In-Field Localization of Gunshots in Azimuth under
Two Prototype Etymotic and Two Production AEARO-Peltor
Hearing Protection/Enhancement Devices
Intended for Military Ground Soldier Applications

by

John G. Casali, Ph.D., CPE
J. Grado Professor, Virginia Tech
Director, Auditory Systems Laboratory

and

John P. Keady, Ph.D., M.B.A., Esq.
CEO Innovation R&D Labs LLC

Contact Information:
John G. Casali, Ph.D., CPE  jcasali@vt.edu  (540) 231-5073
John P. Keady, Ph.D., J.D.  ceo@defendhearing.com  (561) 706-1931

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RESEARCH OVERVIEW AND OBJECTIVES

With very few exceptions, there is a paucity of realistic, empirical research that has been applied to hearing protection/enhancement (hereafter, HPE) devices as to their operational performance in mission-critical military situations (Casali, et al., 2009). As emphasized by military experts in a recent Defense Advanced Research Projects Agency Workshop on potential technologies for significant advancements in soldiers' hearing protection, a common theme was and is the acute need for HPEs which protect the soldier from gunfire and other loud noises, but that do not in any way compromise their situation awareness (DARPA, 2010). Toward this end, it was repeatedly stressed at this DARPA Workshop that a very common shortcoming of current HPEs is their perceived or actual deleterious effect on the ability of soldiers to locate, via their auditory sense, enemy gunshots or other threats to their survivability and lethality.

Very few studies have examined the effect of hearing protection devices (HPDs) on auditory signal localization (see Alali & Casali, in press), and a review of the literature reveals no empirical, controlled field experiments on the auditory localization of gunfire under hearing protection. A few studies have addressed sound localization under hearing protectors, but none have addressed sniper or other similar gunfire situations (Abel & Hay, 1996; Atherley & Noble, 1970; Atherley & Else, 1971; Bolia, et al., 2001). While the technology reviews of augmented hearing protectors and HPEs found in Casali (in press: a,b) point to HPEs which may indeed offer benefit to the localization of gunfire as compared to standard, passive HPDs, there is no experimental or even substantiated anecdotal data to support any claims to that effect.
Therefore, in consideration of the dearth of prior research to explore the effects of HPEs on soldiers' situation awareness, the research described herein undertook what is perhaps the most critical auditory task involving situation awareness, that of localizing gunfire, such as that from a hidden sniper. As such, it represents the first experiment of its kind; that is, based on realistic, in-field scenarios, to ascertain the effects of several HPEs designed and intended for military applications on individuals' abilities to auditorially locate gunshots emanating from hidden positions in 360 degrees of azimuth. In this vein, the research had as its major objective to experimentally determine the effects of 2 commercial, currently-deployed military HPE devices (i.e., third generation Combat Arms level-dependent earplug and Peltor Com-Tac II electronic earmuff), as well as 2 prototype devices that draw upon recent advancements in hearing aid technology with electronic adaptations for use in impulsive (e.g., gunfire) noise (Etymotic Research Electronic BlastPigs, Models EB-1 and EB-15, both set in their ‘Lo’ (low) gain positions (described later). In accomplishing this major objective, the gunshot localization task was performed by all subjects in two levels of ambient noise, rural quiet and 82 dBA heavy military truck idling noise, and by two groups of subjects, those with normal hearing and those suffering from asymmetrical impairments. Each of these independent variables will be described later, and the combination of these independent variables with the 4 HPEs and the open ear condition comprised the ‘original’ or ‘Part 1’ experiment.

Objective dependent measures of localization performance were derived from the subjects’ verbal responses wherein they stated the visual target sign number corresponding to the location from which an actual gunshot was thought to have originated. Subjective dependent measures, in the form of self-report rating scales, were obtained after each subject had completed all trials with a given HPE (or with the open ear), and these tapped into self-report impressions of comfort, ability to localize, confidence in localization, difficulty to localize, how well protected, and how easy it was to communicate.

After the original experiment was well underway, it was believed that certain improvements in the localization accuracy measures might occur with changes to the Etymotic prototypes, so the EB-15 devices were modified, primarily in regard to their overall shape in relation to the concha, and moreover, as to their external (input) microphone location on the plug’s body. These devices, as well as a retest of the open ear condition, comprised the ‘modified’ or ‘Part 2’ of the experiment. Part 2 examined three modified Etymotic EB-15’s, referred to as EB-15-Lo-IN (a low-profile EB-15 with pickup microphone mounted in the side of the device, well within the concha bowl), EB-15-Lo-OUT (a low-profile EB-15 with pickup microphone mounted on the outside end of the device, outside the concha bowl), and EB-15-Lo-TUBE (a standard profile EB-15 with its microphone attached to a thin tube which picked up the sound from inside the concha rather than on the end of the plug outside the pinnae.
In summary, the objectives of the two experiments within this research effort were as follows:

1) To determine how selected military hearing protection/enhancement (HPE) devices affect a soldier’s hearing ability to localize a gunshot, as compared to the open (unprotected) ear, using objective 360-degree angular measurements.

2) To determine how a common military vehicular (heavy truck diesel) masking noise influences the localization performance.

3) To ascertain the localization ability of asymmetrically-hearing-impaired subjects compared to non-hearing impaired subjects.

4) To ascertain, via bipolar rating scales, administered after each HPE’s usage in the experiment, subjects’ impressions of localization ability under each HPE device, as well as comfort, confidence, and other user acceptance dimensions.

5) To determine if a low-profile (i.e., in the concha) device and/or microphone placement locations, made a difference in localization performance for the EB-15 device, which in its standard configuration was a longitudinal earplug-type device which protruded outside the pinnae of most ears.

EXPERIMENTAL METHODOLOGY:
Original Device (Part 1) and Modified Device (Part 2) Experiments

Participants (Subjects)

Original Experiment. The original experiment included a total of 13 participants, 10 males and 3 females, between 22 and 54 years of age, with a mean age of 35. The participants comprised a combination of normal hearing individuals and hearing-impaired individuals. Of the 13 participants, 4 were hearing impaired by the experiment’s operational definition (explained later), or 32%. In a screening session separate from the experimental trials, each participant was given an otoscopic inspection to insure that excessive cerumen or ear lesions were not present, either of which would have precluded the insertion of earplug-type HPEs. Following the otoscopic inspection, subjects were tested with a Beltone Model 119 pure-tone audiometer using a modified Hughson-Westlake procedure. Those subjects who were classified as “normal hearing” for the purposes of the experiment demonstrated hearing levels less than or equal to 25 dBHL at 250, 500, 1000, 2000, 3000, 4000, and 6000 Hz, and less than or equal to 35 dBHL at 8000 Hz, in both ears. Also, bilateral symmetry differences of less than or equal to 25 dBHL from 250 to 6000 Hz was required to avoid any possible hearing asymmetry bias in localizing the gunshots. All subjects whose hearing was worse than these criteria were considered as ‘hearing-impaired’ for the purposes of the study. All subjects classified as ‘impaired’ did, in fact, exhibit hearing thresholds that were significantly worse than those of the normal hearing subjects.
The hearing thresholds for all subjects, as well as their operational hearing classifications for the experiment, may be found in Appendix 1.

