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Performance Assessment of Passive Hearing Protection Devices

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Interim Report

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NOTICE AND SIGNATURE PAGE

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14. ABSTRACT
Military personnel working in operational environments could be exposed to both continuous and impulsive noise while performing tasks such as voice communication, auditory detection and localization. The performance of these tasks is critical to mission success and survival. An objective assessment of the performance of the device provided to troops is essential. Passive hearing protectors, capable of attenuating both continuous and impulsive noise, have been designed to reduce the risk of hearing damage to our troops. Preservation of ambient listening capabilities and situational awareness is necessary for many military operations. Twelve passive earplugs were assessed for: continuous noise attenuation, impulsive peak insertion loss, sound localization, auditory detection, and subjective comfort. A rank order of performance was developed per assessment. These assessments found that passive hearing protectors that provide exceptional noise attenuation have a higher likelihood of negatively affecting sound localization and auditory detection performance and thereby reducing situation awareness.

15. SUBJECT TERMS
Passive hearing protection, level dependent, noise attenuation, localization, auditory detection, blast, impulse, continuous

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

Passive hearing protectors have been used for decades to reduce the risk of noise induced hearing loss by reducing the level of noise at the ear. Level dependent hearing protectors, capable of attenuating both continuous and impulsive noise, have been designed more recently to reduce the risk of hearing damage while preserving ambient listening capabilities and situational awareness. Today's military personnel are exposed to both continuous and impulsive noise, and it is mission critical that accurate and objective assessments of the hearing protection equipment be conducted. The objective of this study was to assess twelve commercially available passive earplugs for: continuous noise attenuation, impulsive peak insertion loss, sound localization, auditory detection measured using an aurally guided visual search task, and subjective comfort. A rank order of the performance of the devices was developed relative to the performance parameters. In general, the performance of the devices varied dependent on the parameter being measured. No single device scored high for all parameters. For example, hearing protectors that provided higher noise attenuation had poorer performance in sound localization and auditory detection, thereby reducing situational awareness. The expected ambient noise environment and the task to be performed should be considered, when selecting a device, so that the device that provides adequate hearing protection performance while maintaining or improving the performance of voice communication, auditory detection and localization, and the desired level of situational awareness.

1.0 INTRODUCTION

Military ground operations take place in complex environments that necessitate creating a balance between operational effectiveness and personnel safety. The goal of effectively protecting the hearing of personnel has been complicated by the need for Marines to maintain access to acoustic cues in the ambient environment (Figure 1). Firing even a small number of rounds from a weapon can cause temporary hearing loss equivalent to wearing an earmuff, therefore producing the undesired result of impairing the ability to monitor the environment. Repeated unprotected exposures to small arms fire that may generate these temporary changes can eventually result in permanent hearing loss. Exposures to larger weapons and blast noise can instantly cause permanent hearing loss if no protection is worn.

Figure 1. Marine ground troops

Today's military personnel often work in a wide range of unpredictable noise environments. The range and uncertainty of environment and mission results in the need for a flexible or adaptive hearing protection to ensure mission success and survival while mitigating the risk of permanent hearing loss. Wearing a hearing protection device may degrade the user's ability to localize and detect low-level sounds, which can both be critical to situation awareness. Understanding the effects of hearing protectors on localization, detection, as well as hearing thresholds provided information for an objective data based selection of hearing protection devices for the warfighter. The weighting of the various performance parameters could be modified relative to specific missions. Accurate measures of the performance of hearing protection/communication devices for a wide range of parameters were necessary to demonstrate sufficient mission capabilities. The assessment parameters included: continuous noise attenuation, impulsive peak insertion loss, sound localization error, auditory detection with localization, and subjective comfort.

2.0 BACKGROUND

Development and military use of level dependent tactical hearing protection required the development and use of new performance metrics and measurement methods[5]. These systems provided some level of ambient listening capability in an attempt to restore the localization cues disrupted by traditional passive earplugs and earmuffs[8,9,10,11,12,13]. Two metrics and measurement methods were developed to measure and quantify these effects. The first was a measure of localization error. This metric quantified the average error in degrees between the target location and the listener's response. A second metric was a measure of reaction time, time to find a visual target, when cued by a 3-D audio or spatial auditory cue. The listener must use the auditory localization information to locate and identify the target in this task. The reaction time was a salient measure of the quality of the localization cue[14,15,16,17,18].

AFRL conducts a series of measures to describe the performance of hearing protection devices. The measures included passive continuous noise attenuation, impulsive noise insertion loss, input/output gain function (for active devices), localization error with short duration (250 ms) and long duration (>1 sec) stimuli, and reaction time from an aurally guided visual search task with distractors.

3.0 METHODS

The objective of this study was to measure the performance of twelve commercially available earplugs for: continuous noise attenuation, impulsive peak insertion loss, sound localization, auditory detection, and subjective comfort. The general approach was to use ANSI standard measurement procedures for continuous noise attenuation and impulsive peak insertion loss and to use AFRL defined procedures for localization error and combined detection and localization. Performance results of these devices can and should be used to determine which protectors will be made available to the warfighters and the results may also lead to design criteria for the next generation of hearing protection devices.

The overall methods are described in the following sections. The first section describes the hearing protectors which were used in the study. The following sections describe each measurement method including a description of the subjects, the facilities, and the details of the specific measurement methods.

3.1 Passive Hearing Protectors

Eleven commercially available passive hearing protectors were chosen for this study: 3M EAR UltraFit, Allen Sound Sensor, Ear Plugz PC, Etymotic ER20 ETY, Hear Defenders DF, Howard Leight Max, Moldex PuraFit, SensGard SG26, SensGard SG31, Sonic Defenders EP3, and Sonic Defenders EP7. One prototype earplug, Hearing Armor, was also chosen for this study. Three of these twelve hearing protectors were level dependent; Sonic Defenders EP3, Sonic Defenders EP7, and Hearing Armor. Level dependent earplugs were designed to provide little attenuation for quiet sounds, thereby preserving some situational awareness, and more attenuation for loud impulsive sounds, providing protection in dangerous noise environments. The Sonic Defenders EP3 and EP7 had two settings: "open" a level-dependent setting for unpredictable noise environments, and "closed" for protection in continuous high noise environments. The Ear Plugz PC came with a cord that attached to the main cavity of the earplug and data was collected with both a "Cord" and "No Cord" condition due to a possible change in attenuation with the cord attached. In total, measurements were collected from fifteen different passive hearing protector conditions.

3.1.1 Triple Flange Earplugs

Five of the fifteen hearing protector configurations had a flange design, Figure 2. The 3M EAR Ultra Fit were triple flange earplugs connected by a cord, available in one size only. The Ear Plugz PC by EAR, Inc. were triple flange earplugs connected by a removable cord. Since the plug for the cord added mass to the earplug, a critical part of increased attenuation, this hearing protector was tested with and without the cord. The Ear Plugz PC were available in small, medium, and large. The Etymotic ER20 ETY Plugs by Etymotic Research were triple flange earplugs equipped with a filter "designed to reduce sound levels evenly across the frequency range without changing the clarity of speech" (quoted from the earplug packaging). The ER20s were available in standard and large fit. The Hear Defenders DF Dual Filters by EAR, Inc. were triple flange earplugs with filters designed to provide the "ability to hear critical sounds better while suppressing unwanted noise" (quoted from the earplug packaging). The DFs were available in small, medium, and large.

Figure 2. Triple flange earplugs

3.1.2 Foam Earplugs

Two of the fifteen hearing protector configurations were made of foam material, Figure 3. The Howard Leight Max by Honeywell were foam earplugs, available in one size only. The Moldex PuraFit were foam earplugs connected by a cord, available in one size only.

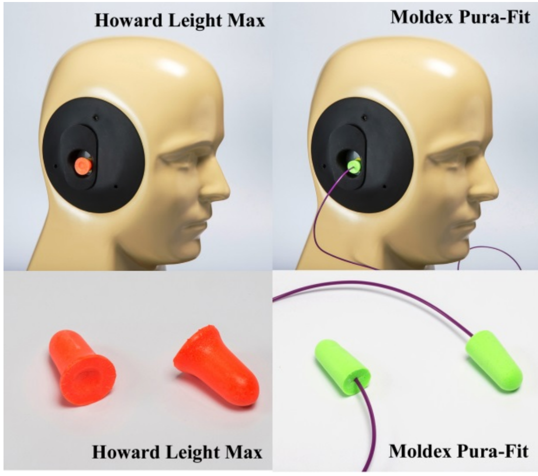

Figure 3. Foam earplugs

3.1.3 Banded Hearing Protectors

Three of the fifteen hearing protector configurations had a headband design, Figure 4. The Allen Sound Sensor, SensGard SG26, and SensGard SG31 were passive noise attenuating headbands. The headbands were designed as a hybrid between an earplug and earmuff. The hearing protector was fit by placing the headband over the crown of the head like earmuffs with the foam tips resting in the outer ear canal. The arms of the headband had resonant chambers designed to absorb sounds before they enter the ear. The chambers of the Allen Sound Sensor were similar in size to those of the SG 26. The chambers on the SG 31 were larger, to provide more protection.

Figure 4. Banded hearing protectors

3.1.4 Level Dependent Earplugs

Five of the fifteen hearing protector configurations were level dependent earplugs, Figure 5. The Sonic Defenders EP3 and EP7 by Surefire were level dependent earplugs equipped with a cap to shift between continuous and impulsive noise protection. With the cap closed, the earplug was designed to protect the user from continuous noise exposure. The open position was designed to protect the user from impulsive noise while not interfering with low level sounds (communications, etc.). The cap could be opened and closed without having to remove the plug from the ear. These earplugs also had an additional hook shape to hold the earplug into the concha bowl of the user. The EP3s were equipped with a double flange tip and the EP7s with a foam Canal Tip by Comply. Both earplugs were available in small, medium, and large. The Hearing Armor were also level dependent, triple flange earplugs with a filter designed to automatically change the attenuation performance based on the noise level (both continuous and impulsive) without having to actively open and close a cap.

