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Sound localization with an army helmet worn in combination with an in-ear advanced communications system

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Abstract

Conventional hearing protection devices result in decrements mainly in the ability to distinguish front from rearward sound sources. The aim of this study was to investigate the effect of wearing an earplug with advanced communications capability, in combination with an army helmet, on horizontal plane speaker identification. Ten normal-hearing male subjects were tested in a semi-reverberant sound proof booth under eight conditions defined by combinations of two levels of ear occlusion (unoccluded and occluded by the earplug) and four levels of the helmet (head bare and fitted with the helmet modified to give no, partial and full ear coverage). Percent correct speaker identification was assessed using a horizontal array of eight loudspeakers surrounding the subject at one meter. These were positioned close to the midline and interaural axes of the head, at ear level. The stimulus was a 75-dB SPL, 300-ms broadband white noise. Both degree of ear coverage and ear occlusion significantly determined outcome. Overall percent correct ranged from 93.6% (bareheaded) to 79.7% (full ear coverage) with the ears unoccluded, and from 83.4%-77.5% with ear occlusion. Both variables affected the prevalence of mirror image confusions for positions 30° apart in front and back of the interaural axis. With ear occlusion, front given back errors were more likely than back given front errors, increasing with degree of ear coverage to 49% and 25.4%, respectively. These errors also increased with ear coverage with the ears unoccluded, but were similar. Both degree of ear coverage and ear occlusion significantly impacted horizontal plane speaker identification, particularly for sources close to the interaural axis. However, overall percent correct was higher than observed in a previous study with conventional and level-dependent hearing protection devices, using the same array.

Keywords: Communication, directional hearing, head protection

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Introduction

Military personnel report that situational awareness, particularly the ability to localize auditory warnings, may be diminished if they wear a standard army helmet which covers the outer ears (pinnae), in combination with a hearing protection device.[1] Scharine *et al.*[2] investigated the effect of amount of ear coverage by a helmet (0, 50, 100%) on sound localization, compared with a no helmet condition, with the ears unoccluded. The test sound, a burst of white noise, was presented using a horizontal array of 12 loudspeakers surrounding the subject at intervals of 30°. Accuracy decreased as the degree of ear coverage increased. The no helmet and helmet with 0% ear coverage conditions were not different but significantly less disruptive than the 50 and 100% coverage conditions. Averaged across the 12 azimuths and four helmet conditions, mean error scores ranged from about 15-20°.

Conventional level-independent HPDs result in decrements mainly in the ability to distinguish front from rearward sound sources.[3] Front/back errors signify disruption primarily of spectral cues provided by the outer ear (pinna), while right/left errors signify disruption of interaural differences in time-of-arrival and intensity.[4,5] Recently, Abel *et al.*[6] reported that an in-ear communications system with ANR capability was more effective in maintaining sound source identification than conventional muffs and plugs. Sound localization was tested in quiet using a horizontal array consisting of eight speakers positioned close to the midline and interaural axes of the head, at ear level. Percent correct, averaged across speakers, was 94% in the unoccluded condition, 46% and 52% in the conventional muff and plug conditions, and 71% for the communications plug. Discrimination of left from right was greater than 90% for all the devices tested. The discrimination of front from back was more problematic and is reflected in the overall percent correct. These data corroborate earlier sound localization studies with conventional HPDs[3,7]

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14. ABSTRACT

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but do not agree with research by Brungart *et al.*[8] In the latter study, eight muff and plug style electronic pass-through hearing protectors (EPHPs) were compared with a conventional passive earplug. Subjects localized a noise burst emanating from an array of 277 loudspeakers mounted 15° apart at the structural vertices of a geodesic sphere. Across EPHPs and speakers, the mean angular error ranged from 35-50°, compared with 12° for unoccluded listening and 22° for the conventional ear plug. The poorer performance with the EPHPs, compared with the Abel *et al.*[6] study, may have been due to the more complex array, which included a larger number of speakers, each with horizontal and vertical coordinates.

