a and P1b are equivalent. This *MC* represents the sound masking to which the employees had been exposed for two preceding years. *MC*s N1–N4 involved water-based sounds. They were chosen according to a listening test where fifteen people ranked the acoustic satisfaction of each sound according to the subjective scales of Ref. (8). It was decided to choose four water-based sounds according to two criteria: participants' preferences and dissimilarity between the water sounds.

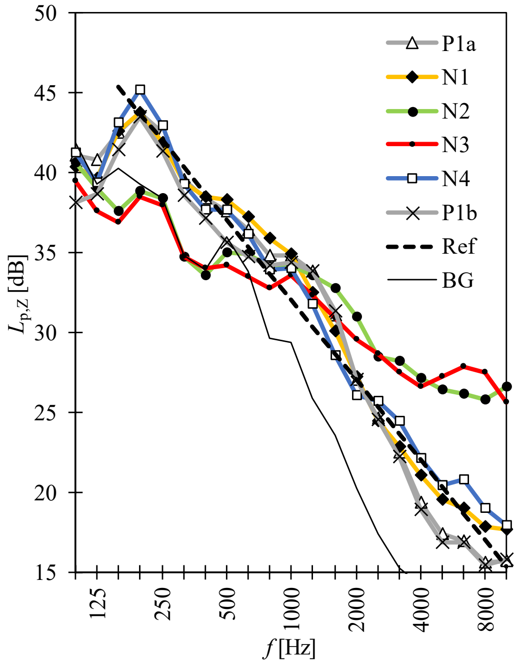
Sound masking was produced using a commercial sound masking system. The system consisted of loudspeaker grid (appr. 1 loudspeaker per 12 m^2) installed over the suspended ceiling. The loudspeakers were not visible to the employees but the they were all aware of the system.

The masking sounds were carefully adjusted by level and spectrum outside working hours before launching a new *MC* to avoid any special attention to sound masking during working hours. The effect of suspended ceiling and room on the spectrum of masking sound was compensated using one-third octave digital filtering (Adobe Audition 3.0), so that we could obtain the desired spectra in the workstations. The sound pressure level (SPL) of a new *MC* was measured in every workstation during the weekend before launching a new *masking condition*. A 15-second integration time was used. Results are shown in Figure 1.

Room acoustics. Suspended ceiling at a height of 2.4 m was covered by 90% with class A sound absorbing material (ISO 11654). Floor was covered by full-area textile carpet. Windowless walls were mostly covered by illustrated sound-absorbing materials (class A) from floor to ceiling. Trefoil-shaped workstation groups involved 1.25 m high screens between tables. The level of sound masking (*MC* P1a) was 43…47 dB L_{Aeq} depending on position.

Room acoustic measurements were conducted in *MC* P1a according to ISO 3382-3. The distraction distance was very low, r_D=5 m. The spatial decay rate of A-weighted speech level was reasonably high, D_{2S}=6.5 dB. The A-weighted speech level at four meter distance from speaker was very low, L_{AS4m}=47 dB. The room acoustic conditions were reasonably good compared to typical conditions measured in e.g. Finnish open-plan offices (2).

Respondents and statistical analyses. The number of respondents to the six questionnaires was 47, 37, 33, 30, 28 and 28. Eighteen employees responded to all questionnaires. Statistical analysis (ANOVA and paired comparison with Benjamini-Hochberg adjustment) was based on these 18 employees using repeated measures design. Our primary interest concerned the differences between *MCs* P1a–N4 (p_1). Furthermore, we conducted a secondary analysis between acoustically equivalent *MCs* P1a and P1b (p_2).



Masking condition	Description of sound	L_{Aeq} M [dB]	SD [dB]
P1a	Pseudorandom noise	44.5	1.1
N1	Waterfall, spectrum close to P1a	44.6	1.1
N2	River (or stream)	43.8	1.6
N3	Babbling river	43.0	1.6
N4	River and occasional birds	44.2	1.3
P1b	As P1a	43.7	1.4

Figure 1 – Descriptions of six *masking conditions*. Left) The unweighted sound pressure level, L_{pZ}, as a function of frequency, f. Ref corresponds to the slope of -5 dB per octave increment. BG corresponds the situation when masking was off (ventilation and computers on). Right) Verbal descriptions of the masking conditions and the mean (M) and standard deviation (SD) of A-weighted sound pressure level on 54 workstations.

