November 2015

Protecting Hearing from Impulsive Noise

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Impulse and impact noises pose a significant risk to the unprotected ear. Workers in manufacturing and construction use tools that can easily generate momentary exposure in excess of 130 decibels peak sound pressure level (dB peak SPL). Persons that use small caliber firearms (e.g., law enforcement, security personnel, military, hunters, and shooters) experience levels anywhere from 140 to 175 dB peak SPL. In the military, large caliber weapons produce impulse noise levels that can be as intense as 185 to over 190 dB peak SPL. As a consequence of high-level impulse and impact noise exposure, the prevalence of hearing loss is greater for persons in these occupations and using these types of equipment (Masterson et al., 2014; Fausti et al., 2005).

Impulses and impacts are typically short-duration events – a gunshot fired outdoors lasts only a few thousandths of a second. The activation of middle ear's acoustic reflex is delayed due to the time required for a signal to travel from the cochlea to the brainstem and auditory cortex and activate the muscles of the middle ear. Thus, in many cases, the event has long since passed before any protective mechanism can have an effect. The middle ear reflex affects the low-frequency components of an impulse while the high-frequency – and more hazardous – components are unfiltered. Our perception of short-duration impulses is somewhat different from sustained high-level sounds. Sufficiently loud short-duration sounds can produce a startle response in the listener.

In the early history of hearing conservation, the military conducted investigations of the effectiveness of a hearing protection device using weapon noise. In the MIL-STD-1474D "Noise Limits," hearing protection was considered to provide a 29-dB protection factor for gunshot and large artillery alike (Department of Defense, 1997). The 29 dB was not derived from the Noise Reduction Rating of the ubiquitous yellow foam earplug but was determined through an exposure study that produced an equivalent amount of temporary threshold shift due to firing a shoulder-mounted anti-tank weapon. The actual earplug was a single flanged V-51R earplug. MIL-STD-1474D simplified earlier damage risk criteria developed by the Committee for Hearing and Bioacoustics (Ward et al., 1968) and defined several curves for unprotected, single-, and double-protected ears. For double protection, the number of exposures is multiplied by 20 raising the maximum exposure level by about 7 dB for short duration impulses. And yet, hearing injuries (noise-induced hearing loss and tinnitus) among service members are the number one and two disability payouts by the Veterans Administration (Fausti et al., 2005).

Starting in the late 1980s an effort commenced to revise the analysis of risk for impulse noises. Price and Kalb (1991) developed a model-based approach to assess the risk of an impulse. Their Auditory Hazard Assessment Algorithm for Human (AHAAH) was an electroacoustic network that simulated the parts of the auditory periphery. The sound wave was propagated through several segments to the eardrum. The eardrum response was modeled as a three-piston system that drove the motion of the stapes. The cochlea was treated as a single element even though the motions produced on the basilar membrane are exceptionally complex. The innovation of the AHAAH model was how it treated the middle ear. In the linear models used by cochlear physiologists, the motion of the stapes is quite small, less than a micron. However, when the linear models are excited by impulses of the magnitude of a gunshot, the derived motion of the stapes could approach several millimeters. Price and Kalb built two nonlinear elements into their model, activation of the middle ear muscle contraction and amplitude limiting of the stapes affected by the annular ligament that suspends the stapes footplate. In this manner, motion of the stapes was limited to about 10-15 microns. The implications of this feature are still being researched.

In 2003, the Environmental Protection Agency (EPA) hosted a public meeting to gather information from researchers in industry, government, and academia to identify possible changes to the labeling requirements (EPA, 2009). Performance rating standards for passive, electronic and level-dependent hearing protectors used in high-level impulsive noise were a need that was identified as a result of the EPA workshop. Passive earplugs are ones that do not have any electronic circuitry to provide level-limiting, active noise cancellation or sound restoration capabilities. Many electronic earplugs and earmuffs provide sound restoration (amplification of low-level environmental sounds) and limit the output of any speaker under the earmuff or in the ear canal to levels below about 82 dB. The number of these nonlinear electronic protectors has increased in recent years. The electronic level-limiting earplugs include offerings from 3M, Etymōtic Research, Phonak, Sensear, Walker Game Ear, Westone and others. Electronic earmuffs have been available for decades. 3M Peltor, Jackson Safety Products, Honeywell, Radians, and others manufacture sound restoration earmuffs that amplify low-level sounds and limit the amplification of high-level continuous and transient sounds to prevent over exposure. Passive level dependent protectors rely upon the increased acoustic resistance as air flows through a small orifice. The Gunfender earplug (Forshaw & Cruchley, 1982) was one of the earliest of such products and relies upon a single pin-hole orifice. The French German Research Institute de Saint-Louis improved upon this concept by placing two orifices in series (Parmentier 1996; Parmentier 2000). The resulting product yielded nearly the same protection as an equivalent solid earplug at very high SPLs, but provide substantial hear through at lower levels. Aearo Technologies (3M) licensed this solution and created the 3M™ Combat Arms™ earplug. Several other companies have variants on the Gunfender orifice: Hocks, Moldex, and Surefire to name a few.

