Hearing Research 349 (2017) 34–36

Contents lists available at ScienceDirect

Hearing Research

journal homepage: www.elsevier.com/locate/heares

Short review

Impulsive noise: A brief review

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ARTICLE INFO

Article history:
Received 29 June 2016
Received in revised form
20 October 2016
Accepted 26 October 2016
Available online 27 October 2016

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 et al., 1991; Hamernik et al., 1994). Impulsive noises are common in manufacturing, construction, public safety and the military. All police and sheriff officers must qualify annually on firearms which generate impulsive noise. The US Veterans Administration's major compensation costs are for former military members noise-induced hearing loss and tinnitus.

The US National Institute for Occupational Safety and Health (NIOSH) (p. xiv, 1998) defines impulsive noise as a noise with sharp rise and rapid decay, 1 s or less in duration. Most researchers would consider a noise impulsive if it is a single pressure peak typically lasting milliseconds to microseconds without regard to intra-impulse interval (e.g. Fig. 1). The US Occupational Safety and Health Administration (OSHA) considers impulsive noises to be continuous if the intra-pulse interval as less than 1 s. OSHA also requires that all continuous and impulsive noises between 80 and 130 dB to be incorporated into the worker's daily dose.

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 (greater than 130 dB) 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 (e.g. Brüel & Kjær 2608 Measuring Amplifier). For about the past 10 years NIOSH has been developing a portable measurement system to measure firearm discharges and other impulsive noise (Kardous, 2013). Their system consists off-the-shelf data acquisition hardware and microphones along with custom software. The NIOSH system has been developed by Structural Dynalysis, Inc. (Cincinnati, OH) into a commercially available system.

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.

In the pre-digital days a microphone attached to a storage oscilloscope captured the time-signature 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 S3.44-1996) and International Standards Organization (ISO 1999:1990) 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, 1991a, 1991b). 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 can 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–11,500 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

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http://dx.doi.org/10.1016/j.heares.2016.10.020
0378-5955/

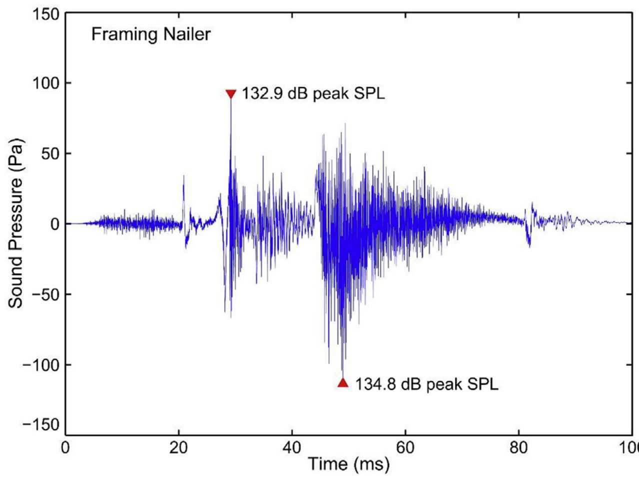

Fig. 1. Pressure tracing of an impulsive noise generated during a cycle of a pneumatic framing nailer. An impulsive noise is characterized by a short time window and instantaneous rise time and short decay time. The pressure peaks can be assigned to striking of the internal drive piston to the nail, the insertion of the nail into the work piece and exhaust of the air pressure. Courtesy of Edward Zechmann, NIOSH.

model for post-hoc prediction of risk to impulsive noise (Price, 2007a, 2007b). 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 h equal energy (LA_{eq8hr}) and the Military Design Standard 1474D (Murphy et al., 2009). They found that of the three risk criteria the AHAAH model was the worst predictor of threshold shift. The best predictor was LA_{eq8hr}. 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 1474E. 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 (β(t)) (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 30-s kurtosis value increases. 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 et al., 2007) and in worker populations (Zhao et al., 2010; Davis et al., 2012). In a cross-sectional study of 240 Chinese workers, Davis et al. (2012) showed that workers exposed to noise with a kurtosis level greater than or equal to β(t) 10 showed significantly greater noise-induced permanent threshold shift (NIPTS) than workers exposed to a kurtosis of β(t) of less than 10.

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.

In addition, 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 (Clavier et al., 2012). 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 pressure 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.