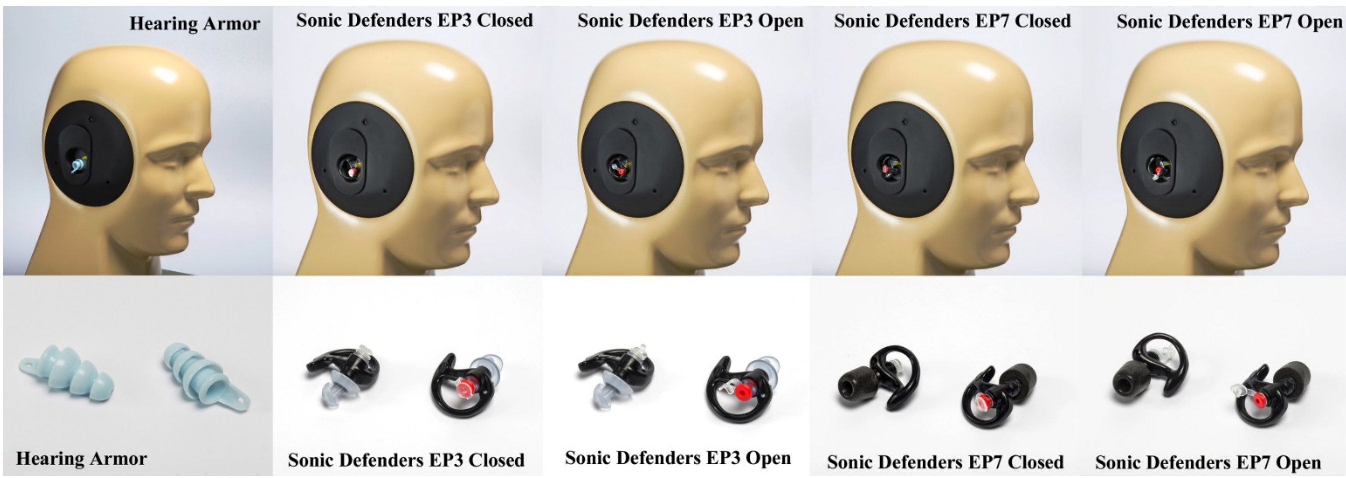

Figure 5. Level dependent earplugs

3.2 Continuous Noise Attenuation

The first part of the assessment involved measuring the continuous noise attenuation performance of the passive hearing protection devices using human subjects. All human subjects were compensated volunteers. There were ten male and ten female subjects, ranging in age from 18 to 34 years. All subjects were required to have a computer administered screening audiogram via Hughson-Westlake method, with behavioral hearing thresholds inside the normal hearing range, which was 25 dB hearing level (HL) or better from 125 Hz to 8000 Hz. Ear canal sizes were verified to be sufficient to accommodate the earplugs measured in this study.

The facility used for this portion of the study was specifically built for the measurement, analysis, and documentation of the sound attenuation properties of passive hearing protection devices. The chamber (Figure 6), its instrumentation, and measurement procedures were in accordance with ANSI S12.6-2008[1]. ANSI S12.6 consisted of measuring the occluded and unoccluded hearing threshold of human subjects using a von Békésy tracking task. The thresholds were measured two times for the unoccluded ear condition and two times for the occluded ear condition (with device in place). The real-ear attenuation at threshold for each subject was computed at each frequency, 125 to 8000 Hz, by averaging the two trials (the difference between open and occluded ear hearing thresholds). The mean and standard deviation was then calculated across all the subjects. Measurements were collected for both the closed and open condition of the

Sonic Defenders EP3 and EP7 earplugs, and the Ear Plugz PC devices with and without the cord.

Figure 6. Facility used to measure the real-ear attenuation of hearing protectors

3.3 Impulse Noise Attenuation

The objective of this portion of the assessment was to evaluate the impulsive noise attenuation performance of fifteen passive hearing protector conditions when exposed to acoustic blast (impulse noise) with high pressure levels and short durations. Impulsive peak insertion loss (IPIL) data was calculated at multiple peak noise levels ranging from 170 dB to 195 dB sound pressure level (SPL).

IPIL (i.e., reduction in peak pressure of the impulse noise) measurements were conducted to determine the effect an acoustic blast may have on the auditory system of the user. Four acoustic test fixtures (ATFs) were used simultaneously in these measurements to allow for the evaluation of different hearing protectors at one time. The ATFs were ISL-1 type heads equipped with ¼" microphones in the ear canals. Each ATF was fit with a hearing protector and was exposed to acoustic blasts, Figure 7. IPIL data was calculated at 170, 185, and 195 dB SPL peak levels. The measurements were collected in accordance with ANSI S12.42-2010[3] Methods for the Measurement of Insertion Loss of Hearing Protection Devices in Continuous or Impulsive Noise using Microphone-In-Real-Ear or Acoustic Test Fixture Procedures. ANSI S12.42 requires a measurement at 130 dB SPL and 150 dB SPL; however, measurements were conducted at 185 and 195 dB SPL which is more typical of a blast that a user may be exposed to in a military setting.

Figure 7. Acoustic test fixture with hearing protector inserted into artificial ear canals

The measurements were conducted on the test range of the French-German Research Institute of St. Louis (ISL) situated in Baldersheim, France. The test area being used for the measurements was equipped in a way to allow the detonation of an equivalent of 300g of C4™ explosive. Using this mass of explosive made it possible to initiate a shockwave with a peak pressure level of up to 195 dB SPL and an A-duration of 1.5 ms. An A-duration of an impulse signal is the time interval between impulse onset and the first crossing with the baseline.

A ¼" microphone or slender probe (tapered pencil gauge) was used to measure the free-field pressure wave according to the International Test Operations Procedures (ITOP) 4-2-822, Electronic Measurement of Airblast Overpressure and Impulse Noise.[4] Figure 8 shows the placement of the ATFs during the blast measurements. For each blast, the sound pressure level at 9 transducers was recorded. This included 8 signals from the ATFs, each equipped with two microphones and pre-amplifiers (one for each "ear drum") and 1 signal from the free-field pressure transducer (slender probe).

Figure 8: Placement of ATFs and free-field pressure transducer

Pressure measurements were recorded using 16-bit digital recorders at a sampling rate of 100 kHz. In order to visualize the movements of the hearing protectors, at least 1 high-speed video (50,000 frames per second) was recorded of the ATFs right ear at 195 dB SPL for each earplug.

Initially, an open ear measurement (no hearing protector) was conducted to calculate the free-field to ear canal transfer function using a 150 dB SPL nominal peak noise level with an A-duration of 2 ms, Figure 9. The Transfer Function of the Open Ear (TFOE) was used to determine the IPIL for each fit of the hearing protector.

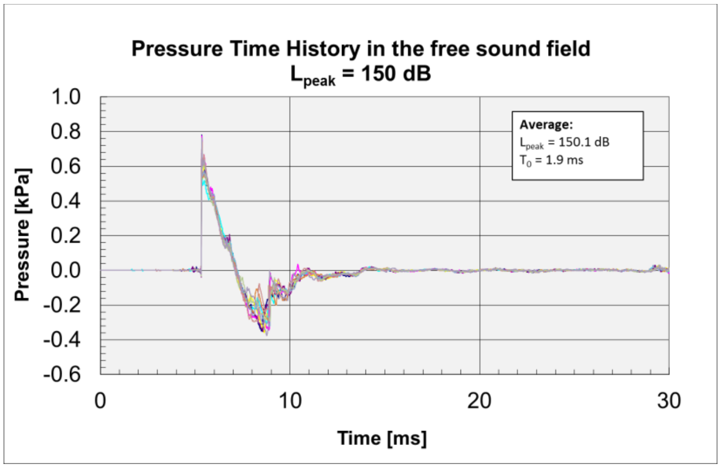

Figure 9. Pressure-time history of the impulses generated for the determination of the TFOE

For the calculation of the Insertion Loss (IL), the TFOE was calculated for all 1/3 octave-bands centered between 25 and 16 kHz. The TFOEs were used to determine the IPIL; the complex transfer function with a resolution of 6.1 Hz has been calculated. Mean TFOE for left and right ears separately are graphed in Figure 10.

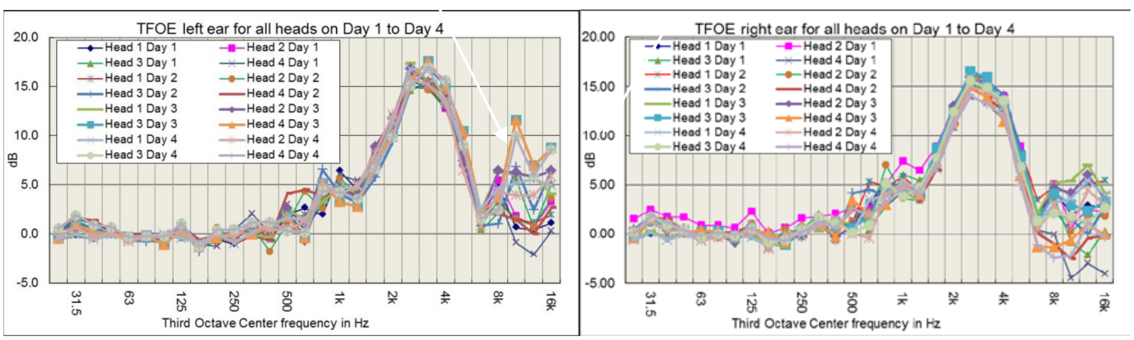

Figure 10. Mean TFOE for each head, each day, left and right ear

After the determination of the TFOE, the measurements were done with the different hearing protectors in place. Each hearing protector was measured five times at each peak noise level; each time, the hearing protector was removed and refitted or replaced by a hearing protector of the same type.

The impulse (blast) waves were generated by explosives. Figure 11 shows a schematic of the set-up. The type and the mass of explosive as well as the distance between the explosive and the ATF determined the peak noise level and the A-duration of the generated signal, Table 1.