During combat, a helmet would typically be worn in combination with a hearing protective device (HPD). Vause and Grantham[9] evaluated an army helmet that partially covered the pinnae, worn alone or in combination with two types of conventional earplugs which provided different amounts of sound reduction. Sound localization ability was assessed using two horizontal arrays of 20 loudspeakers, eight degree apart, in the frontal and lateral (left side) hemifields, respectively. The stimulus was the cocking of an M16 rifle. Relative to the bareheaded/ears unoccluded (control) condition, there was no significant effect of wearing the helmet for either loudspeaker orientation. With the earplugs worn alone, the resulting disruption was minimal for the frontal array but relatively worse for the lateral array. Front-back confusions increased by 4% for the helmet worn alone to about 15% for the helmet worn with the earplugs. Vos *et al.*[10] investigated the effect of a helmet which either left the ears unoccluded or partially covered, in combination with an EPHP system designed for musicians. Subjects sat in a swivel chair with the head positioned at the centre of a hoop of speakers positioned at minus 30 and plus 30° of elevation. By turning the chair to the right or left, it was possible to generate 42 directions with horizontal and vertical coordinates. Relative to unoccluded listening, the mean error increased by approximately 10° when the ears were partially covered by the helmet and by 15° with the EPHP worn. Wearing both the helmet and EPHP did not significantly increase the error relative to each device worn separately. The error due to the EPHP was substantially less than that reported by Brungart *et al.*[8] The discrepancy may relate to the characteristics of the devices chosen for study, as well as the configuration of the speaker array.

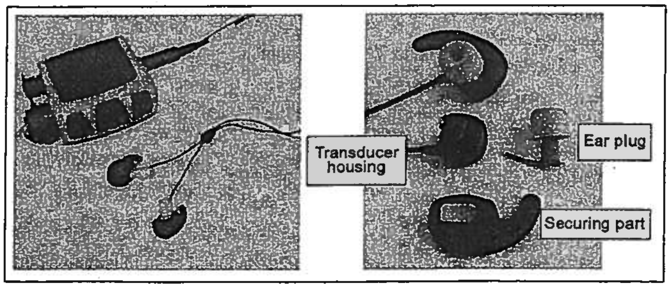

Figure 1: Nacre QUIETPRO® communications earplug. The left panel shows the controller with the in-ear system. Right panel shows parts of the in-ear system. Photographs courtesy Nacre AS

Rationale

The present study assessed the effect on right-left and front-back mirror image reversal errors for azimuthal positions close to the midline and interaural axes of the head of wearing an in-ear communications system [Figure 1], for which a benefit had previously been observed relative to conventional hearing protection devices,[6] in combination with a standard army helmet. The helmet was altered to allow for three levels of coverage of the pinnae, i.e., no coverage, half coverage to approximately the level of the tragus, and full coverage [Figure 2]. Based on the outcomes of the studies reviewed, it was predicted that partial coverage of the ears by a helmet would have a relatively small effect on the overall percent correct, with little additional impact of wearing an EPHP in combination, while full coverage would have a significant impact.

Methods

1. Experimental design

The study protocol was approved in advanced by the Human Research Ethics Committee at our institution. Ten normal-hearing male subjects (military and/or civilian), aged 20-38 years, participated in one three-hour test session. In all, pure tone air conduction hearing thresholds in each ear were less than 20 dB HL at 0.5, 1, 2 and 4 kHz.[11] Interaural differences within subject were no greater than 15 dB at each test frequency, minimizing possible right/left bias in sound localization. Many of the subjects had had some experience in wearing the communications earplug used in this study, and several had previously participated in a sound localization experiment. All provided written informed consent prior to participation.

Horizontal plane speaker identification was assessed under eight experimental conditions defined by combinations of two ear conditions (unoccluded and occluded with an in-ear communications system) and four head conditions (no helmet and fitted with each of three helmets with no, partial