Of the 13 participants, all of whom were naïve in regard to the protocols of the experiment, most had some experience with hearing protection devices, but 7 subjects had minimal usage patterns. Six of the 13 subjects had used hearing protection on a regular basis at least at some point; these consisted of 3 Army personnel who were Virginia Tech students at the time of the study, a machine shop employee, a musician, and a construction worker. One of the 13 subjects was an Etymotic engineer who was unfamiliar with the design of the experiment or its protocols. His objective localization accuracy data for the gunshot trials were included in the data presented herein; however, his subjective rating scale data were not included to avoid any potential biases due to his ability to recognize the company products.

**Modified Device Experiment.** The second experiment included a total of 6 participants who also participated in the first experiment, and consisted of 6 males and no females. Of the 6 participants in the second experiment, only 1 was hearing-impaired. During the experiment, the modified EB-15-Lo-OUT device failed after 3 subjects. Thus, for the modified device experiment, the open ear condition had 4 normal and 1 impaired participant, the EB-15-Lo-IN and EB-15-Lo-TUBE condition had 5 normal and 1 hearing-impaired participant, and the EB-15-Lo-OUT had only 3 normal hearing participants.

**Experimental Designs: Original and Modified Device Experiments**

To assess localization performance with objective accuracy-based measurements, a 5×2 completely within-subjects experimental design with 2 independent variables (HPE/listening condition x Noise Level); was applied in the original experiment (Figure 1), and a 4x2 within-subjects design was applied in the modified device experiment employing the same independent variables and a portion of the subjects from the original experiment (Figure 2). The test range setup (discussed later) was the same for both the original and modified device experiments.
Figure 1. Original device experimental design with assignment of participants to the independent variables.

The Modified Device experimental design, was an unequal-n factorial within-subjects design, as shown in Figure 2. This design was applied to test 3 modifications of the EB-15-Lo, as described below, and was applied to only a subset of the original subjects due to limited availability.

Figure 2. Modified Device experimental design with assignment of participants to the independent variables in unequal-n factorial combination of independent variables. (All subjects had prior participated in the original Part 1 experiment; subject breakdown by hearing ability is described under Participant section above.)
**Noise Level Variable (both experiments).** Both experiments employed masking noise as a fixed-effects independent variable. The two levels of masking noise consisted of: 1) the resting ambient noise level in the test range area, which was most typically in a range of 45-50 dBA, and devoid of any significant noise sources including aircraft flyovers, and farm equipment operations; and 2) 82 dBA military vehicle noise, consisting of the high-idle noise from a stationary diesel-powered truck. The truck noise was a broadband spectrum and remained steady over time, without any transients.

**Hearing Protection/Enhancement Device (HPE)/Listening Condition Variable (Original Experiment).** In the original device experiment, the HPE conditions consisted of: 1) open-ear (i.e., no HPE), 2) the newest version of the AEARO/3M Combat Arms earplug in its open, or level-dependent setting, 3) the Peltor Com-Tac II sound transmission earmuff, 4) the Etymotic Research Blastplg EB-1, and 5) the Etymotic Research Blastplg EB-15.

The newest version (i.e., third generation rocker-switch design) of the **Combat Arms earplug** was used, with the rocker switch set to the 'level-dependent,' 'nonlinear,' or 'open' setting. The Combat Arms earplug is shown in Figure 3, along with its manufacturer-reported attenuation data for its level-dependent setting as used in this experiment. This device was selected because it is a current military-issue device for soldiers, and its level-dependent end provides 10 dB or less attenuation at frequencies below 500 Hz under low-level noise (i.e., non-gunshot) conditions, and its attenuation automatically and instantaneously increases in impulsive noises above about 110-120 dB, such as those occurring with a nearby gunshot (Casali, in press-b). Three flange tips of different sizes are provided with the Combat Arms, and the appropriate size was selected by the experimenter after sizing the ear canal with an AEARO Ear gage, and through careful examination and interaction with the subject.

The **Peltor Com-Tac II** electronic earmuff, shown in Figure 4 along with its manufacturer’s reported attenuation, is also a current military-issue HPE, and was thus selected for testing in the experiment. It comprises a dichotic ‘sound-transmission’ muff with approximately 15 dB of gain and a compression circuit that responds to sharp transient impulses such as gunshots, rapidly decreasing the amplifier’s output. Its pass-through circuit relies on two directional, forward-facing microphones, one mounted on each earcup. The Com-Tac II was tested in its maximum gain position. Additional information on sound transmission earmuffs, including the Peltor Com-Tac II, may be found in Casali (in press: a,b). Furthermore, results from an Army operational performance experiment that examined both the first generation Combats Arms earplug and the Peltor Com-Tac II muff appears in Casali et al. (2009).

Two versions of **Etymotic Research BlastPlgs** were used (Figure 5): 1) the EB-1 was tested in its LO (low gain) position (EB-1-Lo), which yields transparent hearing at levels up to 110 dB; 2) the EB-15 was tested in its LO (low gain) position (EB-15-Lo), which yields transparent hearing below 60 dB, 15 dB insertion loss above 90 dB, and gradual WDRC transition from 60 to 90 dB. For informational purposes, the input-output gain behavior of both of the Etymotic BlastPlgs are provided in Appendix 2. Note in Figure 5 the location of the external microphone on the outer tip of the body of the earplugs; this
microphone transduces signals external to the BlastPlg and transmits them through the hearing aid-type circuitry to the receiver, the output of which is provided to the ear via the sound port in the triple-flanged earplug. Two flange tips of different sizes are provided with the BlastPlgs, and the appropriate size was selected by the experimenter after sizing the ear canal with an AEARO Eargage, and through careful examination and interaction with the subject. Due to the fact that the BlastPlgs are prototype devices, their octave band attenuation spectra were unavailable at the time of the experiments.

Figure 3. Single-sided Combat Arms earplug (with rocker switch in open [level-dependent] position, as used in experiment); 3 sizes of triple-flanged eartips were available; correct size selected for each subject by experimenter. Octave band attenuation and NRR are shown for level-dependent position as used in experiment described herein, based on manufacturer’s data at www.aearo.com/pdf/hearing/ear_atten.pdf
Figure 4. Peltor Com-Tac II sound transmission earmuff (gain was set to maximum for experiment; experimental version did not have a microphone boom as shown). Octave band attenuation and NRR are shown for gain off (passive) position, based on manufacturer’s data at www.aearo.com/peltor.com/atten_data.htm
Figure 5. Etymotic Research BlastPlgs, 2 visually-identical versions used in experiment: EB-1 and EB-15, both used in ‘Lo,’ i.e., low gain, settings in experiment. 2 sizes of triple-flanged eartips available as shown in background on left; correct size selected for each subject by experimenter. Prototype devices--attenuation data not available.