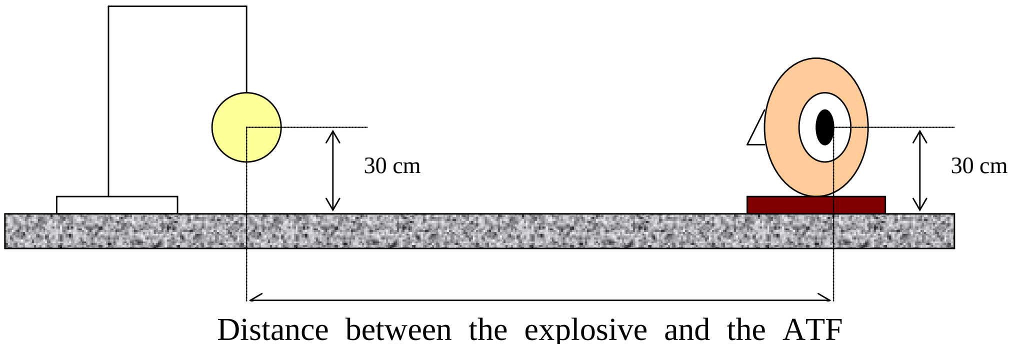

Figure 11. Schematic of the set-up of the explosive charge for the creation of a shock wave

Table 1: Type and mass of explosive and distance between ATF and explosive for different peak pressure levels and A-durations

Peak Noise Level (dB SPL)	Explosive Type	Mass (g)	Distance from ATF (m)	Measured Average A-Duration (ms)	Measured Average Peak Noise Level (dB SPL)
170	Primer (RDX 95/5)	35	6.5	2.3	170.8 (0.991 psi)
185	C4	130	3.4	2.2	184.6 (4.85 psi)
195	C4	300	2.2	1.7	195.9 (17.82 psi)

Figures 12-14 are examples of the pressure time histories of the generated sound waves and their associated 1/3 octave-band spectrum. 1/3 octave-band spectrum provides a more detailed description of the frequency content of noise which is useful when studying noise attenuating devices.

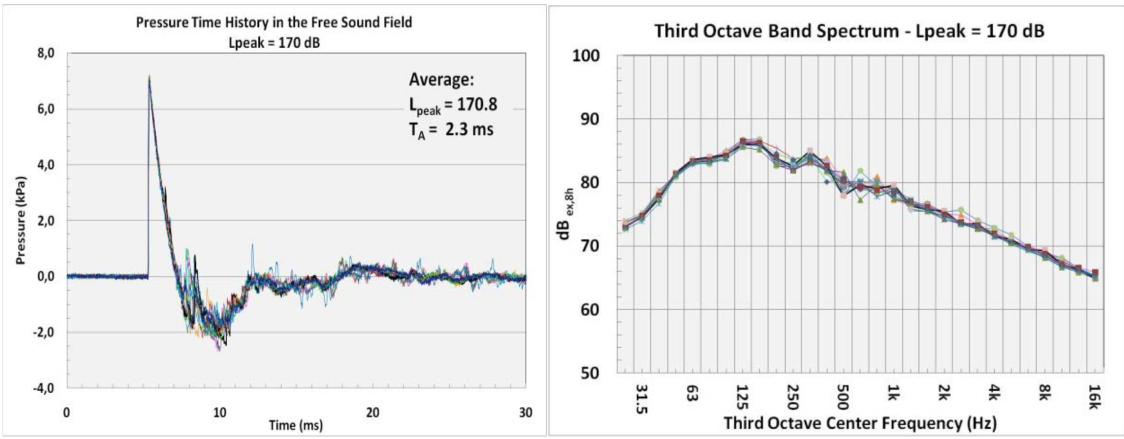

Figure 12: Pressure time history and 1/3 octave band spectrum for the 170 dB SPL noise level

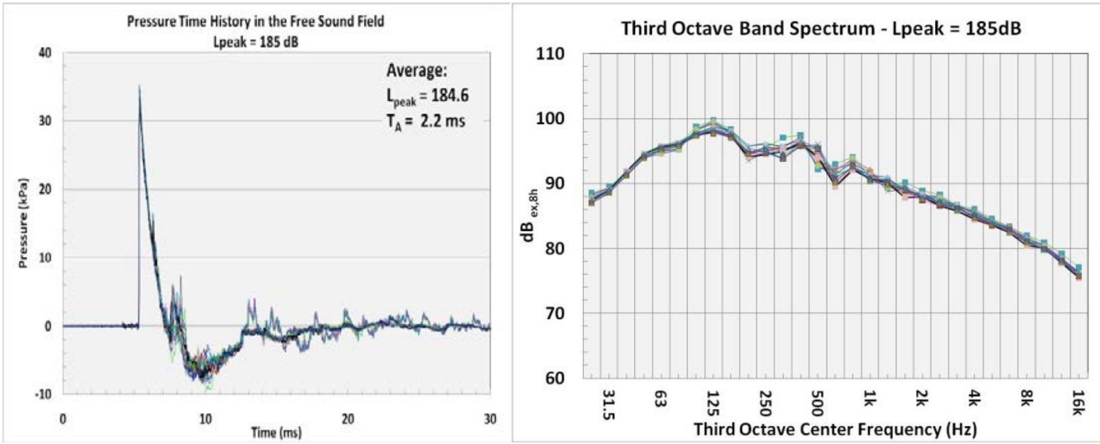

Figure 13. Pressure time history and 1/3 octave band spectrum for the 185 dB SPL noise level

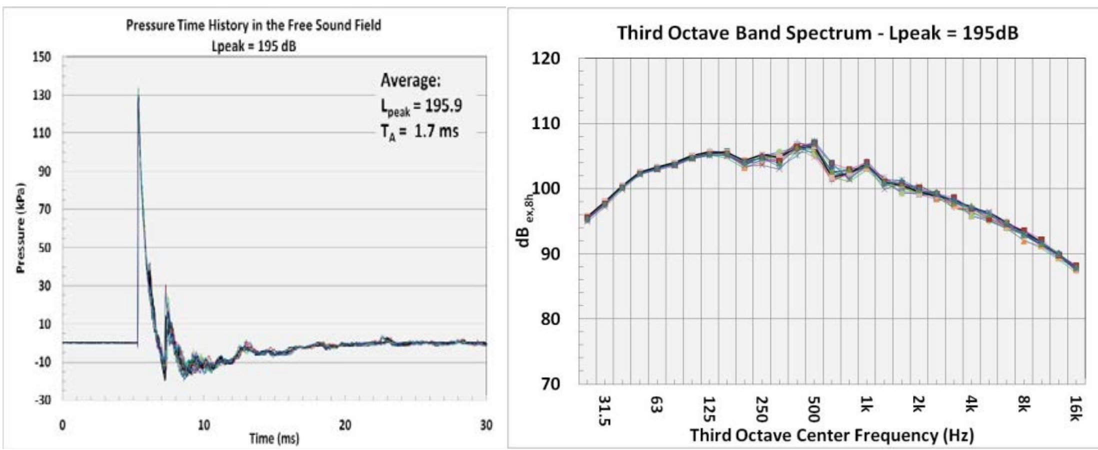

Figure 14. Pressure time history and 1/3 octave band spectrum for the 195 dB SPL noise level

3.4 Sound Localization

Localization response measurements were collected for subjects wearing 15 passive hearing protectors (12 unique hearing protectors, 3 with two settings). Eight paid volunteer subjects participated in the measurements; 4 male and 4 female subjects ranging from 18 to 32 years of age. All subjects had bilateral hearing threshold levels less than or equal to 15 dB from 125 to 8000 Hz.

All measurements were collected in the Audio Localization Facility (ALF) (Figure 15) at WPAFB. The aluminum-frame geodesic sphere is 4.3 meters in diameter with 4.5 inch loudspeakers equipped with 4 light emitting diodes (LEDs) located at each of the 277 vertices on its inside surface. The ALF apparatus is housed within an anechoic chamber. The subject stood on a platform in the center of this sphere. The platform was adjusted in order to center the subject’s head in the center of the sphere. The location of the platform has the potential to distort the signals from the speakers located directly below the subject, therefore only 237 loudspeakers, evenly distributed, above -45° elevation, were used in this study. The distance between speakers ranged roughly between 8° and 15°.

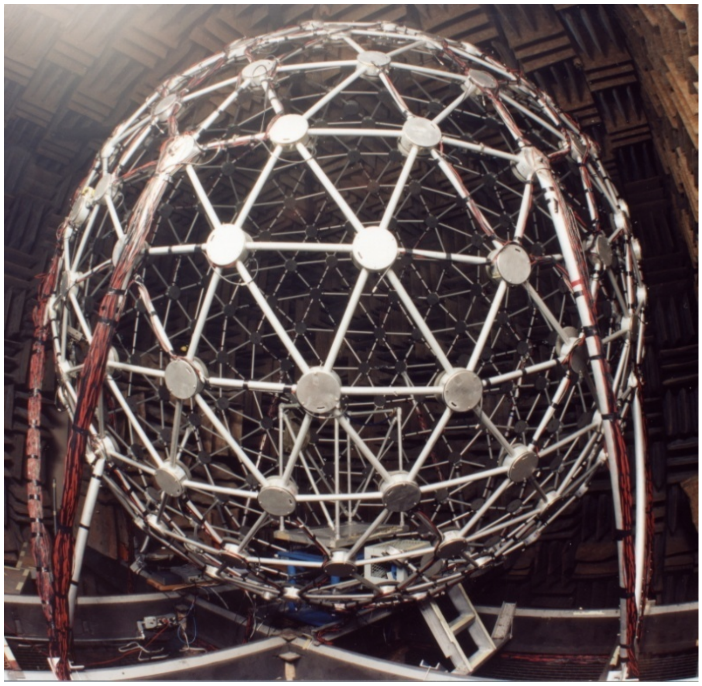

Figure 15: Auditory Localization Facility (ALF) at WPAFB

Subjects registered their responses with an Intersense IS-900 tracking system (Figure 16). The IS-900 used inertial-ultrasonic hybrid tracking technology to provide precise position and orientation information. The tracking system included a head tracker coupled with a response wand. The head tracker was mounted on the subjects' head to provide tracking data on the X, Y, and Z coordinate location of the head, as well as the yaw, pitch, and roll during the duration of each trial. The head tracker also assisted the subject in aligning his/her head to the 0° azimuth, 0° elevation speaker location to begin each trial. The response wand was equipped with a joystick and five buttons which could be programmed for various purposes depending on the task. For this study, the subjects were required to press a single button while pointing the wand at the desired response location.

Figure 16. Intersense IS-900 tracking system

The stimuli were presented to the subjects with two different conditions. In one condition, the stimulus was a 250-ms burst of broadband (200 Hz - 16 kHz) pink noise. This duration was chosen in order to reduce the possibility that a subject would initiate a head movement during the stimulus presentation. Such a movement would provide dynamic localization cues, which would result in improved performance. In addition many real world sounds encountered by the user are likely to be short duration (e.g. weapons fire, explosions). In another condition, a broadband (200 Hz - 16 kHz) pink noise was presented continuously until a localization response was made. This allowed subjects to make use of dynamic localization cues and move their heads during stimulus presentation to orient to the sound.

