Preferred sound masking spectrum

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Summary
Artificial sound masking is generally used in open-plan offices to improve speech privacy and to reduce distraction caused by speech sounds. Pseudorandom continuous noise filtered to a specific spectrum is most frequently used. The spectrum should be carefully chosen to achieve a balance between masking efficiency and pleasantness. The aim of this study was to determine the satisfaction of people to spectrally different broad-band sounds. Twenty three subjects rated the loudness, disturbance, pleasantness and three other variables of eleven spectrally different noises in laboratory conditions. All sounds were presented at 42 dB L_{Aeq} within 50-10000 Hz. The subjects were the most satisfied with spectra having emphasis on low frequencies. A sound having a slope of -7 … -9 dB per octave increment resulted in the highest satisfaction. Subjective ratings could be reasonably predicted by five noise indices. The results are expected to benefit in the design of masking sounds and the product development of other appliances.

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1. Introduction

Based on numerous cross-sectional surveys, noise and lack of speech privacy are among the largest environmental problems in open-plan offices. These problems can be reduced by room acoustic means (absorption, screens, sound masking), sound insulation (isolation of noisy areas from open-plan office), and behavioral means (promotion of silent working habits, flexible use of the spaces, division of the office to silent and communicative areas).

Artificial sound masking is generally used in open-plan offices to improve speech privacy and to reduce distraction caused by speech sounds. Pseudorandom continuous noise filtered to a specific spectrum is most frequently used. The spectrum should be carefully chosen to achieve a balance between masking efficiency and comfort. Very few studies have touched the issue although the market of sound masking is vast [1].

The aim of our study was to understand better which spectrum types of pseudorandom noise people prefer and which noise indices best predict the preference.

The full version of the study is presented in Ref. [2].

2. Methods

A psychoacoustic laboratory experiment was conducted using repeated measures design. The dependent variable was the *sound* (**Figure 1**, **Table I**). All eleven *sounds* were created from pseudorandom noise. The listening level of each *sound* was 42 dB L_{Aeq}. The *sounds* were presented within 50 – 10000 Hz (.wav, 44.1 kHz, Adobe Audition 3).

Twenty-three participants (15 male, mean age 40 y) rated the *sounds*. Rating was given for six separate attributes by a sign on a 20-cm-long line having five verbally labeled points (from “Not at all” to “Extremely”). The sign was transformed to a number from 0 to 100. The subjective attributes are in **Table II**.

The attributes correlated strongly with each other. Therefore, a sum variable, *Acoustic satisfaction*, *AS*, was defined to be the main dependent variable of our study according to

$$AS = [plea + habi + work + (100 - loud) + (100 - dist) + (100 - conc)]/6 \qquad (1)$$

