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Assessment of the Applicability of ANSI S12.42-2010 as a General Measure of Protection from Impulsive Noise by Measurement of Impulsive and Continuous Noise Insertion Loss of the HGU-56/P and the CEP

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14. ABSTRACT

Impulse and continuous noise insertion loss measurements of the communication ear plug (CEP) and HGU-56/P flight helmet were performed in accordance with ANSI S12.42-2010 using a GRAS 45CB acoustic test fixture (ATF). Continuous noise insertion loss measurements were corrected for comparison to real ear attenuation at threshold (REAT) measurements. Results indicate that the hearing protection devices performed better in the ATF than on a human ear. Comments on the applicability and utility of the ANSI standard as a measure of protection are presented, along with recommendations for further development.

15. SUBJECT TERMS

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Introduction

All Army aircraft produce high levels of continuous noise. Aviators, crew, and passengers on board these aircraft are required to wear a hearing protection device (HPD) designed to prevent noise induced hearing loss as a result of exposure to this loud noise. The HPD used by most Army aviators consists of the HGU-56/P flight helmet, and the communication ear plug (CEP). These HPDs have been tested to measure their continuous noise protection (Ahroon and Robinette, 2004; Gordon and Reeves, 2011). Some aircraft, such as the OH-58D Kiowa Warrior or the MH-60 DAP, carry weapon systems that produce very high levels of impulsive noise.

To prevent noise induced hearing loss it is necessary to evaluate both the noise to which personnel will be exposed and the HPD that will be used to protect them. Research has shown that HPDs respond differently to impulse noise than to continuous noise (Murphy et al., 2011). Prior to this study, no test results could be found evaluating the CEP and HGU-56/P specifically for impulsive noise protection. Engineers at the U.S. Army Aeromedical Research Laboratory (USAARL) decided that it was necessary to test how effective these HPDs are at protecting against impulsive noise.

In 2010, an updated version of American National Standards Institute (ANSI) standard S12.42 was published. This updated standard includes a method for evaluating HPDs for impulsive noise. This method utilizes an acoustic test fixture (ATF) which consists of an anthropometric representation of a human head fitted with two ear simulators, including artificial flesh surrounding simulated pinnae, ear canals lined with artificial flesh, and couplers fitted with microphones to simulate the resonances of the human ear and measure the sound pressure levels at the ear drum (ANSI, 2010). The standard specifies a measurement of the impulsive peak insertion loss (IPIL) of an HPD, or the difference in peak sound pressure level measured at the ear drum of the ATF with and without the HPD in place.

The ATF specified in ANSI S12.42 did not exist when the standard was written, and the references cited by the ANSI standard justifying the specifications of the ATF are rather sparse. It is reasonable to question whether measurement of insertion loss made using the ATF will accurately predict the performance of the HPD on a human user. While no standardized method of comparison of impulsive levels between humans and an ATF currently exists, it is possible to compare continuous noise performance on an ATF to actual performance on a human.

The real ear attenuation at threshold (REAT) method is considered to be the best way to measure the amount of protection that an HPD provides against continuous noise exposure. REAT tests compare the hearing threshold of a human subject without an HPD to the subject's threshold with the HPD. This method accounts for sound transmitted to the ear drum via the ear canal, as well as sound that bypasses the external ear and is conducted to the ear via tissue and bone. Insertion loss (continuous or impulsive) as measured by an ATF will only predict the performance of the HPD in attenuating sound conducted through the ear canal (Berger and Kerivan, 1983).

REAT measures are also subject to the occlusion effect and physiological masking. Wearing an HPD that blocks the ear canals can increase a subject's sensitivity to bone conducted sound.

This increase in sensitivity is called the occlusion effect, and changes the hearing threshold as measured by a REAT test. Additionally, blocking the ear canal can amplify the physiological noise that a REAT subject perceives. This physiological noise can mask the test signal used for a REAT test, altering the subject's hearing threshold (hence the term physiological masking) (Berger and Kerivan, 1983).

It is useful to consider REAT measurements as the combination of insertion loss, bone conduction, occlusion effect, and physiological masking. ATF tests only measure insertion loss. A model has been developed to account for bone conduction, the occlusion effect, and physiological masking in an ATF measurement. By applying a correction factor to the ATF measured continuous insertion loss, the ATF corrected insertion loss values may be (according to the authors of this model) directly compared to REAT measurements for the same hearing protection device (Schroeter and Poesselt, 1986). A similar method was used by Berger when evaluating the performance of several new ATFs designed to meet the specifications from ANSI S12.42 (Berger, Kieper, and Stergar, 2011). If the model is assumed to be correct, and if the corrected ATF measures agree with REAT values, then it is not unreasonable to assume that the insertion loss of the HPD as measured on the ATF is similar to the insertion loss that may be achieved on an actual human user.

Study objectives

The primary purpose of this study was to determine how much protection against impulsive noise is provided by the CEP and the HGU-56/P flight helmet. If these HPDs fail to perform well as protection from impulsive noise sources, then aviators flying aircraft which carry loud weapon systems may require a different form of hearing protection. The IPIL metric from ANSI S12.42 was selected to evaluate how well these HPDs attenuate impulsive noise.

As the ATF proposed for use in the standard was relatively new, it was also decided to attempt to determine how well the performance of these HPDs as measured on the ATF compared to the performance of the HPDs as measured on a human user. In order to do so, the continuous noise insertion loss of the HPDs was measured, and corrected for comparison to REAT tests of the same devices (the REAT test results were taken from prior studies). Finally, the test results are used to support comments on the overall applicability of using the IPIL metric from ANSI S12.42-2010 as a general measure of the protection provided by an HPD against impulsive noise.