The subjects were randomly assigned to conditions in order to eliminate any order effects. The test conditions were the 15 passive hearing protector conditions and a control condition labeled as “Open” meaning the subject would run the task without hearing protection. The experiments in ALF were coded and executed using the MATLAB programming language by Mathworks™. For each condition the subject fit him/herself with the appropriate hearing protector according to the directions provided by the manufacturer. The fit was verified by the experimenter. The experimenter then directed the subject from the control room, where the fitting took place, into ALF. Once inside the sphere, the standing subject was raised or lowered by adjusting the height of the platform to ensure the subject’s head was in the center of the sphere.

To start each trial the subject aligned his/her head to a loudspeaker located directly in front of them (0° azimuth, 0° elevation) and pressed a button on the response wand. A stimulus was presented randomly from one of the 237 speakers in the sphere. The stimulus was either a 250 ms burst of pink noise or a presentation of continuous pink noise. The subject would then locate and select the target speaker by pointing at it with the wand and clicking the response button to enter his/her selection. The LEDs on the speakers were tracked to the wand’s movement so the subject could verify the location of his/her response. After a response was recorded, the LEDs of the target speaker were activated to give the subject feedback on his/her performance.

Each of the eight subjects completed 320 trials in the burst noise condition and 64 trials under the continuous noise condition for each of the 15 passive hearing protectors and one control condition in which no hearing protection was worn. The ratio was weighted 5:1 for burst to continuous because the short bursts more accurately represented sounds a user would encounter in a real world environment. Both burst and continuous stimuli could be presented in a single block of trials. All stimuli were presented at 65dB.

3.5 Aurally Guided Visual Search (Auditory Detection)

Auditory detection measurements were collected for subjects in 15 passive hearing protectors (12 unique hearing protectors, 3 with two settings). Eight paid volunteer subjects participated in the measurements; 4 male and 4 female subjects ranging from 18 to 32 years of age. All subjects had bilateral hearing threshold levels less than or equal to 15 dB from 125 to 8000 Hz.

All measurements were collected in the Audio Localization Facility (ALF) at WPAFB. The facility design and setup, as well as the subject fitting procedure and setup procedure once inside facility, are described in detail in the “Sound Localization” section above.

At the center of each speaker in ALF is a cluster of four LEDs. Subjects were asked to complete an aurally guided visual search task where they identified a visual target in the presence of 50 visual distracters at randomly selected positions around the sphere. For this task, the target stimulus was a cluster of LEDs in which either two or four LEDs were illuminated. The distracter stimuli were clusters of LEDs with either one or three illuminated LEDs. In addition, a 250 ms burst of broadband (200 Hz - 16 kHz) pink noise was played from the speaker at the target location at a predetermined sound level.

To start each trial the subject aligned his/her head with a designated loudspeaker located directly in front of them (defined as 0° azimuth, 0° elevation) and pressed the trigger button on the underside of the response wand. At this point, 50 distracter stimuli were illuminated along with the one target stimulus. The subjects’ task was to quickly locate the target stimulus and identify whether two or four LEDs were illuminated at the target location by pressing a response button on the top of the ALF response wand. If two LEDs were illuminated on the target speaker the subject would respond by pressing either the red or yellow button. If four LEDs were illuminated on the target speaker the subject would respond by pressing either the blue or green button (Figure 16). After the subject recorded his/her response, he/she would realign to the front speaker to begin the next trial. The time required for the subject to find and identify the target was measured as a function of the noise-burst SPL with each hearing protector, with open ear as a reference.

The subjects were randomly assigned to conditions in order to eliminate any order effects. The test conditions were the 15 passive hearing protectors and a control condition labeled as “Open” meaning the subject would run the task without hearing protection. Each of the eight subjects completed 240 trials per hearing protector, with 60 trials at four different sound levels. In addition, each subject completed 60 trails in an unoccluded visual only condition. This condition was added to create a worst case scenario situation where the subject was given no auditory clue and forced to visually search for the target. Detection performance with the hearing protectors was measured with a target stimulus SPL ranging from15dB to 80dB. Detection performance was also measured with open ear as a reference with 60 trials at each of the following SPLs: 9dB, 15dB, 30dB, 40dB, and 60dB. Levels were selected for each hearing protector that spanned a range from quiet (inaudible) to clearly audible (approx. 40 dB SPL, but not to exceed 85 dB SPL at the eardrum). Three of the devices with the lowest attenuation values for continuous noise were measured at the 15 dB level, and were not measured at the 80 dB level.

3.6 **Subjective Comfort Questionnaire**

Subjective comfort questionnaires can be very useful tools to identify if devices will be readily accepted by the end user. Fantastic attenuation and performance alone is useless if the device is so uncomfortable that few individuals will tolerate wearing it. The subjects filled out the subjective questionnaire immediately after testing each device. The following questions were provided to the subjects:

For the questions below, please use this rating scale:
1 - Very comfortable
2 - Somewhat comfortable
3 - Neither comfortable or uncomfortable
4 - Somewhat uncomfortable
5 - Very uncomfortable

Describe the level of discomfort during insertion	1 2 3 4 5
Describe the level of discomfort during removal	1 2 3 4 5
Describe the level of discomfort after removal	1 2 3 4 5
After earplug insertion, describe the level of discomfort over time	1 2 3 4 5

4.0 RESULTS

4.1 Continuous Noise Attenuation Results

Passive noise attenuation measurements, for protection in a continuous noise environment, were collected in accordance with ANSI S12.6 for all devices in all conditions. Table 2 displays the mean attenuation and standard deviation (SD) across 1/3-octave bands from 125 to 8000 Hz. Also listed is the calculated Noise Reduction Rating (NRR) for mean minus 1 standard deviation and mean minus 2 standard deviations. Figure 17 displays the mean attenuation minus 2 standard deviations across 1/3-octave bands from 125 to 8000 Hz.

Table 2: Passive mean and standard deviation noise attenuation data for all devices, all conditions

Hearing Protector		Frequency (Hz)							NRR	
		125	250	500	1000	2000	4000	8000	Mean – 1 SD	Mean – 2 SD
3M EAR UltraFit	Mean	22	21	21	24	29	33	39	17	10
	SD	8	8	8	6	4	8	8		
Allen Sound Sensor	Mean	21	24	28	21	25	31	31	15	6
	SD	12	12	7	9	7	7	9		
EarPlugz PC with cord	Mean	21	20	21	24	28	30	28	15	6
	SD	9	9	10	8	8	9	9		
EarPlugz PC without cord	Mean	19	19	19	22	27	30	28	14	5
	SD	9	8	9	9	7	9	8		
Etymotic ER20 ETY	Mean	11	13	15	19	20	19	25	12	8
	SD	4	4	5	4	4	5	3		
Hear Defenders DF	Mean	21	19	21	25	28	29	35	17	10
	SD	8	7	8	6	5	7	8		
Hearing Armor	Mean	21	20	21	22	27	28	36	13	3
	SD	12	10	10	8	8	11	9		
Howard Leight Max	Mean	29	31	33	35	34	43	46	27	20
	SD	8	8	8	8	4	4	5		
Moldex Pura Fit	Mean	38	38	39	39	36	44	47	31	24
	SD	10	10	9	8	5	4	4		
SensGard SG26	Mean	22	25	28	23	26	32	33	17	9
	SD	13	12	8	6	7	6	7		
SensGard SG31	Mean	27	33	29	29	27	32	34	20	13
	SD	12	10	5	5	7	7	8		
Sonic Defenders EP3 Closed	Mean	22	22	23	25	29	27	33	15	5
	SD	9	9	9	10	8	8	6		
Sonic Defenders EP3 Open	Mean	6	8	12	17	23	26	32	11	6
	SD	5	4	4	4	6	7	7		
Sonic Defenders EP7 Closed	Mean	25	26	30	33	33	35	41	26	21
	SD	7	6	5	5	3	4	4		
Sonic Defenders EP7 Open	Mean	5	8	14	23	29	31	39	15	12
	SD	2	3	2	2	3	3	5		

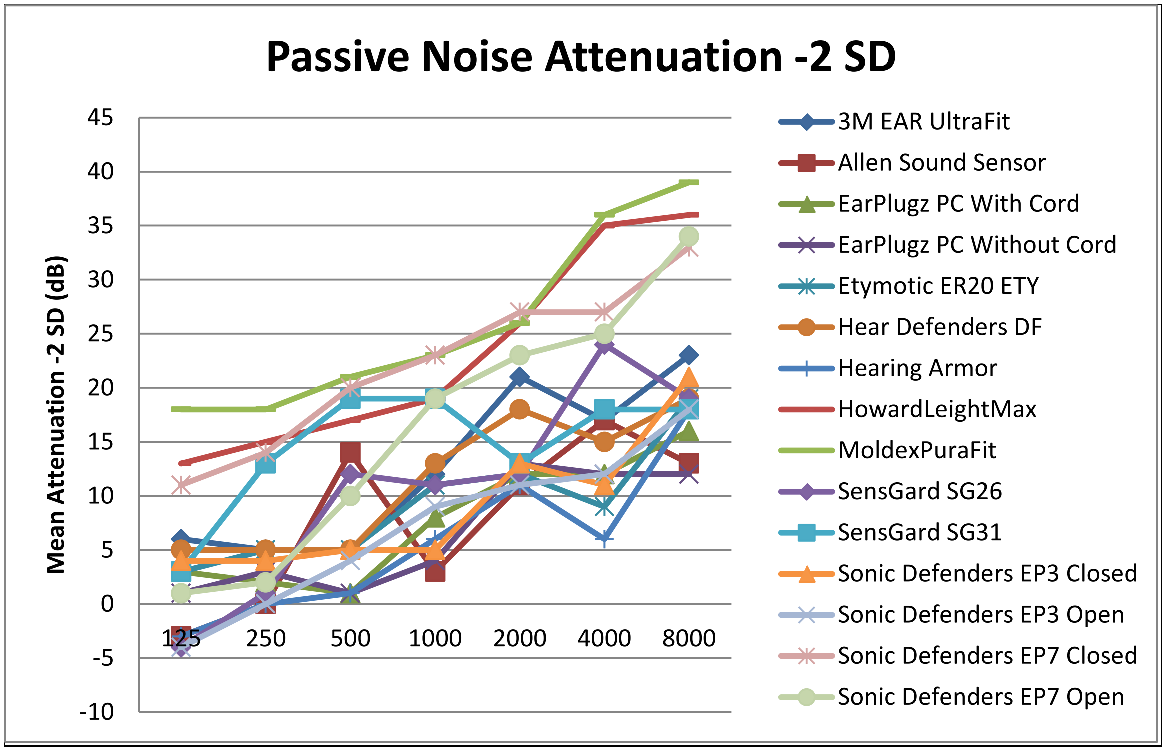

Figure 17. Passive mean minus 2 standard deviation noise attenuation for all devices, all conditions

Passive noise attenuation data was also analyzed using the methods described in ANSI S12.68. This ANSI standard details the methods for estimating the effective A-weighted SPL when hearing protectors are worn. Noise Level Reduction Statistics for use with A-Weighting (NRS_A) and Noise Level Reduction Statistics, Graphical (NRS_G) were calculated for all the earplugs in each condition and listed in Tables 3 and 4, respectively.

