



Sound localization and occupational noise

Pedro de Lemos Menezes,¹ Kelly Cristina Lira de Andrade,² Aline Tenório Lins Carnaúba,² Frantânia B. Cabral,¹ Mariana de Carvalho Leal,² Liliane Desgualdo Pereira³

¹Universidade Estadual de Ciências da Saúde de Alagoas (UNCISAL), Acoustic Instrumentation Laboratory, Maceió/AL, Brazil. ²Universidade Federal de Pernambuco (UFPE), Departamento de Fonoaudiologia, Recife/PE, Brazil. ³Escola Paulista de Medicina (UNIFESP), Departamento de Fonoaudiologia, São Paulo/SP, Brazil.

OBJECTIVE: The aim of this study was to determine the effects of occupational noise on sound localization in different spatial planes and frequencies among normal hearing firefighters.

METHOD: A total of 29 adults with pure-tone hearing thresholds below 25 dB took part in the study. The participants were divided into a group of 19 firefighters exposed to occupational noise and a control group of 10 adults who were not exposed to such noise. All subjects were assigned a sound localization task involving 117 stimuli from 13 sound sources that were spatially distributed in horizontal, vertical, midsagittal and transverse planes. The three stimuli, which were square waves with fundamental frequencies of 500, 2,000 and 4,000 Hz, were presented at a sound level of 70 dB and were randomly repeated three times from each sound source. The angle between the speaker's axis in the same plane was 45°, and the distance to the subject was 1 m.

RESULT: The results demonstrate that the sound localization ability of the firefighters was significantly lower ($p<0.01$) than that of the control group.

CONCLUSION: Exposure to occupational noise, even when not resulting in hearing loss, may lead to a diminished ability to locate a sound source.

KEYWORDS: Noise; Occupational; Sound Localization; Hearing.

Menezes PL, Andrade KC, Carnauba AT, Cabral FB, Leal MC, Pereira LD. Sound localization and occupational noise. Clinics. 2014;69(2):83-86.

Received for publication on May 13, 2013; First review completed on June 11, 2013; Accepted for publication on July 18, 2013

E-mail: pedrodelemosmenezes@gmail.com

Tel.: 55 82 3315-6813

■ INTRODUCTION

Sound localization is a human task that is performed reasonably accurately using binaural hearing. This function is compromised by hearing loss (1,2) or dysfunction of the central auditory nervous system pathways.

The capacity to identify the origin of a sound source is a fundamental feature of human development and is of great importance in the formation of environment perception. Additionally, it provides valuable information regarding ongoing events, mainly those that are occurring out of the visual field. In adults, this ability is especially important for communication and the performance of occupational and safety-related tasks (3).

Some authors (4-6) have discussed the influence of hearing training on spatial sound identification; thus, we were interested in comparing the spatial sound identification capacity of firefighters with that of a control

group to investigate the effects of daily occupational noise exposure on sound localization capacity. Importantly, in many cases, hearing is the only sense that firemen can use to carry out rescues.

Sound localization can be improved with auditory training. This phenomenon is known to occur in musicians, acoustic engineers, firefighters, and others (4-7). However, workers who are exposed to occupational noise, such as firefighters, must orient themselves using sound, including (8) fire station and fire truck sirens as well as urban noises that are inherent to the profession (9).

The aim of this study was to determine the effects of occupational noise exposure on sound localization among normal hearing professional firefighters in different spatial planes and frequencies.

■ METHODS

Subjects

Nineteen firefighters (fifteen men and four women) took part in this experiment. All had pure-tone thresholds that were less than or equal to 25 dB hearing level for frequencies between 250 and 8,000 Hz. Additionally, the hearing differences between the ears of these subjects was less than or equal to 10 dB at each frequencies. The acoustic reflexes of the participants were confirmed using type A

Copyright © 2014 CLINICS – This is an Open Access article distributed under the terms of the Creative Commons Attribution Non-Commercial License (<http://creativecommons.org/licenses/by-nc/3.0/>) which permits unrestricted non-commercial use, distribution, and reproduction in any medium, provided the original work is properly cited.

No potential conflict of interest was reported.

DOI: 10.6061/clinics/2014(02)02



tympanogram testing. All subjects had a minimum 72-hour auditory resting period. The subjects were between 23 and 41 years of age. None of the individuals had previous experience in psychoacoustic tasks, and they had worked as firefighters for at least three years. The control group included ten normal hearing individuals (five men and five women) that were 20 to 45 years of age. These participants had no sound exposure and exhibited the same audiological parameters mentioned earlier for the firefighters. The firefighters, therefore, represented a group who were previously exposed to noise. All tests were performed in the same ambient conditions for both groups.

The participants were not remunerated and consisted of local professionals that accepted an invitation to be included in the study. The study was conducted in an acoustic laboratory in our institution.