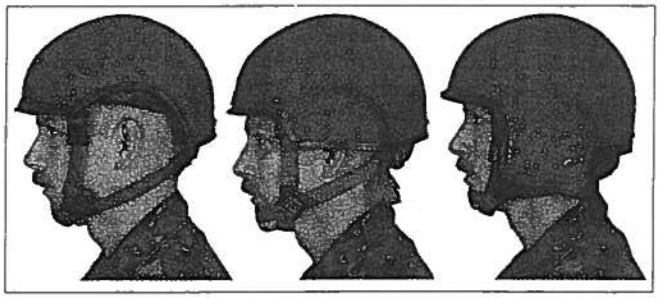

Figure 2: Three variations of the Kevlar army helmet

and full ear coverage). The communications system tested was the Nacre QUIETPRO® in push-to-talk mode, with the volume for external sounds set at 0 dB gain. This device is one of several currently under review for use by Canadian land force personnel. The helmet was the standard Canadian Forces Kevlar combat helmet (Model CG634). It consisted of an outer shell and inner suspension system, head band and chin strap assembly, with the trauma liner removed.

For conditions involving the earplugs and/or helmets, participants were given verbal instructions for fitting the devices before doing so themselves. Fits were then checked by a trained technician to ensure that the devices were well seated. This is a variation of Method A (Experimenter-Supervised Fit) described in ANSI Standard S12.6-1997[12] for the fitting of hearing protection devices. The ears unoccluded with no helmet condition (control) was presented first followed by the ears unoccluded with the three helmets, the order counterbalanced across subjects. These four conditions were followed by the four conditions in which the ears were fitted with the communications system (occluded condition) in combination with the four helmet conditions, their order counterbalanced across subjects.

Sound localization ability was tested by means of a forced-choice speaker identification task.[13] Subjects were surrounded by a horizontal array of eight loudspeakers at a distance of 1 m from the centre head position, at ear height. Two speakers were positioned in each of the four spatial quadrants, 15° from the midline and interaural axes of the head, respectively, at the following azimuth angles: 15, 75, 105, 165, 195 (-165), 255 (-105), 285 (-75) and 345 (-15) degrees, relative to the straight ahead at 0°. This placement enabled determination of right vs. left and front vs. back mirror image reversal errors for azimuths close to each axis. The stimulus was a 75 dB SPL, 300-ms broadband white noise with a 50-ms rise/decay time to minimize onset transients. Broadband noise allows the observer access to both binaural cues (interaural differences in time of arrival and intensity) and spectral cues provided by the pinnae of the ears.[4,5]

2. Subjects

Subjects were recruited with the aid of an email sent to all employees of our institution. Volunteers were screened for a history of ear problems and hearing loss, the use of medications that might affect concentration, and the need for eyeglasses to view objects at close range. There was some concern that the temple bar of glasses might interfere with the fitting of the communications system and helmets. All subjects were fluent in English to ensure that the instructions would be understood. Individuals who met these criteria underwent a hearing screening test to verify normal hearing status. Those who passed the hearing test were fitted with the communication system in one of three available sizes. In all, the fit passed the device's automatic acoustical earplug-seal test.

3. Apparatus

Subjects were tested individually while seated in the center of a double-walled, semi-reverberant sound proof booth (Series 1200; IAC, Bronx, NY) with inner dimensions of 3.5 m (L) × 2.7 m (W) × 2.3 (H) m. Reverberation times were 0.6s at 0.125 kHz and 0.25 kHz, 0.4 s from 0.5 kHz to 4 kHz, and 0.3 s at 6 kHz and 8 kHz. Ambient noise was less than the maximum allowed for audiometric testing.[14] The instrumentation and calibration methods have been described previously.[15] The broadband noise stimulus was produced by a noise generator (Type 1405; Brüel and Kjaer Instruments, Norcross, GA). The stimulus parameters, trial by trial loudspeaker selection, timing of events and logging of responses were controlled by a modular system (Coulbourn Instruments, Lehigh Valley, PA). Stimulus envelope shape and duration were fixed using a selectable envelope shaped rise/fall gate (S84-04; Coulbourn Instruments, Lehigh Valley, PA). The level was specified using a programmable attenuator (S85-08; Coulbourn Instruments, Lehigh Valley, PA) and a set of integrated stereo amplifiers (Realistic SA-150; Radio Shack Corp, Fort Worth, Tx).