NRS_A, as the subscript implies, is calculated by simply subtracting the value from the measured A-weighted noise level to estimate the level of sound at the ear under the hearing protector. This method offers several advantages over the well-known NRR. The NRR is designed to be subtracted from the C-weighted noise exposure, with an easily forgotten 7-dB adjustment that must be applied prior to subtracting it from A-weighted exposure values. C-weighted exposure values are often not even known, and therefore the rating for subtraction from A-weighted exposures with the NRS_A eliminates these problems with the NRR. Another advantage of the NRS_A is that it calculates two levels of protection to indicate the range of performance that was achieved; this range reflects both the variation across the subjects in the test panel providing insight into how hard/easy the device may be to fit, as well as variation in noise level reduction with the noise spectrum in which the device is used[5]. The majority of users (80%) will achieve the performance specified by the lower value in the range, with only the most motivated proficient users (20%) able to achieve or exceed the higher value. A narrow range provides knowledge that the device is more stable and provides more predictable protection. The 20th percentile (higher attenuation number in the range) can also provide overprotection information that may be a safety concern for some users.

Table 3: NRS_A results for passive hearing protectors

Hearing Protector	NRS_A	
	80%	**20%**
3M EAR UltraFit	19.5	30.3
Allen Sound Sensor	16.8	29.5
EarPlugz PC with cord	16.9	31.0
EarPlugz PC without cord	16.0	29.0
Etymotic ER20 ETY	14.3	20.4
Hear Defenders DF	19.3	28.8
Hearing Armor	15.6	30.4
Howard Leight Max	29.1	29.0
Moldex PuraFit	32.6	42.8
SensGard SG26	18.9	30.8
SensGard SG31	22.9	33.3
Sonic Defenders EP3 Closed	18.2	30.9
Sonic Defenders EP3 Open	12.1	19.9
Sonic Defenders EP7 Closed	28.3	34.4
Sonic Defenders EP7 Open	15.6	30.4

The NRS_G rating requires knowledge of both the C- and A-weighted noise levels, and uses this additional information about the noise spectrum to more precisely estimate the range of protection provided. For example, if the C-weighted noise is measured at 100 dB and the A-weighted noise is measured at 94 dB then the difference between the two weighting levels is 6. Therefore, the range of protection provided by the hearing protector could be found in Table 4 where B = 6. NRS_A is appropriate for unpredictable noise environments that may vary widely as is the case with many military operations. However, if one is considering a noise environment that is relatively constant (e.g., dominated by low frequencies such as an aircraft or other vehicles) then NRS_G should be used to calculate more accurate attenuation performance values.

Table 4: NRS_G results for passive hearing protectors

Hearing Protector	NRS_G	B = L_C - L_A			
		-1	2	6	13
3M EAR UltraFit	80%	23.4	18.7	16.4	14.8
	20%	32.9	29.3	28.2	27.8
Allen Sound Sensor	80%	19.5	16.3	15.4	12.0
	20%	31.0	28.8	29.6	30.5
EarPlugz PC with cord	80%	20.2	16.0	14.0	12.8
	20%	33.2	30.3	29.0	28.2
EarPlugz PC without cord	80%	18.8	15.2	13.4	12.4
	20%	30.8	28.5	27.0	26.0
Etymotic ER20 ETY	80%	16.3	14.0	11.8	8.8
	20%	21.9	20.1	18.4	15.5
Hear Defenders DF	80%	22.7	18.4	16.0	14.7
	20%	30.8	28.2	27.0	26.6
Hearing Armor	80%	18.7	14.8	12.9	11.7
	20%	32.6	29.6	29.1	29.5
Howard Leight Max	80%	32.0	28.4	26.5	24.0
	20%	39.9	38.8	38.1	36.4
Moldex Pura Fit	80%	34.5	32.0	31.1	30.2
	20%	42.5	42.9	43.8	44.8
SensGard SG26	80%	21.4	18.6	17.0	13.0
	20%	32.4	30.0	31.0	32.0
SensGard SG31	80%	23.5	23.0	21.9	18.4
	20%	33.9	33.0	33.7	36.0
Sonic Defenders EP3 Closed	80%	20.4	17.5	16.3	15.2
	20%	31.7	30.8	30.4	29.9
Sonic Defenders EP3 Open	80%	17.2	12.0	8.7	4.5
	20%	24.1	17.8	14.2	10.6
Sonic Defenders EP7 Closed	80%	31.4	27.9	24.9	20.5
	20%	35.5	34.2	32.9	30.9
Sonic Defenders EP7 Open	80%	23.8	15.6	10.5	5.0
	20%	26.6	18.7	14.1	8.5

The attenuation performance of the passive hearing protectors was rank ordered in Table 5. A rank of 1 corresponds to the device that provides the most attenuation and 15 corresponds to the device with the least attenuation. Note that too much hearing protection for an expected ambient noise level can be as bad as too little protection. The rank ordering presented here assumes that more attenuation is desired. However, if less attenuation is desired, the rank ordering needed for selecting an appropriate device would change. To rank order the continuous noise attenuation performance of the passive hearing protectors, the NRS_A 80% values were compared. This metric was used rather than NRR, because the NRS_A 80% values more accurately describe the levels that the majority of users will achieve with the devices. The Moldex PuraFit provided the most attenuation while the Sonic Defenders EP3 Open provided the least. Sonic Defenders EP7 Open and Hearing Armor tied for the rank of 12, with identical attenuation results for the NRS_A 80% value.

Table 5: Rank order performance for continuous noise attenuation, ranked from most to least attenuation

Hearing Protector	Rank
Moldex PuraFit	1
Howard Leight Max	2
Sonic Defenders EP7 Closed	3
SensGard SG31	4
3M EAR UltraFit	5
Hear Defenders DF	6
SensGard SG26	7
Sonic Defenders EP3 Closed	8
EarPlugz PC with cord	9
Allen Sound Sensor	10
EarPlugz PC without cord	22
Sonic Defenders EP7 Open	12
Hearing Armor	12
Etymotic ER20 ETY	14
Sonic Defenders EP3 Open	15

4.2 Impulse Noise Attenuation Results

Impulsive peak insertion loss measurements were collected in accordance with ANSI S12.42 for all devices in all conditions. The insertion loss for each ear and each peak pressure level was recorded. Figure 18 displays an example graph of insertion loss using the Moldex PuraFit earplug. Table 6 lists the average IPIL for each device at 170, 185, and 195 dB.

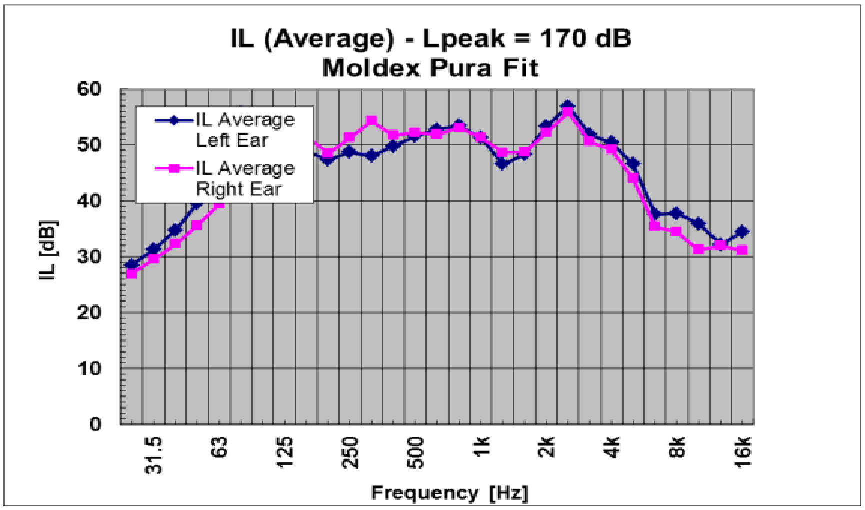

Figure 18. Example insertion loss data from Moldex PuraFit earplug, left and right ears of ATF

Table 6: Average Impulse Peak Insertion Loss (IPIL) data from blast measurements

Hearing Protector	Peak Sound Pressure Level		
	170 dB	185 dB	195 dB
3M EAR UltraFit	35.6	34.8	35.5
Allen Sound Sensor	10.1	21.5	32.7
EarPlugz PC with cord	34.9	35.8	32.5
EarPlugz PC without cord	34.4	35.4	45.3
Etymotic ER20 ETY	24.9	28.0	32.2
Hear Defenders DF	41.2	38.3	38.7
Hearing Armor	35.3	35.7	30.4
Howard Leight Max	54.4	55.8	57.9
Moldex PuraFit	54.2	55.7	54.6
SensGard SG26	31.1	27.0	32.5
SensGard SG31	27.9	20.4	28.6
Sonic Defenders EP3 Closed	27.5	28.4	33.0
Sonic Defenders EP3 Open	26.4	28.1	31.9
Sonic Defenders EP7 Closed	52.9	52.0	51.7
Sonic Defenders EP7 Open	27.9	33.8	40.1

The rank order for the impulsive peak insertion loss performance of the hearing protectors, Table 7, was determined using the IPIL for the 185 dB condition, since this is the level most likely to be encountered in modern military operations. The devices that provided the most attenuation were Howard Leight Max and Moldex PuraFit with virtually identical results. The device that provided the least attenuation was the SensGard SG31 which was blown completely off the head (Figure 19) during the measurements.