Hearing Protection/Enhancement Device (HPE)/Listening Condition Variable (Modified Experiment). A preliminary review of the localization results was made as they were obtained in the original experiment with the Etymotic BlastPlgs. Based on this in-process review, it was decided by Etymotic management, after discussions with the IRDL research team, to make modifications to the EB-15 BlastPlgs to determine if overall shape and location in the ear, as well as microphone placement, would improve localization accuracy in additional experimental trials with a subset of the original subjects. These trials comprised the ‘modified device experiment,’ and the HPEs conditions consisted only of: 1) open-ear (i.e., no HPE); 2) a low profile, in-concha Etymotic research EB-15 BlastPlg with the external microphone located on the interior surface of the plug’s body, pointing toward the ear canal (EB-15-Lo MIC IN) -- Figure 6; 3) a low profile, in-concha Etymotic research EB-15 Blastplg with the external microphone located on the exterior of the plug’s body, pointing away from the ear canal (EB-15-Lo MIC OUT) -- Figure 6, and 4) a standard EB-15, modified by this report’s authors to incorporate an acoustic tube mounted over the external microphone’s port and routed to a position wherein the open end of the tube terminates near the rim of the ear canal, in order to accept sound input only at the canal position and through multiple ports in the side of the tube near its end (EB-15-Lo TUBE) -- Figure 7. As in the original experiment, all modified versions of the EB-15 were operated in their Lo position during the gunshot localization trials. It should be recognized that the ‘modified’ devices were constructed of SLA prototyping materials in the case of the EB-15-Lo MIC IN and EB-15-Lo MIC OUT, or in the case of the EB-15-Lo TUBE, constructed using tubing glued to the original EB-15; therefore, these devices were somewhat fragile and not meant to withstand the rigors of everyday use. Furthermore, it must be emphasized that it was visually obvious that all 3 of the modified devices were not finished, refined products; therefore, the self-report results obtained for these modified devices may have been
biased due to the fact that unlike the HPEs of the original experiment, the modified devices were obviously unfinished products.

Figure 6. Foreground: Low profile, in-concha Etymotic Research EB-15 BlastPlgs as used in Modified Device Experiment,. EB-15-Lo MIC IN shown on left; EB-15-Lo MIC OUT shown on right, both used in ‘Lo,’ i.e., low gain, settings. 2 sizes of triple-flanged eartips available as shown; correct size selected for each subject by experimenter. Prototype devices--attenuation data not available. Background: Standard EB-15 device shown for comparison.
Figure 7. Foreground in both left and right panels: Modified EB-15, denoted EB-15-Lo TUBE, modified by the authors to incorporate an acoustic tube mounted over the external microphone’s port and routed to a position wherein the open end of the tube terminates at the rim of the ear canal, in order to accept sound input only at the canal position through multiple ports near the end of the tube, said ports residing in the annulus created by the large flange. 2 sizes of triple-flanged eartips available; correct size selected for each subject by experimenter. Prototype device—attenuation data not available. Background at right: Standard EB-15 device shown for comparison.

Ordering of Experimental Conditions and Gunshot Locations. In both experiments, a predetermined ordering of the combinations of independent variables (HPE/listening conditions and noise levels), was performed in advance of the subject’s arrival via randomization with a random number table. Ordering of the gunshot locations for each combination of conditions was also randomized with constraints. That is, for each cell of both experimental designs shown in Figures 1 and 2 above, there were 2 gunshots (2 trials) for each of 8 shooter positions in 45-degree increments of azimuth angle around the subject in 360 degrees. The ordering of those shots was randomized within each cell of the experimental designs, with the sole constraint that no two gunshots in succession could emanate from the same position.

Experimental Facility: Outdoor Test Range and Instrumentation

Test Range Design and Site Preparation. The original and modified device experiments were performed on a test range prepared specifically for the research project experiments on a rural farm in Pulaski, VA owned by the first author’s family.
This site was selected due to its remote location, its specific terrain, and the fact that it was unaffected by any continuous noise sources, the only exceptions being an occasional light aircraft flyover or vehicle noise from the nearest rural road about one mile away. The terrain of the site was important, because it comprised a plateau region of about 50 feet in radius around the subject's stationary position and enclosed by a circle of vertical camouflage netting of 5 feet height (Figure 8). Outside this plateau and camouflage netting, the terrain comprised a gradual declination in elevation to a region in which a 'shooter's circle' was constructed at a fixed radius distance of 150 feet away from the subject’s position. In this manner, the slight decline in elevation assisted the shooters in moving along their prescribed circular path in the forest without being visually detected. In the plateau region around the subject’s position, the large trees were removed in a circle of radius 50 feet with the vertical camouflage netting at its circumference; beyond that circle, there were both small and large deciduous trees that interrupted the subjects' line-of-sight to the shooters (Figure 8). The density of trees was consistent within the region, at about 1 tree per 80-100 square feet of land area.

**Subject’s Region and Target Signs.** The subject stood at the center of the camouflage-enclosed circle, and always faced forward toward the United States flag, which was located directly over target sign #1 (Figure 8). Figure 9 provides a schematic of the circular region surrounding the subject, wherein the subject’s visual references were composed of 16 gunshot ‘directions’ labeled with signs, with direction #1 corresponding to 0-degrees azimuth and located under the flag, as depicted in Figure 8. The subject’s primary task on each gunshot trial was to indicate, as accurately and as quickly as possible, the number of the sign (out of 16 total signs) that corresponded to the direction from which the shot originated.
Figure 8. Upper photo showing test site with subject’s position (at umbrella) facing the United States flag, an open clearing within the camouflaged netting which is at a radius of 50 feet from the subject, and the tree forest beyond the clearing. Lower photo showing camouflaged netting and target #1, which subject faced prior to each gunshot trial. The shooters were located in the forest beyond the camouflaged netting at a distance of 150 feet radius from the subject’s position.
Figure 9. Experimental test range configuration around subject’s position, showing the 16 numbered target signs located at a radius of 50 feet and used by subjects for oral identification of the direction of the gunshot on each trial.

Subject’s Position and Signal Generation Equipment. The photo of Figure 10 shows the 4 wooden posts on which were mounted the Klipsch two-way outdoor loudspeakers in a cross-pattern around the subject at a distance of 10 feet. These speakers, as powered by a Pioneer 100W amplifier fed by a Panasonic CD player, were used to present the military truck masking noise from CD at a constant level of 82 dBA at the subject’s head center position. Signals were calibrated with a Quest Model 2200 integrating sound level meter, which was itself calibrated prior to the first session of the day using a Quest QC-10 calibrator at 114 dB at 1000 Hz. The participant stood on the mat under the umbrella in the photo, facing azimuthal direction #1 (under the United States flag shown in Figure 8). Between gunshots, shooters moved quickly to their next shooting positions, and to ensure their movements were not heard, pink noise was played from a Sony CD player at 75 dBA; this CD player was located 8 feet in front of the subject, and it was turned off once the shooters had reached their positions for the next shot and then radioed accordingly to the experimenter. Both the shooter movement masking CD as well as the military truck noise CD were controlled via remote controls held by the experimenter.
Figure 10. Photo of the subject’s standing position at mat under umbrella, with 4 Klipsch outdoor loudspeakers mounted on posts, military vehicle noise generation equipment under blue weatherproof tarp, shooter movement masking noise CD player 8 feet in front of subject position, and target signs numbered 11, 12, and 13 in view. The slight terrain rolloff from the plateau of the subject’s position can be seen in this view.

