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Effect of open-plan office noise on occupant comfort and performance

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SUMMARY

This study investigated effects on comfort, symptoms, and office work performance of exposure to office noise. Forty-nine subjects who were employees working in open-plan offices participated in two full-day experiments simulating an ordinary work day; one day with and one day without exposure to pre-recorded office noise. Exposure to office noise affected negatively ratings of adverse perceptions, selected symptoms, and self-assessed performance, but not the performance of the simulated office tasks. Occupants who in their daily work were disturbed by open-plan office noise were less tolerant to the noise exposure than those who were not.

KEYWORDS

Noise exposure, simulated office work, laboratory study

1 INTRODUCTION

Noise in open-plan offices may reduce well-being and performance and occupants in such offices may even experience higher sickness absence than occupants in cellular offices (Pejtersen et al. 2011, Jahncke et al. 2011). Field studies have shown that noise is one of the most common causes of complaints in offices and especially phones ringing at vacant workplaces and other people's conversation are rated as the most disturbing noise sources in open-plan offices (Pejtersen et al. 2006, Jensen et al. 2005). It has been suggested that acoustic distraction caused especially by irrelevant speech impedes cognitive performance as it may disturb concentration (Liebl et al. 2012, Jahncke et al. 2011). In a laboratory study, Balazova et al. (2008) found that the speed of text typing and false detections of mistakes in a proof-reading task were affected by the acoustic exposure indicating that tasks requiring processing of words may be affected by office noise. However, only modest knowledge exists on the effects of noise on mental tiredness, stress reactions and performance. Most studies until now have used rather specialised cognitive tasks to quantify effects on performance of exposure to noise in open-plan offices and have typically used university students as subjects.

The aim of this study was to investigate effects on comfort, symptoms, office work performance, and stress responses during exposure to office noise with subjects who were employees working in open-plan offices.

2 MATERIALS/METHODS

In balanced order, subjects participated in two full-day experiments simulating an ordinary work day; one day with and one day without exposure to pre-recorded office noise. They were recruited among employees working in open-plan offices in one private (bank) and two public companies (industrial injuries processing and logistics). The selected groups of employees within the three companies first received a mail with a description of the study and an invitation to visit a web site with a comprehensive pre-screening questionnaire, which, among others, contained questions regarding noise exposure and -perception during the usual work day.

Participants

Altogether, 225 employees completed the screening questionnaire and of these 49 persons (32 females aged 44.3±11 years (mean±sd) (range 20-63 years) and 17 males aged 44.4±10 years (range 28-63 years)) agreed to participate in the experiments and completed both experimental sessions. On one of the two exposure days, participants' hearing ability was assessed by measurement of distortions product oto-acoustic emission, which showed that their hearing in general was better than could be expected for their age.

Facilities

The experiments were carried out in a controlled environment office with eight computer workplaces as shown in Figure 1. The office was located at the Technical University of Denmark.

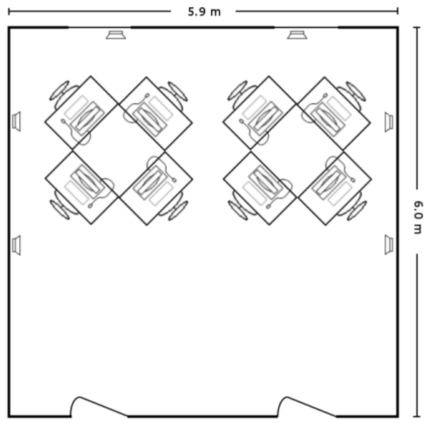

Figure 1. Layout of the office with eight workplaces arranged in two "desk islands".

Air temperature, relative humidity, and CO_2 concentration were logged at 10 min intervals with a small measurement station comprising a HOBO data logger model U12-012 with built-in temperature and humidity sensors and a Vaisala CO_2 transducer model GMW22. The office was mechanically ventilated with a fixed flow rate in all experiments and the temperature was controlled by a combination of radiators located along the exterior facade and the temperature of the supply air. One to eight subjects participated in an experiment at the same time and the CO_2 concentration measured during the exposure time from approximately 10:00 to 15:00 hrs varied between the outdoor concentration and 600 ppm. The thermal load with subjects present in the office caused an increase in the hourly mean temperature from 23.4±0.8°C (mean±sd) during the first hour to 24.4±0.8°C during the final hour. The relative humidity was 41% ± 9% rh.

