



AFRL-RH-WP-TR-2022-0111

INVESTIGATING DOUBLE HEARING PROTECTION: PERFORMANCE OF FILTERED EARPLUGS PAIRED WITH HEADSETS/HELMETS

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JULY 2022

INTERIM REPORT

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REPORT DOCUMENTATION PAGE

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1. REPORT DATE July 2022	2. REPORT TYPE Interim	3. DATES COVERED <table border="1" style="width: 100%; border-collapse: collapse;"> <tr> <td style="width: 50%;">START DATE March 2021</td> <td style="width: 50%;">END DATE July 2022</td> </tr> </table>		START DATE March 2021	END DATE July 2022
START DATE March 2021	END DATE July 2022				
3. TITLE AND SUBTITLE Investigating Double Hearing Protection: Performance of Filtered Earplugs Paired with Headsets/Helmets					
5a. CONTRACT NUMBER FA8650-22-F-6289		5b. GRANT NUMBER			
5d. PROJECT NUMBER		5e. TASK NUMBER			
		5f. WORK UNIT NUMBER H13R			
6. AUTHOR(S) Hilary L. Gallagher / Lt Col Catherine L. Wynn / Maj Daniel A. Williams / Capt Christopher E. Hopkins					
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Air Force Research Laboratory 711 Human Performance Wing Airman Systems Directorate Warfighter Interactions & Readiness Division Wright-Patterson AFB OH 45433			8. PERFORMING ORGANIZATION REPORT NUMBER		
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) Air Force Research Laboratory 711 Human Performance Wing Airman Systems Directorate Warfighter Interactions & Readiness Division Sensory Systems Branch Wright-Patterson AFB OH 45433		10. SPONSOR/MONITOR'S ACRONYM(S)	11. SPONSOR/MONITOR'S REPORT NUMBER(S) AFRL-RH-WP-TR-2022-0111		
12. DISTRIBUTION/AVAILABILITY STATEMENT Distribution A. Approved for public release; distribution unlimited.					
13. SUPPLEMENTARY NOTES AFRL-2023-2256; Cleared 8 Jun 2023					
14. ABSTRACT Hearing protection and communication systems are issued to military members who are required to operate in hazardous noise environments. Double hearing protection is often required to reduce the risk of hearing loss and other hearing related disabilities. The objective of this study was to determine if filtered-type earplugs could be a viable option to replace passive foam earplugs worn in combination with a headset/helmet in order to provide protection and acceptable levels of speech intelligibility performance. Continuous and impulse noise attenuation, sound localization, and speech intelligibility measurements were conducted and analyzed for filtered-type earplugs and foam earplugs in combination with headsets/helmets commonly used by ground forces, aircraft maintainers, and aircrew. Filtered-type earplugs should be considered when additional hearing protection is required and the need to communicate. .					
15. SUBJECT TERMS noise attenuation, sound localization, impulsive noise attenuation, speech intelligibility, REAT, IPIL, SHARC, filtered earplugs, foam earplugs, hearing loss, flight helmets, headsets, communications					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT		
a. REPORT U	b. ABSTRACT U	c. THIS PAGE U	 SAR		
19a. NAME OF RESPONSIBLE PERSON Jacquelyn Waggamon			18. NUMBER OF PAGES 46 19b. PHONE NUMBER (Include area code)		

PREVIOUS EDITION IS OBSOLETE.

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EXECUTIVE SUMMARY

Across all branches of the military there are personnel exposed to hazardous noise. Varying types and configurations of hearing protection devices (HPD) are essential when working in hazardous noise to reduce the risk of hearing loss and hearing-related disabilities while still maintaining maximum mission effectiveness. Double hearing protection is often required in extreme high-noise environments, typically consisting of passive foam earplugs and a circumaural earmuff, headset, or helmet. Although a properly fit foam earplug has the potential to reduce the noise exposure, it also has unintended consequences, such as difficulty hearing an incoming communication signal or an improper fit leading to poor compliance, which can be detrimental to health and mission efficacy.

The objective of this study was to determine if filtered-type earplugs could be a viable option to replace passive foam earplugs worn in combination with a headset/helmet to provide protection and acceptable levels of speech intelligibility performance. Continuous and impulse noise attenuation, sound localization, and speech intelligibility measurements were conducted with foam, and filtered-type earplugs, combined with headsets/helmets.

The devices selected for the study are a combination of commonly used or newly developed, filtered earplugs worn in conjunction with communication headsets and flight helmets. Five earplugs were selected for the study: Etymotic ER20, Earasers Musician's Plugs, Combat Arms Earplugs (CAEP) 4.0, Sonic Defenders EP7, and SoundGuard foam earplugs. Five communication headsets currently in use for ground operations, aircraft maintenance, and aircrew military communities were evaluated in this study: Peltor COMTAC III, Gentex Ops-Core AMP, David Clark 12512G-11, David Clark H10-76, and Bose A20. Two flight helmets were evaluated in this study, one designed for fixed-wing aircrew, and one designed for rotary-wing aircrew.

The general approach to assess HPDs with filtered earplugs was to use American National Standards Institute/Acoustics Society of America (ANSI/ASA) measurement procedures for continuous noise attenuation, impulsive peak insertion loss (IPIL), sound localization, and speech intelligibility (SI) performance. Air Force Research Laboratory (AFRL) defined measurement procedures were used to assess the electro-acoustic characteristics of each device. As expected, the addition of an earplug under a headset/helmet increased the continuous and impulse noise attenuation, regardless of earplug type, when compared to the headset/helmet alone. Trends are presented amongst filtered-type earplugs and in comparison, to foam earplugs using octave band attenuation data, Noise Level Reduction Statistics for use with A-Weighting (NRSA), Noise Reduction Statistics, Graphical (NRS_G), and IPIL data. SI performance was assessed using the Modified Rhyme Test (MRT) in noise environments up to 105 A-weighted decibel (dBA). Results varied for hearing protection configurations that included filtered-type earplugs, but overall, the mean speech intelligibility scores typically exceeded the scores collected with passive foam earplugs. Sound localization measurements were also conducted on a subset of devices to understand the impact of double hearing protection on the user's localization performance. In summary, the addition of filtered-type earplugs to a headset/helmet provided a benefit to the user.

1.0 INTRODUCTION

Military operations frequently occur in complex noise environments that necessitate maintaining a balance between operational effectiveness and personnel safety. Across all branches of the military, there is no shortage of hazardous noise. Military personnel on the flight deck of aircraft carriers and interior compartments are routinely exposed to continuous noise levels. The noise levels vary greatly depending on the location and operation; however, the levels are fairly predictable. Military ground forces also work in varying hazardous noise environments. Their noise exposures are harder to predict due to the nature of their operations and are a combination of continuous and impulse noise. Many aircrew personnel are exposed to hazardous noise both on the ground and in-flight.

For all military personnel exposed to hazardous noise, it is important to reduce their risk of hearing loss and hearing-related disabilities while still maintaining mission effectiveness. HPDs are required and provided when working in hazardous noise. Typically, double hearing protection is required in extreme high-noise environments, usually a combination of insert foam earplugs and a circumaural earmuff, headset, or helmet. Unfortunately, it can be difficult to hear communication signals when wearing properly fit foam earplugs, which may lead to detriments in mission effectiveness. Personnel who struggle with communications often put their hearing health at risk through poor HPDs compliance.

Filtered earplugs were designed to reduce noise exposure while still allowing some sound to pass through the earplug to maintain communication capabilities and situation awareness (SA). Recent work by Gallagher et al.¹ evaluated the attenuation properties of a filtered earplug versus foam earplug and their impact on speech intelligibility when worn under communication headsets. The study found similar levels of protection were provided regardless of the earplug worn under the headset from 2-8 kHz. In addition, acceptable speech intelligibility scores (91%) were measured when subjects wore filtered earplugs under a headset in a 105 dBA noise environment. Scores were unacceptable (56%) when foam earplugs were worn under a headset in the same noise environment.

Further research is needed to determine if the results of the limited dataset would extend to other communication headsets and filtered earplug combinations. The use of filtered earplugs may improve speech intelligibly, but it is currently unknown whether a user can also benefit in the area of situation awareness. This is critical for ground forces who need to be able to localize sounds to successfully complete the mission. It is also unknown if the type of filtered earplug ear tip affects performance (flanged vs foam). Foam ear tips typically provide higher levels of noise attenuation which may also lead to higher levels of degradation in auditory performance tasks. AFRL conducted measurements to determine the level of provided protection as well as the effect on the user's auditory performance with multiple types of filtered earplugs worn in combination with multiple types of communication headsets and flight helmets.

2.0 METHODS

The general approach to assess HPDs was to use ANSI/ASA measurement procedures for continuous noise attenuation, impulsive peak insertion loss, sound localization, and speech intelligibility performance. Noise attenuation measurements were collected in accordance with the ANSI/ASA S12.6-2016 Methods for Measuring the Real-Ear Attenuation of Hearing Protectors.² Impulsive noise attenuation measurements were collected in accordance with ANSI/ASA S12.42-2010 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.³ Sound localization measurements were collected in accordance with ANSI S3.71-2019 Methods for Measuring the Effect of Head-worn Devices on Directional Sound Localization in the Horizontal Plane.⁴ Speech intelligibility measurements were collected in accordance with ANSI S3.2-2020 Method for Measuring the Intelligibility of Speech Over Communication Systems.⁵ AFRL-defined measurement procedures were used to assess the electro-acoustic characteristics of each device. Measurements were conducted with human research subjects at the AFRL acoustic facilities at Wright-Patterson Air Force Base (WPAFB) from March 2021 to July 2022.

2.1 Equipment

The devices selected for the study are a combination of commonly used or newly developed, filtered earplugs worn in combination with communication headsets and helmets. Five earplugs were selected for the study: Etymotic ER20, Earasers Musician's Plugs, CAEP 4.0, Sonic Defenders EP7, and Sound Guard foam earplugs (Figure 1). Two frequency filtered earplugs, two level-dependent earplugs, and one passive foam earplug were selected to provide a comparison within and across earplug styles. The ER20 and Earasers are frequency filtered earplugs originally designed for musicians and the live performance community. Unlike traditional foam and flanged earplugs that attenuate proportionally more high-frequency than low-frequency sound, creating a 'muffled' or 'underwater' effect, these filtered earplugs were designed to replicate the natural response of the ear canal and preserve the clarity of speech and fidelity of music, only at a quieter volume. The CAEP 4.0 and EP7 are level-dependent earplugs designed to provide military personnel protection from impulse noises, like gunfire or explosions, while allowing them to hear low-level sounds, like speech or footsteps in order to maintain SA. For all measurements in this study, the CAEP 4.0 and EP7 were worn in the open filtered position. Foam earplugs have historically been used for most industrial and military hearing conservation applications. Sound Guard foam earplugs were selected to provide baseline or legacy earplug performance data. The ER20 and CAEP 4.0 have flanged ear tips, the Earasers have soft silicone, hearing-aid style ear tips, and the EP7 have foam Comply™ Canal Tips.

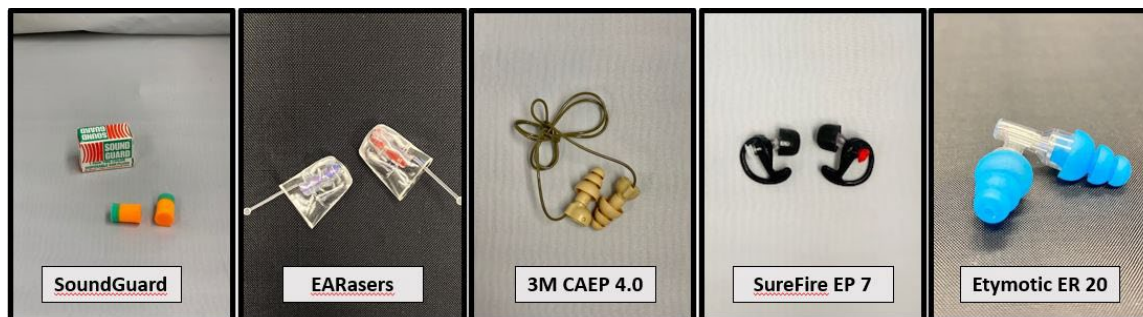


Figure 1. Earplugs Selected for the Study.