Table 7: Rank order performance for impulsive peak insertion loss from most attenuation to least attenuation

Hearing Protector	Rank
Howard Leight Max	1
Moldex PuraFit	2
Sonic Defenders EP7 Closed	3
Hear Defenders DF	4
EarPlugz PC with cord	5
Hearing Armor	6
EarPlugz PC without cord	7
3M EAR UltraFit	8
Sonic Defenders EP7 Open	9
Sonic Defenders EP3 Closed	10
Sonic Defenders EP3 Open	22
Etymotic ER20 ETY	12
SensGard SG26	13
Allen Sound Sensor	14
SensGard SG31	15

Figure 19: SensGard SG31 blown over 300 cm from ATF during blast measurements

4.3 Sound Localization Results

Two metrics of particular interest for the localization measurements were percentage of angular errors > 45˚ and percentage of front-back reversals. Table 8 and Figure 20 show the percentage of mean angular errors that were greater than 45˚ with each hearing protector for the burst and continuous noise conditions. Angular error for this metric was calculated as the difference between the actual target location and the subject's response location as measured by the distance between the two points along the surface of the sphere. The rationale behind including this measurement was its operational relevance. In general, it is assumed that if an operator's attention can be directed to within 45°, he/she will then be able to use other sensory information, especially vision, to acquire the target. Subject data was collected with an "open" ear configuration (no hearing protection device). In this configuration the subjects only had errors greater than 45° 1.5% of the time in the burst noise condition and 0.2% in the continuous noise condition. Localization performance is degraded when a hearing protection device is worn. For both burst and continuous conditions, the hearing protector with the lowest percentage of errors greater than 45˚ was the Etymotic ER20 ETY Plug, the hearing protector with the highest percentage was the Moldex PuraFit.

Table 8: Percentage of mean angular errors > 45˚ for burst and continuous noise conditions

Hearing Protector	Errors > 45˚ (%)	
	Burst	Continuous
Open Ear	1.5	0.2
3M EAR UltraFit	25.7	5.0
Allen Sound Sensor	31.5	10.3
EarPlugz PC with cord	23.2	7.3
EarPlugz PC without cord	20.1	3.2
Etymotic ER20 ETY	5.9	0.4
Hear Defenders DF	19.3	3.0
Hearing Armor	20.6	3.4
Howard Leight Max	42.1	15.4
Moldex PuraFit	50.8	29.9
SensGard SG26	29.0	10.2
SensGard SG31	26.2	7.0
Sonic Defenders EP3 Closed	21.6	2.9
Sonic Defenders EP3 Open	16.4	0.4
Sonic Defenders EP7 Closed	24.3	7.7
Sonic Defenders EP7 Open	19.5	4.0

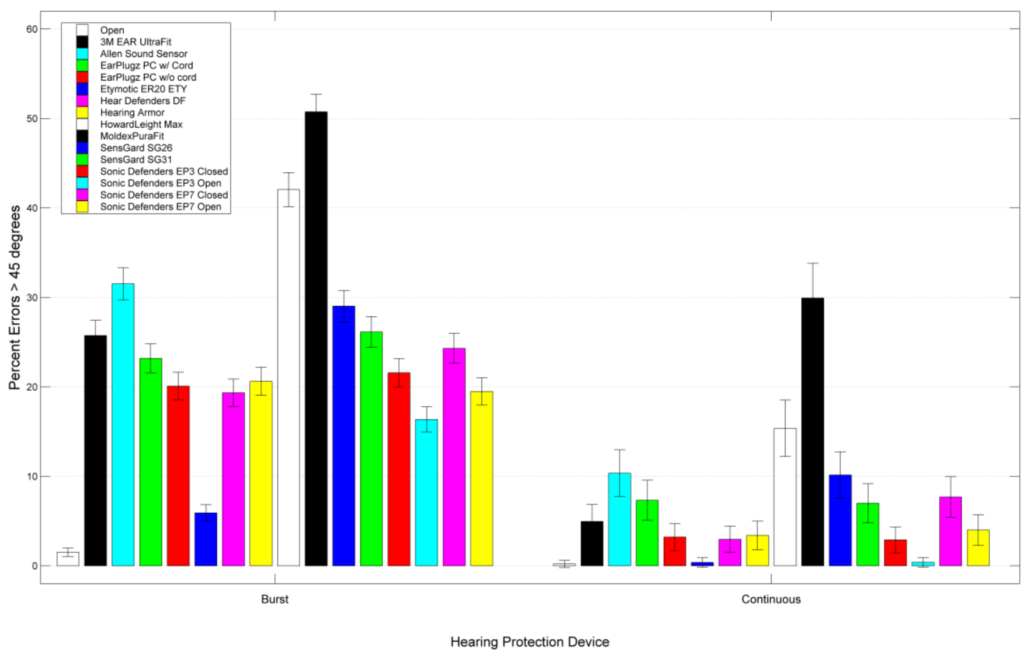

Figure 20. Percentage of mean angular errors > 45˚ for burst and continuous noise conditions

Front-back reversals occur when a subject is unable to determine whether a sound is in front of them or behind them. The percentage of front-back reversals is displayed in Table 9 and Figure 21. Again, subject data was collected with an "open" ear configuration (no hearing protection device). In this configuration the subjects only had front-back reversals 5.6% of the time in the burst noise condition and 0.0% in the continuous noise condition. The percentage of front-back reversals for the continuous noise conditions more closely matched the open ear data with a range of 0.9% to 9.7%. As with the previous metric, the percentage of front-back reversals was the lowest with the Etymotic ER20 ETY Plugs and the highest with the Moldex PuraFit.

Table 9: Percentage of front-back reversals for the burst and continuous noise conditions

Hearing Protector	Front-Back Reversals (%)	
	Burst	**Continuous**
Open Ear	5.6	0.0
3M EAR UltraFit	25.2	2.4
Allen Sound Sensor	25.1	2.1
EarPlugz PC with cord	22.2	3.7
EarPlugz PC without cord	19.7	1.5
Etymotic ER20 ETY	9.7	0.9
Hear Defenders DF	17.3	1.2
Hearing Armor	19.6	2.2
Howard Leight Max	32.4	3.6
Moldex PuraFit	37.3	9.7
SensGard SG26	21.5	2.1
SensGard SG31	21.4	1.0
Sonic Defenders EP3 Closed	21.5	2.3
Sonic Defenders EP3 Open	16.9	1.4
Sonic Defenders EP7 Closed	20.4	2.6
Sonic Defenders EP7 Open	18.2	1.6

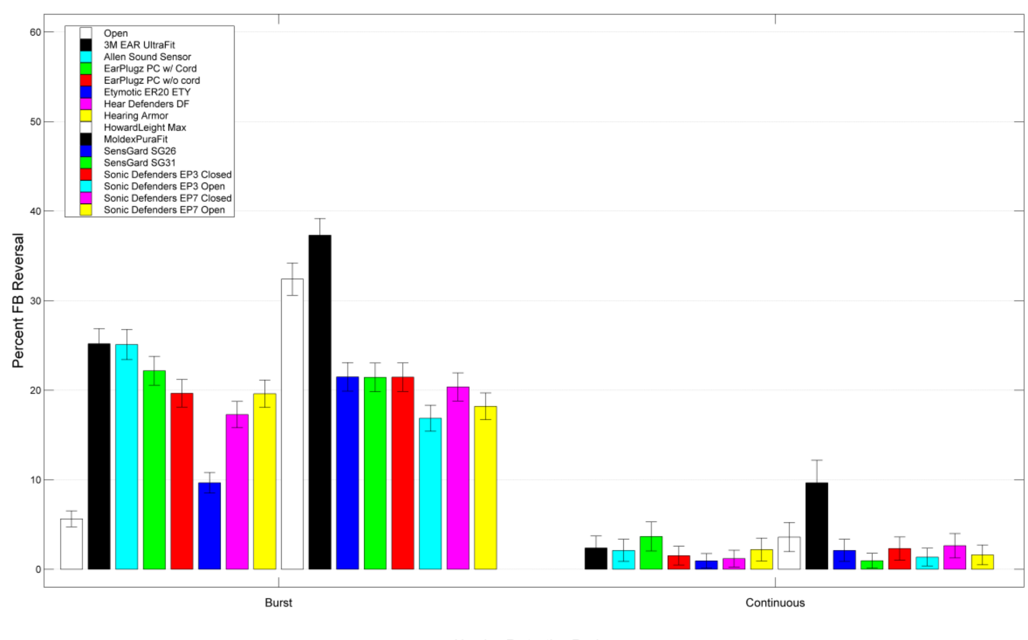

Figure 21: Percentage of front-back reversals for the burst and continuous noise conditions

To directly compare the effect hearing protectors may have on the user's ability to localize sound, the results of both metrics were rank ordered for the burst noise condition. The rank order was based on the comparison of responses to the Open condition. The two metrics were regarded as equally important so no weighting was used. The hearing protector yielding performance most similar to the Open condition received a score of 1 while the hearing protector with the greatest difference received a 15. Table 10 shows the rank order for each hearing protector, each metric in the burst noise condition, and a combined total for overall effect.

Table 10: Rank order performance assessment – localization performance

Hearing Protector	Errors > 45° (%)	Front-Back Reversals (%)	Total	Rank
	Burst	Burst		
Etymotic ER20 ETY	5.9	9.7	15.6	1
Sonic Defenders EP3 Open	16.4	16.9	33.2	2
Hear Defenders DF	19.3	17.3	36.6	3
Sonic Defenders EP7 Open	19.5	18.2	37.7	4
EarPlugz PC without cord	20.1	19.7	39.7	5
Hearing Armor	20.6	19.6	40.2	6
Sonic Defenders EP3 Closed	21.6	21.5	43.0	7
Sonic Defenders EP7 Closed	24.3	20.4	44.7	8
EarPlugz PC with cord	23.2	22.2	45.4	9
SensGard SG31	26.2	21.4	47.6	10
SensGard SG26	29.0	21.5	50.5	11
3M EAR UltraFit	25.7	25.2	50.9	12
Allen Sound Sensor	31.5	25.1	56.6	13
Howard Leight Max	42.1	32.4	74.5	14
Moldex PuraFit	50.8	37.3	88.1	15

4.4 Aurally Guided Visual Search (Auditory Detection) Results

Auditory detection data was collected using an aurally guided visual search task. Subjects also completed a visual only search task with no aural guide to act as a baseline. The subjects averaged a response time of 12.2 seconds to find the target when no aural guide was provided.

