The influence of head protectors on warning sound localization ability in the horizontal plane

Martin Fortin and Raymond Hétu,
Groupe d'acoustique de l'université de Montréal,
C.P. 6128, Succ. Centre-ville, Montréal, H3C 3J7

Head protectors are extensivley used in the industrial work environment. To the best of our knowledge, their potential influence on sound localization ability has not as yet been investigated. Previous studies [1-2] have shown that hearing protectors impair sound localization in the horizontal plane to a significant degree and that this influence is likely due to disruption in spatial resolution resulting from their effect on the geometry of the pinna and/or concha [1-2]. Findings from these studies have shown increased within-quadrant and front-rear confusions for both broadband noise signals and third - octave band noises in quietnon-reverberant conditions. Data are currently being collected in our laboratory on insertion loss and directional transfer functions associated with head protectors. Preliminary analyses indicate that their effect on the geometry of the head or pinna might also disrupt the ability to localize warning signals. This may have serious implications in terms of occupational safety in industrial settings. The purpose of this study is to characterize localization errors in the horizontal plane, for a quiet non-reverberant situation, arising from wearing head protectors, with a view of adapting the acoustic characteristics of warning signals accordingly.

Methods

Participants

Twelve normal hearing listeners with mean age of 23,5 (±2) years were recruited among the students of the Université de Montréal. None had prior experience with sound localization experiments. Participants had to meet the following inclusion criteria:

-audiometric thresholds no higher than 20 dB HL (re:AINSI-S3.6 [3]) between 0.25 and 6 kHz;
-interaural difference in hearing thresholds smaller than 20 dB between 0.25 and 6 kHz;
-normal tympanogram;
-negative history of professionnal noise exposure;
-negative history of pathologies associated with hearing loss.

Procedure

The experimental paradigm was the identification of visible sources or categorization. Sixteen loudspeakers, 22.5° apart and 90 cm away from the center of the head of the listener, were operated in a hemi-anechoic chamber. The twelve subjects were tested under six listening conditions: unprotected, wearing a fire-fighter helmet, a Tyvek hood, a welder's mask, an aluminized hood and Bilsom Vicking 29 earmuffs. Two signal spectra were tested in each listening condition: a random noise with a flat spectrum between 125 and 8000 Hz (pink noise) and a six harmonics complex sound (warning sound) the fundamental of which was 500 Hz. The two signals were numerically desgined and equalized to take into account the frequency response of the loudspeakers. Two signal durations were tested in each listening condition, namely, 0.25 and 1.5 seconds.The latter allowed the contribution of free head/torso movements on the part of the subject but the former did not.

A complete run in a listening condition consisted of 2 stimuli for each loudspeaker, for a total of 32, presented in a quasi-random order. Signal level was set at 80 dBA with a ±2 dB randomized variation. The order of testing of the listening conditions, the signal spectra and duration were all randomized. Statistical analysis of the dara was performed using randomized block factorial design Anova.

Results and discussion

Table 1 presents the means and standard deviations of the localization errors in terms of total percentages; percentages are also given for within quadrant errors, front-rear and left-right confusions as a function of the three independent variables considered. A powerful effect of signal duration on global sound localization performances in the horizontal plane can be observed. Compared to long duration signals, short signals led to a significant increase in sound localization errors ($p<0.0001$ for all listening conditions). Spectral content had a significant effect for long duration signals ($p<0.0001$). Compared to the wideband noises, the warning sounds led to a significant increase in sound localisation errors for all test conditions.

Furthermore, a significant duration and spectral content interaction ($p<0.01$) was found. Generally speaking, earmuffs and the aluminized hood were the only protectors that led to a significant increase in sound localization errors when the long duration wideband noise was presented. On the whole, all protectors disrupted to some extent sound localization ability in the horizontal plane but performance differed from one protection condition to another with exception of the Tyvek hood compared to the welder's mask ($p=0.2625$). The aluminized hood was the most disruptive head protector in regard to global spatial resolution. Compared to all other head protectors, the aluminized hood led to a significant increase in errors for most of the signals except for the 0.25 s warning sound where performance was similar to the one associated with the earmuff condition ($p=0.5284$).

Within quadrant errors refer to sharp spatial resolution as compared to gross orientation. Since whereabout orientation remains relatively intact, these errors are not critical with respect to safety in the workplace. As in global sound localization performances, findings for within quadrant resolution indicate a signal duration effect, and a spectral content effect with long duration signals. However, there are no significant signal duration ($p=0.8694$) and spectral content ($p=0.5468$) effect with the aluminized hood, the most disruptive head protector with regard to this type of error. Interestingly, on the whole, within quadrant resolution was not blurred by wearing the fire-fighter helmet ($p=0.4662$).

Front-rear confusions refer to gross orientation and, consequently, are the most important type of error in danger signal localization in the workplace. Signal duration was again the most powerful factor with regard to front-rear resolution in the horizontal plane ($p<0.0001$ for all conditions). With long duration signals, there are virtually no front-back confusion whatever the protection condition, with the exception of the aluminized hood.