Communication headsets/helmets with different microphones and speaker sets were selected for comparison within and across device type. Five communication headsets were evaluated in this study: Peltor COMTAC V, Gentex Ops-Core AMP, David Clark 12512G-11, David Clark H10-76, and Bose A20. The COMTAC V and Ops-Core AMP (Figure 2) are tactical communication headsets used in military operations to provide a voice communication interface between military personnel and to improve situation awareness by providing an active, hear-thru system that allows the operator to hear non-hazardous sounds, such as speech or footsteps, while reducing the risk of hearing loss and tinnitus caused by exposure to loud, continuous and impulse noise.

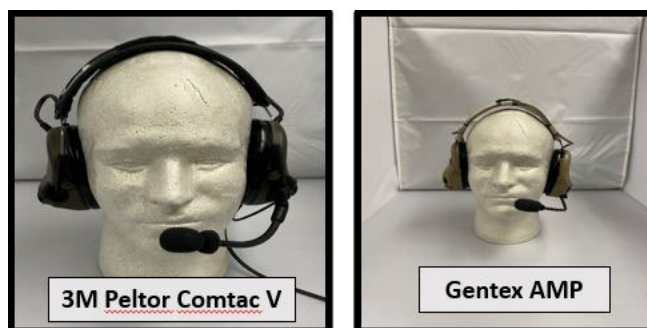


Figure 2. Tactical Headsets for Ground Forces.

The David Clark 12512G-11 and a legacy headset, David Clark H10-76, are communication headsets used by aircraft maintainers to reduce noise exposure on flight lines and to provide satisfactory voice communications between flight line personnel and aircrew (Figure 3).

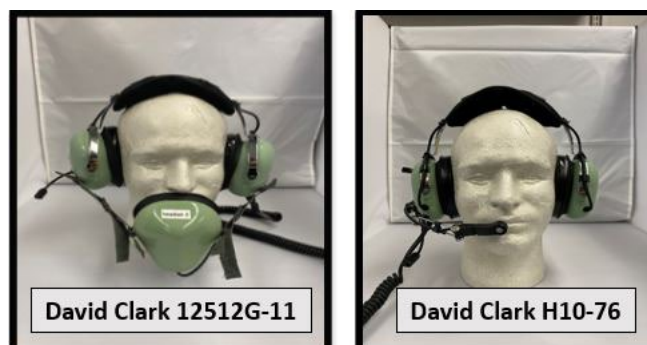


Figure 3. Aircraft Maintainer Headsets.

The Bose A20 and David Clark H10-76 are communication headsets used by aircrew to reduce noise exposure in-flight and to provide satisfactory voice communications (Figure 4). Two communication flight helmets were evaluated in this study, one designed for fixed-wing aircrew, and one designed for rotary-wing aircrew (Figure 5).

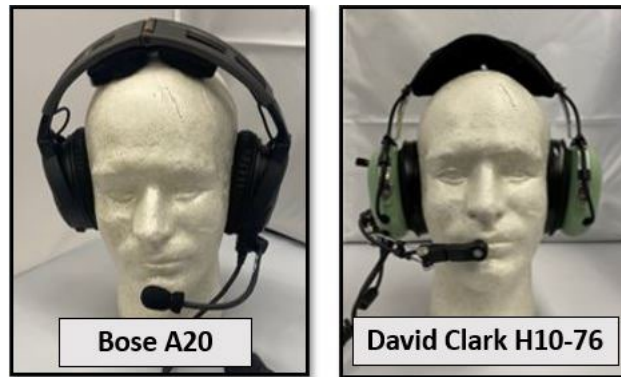


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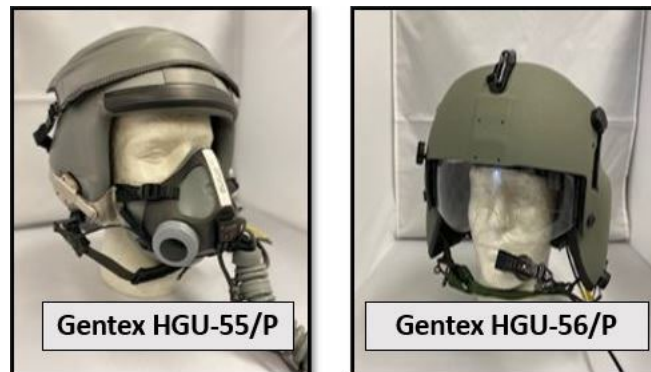


Figure 5. Fixed-Wing Aircrew Helmet (left) and Rotary-Wing Aircrew Helmet (right).

Combinations of earplugs and headsets/helmets were largely based on potential real-world applications. The COMTAC V and Ops-Core AMP were paired with earplugs that have tactical applications like the CAEP 4.0 and EP7. Sound Guard foam earplugs were combined with the David Clark 12512G-11, Bose A20, David Clark H10-76, and the flight helmets based on the requirement for double hearing protection on the flight line and in many aircraft. ER20 and Earasers will be combined with all five headsets and both helmets to provide a comparison point for all configurations.

2.2 Subjects

All acoustic measurements were collected with human subjects except the electro-acoustic characterizations and impulsive peak insertion loss measurements, which were collected with an acoustic test fixture (ATF). ANSI S12.6² and S3.71⁴ requires a minimum of ten subjects per circumaural HPD and twenty subjects per HPD with an insert device. For continuous noise

attenuation measurements seventeen male and ten female subjects, ranging from 18 to 36 years, participated. There were multiple combinations of male and female subjects equaling a total of 10 or 20 subjects total depending on the device type. A subset of six male and four female subjects completed the sound localization measurements and a subset of three male and three female subjects completed the SI measurements. All subjects were given a screening audiogram via the Hughson-Westlake method and were required to have hearing thresholds within the normal hearing range: 20 decibel (dB) Hearing Level or better from 125 to 8000 hertz (Hz). Each subject fit his/her own HPD for the measurements after being fit and trained from the test administrator. Prior to each measurement, all subjects received training outlined by the corresponding ANSI/ASA standard.

2.3 Electro-Acoustic Characterization

The Gentex AMP and Peltor Comtac V are equipped with active, hear-thru capability designed to amplify soft ambient sounds and conversational speech while suppressing loud, impulse noises. From a tactical standpoint, this should protect the operator from events such as gunfire, door charges, and explosions while allowing them to maintain and monitor the acoustic cues in his/her surrounding environment. The hear-thru mode of the tactical headset operates independently of the external communication capability, allowing the operator greater control over how he/she receives acoustic signals. The Gentex AMP hear-thru mode has eight gain settings, and the Peltor Comtac V has five gain settings.

Donning a headset adds some degree of passive attenuation; the unity gain is the hear-thru setting that provides enough gain to compensate for the attenuation created by wearing the headset. Essentially, the unity gain is the device setting that would be most similar to the operator's hearing without the headset. The unity gain for each headset was determined by comparing the input/output gain curves of each device's hear-thru settings to the input/output gain curve of a GRAS 45CB-S1 ATF (Figure 6). The hear-thru setting gain curve that most closely matched the ATF gain curve was selected as the unity gain setting for that headset. Matching the gain structure of each headset to the GRAS 45CB-S1 ATF creates a baseline gain setting for comparison across devices and is most representative of human hearing.

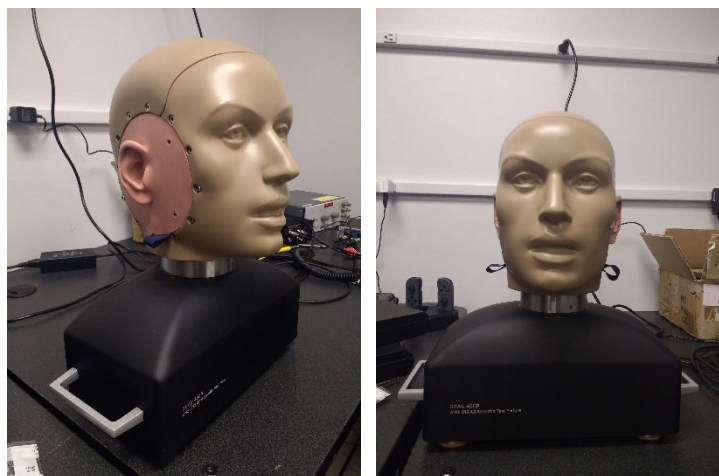


Figure 6. GRAS ATF.

Measurements were conducted in AFRL's Auditory Localization Facility (ALF) at WPAFB with GRAS 45CB-S1 ATF. The GRAS 45CB-S1 ATF is equipped with two GRAS Type 40-AG preamplifiers and 40AO externally polarized pressure microphones positioned inside the head with the microphone diaphragms aligned to each ear canal. The input/output gain curve for GRAS 45CB-S1 ATF was obtained by measuring a series of broadband (200 Hz – 16 kilohertz [kHz]) pink noise stimuli in ALF with the ATF's ears unoccluded (without headset in place). The ATF's gain structure is linear; if the sound pressure level (SPL) of the system input in ALF was 70 dB, the recorded output at heads ears was also 70 dB. The input/output gain curves for each headset configuration were obtained by selecting a hear-thru setting, equipping the GRAS 45CB-S1 ATF with the headset, and collecting the same series of stimuli. This procedure was repeated with each hear-thru setting for each headset configuration.

2.4 Continuous Noise Attenuation

The AFRL facility used for continuous noise attenuation measurements was specifically built for the measurement of the sound attenuation properties of passive hearing protection devices. The chamber, its instrumentation, and measurement procedures employed were in accordance with ANSI/ASA S12.6-2016.² The facility is comprised of 12 loudspeakers, three mounted in each of the four corners of the room, with a chair positioned in the center of the room for the subject (Figure 7).



Figure 7. Facility Used for Measurement of Passive Continuous Noise Attenuation.

Once seated in the room, the subject was required to detect 1/3-octave band stimuli centered at each of the seven octave band frequencies, ranging from 125 to 8000 Hz. The subject responses were collected via a hand-held response wand (Figure 8). The Békésy tracking procedure was employed to complete the measurement. When the stimulus was audible, the subject would respond by pressing and holding a button on the response wand. Once the stimulus was inaudible, the subject would release the response button until the stimulus was audible again.

This procedure was repeated until a minimum of three comparable thresholds were recorded for each measured octave band.

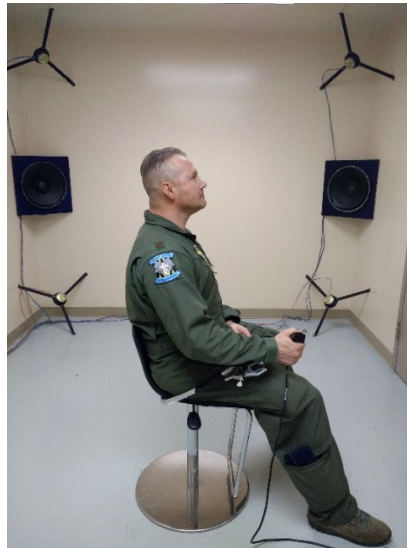


Figure 8. Subject Completing a Continuous Noise Attenuation Measurement.

Passive noise attenuation data were analyzed using the methods described in ANSI/ASA S12.68-2007 *Methods of Estimating Effective A-Weighted Sound Pressure Levels When Hearing Protectors are Worn*.⁶ The thresholds for each of the test subjects were measured twice for each configuration, paired by unoccluded and occluded ear conditions. The real ear attenuation at threshold (REAT) for each subject, with each configuration, was computed at each octave frequency, 125 to 8000 Hz, by subtracting the unoccluded ear threshold from the occluded ear threshold. The attenuation was then averaged across the two trials for each subject. Mean and standard deviation (SD) noise attenuation data were calculated across subjects at each octave frequency band ranging from 125 to 8000 Hz.

Octave band data can be directly applied to the frequency content of the measured noise environment where the HPD will be employed, thereby providing the highest confidence in estimating the operator's noise exposure. NRS_A was also calculated. NRS_A reduces the octave band data into a range of attenuation values that an operator could expect to achieve when using an HPD. This range reflects the variation across the subjects in the measurement, providing insight into how hard/easy the device may be to fit, as well as variation in the noise level reduction with the noise spectrum in which the device is used. The lower value indicates the level of attenuation that the majority (80%) of operators will be able to obtain; the higher value indicates the level of attenuation that only the most motivated, proficient operators (20%) will be able to attain. A narrow range indicates the hearing protection device provides stable and predictable levels of protection. To estimate the level of sound at the ear under the HPD, the operator would simply subtract the NRS_A attenuation value of the device directly from the measured A-weighted overall noise level of the environment. NRS_A is used in place of the more commonly used Noise Reduction Rating (NRR). The NRR was developed to be subtracted from C-weighted noise levels. Typically, A-weighted noise levels are reported since A-weighting filters low frequency values in a manner similar to the response of the human ear. If only A-weighted noise levels are known, a correction factor (minus 7 dB) must be applied to the NRR

for spectral uncertainty. Using the NRS_A eliminates this additional calculation, although it is not recommended for use when noise levels exceed 100 dBA or when the noise environment has high levels of low-frequency content.

