

The effect of integrated hearing protection surround levels on sound localization

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DRDC – Toronto Research Centre

Defence Research and Development Canada

Scientific Report

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IMPORTANT INFORMATIVE STATEMENTS

The protocol for the study reported herein was reviewed and approved by the Human Research Ethics Committee of Defence Research and Development Canada.

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Abstract

Advanced hearing protection technologies enhance speech understanding while protecting against injurious noise. This experiment assessed horizontal plane sound localization with three communication devices with integrated hearing protection that could amplify environmental sounds. Normal-hearing adults localized a brief noise burst with ears unoccluded and fitted with the Nacre QUIETPRO earplug, Peltor PowerCom Plus earmuff, and Sensear SDP earmuff-earplug combination. These were tested in the passive OFF mode and in the active ON mode at three volume settings. The stimulus was presented by an array of eight loudspeakers surrounding the listener. One block of 80 randomized loudspeaker identification trials was presented under each listening condition. Participants responded using a response box with eight buttons in the same configuration as the array. With ears unoccluded, mean scores were above 90% correct. With the devices in the OFF mode, mean scores were less than 50%, mainly due to confusion of front and back. With the devices ON, an improvement of 21% to 33% was realized. Azimuthal percent correct was highest for sound sources located on either side of the midline axis in front, decreasing front to back, reflecting the placement of the external microphones on the devices. Increasing the volume had no effect.

Significance to defence and security

Military operations are characterized by high level noise from a variety of sources, including vehicles engines, aircraft flyovers and weapons. While the use of conventional personal hearing protection proves effective, the escalating cost of claims for hearing loss internationally indicates that this solution may not be entirely practicable if situational awareness is compromised. Advanced technologies enhance speech while protecting hearing. This research demonstrated benefits for sound localization.

Résumé

Les technologies de pointe en matière de protection auditive améliorent la compréhension de la parole tout en protégeant contre les niveaux de bruit dommageables. Cette expérience a permis de déterminer la localisation d'une source sonore sur le plan horizontal au moyen de trois dispositifs de communication munis de systèmes de protection auditive intégrés capables d'amplifier les bruits ambiants. Les adultes dont l'audition était normale ont été en mesure de localiser une courte rafale de bruits sans occlusion des oreilles, puis avec des bouchons d'oreilles Nacre QUIETPRO, un casque antibruit Peltor PowerCom Plus ou une combinaison de bouchons et d'un casque antibruit Sensear SDP. Ces dispositifs ont été mis à l'essai en mode passif (OFF) et en mode actif (ON), à trois différents réglages de volume. Le stimulus était présenté par un réseau de huit haut-parleurs entourant l'auditeur. Un bloc de 80 essais d'identification du haut-parleur aléatoire a été présenté pour chaque condition d'écoute. Les participants répondaient au moyen d'une boîte de réponse à huit boutons disposés de la même façon que les haut-parleurs. Sans occlusion des oreilles, les notes moyennes étaient correctes dans plus de 90 % des cas. Lorsque les dispositifs étaient en mode passif (OFF), les notes moyennes étaient correctes dans moins de 50 % des cas, principalement en raison de la confusion entre l'avant et l'arrière. Lorsque les dispositifs étaient en mode actif (ON), on a obtenu une amélioration de 21 % à 33 %. Le pourcentage azimutal de réponses correctes était plus élevé pour les sources sonores localisées des deux côtés de l'axe de la ligne médiane à l'avant, et à la baisse de l'avant vers l'arrière, révélant l'emplacement des microphones externes sur les dispositifs. La hausse du volume n'a eu aucun effet.

Importance pour la défense et la sécurité

Les opérations militaires sont caractérisées par des niveaux de bruit élevés qui proviennent de diverses sources, notamment de moteurs de véhicules, d'aéronefs en survol et d'armes. Bien que l'utilisation des dispositifs conventionnels de protection auditive personnelle soit efficace, les coûts croissants associés aux demandes d'indemnisation pour la perte auditive à l'échelle internationale indiquent que cette solution n'est pas toujours possible lorsque la connaissance de la situation est compromise. Les technologies de pointe améliorent la communication tout en protégeant l'audition. La présente recherche démontre les avantages de la localisation sonore.

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1 Introduction

Military operations are characterized by high level noise from a variety of sources, including vehicles engines, aircraft flyovers and weapons. Continuous exposure to steady-state levels exceeding 85 dBA (decibels, A-weighted) or impulsive sounds in excess of 140 dB SPL (sound pressure level) may result in noise-induced hearing loss (Humes, L.E., Joellenbeck, J.M., Durch, J.S., eds., 2006). Reduction of levels at source is difficult, if not impossible, to achieve (Sheen and Hsiao, 2007). An alternative solution, the wearing of personal Hearing Protection Devices (HPDs), is easily implemented and cost-effective. However, the escalating cost of claims for hearing loss borne by Veterans Affairs Canada, which is currently in excess of \$180 million annually, indicates that this alternative may not be entirely practicable (Thompson and Boswall, 2011). Focus group discussions involving military members engaged in combat trades, as well as laboratory studies, point to a number of difficulties associated with the wearing of HPDs (Abel, 2008). These include inadequate sizing (Abel, S.M., Rockley, T., Goldfarb, D., Hawke, M., 1990), incompatibility with other gear (Abel, S.M., Sass-Kortsak, A., Kielar, A., 2002; Abel, S.M., DuCharme, M.B., van der Werf, D., 2010), discomfort (Berger, 2000), insufficient attenuation of low frequency sounds (Giguère C, Abel SM, Arrabito R., 2000), and perhaps most importantly, interference with the performance of auditory tasks that are essential to the success of the mission. These include the detection and localization of auditory warnings and speech communication (Abel, 2008).