System description

HGU-56/P flight helmet

The HGU-56/P flight helmet is the helmet worn by the majority of U.S. Army helicopter pilots. It provides communication and hearing protection through the built in ear cups, and is typically modified for use with the CEP (Gentex Corporation; CEP, Inc., 2004). Figure 2 shows the HGU-56/P.

Communication ear plug

The CEP is a communication enhancement system commonly used by U.S. Army aviators. The system consists of a pair of plastic earphones which mate with expandable foam ear tips. The system plugs into a connector on the HGU-56P helmet, which redirects the communication signals from the ear cups in the helmet and into the earphones. The result is a set of double hearing protection (ear cups and earplugs), which allow the wearer to clearly hear communication signals (CEP, Inc., 2004). Figure 2 shows the CEP.

Acoustic test fixture

A GRAS Sound and Vibration 45CB ATF was used for all testing. The 45CB is a commercially available ATF that meets all of the specifications listed in ANSI S12.42. It features two instrumented ears capable of measuring peak sound pressure levels over 170 decibels (dB), artificial flesh lined ear canals, artificial pinnae surrounded by artificial flesh, and a heater to raise the artificial flesh temperature to 37 degrees Celsius. Full requirements and specifications for the ATF can be found in ANSI S12.42, or in the product literature from GRAS (ANSI, 2010; GRAS Sound and Vibration). Figure 3 shows the GRAS 45CB.

Methods

Continuous noise insertion loss

Data were collected in a 2.84 by 3.05 by 1.98 meter (m) reverberant sound chamber built by Industrial Acoustics Corporation. The test signal was generated by the REATMaster software package. The sound field in the chamber was verified using a 1-inch Brüel and Kjær 4145 microphone on a 2669C preamplifier. Levels from the reference microphone and ATF ears were measured using the Trident software package. Both the reference microphone and the microphones in the ATF were powered using GRAS 12AA microphone power supplies. Each of the individual measurements was 20 seconds in duration.

Figure 1. HGU-56/P flight helmet (Gentex Corporation).

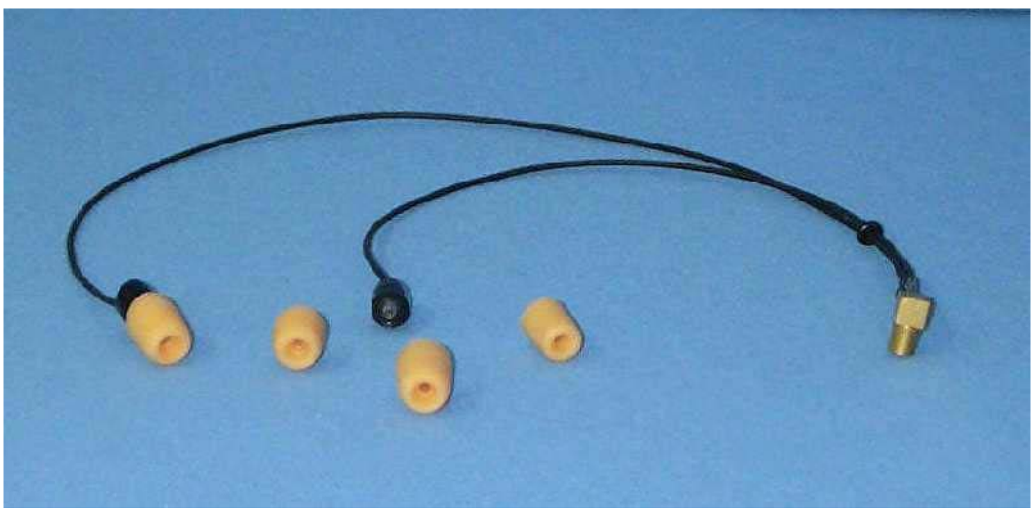

Figure 2. Communication ear plug (CEP, Inc., 2004).

Initial testing using the GRAS 45CB to collect continuous noise insertion loss values resulted in protected recordings with octave band levels no higher than the noise floor of the microphones. The noise floor of the system was checked by measuring the octave band levels in each ear with the ATF inside the test chamber with the test signal turned off. The 45CB is fitted with an ear coupler with a ¼ inch microphone that has a nominal sensitivity of 1.5 millivolts per Pascal. This coupler/microphone combination is used so the ATF can measure higher peak pressure levels during impulsive noise tests. It was determined that it would be necessary to replace the couplers with a lower noise coupler to achieve an adequate signal to noise ratio for continuous noise tests. For all of the continuous noise tests, the couplers from the 45CB were replaced with RA0045 couplers borrowed from a GRAS 45CA hearing protector test fixture. Figure 4 shows the noise floor of the modified 45CB, as well as the noise floor of the un-modified 45CB. The modified ATF has nearly a 20 dB lower noise floor in each octave band.

Figure 3. GRAS 45CB ATF (GRAS Sound and Vibration).

The self insertion loss of an ATF is the difference between the open levels measured using a test signal, and the levels measured in the same noise environment with the couplers plugged using an ideal plug (in the case of the 45CB the ideal plug consists of a cover that screws over the end of the coupler). The self insertion loss represents flanking paths for sound in the ATF, and ANSI S12.42 requires a 60 dB self insertion loss for the ATF (ANSI, 2010). The self insertion loss for the modified ATF was measured with pink noise at 100 dB in the same test chamber as was used for the continuous insertion loss measurements. The self insertion loss is shown in figure 5. The modified ATF had a greater than 60 dB self insertion loss in all of the octave bands of interest, except for the 8 kilohertz (kHz) band.

Both the system noise floor and self insertion loss measurements were performed once (i.e., with an *N* of 1). This procedure was acceptable as the system noise floor and self insertion loss for ATF were not expected to change significantly over the duration of the tests.