Table 1. Mean (+standard deviation) pourcentage localization errors as a function of signal parameters and listening condition.

Signals	Listening condition	Total pourcentage	Within quadrants	Front-rear confusions	Left-right confusions
Short (0.25 s) warning signal	Unprotected	25.8(17.0)	16.1(11.1)	10.7(8.6)	0.3(1.0)
	Fire-fighter helmet	48.2(9.0)	27.3(8.0)	23.5(7.7)	0.3(1.0)
	Tyvek hood	62.2(13.9)	26.3(8.2)	40.2(11.9)	0.9(1.6)
	Welder's mask	65.1(12.3)	35.9(10.5)	33.0(13.1)	0.3(1.0)
	Earmuffs	74.7(10.2)	33.3(8.6)	45.8(8.6)	1.5(3.2)
	Aluminized hood	80.7(10.3)	33.1(10.2)	44.9(11.4)	9.5(10.6)
Short (0.25 s) pink noise	Unprotected	18.0(10.4)	15.1(9.1)	3.0(4.0)	0.3(1.0)
	Fire-fighter helmet	44.8(15.8)	21.6(7.5)	25.9(12.0)	0.6(1.4)
	Tyvek hood	58.3(9.5)	28.1(10.7)	34.5(11.1)	0.0(0.0)
	Welder's mask	63.0(8.3)	37.5(7.9)	29.2(12.1)	0.0(0.0)
	Earmuffs	63.8(11.7)	26.3(10.4)	42.9(9.5)	0.0(0.0)
	Aluminized hood	75.0(7.9)	36.2(8.0)	43.8(9.9)	0.6(1.4)
Long (1.25 s) warning signal	Unprotected	0.5(1.2)	0.5(1.2)	0.0(0.0)	0.0(0.0)
	Fire-fighter helmet	8.1(11.4)	7.8(11.5)	0.3(1.0)	0.0(0.0)
	Tyvek hood	23.2(15.5)	20.1(13.4)	3.3(3.9)	0.3(1.1)
	Welder's mask	27.3(15.8)	24.5(14.9)	3.3(4.4)	0.0(0.0)
	Earmuffs	39.1(20.0)	35.4(20.5)	3.9(5.6)	0.3(1.0)
	Aluminized hood	65.9(20.2)	37.8(13.0)	20.2(16.1)	11.9(13.9)
Long (1.25 s) pink noise	Unprotected	1.3(2.1)	0.8(1.4)	0.3 (1.0)	0.6(1.4)
	Fire-fighter helmet	1.6(2.1)	1.0(2.0)	0.6 (1.4)	0.0(0.0)
	Tyvek hood	8.1(7.0)	3.9(5.0)	4.2 (5.2)	0.6(1.4)
	Welder's mask	6.5(3.9)	5.2(3.6)	1.5 (2.4)	0.0(0.0)
	Earmuffs	16.9(14.9)	14.6(12.4)	2.4 (3.5)	0.3(1.0)
	Aluminized hood	36.7(21.7)	31.3(17.8)	6.25(8.9)	0.0(0.0)

In order to achieve, with the aluminized hood, the same level of performance as with the other models of protector, subjects had to benefit from both the long duration and the wide spectrum of the signal. Therefore, spectral content had a significant effect only when combined with the long duration signal attended to with the aluminized hood ($p<0.0001$).

Contralateral confusions occur only with highly distorted interaural difference information. As can be seen from Table 1, the aluminized hood was the only model of protector associated with a significant degree of left-right confusions. Interestingly, spectral content was the only significant factor regarding the aluminized hood contralateral resolution ($p<0.0001$); signal duration had no effect ($p=0.9491$). Using a wide spectrum signal, almost no contralateral confusion could be osberved.

To sum up, all the protectors tested had some disruptive influence on sound localization ability in the horizontal plane, the worst being the aluminized hood. It is interesting to note that significant front-rear confusions were observed a plastic coated paper (Tyvek) hood equipped with a transparent plastic screen for vision. Such errors were generally prevented when the subjects had enough time to move their head while judging the whereabouts of sound signals. Such finding bears implications for auditory warning signal design for industrial settings.

Acknowledgement

The research presented above has been financially supported by the Institut de recherche en santé et en sécurité du travail de Québec. The protectors were kindly provided by Safety Supply inc.

References

[1] Noble,W. & al.(1990). The effect of various hearing protectors on sound localization in the horizontal and vertical planes. Am.Ind.Hyg. Assoc.J. 51(7):370-77.

[2] Abel, S.M. & Armstrong, N.M.(1993). Sound localization with hearing protectors. The Journal of Otolaryngology 22(5):357-63.

[3] ANSI-S3.6. (1969). Specifications for Audiometers, R1979, American National Standard Institute, New-York.