A number of advanced hearing protection technologies have appeared on the market in recent years to manage the issues described above. For example, passive level-dependent earmuffs and earplugs are sensitive to the level of background sounds. These provide relatively less attenuation than conventional devices at safe sound levels, enabling the understanding of spoken commands (Abel and Powlesland, 2010). The attenuation increases instantaneously in the presence of impulsive sounds from weapons' fire. Devices incorporating Active Noise Reduction (ANR) are equipped with microphones that sample the background noise and add it out of phase to the original, increasing the attenuation below 1 kHz (Abel and Spencer, 1997). Integrated Hearing Protection Devices (IHPDs) are designed to support radio communications while simultaneously protecting the wearer from high-level background noise. Some IHPD models allow the user to amplify environmental (surround) sounds to facilitate face-to-face conversation and the detection of auditory warnings. Studies have demonstrated that such devices do enhance both radio and face-to-face speech understanding, while affording sufficient protection against injurious noise exposure (Abel, S.M., Nakashima, A., Saunders, D., 2011). The results to date with respect to improvements in sound localization have been mixed (e.g., Noble, W., Murray, N., Waugh, R., 1990; Bolia, R.S., D'Angelo, W.R., Mishler, P.J., Morris, L.J., 2001; Carmichael, E.L., Harris, F.P., Story, B.H., 2007; Abel, S.M., Tsang, S., Boyne, S., 2007; and Robinette and Casali, 2014).

2 Purpose

The present experiment investigated the possible benefits and drawbacks for horizontal plane sound localization of wearing three commercial off-the-shelf IHPDs, compared with unoccluded listening. The devices selected for study allowed for a limited comparison of earplug, earmuff and muff-plug combination types: the Nacre AS QUIETPRO® In-Ear Communication Headset (Nacre; Trondheim, Norway), the 3MTM Peltor™ PowerCom Plus™ Headset (Peltor; St Paul, MN), and the Sensear SDP Double Hearing Protection Headset (Sensear; San Francisco, CA). These are shown in Figure 1. All three devices are designed to enhance face-to-face conversation and radio communications, while ensuring that continuous high-level noise and impulsive sounds are maintained at safe levels. They also have the additional capability for limited user control of the volume of surround sounds. In a previous study we demonstrated that when the talk-through circuitry of two IHPDs currently used during military operations, the Nacre AS QUIETPRO® and Racal Acoustics RA108 Slimgard II High-Noise Headset, was operational, the localization of broadband noise bursts was enhanced compared with conventional passive sound attenuating devices but poorer than unoccluded listening (Abel et al., 2007). The aim was to determine the effect on sound localization of the volume of the surround over the safe range for hearing.

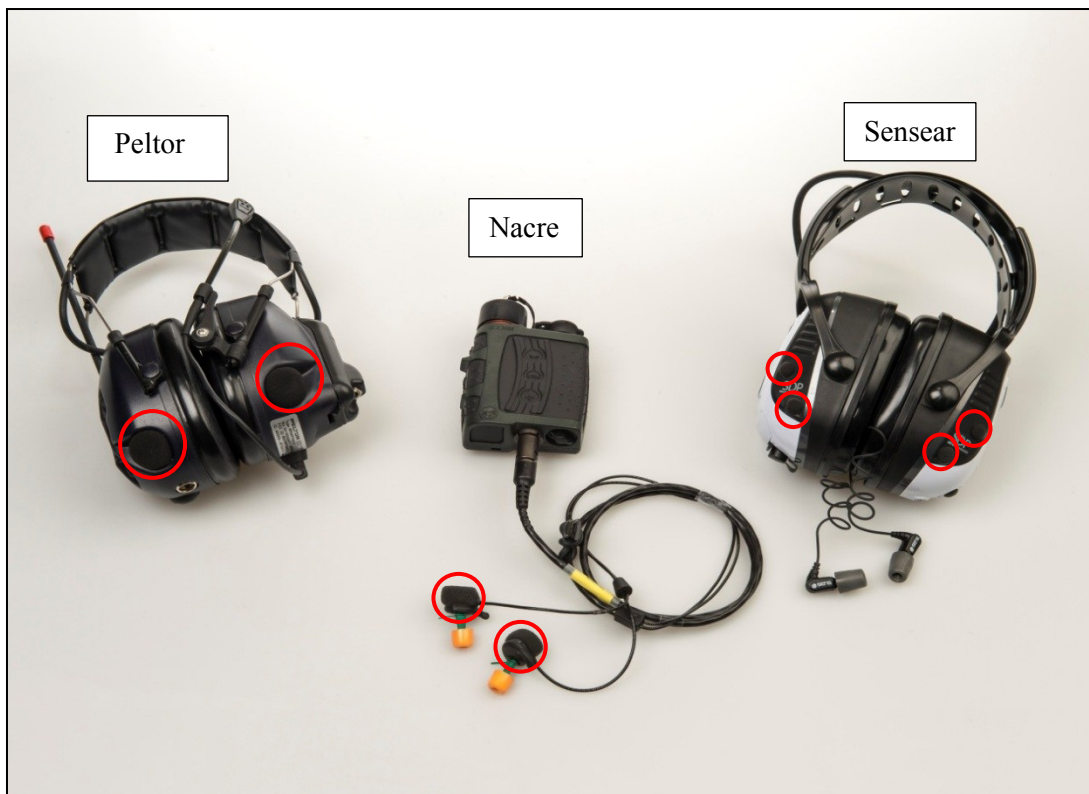


Figure 1: The Peltor PowerCom Plus (Peltor), Nacre QUIETPRO (Nacre) and Sensear SDP (Sensear) integrated hearing protection devices that were used in the study. The external microphones are circled.

3 Methods and materials

3.1 Research design

The ability of participants to localize a 65 dBA, 300-millisecond, white noise (equal energy per Hz) burst was assessed with both ears unoccluded and subsequently fitted with the Nacre earplugs, Peltor earmuffs, and Sensear earmuff-earplug combination. All three devices are battery-powered and have both passive conventional attenuation (OFF mode) and continuous talk-through (ON mode) capability. According to the manufacturers' specifications, in the OFF mode the Nacre attenuates ambient sounds from 0.125-8 kHz by 24-42 dB, the Peltor by 19-39 dB, and the Sensear by 21-39 dB. These values were not confirmed in the present study. In the ON mode, the Nacre allows the user to select from among eleven possible surround volume settings. The Peltor incorporates five possible settings and the Sensear incorporates seven possible settings. White noise was chosen as the stimulus because it provides the listener with both binaural cues (interaural time of arrival and level differences) that are essential for accurate right-left discrimination and spectral cues for front-back discrimination (Blauert, 1997).