To measure the continuous noise insertion loss for each HPD, the ATF was exposed to pink noise at a sound pressure level of 100 dB without any HPD in place, and the octave band levels at each ear were measured, giving the open or unprotected levels (Octave bands were used as opposed to one-third octave bands for direct comparison to REAT values). The ATF was then fitted with the HPD, exposed to the same test signal, and the octave band levels at each ear were measured again, giving the closed or protected levels. The difference between the open and closed levels in each octave band is the insertion loss for that band.

Five samples of the CEP were tested. Each sample was fit to the ATF twice. The insertion loss values for all of the samples and fittings for both ears were averaged (*N* = 20, CEP only). One sample of the HGU-56/P was tested. It was fit to the ATF five times, and the insertion loss values for all of the fittings and both ears were averaged (*N* = 10, HGU-56/P only). All five CEP samples were tested in combination with the helmet, with two fittings per CEP sample (*N* = 20, CEP with the HGU-56/P).

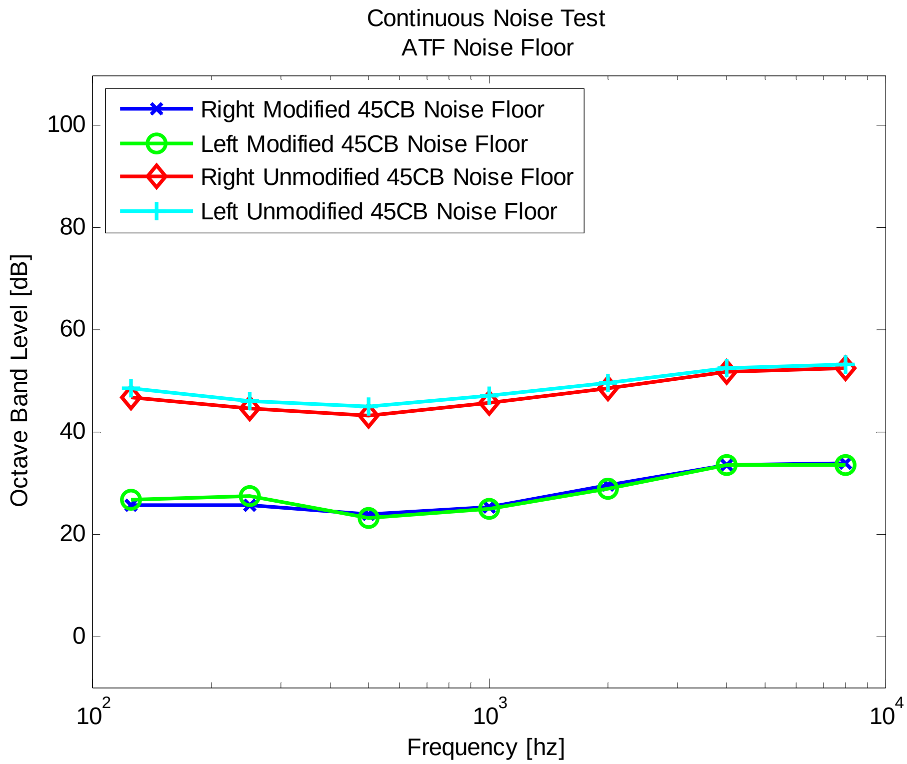

Figure 4. Modified ATF noise floor.

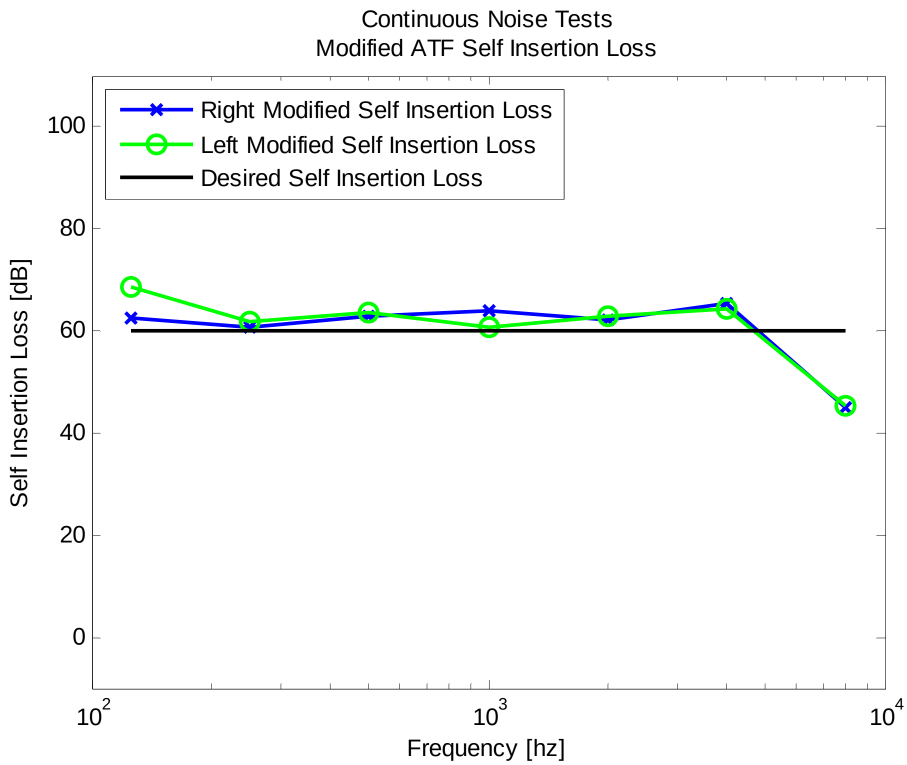

Figure 5. Modified ATF self insertion loss.