$NRSG$ was also calculated. $NRSG$ can be used to calculate attenuation performance values that are only marginally less accurate than the gold standard octave band method and do not have a noise level limitation like NRS_A . $NRSG$ ratings model the hearing protector attenuation performance in reducing the A-weighted level at the ear using 130 defined industrial and military noise environments. $NRSG$ 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. To approximate the response of the human auditory system, A-weighted noise measurements give less weight to low frequencies relative to mid-high frequencies. C-weighted noise measurements do not differentially weight low frequencies, therefore, the difference between A- and C-weighted noise levels describe the low frequency content. For example, if the C-weighted noise was measured at 100 dB and the A-weighted noise was measured at 94 dB then the difference between the two weighting levels would be 6. $NRSG$ also provides a range of attenuation values.

2.5 Impulsive Peak Insertion Loss

Impulsive noise attenuation measurements were collected in accordance with ANSI/ASA S12.42-2010² for the HPDs, with all earplug configurations, to determine the level of protection provided by the device. Measurements were conducted with peak sound pressure levels (P SPL) ranging from 168-172 peak decibel level (dBp). An ATF and a GRAS 67SB probe microphone were used to simultaneously measure the sound pressure level the operator would experience at the ear as well as the true pressure level of the source. The ATF was an Institute of Saint-Louis (ISL)-1 type head equipped with 1/4" microphones in both ear canals (Figure 9).

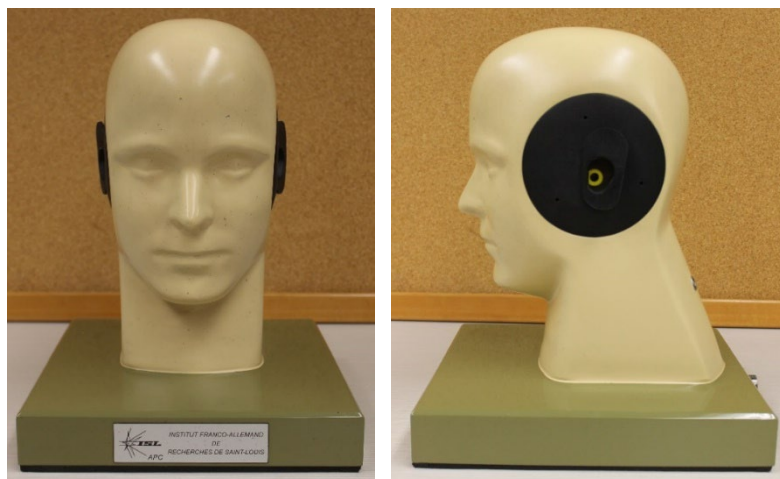


Figure 9. ISL ATF.

The impulsive noise measurements were conducted at AFRL in a three-story, vaulted laboratory. The laboratory was large enough to support the positioning of the impulse cannon, probe microphone, and ATF in such a way that no reflections would be present during the A-duration of the impulsive signal. The A-duration is the duration of an impulsive sound from the time of its

initial sharp increase in positive sound pressure to the time when the sound pressure becomes negative. A-durations in the laboratory ranged between 1-2 milliseconds (ms).

The stimulus was generated via a custom-made, impulse cannon (Figure 10). The impulse cannon is comprised of three parts: a compressed air system, an acoustic shock tube, and an exponential horn. The compressed air system uses a 60-gallon vertical air compressor that operates up to 120 pounds per square inch. Each impulse was generated by placing a .05-millimeter-thick Mylar film between the pressure tank and shock tube of the impulse cannon. The seal between the pressure tank and acoustic shock tube allowed pressure to build up behind the film. The pressure in the pressure tank was increased to 200 kilo Pascals and a pneumatic lance was used to puncture the film, generating a pressure wave that propagated through the exponential horn attached to the shock tube. The pressure wave was recorded at a distance of 0.5 meters (m) from the horn and ± 0.2 m from the centerline of the horn. Measurements were recorded using a National Instruments PXIe 1073 32-bit digital recorder at a sampling rate of 192 kHz.

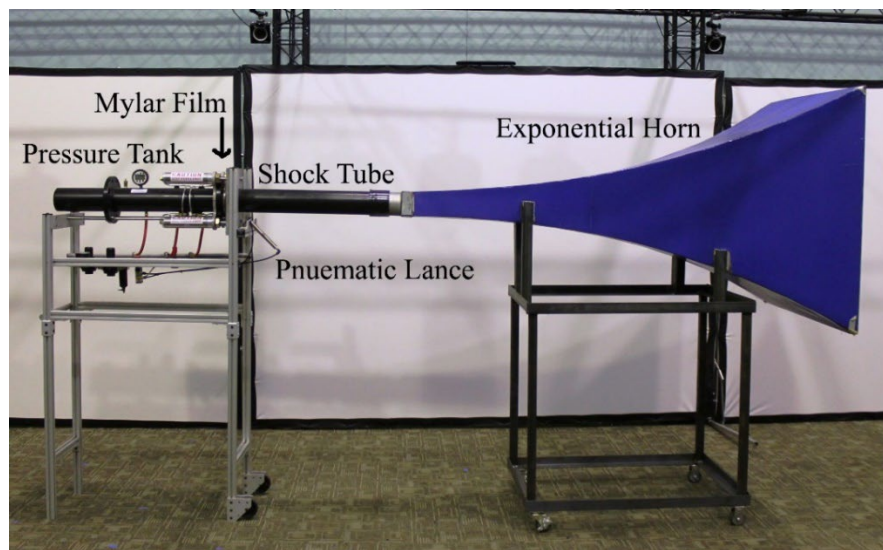


Figure 10. Impulse Cannon.

For all measurements, the ATF and the probe microphone were calibrated at the beginning of the measurement day. Additionally, a time-calibration procedure was performed to ensure the probe mic and the left and right ear of the ATF were equidistant from the impulsive noise source. This procedure was performed by generating a 150 dB SPL impulse and measuring the time the peak of the impulse arrived at each microphone. The ATFs and probe microphone were then adjusted until the peak of the impulsive noise arrived at all microphones at the same time.

Measurements were performed to calculate the transfer function between the unoccluded ear and the probe microphone. This transfer function, known as the transfer function of the open ear (TFOE), is the transform of the output signal of the impulse cannon from the probe microphone to the transform of the input signal of the unoccluded ATF, accounting for the signal change that occurs as sound travels through the ear canal of the ATF. The TFOE was calculated by recording five impulses ranging from 148 – 152 dB SPL sound pressure level (SPL) with an A-duration of 1-2

ms and averaging the transfer function of these five measurements. Equation 1 was used to calculate the TFOE.

$$TFOE (dB) = \frac{\sum Left Ear (dB) + Right Ear (dB)}{10} - \frac{\sum Probe Mic (dB)}{5}$$

Equation 1. TFOE

Additionally, the transfer function of each 1/3-octave band was calculated from 100 Hz to 20 kHz. Figure 11 shows an example of the mean TFOE values for the left and right ears graphed separately.

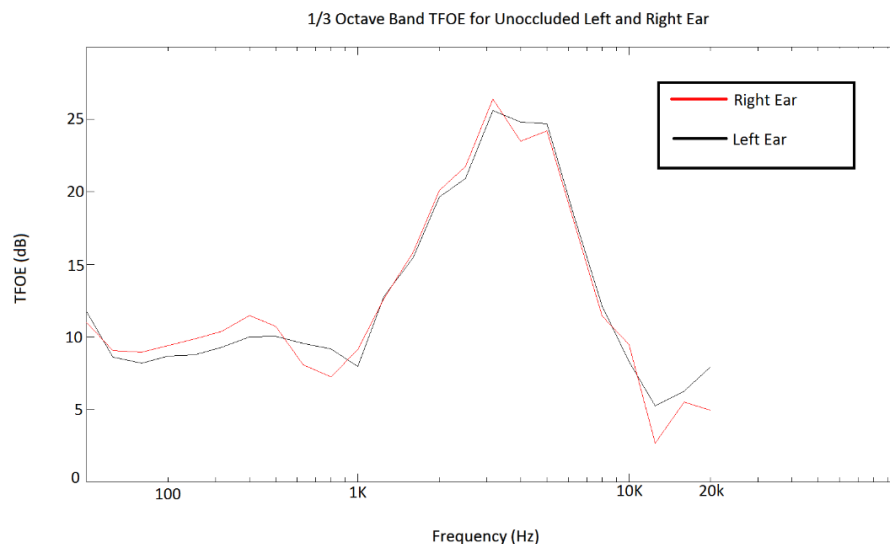


Figure 11. 1/3-Octave Band TFOE for Left and Right Ear

After determining the TFOE and establishing the transfer function of each 1/3 octave band, five measurements were recorded at 170 dBP SPL with each HPD powered off. The systems were removed from the head and refit between each measurement. ANSI/ASA S12.42 also requires measurements of 130 and 150 dBP SPL, however, 170 dBP SPL was selected as the focus for these measurements since this SPL is closer to the range of impulses that an operator may be exposed to in a military setting. Also, a dBP SPL of 170 dB was the maximum impulsive noise level generated in AFRL and the upper pressure level limit that can be generated by the impulse cannon.

IPIL data were calculated in order to determine the level of protection provided by an HPD. Insertion loss is defined as the algebraic difference, in dB, between the SPL measured at a reference point with and without the hearing protector in place. IPIL is the reduction in peak pressure of the impulse noise. For each impulse, the SPL of the probe microphone and the 1/4" microphones in each ear of the ATF were recorded. The IPIL was calculated for each device

using Equation 2 below. The TFOE is used in the IPIL calculation for each fit of the hearing protectors.

$$IPIL = \frac{\sum Probe\ Mic\ (dB)}{5} - \frac{\sum Left\ Ear\ (dB) + Right\ ear\ (dB)}{10} + TFOE\ (dB)$$

Equation 2. IPIL.

2.6 Sound Localization

The auditory localization measurements were conducted in accordance with ANSI/ASA S3.71, Method 2, except that only ten subjects were used for data collection instead of the required 20 subjects necessary for HPD with insert earplugs. The measurements were collected in the Spatial Hearing and Acoustic Research Chamber (SHARC) at WPAFB, Figure 12. SHARC is a small anechoic chamber, with a ring of 36 loudspeakers, each 10 degrees apart, with a radius of 5 feet. The subject sat in the center of the ring and the loudspeakers were obscured from the subject's view by an acoustically transparent speaker cloth. The subjects did not know how many loudspeakers were in the array, nor the location of each loudspeaker. The position and orientation of the subject's head was tracked during the experiment via a reflective ball array fixed on top of the subject's head, and an optical motion capture system (Optitrack Trio). The orientation of the subject's head was indicated to the subject via the illumination of a corresponding Light-Emitting Diode (LED) in a circular LED array, concentric with the loudspeaker array, with 1208 individually addressable LEDs (approximately. 0.3 degrees/LED).



Figure 12. Facility Used for Measurement of Sound Localization.

Each subject fit the device, the device was powered on, and the gain was set to the unity gain setting established during the electro-acoustic characterization. The test administrator then directed the subject from the control room, where the fitting took place, into SHARC. Once inside the facility, the seated subject was raised or lowered by adjusting the height of the platform to ensure the subject's ears were aligned with the speaker plane. For each trial, the

subjects first aligned their head in the center of the ring and faced zero degrees azimuth (where a speaker was located), and then heard either a burst of noise (pink spectrum, bandlimited between 200 Hz and 14 kHz), with a duration of 250 ms, including 10 ms on and off ramps, or repeated bursts of noise with the same specifications and a 250 ms silent period between bursts for up to 7 s. The noise bursts were presented at a level of 60, 65, or 70 dBA, randomly selected on each trial. Then the subjects were asked to turn their head to indicate the direction from which they thought the noise had originated. During the response period, the subject's head orientation controlled a cursor on the LED array, such that the cursor was always in front of the subject. When the cursor was on the desired response location, the subject then pressed a button on a handheld, wireless response interface. This procedure repeated for a block of 108 trials, with the target location and duration pseudo-randomly selected for each trial, such that each subject completed nine single-burst trials and three repeated-burst trials per target location per device under test, including an open-ear condition for baseline comparison.

