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Impulsive Noise

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Disclaimer: The findings and conclusions of this report are those of the author and do not necessarily represent the views of the National Institute for Occupational Safety and Health.

Why are we interested in impulsive noise?

Short duration impulsive noise is typically generated by a release of pressure (impulse) or a collision of solid objects (impact). In animal models these noises have been shown to be more damaging to the ear than continuous noise of equal energy (Hamernik and Henderson 1974, Dunn, Davis et al. 1991, Hamernik, Ahroon et al. 1994). Impulsive noises are common in manufacturing, construction, public service and the military. All police and sheriff officers must qualify annually on firearms which generate impulsive noise.

What is an impulsive noise?

The US Occupational Safety and Health Administration (OSHA) definition of impulsive noise includes noises most researchers do not consider impulsive: "If the variations in noise level involve maxima at intervals of 1 second or less, it is to be considered continuous." That is, if maxima are 1 second or less, noises are considered impulsive. Most researchers would consider a noise impulsive if it is a single pressure peak typically lasting milliseconds to microseconds.

How do we measure impulsive noises?

The use of standard industrial hygiene noise dosimeters to measure impulsive noises is inappropriate (Kardous and Willson 2004). Dosimeter electronics "clip" at high input levels and do not have a fast enough time constant to capture impulses. Many sound level meters may be able to capture peak levels with a peak hold circuit depending upon the microphone and amplifier. For about the past 10 years the National Institute for Occupational Safety and Health (NIOSH) has been developing a portable measurement system to measure firearm discharges and other impulsive noise. The directional nature of impulsive sounds may require multiple sensors to capture the sound. One approach is to use a stand-alone probe with multiple microphones separated by well-known distances in a calibrated capsule such as the G.R.A.S. (Holte, Denmark) sphere. This probe consists of four matched G.R.A.S. ¼", 40-BH pressure microphones in a 1"-diameter machined aluminum sphere. The four preamplifiers for the microphones are located inside the sphere. However, the sphere itself may affect the measurement.

What to measure for risk analysis?

In the pre-digital days a microphone attached to a storage oscilloscope captured the configuration of the impulsive noise. The dimensions that are easily measured on an oscilloscope screen are peak pressure level and duration. A number of conventions have evolved to characterize impulses: A, B, C and D duration, etc. Although codified into American National Standards Institute (ANSI) and International Standards Organization (ISO) standards and even law, there is little evidence to correlate any of these dimensions with risk of hearing loss. OSHA and NIOSH indicate that no one should be exposed to impulses in excess of 140 dBA.

In recent years a number of additional metrics have evolved for impulsive noises. In 1991 Richard Price and Joel Kalb published the first papers on the auditory hazard assessment algorithm for the human (AHAAH) model (Price and Kalb 1991, 1991). The most recent version of the model is electronically available and has been thoroughly described by Fedele et al. (2013). The model has good face validity. Functional data on the human outer, middle and inner ear have been integrated into a model through which digital representations of impulsive noises could be analyzed. The essence of the analysis is to integrate the square of positive displacements of the basilar membrane measured in microns at 23 locations spanning the frequency range from approximately 250 Hz to 11500 Hz. From this motion the model predicts Auditory Risk Units (ARUs). Based on cat data the authors established limits for the number of ARUs that the ear can be exposed to without producing more than 20 dB permanent threshold shift. Price has published and presented a number of analyses demonstrating the use of the AHAAH model for post-hoc prediction of risk to impulsive noise (Price 2007, 2007). Other researchers have devoted time to validate the AHAAH model. The initial model was written in the Delphi language which is no longer supported. Graduate students at the

University of Cincinnati have re-written the model in C/C++ and in MATLAB to allow continued experimentation with the model. William Murphy at NIOSH has re-analyzed one of Price's analyses: the US Army Blast Overpressure Study. His analysis used three criteria: AHAAH, A-weighted 8 hour equal energy (LAeq8hr) and the Military Design Standard 1474D (Murphy, Khan et al. 2009)[The report is available at http://www.cdc.gov/niosh/surveyreports/pdfs/309-05h.pdf]. They found that of the three risk criteria the AHAAH model was the worst predictor of threshold shift. The best predictor was LAeq8hr. The AHAAH model is extremely complex and requires a lot of computer resources to calculate. The AHAAH model is proposed as one of the accepted methods for calculating acoustic limits under the Military Design Standard 1747E. At this time the standard is undergoing peer review through the ANSI approval process. The Department of Defense is currently in the process of updating the AHAAH model to determine if it can better meet the needs of the hearing conservation community.