The audio equipment for presentation of the military truck noise was powered by a Honda generator placed behind a stump at 48 feet from the subject (Figure 11), so as to minimize any generator noise contribution at the subject’s location; the generator noise level was 53 dBA at the unit, but due to the stump and distance from the subject, its level did not contribute to the 82 dBA military vehicle noise’s masking effect in the experiment.
Figure 11. Honda generator used to power audio equipment to present military truck noise in experimental trials. Generator located behind stump, 48 feet away from subject, so contribution to masking levels was negligible. Generator was shut off during noise conditions of rural ambient (quiet).

Shooter's Circular Path and Actual Shot Locations. Unbeknownst to the subject, there were only 8 actual angular positions, in 45-degree increments, from which gunshots emanated, rather than from the 16 locations that were indicated to the subject by the target signs that were located in 22.5-degree increments. Figure 12 provides a schematic of the 8 actual shooter positions, all of which were located on a circular path in the forest, on which the shooters moved and shot at a radial distance of 150 feet from the subject. All shooter locations were positioned so that they were not visible to the participant, and a survey transit and tape measure were used to determine the exact angular and linear distance placement of each shooter's position (Figure 13). During the experiment there were always either 2 or 3 shooters each using a 22-caliber revolver, who moved between shooter positions along the cleared, circular path. The shooter positions were labeled for the shooter's use and for coding purposes with letters from A to H.
Figure 12. Experimental test range configuration around subject's position, showing the 8 actual shooter positions located at a radius of 150 feet in the tree forest, and used by shooters for origination of the gunshot on each trial.

Figure 13. Photo of the survey operation to position the exact 8 shooter positions, as well as the 16 gunshot target signs. The survey transit is located at the subject's position.
Each of the 8 shooter positions was visually obscured from the subject via a combination of the camouflage netting curtain, the slight rolloff in terrain elevation, and the presence of the forest beyond the 50-foot radius of the target signs. An example of one of the shooter's stations is shown in Figure 14. As stated previously, for each cell of the experimental designs, 2 gunshots (i.e., 2 trials) from each of the 8 azimuthal angular positions occurred in randomized fashion, with the sole constraint that successive gunshots never came from the same position; that is, the shots always originated from a different position from one trial to the next.

Figure 14. Example of one of the 8 shooter's stations, shown adjacent to the shooter's movement path. The shooter at this particular station was elevated slightly by the application of the stepladder to bring him/her to the approximate elevation of the other positions.

**Gunshot Apparatus and Measurements**

All gunshots were produced using three 22-caliber revolvers (pistols) shooting 22-caliber long-rifle blanks (i.e., bullets without projectile tips). Via measurement with the aforementioned Quest sound level meter set on true peak dB, maximum hold, and
dB(linear) (i.e., hereafter, dBZ), the true peak (non-rms) levels at the subject’s ear that resulted from shots at each of the 8 azimuthal shooter positions ranged from 100 to 104 dBZ. This was determined during pre-experimental calibration after site preparation work was completed. To ensure that all gunshots fell within this range, it was necessary to balance the natural influences on sound propagation/attenuation between each shooter’s position and the subject’s position by either cutting foliage, adding piles of light brush, and/or slightly elevating the shooter, and retesting with blanks to establish the levels at the subject’s ear position within the desired range of 100-104 dBZ true peak.

Figure 15 shows the test setup for measuring the gunshots from arm’s length at the shooter’s ear. To perform this measurement, a shooter fired several rounds with his ear positioned next to a Larson-Davis 1/2-inch measurement microphone connected remotely via cable to a Larson-Davis 2800 real-time spectrum analyzer. The analyzer was set to measure the maximum rms sound pressure level in dB, using a 0.015-second time constant. A typical sample 1/3-octave band spectrum for a gunshot as measured from arm’s length at the shooter’s ear is shown in Figure 16. The overall maximum rms level reached during the burst is 117.3 dBZ or 115.6 dBA. Additional gunshot spectra were obtained to quantify the sound levels at the subject’s ear when the shot occurred from the shooter’s positions. Thus, with the microphone at the subject’s ear position, and with the gun located at shooter’s position C on the circle at 150 feet away, the measurement shown in Figure 17 was obtained, with the overall result being an rms level of 96.3 dBZ or 96.7 dBA. As stated earlier, the true peak levels ranged from 100 to 104 dB at the subject’s ear.

Shooters wore camouflage clothing and hearing protection (triple-flanged earplugs), and aimed the gun to a level just above the subject’s head position when firing.

Figure 15. Test setup for measuring sound level of 22-caliber long-rifle blanks, as measured at shooter’s ear.
Figure 16. Spectrum, dBZ(sum) and dBA of gunshot at shooter's ear per Figure 15; pistol at arm's length, 22-caliber long-rifle cartridge; measurement taken with Larson-Davis 1/3 octave band analyzer, Lmax using 0.015-second time constant.

Figure 17. Spectrum, dBZ(sum) and dBA of gunshot at subject's ear with pistol at 150 feet away at shooter's position, 22-caliber long-rifle cartridge; measurement taken with Larson-Davis 1/3 octave band analyzer, Lmax using 0.015-second time constant.
Data Collection: Screening Session

During a screening session that was separate from the actual experiment, the subject read and signed an informed consent document approved by the Virginia Tech Institutional Review Board, provided a brief history of noise exposure and use of hearing protection, and then underwent the otoscopic inspection and audiometric test, using a Beltone Model 119 pure-tone air conduction audiometer, as described in the Participants section above. Also during this session, the participant was briefed on the general procedures of the experiment, but not given instruction on the specific tasks or HPEs to be used. Following the experimenter’s review of the audiogram data, the subject was classified as normal hearing or hearing-impaired, according to the operational definitions given in the Participant section above, and this classification was recorded (see Appendix 1 for all audiometric data).

Data Collection: Experimental Session

There was a one experimental session lasting 4 to 5 hours for the original experiment, and for those subjects also participating in the modified device experiment, there was a separate experimental session on a different day lasting 3 to 4 hours. Each experimental session included factorial combinations of the HPE/listening condition and the noise level independent variables (per the experimental designs shown in Figures 1 and 2). During the experimental sessions, the experimenter and shooters were in constant communications contact via Cobra two-way radios. Radio transmissions were kept to a minimum, and basically consisted of verbal notification by the experimenter of readiness for shooters to move, and of readiness to shoot by the shooters.

Familiarization and Practice Trials. Upon arrival at the testing range, the subject was briefed in the purposes and procedures of the experiment, shown the guns and blanks, and allowed to ask questions, which were answered by the experimenter unless the answer could have biased the results of the study. Subjects were shown the 16 target signs (Figures 9, 10), shown where to stand on the mat and face the flag (Figure 8) and target sign #1, and then given specific instructions (Appendix 3) about verbalizing aloud the target sign which most closely corresponded to the gunshot just heard, as accurately and as quickly as possible.