The stimulus was presented by a set of eight loudspeakers (Minimus 3.5; Radio Shack Corp, Fort Worth, Tx), closely balanced with respect to output levels (1.5 dB) and frequency response from 0.125-12 kHz (2.5 dB). Subjects signified their spatial judgments by means of a specially designed laptop response box with a set of eight micro switches in the same configuration as the speaker array, both in number of elements and azimuth angles. The audio system was accessed by a personal computer via IEEE-488 (Institute of Electrical and Electronics Engineers, Inc., New York, NY), Lablinc interfaces (Coulbourn Instruments, Lehigh Valley, PA), and digital I/O lines.

4. Procedure

One block of 120 trials was given for each of the eight experimental conditions. A trial block comprised 15 presentations of the stimulus through each of the eight loudspeakers, in randomized sets of eight, for a total of 120 trials. The rate of presentation of trials was approximately one every seven seconds. Each trial began with a ½-sec warning light on the response box, followed by a ½-sec delay and then the presentation of the 300-msec broadband noise stimulus. Flash of the warning light was the subject's cue to 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. The subject was instructed to sit squarely and to try to minimize head movement, although the head was not restrained. Previous research has shown that head movements may help to resolve front/back confusions.[16] Following each stimulus presentation, the subject pushed the micro switch on the response box corresponding to the loudspeaker that he thought had emitted the stimulus. He was advised to use both hands for responding, the right hand for micro switches on the right and the left hand for micro switches on the left, to eliminate the possibility of errors from crossing the hand to the contra lateral side. Guessing, if uncertain, was encouraged. No feedback was given about the correctness of the judgments.

A set of two practice trials/loudspeaker with feedback (i.e., 16 trials) was given at the start of the session with the ears unoccluded and no helmet worn to provide the subject with a spatial sense of the loudspeaker array relative to the response buttons, and to ensure that the instructions had been understood.

Results

Outcome measures for each of the eight ear by helmet conditions included the overall percent correct, percent correct by spatial hemifield (right, left, front and back), percent correct for each of the eight loudspeaker azimuths, and percentage of mirror image reversal errors.

1. Overall percent correct

Table 1 shows the mean overall percent correct and standard deviation for each of the eight conditions, calculated using the data for the 10 subjects. The two ear conditions are labeled unoccluded (no ear protection) and occluded (Nacre QUIETPRO® in-ear communications system). The four helmet conditions are labeled None (no helmet worn), Up (helmet worn with no coverage of the pinnae), Half (helmet worn with the pinnae covered to the level of the tragus) and Full (helmet worn with the pinnae fully covered). A repeated measures analysis of variance (ANOVA),[17] implemented using SPSS software (SPSS Inc., Chicago, Ill) indicated that there were significant main effects of both ear occlusion ($p < 0.05$) and pinnae coverage by the helmet ($p < 0.001$) but not their interaction. With the ears unoccluded, the overall percent correct ranged from 93.6% for no helmet to 79.7% for the pinnae fully covered by the helmet. With the ears occluded the overall percent correct ranged from 83.4% for no helmet to 77.5% for the pinnae fully covered by the helmet. Post hoc pair wise comparisons indicated that there was no difference between the no helmet and helmet with no pinnae coverage conditions.

In order to determine whether there was a learning effect, a comparison was made of the overall percent observed for the first and last 16 trials for each of the eight experimental conditions. Across conditions, changes ranged from -1.8% (ears unoccluded, helmet Up) to 5% (ears unoccluded, no helmet). Repeated measures ANOVA run on data showed that the mean practice effect of 1.6% was not statistically significant nor were there significant interactions with the ear or helmet conditions.

Table 1: Overall % correct in horizontal plane sound localization. Effect of ear and helmet conditions

	Helmet			
Ear	**None**	**Up**	**Half**	**Full**
Unoccluded	93.6 (5.2)*	91.0 (6.7)	86.1 (6.0)	79.7 (5.3)
Occluded	83.4 (9.3)	85.7 (8.4)	81.3 (7.5)	77.5 (6.9)