In 2009, the EPA proposed a measurement method to capture the impulse peak insertion loss (IPIL) of a protector. Impulses are generated at three levels: 132, 150 and 168 dB peak SPL. The source of the impulse can be an explosive, a small-caliber weapon or an acoustic shock tube. An acoustic test fixture (ATF) equipped with ¼" microphones and ear simulators is used to measure the "eardrum" level for the unprotected and protected conditions. The reference SPLs of the impulses are measured by a blast probe microphone located in proximity to the test fixture. The EPA's method served as the basis to update the ANSI S12.42 standard in 2010 (ANSI/ASA, 2010). The standard provided the framework for the calculations to estimate the eardrum level from an external field microphone (blast probe) when the ATF is in the occluded condition (EPA, 2009).

The level and spectrum of the impulse affect the attenuation produced by the protector. As well, the depth of insertion of the protector affects the amount of attenuation observed while testing earplugs. Starting in 2010, NIOSH collaborated with researchers in academia, government, and the hearing protector industry to investigate the impulse peak insertion loss (IPIL) metric, which is measured with an acoustic test fixture as specified in ANSI S12.42-2010. The version 4 of the 3M™ Combat Arms™ earplug (CAE) has been included in several of our measurement studies. The 3M™ Combat Arms™ version 4 earplug has a toggle that allows sound to flow through acoustic filter (see Figure 1). In 2010, the CAE was tested using an Institute de Saint Louis (ISL) fixture with a 10-mm ear canal and a Colt AR-15 .223 caliber rifle. In 2012 and 2013, two ISL fixtures with 13- and 16-mm ear canals were used to test the CAE with an acoustic shock tube. In 2014, the same two ISL fixtures were used to test the CAE with a Rock River Arms AR-15 .223 caliber rifle. Finally, in 2014, tests of the CAE earplug were conducted with two GRAS 45CB fixtures with 18-mm ear canals and an acoustic shock tube impulse source. The impulses from the rifles had their peak spectral energy at about 1000 Hz. The impulses from the acoustic shock tubes have peak spectral energy at about 100 to 125 Hz (Murphy et al., 2012; Khan et al., 2013; Murphy et al 2014; Murphy et al. 2015a; Murphy et al. 2015b).

The results from these studies are shown in Figure 1 for the open-filter condition. The open-filter IPIL data for the ISL (blue squares and circles with a solid line) and two identical GRAS fixtures (NIOSH - magenta diamonds with a dotted line, Western Michigan University – magenta triangles dotted line) exhibit good agreement for the acoustic shock tubes even though the products are measured in two different labs over the course of about 3 years. These data are plotted as a function of the impulse level at the blast probe. The two data sets from the gunshot impulse source for the open-filter condition do not agree well. In this case, the length of the ear canal could be an important factor because the shorter 10-mm ear canal (black triangles with dashed line) did not permit making a good seal with the third flange of the CAE earplug. The ISL fixture with the 13 mm ear canal yielded greater IPIL (black squares with dashed line).