The fifteen passive hearing protector conditions showed significant deficits in relation to the open-ear condition in the auditory detection task. The measured response times show a decrease in response time with increasing presentation level as the auditory stimuli become more audible and localizable. Performance with the majority of the hearing protectors begins to approach that of the open ear condition with presentation levels of 80 dB SPL. The average response times for all devices is presented in Figure 22. Figures 23, 24, and 25 present the same data for clarity with only five devices, arranged alphabetically, per figure.

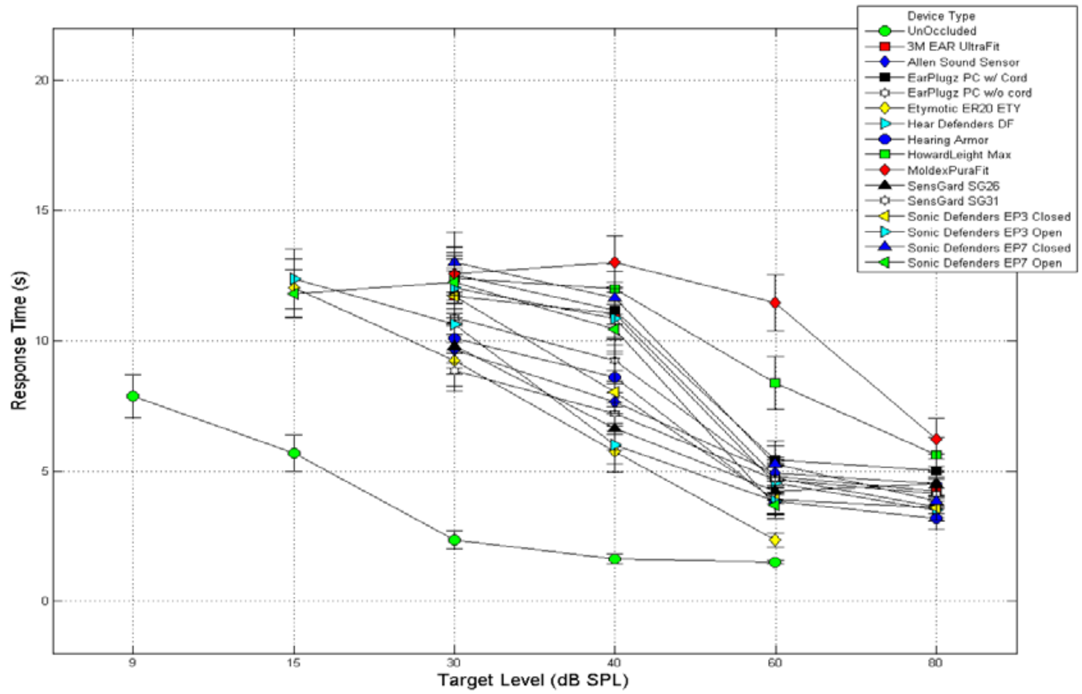

Figure 22: Average response time (all passive devices)

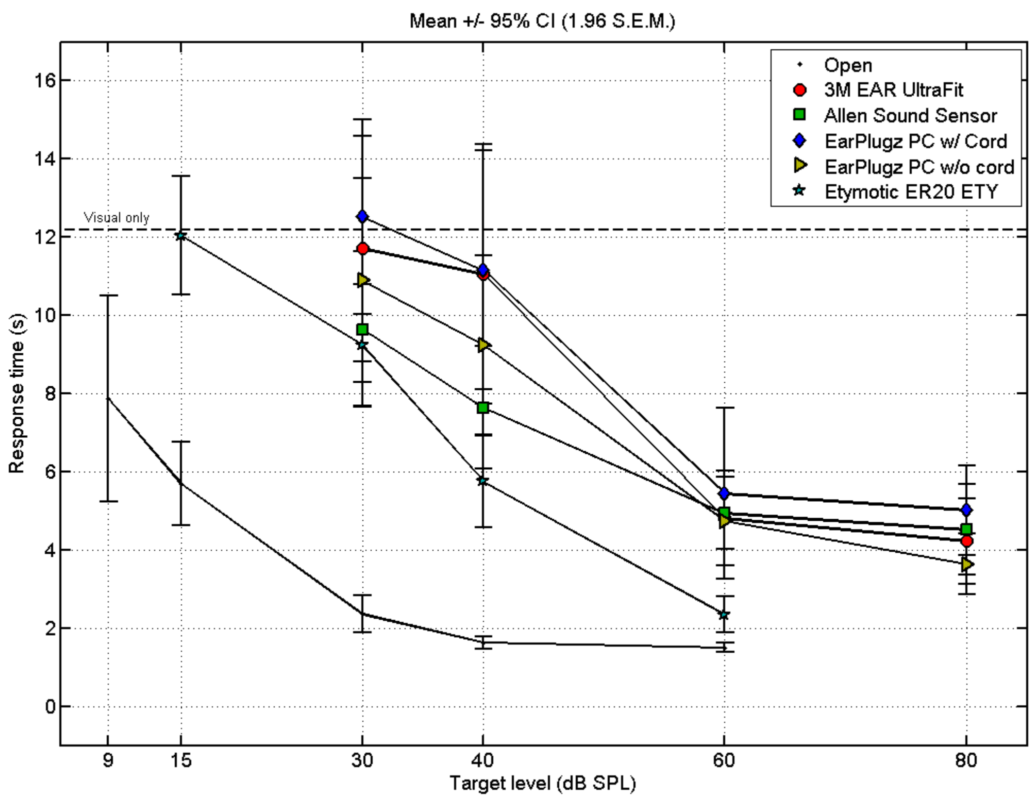

Figure 23: Average response time (5 passive devices)

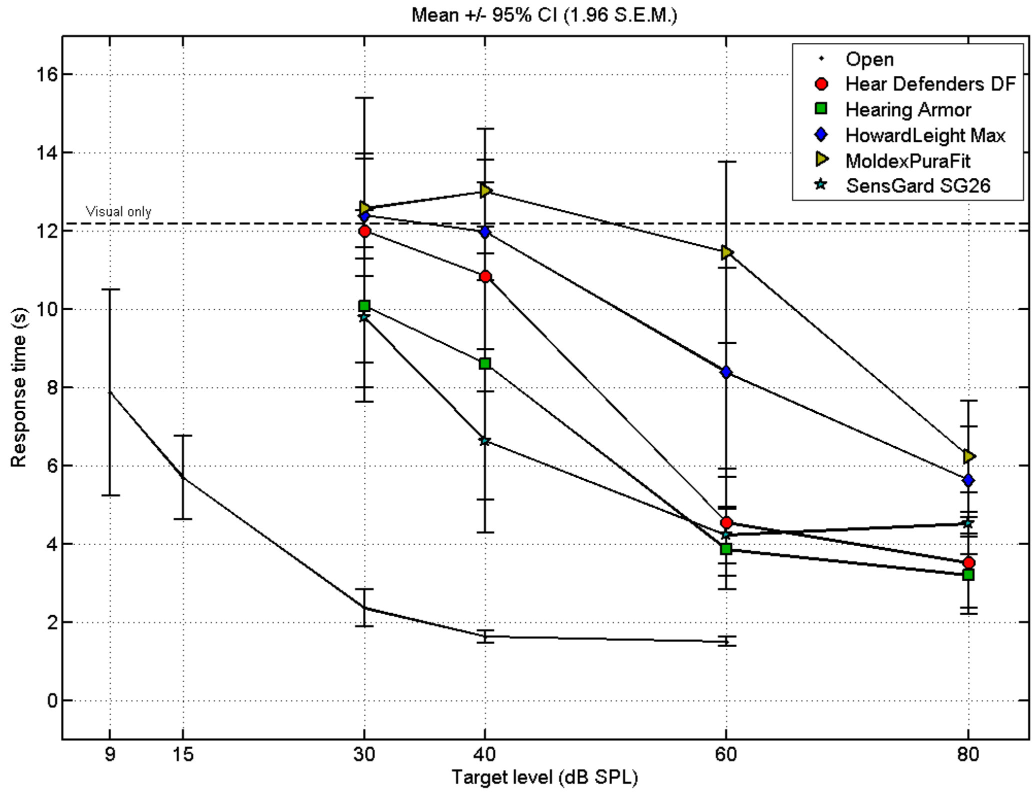

Figure 24: Average response time (5 passive devices)

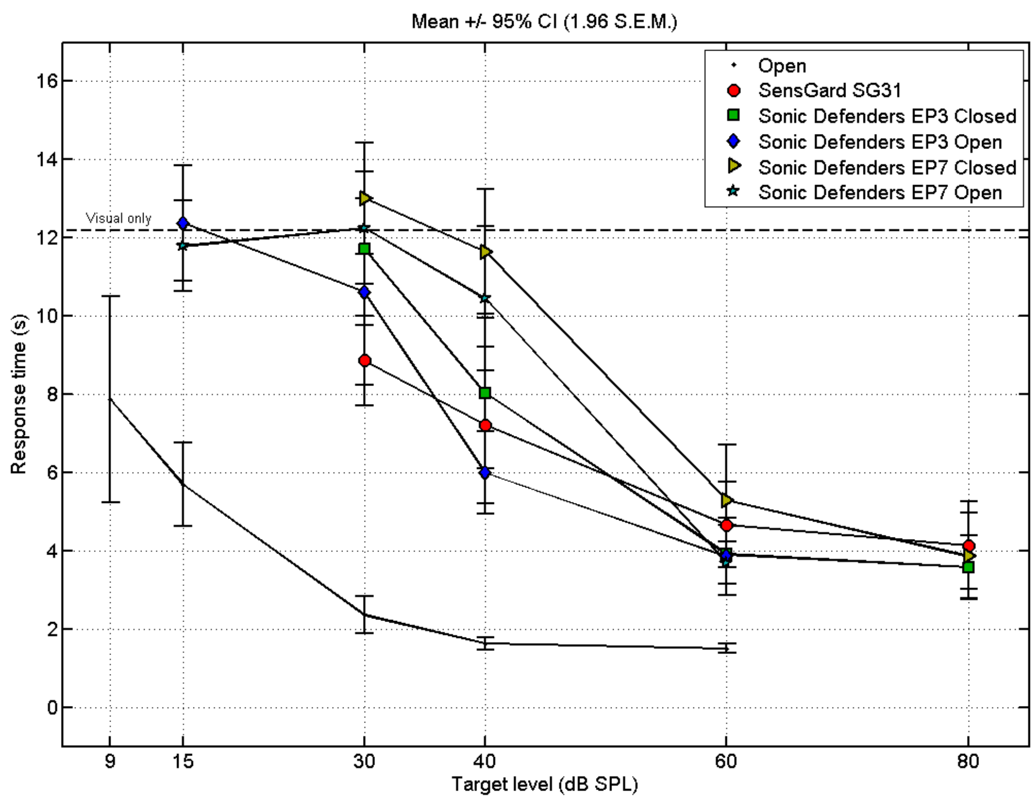

Figure 25: Average response time (5 passive devices)