A risk calculation which seems to be more valuable is measurement of kurtosis of the impulse (Henderson and Hamernik 2012). The mean of a statistical distribution is the first moment; variance is the second moment; skew is the third moment; and kurtosis is the fourth moment. Gaussian noise (white noise) has a kurtosis value of 3. As the noise becomes more impulsive in nature the kurtosis value increases and may reach double digits. Hamernik's group has shown that as the kurtosis of the noise increases the amount of permanent threshold shift increases in chinchillas (Hamernik and Qiu 2001, Hamernik, Qiu et al. 2007) and now in worker populations (Zhao, Qiu et al. 2010, Davis, Qiu et al. 2012).

It has also been shown that when there is exposure to a high level acoustic impulse noise, such as from a weapon, the impulsive noise is transmitted to the cochlea through bone conduction pathways. The amplitude of the responses at the temporal bone and inside the head simulator appears to be linear with peak impulse amplitude. As a result hearing protection that has been designed to reduce the effects of bone-conducted sound for continuous noise exposure can indeed reduce the peak amplitude inside the head as well as the vibrations of the temporal bone. However, a helmet has the effect of increasing the duration of the wave inside the head. It is unknown at this time, whether such vibrations and acoustic levels inside the head can lead to cochlear or neurological damage in the case of repeated exposure. However, it is clear that the impulsive noise is transmitted through the head to the cochlea via bone conduction.

What are the research questions that remain with impulsive noise?

The overarching question is "Can a damage risk criterion be developed for impulsive noise?" The answer is important for workers and warfighters who are exposed regularly or occasionally to impulsive noise.

What is happening inside the cochlea to increase the damaging effect of impulsive noise compared to continuous noise?

Two major contributors exist: 1) The short duration of impulsive noise does not allow the middle ear muscles to contract and reduce the input to the cochlea; 2) Non-linearities in the cochlea may be interacting with the noise to increase the hazard. Some of the nonlinearities include the annular ligament of the stapes footplate, basilar membrane stiffness, organ of Corti structure, and stria vascularis support.

Can tools that produce impulsive noise be re-designed reduce risk? Are there mechanical ways to change the blastwave of a pistol to make it less risky? Can a nailgun be re-designed to reduce the risk of hearing loss over a 40-year career?

These questions need to be answered. An interesting example is a rivet removal gun that significantly reduced the risk of noise exposure in workers while improving quality: http://www.ncms.org/index.php/portfolio/fastener-removal-improvement-technology-adoption-frita/ .

Are earplugs and earmuffs adequate for protection from impulsive noise? And how should they be labeled to convey that information? NIOSH has undertaken studies of hearing protection device effectiveness using mannequins exposed to firearm and shock tube impulses. For peak sound pressure levels below about 170 dBA NIOSH has found that the hearing protection devices interact with the blast wave in a non-linear manner and produce more attenuation than what is currently given by the Noise Reduction Rating. However, the bone conducted transmission path appears to remain linear in the presence of impulsive noise and must therefore be taken into account when assessing damage-risk criteria for impulse noise. They have also found that seemingly insignificant differences in test setups can produce significant differences, on the order of 1 to 3 dB, in outcome measurements. NIOSH has been working closely with the U.S. Environmental Protection Agency to develop revised regulation to labeling hearing protection devices for impulsive noises. Unfortunately, the EPA has not yet promulgated the final rule.

The effect of impulsive noise on workers is an important question. In order to make recommendations for a national standard for impulsive noise, audiometric data from workers and accurate assessments of their exposures are necessary. American industry is probably not ideal since the current generation of workers have worked under the OSHA hearing conservation laws (although there is some indication that these regulations may not be protecting hearing (Groenewold, Masterson et al. 2014, Masterson, Sweeney et al. 2014)). It is important to study a population of workers who have not benefited from those protections in order to study the working life effects of impulsive noise. Given these needs our research may have to be conducted outside of the United States in an ethical manner.

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