The subject was next fit with a digital recorder, which enabled an audio recording to be made for the full session. This recorder captured the experimenter’s voiced documentations of each condition just prior to its implementation, as well as the gunshot and the subject’s verbal response on each trial. The recordings enabled post-data-collection checks to be made against the experimenter’s handwritten recordings of the subject’s target sign responses on a data sheet, and also enabled the time between gunshot and subject’s response to be measured, corroborating the digital stopwatch timing of the subject’s response time that was performed in real time by the
The subject was then practiced in a familiarization task that included all elements of the protocol for each gunshot localization trial. This familiarization task required him/her to localize 2 gunshots in the open ear condition, for the particular noise condition (rural ambient or 82 dBA military truck noise) which was assigned as coming first in the randomization order.

**Gunshot Localization Trials.** Next, the session turned to actual data collection trials, wherein, as previously discussed, the presentation order of the experimental variables and the gunshot locations was accomplished in a pre-determined random fashion, to avoid order and practice effects. For each individual experimental design cell of Figures 1 and 2 (i.e., combination of HPE/listening condition and noise level), the experimenter used a unique data sheet which prompted her on the correct random ordering. Likewise, each shooter had a set of cue cards which guided him/her in the correct random ordering of gunshots from prescribed azimuthal positions.

At the beginning of each test condition, the participant was first fit by the experimenter with the assigned HPE (or open ear was used), depending upon the condition. For the Combat Arms earplug and the Etymotic BlastPlgs, an AEARO Eargage was used to first estimate the ear canal size, and then, by visual inspection and manual manipulation, the experimenter selected the triple-flanged eartip sizes which best fit the subject’s canals. For the Peltor Com-Tac II earmuff, the gain was set to the maximum setting, the Combat Arms plug was set to the open (level-dependent) position, and the BlastPlgs were set to their ‘Lo’ gain positions; all settings were made by the experimenter.

The subject was also fit with an occluding visor, consisting of a pair of safety glasses painted with black paint. This was used to occlude the subject between trials, while the shooters were moving to the next position, and then the experimenter instructed the subject to doff the visor, immediately after the shooters signaled by radio to the experimenter that they were in position. Also during the period in which the shooters were moving, a 75 dBA masking pink noise was played so that there was no chance of the subject hearing the shooter’s movements. A close-up view of a fully instrumented subject is shown in Figure 18, and Figure 19 depicts a subject in position, ready for the next gunshot trial.

Once the shooters notified the experimenter by radio that they were in position, the experimenter indicated to the participant to remove the visual occluding visor by stating “get ready,” and then turned the masking pink noise off. The shooter then waited for a random period of 10 to 30 seconds (to offset anticipation by the subject), and then fired one shot from the prescribed position. Upon a shot being fired, the subject was allowed to turn his/her head and body, and he/she verbalized the number of the sign associated with the direction from which he/she thought the shot originated. The experimenter measured the response time by stopwatch, recorded this response on the data sheet,
and then turned on the masking pink noise to prepare for the next gunshot trial. At this point, the shooters moved to their next positions.

A complete step-by-step sequence of the experimental protocol for each gunshot trial appears in Appendix 5.

Figure 18. Instrumented subject, with digital recorder and dosimeter microphones on shoulder, occluding visor, and an Etymotic BlastPlg in ear.
Figure 19. Instrumented subject, standing on mat and facing target sign #1, in preparation for a gunshot trial.
In each experimental session in the original experiment, each subject performed the localization task in 160 experimental gunshot trials. There were 16 trials (2 per each of 8 azimuthal shooter positions) for each of the 2 noise conditions per HPE, for a total of 32 per HPE. In the original experiment, there were 5 HPE/Listening conditions (see Figure 1), resulting in the 160 trials (32 x 5).

In each experimental session in the modified device experiment, each subject performed the localization task in 128 experimental gunshot trials. Again, there were 16 trials (2 per each of 8 azimuthal shooter positions) for each of the 2 noise conditions per HPE, for a total of 32 per HPE. In the modified device experiment, there were 4 HPE/Listening conditions (see Figure 2), resulting in the 128 trials (32 x 4).

Immediately after the 32 gunshot trials for each HPE/Listening condition, the subject was seated while filling out the Rating Scale of Appendix 4, and while still wearing the assigned HPE (or with open ears, if that was the assigned condition). Then, the subject was given a very short break before the assigned HPE for the next condition was donned.

Overall, the experimental sessions lasted 4-5 hours for the original experiment, and 3-4 hours for the modified device experiment. Following the completion of all trials, the subject was debriefed and paid $15 per hour for their driving time and experimental participation time, as well as a mileage reimbursement.

DATA REDUCTION AND DEPENDENT MEASURES

Dependent Measures of Localization Performance

The primary performance measure in this experiment was the accuracy with which subjects localized each gunshot by verbalizing which target sign most closely corresponded to each gunshot’s direction. As stated above, for each shooter position, 2 gunshots were made for each experimental condition, comprising redundant trials.

Five objective, quantitative dependent measures were then obtained from the subjects’ verbalizations of target signs after each gunshot to assess participants’ localization performance, as follows:

1) localization absolute deviation in degrees from the shot’s azimuthal direction, i.e., the error in judgment from the shot’s actual direction, which ranged from 0° to 180° and was measured in 22.5° increments, as dictated by the target sign locations in that increment;
2) *percentage correct localization within* $\pm 22.5^\circ$, i.e., any response within one target sign (i.e., within $22.5^\circ$) to the right or left of the shot’s actual azimuthal direction was considered correct;

3) *percentage correct localization exact*, i.e., any response not exactly at the target sign corresponding to the shot’s correct actual azimuthal direction was considered incorrect;

4) *percentage of front-rear localization errors*, i.e., a front-rear error occurred when a shot that emanated from within an angle of $\pm 45^\circ$ from directly to the front of the subject was judged as coming from the rear, and vice-versa; by this criteria; for a shot coming from any one of the 3 sign positions to the front or rear of the subject, which were scored as correct if the subject gave any one of the 5 sign numbers in that 90-degrees of arc ($15, 16, 1, 2, 3$ or $7, 8, 9, 10, 11$) on the correct side, there were 5 remaining sign positions on the opposite side that were considered incorrect, this is depicted in the right panel of Figure 20; and

5) *percentage of right-left localization errors*, i.e., a right-left error occurred when a shot that emanated from within an angle of $\pm 45^\circ$ from directly to the right of the subject was judged as coming from the left, and vice-versa; by this criteria; for a shot coming from any one of the 3 sign positions to the right or left of the subject, which were scored as correct if the subject gave any one of the 5 sign numbers in that 90-degrees of arc ($11-15$ or $3-7$) on the correct side, there were 5 remaining sign positions on the opposite side that were considered incorrect, this is depicted in the left panel of Figure 20.
Localization Data Reduction and Graphing of Results

The subject’s target sign vocalizations were recorded on a data sheet and reduced to a Microsoft Excel spreadsheet. In each session for each participant, for each combination of hearing protector/listening condition and masking noise condition, the two redundant trials obtained for the factorial combination of conditions were averaged together. Then for each subject, that 2-trial average value was used as the observation value in computing the means and 95% confidence intervals about the mean for developing the graphs which follow.