Auditory localization performance measurements were collected for each HPD configuration and for the open ear control condition. The Open Ear condition served as a baseline for determining how wearing the HPD affected localization performance. The data were analyzed to determine the mean unsigned angular error and the proportion of front-back reversals, as defined in ANSI/ASA S3.71.³ The mean unsigned errors after correcting for front-back reversals was also calculated.

2.7 Speech Intelligibility

Speech intelligibility measurements were conducted in accordance with ANSI/ASA S3.2⁴ in AFRL's VOice Communication Research and Evaluation System (VOCRES). VOCRES was designed to evaluate voice communication effectiveness in operationally-realistic acoustic environments. The facility consists of a programmable, high-power sound system housed in a large reverberant chamber, capable of generating pink noise at levels ranging from 55 to 125 dBA emulating acoustic environments in operational situations.

Subject workstations are positioned in the facility (Figure 13), each equipped with a touch-screen display and communication system capable of replicating end-to-end military communication chains (e.g., intercoms, radios, oxygen systems, headsets, microphones, and helmets). In this way, full communication systems, as well as individual system components, may be evaluated under operational conditions to determine the impact these systems might have on speech intelligibility.



Figure 13. AFRL's VOCRES Facility Used to Measure Speech Intelligibility Performance

The MRT was selected for the test material and the stimuli were presented by live talker. The MRT consists of 50, six-word lists of monosyllabic English words, differing only in initial or final consonant (e.g., toil/boil and came/cane). The goal was to quantify the ability of trained listeners to correctly identify target words transmitted by a trained talker using the various HPDs. Cueing of target words for the talker and recording of listener responses were both accomplished via a custom Matrix Laboratory (MATLAB) application. A tablet with a graphical user interface was utilized for subject response. Speech intelligibility measurements were collected with PRC-148 Multiband Inter/Intra Team Radios (MBITR) and AIC-25 Aircraft Intercom system depending on the HPD.

ANSI/ASA S3.2⁴ requires a minimum of five talkers with a minimum number of listeners that is greater than or equal to the number of talkers. ANSI S3.2⁴ also requires each talker to speak a minimum of three MRT lists. Subjects had control over their volume settings. Speech intelligibility measurements were collected in a high-noise environment (95 and 105 dBA depending on the HPD).

During the experimental task, the talker was presented with the stimulus on the computer screen ("you will mark <MRT word> please"). Listeners selected the target word by using a pen to click on the heard word from a list of six words on the tablet screen. Responses were recorded and an average score was calculated. An example of the MRT format for the talker and listener workstations is provided in Figure 14.

Number 1, you will mark WENT please.	1.	Went	Sent	Bent
		Dent	Tent	Rent
Number 2, you will mark HOLD please.	2.	Sold	Cold	Told
Number 3, you will mark PAT please.		Fold	Hold	Gold
.	3.	Pan	Pad	Pat
.		Path	Pack	Pass
.				

Figure 14. Examples of the Talker Prompt (left) and Listener Response Matrix (right).

The subjects' scores were adjusted for guessing, per subject, as described in ANSI/ASA S3.2⁴ and Equation 3 below. An overall average was then calculated for all subjects in each condition.

$$Score = 2(R - \frac{W}{n-1})$$

Where: *Score* = Percent Correct (Adjusted For Guessing)
R = Number Correct
W = Number Incorrect
n = 6 (number of choices available to listener)

Equation 3. MRT Adjustment for Chance/Guessing.

3.0 RESULTS

ANSI/ASA standard measurement procedures were used to assess HPDs for continuous noise attenuation, impulsive peak insertion loss, sound localization, and speech intelligibility performance. Results are broken out for each respective community: ground forces, aircraft Maintainers, and aircrew wearing flight headsets or flight helmets. AFRL defined measurement procedures were used to assess the electro-acoustic characteristics of each device.

3.1 Electro-Acoustic Characterization

Input/output gain curves for the Peltor Comtac V and Gentex Adaptive Mission Platform (AMP) are shown in Figures 15-16, respectively. Based on these results, the unity gain for the Peltor Comtac V was set at “Maximum -2.” The unity gain for the Gentex AMP was set at “Maximum -5.” During sound localization measurements, the headsets were set to these unity gain settings.

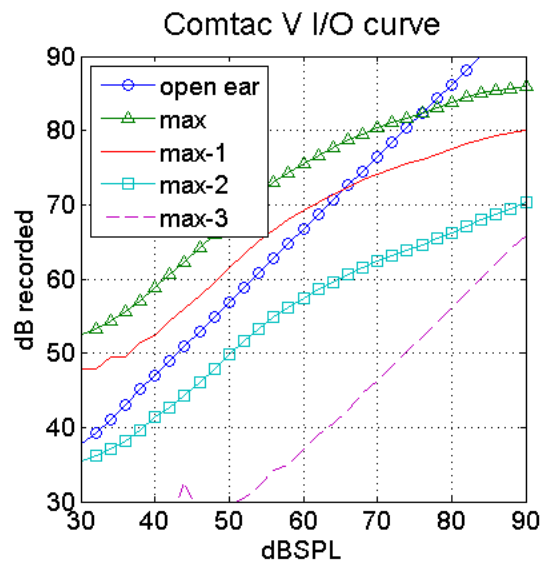


Figure 15. Input/Output Gain Curves for Peltor Comtac V.

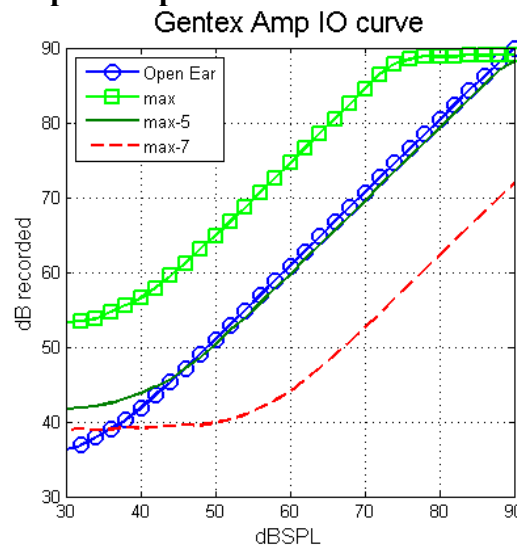


Figure 16. Input/Output Gain Curves for Gentex AMP.

In addition to establishing the unity gain for each tactical headset, the input/output gain curves in Figures 15-16 demonstrate the broadband electro-acoustic response of each device at select hear-thru settings. For example, in an 80-dB continuous pink noise environment, an operator donning the Peltor Comtac V would expect the following noise levels at the ear: 83 dB at Maximum, 67 dB at Maximum -2 (Unity Gain), and 56 dB at Maximum -3.

3.2 Earplugs: Continuous Noise Attenuation

In order to establish a continuous noise attenuation baseline, data was collected for each earplug without any accompanying headset or helmet. Mean passive attenuation results are shown in Figure 17 at each measured frequency for the four filtered-type earplugs as well as the SoundGuard foam earplug. Table 1 contains octave band data (mean, SD) and NRS_A range for each earplug individually. Table 2 has the NRS_G range for each earplug with noise spectral balance values at -1, 2, 6, and 13. As expected, the foam earplugs provided the greatest level of protection across all frequencies. The ER20 provided a fairly flat level of attenuation across all frequencies as expected while the Earasers, CAEP 4.0, and EP7 provided little attenuation in the low frequencies and increased attenuation in the high frequencies.

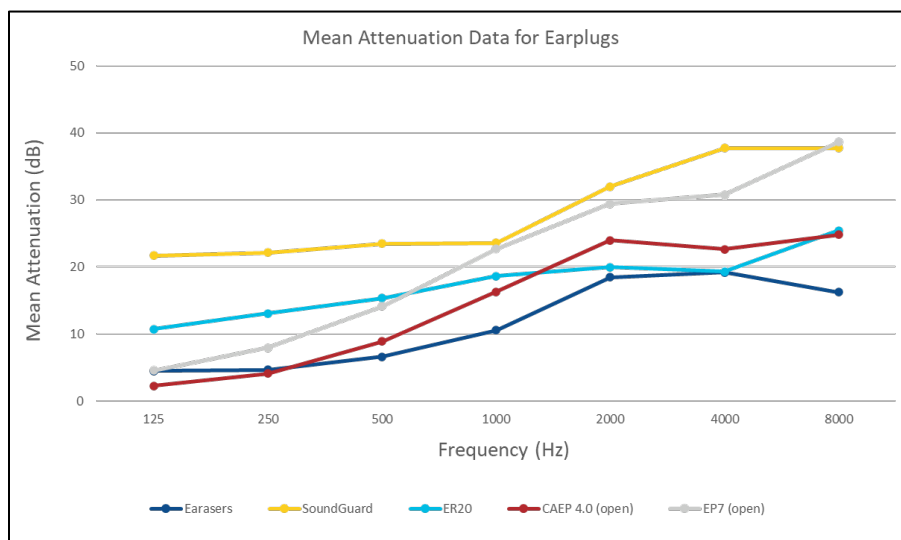


Figure 17. Passive Mean Noise Attenuation Data (earplugs).

Table 1. Passive Noise Attenuation Data in dB (earplugs).

Hearing Protection		Frequency (Hz)								NRSA	
Headset	Earplug		125	250	500	1000	2000	4000	8000	80%	20%
none	Erasers	Mean	4	5	7	11	18	19	16	7	16
		SD	4	5	5	5	6	5	5		
none	SoundGuard	Mean	22	22	23	24	32	38	38	22	31
		SD	6	6	7	6	2	4	6		
none	ER20	Mean	11	13	15	19	20	19	25	14	20
		SD	4	4	5	4	4	5	3		
none	CAEP 4.0 (open)	Mean	2	4	9	16	24	23	25	10	17
		SD	3	4	3	2	3	4	3		
none	EP7 (open)	Mean	5	8	14	23	29	31	39	15	23
		SD	2	3	2	2	3	3	5		

Table 2. NRS_G Data (earplugs).

Headset	Earplug		Noise Spectral Balance (C-A)			
			-1	2	6	13
None	Erasers	80%	11	6	4	2
		20%	19	14	11	9
None	SoundGuard	80%	26	20	19	18
		20%	33	30	28	27
None	ER20	80%	16.3	14	11.8	8.8
		20%	21.9	20.1	18.4	15.5
None	CAEP 4.0 (open)	80%	17.4	10.3	5.8	1.6
		20%	20.9	14.3	10.8	6.3
None	EP7 (open)	80%	23.8	15.6	10.5	5
		20%	26.6	18.7	14.1	8.5

3.3 Ground Forces: Continuous Noise Attenuation

Continuous noise attenuation data for HPD configurations, potentially used by ground forces, was collected for the Gentex AMP and Peltor Comtac V headsets alone, and with each of the four filtered-type earplugs. Mean passive attenuation results are shown in Figure 18 at each measured frequency for Gentex AMP alone and paired with each filtered-type earplug. Table 3 contains octave band data (mean, SD) and NRSA data for the Gentex AMP headset alone and with each filtered-type earplug. Table 4 has the NRS_G data for each configuration with noise spectral balance values at -1, 2, 6, and 13. The addition of a filtered-type earplug to the Gentex AMP varied in its added protection. The ER20 and EP7 provided the greatest benefit across all frequencies based on mean octave band data.

