Effects of Noise Frequency on Performance and Well-Being

Jorge Sousa, Raquel Monteiro, David Tomé and Matilde A. Rodrigues

Abstract The features of occupational noise, in particular sound pressure levels, the type of noise and its frequency can be related to several physiological and non-physiological effects. However, studies about the influence of occupational noise on non-physiological effects are still scarce. The aim of this study was to investigate effect of intermittent sound patterns with different frequency on subjects' performance and well-being. Five conditions were simulated and tested through an experimental study: Standard Condition (C0); Industrial noise with alert sounds at 500 Hz (C1); Industrial noise with alert sounds at 1000 Hz (C2); Industrial noise with alert sounds at 2000 Hz (C3); Industrial noise with alert sounds at 3000 Hz (C4). The noise levels were fixed at 45 ± 0.3 dB (A) in C0, and in 68 ± 0.5 dB (A) in the other conditions. The influence of noise on participants' attention and short-term memory was assessed with the serial recall and response inhibition tests. Discomfort, stress and annoyance were accessed using Visual Analog Scales (VAS). Sixteen undergraduate students were included in this study

J. Sousa · R. Monteiro · M. A. Rodrigues (✉)
Department of Environmental Health, School of Health of Polytechnic Institute of Porto, Porto, Portugal
e-mail: mar@ess.ipp.pt

J. Sousa
e-mail: jorge.17.andre@gmail.com

R. Monteiro
e-mail: raquelmonteiro23@hotmail.com

D. Tomé
Department of Audiology, School of Health of Polytechnic Institute of Porto, Porto, Portugal
e-mail: dts@eu.ipp.pt

D. Tomé
Neurocognition Group, Laboratory of Psychossocial Rehabilitation, School of Health of Polytechnic Institute of Porto, Porto, Portugal

M. A. Rodrigues
Research Centre on Environment and Health, School of Health of Polytechnic Institute of Porto, Porto, Portugal

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(8 male; age: M = 22.25 yrs; SD = 0.7 yrs). Higher discomfort, stress and annoyance perceptions were found in condition C4; however, for task performance, no significant differences were found between conditions. This study provided important insights about the influence of different noise frequencies on subject's performance and well-being. Future research should involve workers and how they react in the field to these conditions.

Keywords Annoyance · Discomfort · Occupational noise · Noise frequency · Performance

1 Introduction

Increasing employees' productivity and efficiency, without affecting their safety and health, is one of the most important challenges for companies. In fact, employers need to realize that ensure safe and healthy workplaces for their employees is not only a legal requirement, but also an important strategy to improve proficiency and enhance the company's image and brand. However, it is broadly recognized that several persons work under inappropriate environmental conditions, i.e., inappropriate thermal environments [1], workplaces with poor lighting [2], vibrations [3, 4], occupational noise [5–8], among others. Beyond the well-known health effects, occupational exposure to these hazards can also affect employees' performance and well-being [4].

Noise is one of the most important occupational risk factors identified in the literature. Exposure to high sound pressure levels results in damages to the auditory system [9]. Additionally, it was related to several negative non-physiological effects such as annoyance, stress and discomfort [10–12], impaired conversation [11, 12], as well as negative effects on attention and working memory [13, 14].

The relation between the noise exposure and employees' performance is not a simple matter. According to Banbury et al. [15], the type of noise and its characteristics, as well as the cognitive task being performed mediates the influence of noise on subjects' performance. The randomness of patterns in intermittent sounds showed that errors rates can differ [16]. Clark and Stansfeld [17] state that this type of noise have a higher significant impact in cognitive performance than steady continuous sounds. Nassiri et al. [7] found that intermittent noise with intensities of 85 dB are more likely to cause errors at the speed response levels. On the other hand, Lercher et al. [18] showed that continuous noise had lower effect during complex tasks, like the ones that require working memory, in comparison with intermittent noise. Sound pressure levels are also frequently noticed as an important noise characteristic that can have a negative effect on employees' performance. Nassiri et al. [7] found that sound pressure levels at 95 dB can increase the amount of errors. Alimohammadi et al. [19] found that performance time decreased in an environment where noise was present comparatively to a noiseless one. However, the same authors not found differences in performance when noise levels were between 50 dB (A) and 70 dB (A). Previous studies also showed that at the same sound pressure level, the difference in the frequency may have different effects on subjects' performance. Nassiri et al. [7] verified that high frequencies can lead to a decrease in precision in task completion. However, low frequencies can also be harmful, increasing workers fatigue [20]. In view of this, it is of particular importance to take into consideration sound pressure levels, noise type and frequency when workplaces are being optimized and designed in order to improve employees' performance.