Digital recordings of office noise were played from a surround sound amplifier by six loudspeakers located as shown in Figure 1. The sound track consisted of typical office noises such as people talking on telephone, people engaged in conversations, occasional laughter, telephones ringing, fax and printer sounds, etc. A detailed description of the sound track can be found in Witterseh et al. (2004). The sound track had been re-sampled and digitized in order to support the surround effect (Kristiansen et al. 2009).

The background sound level measured in the empty office was 42 dBA. With subjects present but without playing the office noise it was 50.7±1.2 dBA and with noise exposure it was 55.0±1.2 dBA. Mean sound levels included only the exposure periods and excluded the break periods when subjects moved around, talked, and the door between the office and the adjacent corridor was open.

Experimental procedure

An experimental day started at 8:30 hrs with a brief introduction by one of the experimenters after which subjects collected saliva in sampling tubes, delivered a urine sample and fixed the heart rate transmitter. Results on biomarkers will not be reported in this paper and these measurements are only referred to as they were an integrated part of the overall experimental procedure. Subjects then entered the office and carried out initial cognitive tests after which three one-hour modules with combinations of simulated office tasks and questionnaires commenced. After the first module, biological sampling was repeated and then subjects had a 30 min lunch break. Between the second and third modules subjects had a 15 min break and after the third module biological sampling and cognitive testing were repeated before the day ended at around 16:00 hrs.

Simulated office tasks and questionnaires

The performance test battery combined simulated office tasks involving different component skills. The tasks included text typing; proof reading; mental arithmetic; dictation, in which a recording of a text was played while subjects read the same text and marked errors that deliberately were inserted in their version of the text; logical reasoning, in which three consonants were shown one-by-one at 0.5 s intervals after which subjects had 12 seconds to decide if a statement on two of the letters (randomly selected) was true or false, e.g. "k did not appear after z". The duration of the different tests varied from 7 min to 19 min. Within each module the order of the different tests was the same, i.e. subjects experienced the same tests at the same stage with and without noise, but the test content was different. The order of presentation of the two test batteries was balanced between subjects. Only the performance of some tasks is included in this paper. Several questionnaires were completed throughout the day. A comprehensive questionnaire filled in before the first and after the third module of simulated office tasks focused on tiredness and the mental state of the participant. At the beginning (questionnaire #1) and end (questionnaire #2) of the first module and at the end of the second (questionnaire #3) and third modules (questionnaire #4), an indoor environment questionnaire, which focused on comfort and the intensity of adverse perceptions and symptoms, was presented to the subjects. All tasks and questionnaires were completed in a standard web browser.

Data analysis

The effect of noise exposure was first tested in a simple linear mixed effects model with participant as random and noise exposure as a deterministic main effect. Then participants' daily disturbance to colleagues' noise was included together with noise exposure in a full model. With non-normally distributed data, a non-parametric χ^2 test was used.

3 RESULTS

As shown in Figure 1, subjects' could clearly discriminate between the condition with and without noise exposure, even from the start of the first simulated office task module ($p < 0.05$). Also, the acceptability of the noise was significantly lower with noise than without ($p < 0.05$). However, the noise exposure did not in the same way affect their perception of the general indoor environment conditions, which was the same with and without noise exposure (not shown). Noise acceptability decreased with time with noise exposure, maybe as a result of increased annoyance caused by increased tiredness.