Accuracy in horizontal plane sound localization was measured for thirteen conditions: ears unoccluded; fitted with the Nacre in the OFF mode and in the ON mode at surround volume Settings 2, 4 and 6; fitted with the Peltor in the OFF mode and in the ON mode at surround volume Settings 1, 3 and 5; and fitted with the Sensear in the OFF mode and in the ON mode at surround volume settings 2, 4 and 6. Based on measurements published by Giguère, C., Laroche, C., Vaillancourt, V. (2011), Settings 2 and 1 for the Nacre and Peltor devices, respectively, would change the at-ear level of stimulus by only a negligible amount, thus 65 dBA. Settings 4 for the Nacre and 3 for the Peltor would increase the level of the stimulus to 73 dBA. Levels 6 and 5 for the two devices, respectively, would increase the level to 80 dBA. Comparable data were not available from the manufacturer for the Sensear device. In listening tests, the experimenters determined that Levels 2, 4 and 6 appeared to generate similar outputs as Levels 1, 3 and 5 for the Peltor. To simplify comparison across devices, hereafter the OFF mode has been labelled 0, and the three selected surround volume settings in the ON mode have been labelled 1, 2 and 3. Although these devices might rarely be used in the passive OFF mode, this condition served as a baseline against which to assess the benefit of the ON surround volume settings for sound localization.

3.2 Participants

Sixteen normal-hearing participants (eight males and eight females), aged 18-60 years, were recruited with the aid of an information sheet sent by email to employees of Defence Research and Development Canada – Toronto Research Centre (DRDC – Toronto Research Centre), the Canadian Forces Environmental Medicine Establishment (CFEME) and the Land Force Central Area Headquarters and Area Support Unit (LFCA ASU) Toronto. Since the participants would be tested in a sound proof room for an extended period of time with auditory materials, volunteers were screened by telephone for a history of claustrophobia, the use of medications that might affect the ability to complete the study and ear disease, including excess wax build up, known or perceived hearing loss, and tinnitus.

Individuals who met the telephone screening criteria were examined by a qualified health care professional for any ear conditions that would preclude the fitting of an earplug (e.g., excessive wax buildup, ear infections or a tendency to have a collapsing ear canal). Those who passed this examination underwent a hearing test conducted by a trained technician to ensure that they had normal hearing, i.e., pure-tone air conduction thresholds no greater than 20 dB HL (decibels, hearing level) from 500 to 4000 Hz (Yantis, 1985), and interaural differences in threshold no greater than 15 dB in this frequency range. The latter constraint was designed to reduce a possible right-left bias in sound localization.

3.3 Apparatus

Participants were tested individually while seated in the centre of a circular array of eight loudspeakers situated within a double-walled sound proof booth (Series 1200; IAC Acoustics, Winchester, UK) with inner dimensions of 3.5 (L) X 2.7 (W) X 2.3 (H) meters. This facility meets the requirements for hearing protector testing specified in American National Standard S12.6-2008 (ANSI, 2008). The reverberation times were 0.6, 0.4 and 0.3 seconds for 1/3 octave bands centred at 125-250 Hz, 500-4000 Hz, and 6300-8000 Hz, respectively. Ambient noise levels were 26, 18 and 9 dB SPL for 1/3 octave bands centred at 125, 250 and 500 Hz, respectively, and close to zero for 1/3 octave bands centred at 1000, 2000, 3150, 4000, 6300 and 8000 Hz (Giguère and Abel, 1990). The white noise stimulus was presented by means of an array of eight loudspeakers, shown in Figure 2. Two loudspeakers were positioned 30 degrees apart in each of the four spatial quadrants at the following azimuth angles: 30, 60, 120, 150, 210 (-150), 240 (-120), 300 (-60) and 330 (-30) deg, at a distance of 1 m from the subject's centre head position and at the approximate height of the ears. Participants responded using a specially designed laptop response box with eight response buttons arranged in the same configuration as the loudspeaker array.

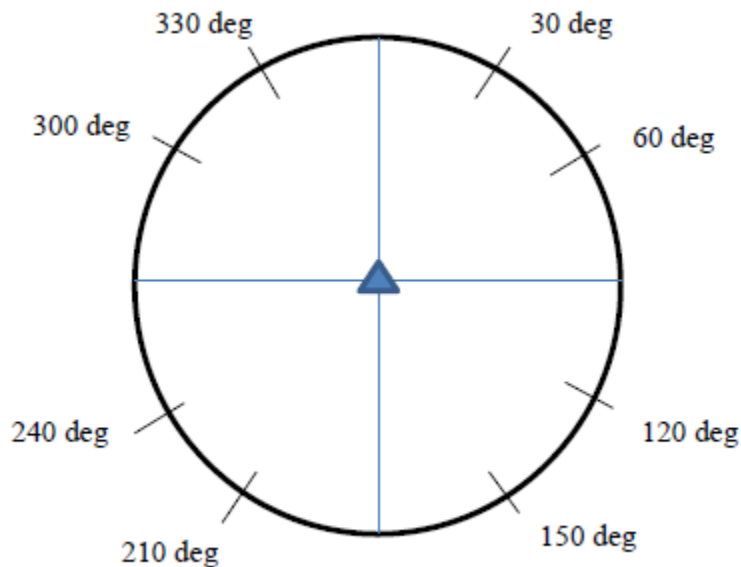


Figure 2: A schematic of the loudspeaker array.