Despite the importance of occupational noise in workers' performance and well-being, studies about this subject are still scarce. Therefore, the aim of this study was to investigate effect of intermittent sound patterns with different frequency on subjects' performance and well-being.

2 Methodology

2.1 Participants

The present study included 16 undergraduate school students, who volunteered to participate. The participants were aged between 21 and 23 (M = 22.25; SD = 0.7; 50% male; 50% female). Inclusion criteria for this study was normal hearing, lack of visual disorders, non-smoking, lack of sleep disorders in the past 24 h and absence of mental health disorders. This information was obtained through questionnaires. Information about the questionnaires applied are further described in Monteiro et al. [13]. All the experiments were done ensuring that the subjects had slept at least 7 h the night before.

The study was approved by the Ethical Committee of the institution where it was carried out.

2.2 Procedures and instruments

In order to respond to the defined objectives, an experimental procedure that involved 5 acoustic conditions was designed: (C0) Standard condition 45 $\pm$ 0.3 dB (A); (C1) Industrial noise with alert sounds at 500 Hz 68 $\pm$ 0.5 dB(A); (C2) Industrial noise with alert sounds at 1000 Hz 68 $\pm$ 0.5 dB(A); (C3) Industrial noise with alert sounds at 2000 Hz 68 $\pm$ 0.5 dB(A); (C4) Industrial noise with alert sounds at 3000 Hz 68 $\pm$ 0.5 dB(A).

For the experiment, an audiology laboratory was adapted to create a simulated environment. A desk, which allowed each participant to be seated during the tests, was placed in the room. Four speakers, two on the front and two on each side were placed around the desk, projecting recorded environmental noise collected by

Monteiro et al. [13] in a previous study and producing the other alert sounds. Under each noise condition, subjects were asked to complete two tests: Serial Recall and Response Inhibition. After each trial, a visual analogue scale (VAS) was used to measure the discomfort, stress, annoyance, sound perception of the stimulus and interference with the tasks at hand. The VAS consisted of a line with 100 mm in length, labelled at each end as "Not at all…" at the left end, and "Extremely…" at the right. Subjects were asked to mark across the line the point that indicated the level of discomfort, stress, annoyance, sound perception, and interference that they were feeling. Since the sound perception and the interference parameters were allusive to the stimulus, they were not measured on the C0 noise conditions. Sound pressure levels were monitored with a CESVA SC310 Sound Level Meter. According to the intermittent sound frequency, sound pressure levels were adjusted in order to achieve the target of 68 ± 0.5 dB (A).

2.3 Data Analysis

Nonparametric Shapiro–Wilk test was used to test normality. Subsequently, since normality assumptions were violated, comparisons of the means were made using the nonparametric Wilcoxon test and Friedman's test. Correlation was analyzed using Spearman's correlation coefficient. A significance level of $\alpha = 5\%$ was considered in the present study. All analysis were performed using the statistical software package Statistical Package for Social Sciences (IBM SPSS®) version 23.

3 Results

Regarding the results of the experiment, Table 1 presents the descriptive statistics and compares the results of different parameters in the five noise conditions.

No significant differences were observed between the different noise conditions for Serial Recall and Response Inhibition tests ($p > 0.05$). Similar results were obtained for the stimulus perception and perceptions of the interference of stimulus ($p > 0.05$). However, in what regards to discomfort, stress and annoyance results shows significant differences between the conditions under analysis for these variables ($p < 0.05$).

Data suggests that as the stimulus frequency increases, the discomfort, stress and annoyance levels also increase. In the condition C4 were observed the higher levels of discomfort (55.06 ± 26.06), stress (43.25 ± 32.89) and annoyance (63.56 ± 32.14). It was also observed that the parameter annoyance did not increase in a steady way. The condition C2 presents a higher rate of annoyance (55.06 ± 32.59) than the condition C3. The condition C0 showed the lowest values of discomfort (13.93 ± 21.9), stress (17.56 ± 19.33), annoyance (6.43 ± 13.25), perception of the stimulus (59.75 ± 28.07) and interference (40.5 ± 27.33).