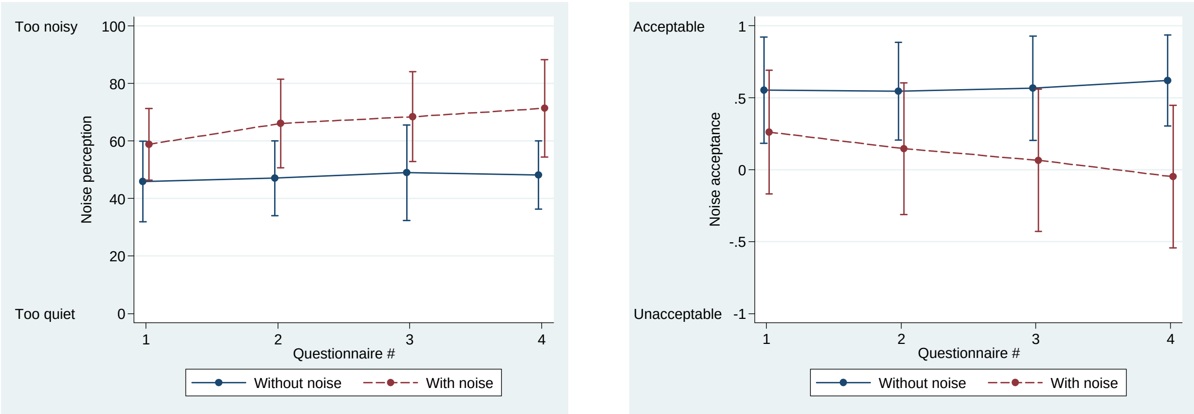

Figure 1. Ratings of the perception of noise (mean±sd) (left) and noise acceptability (right) at the beginning of the first simulated office task module (#1) and at the end of each of all three one-hour task modules (#2, #3, and #4).

Table 1 shows the performance of some of the simulated office tasks, subjects engaged in during the exposure. Office noise did not affect significantly the performance of any of the tasks shown in the table.

Table 1. Performance of the simulated office tasks.

Test	Outcome	Unit	Exposure	Mean	Median	s.d.	p[1)]
Logical reasoning	speed	correct per min	w/o	13.7	13.4	3.6	0.55
			w	13.0	12.4	3.4	
	errors	incorrect per min	w/o	1.6	1.2	1.2	0.52
			w	1.8	1.4	1.6	
Multipli-cation	speed	correct per min	w/o	1.9	1.9	0.9	0.60
			w	1.9	1.9	0.8	
	errors	errors per min	w/o	0.4	0.3	0.3	0.66
			w	0.4	0.3	0.3	
Dictation	correct	fraction[2)]	w/o	0.5	0.5	0.2	0.14
			w	0.4	0.4	0.2	
	errors	fraction[3)]	w/o	0.6	0.6	0.2	0.40
			w	0.6	0.7	0.2	
Text typing	speed	characters per min	w/o	163	171	44	0.89
			w	164	159	44	
	errors	incorrect per min[4)]	w/o	2.2	1.7	2.3	0.90
			w	2.0	1.4	1.5	
Reading comp.	correct answers	correct answers	w/o	5.8	6	2.0	0.31
			w	5.4	5	2.1	

1) Linear mixed effects analysis p-value for the effect of the noise exposure, except for text typing where a χ^2 test was used

2) Ratio of correctly detected words and the sum of correctly detected and missed correct words

3) Ratio of incorrectly detected + missed correct words and correctly + incorrectly + missed correct words

4) Evaluated by Levenshtein's distance - the smallest number of deletions, insertions, or substitutions required to transform the typed text into the correct text

With noise self-assessed performance decreased from the beginning of the first module of simulated office tasks, whereas without noise the decrease in self-assessed performance was apparent after the second module (Figure 2). Even though no significant difference in the performance of the simulated office tasks was observed, there was a difference in how subjects themselves felt they were able to perform ($p < 0.01$ at questionnaire #2, #3, and #4). Subjects' ratings indicated a higher intensity of headache after some hours' exposure to office noise, although the difference was significant only at questionnaire #3.