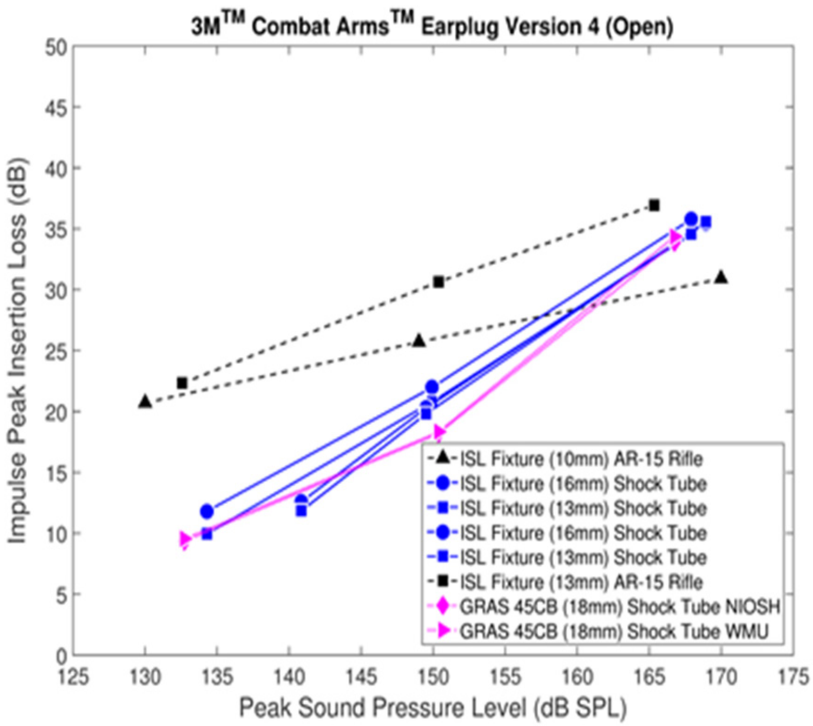

Figure 1 – Impulse Peak Insertion Loss (IPIL) measured for the 3M™ Combat Arms™ Earplug Version 4 in the open-filter condition. As a function of peak sound pressure level, the IPIL tended to increase at a greater rate for the open-filter condition than for the closed-filter condition. The open-filter condition exhibited better agreement across test fixtures due to the filter being the primary acoustic pathway. Test fixtures with a longer ear canal tended to provide a higher IPIL. The IPIL measured with a gunshot was 5 to 12 dB greater than the IPIL measured with the acoustic shock tube due to the increased high-frequency energy of the rifle impulse.

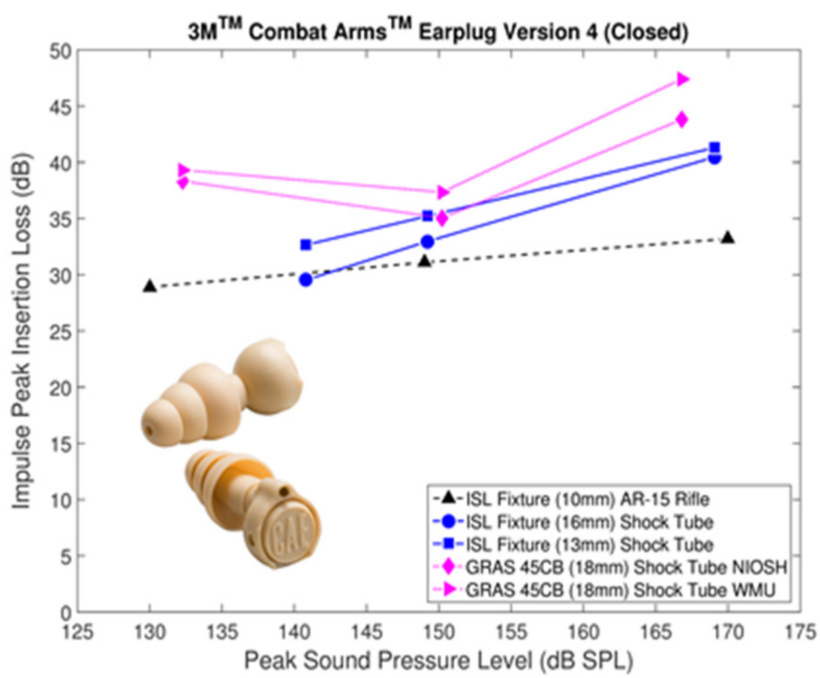

Figure 2. Impulse Peak Insertion Loss (IPIL) measured for the 3M™ Combat Arms™ Earplug Version 4 in the closed-filter condition. The IPIL values were greater for the test fixture with a longer ear canal. The GRAS fixture (dashed line) tends to have more contact with the earplug when fully inserted.