*Mean (SD), N=10

2. Hemifield discrimination

Subjects' ability to accurately determine that the test stimulus emanated from the right, left, front and back hemifields was assessed. For each of these, the response on each trial was scored as correct, if the subject correctly identified the correct hemifield regardless of whether the correct azimuth was selected, that is, right response given right stimulus (15, 75, 105 and 165 degree), left response given left stimulus (195, 255, 285 and 345 degree), front response given front stimulus (285, 345, 15 and 75 degree), and back response given back stimulus (105, 165, 195 and 255 degree). The results are shown in Table 2. Regardless of the ear by helmet condition, subjects had no difficulty in determining that the source was on the right or left side of space. Mean percent correct was 98.3% or better across the 16 ear occlusion by helmet by hemifield conditions. By comparison, mean percent correct for front and back ranged from 95.5% (unoccluded/no helmet/front) to 72.3% (occluded/helmet with full pinnae coverage/back). A repeated measures ANOVA applied to the datasets for the front and back hemifields showed significant effects of ear occlusion ($p < 0.04$) and helmet ($p < 0.0001$). The difference due to hemifield did not reach statistical significance. For both the front and back hemifields, percent correct decreased as the degree of pinnae coverage by the helmet increased, and except in one instance (helmet with full pinnae coverage, front) was relatively less for the occluded than the unoccluded condition.

3. Azimuthal percent correct

The mean percent correct observed for each of the eight loudspeaker azimuths is shown in Figure 3a and b for the two ear conditions, unoccluded (U) and occluded (O), respectively. The parameter in each figure is the degree of

Table 2: Hemifield % correct in horizontal plane sound localization. Effect of ear and helmet conditions

		Helmet			
Ear	**Hemifield**	**None**	**Up**	**Half**	**Full**
Unoccluded	Right	99.3 (2.1)*	100.0 (0.0)	99.7 (0.7)	99.0 (1.6)
	Left	99.7 (0.7)	100.0 (0.0)	100.0 (0.0)	98.7 (1.7)
	Front	95.5 (6.3)	91.7 (8.3)	85.9 (10.2)	79.0 (10.0)
	Back	92.8 (7.7)	91.0 (7.5)	86.8 (10.0)	85.3 (8.3)
Occluded	Right	99.7 (1.0)	99.8 (0.5)	99.5 (0.8)	99.3 (1.6)
	Left	99.5 (1.1)	99.7 (0.7)	99.5 (0.8)	98.3 (2.1)
	Front	88.3 (12.9)	88.3 (13.7)	84.0 (11.8)	84.5 (16.3)
	Back	80.0(10.3)	84.8 (10.1)	79.5 (10.4)	72.3 (16.1)

*Mean (SD), N=10

pinnae coverage by the helmet (N-no helmet, U-helmet with no pinnae coverage, H-helmet with half pinnae coverage, and F-helmet with full pinnae coverage). A repeated measures ANOVA applied these data showed significant effects of ear occlusion ($p < 0.05$), pinnae coverage by the helmet ($p < 0.0001$), azimuth ($p < 0.0001$), ear occlusion by azimuth ($p < 0.01$), and helmet coverage by azimuth ($p < 0.05$).

With the ears unoccluded [Figure 3a], accuracy in identifying the four positions near the midline axis (15, 165, 195 and 345 degree) was close to 100%. In contrast, progressive decrements with increasing pinna coverage were observed for positions near the interaural axis, particularly for azimuths in front of the axis at 75° on the right and 285° on the left. A paired sample t-test indicated that the outcomes for these two azimuths were not different, and the results were averaged. As coverage increased, percent correct decreased from 91.3 to 58.3%. A similar pattern was observed when the ears were occluded [Figure 3b]. Again percent correct for the midline positions was close to 100%. Progressive decrements with ear coverage by the helmet were observed for the interaural positions. However, the relatively greatest change now occurred for azimuths behind the interaural axis at 105° on the right and 255° on the left. The data for these two azimuths were averaged since they were not different statistically. Percent correct decreased from 70.3% in the helmet Up condition to 50.7% in the helmet Full condition.

In both the unoccluded and occluded conditions, the standard deviations for the interaural positions generally exceeded those of the midline positions, indicating a relatively wider range of difficulty for the latter. In the unoccluded condition, standard deviations were 2.7% on average for the midline positions while those for the interaural positions were 22.0% on average. Standard deviations of the same order of magnitude were observed in the occluded condition.