3.4 Procedure

The protocol was reviewed and approved by the Human Research Ethics Committee (HREC) of Defence Research and Development Canada (DRDC). Those who volunteered for the study read and signed a consent form prior to participation. Individuals who met the screening criteria completed the experiment in three 2-hour sessions scheduled on different days over the course of two weeks. During the first session, which included the ear examination and hearing test, the three devices were fitted by one of the experimenters. The eartip for the Sensear was available in only one size. Individuals for whom this size was unsuitable were disqualified. The eartips associated with the Nacre were available in five sizes. The device's in-ear fit-check program was used to determine whether the selected eartips were the correct size and well-seated in the ear canals. The headbands of the Peltor and Sensear devices were adjusted to ensure a secure fit of the muffs to the outer ears. The sound localization study was carried out during the second and third sessions.

One block of forced-choice loudspeaker identification trials was presented for each of the thirteen conditions. The unoccluded condition was presented first followed by the three devices, their order and the order of the OFF and three ON surround volume settings within each, was counterbalanced across the sixteen participants. Each trial block consisted of 10 presentations of the stimulus (trials) from each of the eight loudspeakers, in randomized sets of eight, for a total of 80 trials. Levels were checked prior to the testing of each participant to prevent the possibility of accidental exposure to injurious levels above 87 dBA (Department of Justice (DOJ), 2009).

A trial began with a ½-second warning light on the laptop response box, followed by a ½-second delay, and then the presentation of the 300-millisecond stimulus. The warning light served as the participant's cue to sit squarely with the head steady and focus on a straight-ahead visual target affixed to the wall of the booth. This ensured that the speaker array and coordinate system of the head were aligned (Abel et al., 2007). Following each stimulus presentation, participants were required to depress the button on the response box that, in their opinion, corresponded to the loudspeaker that had emitted the stimulus. The rate of presentation of trials was approximately one every seven seconds. Guessing if uncertain was encouraged and no feedback was given about the correctness of the judgments. At the start of the experiment a set of two practice trials/loudspeaker with feedback (i.e., 16 trials) was given to provide the participant with a spatial sense of the loudspeaker array relative to the response buttons, and to ensure that the instructions had been understood. For these practice trials, the ears were unoccluded.

4 Results

4.1 Overall percentage correct sound localization judgments

The mean percentages correct sound localization judgements (without regard to azimuth) for the unoccluded (UN) and protected (Nacre, Peltor and Sensear) conditions are displayed in Table 1, separately for male and female participants. For the protected conditions, results are given for the devices in the OFF mode (0) and ON mode at the three volume settings (1, 2 and 3).

Table 1: The total percentage correct sound localization judgments.

Ear Condition	Group	Volume Setting			
		0	1	2	3
UN	Males	94.5 (4.5)*	----	----	----
	Females	92.5 (5.4)	----	----	----
Nacre	Males	50.8 (21.9)	74.7 (18.3)	68.4 (19.4)	70.5 (19.4)
	Females	46.1 (12.7)	66.6 (10.5)	70.3 (16.7)	65.6 (14.7)
Peltor	Males	34.5 (7.0)	66.1 (16.2)	70.0 (11.8)	59.5 (14.4)
	Females	31.6 (4.9)	69.1 (17.6)	64.5 (17.4)	65.6 (13.6)
Sensear	Males	25.0 (9.2)	46.6 (16.8)	51.3 (15.1)	50.8 (20.2)
	Females	21.9 (5.3)	41.6 (8.3)	43.9 (10.3)	51.6 (11.6)

*N=8; Mean (SD)

A repeated measures Analysis Of Variance (ANOVA; Daniel, 1983) applied to the results for the unoccluded condition and the three devices in the OFF mode indicated that device was a statistically significant factor ($F_{3,42}=139.1$; $p<0.0001$) but gender was not. Post hoc pairwise comparisons using Fisher's Least Significant Difference (LSD) test ($\alpha=0.05$) showed that, averaged across the gender subgroups, the percentage correct for the unoccluded condition was significantly greater than that for each of the Nacre, Peltor and Sensear devices (94% vs 48%, 33% and 23%, respectively). The percentage correct for the Nacre device was significantly greater than that for both the Peltor and Sensear devices which were no different.

A second ANOVA was applied to the percentages correct observed for the three devices in the OFF mode and in the ON mode at the three volume settings, without regard to gender. There were statistically significant effects of device ($F_{2,28}=25.3$; $p<0.0001$), volume ($F_{3,42}=48.2$; $p<0.0001$) and volume by device ($F_{6,84}=2.4$; $p<0.03$). The volume by device interaction is displayed in Figure 3. Post hoc pairwise comparisons indicated that when the three devices were turned ON there was a significant increase in the percentage correct responses with respect to the OFF

condition. The change ranged from 21% to 33%, averaged across volumes. However, the effect of increasing the volume over the range studied was not statistically significant.

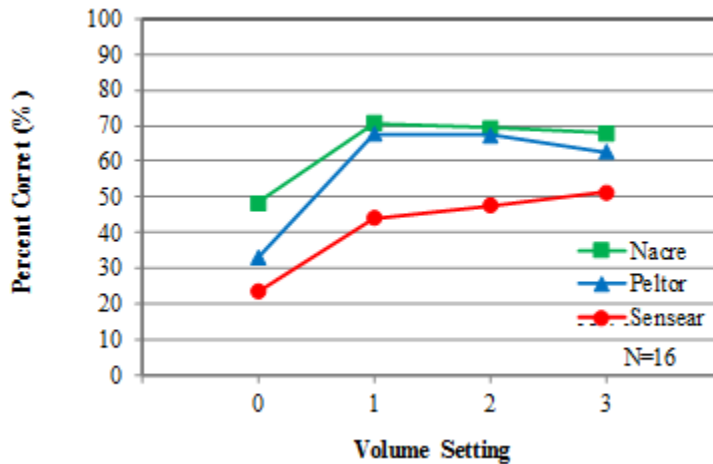


Figure 3: The percentage correct sound localization judgments for the three devices in the OFF and ON modes.