Because of the small sample sizes (i.e., n < 30 subjects in all cases: n = 13 for the original experiment and n ≤ 6 for the modified device experiment), the t-distribution was used in computing the 95% confidence intervals. Therefore, for the devices that were modified after the original experiment, which were tested with a few subjects ranging from 3-6 by noise type or 0-5 by hearing ability, the confidence limits are large in certain instances; of course, this was in part caused by the large effect of sample size on the confidence interval when using the t-distribution. For the original experiment (with “unmodified” devices), there were 13 subjects by noise type, and 9 normal hearing and 4 hearing-impaired; therefore, the confidence limits are generally more narrow than with the modified devices. In all graphs, the actual number of subjects that were used in

Figure 20. Dependent measures of right-left and front-rear localization errors, as derived from subject’s gunshot localization response. Explanations of measures provided in detail in text.
computation of the means and confidence intervals is shown below the horizontal axis.

Note that all of the ensuing data graphs in the next section follow the same formatting convention; that is, the dependent measure (as defined above) is on the vertical axis, and the HPE/listening condition is on the horizontal axis. The original set of 5 hearing protection/listening conditions is shown as a group on the left, and the modified set (3 modified EB-15-Lo devices and a second open-ear measurement) are shown as a group on the right. As previously noted, the number of subjects in each condition is shown under the horizontal axis, corresponding to the bars for that condition. The mean value for each bar appears at the top of the bar, while the 95% confidence limits, again based on the $t$-distribution, are shown as brackets above and below the means. With the confidence limits shown, and lacking equal subject numbers and ordering commonality across the original and modified experimental designs, the reader may simply use the confidence limits on the ensuing graphs to visually gauge statistical differences between conditions across the two experiments. However, strong caution is advised in drawing strict conclusions from the ensuing localization accuracy graphs. This especially is noted in the case of the means for the modified devices, shown on the right side of the horizontal axes, which were based on very small sample sizes due to limited availability of subjects returning from the original experiment, so any conclusions drawn about the modified devices’ effect on localization performance would be tenuous at best.

**Dependent Measures from Rating Scales**

The data from each of the 6 rating scales appearing as Appendix 4 were tabulated separately and plotted for each HPE and the open-ear condition. The reader is referred to the actual scales in Appendix 4 for an understanding of the directionality of the numerical scales, as well as each bipolar scale descriptor. The data graphs for each rating scale appear in Appendix 6, and these graphs were constructed using the same convention for computing the means and 95% confidence intervals about the mean, based on the $t$-distribution for small sample sizes. Again, the reader is cautioned that the mean values for the modified devices, shown on the right side of the horizontal axes, were based on very small sample sizes due to limited availability of subjects returning from the original experiment; therefore, any conclusions drawn about the ratings for the modified devices would be tenuous at best.
LOCALIZATION DATA RESULTS IN GRAPHICAL FORM

Refer to text above for descriptions of experimental conditions, variables, and dependent measures shown on axes in the ensuing graphs.

Figure 21. Noise type (rural ambient vs. 82 dBA military truck idle) graphs for mean degrees of absolute value of deviation where deviations from the actual response are 22.5 degree increments between 0 and 180. Means are given above bar; brackets represent 95% confidence interval based on t-distribution.
Figure 22. Noise type (rural ambient vs. 82 dBA military truck idle) graphs for mean percent correct response where deviations of 22.5 degrees (one sign number to the left or right of the correct response) ARE counted as correct. Means are given above bar; brackets represent 95% confidence interval based on $t$-distribution.
Figure 23. Noise type (rural ambient vs. 82 dBA military truck idle) graphs for mean percent correct response where deviations of 22.5 degrees (one sign number to the left or right of the correct response) ARE NOT counted as correct. Means are given above bar; brackets represent 95% confidence interval based on $t$-distribution.
Figure 24. Noise type (rural ambient vs. 82 dBA military truck idle) graphs for mean percent of front-rear and rear-front errors. A front-rear localization error occurred if the shot came from or within an angle of +/- 45° degrees from directly in front of the participant (i.e., from actual shooter positions 1, 3, 15) and was perceived to be to the rear of the participant (i.e., responses 7, 8, 9, 10, 11) and vice-versa. The percent of front-rear errors was the number of errors committed out of the total possible front-rear errors. Means are given above bar; brackets represent 95% confidence interval based on t-distribution.
Figure 25. Noise type (rural ambient vs. 82 dBA military truck idle) graphs for mean percent of right-left and left-right errors. A right-left localization error occurred if the shot came from or within an angle of +/- 45° degrees from directly to the right of the participant (i.e., from actual shooter positions 3, 5, 7) and was perceived to be to the left of the participant (i.e., responses 11, 12, 13, 14, 15) and vice-versa. The percent of right-left errors was the number of errors committed out of the total possible right-left errors. Means are given above bar; brackets represent 95% confidence interval based on t-distribution.
Figure 26. Hearing ability (normal vs. impaired) graphs for mean degrees of absolute value of deviation where deviations from the actual response are 22.5 degree increments between 0 and 180. Means are given above bar; brackets represent 95% confidence interval based on $t$-distribution.
Figure 27. Hearing ability (normal vs. impaired) graphs for mean percent correct response where deviations of 22.5 degrees (one sign number to the left or right of the correct response) ARE counted as correct. Means are given above bar; brackets represent 95% confidence interval based on *t*-distribution.
Figure 28. Hearing ability (normal vs. impaired) graphs for mean percent correct response where deviations of 22.5 degrees (one sign number to the left or right of the correct response) ARE NOT counted as correct. Means are given above bar; brackets represent 95% confidence interval based on t-distribution.
Figure 29. Hearing ability (normal vs. impaired) graphs for mean percent of front-rear errors. A front-rear localization error occurred if the shot came from or within an angle of +/- 45° degrees from directly to the front of the participant (i.e., from actual shooter positions 1, 3, 15) and was perceived to be to the rear of the participant (i.e., responses 7, 8, 9, 10, 11) and vice-versa. The percent of front-rear errors was the number of errors committed out of the total possible front-rear errors. Means are given above bar; brackets represent 95% confidence interval based on t-distribution.
Figure 30. Hearing ability (normal vs. impaired) graphs for mean percent of right-left and left-right errors. A right-left localization error occurred if the shot came from or within an angle of +/- 45° degrees from directly to the right of the participant (i.e., from actual shooter positions 3, 5, 7) and was perceived to be to the left of the participant (i.e., responses 11, 12, 13, 14, 15) and vice-versa. The percent of right-left errors was the number of errors committed out of the total possible right-left errors. Means are given above bar; brackets represent 95% confidence interval based on t-distribution.
QUALIFIED CONCLUSIONS FROM THE GRAPHS

To reemphasize what was stated previously:

With the confidence limits shown, and lacking equal subject numbers and ordering commonality across the original and modified experimental designs, the reader may simply use the confidence limits on the ensuing graphs to visually gauge statistical differences between conditions across the two experiments. However, strong caution is advised in drawing strict conclusions from the ensuing localization accuracy graphs. This especially is noted in the case of the means for the modified devices, shown on the right side of the horizontal axes, which were based on very small sample sizes due to limited availability of subjects returning from the original experiment, so any conclusions drawn about the modified devices’ effect on localization performance would be tenuous at best.