The auditory detection performance of subjects wearing one of the fifteen passive hearing protectors was rank ordered in Table 11. The order was selected based on the comparison of responses to the Open condition. Performance at each of the three middle sound levels was regarded as equally important, so no weighting was used. The lowest and highest sound levels were not included in the ranking, since attenuation differences in the devices made it impossible to test every device in these extreme sound levels. The hearing protector yielding performance most similar to the Open condition received a score of 1, while the hearing protector with the greatest difference received a 15. On average, subjects clocked the shortest search times when wearing the Etymotic ER20 ETY Plugs, and the longest search times when wearing the Moldex PuraFit.

Table 11: Rank order performance assessment – auditory detection

Hearing Protector	Target Level (dB SPL)					Total (30, 40, 60)	Rank
	15	30	40	60	80		
Etymotic ER20 ETY	12.0	9.3	5.8	2.5		17.6	1
Sonic Defenders EP3 Open	12.2	10.8	6.0	4.0		20.8	2
SensGard SG26		9.9	6.8	4.2	4.6	20.9	3
SensGard SG31		9.0	7.0	5.0	4.0	21.0	4
Allen Sound Sensor		9.5	7.8	5.0	4.6	22.3	5
Hearing Armor		10.0	8.8	4.9	3.1	23.7	6
Sonic Defenders EP3 Closed		11.8	8.0	4.0	3.8	23.8	7
EarPlugz PC without cord		11.0	9.2	5.0	3.8	25.2	8
Sonic Defenders EP7 Open	11.9	12.2	10.2	4.0		26.4	9
Hear Defenders DF		12.0	11.0	4.8	3.5	27.8	10
3M EAR UltraFit		11.8	11.0	5.0	4.2	27.8	10
EarPlugz PC with cord		12.5	11.0	5.5	5.0	29.0	12
Sonic Defenders EP7 Closed		13.0	11.8	5.2	4.0	30.0	13
Howard Leight Max		12.3	12.0	8.4	5.8	32.7	14
Moldex PuraFit		12.3	13.0	11.5	6.2	36.8	15

4.5 Subjective Comfort Questionnaire Results

Equal weighting was used for all the questions that made up the subjective questionnaire. The devices were ranked using the average scores from all subjects. While some of the subjects may have rated some of the devices as very uncomfortable on an individual basis, the average results from all subjects indicated that none of the devices tested should be excluded solely on comfort. Table 12 shows the average subjective comfort scores of each device as well as the descriptive comfort category that was associated with the numerical value.

Table 12: Rank order performance assessment for subjective comfort

Hearing Protector	Average Comfort Value	Description of Comfort	Rank
Howard Leight Max	1.45	Very comfortable	1
Moldex PuraFit	1.51	Somewhat comfortable	2
Sonic Defenders EP7 Open	1.65	Somewhat comfortable	3
Hearing Armor	1.66	Somewhat comfortable	4
Sonic Defenders EP3 Open	1.70	Somewhat comfortable	5
Sonic Defenders EP7 Closed	1.80	Somewhat comfortable	6
Sonic Defenders EP3 Closed	1.91	Somewhat comfortable	7
Etymotic ER20 ETY	2.06	Somewhat comfortable	8
SensGard SG31	2.36	Somewhat comfortable	9
3M EAR UltraFit	2.43	Somewhat comfortable	10
EarPlugz PC without cord	2.45	Somewhat comfortable	22
Allen Sound Sensor	2.48	Somewhat comfortable	12
SensGard SG26	2.63	Neither comfortable nor uncomfortable	13
Hear Defenders DF	2.73	Neither comfortable nor uncomfortable	14
EarPlugz PC with cord	2.85	Neither comfortable nor uncomfortable	15

5.0 DISCUSSION

Passive hearing protection devices can and should be assessed in multiple ways to describe the performance of the device and the effects on the user's auditory perception. Subjective and objective measurements can be conducted to characterize a device's noise attenuation performance as well as any negative effect on situational awareness capabilities that may result. Noise attenuation in both continuous and impulse noise environments, sound localization capabilities, auditory detection capabilities, and subjective comfort were all assessed for the devices in this study.

Note that different operational scenarios may require different weightings. In some situations/missions, auditory detection and/or localization may be more important than sound attenuation while for other situations/missions attenuation may be more important than localization or detection. These different weightings should be considered by those who are selecting hearing protection devices for a particular mission or group of users. It is critical to consider the environment of the end user, and evaluate the pros and cons for each assessment area independently for an informed decision. It is more advisable to pick a top performing device in the area that is most critical to the task, and to consider other variables when choosing a device. For example, there may be some missions where the expected noise levels are high, the risk of impulsive noise is low and the need for situation awareness is also low. For this mission, a device should be chosen based primarily on the continuous noise attenuation performance. However, for a different mission where ambient noise levels are expected to be low, there is some risk of impulsive noise, and good situation awareness is desired, a device should be chosen based on IPIL, localization and detection performance.

Other considerations beyond these performance areas exist when evaluating hearing protectors. Sizing is one such consideration. Two of the triple flange earplugs assessed in this study, 3M EAR UltraFit and Hearing Armor, are only available in one size. Not having the appropriate size can reduce the attenuation potential for individuals with smaller or larger than average ear canals. Three of the twenty subjects that participated in the continuous noise attenuation measurements had larger than average ear canals. These individuals could fit the entire third flange of both the 3M EAR UltraFit and Hearing Armor inside his/her canals. Consequently, these individuals had a looser fit and therefore lower attenuation numbers when compared to other participants wearing the same earplugs. Sizing was also an issue with the Ear Plugz PC with and without the cord and Hear Defenders DF. The Ear Plugz PC and Hear Defenders DF were available in three sizes, but from visual inspection and participant feedback, the small size was not small enough. Fifteen of the twenty subjects in the continuous noise attenuation measurements were fitted with the small size of these plugs. Of those fifteen, four subjects noted that the plugs felt too large and were uncomfortable to wear. The difference in gauge between the small and medium was also significant. Three subjects were fitted with a looser fitting small earplug because they could not accommodate the medium. In addition to improper sizing, the Ear Plugz PC with and without the cord and Hear Defenders DF were also described as being very rigid, which contributed to their rank among the bottom five hearing protectors in the subjective comfort questionnaire. The Allen Sound Sensor, SensGard SG26, and SensGard SG31 were designed with an adjustable headband, but the sizing options were only suitable for head circumferences between 55cm and 60cm. The three subjects with head circumferences less than 55cm noted that there was not enough tension on the headband to achieve a proper seal, even at the smallest setting. One subject with a head circumference greater than 60cm could barely fit the bands across his head. Even with the bands adjusted to the largest setting, the earpieces would not sit flush in his ears, leaving a small break in the seal.

Hearing protector design is another consideration. Design was of particular concern with the Allen Sound Sensor, SensGard SG26, and SensGard SG31. The headband design was not constructed to stay in place in situations with active movement. During the localization and auditory detection measurements in ALF, subjects noted that they had to readjust the headbands several times throughout the measurement because the headbands would slip out of position when they moved their head around. During the impulse noise measurements, all three headbands were blown off the ATF at least once during the 195dB condition. The SensGard SG31 came off with every shot at 195dB. By design, these hearing protectors are more suited for low movement environments like a firing range or spectating.

6.0 CONCLUSIONS

All hearing protective devices are not equally effective and their performance varies with the different measurement parameters. A full assessment should be conducted for all hearing protectors to include: continuous and impulsive noise attenuation, sound localization, auditory detection measurements and in some cases speech intelligibility before such devices are used in military applications. The earplugs assessed in this study provided a range of performances. The Moldex PuraFit and the Howard Leight Max provided the most attenuation for users in a continuous and/or impulsive noise environment, but were among the worst performers for users required to localize and detect sounds. The reverse can be said about the Etymotic ER20 ETY and Hearing Armor. This inverse relationship between attenuation performance and localization/detection performance manifests across the hearing protectors measured in this study. In other words, based on the results of these measurements, if a hearing protector provides exceptional noise attenuation, it has a much higher likelihood of negatively affecting localization/detection performance and thereby reducing situation awareness. The Sonic Defender EP7 was the exception to this rule. With the filter cap closed, the EP7 received a rank of 3 for the continuous and impulse noise measurements. With the filter cap open, the EP7 ranked 5 for the localization measurements, and 8 for the auditory detection measurements. The EP7 was also designed to protect the user from impulse noises even with the cap open. The EP7 performed as designed, ranking 4 at 185 dB in the open filter condition during the impulse noise measurements. The EP7s are available in three sizes and come packaged with replaceable foam Comply Canal Tips. These foam tips were available in slim, short, and standard. All of the EP7 sizing options increase the likelihood the user will be able to find a good fit. Based on the results of the measurements described here, the Sonic Defenders EP7 would provide the best combination of fit and comfort as well as the best attenuation with the lowest reduction in situational awareness given the option to wear in an open or closed filter condition. However, the user must be aware of the protection needs and know when to open or close the cap to achieve optimal performance. Performance results of hearing protection devices can and should be used to determine the protectors will be made available to the warfighters. The results of the hearing protector performance assessments may give insight into new technologies and/or design criteria for the next generation of hearing protection devices.

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