4.2 Right-left discrimination

Participants had relatively little difficulty distinguishing between loudspeakers located on the right side (30, 60, 120, and 150 deg) and on the left side (210, 240, 300 and 330 deg), regardless of the ear condition. Judgements were scored as right vs left hemisphere correct or incorrect without regard to azimuth. The mean percentage correct, averaged across male and female participants and hemisphere was 100% for unoccluded listening, compared with 99% for the Nacre, 97% for the Peltor, and 84% for the Sensear devices, in the OFF mode. A repeated measures ANOVA on the data obtained for these conditions confirmed that device was a statistically significant factor ($F_{3,45}=17.6$; $p<0.0001$) but hemisphere was not. Post hoc pairwise comparisons indicated that the outcome for the Sensear device in the OFF mode was significantly less than scores obtained for the unoccluded condition and the Nacre and Peltor devices, all three of which were no different. A repeated measures ANOVA was also applied to the percentages correct for the right and left hemispheres for the three devices in OFF and ON modes. There were significant effects of device ($F_{2,30}=12.5$; $p<0.0001$), volume ($F_{3,45}=21.3$; $p<0.0001$), and volume by device ($F_{6,90}=9.7$; $p<0.0001$). Hemisphere was again not significant. The volume by device interaction is displayed in Figure 4. Post hoc pairwise comparisons showed that for the Nacre device the percentages correct were not significantly different at 99% to 100%, regardless of whether the device was OFF or ON. For the Peltor and Sensear devices, scores increased significantly from 97% to 100% and 84% to 98%, respectively, when turned ON. For none of the three devices was there a significant effect of volume in the ON mode.

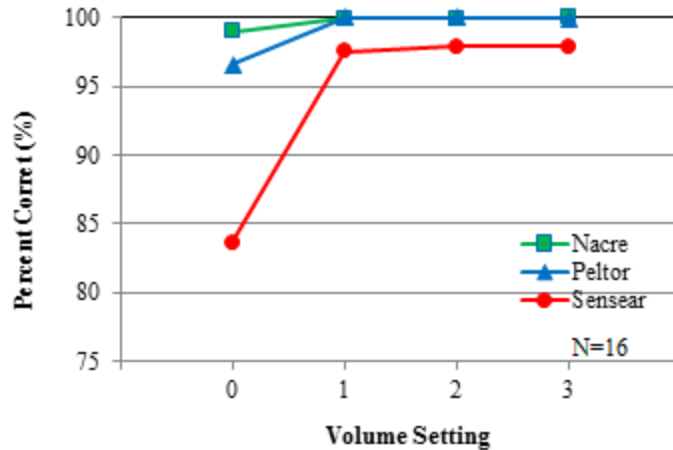


Figure 4: Right-left hemisphere discrimination for the three devices in the OFF and ON modes.

4.3 Front-back discrimination

An analysis was carried out to evaluate participants' ability to distinguish between loudspeakers positioned in the Front Hemisphere, FHEM (300, 330, 30 and 60 deg) and in the Back Hemisphere, BHEM (120, 150, 210, and 240 deg). Judgments were scored as correct or incorrect hemisphere, without regard to azimuth. The mean percentage correct, averaged across FHEM and BHEM and male and female participants was 99% for the unoccluded condition, followed, in the OFF mode, by 71%, 52% and 50% for the Nacre, Peltor and Sensear devices, respectively. A repeated measures ANOVA applied to the percentages correct observed for FHEM and BHEM (averaged across male and female participants) for the unoccluded condition and the three devices in the OFF mode indicated statistically significant effects of device ($F_{3,45}=83.3$; $p<0.0001$) and hemisphere by device ($F_{3,45}=2.8$; $p<0.05$). The significant hemisphere by device interaction is displayed in Figure 5. Post hoc pairwise comparisons showed that the percentages correct for each of FHEM and BHEM were significantly greater in the unoccluded condition (99%) than with any of the three devices. For the latter, the percentage correct for FHEM was significantly greatest for the Nacre (78%) which significantly exceeded the percentages correct for the Peltor (50%) and Sensear (40%) devices which were no different. For BHEM, the percentages correct were not significantly different for the three devices, ranging from 54% to 63%. Only for the Sensear device was there a significant difference (19%) in the percentages correct for FHEM and BHEM, favouring BHEM.

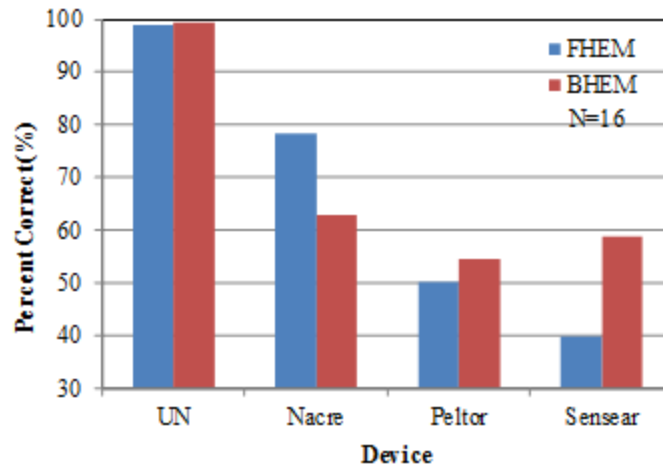


Figure 5: *Front-back discrimination with the ears unoccluded and fitted with the three devices in the OFF mode.*

A repeated measures ANOVA was also applied to the percentages correct for FHEM and BHEM observed for the three devices in the OFF and ON modes. There were statistically significant effects of device ($F_{2,30}=22.3$; $p<0.0001$), volume ($F_{3,45}=21.1$; $p<0.0001$), volume by device ($F_{6,90}=4.2$; $p<0.001$), volume by hemisphere ($F_{3,45}=7.8$; $p<0.0001$), and volume by hemisphere by device ($F_{6,90}=3.4$; $p<0.005$). The significant three-way volume by hemisphere by device interaction is shown in Figure 6. Post hoc pairwise comparisons indicated that only for the Peltor FHEM and BHEM and Sensear FHEM did the percentage correct increase significantly when the devices were turned on to the lowest of the three volumes. There was no additional benefit from increasing the volume further. In the case of the Peltor, the gain was 39% for FHEM and 13% for BHEM, averaged across the three volumes. In the case of the Sensear, the gain was 37% for FHEM. When the devices were turned ON, the percentage correct for FHEM significantly exceeded the percentage correct for BHEM by 15%, 22% and 26% for the Nacre, Peltor and Sensear devices, respectively, averaged across the three volume settings.