The ATF insertion loss measurements were corrected for the effects of bone conduction, ear canal occlusion, and physiological noise masking using a model developed by Schroeter and Poesselt (1986). The relevant equation for this model is

$$\overline{A}(f) = -20log_{10}\left(10^{-IL(f)/20} + 10^{-\left(MAFB(f)-MAF(f)-OE(f)\right)/20}\right) + PM(f)$$

where $\overline{A}(f)$ is the corrected ATF insertion loss value (REAT estimate), $IL(f)$ is the ATF measured insertion loss, $MAFB(f) - MAF(f)$ is the difference between the minimum audible field threshold for bone conduction (with air conduction pathways totally eliminated), and the minimum audible field threshold for the un-occluded ear, $OE(f)$ is a coefficient for the occlusion effect, and $PM(f)$ is a coefficient for the effect of physiological masking. All of the variables have the units of dB. A full derivation of this model may be found in Schroeter and Poesselt (1986).

Previously measured values for $MAFB(f) - MAF(f)$, $OE(f)$, and $PM(f)$ were used to correct the data measured for this report (Schroeter and Poesselt, 1986; Giguère and Kunov, 1989). The correction factor values used are given in table 1. For the double protection case, the values for ear plugs were used.

Table 1.
Model coefficient values.

Band Center Frequency	$MAFB - MAF$	OE (Circum-Aural)	OE (Earplugs)	PM (Circum-Aural)	PM (Earplugs)
125	47	16.9	20.9	3.9	2.2
250	51	13.7	17.2	1.3	2.4
500	57	6.8	14.3	0.4	2.2
1000	47	4.5	9.1	0	0
2000	39	0.7	-3	0	0
4000	49	0	0	0	0
8000	49	0	0	0	0

Impulsive noise insertion loss

The impulsive noise tests were performed using the USAARL Acoustics Branch shock tube. The shock tube generates impulsive noises using compressed air as opposed to an explosive. A membrane of paper, aluminum foil, or Mylar is placed over the open end of a pressure vessel, which is sealed against the barrel of the shock tube using a hydraulic ram. The pressure vessel is then pressurized until the membrane bursts, sending a shock wave down the tube and into the exposure area. By varying the placement of the ATF and the type of membrane used, it is possible to vary the strength of the shock wave. ANSI S12.42 calls for three, free-field peak levels of impulses: 166 to 170 dB, 148 to 152 dB, and 130 to 134 dB, all with an A-duration between 0.5 and 2 milliseconds (ms). For this series of tests, 90 shots were fired in the 166 to 170 dB range, resulting in an average peak pressure level of 166.7 dB (standard deviation: 0.15 dB), and an average A-duration of 1.1 ms (standard deviation: 0.01 ms). Seventy shots were fired in the 148 to 152 dB range, resulting in an average peak pressure level of 151.3 dB (standard deviation: 0.40 dB), and an average A-duration of 1.0 ms (standard deviation: 0.06 ms). The impulses with peaks between 130 and 134 dB cannot be easily produced using the USAARL shock tube, and were not attempted for this series of tests.

An un-modified GRAS 45CB was used as the ATF for the impulsive noise tests. The ATF was centered in front of the shock tube's horn in the exposure area. A PCB 137A23 piezoelectric blast probe was set to the right-hand side of the head pointed toward the horn of the shock tube. The height of all the transducers was 1.56 m (approximately the height of the center of the shock tube horn). Figure 6 shows the layout of the transducers in the exposure area.

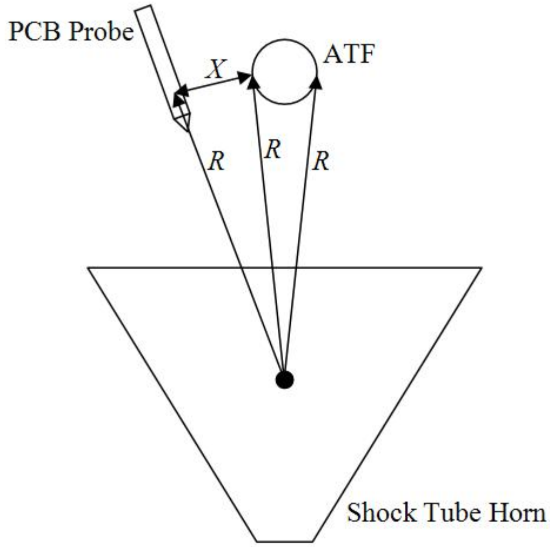

Figure 6. Exposure area layout for impulsive noise tests.

The sensing element of the PCB probe and the ends of the ATF ear canals were each located an equal distance from a reference point in the horn of the shock tube. This distance is noted as *R* in the figure above. The sensing element of the PCB probe, then was located a distance *X* from the right ear canal extension. Though the figure above is two-dimensional, *R* was measured as the straight line distance from an eye-bolt located in the shock tube horn, which was actually above the transducers. For the shots with 166 dB peaks, *R* was equal to 1.70 m, and *X* was equal to 0.3 m. The membrane material used was Mylar with a thickness of 2 mils (0.002 inches). The membrane was pressurized until it burst at approximately 22 pounds per square inch (psi). For the shots with 150 dB peaks, *R* was equal to 2.93 m, while *X* was equal to 0.5 m. The membrane material for those shots was 20 pound weight printer paper, which burst at a pressure between 2 and 4 psi.

Twenty un-protected shots (no HPD in place) were recorded at each peak level (10 before testing, and 10 following testing). Five CEP samples were tested, along with one HGU-56/P. A CEP sample was fit to the ATF, and two shots were recorded (protected shots). Then the HGU-56/P sample was fit over the CEP without re-fitting the CEP, and two additional shots were recorded. The process was repeated, so that each CEP sample was fit twice. A single helmet sample was also tested alone, but fitted five times, with two shots per fitting.