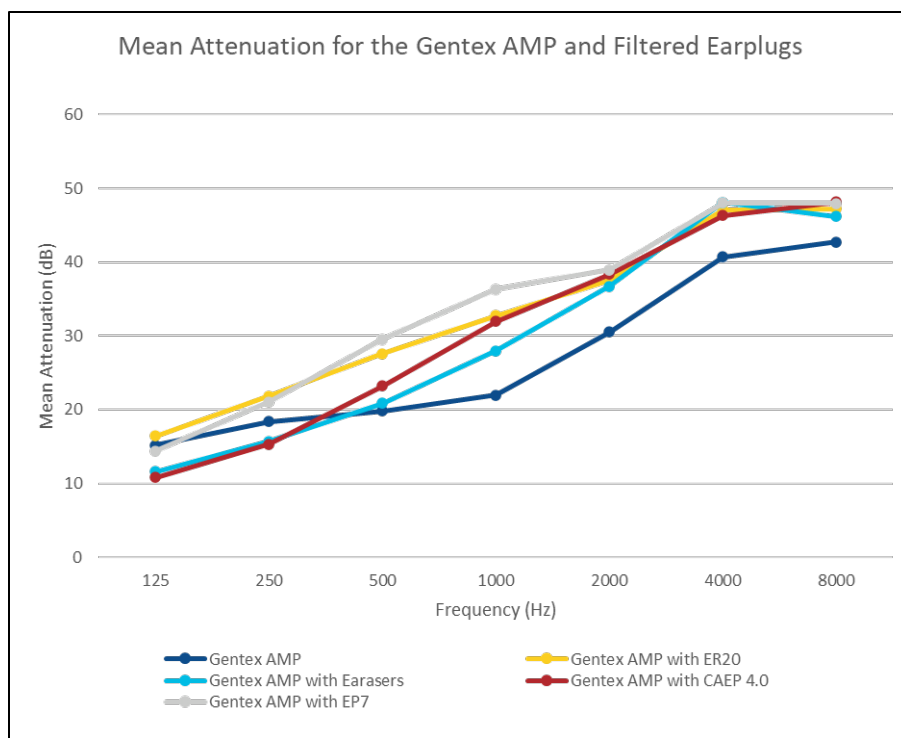


Figure 18. Passive Mean Noise Attenuation Data (Gentex AMP).

Table 3. Passive Noise Attenuation Data in dB (Gentex AMP).

Hearing Protection			Frequency (Hz)							NRSA	
Headset	Earplug		125	250	500	1000	2000	4000	8000	80%	20%
Gentex AMP	none	Mean	15	18	20	22	31	41	43	21	27
		SD	5	3	2	3	2	3	4		
Gentex AMP	ER20	Mean	16	21	27	32	37	46	47	26	35
		SD	4	5	7	5	3	3	3		
Gentex AMP	Earasers	Mean	12	16	21	28	37	48	46	21	30
		SD	4	3	5	5	4	3	2		
Gentex AMP	CAEP 4.0 (open)	Mean	9	15	23	32	38	46	48	22	31
		SD	2	3	5	6	4	4	4		
Gentex AMP	EP7 (open)	Mean	14	21	29	36	39	47	48	27	36
		SD	5	4	5	3	3	4	3		

Table 4. NSR_G Data (Gentex AMP).

Infantry Headset	Earplug		Noise Spectral Balance (C-A)			
			-1	2	6	13
Gentex AMP	None	80%	26.7	20.6	18.2	13.7
		20%	30.7	24.6	22.2	20
Gentex AMP	ER20	80%	33	25	21	16
		20%	39	33	29	23
Gentex AMP	Earasers	80%	29	21	17	11
		20%	35	26	22	17
Gentex AMP	CAEP 4.0 (open)	80%	31	22	17	11
		20%	36	28	22	16
Gentex AMP	EP7 (open)	80%	36	27	22	14
		20%	40	33	27	21

Mean passive attenuation results are shown in Figure 19 at each measured frequency for Peltor Comtac V alone and paired with each filtered-type earplug. Table 5 contains octave band data (mean, SD) and NRSA data for the Peltor Comtac V with each filtered-type earplug. Table 6 has the NRS_G data for each configuration with noise spectral balance values at -1, 2, 6, and 13. The addition of a filtered-type earplug to the Comtac V varied in its added protection. The benefit of the earplug is seen for all earplugs at 1000 Hz and above based on mean octave band data.

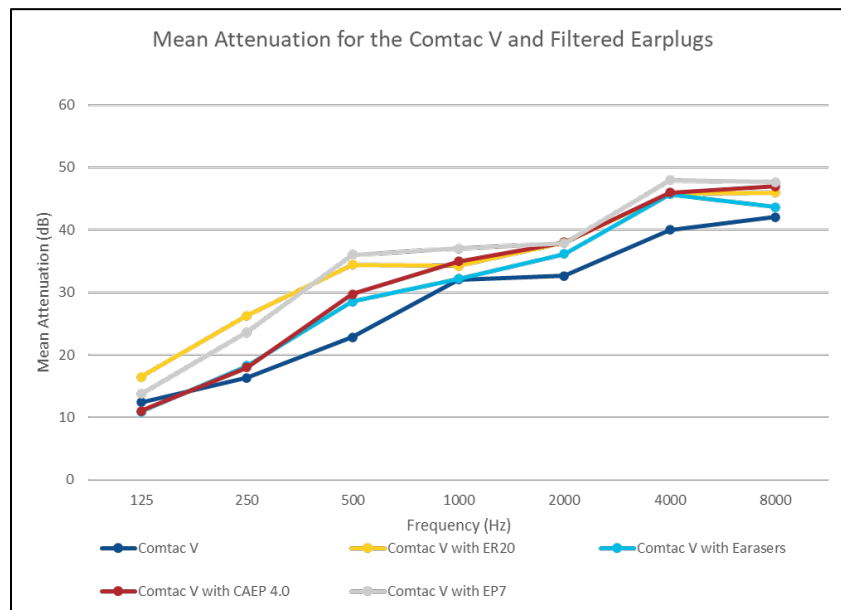


Figure 19. Passive Mean Noise Attenuation Data (Comtac V).

Table 5. Passive Noise Attenuation Data in dB (Comtac V).

Hearing Protection			Frequency (Hz)							NRSA	
Headset	Earplug		125	250	500	1000	2000	4000	8000	80%	20%
Peltor Comtac V	none	Mean	12	16	23	32	33	40	42	23	31
		SD	4	3	3	2	3	3	3		
Peltor Comtac V	ER20	Mean	16	26	34	34	37	46	46	28	36
		SD	5	6	6	4	3	4	3		
Peltor Comtac V	Erasers	Mean	11	18	29	32	36	46	44	23	33
		SD	3	6	7	4	3	4	3		
Peltor Comtac V	CAEP 4.0 (open)	Mean	10	16	30	35	37	45	46	23	34
		SD	3	6	6	4	3	4	3		
Peltor Comtac V	EP7 (open)	Mean	14	24	35	36	38	47	48	28	37
		SD	5	6	5	4	3	4	3		

Table 6. NRS_G Data (Peltor Comtac V).

Infantry Headset	Earplug		Noise Spectral Balance (C-A)			
			-1	2	6	13
Peltor Comtac V	None	80%	30.8	23.5	18.2	11.5
		20%	34.1	27.6	23	18
Peltor Comtac V	ER20	80%	35	29	23	16
		20%	40	35	31	24
Peltor Comtac V	Erasers	80%	32	24	18	11
		20%	38	31	25	17
Peltor Comtac V	CAEP 4.0 (open)	80%	33	24	17	11
		20%	39	31	25	17
Peltor Comtac V	EP7 (open)	80%	36	28	22	13
		20%	41	35	29	21

3.4 Ground Forces Impulsive Peak Insertion Loss

IPIL data was collected on the Gentex AMP and Peltor Comtac V headsets alone and with each of the four filtered-type earplugs. Average IPIL data for each device is shown in Table 7 and Figure 20. Department of Defense (DoD) Military Standard (MIL-STD)-1474E⁷ states that IPIL calculations shall not exceed 41 dB due to bone conducted noise. No adjustments were required for this study. ANSI/ASA S12.42 is currently under revision and will include correction factors for IPIL calculations in the next revision to better address exposure to noise via the bone-conduction pathway. For both tactical headsets, the addition of filtered-type earplugs provided increased insertion loss. The ER20 provided the highest level of protection from a 170 dBP SPL exposure.

Table 7. Average IPIL Data.

Hearing Protection		IPIL (dB)
Headset	Earplug	Mean
Gentex AMP	None	32
	ER20	39
	Earasers	34
	CAEP 4.0 (open)	38
	EP7 (open)	38
Comtac V	None	32
	ER20	40
	Earasers	35
	CAEP 4.0 (open)	39
	EP7 (open)	38

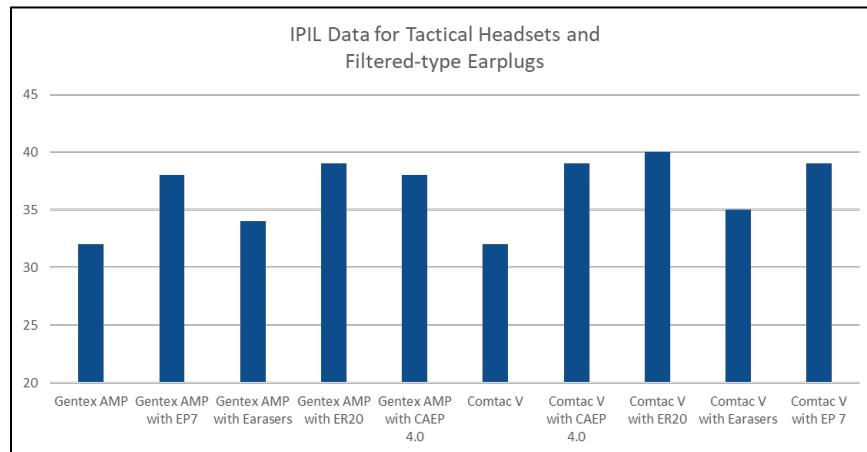


Figure 20. Average IPIL Data

3.5 Ground Forces Sound Localization

Sound localization data were collected with no hearing protection and with earplugs and tactical headsets alone and in combination. Three metrics were used to determine the HPD effect on localization performance: mean unsigned angular error, the proportion of front-back reversals, and the mean unsigned error after correcting for front-back reversals. Angular error is the difference between the actual target location and the subject's response location as measured by the distance between the two points. Angular error is a general measure that reflects overall localization performance. Front-back reversals occur when a subject is unable to determine whether a sound is in front of them or behind them and are frequently seen with degraded sound localization cues. They can lead to an increase in the amount of time it takes an operator to identify the location of a threat. Angular errors include front-back reversals, therefore, a correction removing the front-back reversals was also calculated. Measurements were collected in a burst (short) or continuous (long) noise condition. Table 8 displays the effect on localization performance for open ear and for each earplug alone to include: mean unsigned angular error, the

proportion of front-back reversals, and the mean unsigned error after correcting for front-back reversals. Figures 21 shows the mean unsigned angular error (both with and without the correction for front-back reversals) for the burst noise condition. The image on the left in Figure 21 shows that subjects had a higher degree of error when wearing the SoundGuard earplugs when compared to the filtered-type earplugs. However, the image on the right in Figure 21 shows that after the angular error is corrected for front-back reversals, the earplugs are similar. In general, auditory localization performance decreased with the use of the HPD when compared to open ear performance and was worse for the burst noise conditions than continuous noise conditions.

Table 8. Sound Localization Results (earplug only).

Device Configuration		Angular Error (°)		Corrected Angular Error (°)		Front Back Reversals (%)	
Headset	Earplug	Burst	Continuous	Burst	Continuous		Burst
None	None (open ear)	9.6	4.9	9.5	4.9	0.2	0
None	Soundguard	12.6	6.5	10.4	6.4	2	0.1
None	ER20	11.0	5.9	10.3	5.9	0.6	0
None	Earasers	14.1	6.1	10.7	6.0	3.1	0.1
None	CAEP 4.0 Open	13.6	6.4	11.1	6.1	2.4	0.2
None	EP7 Open	18.6	6.9	12.0	6.9	6.3	0

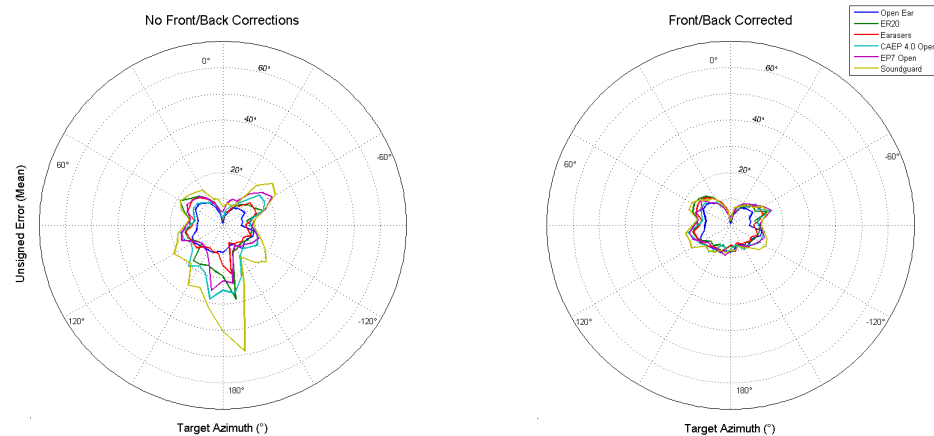


Figure 21. Unsigned Angular Error, with and without Correction for Front-Back Reversals, for the Burst (short) noise Condition for Open Ear and Earplugs Alone.