3. RESULTS

Satisfaction with acoustic environment reduced every time when a new water-based *masking condition* (*MC*) was introduced. *MCs* P1a and P1b were equally rated (Figure 2a).

Perceived negative effects caused by different environmental factors remained quite much the same between *MCs*. The exception was noise and lack of speech privacy. Their negative effects increased every time when a new water-based *MC* was introduced (Table 1). Perceived negative effects caused by noise did not return to the level of *MC* P1a in the end which suggests that noise caused by working activities were not equal during the *MC*s P1a and P1b.

Perceived disturbance of work due to different sound sources was larger in water-based *MC*s (Table 2, Figure 2b) than in P1a. P1A and P1b did not differ from each other.

Sound quality assessments of masking sound during different MCs (Table 3) suggested that P1a and P1b were identical, as expected. *MC* N4 was unfavorable compared to P1a for all sound quality attributes. The best rating among water-based *MC*s was given to N1. It differed from P1a only for two attributes out of nine.

Job satisfaction reduced from P1a to N1 and did not return to the original level in the end. Perceived possibilities to influence on matters at the workplace were lower in the end (P1b) than in the beginning (P1a). Perceived stress did not change during the experiment.

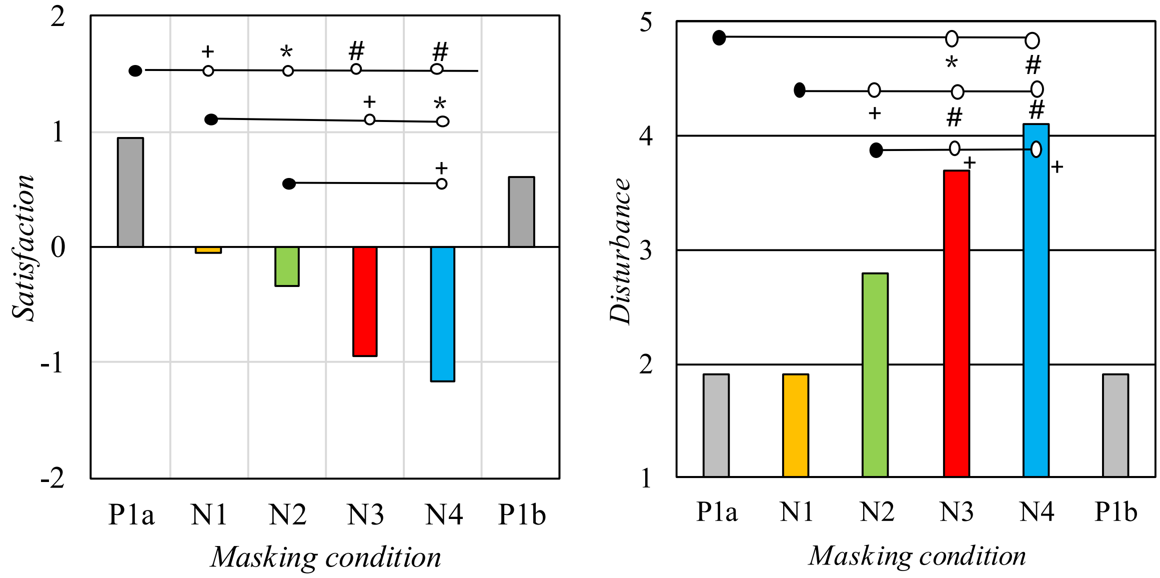


Figure 2 – (Left) Mean satisfaction with the office noise and acoustic environment of the office as a whole in six *masking conditions*. Range: -2 Very dissatisfied; +2 Very satisfied. (Right) The mean disturbance of work due to masking sound. Scale: 1 Not at all, 5 Very much. Labels indicate the statistical significance compared to *masking condition* P1a according to + $p<0.05$, * $p<0.01$, # $p<0.001$.