The qualified conclusions which follow are based solely on the visual interpretation of the confidence limits on the graphs. Inferential data analyses are recommended before firm conclusions are drawn. Finally, it must be kept in mind that the modified device experiment, for which the results are depicted on the right side of each graph, was performed as a quick study after two non-production EB-15 SLA prototypes and one tubed-retrofit prototype were constructed while the original experiment was still in process. Thus, this modified device experiment can only be considered in the light that it was an exploratory study. In other words, the modified device study was undertaken only to explore whether (or not) relocation of microphone ports and/or a low-profile EB-15 housing shape might lead to benefits in auditory localization, as compared to the original BlastPlg design which has a longer earplug shape with the microphone port located beyond the outer vertical plane of the pinnae. Furthermore, given the small number of subjects run on the modified devices, no statistical analyses or conclusions are justifiable.

Next, with all these cautions as a preface, the following general conclusions are offered.

1) On most measures and across the two noise conditions, both of the Etymotic BlastPlg devices (EB-1-Lo, EB-15-Lo) exhibited localization performance that was close in line with the level-dependent end of the Combat Arms earplug, which is the most common enhanced hearing protector currently used by the U.S. military. In all cases, the open ear condition ranked as best in performance when compared to these 3 earplug-configuration devices.

2) The presence of the 82 dBA military truck masking noise did not result in marked decrements in localization performance over that obtained in the rural quiet ambient for most of the HPEs, with the exception of the Peltor Com-Tac II (Figures 21, 22, 23, and 24), where decreased performance in military truck noise occurred.
3) In nearly all graphs and on all measures of localization performance, the Peltor Com-Tac II earmuff-based device ranked as the lowest in localization performance when compared to the two Etymotic BlastPlg devices, the AEARO Combat Arms earplug (level-dependent end), and the open ear. Perhaps the detriment occurred due to the Com-Tac II’s full coverage of the pinnae of the ear and/or its particular gain/compression behavior. In any case, the Com-Tac II, at least based on these azimuthal localization data, cannot be recommended with confidence for use in military situations where localization of gunshots is of critical importance to the soldier.

4) On the measure of right-left errors, as defined operationally herein (Figure 20), and across all HPEs as well as the open ear, there were very few confusions of whether gunshots were coming from the right or left. Right-left confusions were substantially fewer than front-rear confusions when using almost any HPE, perhaps serving as evidence of the importance of interaural time and interaural level difference cues in localization, as well as the need for turning the head to aid in localization by employing these acoustical cues. Furthermore, it was somewhat surprising that the hearing-impaired individuals did not show a distinct disadvantage as compared to normal hearers when it came to discerning the right-left orientation of gunshots. However, this result should be interpreted with care, due to the specific audiometric profile of hearing loss in these individual subjects, as well as the small number (4) of hearing-impaired subjects.

5) The changes to the EB-15 earplug body shape (i.e., from longitudinal to low profile) and the relocation of microphone ports on the modified devices did not appear to render marked improvements in localization on any measure, as compared to the unmodified EB-15. Nonetheless, it is worth noting that based on Figure 24, albeit with caution, the front-rear errors with the two modified EB-15’s (EB-15-Lo MIC IN and EB-15-Lo TUBE) which included microphone inlet ports near the ear canal rim, were lower than those with the other modified device (EB-15-Lo MIC OUT), which incorporated a microphone port on the outside end of the device body, thus positioning the microphone slightly outside the concha bowl. Furthermore, when examining only the mean bars (i.e., solid) for the truck noise condition, the EB-15-Lo MIC IN and EB-15-Lo TUBE, with their microphones near the ear canal, appeared to offer better front-rear localization performance than the original EB-1-Lo and EB-15-Lo devices, as well as the EB-15-Lo MIC OUT modified device, all 3 of which had outward-facing microphones mounted beyond the concha bowl. In any case, these results are based on only 3-6 subjects depending upon noise condition, and should be taken with caution.

6) **Future research implications.** Localization is but one, albeit a very important, auditory task that is associated with military soldier situation awareness. Clearly, more research is justified, if for no other reason that it was determined via these experiments that there are differences among HPE devices as to their effect on auditory localization of gunshots, and that certain HPEs degrade localization over that achieved with the open ear. Thus, the soldier will have a somewhat unnatural
auditory experience that can affect mission performance. Also, results from the modified device experiment give implication for a potential trend in fostering localization, at least on some metrics, when the sound inlet port is located close to the ear canal rim; this issue warrants further research inquiry. *Furthermore, this research needs to be extended to the auditory task of detection distances and detection thresholds for critical military signals, including threats.*

**REFERENCES CITED**


### APPENDIX 1:
#### Hearing Levels of Subjects as Determined via Air-Conduction Pure Tone Audiometry

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**Classification**
- Normal
- Impaired
APPENDIX 2: Input-Output Characteristics of Etymotic Research EB1, EB15 BlastPlgs (courtesy of Dr. Mead Killion of Etymotic Research, Inc.)

Input-Output Characteristics of EB1

Input-Output of EB1 Switch Lo Position

Blue curve: Lo Switch position
EB1 is acoustically transparent from 0 to 115 dB SPL. No insertion loss: The wearer hears as with open ears.

Dashed red curve: Turned off
EB1 provides approximately 35 dB of attenuation at all levels.

Input-Output of EB1 Switch Hi Position

Green curve: Hi Switch position
EB1 is acoustically transparent between 90 and 115 dB SPL and provides 15 dB high-frequency boost for quiet sounds below 60 dB SPL.

Dashed red curve: Turned off
EB1 provides approximately 35 dB of attenuation at all levels.
APPENDIX 2 (continued):
Input-Output Characteristics of Etymotic Research EB-1, EB-15 BlastPlgs
(courtesy of Dr. Mead Killion of Etymotic Research, Inc.)

Input-Output Characteristics of EB15

**Input-Output of EB15 vs. Combat Arms**

**Blue Curve:** Lo switch position
EB15 acts as a 15 dB earplug for loud sounds between 85 and 115 dB SPL, where it acts somewhat like the Combat Arms earplug “open orifice” (dashed black curve).

EB15 is acoustically transparent, however, for quiet sounds below 60 dB SPL and provides superior blast protection in the 120-190 dB SPL range.

**Dashed red curve:** Turned off
EB15 provides approximately 35 dB of attenuation, similar to the Combat Arms earplug “closed orifice.”