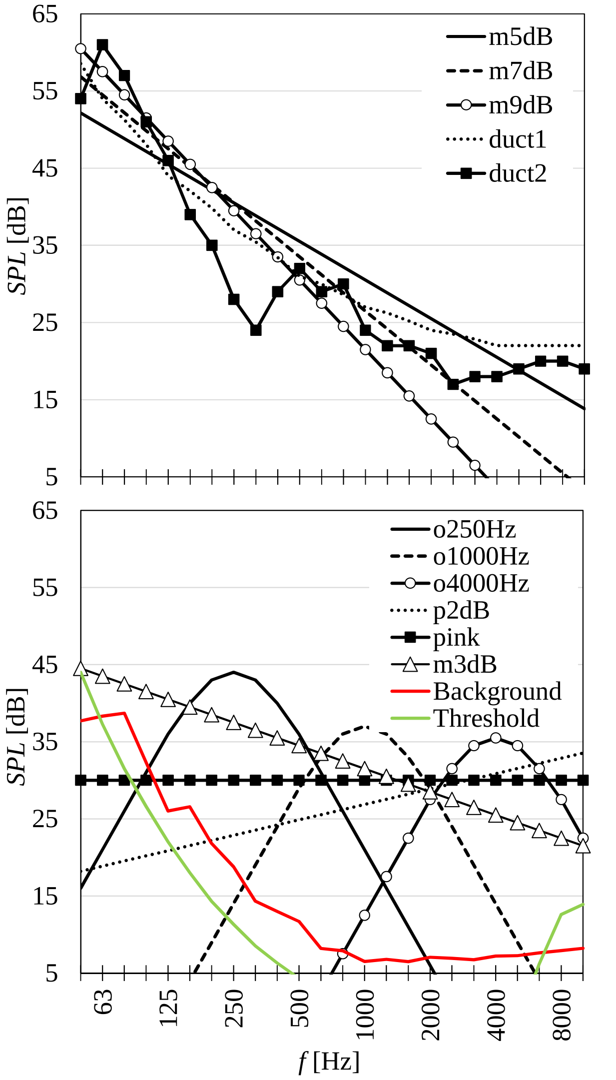

Figure 1. The target sound pressure level, *SPL*, as a function of frequency, *f*, for the 11 studied *sounds*, background noise of the room (Background), and hearing threshold (Threshold). The measured spectrum for each *sound* was the mix of background and the target SPL.

Table I. The description of the experimental *sounds*.

Sound	Description
p2dB	Slope of +2 dB per octave
pink	Flat spectrum, pink noise
m3dB	Slope of -3 dB per octave
m5dB	Slope of -5 dB per octave
m7dB	Slope of -7 dB per octave
m9dB	Slope of -9 dB per octave
o250Hz	Octave band pass at 250 Hz, a rumbly sound
o1000Hz	Octave band pass at 1000 Hz, a roaring sound
o4000Hz	Octave band pass at 4000 Hz, a hissy sound
duct1	Ventilation noise 1
duct2	Ventilation noise 2

Table II. The six attributes used to rate the sound. Negative attributes are marked by an asterisk.

Variable	Question
*loud**	How loud is the noise?
plea	How pleasant is the noise?
*dist**	How disturbing is the noise?
habi	How easy is the noise to get used to?
*conc**	How much the noise would impair your concentration during working?
work	I could work efficiently with this noise for long periods of time.

The values of *AS* range from 0 to 100.

The experiment took 30–60 minutes to execute. It involved three phases: hearing ability test, rehearsal, and actual experiment. One participant at a time was conducting the experiment. The participants were told that our purpose was to investigate how different ventilation sounds are experienced. The participant was sitting in the middle of the room (6.7 x 4.6 x 2.7 m). The background noise level, 24 dB L_{Aeq}, was well below the overall level of the experimental *sounds*. The subjects were not working during the test but they were instructed to imagine that they were in a corresponding acoustic environment for a whole work day.

Each *sound* was played for 90 seconds before the rating was enabled. The order of *sounds* was randomized between participants.

The experiment (playback and responses) was run with the computer in front of the participant using a custom-made software (MS Visual Basic 6). The sounds were played with loudspeakers. Computer was connected to a sound card (Fireface RME 400), which controlled four loudspeakers (Genelec 8010) and one subwoofer. The sound pressure level in third-octave bands 50–10000 Hz was adjusted (Adobe Audition 3.0) to meet the target using 6 microphone positions of a sound level meter (B&K 2260) around the listener's head.

Fifteen different noise indices were calculated for each *sound*. Their definitions and values are given in **Table III**.

Non-parametric Friedman's test was used to determine the statistical difference between the *acoustic satisfaction* of *sounds*. Paired comparison was made using non-parametric Wilcoxon signed rank test between all 55 pairs of *sounds*. Benjamini-Hochberg correction was applied to reduce the probability of false findings. The association between the fifteen noise indices and *acoustic*

Table III. The values of 15 noise indices for the 11 studied *sounds*. The values are determined for the measured spectrum of the *sound* being a mix of the background noise and the target spectrum. The noise indices are defined below.