Table 1 – Perceived negative effects caused by different environmental factors. Mean values. Response scale: 1 Not at all, 5 Very much. Column p_1 describes the significance level of the main effect of *masking conditions* P1a–N4. Column p_2 describes the significance level between *masking conditions* P1a and P1b. Label n.s. means a non-significant difference.

	Masking condition							
Environmental factor	**P1a**	**N1**	**N2**	**N3**	**N4**	**P1b**	p_1	p_2
Draught	1.9	1.4	1.7	2.1	1.8	1.7	n.s.	n.s.
Cold	2.4	1.7	1.8	2.3	2.1	1.8	n.s.	0.029
Hot	2.4	2.3	2.3	2.4	2.0	1.9	n.s.	n.s.
Stuffy air	1.5	1.5	1.6	1.9	1.5	1.6	n.s.	n.s.
Noise	2.1	2.9	3.0	3.7	3.5	2.8	<0.001	<0004
Lack of speech privacy	2.1	2.7	3.0	3.3	3.0	2.6	0.018	n.s.
Lighting	1.4	1.4	1.2	1.5	1.5	1.6	n.s.	n.s.
Glare or reflections	1.5	1.1	1.2	1.4	1.4	1.8	n.s.	n.s.
Dust or dirt	1.4	1.1	1.2	1.2	1.1	1.2	n.s.	n.s.
Smells	1.2	1.0	1.0	1.2	1.2	1.3	n.s.	n.s.
Disorder	1.3	1.3	1.2	1.3	1.2	1.5	n.s.	n.s.
Crowdedness	1.0	1.1	1.1	1.4	1.3	1.5	n.s.	0.024
Movements in vision	1.7	1.2	1.4	1.7	1.4	1.7	0.046	n.s.
Openness	1.3	1.2	1.4	1.7	1.6	1.5	n.s.	n.s.

Table 2 – Perceived disturbance of work due to different sound sources. Mean values. Response scale: 1 Not at all, 5 Very much. Column p_1 describes the significance level of the main effect of *masking conditions* P1a–N4. Column p_2 describes the significance level between *masking conditions* P1a and P1b. Label n.s. means a non-significant difference.

Sound source	Masking condition							
	P1a	N1	N2	N3	N4	P1b	p_1	p_2
Talking and laughing in other desks	2.1	2.7	2.5	3.3	2.9	2.2	0.017	n.s.
Talking in jointly used spaces	1.5	2.2	2.1	2.9	2.8	1.7	0.002	n.s.
Ventilation and air-conditioning	1.7	1.4	1.8	2.4	2	1.6	0.029	n.s.
Sound masking	1.9	1.9	2.8	3.7	4.1	1.9	<0.001	n.s.
Work-related sounds generated by others	1.4	2.1	2.2	2.4	2.5	1.6	0.024	n.s.
Jointly used office equipment	1.2	1.7	1.8	2.1	1.9	1.2	0.013	n.s.
Phones ringing	1.2	1.4	1.3	1.4	1.5	1.2	n.s.	n.s.

Table 3 – The mean values of some attributes describing the quality of sound masking. Scale: -3 Strongly disagree, +3 Strongly agree. Bolded value means that the *masking condition* differs significantly from P1a. Small value is desirable for attributes with an asterisk. Large value is desirable for attributes without an asterisk.

Attribute	Masking condition							
	P1a	N1	N2	N3	N4	P1b	p_1	p_2
Easy to habituate to	1.4	0.8	**-0.2**	**-1.8**	**-2.2**	1.4	<0.001	n.s.
*Distracting**	-1.2	-1.1	-0.1	**1.3**	**1.3**	-1.5	<0.001	n.s.
Pleasant	-0.6	-0.7	-1.2	**-1.9**	**-2.3**	0.2	<0.001	n.s.
*Stressful**	-1.8	-1.2	-0.9	**0.1**	**0.8**	-1.7	<0.001	n.s.
Natural	-0.9	-0.7	-1.1	-1.8	**-2.3**	-0.5	0.012	n.s.
*Annoying**	-1.9	**-0.9**	**0.1**	**1.0**	**2.3**	-1.3	<0.001	n.s.
*Tiring**	-1.9	**-1.0**	**-0.7**	**0.2**	**1.1**	-1.4	<0.001	n.s.
Acceptable	0.7	0.0	**-0.7**	**-1.8**	**-2.3**	1.2	<0.001	n.s.
Helpful for my work	0.3	-0.2	**-1.2**	**-1.6**	**-2.4**	0.6	<0.001	n.s.