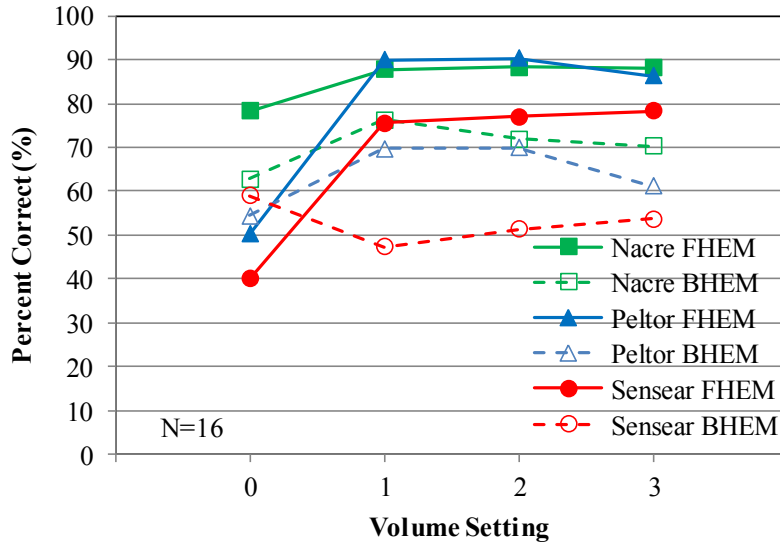


Figure 6: Front-back discrimination with the three devices in the OFF and ON modes.

4.4 Azimuthal discrimination

A comparison of the mean percentages correct observed for each of the eight azimuths in the unoccluded condition and with each of the three devices in the OFF mode, averaged across male and female participants, is displayed in Figure 7. In the case of unoccluded listening, with the exception of the most rearward azimuths (150 deg and 210 deg) where scores were 88% and 79%, respectively, scores ranged from 93% to 100%. Mean percentages correct were significantly lower when each of the three devices was worn in the OFF mode, ranging from 22-76% for the Nacre, 14-49% for the Peltor and 9-34% for the Sensear. In general, for all three devices, relatively highest scores were observed for azimuths directly in front of (60 deg and 300 deg) and behind (120 deg and 240 deg) the ear, on the right and left sides of space. A repeated measures ANOVA applied to these data indicated that there were statistically significant effects of device ($F_{3,45}=148.6$; $p<0.0001$), azimuth ($F_{7,105}=6.9$; $p<0.0001$), and azimuth by device $F_{21,315}=2.7$; $p<0.0001$). Post hoc pairwise comparison of the percentages correct for the four ear conditions indicated that the result for unoccluded listening was significantly greater than that for the Nacre device, and the result for the Nacre was significantly greater than that for the Peltor and Sensear devices.

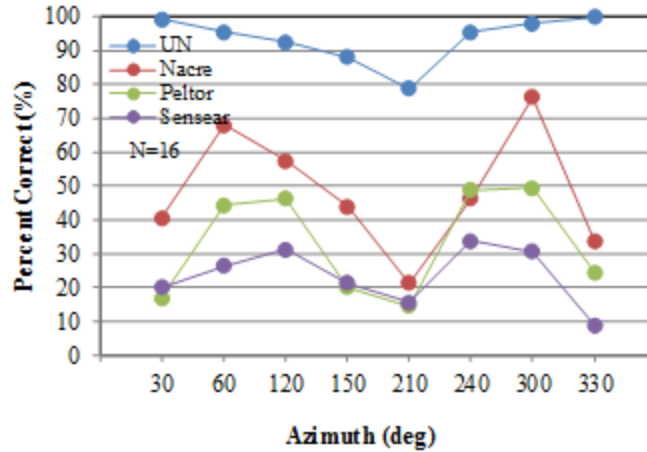


Figure 7: Azimuthal percentage correct with the ears unoccluded and fitted with the three devices in the OFF mode.

Figure 8 displays the effect of volume on the azimuthal percentage correct for the three devices, in three separate panels, respectively. These data show that turning the device ON had a beneficial effect that was greatest for the azimuths on either side of the midline, in front (30 deg and 330 deg), and decreased progressively from front to back. A repeated measures ANOVA applied to these data indicated statistically significant effects for device ($F_{2,30}=26.7$; $p<0.0001$), volume ($F_{3,45}=50.5$; $p<0.0001$), azimuth ($F_{7,105}=20.6$; $p<0.0001$), volume by device ($F_{6,90}=2.4$; $p<0.03$), volume by azimuth ($F_{21,315}=11.2$; $p<0.0001$), and device by volume by azimuth ($F_{42,630}=1.5$; $p<0.02$). Post hoc pairwise comparisons of the percentages correct achieved with each of the three devices indicated that, in the case of the Nacre and Peltor devices, the effect of turning the device ON was statistically significant for all but the most rearward azimuth on the right (150 deg). For the Sensear device, there were significant gains only for the two azimuths in front of the ear, on the right (30 deg and 60 deg) and left (300 deg and 330 deg). For none of the devices was there a difference due to an increase in volume. Averaged across volume settings, the maximum change in the percentage correct observed was 42% for the Nacre, 81% for the Peltor and 57% for the Sensear.