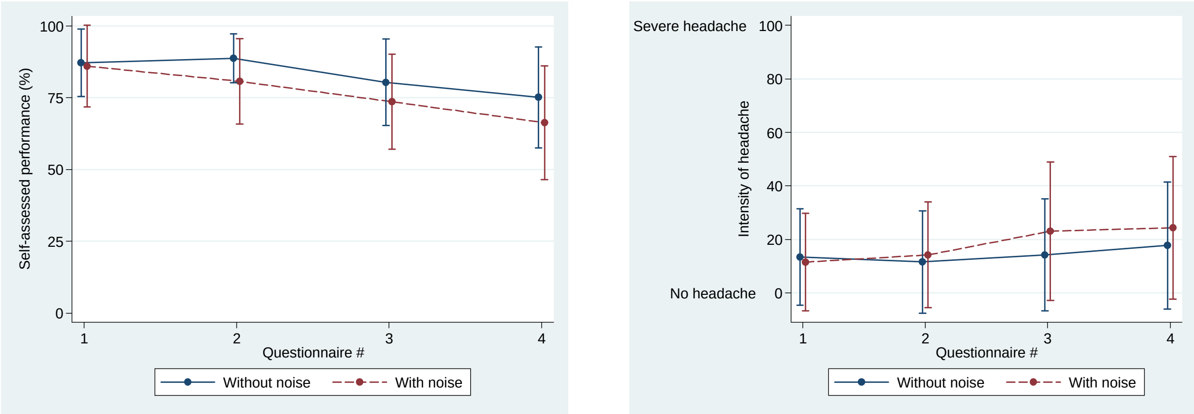

Figure 2. Ratings of self-assessed performance (mean±sd) (left) and intensity of headache (right) at the beginning of the first simulated office task module (#1) and at the end of each of all three one-hr task modules (#2, #3, and #4).

One aim of the study was to compare responses to open-plan office noise from employees who are often disturbed by noise and those who are not. Two items in the screening questionnaire were used to classify these sub-populations; the affected were those who were disturbed by noise more than 25% of the working hours and at the same time perceived the noise from colleagues' activities (internal and phone conversation, etc.) to be very disturbing or even intolerable. This group counted 25 of the 49 participants. With noise exposure, noise acceptability and self-estimated performance were lower and the intensity of headache higher among the subjects who were disturbed by noise in their daily work, i.e. they responded stronger to the exposure than the other group. However, this significant interaction between group and exposure was not seen with the performance of the simulated office tasks.

4 DISCUSSION

In our study, subjective responses were clearly affected by exposure to office noise, whereas the first analyses of the performance of the simulated office tasks did not reveal any clear effect of the exposure. In contrast, Witterseh et al. (2004) reported that the performance of mentally demanding tasks, such as mental arithmetic or proof reading, were reduced during exposure to the same noise as used in the current study, but the performance of less demanding tasks was not affected. However, Balazova et al. (2008) found that office noise exposure and type of acoustic environment significantly affected tasks that included word processing, but not mental arithmetic. Jahncke et al. (2011) found that the memory performance of their study participants declined with exposure to noise and Liebl et al. (2012) found that increased background sound (intelligible background speech) increased the error rates for some tests, e.g. grammatical reasoning, but not for others. Likewise, Banbury and Berry (1998) found that the performance on memory for prose and mental arithmetic was reduced by exposure to background irrelevant speech. Kristiansen et al. (2009), however, did not detect an effect of office noise exposure on mousework (drawing) or logical reasoning. Thus, the performance of some tasks, particularly those requiring a concentration or are dealing with the processing of words, were affected by office noise in several other studies, but we did not observe this effect. One possible explanation is that the duration of the applied performance tasks was too short or the difference in the noise levels between the two exposures was insufficient. This will be studied in continued analyses.

One interesting finding was that participants who in their daily work were disturbed by colleagues' noise responded stronger to the noise exposure. However, the increased noise sensitivity did not result in decreased task performance for these participants, even though they assessed their performance as being lower.

The current study included also the measurement of parameters related with physiological stress reactions, including heart rate variability and cortisol in saliva and urine. These and additional performance and psycho-physiological parameters will be analysed and reported in future publications.

5 CONCLUSIONS

Exposure to office noise affected negatively ratings of adverse perceptions, selected symptoms, and self-assessed performance, but not the performance of the simulated office tasks included in the analysis. Occupants who in their daily work were disturbed by open-plan office noise responded differently to noise than those who were not. In addition to other studies in the literature, our study showed that the design and layout of office work environments affect the wellbeing of the employees and that everyday exposure to noise disturbance even may affect their judgment of the noise exposure.

ACKNOWLEDGEMENT

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