Table 9 displays the effect on localization performance of the Gentex AMP alone and with each filtered-type earplug. Mean unsigned angular error, the proportion of front-back reversals, and the mean unsigned error after correcting for front-back reversals are documented. Figures 22 shows the mean unsigned angular error (both with and without the correction for front-back reversals) for the burst noise condition.

Table 9. Sound Localization Results (Gentex AMP).

Device Configuration		Angular Error (°)		Corrected Angular Error (°)		Front Back Reversals (%)	
Headset	Earplug	Burst	Continuous	Burst	Continuous	Burst	Continuous
Gentex AMP Max-5	None	17.9	5.5	12.6	5.5	5.9	0
Gentex AMP Max-5	ER 20	20.6	6.3	13.2	6.3	7.8	0
Gentex AMP Max-5	Earasers	18.6	6.4	13.0	6.4	6.1	0
Gentex AMP Max-5	CAEP 4.0 Open	22.8	6.1	13.5	6.1	9.5	0
Gentex AMP Max-5	EP7 Open	23.4	6.4	14.5	6.4	10.3	0

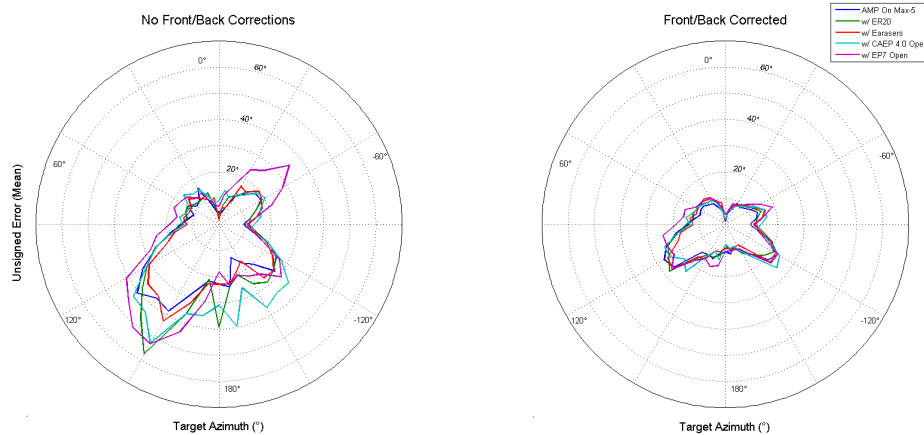


Figure 22. Unsigned Angular Error, with and without correction for Front-Back Reversals, for the Burst (short) Noise Condition (Gentex AMP).

Table 10 displays the effect on localization performance of the Comtac V alone and with each filtered earplug. Mean unsigned angular error, the proportion of front-back reversals, and the mean unsigned error after correcting for front-back reversals are documented. Figure 23 shows the mean unsigned angular error (both with and without the correction for front-back reversals) for the burst noise condition.

Table 10. Sound Localization Results (Comtac V).

Device Configuration		Angular Error (°)		Corrected Angular Error (°)		Front Back Reversals (%)	
Headset	Earplug	Burst	Continuous	Burst	Continuous	Burst	Continuous
Comtac V Max-2	None	20.3	6.5	14.1	6.5	6.5	0.0
Comtac V Max-2	ER20	22.2	6.6	14.6	6.6	8.1	0.0
Comtac V Max-2	Earasers	21.0	7.1	14.3	7.1	7.3	0.1
Comtac V Max-2	CAEP 4.0 Open	23.9	6.6	14.5	6.6	10.3	0.0
Comtac V Max-2	EP7 Open	25.9	7.2	14.6	7.1	12.0	0.1

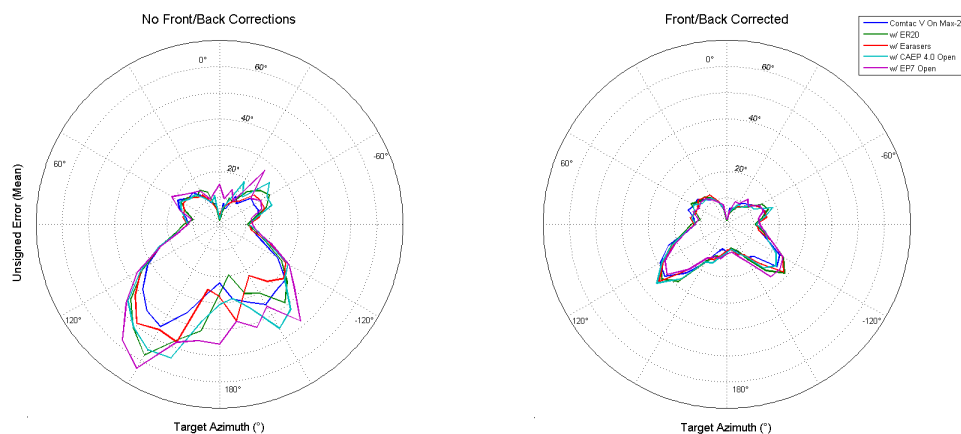


Figure 23. Unsigned Angular Error, with and without Correction for Front-Back Reversals, for the Burst (short) Noise Condition (Comtac V).

Figure 24 shows the percentage of front-back reversals for the burst and continuous noise conditions for all conditions: open ear, earplugs alone, tactical headsets alone and in combination with earplugs. With open ear, less than 1% of the subject response errors were front-back reversals in the burst noise condition. Donning a headset, without an earplug, increased the subjects' percentage of front-back reversals by 5-6% when compared to open ear. An addition of a filtered-type earplug continued to increase the percentage of front-back reversals. The combination of the Comtac V and EP7 earplugs had the greatest negative impact on subjects' performance in the burst conditions. In the continuous noise condition, subjects had adequate time to localize the sound and there were very few front-back reversal responses and no higher than 0.1% of any response subset.

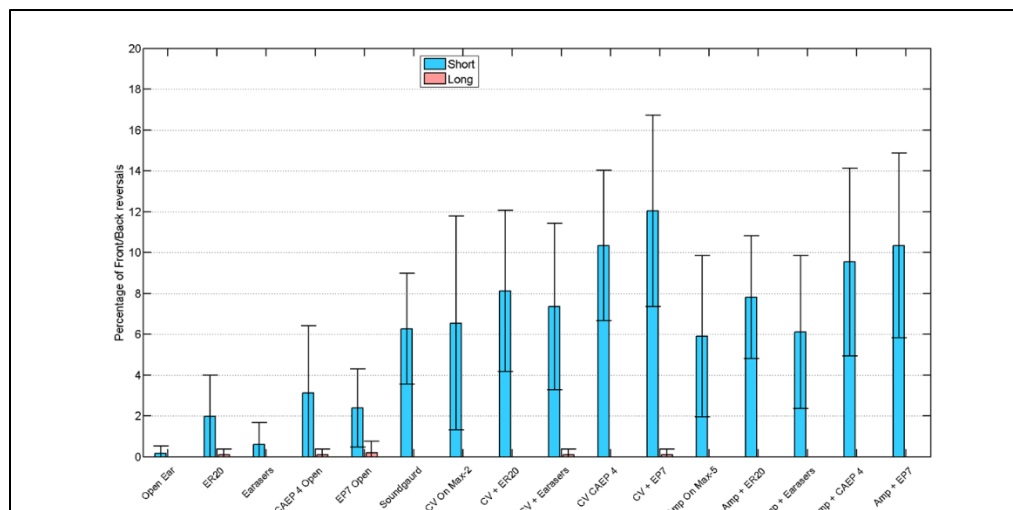


Figure 24. Percentage of Front-Back Reversals for the Burst (short) and Continuous (long) Noise Condition.

3.6 Ground Forces SI

SI measurements were conducted in a 95 dBA noise environment. Average SI scores are shown in Table 11. MIL-STD-1474E⁷ states that objective speech intelligibility performance should meet or exceed an average score of 80% to achieve good communication performance. Subjects achieved mean speech intelligibility scores of approximately 80% or better in the 95 dBA noise environment when wearing the Gentex AMP headset with filtered-type earplugs. The Comtac V paired with ER20 filtered-type earplugs provided the highest mean SI score of 96%.

Table 11. SI Performance of Ground Force HPDs (95 dB.)

Speech Intelligibility			
Headset	Earplug	Mean Score (%)	Standard Deviation
Gentex AMP	ER20	81	11
	Earasers	79	10
	CAEP 4.0 (open)	84	7
	EP7 (open)	80	11
Comtac V	ER20	96	5
	Earasers	85	9
	CAEP 4.0 (open)	85	8
	EP7 (open)	85	8

3.7 Aircraft Maintainers: Continuous Noise Attenuation

Continuous noise attenuation data was collected for both the David Clark 121512G-11 and David Clark H10-76. Data was collected on the headsets alone as well as with two frequency filtered earplugs (ER20 and Earasers) and the foam SoundGuard earplugs. Mean passive attenuation results are shown in Figure 25 at each measured frequency for the David Clark 121512G-11 alone, paired with the two filtered-type earplugs, and a standard foam earplug. Table 12 contains octave band data (mean, SD) and NRSA data. Table 13 has the NRSG data for each configuration with noise spectral balance values at -1, 2, 6, and 13. Interestingly, the ER20 and the SoundGuard provided similar mean attenuation across all frequencies when combined with the headset.

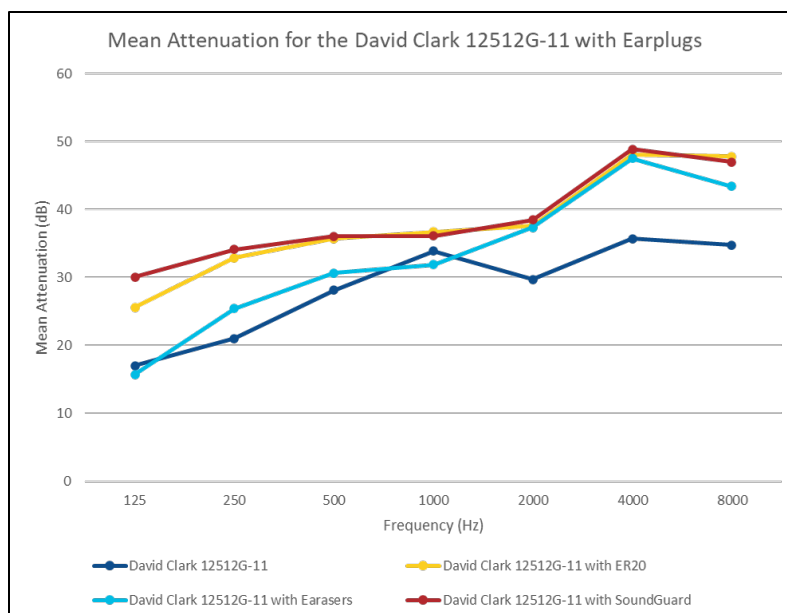


Figure 25. Passive Mean Noise Attenuation Data (David Clark 12512G-11).

Table 12. Passive noise attenuation data in dB (David Clark 12512G-11).

Hearing Protection		Frequency (Hz)								NRSA	
Headset	Earplug		125	250	500	1000	2000	4000	8000	80%	20%
David Clark 12512G-11	none	Mean	17	21	28	34	30	36	35	27	31
		SD	4	1	2	3	3	4	4		
David Clark 12512G-11	SoundGuard	Mean	30	34	36	36	38	49	47	35	39
		SD	6	6	6	3	3	3	3		
David Clark 12512G-11	ER20	Mean	26	33	36	37	38	48	48	33	39
		SD	6	5	6	4	4	4	6		
David Clark 12512G-11	Earasers	Mean	16	25	31	32	37	48	43	28	35
		SD	5	5	3	2	4	4	4		

Table 13. NRS_G Data (David Clark 1512G-11).