Experimental design

The equipment used to determine the spatial sound localization ability of the participants was conceived and developed in the Department of Biophysics and Radiobiology of the Federal University of Pernambuco (UFPE), based on a number of existing models. The instrument consisted of a 2 m × 0.5 cm horizontal structure of circular aluminum bars with a radius of 1 m. Speakers were fixed at 45° between each of the bars and two other perpendicular semicircles with the same width, and they were offset by 90°. These semicircles had one central speaker and four speakers on each side with 45° elevation, for a total of thirteen sound sources. The device, which was composed of a metallic structure, speakers, cables and consoles, was designated as the Spatial Sound Perception Analyzer (ASPE). The individuals tested were instructed to indicate the origin of each sound source using push buttons that represented each sound source, according to the sequence

presented by the researcher in a 3 × 3 m reverberating room (6).

The sound stimuli selected were square waves, and three tests were conducted with each of the individuals, using different square waves for each test. These tests included fundamental frequencies of 500, 2,000 and 4,000 Hz. All of the stimuli were presented for one-second durations at an intensity of 70 dBA. The test consisted of sound stimuli (three square waves) that were randomly repeated three times in each sound source (13 speakers), constituting 117 stimuli. Subjects were trained for 30 minutes before the test to allow for adaptation to the system.

The data were processed using the SPSS 11.01 software, and the means, standard deviations, 10th and 90th percentiles and hypothesis tests are presented in tabular and graphical forms.

The total number of the correct sound source localizations in the control group was compared with that of the test group using the Student's t-test, and the planes and frequencies were compared using an analysis of variance (ANOVA), followed by a Tukey's test. The values were considered significant when p was less than 0.05 ($p<0.05$).

The protocol for this study (no. 1182003) is based on CNS/MS (National Health Council/Ministry of Health) resolutions 196/96 and 251/97 for studies with humans and was approved by the Alagoas State University of Health Sciences Ethics Committee (Alagoas, Brazil).

RESULTS

The results were obtained from a cohort of fifteen men and four women ($n=19$). The test subjects' ages ranged from 23 to 41 years (mean = 31.4 with a standard deviation of 5.5 years, and the 10th and 90th percentiles were 23 and 40 years, respectively). The control group ages ranged between

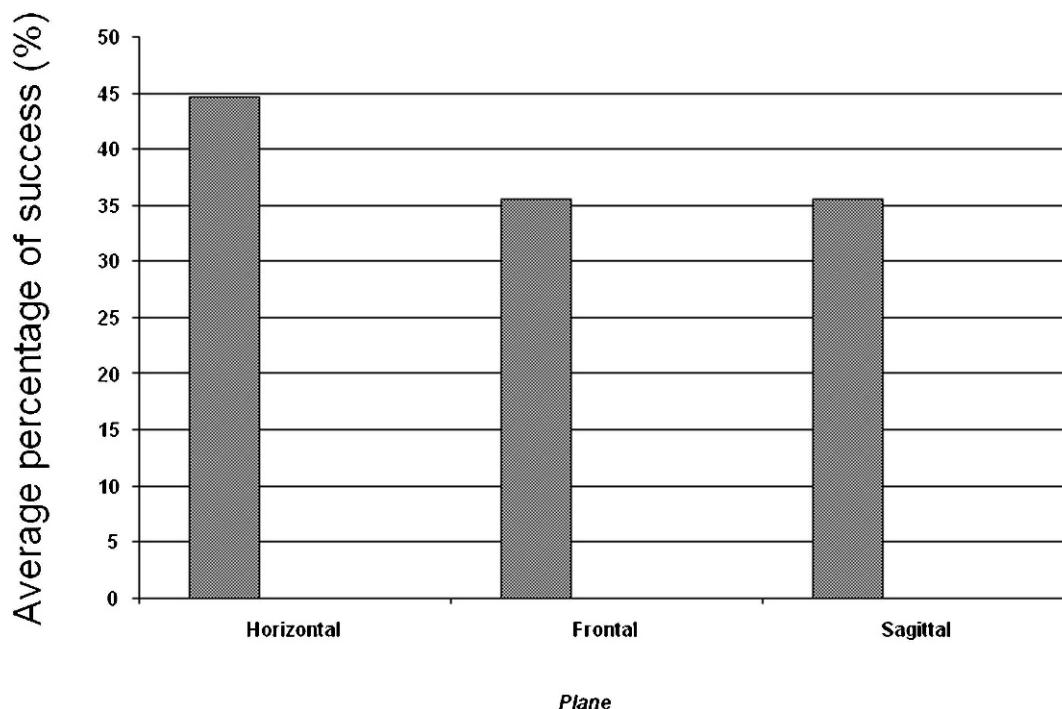


Figure 1 - A comparison of the average percentage of correct sound localization responses for each plane.