Data were acquired using a National Instruments 4462 data acquisition card, and software written in MATLAB. The sampling rate for the data acquisition system was set at 204,800 samples per second. The GRAS 45CB was powered using a GRAS 12AA microphone power supply, while the PCB probe was powered using a PCB constant current power supply.

Calculating the impulsive noise insertion loss required both the un-protected shots, and the protected shots. First, all of the signals were truncated to only include data from 10 ms before the peak (as measured by the PCB probe) until 300 ms after the peak (the ANSI standard requires a minimum of 1 ms prior to the peak and 300 ms following the peak). Then the data were filtered using a digital implementation of a 6-pole Bessel filter with a 3 dB down frequency of 20 kHz. The filter is a requirement of the ANSI standard. Use of the filter resulted in no appreciable difference in peak level, peak insertion loss, or A-duration.

Next, the fast Fourier transform (FFT) of the signal from each unprotected ear was divided by the FFT of the signal from the PCB probe for each un-protected shot. This gave a frequency dependant transfer function from the probe to the un-protected ear. These transfer functions were averaged for all of the un-protected shots at a given peak level to give an overall average transfer function at that level.

For each protected shot, the FFT of the PCB probe signal was multiplied by the transfer function for that peak level, and the inverse FFT of the result was taken, giving an estimated unprotected ear signal for each protected measurement. The IPIL was calculated as the peak sound pressure level of the estimated unprotected ear signal minus the peak sound pressure level of the measured protected ear signal. IPIL values for all samples and fittings for both ears were averaged.

Results

Continuous noise insertion loss

The approximate signal to noise ratio (SNR) in each octave band for the continuous noise measurements was calculated as the average protected level for each HPD tested (CEP, HGU-56/P, both), minus the average level recorded by the ATF in the sound room with no test signal present (the approximate noise floor for the system). Those SNRs are plotted in figure 7, along with a line indicating the minimum desired signal to noise ratio (10 dB).

Figure 7 shows that in spite of the modification of the ATF to have a lower noise floor, the protected levels measured when using the CEP alone did not maintain a desirable SNR above 2 kHz, while the protected levels measured when using the CEP with the HGU-56/P failed to maintain an adequate SNR above 1 kHz, and had an SNR of nearly zero at 4 kHz and 8 kHz.

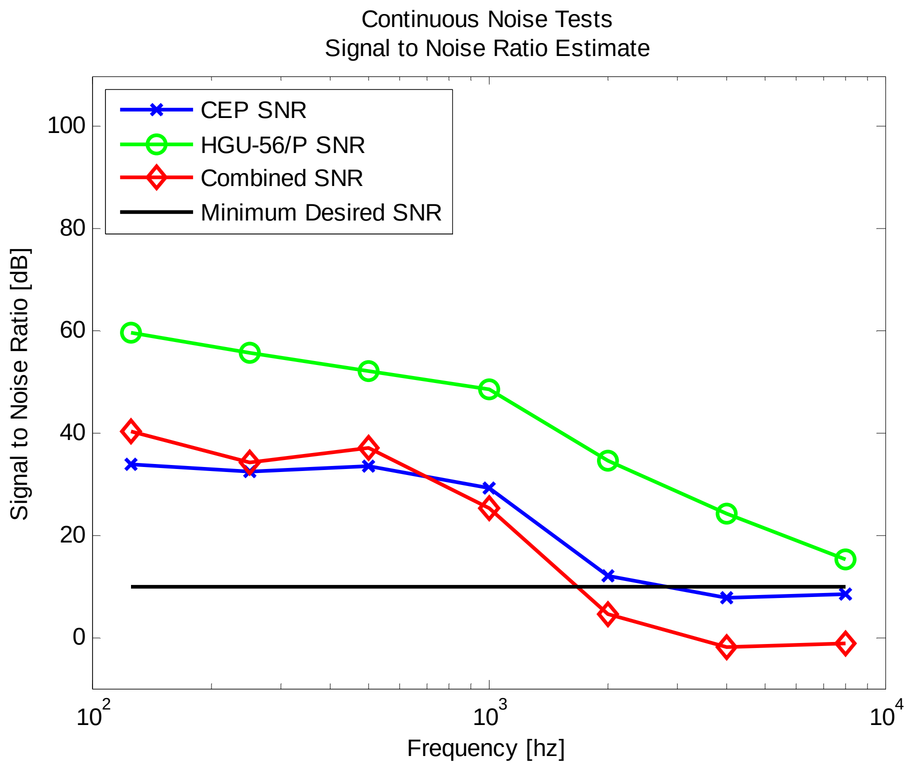

Figure 7. Continuous test signal to noise ratios.

Figures 8, 9, and 10 show the averaged insertion losses measured using the HGU-56/P only, the CEP only, and both the CEP and the HGU-56/P together, along with the corrected insertion losses, and REAT values for each device (Ahroon and Robinette, 2004; Gordon and Reeves, 2011). The REAT values are averaged according to the referenced measurements. Error bars indicate one standard deviation.

The absolute difference between the corrected ATF insertion loss and REAT values for the HGU-56/P when measured alone was below 5 dB for each of the frequency bands measured. This put the corrected ATF insertion loss within one standard deviation of the REAT values.

The insertion loss values for the CEP alone showed a poorer agreement with the REAT values. In this case, the absolute difference between REAT and corrected ATF insertion loss was below 10 dB for all but one of the frequency bands tested. The corrected ATF insertion loss values for the CEP alone indicate more attenuation than the REAT values.