**Green Curve:** Hi switch position
EB15 is transparent for loud sounds between 85 and 115 dB SPL, EB15 provides 15 dB gain for quiet sounds between 0 – 60 dB SPL, and provides blast protection in the 120-190 dB SPL range.

**Dashed red curve:** Turned off
EB15 provides approximately 35 dB of attenuation, similar to the Combat Arms earplug “closed orifice.”
APPENDIX 3
Directions to Subjects: Experimental Session

Directions to subjects read prior to practice trial, and again summarized briefly prior to experimental trials:

Gunshots, always using blanks (that is, non-bullet ammunition) will always come from shooting positions in a large circle out in the forest around you. Note the signs labeled from 1 to 16 in a circle around you. These are the 16 shooting positions that correspond to the directions from which gunshots may be fired. When the experimenter speaks to you to “get ready,” you should immediately remove your black glasses, because this is an indication that a blank gunshot is about to occur. You should always face and look forward at Sign #1 underneath the American Flag until you hear the gunshot. After the gunshot, you may turn your eyes, head, and body as needed, but always stay on the carpet mat.

Immediately upon hearing the gunshot, you should indicate the direction that you heard it come from by quickly and loudly stating the # of the sign (from 1 to 16) that most closely corresponds to its direction. You are being scored on both your accuracy of locating the direction of the gunshot, which is most important, as well as your speed in stating that direction by loudly saying the number of the sign which most closely corresponds to that direction. Please keep in mind that gunshots can come from any one of the 16 directions, and may or may not come from some of the directions during any given set of tests. That is, you may or may not need all 16 signs to indicate directions during a set of tests.

Also, if you happen to see or hear someone in the woods, you should ignore that and not rely on it to decide upon a gunshot’s direction. Those individuals may or may not be the shooters, and they have other roles in the experiment. Always rely strictly on what you HEAR as the direction of the gunshot, and loudly state your answer as a sign number as accurately and quickly as possible.

Remember not to adjust your hearing protectors during the tests. If a protector starts to feel loose or has any other problem, inform the experimenter.

Again, always face toward sign #1 and the American Flag until after you hear the gunshot, and then you may immediately move your head, eyes, and body to locate and state the sign # that most closely corresponds to the gunshot’s direction.

Do you have any questions?
APPENDIX 4
Rating Scale for Post-HPE/Listening Condition Subject Self-Report Ratings

1. Please rate how this hearing protection device (or open ear) condition interfered with your ability to localize the gunshots.

2. Please rate how confident you were about your ability to locate the gunshots in this hearing protection device (or open ear) condition.

3. Please rate how well-protected your hearing was in the presence of gunshots when using this hearing protection device (or open ear) condition.

4. Please rate how difficult it was to judge the location of the gunshots in this hearing protection (or open ear) condition.

5. Please rate how comfortable this hearing protection device (or open ear) condition was while wearing it during the experiment.

6. Please rate how easy it was to communicate with the experimenter while wearing this hearing protection device (or open ear) condition during the experiment.
APPENDIX 5
Step-by-Step Sequence of the Experimental Protocol for each Gunshot Trial

BEFORE TRIAL: All noises calibrated to levels: 82 dBA for military truck noise, 75 dBA for between-trial masking pink noise. Subject (S) is refamiliarized with instructions for experiment, shown the target signs, fitted with proper earplug for earplug-type HPEs, fitted with HPE by experimenter (E), gain is adjusted to proper setting by E, S is fitted with dosimeter which is cleared and turned on to run, and then walked to the position where he/she will STAND during trials, S is fitted with digital recorder. Shooters (Str) prepare by loading pistols with blanks, checking 2-way radios, and obtaining cue cards to guide shot sequencing.

1. S is always told to face toward 0-degrees (pos 1 under flag) at beginning of trial, and verified by E (but can move head and turn around once shot is made). Digital recorder is in the ON position and E vocalizes subject number, HPE number, noise condition, trial number, and "START." Recorder then left running for capture of gunshot and S’s verbalization of sign for response time. Military vehicle noise is turned on (i.e., CD ON) if that is assigned condition. (NOTE: if Military vehicle noise is the assigned noise condition, 2 trials at all 8 positions are completed in that condition, before moving to the Rural Ambient noise condition)

2. E occludes S visually by flipping visor down, and reminds subject to flip it up again immediately after the shot, so that S can verbally state the number on the sign corresponding to the direction that S thinks the shot came from.

3. E presses remote control to start 75 dBA pink noise on CD to mask Strs' movements, then notifies the Strs with a call button on the communication device (2-way radio) which produces a ring on each shooter's radio notifying them it is safe to move to the next position (NOTE: This noise occurs in both of the environmental [military truck and rural ambient] noise conditions, and is ONLY ON while shooters are moving, to mask their movements. It has nothing to do with the independent variable of masking noise.)

4. Strs move quickly to their next assigned positions when they hear the call sign from their communication device.

5. When reaching their position, the Str that shoots next calls in first "shooter # ready or in position", then numerically sequential shooters confirm their readiness at to position in sequence. This procedure serves as a check to make sure that the Str sequence is accurate (i.e., the other shooters will correct the first Str when there is an error), it also allows the firing Str to get into position for firing with minimal time between all Strs' confirmation, minimizing time delay errors that may result in the experimenter not proceeding to step 6.

6. When the last Str confirms his readiness, E states “GET READY” to the subject, and then presses remote control to stop 75 dBA pink noise on CD. S immediately flips up visor

7. The firing Str waits a random interval of 10-30 seconds to ensure that the E has performed step 6, and that the subject cannot anticipate the exact timing of the shot. E starts stopwatch upon gunshot.

8. Upon hearing the shot S vocalizes the sign # (1-16) most closely corresponding to the angle of the shot. E stops the stopwatch to measure the response time, and then records S’s response.

9. E vocalizes “END” to signify the end of the trial.

10. Sequence begins again for next trial at Step 1.

11. Once the assigned HPE is run through both of the noise conditions, all noise is turned off and the S completes the rating scale for that HPE. Strs reload and prepare for next experimental condition.
APPENDIX 6
Graphs of Rating Scale Data from Post-HPE/Listening Condition Subject Self-Report Ratings

These graphs represent data from each of the 6 rating scales of Appendix 2, which were tabulated separately and plotted for each HPE and the open-ear condition. The reader is referred to the actual scales in Appendix 2 for an understanding of the directionality of the numerical scales, as well as each bipolar scale descriptor. The data graphs were constructed using arithmetic means and 95% confidence intervals about the mean, based on the $t$-distribution for small sample sizes. The reader is cautioned that the mean values for the modified devices, shown on the right side of the horizontal axes, were based on very small sample sizes due to limited availability of subjects returning from the original experiment; therefore, any conclusions drawn about those ratings would be tenuous at best.
The bar chart shows the comparison of 'How Easy to Communicate' across different conditions. The conditions include Combat Arms-open nonlinear, Petitor Com-Tac II full beam, 1st Open Ear, 2nd Open Ear, EB 15-lo MIC IN, EB 15-lo MIC OUT, Tubed Mic-to-Cnaal EB 15-lo.