	L_A [dB]	L_Z [dB]	$L_{N,ANSI}$ [phon]	$L_{N,ISO}$ [phon]	*SIL* [dB]	*STI1*	*STI2*	$L_{Lo\text{-}Hi}$ [dB]	*NC*	*RNC*	*RC*	*QAI*	NR	*NCB*	*PNC*
p2dB	42.0	52.8	65.6	57.3	33.0	0.49	0.31	-13.2	40	47	32	20.6	44	33	32
pink	42.1	54.4	66.9	57.2	35.3	0.50	0.24	-6.6	38	44	35	14.1	41	35	35
m3dB	41.9	54.9	66.1	55.3	34.8	0.53	0.18	-1.2	36	37	36	10.8	37	35	36
m5dB	42.4	57.9	64.8	56.2	33.0	0.56	0.21	3.8	36	34	35	4.0	37	33	35
m7dB	41.5	60.5	60.9	54.5	28.1	0.61	0.33	8.2	36	34	32	5.5	36	28	32
m9dB	42.2	64.0	58.1	56.1	23.8	0.61	0.4	14.7	39	38	27	13.5	38	24	27
o250Hz	42.0	55.3	57.2	51.9	24.5	0.65	0.44	14.4	38	36	28	11.2	39	25	28
o1000Hz	42.4	53.1	60.8	52.4	32.7	0.61	0.36	-9.9	40	38	36	13.9	41	33	37
o4000Hz	42.0	52.9	62.3	56.3	27.7	0.51	0.38	-19.1	42	45	24	28.7	44	28	24
duct1	40.8	61.2	63.9	56.7	31.4	0.56	0.22	3.5	35	37	33	2.5	34	31	33
duct2	41.9	68.0	60.9	59.7	28.7	0.58	0.29	7.7	40	39	30	8.9	36	29	30

L_A	A-weighted *SPL*. The purpose of the experiment was to reach 42 dB for each sound.
L_L	Linear unweighted *SPL*.
$L_{N,ANSI}$	Loudness level by ANSI S3.4 (2007).
$L_{N,ISO}$	Loudness level by ISO 532-B (1975).
SIL	Speech Interference Level by ANSI S12.2 (2008).
STI1	Speech Transmission Index for a nearby speech (54 dB L_{Aeq}) by Keränen and Hongisto (2013).
STI2	Speech Transmission Index for a distant speech (38 dB L_{Aeq}) by Keränen and Hongisto (2013).
$L_{Lo\text{-}Hi}$	Bass content by Veitch et al. (2002). It is the difference between $L_{A,31.5\text{-}500Hz}$ and $L_{A,1k\text{-}8kHz}$.
NC	Noise Criteria by ANSI S12.2 (2008)
RNC	Room Noise Criteria by ANSI S12.2 (2008).
RC	Room Criteria by Blazier (1997) and ANSI S12.2 (2008).
QAI	Quality Assessment Indicator by Blazier (1997).
NR	Noise Rating by BS 8233 (1999).
NCB	Balanced Noise Criterion by Beranek et al. (1971) and Beranek (1989).
PNC	Preferred Noise Criterion by Beranek et al. (1971) and Beranek (1989).

satisfaction was described using Pearson's correlation coefficient, r_P.

3. Results

Friedman's test revealed a statistically significant difference between the 11 *sounds* for all six attributes ($p < 0.000$, F_R values 51–172). **Figure 2** shows the results for *Acoustic Satisfaction*. Paired comparison revealed that three *sounds*, o250Hz, m9dB, and m7dB had the largest value of *Acoustic Satisfaction* without statistically significant difference between them (Group A). Similarly, paired comparison revealed that four *sounds*, p2dB, pink, m3dB, and o4000Hz, had the smallest values of *Acoustic Satisfaction* without statistically significant difference between them (Group B).

Absolute values of Pearson's correlation coefficients between *acoustic satisfaction* and 15 noise indices among the 11 studied *sounds* are shown in **Figure 3**.

4. Discussion

Spectrum affected significantly the *acoustic satisfaction* of wide-band *sounds* presented at the overall level 42 dB L_{Aeq}. *Sounds* involving large proportion of low-frequency noise (rumbly sounds) received higher *acoustic satisfaction* ratings than *sounds* involving large proportion of high-frequency noise (hissy sounds).

The finding is expected to have practical importance to the design of appropriate masking sounds to be used in open-plan offices. Our study did not contain many spectra so that it is likely that more pleasant sounds can be achieved than those of Group A. The topic deserves future research.