The insertion loss for the HGU-56/P with the CEP agreed reasonably well with the REAT values once corrected for bone conduction, occlusion effect, and physiological masking. The corrected insertion loss value at 8 kHz fell significantly below the REAT value at that frequency. It is worth recalling, however, that the SNR for the double protection case at 2, 4, and 8 kHz was well below 10 dB. As a result, the protected measurement in those upper bands may have been a measure of the system noise floor, not the protected sound pressure level, which may have resulted in an under-measurement of insertion loss. If the ATF had a lower noise floor at higher frequencies, it is possible that the results would differ.

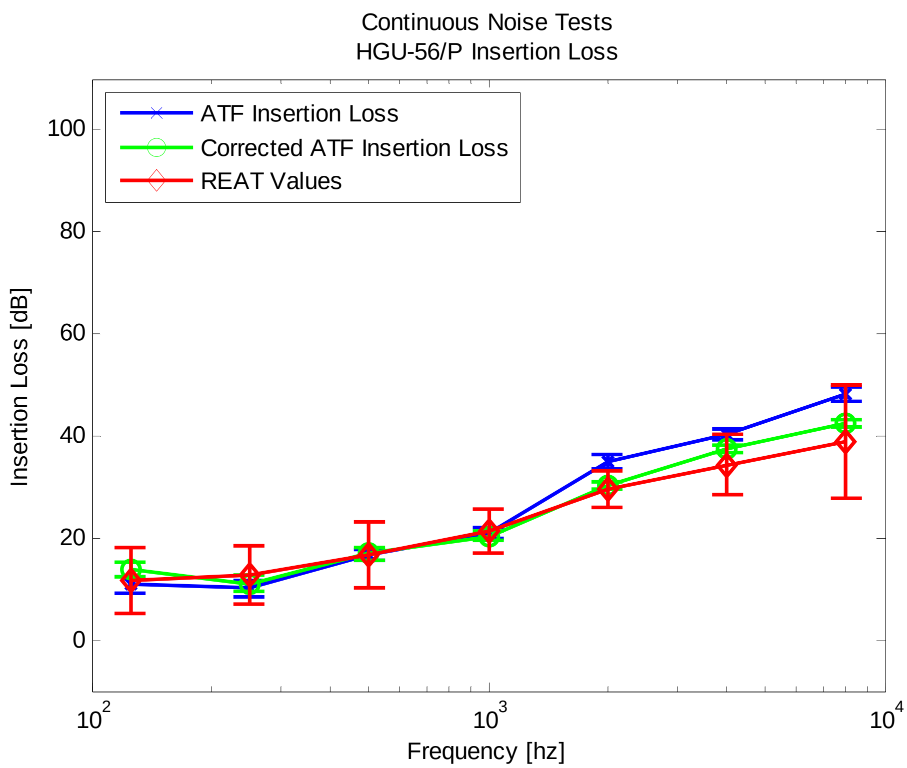

Figure 8. HGU-56/P continuous noise insertion loss.

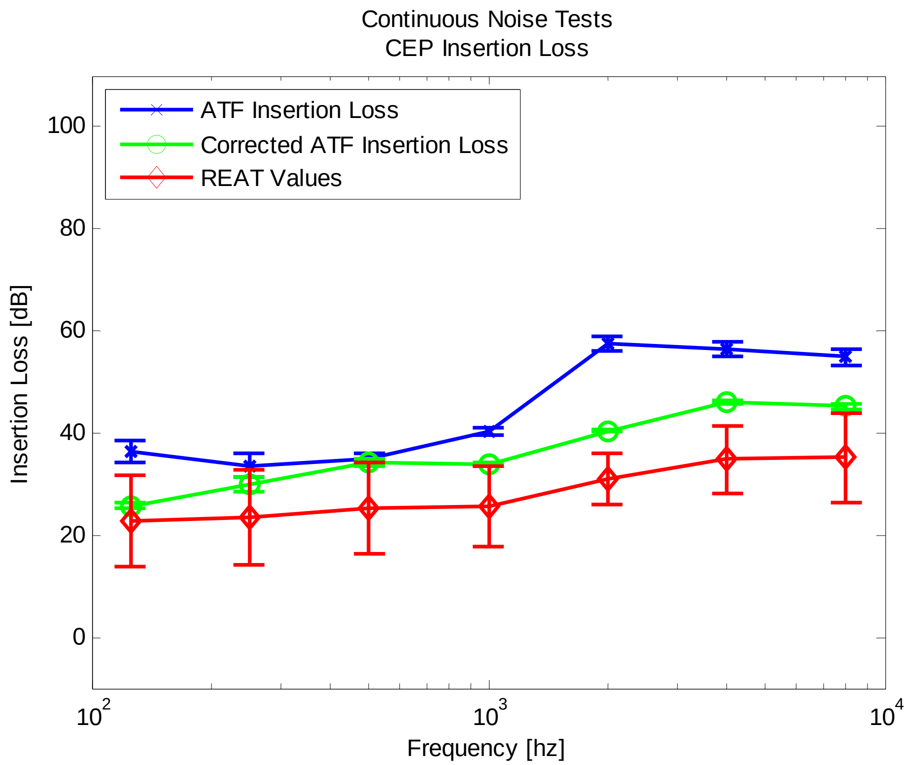

Figure 9. CEP continuous noise insertion loss.