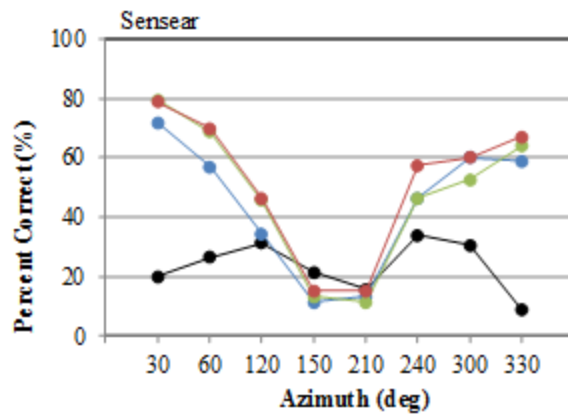
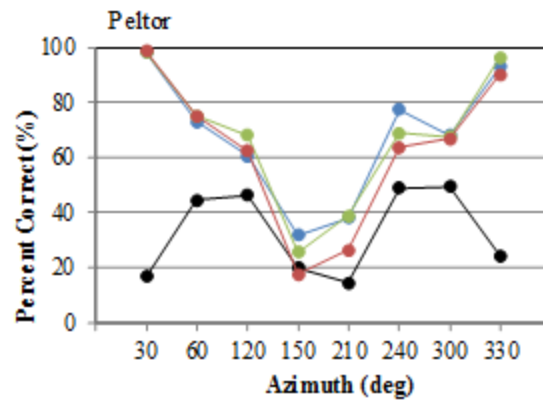
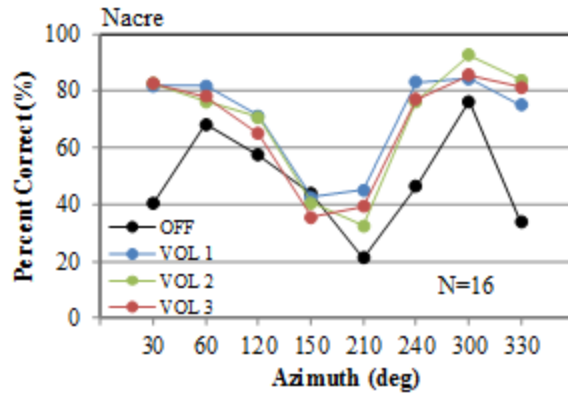


Figure 8: Azimuthal percentage correct for the three devices in the OFF and ON modes, for the three devices.

5 Discussion

This study was undertaken to investigate the effect on sound localization of increasing the surround volume from 65 dBA to 80 dBA on three communication devices that incorporate hearing protection. In a previous study, and in line with the findings of other researchers, we demonstrated that, with the ears unoccluded, normal-hearing listeners had no difficulty localizing broadband noise emanating from loudspeakers surrounding them in the horizontal plane (Abel et al., 2007). Scores for right-left discrimination based mainly on binaural cues (interaural differences in time-of-arrival and level), and front-back discrimination based on spectral cues (that derive from direction-dependent filtering effect of the outer ear) were both greater than 90%. With conventional hearing protection earmuffs and earplugs fitted, right-left discrimination remained intact but scores for front-back discrimination decreased to close to 50% (chance performance). These results suggest that such devices interfere mainly with spectral cues (Blauert, 1997). Fitting with two different (muff and plug style) IHPDs operating in talk-through mode significantly improved front/back discrimination to 75%, and overall performance to 70%. These results were superior to Carmichel et al.'s (2007) findings of 54% to 67% for three binaural level-dependent devices for localization of two real-world broadband stimuli, firearm loading and telephone ringing.

The results of the present study replicated previous findings for unoccluded listening. The localization of broadband sounds delivered by eight loudspeakers surrounding the listener in the horizontal plane was close to 95% correct. When the three devices selected for study were worn in the OFF mode, mean scores decreased significantly, ranging between 48% for the Nacre to 33% for the Peltor and 23% for the Sensear. These decrements were primarily due to confusion of front and rearward sound sources. Right-left discrimination was close to 95% for the Nacre and Peltor devices and 84% for the Sensear. By comparison, front-back discrimination scores ranged from 50% and 52% for the Sensear and Peltor devices, respectively, to 71% for the Nacre device. As for the studies described above, these data suggest that the binaural cues remained intact but spectral cues were compromised. The poorest performance observed for the Sensear device might have been due to the fact that it consisted of both a plug and a muff. The wearing of double hearing protection has been found to compromise right-left as well as front-back localization of horizontal plane sound sources (Brungart, D.S., Kordik, A.J., Simpson, B.D., McKinley, R.L., 2003).

Listeners showed an improvement in overall sound localization scores of 21% to 33% when wearing the three devices in the ON mode. While right-left discrimination showed little change for the Nacre and Peltor devices (which yielded scores close to 100% correct), performance with the Sensear device increased from 84% to 98%. Significant gains were also realized for front-back discrimination for the Peltor and Sensear devices. With the Peltor in the ON mode, performance improved by 39% for sources in front and by 13% for sources in back. For the Sensear, scores improved by 37% for sources in front. However, for none of the devices was there evidence of further improvements due to increasing the level of the broadband noise stimulus from 65 dBA to 80 dBA. These findings corroborate results reported by Macpherson and Middlebrooks (2000) for the localization of clicks and 3-msec and 100-msec noise bursts. For the 100-msec noise burst stimulus which was most comparable to that of the present study, there was no change in outcome with an increase in the level from 35 to 55 dB above participants' detection thresholds.

Investigation of azimuthal performance showed that the three devices behaved similarly in the ON mode. When the devices were in the OFF mode, the relatively best performance was observed for the loudspeakers directly in front of and behind the ear at 60 deg and 120 deg on the right and at 300 deg and 240 deg on the left sides of space. When the devices were turned ON, the azimuthal percent correct was highest for the loudspeakers on either side of the midline axis at 30 deg and 330 deg, generally with progressive decreases toward the back. For the Nacre the percentage correct was similar at 80% for 30, 60 and 120 deg on the right and 330, 300 and 240 deg on the left, with a steep dropoff to 40% for the two rearward loudspeakers. This pattern may have been due to the placement of the microphones in the ear (see Figure 1). For the Peltor, azimuthal percent correct decreased sharply from 100% to 20%, front to back. The microphones for this device were on the front of the earmuffs, facing forward. For the Sensear, azimuthal percent correct showed a more gradual falloff front to back of 80% to 20% on the right and 60% to 20% in back. For this device there were two microphones on each ear cup, two situated directly in front, pointing forward, and two placed more laterally, right and left.