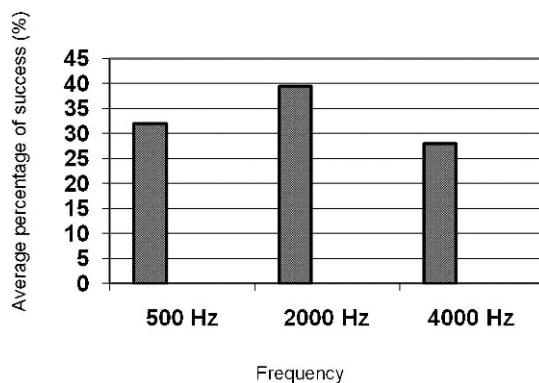


Figure 2 - A comparison of the average percentage of success (correct responses) among the frequencies.

20 and 45 years (mean = 29.6 with a standard deviation of 6.2 years).

Correct sound source localization by the normal hearing firefighters is depicted in Figure 1. A higher percentage of correct responses was observed in the horizontal plane, followed by the frontal and vertical planes, where the numbers of correct answers were equal.

Utilization of the ANOVA and Tukey's tests, however, demonstrated that the percentage of correct sound localization responses was statistically significant in the horizontal plane ($p = 0.01$). Conversely, those in the frontal plane were not statistically identical to the vertical plane ($p = 0.03$). The responses between the frontal and vertical planes were only equal with regards to the mean.

Figure 2 presents the firefighters responses in relation to the frequencies used. Very similar values were observed, and the mean percentages of correct answer for the 500, 2,000 and 4,000 Hz frequencies were 31.9%, 30.4% and 28.07%, respectively.

Differences between the frequencies, as determined by the ANOVA and Tukey tests, were not statistically significant (Table 1). A comparison between the results obtained from the firefighter group and the control group is illustrated in Figure 3. The numbers of correct responses, by spatial plane, between the control and test groups were significantly different (with p -values less than 0.01, after applying the Student's t-test).

Figure 4 compares the mean correct responses between the control and test groups according to the stimulus frequency. The control group obtained means that were 24%, 21% and 25% higher than those of the test group for the 500, 2,000 and 4,000 Hz frequencies, respectively.

A comparison of the responses between the groups revealed that the number of correct responses was greater in the control group at all frequencies (p -values were less than 0.01 using the Student's t-test).

Table 1 - Firefighters responses in relation to the frequencies used (500, 2,200 and 4,000) (Figure 2).

Frequencies	p -values
500–2,000 Hz	0.829
500–4,000 Hz	0.276
2,000–4,000 Hz	0.606

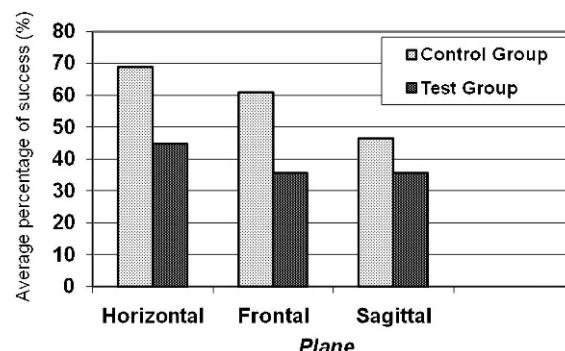


Figure 3 - A comparison of the average percentage of success between the groups according to plane.

DISCUSSION

The results of this research demonstrated that sound localization is more efficient in the horizontal plane, which is consistent with earlier studies (4-6). These findings are explained by the greater interaural differences in this plane than in the others.

Previous studies (5) reported that localization in the frontal plane could sometimes be considered similar to that of the vertical plane, but not necessarily identical, as was determined here.

With respect to the frequencies used in the present study, there was a similarity in the correct responses at 500, 2,000 and 4,000 Hz. This finding contrasts with a previous study (10), in which it was reported that a lower index of correct responses occurred at 2,000 Hz.

At a frequency of 2,000 Hz, sound reaches both ears at the same time and with the same intensity because this frequency has a wavelength that is similar to the size of human head (6). The similar responses among the three frequencies studied can be explained by two factors. First, narrow band tones are more difficult to localize (11). Second, firefighters are exposed to noises that diminish localization acuity such that no differences between the frequencies are detected (9).