The finding is important also for the assessment of residential noises. If certain spectra are more annoying than the others, penalty principles might be justified for certain spectra types, just as those already used for environmental noise involving tonal or impulsive character.

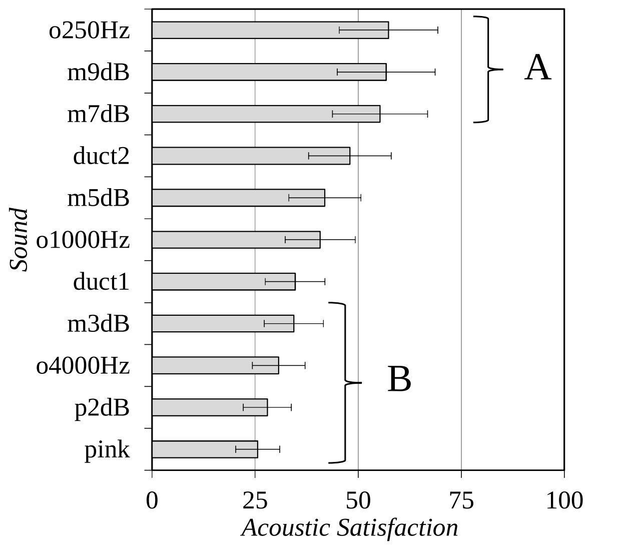

Figure 2. Mean and standard error of the mean for the *Acoustic Satisfaction* of the eleven studied *sounds*. Group A represents the sounds with the largest ratings of *Acoustic Satisfaction.*

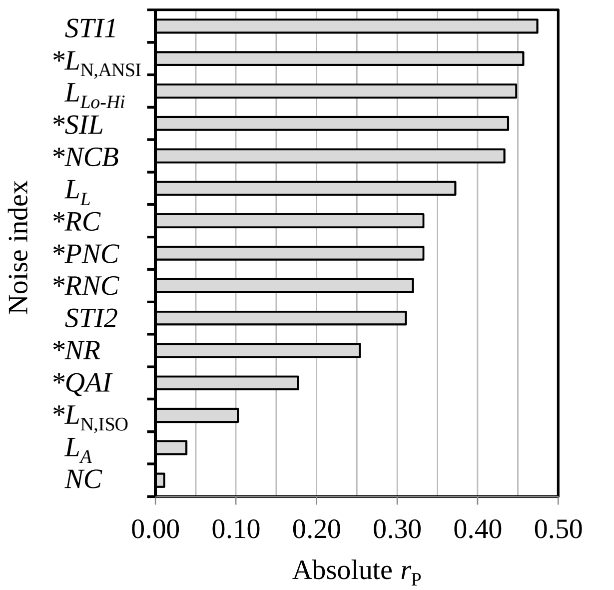

Figure 3. Absolute values of Pearson's correlation coefficients between *acoustic satisfaction* and 15 noise indices among the 11 studied *sounds*. Value of $r_p > 0.25$ means statistically highly significant association ($p < 0.001$). * Original r_p value was negative.

Ideal masking sound would not be annoying and would masks speech efficiently. *STI2* is a noise index which describes best the speech masking efficiency in office environments. The most efficient speech maskers, i.e. the lowest *STI2* values, belonged to the hissy sounds (p2dB, pink, m3dB, o4000Hz), i.e. those receiving the lowest ratings of *acoustic satisfaction*. Unpleasant sounds were the best speech maskers. *Sound m5dB* might be an optimum balance between pleasantness and masking efficiency.

Five noise indices explained the *acoustic satisfaction* reasonably (**Figure 3**). However, the r_P values were under 0.50, which is very low. The experimental room had some background noise. Although the background was close to the hearing threshold, most noise indices behave illogically for third-octave bands close to or below hearing threshold since these bands have lost their importance but still they are considered in the calculation of the noise index. Further research is needed in this field to find proper objective models to predict the acoustic satisfaction and annoyance of wide-band low level sounds.

5. Conclusions

The spectrum of background sound affects strongly the acoustic satisfaction. The results are expected to benefit in the design of masking sounds and the product development of other appliances. Further research in this field is justified.

Acknowledgements

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