4. DISCUSSION

It is obvious that water-based *masking conditions* (*MC*s) were rated more negatively than *MCs* with pseudorandom noise. However, we cannot suggest that water-based masking sounds should not be used because of several methodological weaknesses of our study:

- The employees were used to *MC* P1a for 2 years. Exposure time for water-based *MC*s was only 1.5 to 3 weeks before responding to the questionnaire. Unequal exposure time to different *MC*s has caused at least some bias to the result.
- Order effect may have biased the results. In laboratory experiments, order effect can be minimized by using counterbalanced order of experimental conditions for different participants. We could not consider this in field setting. Future studies should have only one *MC* instead of four.
- Employees did not have any control over the experiment although it concerned their physical workplace. Employees usually appreciate the possibility to control changes in their work environment. Satisfaction with changes made in workplace are usually higher if the employees can influence the decisions (10).
- The study was conducted in one workplace. The results might be different in another workplace.
- The experiment was very long (18 weeks). The response rate reduced during the experiment. The results did not represented the opinion of the whole staff.

5. CONCLUSIONS

We conducted an experiment in an office workplace where the employees were exposed to pseudorandom masking sound, four water-based masking sounds, and again the original pseudorandom masking sound. All conditions were presented at the same level, 44 dB. Water-based *masking conditions* were rated more negatively than *masking conditions* with pseudorandom sound. However, we cannot suggest that water-based masking sounds should not be used because of several methodological weaknesses of our study. More research is warranted in this field. Full version of this work has been published in Ref. (11).

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REFERENCES

1. Haapakangas A, Hongisto V, Eerola M, Kuusisto T. Distraction distance and disturbance by noise – An analysis of 21 open-plan offices. J Acoust Soc Am 2017;141(1):127-136.
2. Virjonen P, Keränen J, Hongisto V. Determination of acoustical conditions in open-plan offices - Proposal for new measurement method and target values. Acta Acust Acust 2009;95(2):279-290.
3. Hongisto V. A model predicting the effect of speech of varying intelligibility on work performance. Indoor Air 2005;15:458-468.
4. Haapakangas A, Hongisto V, Liebl A. The Relation between the Intelligibility of Background Speech and Cognitive Performance – A Revised Model. Manuscript submitted for publication, 10 April, 2019.
5. Virjonen P, Keränen J, Helenius R, Hakala J, Hongisto V. Speech privacy between neighboring workstations in an open office - a laboratory study. Acta Acust Acust 2007;93:771-782.
6. Keränen J, Hongisto V. Prediction of the spatial decay of speech in open-plan offices. Appl Acoust 2013;74:1315-1325.
7. Keränen, J., Hongisto, V., Hakala, J., Oliva, D. (2011). Speech privacy in an open-plan office with different room acoustic conditions, Forum Acusticum 2011, paper 135, 1897-1900, 27 June - 1 July, Aalborg, Denmark.
8. Hongisto V, Oliva D, Rekola L. Subjective and objective rating of spectrally different pseudorandom noises – Implications for speech masking design. J Acoust Soc Am 2015;137(3):1344-1355.
9. Haapakangas A, Kankkunen E, Hongisto V, Virjonen P, Oliva D, Keskinen E. Effects of five speech masking sounds on performance and acoustic satisfaction - implications for open-plan offices. Acta Acust Acust 2011;97(4):641-655.
10. Hongisto V, Haapakangas A, Varjo J, Helenius R, Koskela H. Refurbishment of an open-plan office – environmental and job satisfaction. J Environ Psychol 2016;45:176-191.
11. Hongisto V, Varjo J, Oliva D, Haapakangas A, Benway E. Perception of water-based masking sounds – Long-term experiment in an open-plan office. Front Psychol 2017;8:1117. Open access at: https://doi.org/10.3389/fpsyg.2017.01177.