4. Front-back mirror image reversal errors

A further analysis was undertaken to determine the degree to which difficulty in discriminating between front and rearward sound sources was due to front-back mirror image reversal errors. The results are shown in Table 3. The mean percentage of trials (out of 20) on which subjects made a mirror image reversal error (either responding back when given front – B/F or front when given back – F/B) is shown for mirror image pairs close to the midline axis (15° and 165° on the right; 345° and 195° on the left) and interaural axis (75° and 105° on the right; 285° and 255° on the left). Data for right and left sides were similar and were averaged.

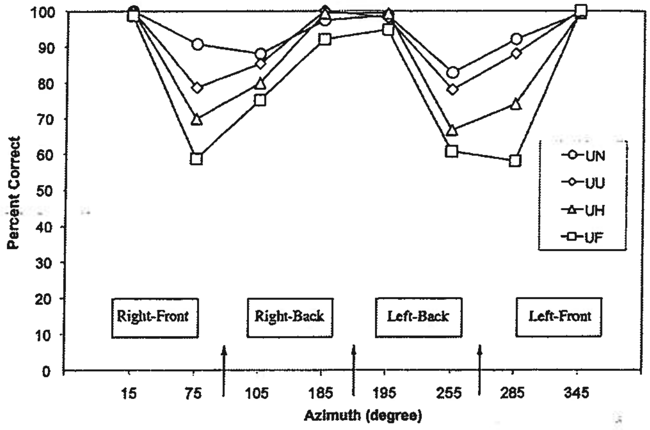

Figure 3a: Azimuthal percent correct in horizontal plane speaker identification for four helmet conditions. Ears unoccluded (U)

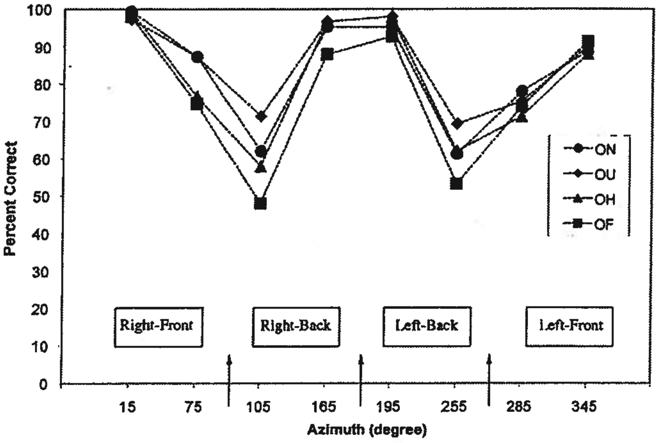

Figure 3b: Azimuthal percent correct in horizontal plane speaker identification for four helmet conditions. Ears occluded (O)

Table 3: Percentage of back given front and front given back mirror image reversal errors for azimuths near midline and interaural axes of head at ear level

		Helmet			
Ear condition	**Error**	**None**	**Up**	**Half**	**Full**
Midline axis					
Unoccluded	B/F	0.0 (0.0)	0.0 (0.0)	0.3 (1.1)	0.3 (1.1)
	F/B	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
Occluded	B/F	5.7 (14.6)	4.7 (6.1)	5.3 (13.7)	4.3 (12.6)
	F/B	1.7 (4.2)	0.7 (2.1)	0.3 (1.1)	4.7 (13.6)
Interaural axis					
Unoccluded	B/F	8.7 (12.9)	16.7 (16.6)	27.7 (20.2)	41.7 (19.9)
	F/B	10.7 (7.3)	18.0 (15.1)	24.3 (21.7)	29.0 (16.8)
Occluded	B/F	16.0 (18.9)	18.3 (21.6)	26.0 (15.5)	25.4 (22.9)
	F/B	33.3 (21.8)	24.3 (20.6)	37.7 (19.5)	49.0 (22.8)

*Mean percent (SD), N=10, B/F = Back given front, F/B = Front given back

For mirror image pairs close to the midline axis the prevalence of B/F and F/B errors was relatively low at less than 1% in the unoccluded condition and no more than 5.7% in the occluded condition. By comparison, for mirror image azimuthal positions on either side of the interaural axis, the prevalence of B/F and F/B errors ranged from 8.7-41.7% in the unoccluded condition and from 16.0-49.0% in the occluded condition. In general, for both the unoccluded and occluded ear conditions, the greater the degree of coverage of the pinnae by the helmet the greater the percentage of mirror image reversal errors. In the occluded condition, F/B errors exceeded B/F errors. The pattern was not consistent in the unoccluded condition.