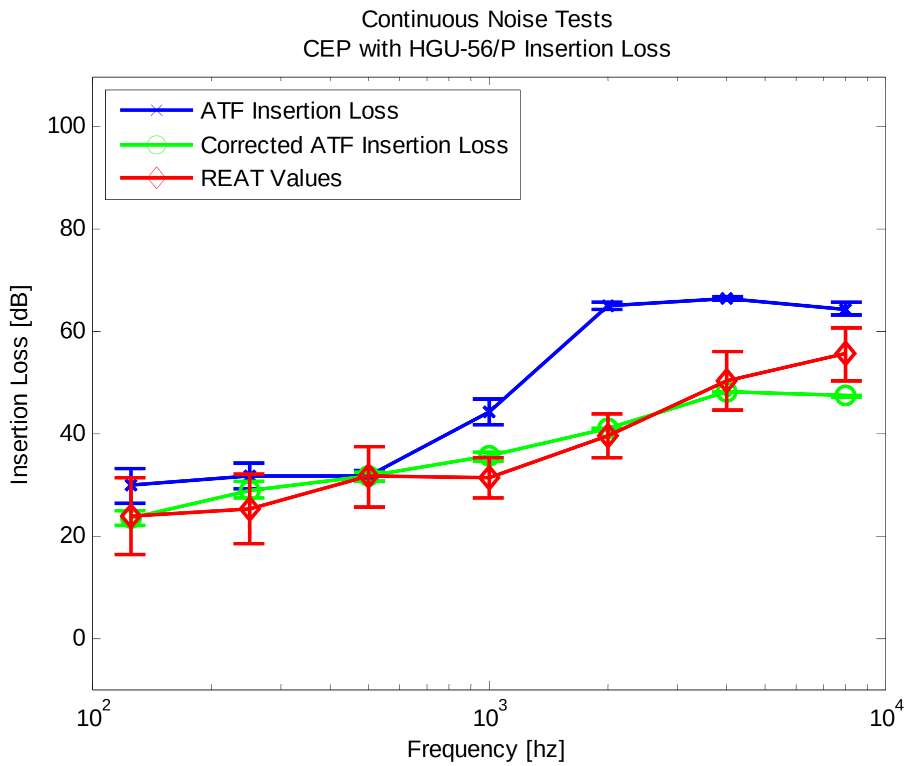

Figure 10. CEP with HGU-56/P continuous noise insertion loss.

Using the standard deviations as a measure of variability, the ATF measures seem to be very repeatable from fitting to fitting, and sample to sample. The variation observed is well below that of the REAT test results.

Impulsive noise insertion loss

Table 2 gives the average and standard deviation for the impulsive peak insertion loss values for the HGU-56/P only, the CEP only, and both together.

On average, none of the HPDs tested showed a significant difference in peak insertion loss between the two levels measured. Similar tests performed by other researchers using different HPDs indicate an increase in peak insertion loss as peak sound pressure level increases (Murphy et al., 2011). The reason for this disparity is not known. It is possible that a change in insertion loss based on peak level would be seen if measurements were completed at 130 dB.

Table 2.
Impulsive peak insertion loss.

HPD	IPIL at 166 dB Peak [dB]		IPIL at 151 dB Peak [dB]	
	Mean	Standard Deviation	Mean	Standard Deviation
HGU-56/P	28.9	0.53	29.4	1.68
CEP	48.3	1.00	48.3	1.78
HGU-56/P w/ CEP	50.9	2.23	50.4	2.32

Each HPD tested had a high insertion loss for impulsive noise. The HGU-56/P gave an almost 30 dB reduction in peak level measured at the ATF 'ear drum,' while the CEP alone provided approximately 48 dB of peak reduction. When both devices are used together, the peak insertion loss was over 50 dB.

Discussion

The stated objective of this study was to determine how much protection the CEP and HGU-56/P provide against impulsive noise. Because an ATF was used for the test procedures, continuous noise measurements were first completed to examine how well HPD performance measured on the new test fixture compares to HPD performance on a human user.

Using the model to correct the ATF measurements indicated that the HPDs generally performed better on the ATF than on human users during REAT tests. This is more significant with the CEP alone than with the helmet alone or in combination with the CEP. Research has shown that laboratory REAT tests may overestimate the amount of protection that an HPD will provide during actual use (Kozlowski and Kotarbinska, 2008), and the continuous noise test results given above show that the ATF (in general) predicts a greater amount of protection than

REAT tests (at least for the HPDs tested for this report). Given those results, it seems optimistic to conclude that the HPD performance as measured on the ATF is comparable to performance on a human user.

It is worth mentioning that the use of this model to compare continuous insertion loss to REAT data as a measure of how well the data collected on an ATF will compare to actual use is an assumption. Similar comparisons have been published (Berger, Kieper, and Stergar, 2011), but they were not used to claim that the HPD performed better or worse on the ATF than it would on a human, but rather to judge the performance of the ATF in matching REAT test results.

Certain factors, which were considered as a result of performing this test, call into question the applicability of the ANSI S12.42 tests as a general measure of protection from impulsive noise. The standard calls for the impulsive noise source used for testing to have an A-duration (initial positive pressure duration) of between 0.5 and 2 ms. Using the mathematical formula for an ideal Friedlander wave, the peak in spectral energy for such a noise source will be between approximately 320 and 80 Hz (Hamernik and Hsueh, 1991). If the peak insertion loss for an HPD is measured using a short duration wave, which has its spectral energy concentrated at higher frequencies (such as might be created by a rifle or pistol), the results may not represent the insertion loss for a longer duration wave (such as might be created by artillery or air-blasts from explosives).

The ATF does not account for bone conducted sound, which recent studies have indicated is affected by the use of HPDs, especially those which cover a large portion of the head (helmets) (Clavier et al., 2012). The significance of bone and tissue conducted sound specifically as a result of exposure to impulsive noise has not been widely studied. The so-called bone conduction limit is given as a maximum value of protection provided from continuous noise sources (Dietz et al., 2011), and it is not unreasonable to conclude that a similar limit will exist for impulsive noise. What that limit is cannot be determined from the current test procedures or results.