Headset	Earplug		Noise Spectral Balance (C-A)			
			-1	2	6	13
David Clark 12512G-11	none	x = 20%	33.5	30.1	26.4	22
		x = 80%	29.5	27.5	23.4	16.5
David Clark 12512G-11	SoundGuard	x = 20%	41	38	38	35
		x = 80%	38	34	32	28
David Clark 12512G-11	ER20	x = 20%	41.9	38.3	35.9	31.8
		x = 80%	36.5	33.2	30.3	24
David Clark 12512G-11	Earasers	x = 20%	39	33	29	23
		x = 80%	34	28	23	15

Mean passive attenuation results are shown in Figure 26 at each measured frequency for the David Clark H10-76 alone, paired with the two filtered-type earplugs, and paired a standard foam earplug. Table 14 contains octave band data (mean, SD) and NRSA data. Table 15 has the

NRS_G data for each configuration with noise spectral balance values at -1, 2, 6, and 13. As expected, the SoundGuard provided more mean attenuation across all frequencies than the filtered-type earplugs when combined with the headset.

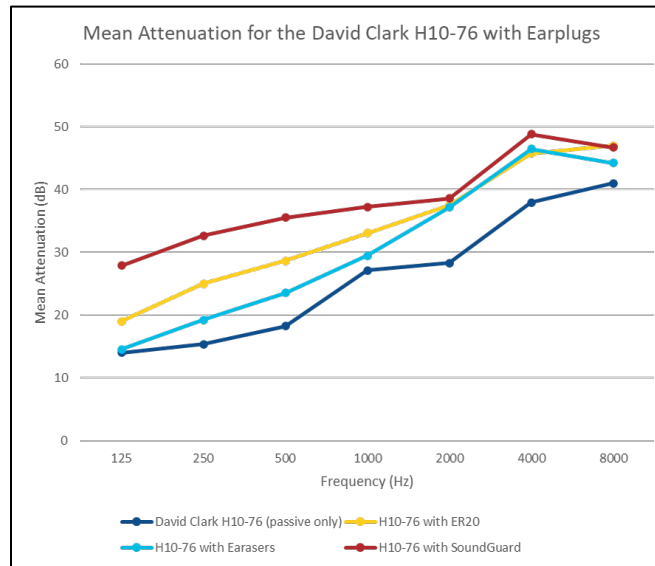


Figure 26. Passive mean noise attenuation data (David Clark H10-76)

Table 14. Passive noise attenuation data in dB (David Clark H10-76).

Hearing Protection			Frequency (Hz)								NRSA	
Headset	Earplug		125	250	500	1000	2000	4000	8000		80%	20%
David Clark H10-76 (passive only)	none	Mean	14	15	18	27	28	38	41		20	28
		SD	3	2	2	5	6	4	2			
David Clark H10-76 (passive only)	SoundGuard	Mean	28	33	36	37	39	49	47		34	40
		SD	6	6	6	3	3	4	3			
David Clark H10-76 (passive only)	ER20	Mean	19	25	29	33	38	46	47		28	36
		SD	5	7	6	4	3	3	3			
David Clark H10-76 (passive only)	Earasers	Mean	15	19	24	29	37	46	44		23	33
		SD	5	5	6	4	4	3	3			

Table 15. NRS_G Data (David Clark H10-76).

Headset	Earplug		Noise Spectral Balance (C-A)			
			-1	2	6	13
David Clark H10-76 (passive only)	none	x = 20%	32	24.9	20.8	17.3
		x = 80%	25.6	20.5	17.3	13.6
David Clark H10-76 (passive only)	SoundGuard	x = 20%	42	39	38	35
		x = 80%	38	33	30	25
David Clark H10-76 (passive only)	ER20	x = 20%	39	34	31	26
		x = 80%	34	27	23	17
David Clark H10-76 (passive only)	Earasers	x = 20%	37	30	26	21
		x = 80%	31	23	18	13

3.8 Aircraft Maintainers: SI

SI measurements were conducted in a 105 dBA noise environment. Average SI scores are shown in Table 16. MIL-STD-1474E⁷ states that objective speech intelligibility performance should meet or exceed an average score of 80% to achieve good communication performance. Subjects achieved mean speech intelligibility scores of roughly 80% or better in the 105 dBA noise environment with all HPDs. However, when both David Clark headsets were worn with filtered-type earplugs, the mean scores were higher compared to the headsets with foam earplugs.

Table 16. SI Performance of Aircraft Mx HPDs (105 dB).

Speech Intelligibility			
Headset	Earplug	Mean Score (%)	Standard Deviation
David Clark 12512G-11	ER20	91	7
	Earasers	94	5
	SoundGuard	86	9
David Clark H10-76	ER20	88	9
	Earasers	90	8
	SoundGuard	78	13

3.9 Aircrew Headset/Helmet: Continuous Noise Attenuation

Depending on the airframe and mission, aircrew may wear a helmet or headset. For example, a cargo aircraft on long, high-altitude missions, will likely only wear a headset, no helmet. On low flying combat support or rescue missions, aircrew would require a helmet. In this section, we review two headset configurations and two helmet configurations.

Continuous noise attenuation data was collected for both the Bose A20 and David Clark H10-76 aircrew headsets (data already reported in Section 3.7). Data was collected on the headsets alone, as well as, with two frequency filtered earplugs (ER20 and Earasers) and the foam SoundGuard earplugs. Mean passive attenuation results are shown in Figure 27 at each measured frequency for the Bose A20 headset alone, paired with each filtered-type earplug, and a standard foam earplug. The Bose A20 is a headset with Active Noise Reduction (ANR) technology that reduces low frequency noise. The results in this report are of passive attenuation only. No ANR measurements were collected for this study. Table 17 contains octave band data (mean, SD) and NRSA data. Table 18 has the NRSG data for each configuration with noise spectral balance values at -1, 2, 6, and 13. As expected, the SoundGuard provided more mean attenuation across all frequencies than the filtered-type earplugs when combined with the headset.

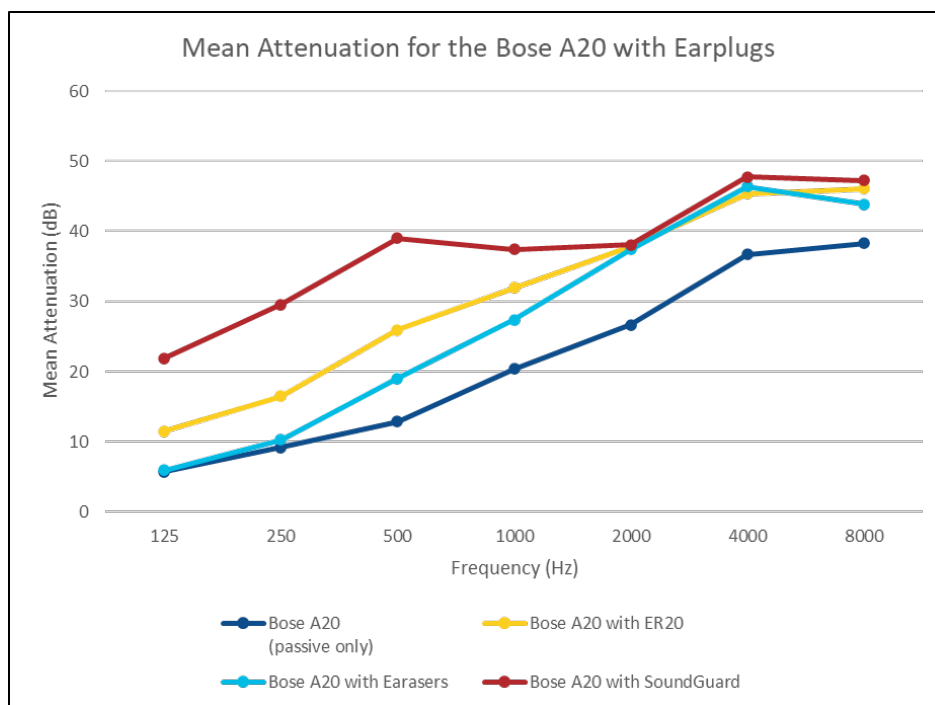


Figure 27. Passive Mean Noise Attenuation Data (Bose A20).

** Bose A20 is an ANR system, this dataset shows passive protection only.*

Table 17. Passive Noise Attenuation Data in dB (Bose A20).

Hearing Protection		Frequency (Hz)								NRSA	
Headset	Earplug		125	250	500	1000	2000	4000	8000	80%	20%
Bose A20 (passive only)	none	Mean	6	9	13	20	27	37	38	15	22
		SD	2	3	3	3	3	4	5		
Bose A20 (passive only)	SoundGuard	Mean	22	30	39	37	38	48	47	32	40
		SD	7	7	8	3	3	5	3		
Bose A20 (passive only)	ER20	Mean	11	16	26	32	38	45	46	21	33
		SD	6	7	10	5	4	4	4		
Bose A20 (passive only)	Earasers	Mean	6	10	19	27	37	46	44	17	27
		SD	4	4	5	5	4	4	3		

Table 18. NRS_G Data (Bose A20).

Headset	Earplug		Noise Spectral Balance (C-A)			
			-1	2	6	13
Bose A20 (passive only)	none	x = 20%	26.5	18.8	14.6	9.3
		x = 80%	22.5	15	10.9	6.3
Bose A20 (passive only)	SoundGuard	x = 20%	42	39	37	30
		x = 80%	37	32	27	19
Bose A20 (passive only)	ER20	x = 20%	38	31	26	19
		x = 80%	29	20	15	9
Bose A20 (passive only)	Earasers	x = 20%	33	24	18	11
		x = 80%	27	17	12	5

Continuous noise attenuation data was collected for both the HGU-55/P, fixed-wing helmet, and the HGU-56/P, rotary-wing helmet. Data was collected on the helmets alone as well as with two frequency filtered earplugs (ER20 and Earasers) and the standard foam SoundGuard earplug.

Mean passive attenuation results are shown in Figure 28 at each measured frequency for the HGU-55/P helmet alone, paired with each filtered-type earplug, and a standard foam earplug. Table 19 contains octave band data (mean, SD) and NRSA data. Table 20 has NRSG data for each configuration with noise spectral balance values at -1, 2, 6, and 13. Although the SoundGuard earplug provided the greatest added attenuation, the filtered-type earplugs also provided additional protection when combined with the flight helmet.

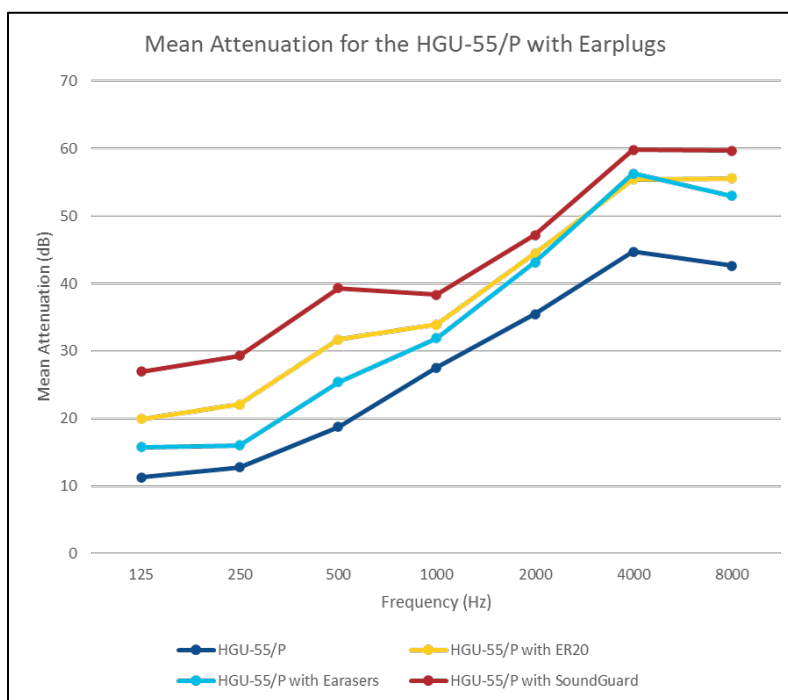


Figure 28. Passive Mean Noise Attenuation Data (HGU-55/P).

Table 19. Passive Noise Attenuation Data in dB (HGU-55/P).