Table 1 Summary of results for the different parameters in the five noise conditions

Parameter	Noise condition	Mean	SD	*p*-value
Serial recall errors	C0	7.75	5.77	0.292
	C1	7.56	7.56	
	C2	5.94	3.15	
	C3	7.94	6.01	
	C4	6.25	4.14	
Response inhibition commission errors	C0	0.38	0.81	0.655
	C1	0.38	0.71	
	C2	0.81	2.74	
	C3	0.75	0.86	
	C4	0.69	1.07	
Response inhibition omission errors	C0	0.37	0.50	0.081
	C1	0.25	0.58	
	C2	0.18	0.40	
	C3	0.19	0.54	
	C4	0.25	0.45	
Discomfort level	C0	13.93	21.90	0.001
	C1	45.18	29.80	
	C2	44.18	28.79	
	C3	44.00	28.35	
	C4	55.06	26.06	
Stress level	C0	17.56	19.33	0.001
	C1	34.93	31.68	
	C2	39.68	30.15	
	C3	37.62	28.72	
	C4	43.25	32.89	
Annoyance level	C0	6.43	13.25	0.000
	C1	47.43	34.11	
	C2	55.06	32.59	
	C3	48.00	32.35	
	C4	63.56	32.14	
Perception level	C0	–	–	0.760
	C1	59.75	28.07	
	C2	60.68	24.79	
	C3	60.12	29.90	
	C4	61.56	23.18	
Interference level	C0	–	–	0.713
	C1	40.50	27.33	
	C2	48.18	29.57	
	C3	42.87	25.47	
	C4	49.12	27.38	

Note C0—Standard condition; C1—Industrial noise with alert sounds at 500 Hz; C2—Industrial noise with alert sounds at 1000 Hz; C3—Industrial noise with alert sounds at 2000 Hz; C4—Industrial noise with alert sounds at 3000 Hz

Significant pairwise comparisons were found in the parameters discomfort, stress and annoyance ($p < 0.05$).

In condition C0 a positive correlation was observed between discomfort and stress ($r = 0.555$; $p < 0.05$). In all other conditions, positive correlations were observed between discomfort, stress, annoyance and interference with tasks ($p < 0.01$).

4 Discussion

The experimental study focused on the analysis of subjects performance and well-being on five different conditions of noise. No significant differences between the five different noise conditions were found for Serial Recall and Response Inhibition test results. Both the fact that students were included in this experiment instead of workers and the limited sample used can have contributed to these results. It was expected to find differences between the standard condition and the conditions where the intermittent stimulus was produced. The study conducted by Monteiro et al. [13] showed that under the condition with noise and intermittent stimulus at 1000 Hz (C2) the number of errors increased when compared to the standard condition (C0) or the condition without environment noise. This was not observed in the present study. One explanation for the results can be the arousal theory. Arousability represents the activity of the central nervous system and it fluctuates between sleep and alertness, adjusting the response to stimulus [21]. Maybe if a more extensive range of sound pressures and frequencies were used in this research, the performance would be different. Adding to uncertainty of results, there has been a debate whether the range of 600 Hz and 4000 Hz has the most effects like sleep disturbance, hypertension, and noise induced annoyance as well as fatigue and lack of concentration that can interfere with tasks [22]. It is important to note that between the frequencies of 500 and 3000 Hz exists a higher risk of hearing-loss as well [23].

The present study also found out that discomfort, stress and annoyance perceptions increased significantly with the frequency of the stimulus. In all the three parameters the condition of 68 ± 0.5 dB (A) with stimulus at 3000 Hz (C4) had the higher values in each scale. According to Salvendy [24], human hearing is its most sensitive at the range of 4000 Hz, so being the C4 the condition that approximates the best to that range with 3000 Hz, the results can be compared. This also explains the non-significant differences in the perception of the stimulus scale. Another study by Ménard et al. [25] showed that the perception of sound differs insignificantly with changes in the frequency at the same sound pressure levels. However, it is important to note that in the condition C2 the parameter annoyance presented a high value compared to condition C3 and C1 although no studies were found that explained this phenomenon. According to Kumar et al. [26], discomfort is more associated with sound frequencies between 2400 and 5500 Hz. The results also suggest that exists a relationship between the annoyance, stress, discomfort and interference. Similar results were previously found by Monteiro et al. [10].

5 Conclusion

The objective of the study was achieved, giving insights about the effect of the different sound frequencies on subjects' performance and well-being. These results are important to design control measures, in particular changes in alert sound emitted by machinery in a fast food restaurant. Despite the results showed that no significant differences were found in subject's performance, this can mean that the frequencies tested does not have a significant impact in the performance of tasks that require attention and short-term memory. These findings show that alarms and intermittent sounds with frequencies like the ones used in this research do not have direct effects on subjects' performance. However, there is an important impact on subject's discomfort, stress, and annoyance, which increased with higher frequency stimulus, possibly interfering with workers concentration and increasing fatigue with the time of exposure.

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