The ANSI standard calls for a limited range peak pressure level, the highest of which may be considered relatively low, especially if the pressure levels generated by air blasts and large artillery pieces are considered. Previous tests have shown that peak insertion loss increases as peak pressure increases up to a limit. When testing at levels higher than this limit, the insertion loss will decrease as peak pressure increases (McKinley et al., 2008). Application of the IPIL test results outside the range of peak pressures for which they are tested could be inaccurate.

Most damage risk criteria (DRC) do not use peak pressure level for assessing the hazard of impulsive noise exposure. A paper presented in 2012 explains how to use the IPIL metric with impulse noise DRCs (McKinley, Gallagher, and Murphy, 2012). That presentation aside, IPIL does not provide a metric to estimate the allowable exposure to impulse noise while wearing the HPD under test.

In summary, merely subtracting the IPIL from the peak sound pressure level produced by an impulsive noise source and claiming that the resulting quantity is the effective exposure experienced by a user of the HPD under test is overly simplistic, potentially inaccurate, and not considered an effective assessment of impulse noise exposure by most impulse noise damage risk criteria.

The discussion of the interpretation of IPIL test results is of concern because manufacturers are using the ANSI S12.42 IPIL results in their sales literature for hearing protection devices, specifically those devices geared at the military. At a minimum, these results are being presented with the implication that, “more insertion loss is better.” Based on the assumptions and limitations presented, this may be true, but the available data do not show that it is necessarily true.

The IPIL test is not without utility, especially in comparing different devices or examining the performance of active and passive non-linear HPDs. It is necessary, however, for the individuals tasked with selecting hearing protection devices to understand what test results mean, and how those results may be applied. Absolute attenuation of sound is not the only factor to be considered in choosing hearing protection, but it is an important consideration. These results indicate that it may be incautious to present the IPIL results as an estimate of the amount of protection provided by a hearing protector. Furthermore, the results should be presented with the caveat that they are reasonable only within the pressure ranges and durations at which devices are tested.

Conclusions

Continuous noise testing of the CEP and HGU-56/P on the manikin specified in ANSI S12.42-2010 generally demonstrated greater attenuation than were measured during tests of the HPDs on human users. The combination of the HGU-56/P and CEP resulted in an IPIL of over 50 dB when exposed to peak pressure levels up to approximately 166 dB. For the sake of comparison, the IPIL for the Combat Arms earplug (in the unvented configuration) has been measured between 29 and 33 dB (Murphy et al., 2011). It is not unreasonable to assume that the CEP and HGU-56/P provide protection against impulsive noise.

The stated objective of this study, however, was to measure how much protection against impulsive noise is provided by the CEP and HGU-56/P. Based on analysis of the test results and the test method, there is little confidence that the IPIL provides an accurate estimate of the amount of protection provided.

Given the superior performance of these HPDs on the ATF and the inherent limitations and assumptions of the measurement technique, care should be taken when using ATF measurements to determine the amount of protection provided by a hearing protector.

Recommendations

Ideally, laboratory tests of HPDs should provide an estimate for how much protection the HPD provides, and thus tell how the HPD changes the allowable exposure to noise. Examination of the study applying the IPIL metric with impulsive DRC, or further research is recommended to either correlate the IPIL metric with a change in allowable exposure to impulsive noise, or to determine a suitable metric for testing HPDs that will indicate an allowable change in exposure (McKinley, Gallagher, and Murphy, 2012).

IPIL measurements according to the ANSI standard are to be performed using impulses with initial positive phase durations ranging between 0.5 ms and 2 ms, and with a limited range in peak pressure. Further examination of how these factors change the IPIL is warranted. It is also recommended that hearing protectors be tested against noise sources similar to what they are proposed to protect from.

The significance to hearing damage of bone conducted noise is not currently well understood. Recent work has been done to create test fixtures and methods to directly measure the amount of energy transmitted into the head as bone conducted noise, but the correlation between this energy and damage is either not well understood, or understood only by a limited number of people. Furthermore, HPDs (especially helmets) may have a significant effect on this energy. Further study is recommended to determine the significance of bone conducted noise to hearing damage. Such study could also be useful in creating a ‘bone conduction limit’ for impulsive noise.

If continuous noise insertion loss measurements are to be made using an ATF, I recommend an investigation of the methods to maintain a higher SNR. One potential solution is to use test signals at higher sound pressure levels. The booth used for this testing is designed to act as a REAT facility, and has a safety limit of noise levels at 115 dB. Cursory examination by USAARL engineers failed to produce signals over approximately 105 to 110 dB. The practical limit to how high the signal levels may be raised is further complicated if electronic HPDs (especially those using active noise reduction [ANR]) are to be tested. Some ANR devices will not function properly over a certain signal level, which could lead to erroneous test results.

Another solution might be found in building an ear coupler that could fit the 45CB with a higher sensitivity microphone and lower noise floor. This would be useful for testing at lower signal levels, especially with devices fitted with talk through circuits that might require testing at different signal levels, or with ANR devices that can overload at higher signal levels. Complication might arise in getting the frequency response correct when using a more sensitive microphone, and in ensuring that the microphone has the dynamic range to handle unprotected signal levels at high sound pressure levels.

Finally, the modified 45CB did not maintain a 60-dB self insertion loss as required by the ANSI standard. The original couplers have a built up back plate that may influence the self insertion loss of the complete ATF. If continuous noise tests are to be performed using the 45CB, it may be advisable to attempt to create a set of couplers built like those for the 45CB, but with a larger diameter microphone and a lower noise floor to see if the back plate improves the self insertion loss.

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