Hearing Protection		Frequency (Hz)								NRSA	
Headset	Earplug		125	250	500	1000	2000	4000	8000	80%	20%
HGU-55/P	none	Mean	11	13	19	28	35	45	43	17	29
		SD	7	6	6	6	8	12	12		
HGU-55/P	SoundGuard	Mean	27	29	39	38	47	60	60	32	44
		SD	8	8	12	5	4	4	4		
HGU-55/P	ER20	Mean	20	22	32	34	44	55	56	25	39
		SD	8	9	11	6	7	9	11		
HGU-55/P	Earasers	Mean	16	16	25	32	43	56	53	21	35
		SD	8	7	9	5	7	9	13		

Table 20. NRS_G Data (HGU-55/P).

Helmet	Earplug		Noise Spectral Balance (C-A)			
			-1	2	6	13
HGU-55/P	none	x = 20%	35	26	22	17
		x = 80%	24	17	13	8
HGU-55/P	SoundGuard	x = 20%	48	42	40	37
		x = 80%	39	31	27	22
HGU-55/P	ER20	x = 20%	45	37	33	28
		x = 80%	33	24	19	15
HGU-55/P	Erasers	x = 20%	41	32	27	23
		x = 80%	29	20	15	11

Mean passive attenuation results are shown in Figure 29 at each measured frequency for the HGU-56/P helmet alone, paired with each filtered-type earplug, and a standard foam earplug. Table 21 contains octave band data (mean, SD) and NRS_A data. Table 22 has NRS_G data for each configuration with noise spectral balance values at -1, 2, 6, and 13. Again, the SoundGuard earplug provided the greatest added attenuation, but the filtered-type earplugs also provided additional protection when combined with the flight helmet.

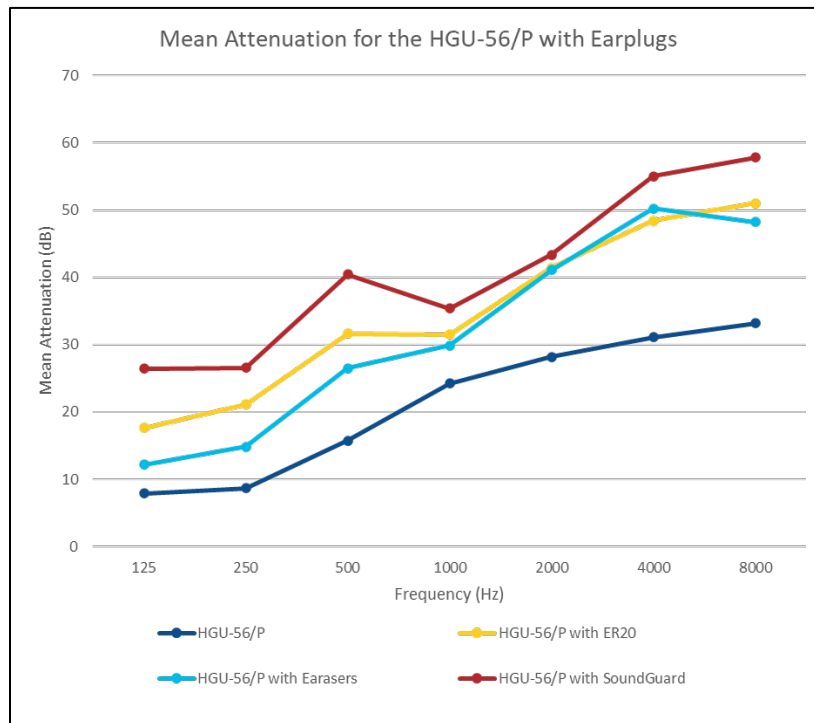


Figure 29. Passive Mean Noise Attenuation Data (HGU-56/P).

Table 21. Passive Noise Attenuation Data in dB (HGU-56/P).

Hearing Protection			Frequency (Hz)							NRSA	
Headset	Earplug		125	250	500	1000	2000	4000	8000	80%	20%
HGU-56/P	none	Mean	8	9	16	24	28	31	33	13	26
		SD	5	5	9	5	6	10	10		
HGU-56/P	SoundGuard	Mean	26	27	40	35	43	55	58	31	41
		SD	9	8	9	4	3	5	5		
HGU-56/P	ER20	Mean	18	21	32	31	41	48	51	24	38
		SD	6	8	10	8	6	9	10		
HGU-56/P	Erasers	Mean	12	15	27	30	41	50	48	21	32
		SD	6	6	6	3	4	9	9		

Table 22. NRSB Data (HGU- 56/P.)

Helmet	Earplug		Noise Spectral Balance (C-A)			
			-1	2	6	13
HGU-56/P	none	x = 20%	31	23	18	13
		x = 80%	20	12	8	5
HGU-56/P	SoundGuard	x = 20%	44	39	37	34
		x = 80%	38	30	26	21
HGU-56/P	ER20	x = 20%	43	36	31	25
		x = 80%	31	23	19	14
HGU-56/P	Erasers	x = 20%	38	29	24	19
		x = 80%	30	21	15	9

3.10 Aircrew Headsets/Helmets: SI

SI measurements were conducted in a 105 dBA noise environment for both flight headsets and helmets. Average SI scores are shown in Tables 23-24. MIL-STD-1474E states that objective SI performance should meet or exceed an average score of 80% to achieve good communication performance.

Subjects wearing the flight headsets achieved mean speech intelligibility scores of roughly 80% or better in the 105 dBA noise environment with all HPD configurations except with the Bose A20 and SoundGuard earplugs. A mean score of 61% representing degraded SI. The David Clark H10-76 combined with Earasers provided the highest SI score of 90%.

Table 23. SI Performance of Aircrew HPDs (105 dB).

Speech Intelligibility			
Headset	Earplug	Mean Score (%)	Standard Deviation
Bose A20*	ER20	80	16
	Erasers	87	11
	SoundGuard	61	13
David Clark H10-76	ER20	88	9
	Erasers	90	8
	SoundGuard	78	13

* Bose A20 powered on (ANR on) for these measurements

Subjects wearing the flight helmets achieved mean speech intelligibility scores of roughly 80% or better in the 105 dBA noise environment with all HPD configurations except HGU-56/P helmet and SoundGuard earplugs. A mean score of 72%. Notably, the foam earplugs did not degrade SI performance as expected when combined with a flight helmet.

Table 24. SI Performance of Aircrew Helmets (105 dB).

Speech Intelligibility			
Headset	Earplug	Mean Score (%)	Standard Deviation
HGU-55/P	ER20	94	6
	Earasers	92	7
	SoundGuard	93	7
HGU-56/P	ER20	79	14
	Earasers	82	14
	SoundGuard	72	16

4.0 DISCUSSION

All HPDs should be assessed in multiple ways to describe the performance of the headset/helmet, its combination with secondary earplug protection, and the effects on an operator's ability to perform varying missions with diverse auditory requirements. Objective measurements should be conducted to characterize a device's noise attenuation performance as well as any negative effect on situation awareness and speech intelligibility that may result. Noise attenuation in both continuous and impulse noise environments, auditory localization performance, speech intelligibility, and electro-acoustic features were all assessed for the HPDs in this study.

It was expected to see an increase in passive attenuation when any earplug was worn in combination with a headset/helmet. Foam earplugs provided a range of 6-18 dB of added protection when compared to the headset/helmet alone (NRS_G, 80%). The filtered-type earplugs provide 0-11 dB of added protection when compared to the headset/helmet alone (NRS_G, 80%). With the HPDs assessed in this study, for most combinations, the ER20 (flanged ear tip) and the EP7 (foam ear tip) provided the highest level of protection; Earasers (molded ear tip) and CAEP 4.0 (flanged ear tip) provided the lowest level of protection. It was also expected to see an increase in IPIL when an earplug was worn in combination with a tactical headset. The filtered-type earplugs provided 2-8 dB of added to protection from impulse noise when compared to the tactical headsets alone (IPIL, 170 dB).

For sound localization, it was expected to see a slight increase in angular errors and front-back confusions when an earplug was worn with a tactical headset. The foam earplug alone was similar to the tactical headsets alone when comparing sound localization performance. When combining any filtered-type earplug with a tactical headset, the corrected angular error increased 0.2-1.9 degrees and the front-back reversals increased 0.2-5.5% more when compared to headset alone.

When evaluating speech intelligibility, it was expected to have recorded mean scores of 80% or more when filtered-type earplugs were worn with headsets/helmets, and less than 80% with foam earplugs worn in combination. This was true for many combinations, but some combinations, regardless of earplug type performed similarly.

The ER-20s provided an unexpected benefit in environments where they are not typically used. Both attenuation and speech intelligibility were high in all the targeted use populations, indicating a much broader use of this device than originally intended. Also unexpected was the amount of attenuation provided by double hearing protection. Typical hearing conservation practice and DoD policy suggest an estimated level of protection in the 3-5 dB range.⁸⁻⁹ However, the results on foam earplugs showed a broad range of attenuation between 6-18 dB, suggesting the 3-5 dB of additional attenuation is conservative. This indicates overprotection from double hearing protection devices and could be an issue therefore contributing to the lack of wear by individuals in loud environments. Further, filtered earplugs in the double hearing protection conditions showed a range of 0-11 dB, suggesting both over and under protection could be occurring in these scenarios. Therefore, it is critical to collect empirical measurements of attenuation of combined HPDs and consider using digital models to predict overall efficacy instead of relying solely on current policies and practices.

When selecting a HPD, it is important to consider the characteristics of the operational environment in which they will be employed and evaluate the pros and cons in each assessment area to come to an informed decision. It is advisable to pick a top performing device in the area that is most appropriate to the mission and then consider other variables when selecting a device. Other considerations beyond these performance areas also exist when assessing HPDs such as sizing, fit, and comfort.

5.0 CONCLUSION

Filtered-type earplugs were designed to allow the user to maintain natural hearing and communication capabilities while protecting his/her hearing from continuous and impulsive noises like gunfire, explosions, vehicles, and machinery. A variety of cross mission HPD devices were tested in this study. The objective was to investigate the benefits of filtered-type earplugs, instead of foam earplugs, for situations where double hearing protection is required. Multiple HPD configurations were assessed for: continuous and impulsive noise attenuation, auditory localization, and speech intelligibility. There were a variety of headset/helmet/earplug combinations that provided appropriate attenuation and communication capabilities in hazardous noise. When considering HPDs, it is necessary to prioritize the needs of the user and his/her operational environment to determine the potential impact of various systems on overall mission effectiveness, as well as the performance of the device. This results from this study provide confidence that there are earplug options to a traditional foam earplug, and thus should allow ground forces, aircraft maintainers, and aircrew the ability to choose from a variety of devices that best address their mission needs, comfort, and performance requirements.

6.0 REFERENCES

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5. ANSI/ASA S3.2-2020 Method for Measuring the Intelligibility of Speech Over Communication Systems.
6. ANSI/ASA S12.68-2012R Methods of Estimating Effective A-Weighted Sound Pressure Levels When Hearing Protectors are Worn.
7. Department of Defense (DoD). Design Criteria Standard: Noise Limits. MIL-STD-1474E.
8. OSHA Technical Manual Section, Chapter 5, Appendix F –Noise Reduction Rating.
9. Air Force Instruction 48-127, Occupational Noise and Hearing Conservation Program, Attachment 4, paragraph A4.4.1.

7.0 LIST OF ACRONYMS

AFRL	Air Force Research Laboratory
ALF	Auditory Localization
ANR	Active Noise Reduction
ANSI	American National Standards Institute
ASA	Acoustics Society of America
ATF	Acoustic Test Fixture
ATP	Adaptive Mission Platform
CAEP	Combat Arms Earplugs
dB	Decibel
dBa	A-Weighted Decibel Level
dBp	Peak Decibel Level
DoD	Department of Defense
HPD	Hearing Protection Device
Hz	Hertz
IPIL	Impulsive Peak Insertion Loss
ISL	Institute of Saint Louis
kHz	Kilohertz
LED	Light-Emitting Diode
m	Meters
MATLAB	Matrix Laboratory
MBITR	Multiband Inter/Intra Team Radio
MIL-STD	Military Standard
MRT	Modified Rhyme Test
ms	Milliseconds
NRR	Noise Reduction rating
NRSA	Noise Level Reduction Statistics for use with A-Weighting
NRSG	Noise Reduction Statistics, Graphical
REAT	Real Ear Attenuation at Threshold
SA	Situation Awareness
SD	Standard Deviation
SHARC	Spatial Hearing and Acoustic Research Chamber

SI	Speech Intelligibility
SPL	Sound Pressure Level
SPL	Sound Pressure Level
TFOE	Transfer Function of the Open Ear
VOCRES	VOice Communication Research and Evaluation System
WPAFB	Wright-Patterson Air Force Base