When the sound localization tests between the control and test groups were compared between the groups with relation to the planes of the stimuli and the frequencies used, the control group performed better in both instances. This finding reinforces the results obtained from earlier studies (9), in which it was reported that previous exposure

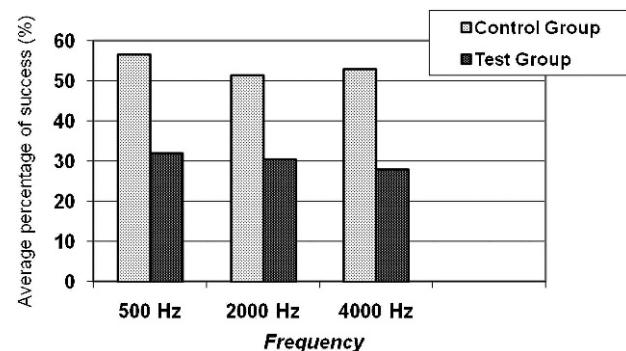


Figure 4 - A comparison of the average percentage of success between the groups according to frequency.



to noise could lead to reduced sound source identification. However, we found no report on the effects of prolonged noise exposure (at least three years) in professionals in which a minimum rest period of 72 hours was applied in normal hearing firefighters, as was done in the present study.

Even though firefighters undergo unconditional auditory training, which improves sound localization (12,13), this improvement was not observed, or was masked by noise exposure. The results suggest that firefighters should be enrolled in a hearing conservation program because, although it did not cause hearing loss in the subjects studied, noise exposure may compromise sound source localization, which is vital in this profession.

With regard to the spatial plane, the firemen in the present study had the highest number of correct responses in the horizontal plane, followed by the frontal and vertical planes. Additionally, the percentages of correct answers for the frequencies studied were very similar. The numbers of correct sound source localization responses were lower than those in a control population that was not exposed to noise. These findings are important because they demonstrate that it is necessary to consider the measures that should be taken to preserve the hearing of these professionals.

■ ACKNOWLEDGMENTS

This study was funded by the Research Support Foundation of Alagoas State (FAPEAL). We are grateful to Prof. Ruth Litovsky for sending articles and the invaluable help provided by the late Prof. Dr. Mauricy Alves da Motta.

■ AUTHOR CONTRIBUTIONS

Menezes PL, Carnauba AT, Leal MC and Andrade KC conceived the study. Menezes PL, Andrade KC and Cabral FB conducted the research.

Menezes PL, Andrade KC, Cabral FB and Pereira LD wrote the manuscript. Leal MC and Pereira LD provided additional advice when needed.

■ REFERENCES

1. Clark WW, Bohne BA. Effects of noise on hearing. *JAMA*. 1999;281(17):1658-9, <http://dx.doi.org/10.1001/jama.281.17.1658>.
2. Dizon RM, Litovsky RY. Localization dominance in the median-sagittal plane: effect of stimulus duration. *J Acoust Soc Am*. 2004;115(6):3142-55, <http://dx.doi.org/10.1121/1.1738687>.
3. Blauert J. *Spatial Hearing: The Psychophysics of Human Sound Localization*; MIT Press; 1997.
4. Brown CH, May BJ. *Sound localization and binaural process*. New York: John Wiley; 1999. p. 247-283.
5. Middlebrooks JC, Green DM. Sound localization by human listeners. *Annu Rev Psychol*. 1991;42:135-59, <http://dx.doi.org/10.1146/annurev.ps.42.020191.001031>.
6. Menezes PL, Soares IA, Caldas Neto S, Maciel R, Motta M. Sound Localization in Normal Hearing. *J Bras Fonoaudiol*. 2003;15(4):109-13.
7. Constantinides H, Rose MM, Moore DR. Training in binaural hearing: towards its therapeutic use in clinical practice. *International Congress Series*. 2003;1254(1):481-5, [http://dx.doi.org/10.1016/S0531-5131\(03\)01024-0](http://dx.doi.org/10.1016/S0531-5131(03)01024-0).
8. Melius J. Occupational health for firefighters. *Occup Med*. 2001;16(1):101-8.
9. Carlile S, Hyams S, Delaney S. Systematic distortions of auditory space perception following prolonged exposure to broadband noise. *J Acoust Soc Am*. 2001;110(1):416-24, <http://dx.doi.org/10.1121/1.1375843>.
10. Konishi M. Study of sound localization by owls and its relevance to humans. *Comp Biochem Physiol A Mol Integr Physiol*. 2000;126(4):459-69, [http://dx.doi.org/10.1016/S1095-6433\(00\)00232-4](http://dx.doi.org/10.1016/S1095-6433(00)00232-4).
11. Rakcerd B, Hartmann WM, McCaskey TL. Identification and localization of sound sources in the median sagittal plane. *J Acoust Soc Am*. 1999;106(5):2812-20, <http://dx.doi.org/10.1121/1.428129>.
12. Hofman PM, Van Riswick JG, Van Opstal AJ. Relearning sound localization with new ears. *Nat Neurosci*. 1998;1(5):417-21, <http://dx.doi.org/10.1038/1633>.
13. Abel SM, Shelly Paik JE. The benefit of practice for sound localization without sight. *Appl Acoust*. 2004;65(3):229-41, <http://dx.doi.org/10.1016/j.apacoust.2003.10.003>.