Discussion

This study was undertaken to determine the effect on identification of selected speakers in the horizontal plane of wearing an army helmet with three levels of coverage of the pinnae, in combination with an advanced in-ear communications system. Bareheaded and with the ears unoccluded, subjects achieved an overall score of 93.6%. This outcome was virtually identical to results reported previously.[6] The decrement in overall percent correct when the ears were occluded by the Nacre QUIETPRO® communications system was only 10%, in comparison with 24% observed in the earlier study. A possible explanation for the discrepancy is that an upgraded model of this device was used in the present study. Sound localization was substantially better than previously observed when hearing protection with conventional attenuation, limited dichotic or diotic amplification or active noise reduction was worn.[3,6,18] The wearing of the helmet had a relatively small effect. Although increasing coverage of the ear resulted in a significant progressive decrement in accuracy, subjects were able to score at least 78-80% correct with the pinnae fully covered, regardless of whether the ears were unoccluded or occluded. This finding is in line with findings of both Scharine *et al.*[2] and Vause and Grantham.[9] An assessment of changes in outcome over the course of each block of trials indicated that subjects did not benefit from practice in any of the experimental conditions. This finding is consistent with the results of previous studies.[9]

With respect to hemifield discrimination, neither the wearing of the helmet nor the in-ear communications system compromised subjects' ability to judge whether the stimulus had been presented from the right or left.[6] In contrast, front-back discrimination was significantly affected by both these devices. The greater the coverage of the pinnae by the helmet, the greater the difficulty in discriminating between front and back presentations of the stimulus. Nonetheless, with the ears fully covered scores were still relatively high at 82% correct for the unoccluded condition and 78% for the occluded condition, averaged across front and back hemifields. Vause and Grantham[9] reported a similar outcome for a helmet partially covering the ears. Their scores for occluded listening with conventional earplugs were comparatively lower, underscoring the benefits of the in-ear communications system.

While hemifield accuracy scores were relatively high, an analysis of azimuthal percent correct showed that subjects did have difficulty in localizing sounds emanating from positions in front of and behind the interaural axis. With full coverage of the pinnae by the helmet, they scored only 60% correct for azimuths in front of the axis with the ears unoccluded and 50% correct for azimuths behind the axis with the ears occluded. By comparison, without the helmet worn and with the ears unoccluded, scores for azimuths in front and behind the interaural axis were 91.3% and 85.3%, respectively, averaged across right and left sides Largely, these errors were mirror image front-back reversal errors. These increased with the degree of pinnae coverage by the helmet. With full coverage by the helmet and the ears occluded, F/B errors were more likely than B/F errors, 49% vs. 25.4%, averaged across right and left sides. A similar pattern was reported by Carmichel *et al.*,[18] who observed that with electronic amplitude-sensitive earmuffs covering the ears, azimuthal percent correct was higher in front than in back. In the present study, with less coverage of the pinnae, the frontal hemifield advantage was still evident, although the differences were less. The same outcome was reported by Abel *et al.*[6] and was attributed to placement of the external microphones. With the ears unoccluded, the direction of the difference was not consistent across the four helmet conditions.

The results of this study showed that there were increasing decrements in overall percent correct for horizontal plane speaker identification with both increasing coverage of the pinnae by the helmet and the use of an in-ear communications device. However, performance levels were generally higher than observed previously with conventional and level-dependent hearing protection devices that are typically used in military operational settings. Relative to the unoccluded, bareheaded condition, subjects had difficulty mainly in distinguishing between sound sources located in front of and behind the interaural axis of the head. These sources were 30 degrees apart and it is unlikely that this degree of resolution would be required during field operations. Hemifield discrimination, which included discrimination between sources located closer to the midline axis, was relatively good and would most likely be sufficient during active combat.

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