While performance with the three devices was significantly different, it cannot be concluded that one particular model would be the better choice for military operations. Selection depends on a wide range of factors. These include compatibility with other headgear worn, including helmets, face shields, and eye glasses (Abel et al., 2002; Abel et al., 2010); the availability of sizing to achieve maximum comfort (Abel et al., 1990); the hearing status of the listener (Abel and Hay, 1996); and the auditory tasks that will need to be carried out. Tasks may include the detection and identification of auditory warnings and speech perception in high-level battlefield noise (Abel et al., 2011), in addition to sound localization. Importantly, devices of the same general type may perform differently (Abel et al., 2007).

6 Conclusions

With their ears unoccluded, normal-hearing listeners had no difficulty localizing a short-duration broad band noise emanating from loudspeakers surrounding them in the horizontal plane. They achieved mean scores that were above 90% correct. The gender of listeners was not a significant factor.

When listeners wore any of three selected IHPDs in the OFF mode, mean localization scores were less than 50%. The decrease was almost entirely due to difficulty discriminating between front and rearward sound sources. This suggests that the devices interfered with spectral cues provided by the outer ears.

When the devices were worn in the ON mode, overall localization scores improved by 21% to 33%, relative to the OFF mode. Significant gains of 39% and 13% for the front and rearward hemisphere, respectively, were observed for the Peltor device. Significant gains of 14% in right-left discrimination and 37% for the frontal hemisphere were observed for the Sensear device.

When the devices were worn in the ON mode, azimuthal percent correct was highest for sound sources located on either side of the midline axis in front, decreasing front to back. The patterns observed reflected the placement of the external microphones on the devices.

There were no additional benefit of turning up the surround volume from 65 dBA to 80 dBA.

While the three devices were clearly different in terms of their effect on sound localization, device selection will depend on many factors, including compatibility with other gear, comfort, the hearing status of the listener, type and level of background noise, and auditory tasks that will be carried out.

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List of symbols/abbreviations/acronyms/initialisms

ANOVA	analysis of variance
ANR	active noise reduction
ANSI	American National Standards Institute
ASU	Area Support Unit
BHEM	Azimuths in the back hemisphere (120, 150, 210 and 240 deg)
CFEME	Canadian Forces Environmental Medicine Establishment
dBa	decibels; a measure of sound level, A-weighted to model human frequency sensitivity
dB SPL	decibels sound pressure level; a measure of sound level relative to 0.0002 μ bar
dB HL	decibels hearing level; a measure of sound level relative to normal hearing threshold
DOJ	Department of Justice
DRDC	Defence Research and Development Canada
FHEM	Azimuths in the frontal hemisphere (300, 330, 30 and 60 deg)
HPD	hearing protective device
HREC	Human Research Ethics Committee
Hz	hertz; cycles per second, a measure of stimulus frequency
IHPD	integrated hearing protective device
kHz	kilohertz; one thousand cycles per second, a measure of stimulus frequency
LFCA	Land Force Central Area
Nacre	Nacre AS QUIETPRO® In-Ear Communication Headset
Peltor	3M™ Peltor™ PowerCom Plus™ Headset
Sensear	Sensear SDP Double Hearing Protection Headset
UN	Ears unoccluded

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Advanced hearing protection technologies enhance speech understanding while protecting against injurious noise. This experiment assessed horizontal plane sound localization with three communication devices with integrated hearing protection, that could amplify environmental sounds. Normal-hearing adults localized a brief noise burst with ears unoccluded and fitted with the Nacre QUIETPRO earplug, Peltor PowerCom Plus earmuff, and Sensear SDP earmuff-earplug combination. These were tested in the passive OFF mode and in the active ON mode at three volume settings. The stimulus was presented by an array of eight loudspeakers surrounding the listener. One block of 80 randomized loudspeaker identification trials was presented under each listening condition. Participants responded using a response box with eight buttons in the same configuration as the array. With ears unoccluded, mean scores were above 90% correct. With the devices in the OFF mode, mean scores were less than 50%, mainly due to confusion of front and back. With the devices ON, an improvement of 21% to 33% was realized. Azimuthal percent correct was highest for sound sources located on either side of the midline axis in front, decreasing front to back, reflecting the placement of the external microphones on the devices. Increasing the volume had no effect.

Les technologies de pointe en matière de protection auditive améliorent la compréhension de la parole tout en protégeant contre les niveaux de bruit dommageables. Cette expérience a permis de déterminer la localisation d'une source sonore sur le plan horizontal au moyen de trois dispositifs de communication munis de systèmes de protection auditive intégrés capables d'amplifier les bruits ambiants. Les adultes dont l'audition était normale ont été en mesure de localiser une courte rafale de bruits sans occlusion des oreilles, puis avec des bouchons d'oreilles Nacre QUIETPRO, un casque antibruit Peltor PowerCom Plus ou une combinaison de bouchons et d'un casque antibruit Sensear SDP. Ces dispositifs ont été mis à l'essai en mode passif (OFF) et en mode actif (ON), à trois différents réglages de volume. Le stimulus était présenté par un réseau de huit haut-parleurs entourant l'auditeur. Un bloc de 80 essais d'identification du haut-parleur aléatoire a été présenté pour chaque condition d'écoute. Les participants répondaient au moyen d'une boîte de réponse à huit boutons disposés de la même façon que les haut-parleurs. Sans occlusion des oreilles, les notes moyennes étaient correctes dans plus de 90 % des cas. Lorsque les dispositifs étaient en mode passif (OFF), les notes moyennes étaient correctes dans moins de 50 % des cas, principalement en raison de la confusion entre l'avant et l'arrière. Lorsque les dispositifs étaient en mode actif (ON), on a obtenu une amélioration de 21 % à 33 %. Le pourcentage azimutal de réponses correctes était plus élevé pour les sources sonores localisées des deux côtés de l'axe de la ligne médiane à l'avant, et à la baisse de l'avant vers l'arrière, révélant l'emplacement des microphones externes sur les dispositifs. La hausse du volume n'a eu aucun effet.

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directional hearing, hearing protection