For the closed-filter condition shown in Figure 2, the results have poor agreement between shock tubes and fixtures. In the case of the two GRAS 45CB fixtures (NIOSH - magenta diamonds with a dotted line, Western Michigan University – magenta triangles dotted line), the ear canal is longer and yields higher IPIL than the ISL fixture. Slight differences between the pinna and ear canals have significant effects upon the attenuation. The NIOSH GRAS 45 CB fixture had a small tear in the pinna material at the opening of the ear canal. Because the pinna of the GRAS ear has a realistic shape and more elastic material compared to the ISL pinna and ear canal, the fit of the earplug is somewhat more sheltered from the grazing incidence shock wave and the outermost flanges have a slightly better fit than the ISL fixture when compared for the acoustic shock tube (blue squares and circles with solid line). The IPIL results from the AR-15 rifle (black triangle, dashed line) are significantly lower than the shock tube IPIL results. However, the ear canal for the ISL fixture used for rifle testing was 10-mm long and therefore the seal of the third flange could be the cause of the reduced IPIL.

The results from these studies suggest that the ANSI/ASA S12.42-2010 standard has potential to identify performance agreement across fixtures for earplugs that are operating in a level-dependent (open-filter) condition. That is, the primary acoustic path for sound to enter the acoustic test fixture is through the filter. However, when earplugs are operating in the closed-filter condition, the fit of the earplug and the isolation of the test fixture have a significant effect on the measured performance. Furthermore, these IPIL data demonstrate that the impulse source has a significant effect on the performance of the protector. In this case, the rifle impulses with greater high-frequency content were attenuated more than the lower-frequency impulses produced by the acoustic shock tube.

The ANSI/ASA S12.42-2010 standard has proven useful to characterize hearing protector performance. The ANSI S12 Working Group 11 responsible to update the standard has been considering other improvements to the measurements. First and foremost, the working group needs to understand effects of the spectral difference on the IPIL results. Second, while the acoustic shock tube produces well-developed shock waves for levels above 140 to 150 dB, the generation of impulses at 130 to 140 dB needs further investigation. Finally, the problem of accounting for bone conduction has not been addressed well (Clavier et al., 2012; Murphy et al, 2015). NIOSH and 3M scientists have tried some preliminary approaches; however, future methods must consider the frequency-dependent nature of the bone-conduction pathways.

Disclaimer: The findings and conclusions in this report are those of the authors and do not represent any official policy of the Centers for Disease Control and Prevention or the National Institute for Occupational Safety and Health. Mention of company names and products does not constitute endorsement by CDC or NIOSH.

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spectrum
a publication of the national hearing conservation association
November 2015
Volume 32 (Issue 2)

Note from the NHCA Director of Marketing and Public Relations

by M. Joel Jennings

NHCA uses social media to keep members connected and informed. Whether it's the NHCA website, Facebook, LinkedIn or Twitter, there is something for every member.

NHCA is introducing some new features to our social media platforms. Soon members will be able to have easy access to NHCA event photographs and will be able to recruit new hires through the new "Jobs" feature on both the NHCA website and LinkedIn. Just a few new ways your NHCA membership can help to increase cooperation and networking within our field and our organization!

The new "Jobs" feature will be available on both our website and our LinkedIn site. If you or your organization are hiring, use our sites to help recruit for the position. For posting on the website, please draft a job announcement with the pertinent details and contact information. The draft should be emailed to the Director of Marketing and Public Relations (DoMPR) office through the NHCA website contact page. For LinkedIn, place the job posting in the "Jobs" tab, and once it has been approved for posting, it will be available for all to see.

Remember, Facebook and LinkedIn sites are moderated. So if you would like to see something added or removed, feel free to contact the DoMPR through the NHCA website.

If you have not taken the opportunity to join NHCA on social media, now is the time! Please join our groups on Facebook, LinkedIn and be sure to follow us on Twitter.

Thanks to each of you for what you do for Hearing Conservation, and thank you for your membership in NHCA.

in this issue

NHCA
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 ISSN 1083-7388.

Spectrum is a publication of the National Hearing Conservation Association (NHCA), 12011 Tejon Street, Suite 700, Westminster, CO 80234 which is published 3 times yearly around April, July and October. For 2015, two issues of Spectrum will be published (July and November). A Spectrum Supplement is provided prior to each year's Annual NHCA Conference. The information contained herein is designed to promote action and discussion among members. The information has been obtained from sources believed reliable, and the editors have exercised reasonable care to assure its accuracy. However, the NHCA does not guarantee that the contents of this publication are correct and statements published do not necessarily reflect the opinion or official position of the NHCA.

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The mission of the National Hearing Conservation Association is to prevent hearing loss due to noise and other environmental factors in all sectors of society.

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