Military and civilian regulators are tasked to develop damage-risk criteria designed to protect military members and workers health. Many times these regulations must rest on results and theory that are best guesses by experts or "preliminary data." The overarching question is whether protective straightforward damage-risk criteria can be developed for impulsive noise? The answer is important for protecting workers and warfighters who are exposed regularly or occasionally to impulsive noise.

Are earplugs and earmuffs adequate for protection from impulsive noise? And how should they be labeled to convey that information to the exposed worker? 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 currently listed 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 (Clavier et al., 2012). They have also found that seemingly insignificant differences in test setups can produce significant differences, on the order of 1–3 dB, in outcome measurements. NIOSH has been working closely with the U.S. Environmental Protection Agency to develop a revised regulation for labeling hearing protection devices for impulsive noises. Unfortunately, the EPA has not yet promulgated the final rule. (In the United States the Environmental Protection Agency is charged with enforcing the Noise Reduction Rating label present on all occupational hearing protectors.)

Rather than trying to regulate behavior, most occupational noise professionals would recommend controlling the impulsive noise at the source (noise control). Can tools be re-designed to reduce impulsive noise risk? We know from spy movies that pistols can be fitted with a silencer to reduce muzzle blast. Although in the real world these silencers are not nearly as effective as on the movie screen (Lobarinas, E. et al., 2016) are the weapons less risky to hearing? Can a nailgun be re-designed to reduce the risk of hearing loss over a 40-year career? An interesting example of impulse noise control 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/.

The effect of impulsive noise on worker hearing is an important question. In order to make recommendations for an international standard for impulsive noise, audiometric data from workers and accurate assessments of their exposures are necessary. American industry is probably not an ideal laboratory since the current generation of US workers have worked under the OSHA hearing conservation laws (although there is some indication that these regulations may not be protecting hearing (Groenewold et al., 2014; Masterson 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 this research may have to be conducted outside of the United States in an ethical manner (e.g. Davis et al., 2012).

References

Clavier, O.H., Dietz, A.J., Wilbur, J.C., Zechmann, E.L., Murphy, W., 2012. Measurements of bone conducted impulse noise from weapons using a head simulator. J. Acoust. Soc. Am. 132 (3), 2014.

Davis, R.I., Qiu, W., Heyer, N.J., Zhao, Y.M., Yang, Q.L., Li, N., Tao, L.Y., Zhu, L.L., Zeng, L., Yao, D.H., 2012. The use of the kurtosis metric in the evaluation of occupational hearing loss in workers in China: implications for hearing risk assessment. Noise Health 14 (61), 330–342.

Dunn, D.E., Davis, R.R., Merry, C.J., Franks, J.R., 1991. Hearing-loss in the chinchilla from impact and continuous noise exposure. J. Acoust. Soc. Am. 90 (4), 1979–1985.

Fedele, P.D., Binseel, M.S., Kalb, J.T., Price, G.R., 2013. Using the Auditory Hazard Assessment Algorithm for Humans (AHAAH) with Hearing Protection Software. Release MIL-STD-1474E. A. R. L. Department of Defense. Aberdeen Proving Ground, MD, U.S. Army, pp. 1–106.

Groenewold, M.R., Masterson, E.A., Themann, C.L., Davis, R.R., 2014. Do hearing protectors protect hearing? Am. J. Industrial Med. 57 (9), 1001–1010.

Hamernik, R.P., Ahroon, W.A., Davis, R.I., Lei, S.F., 1994. Hearing threshold shifts from repeated 6-h daily exposure to impact noise. J. Acoust. Soc. Am. 95 (1), 444–453.

Hamernik, R.P., Henderson, D., 1974. Impulse noise trauma. A study of histological susceptibility. Arch. Otolaryngol. 99 (2), 118–121.

Hamernik, R.P., Qiu, W., 2001. Energy-independent factors influencing noise-induced hearing loss in the chinchilla model. J. Acoust. Soc. Am. 110 (6), 3163–3168.

Hamernik, R.P., Qiu, W., Davis, B., 2007. Hearing loss from interrupted, intermittent, and time varying non-Gaussian noise exposure: the applicability of the equal energy hypothesis. J. Acoust. Soc. Am. 122 (4), 2245–2254.

Henderson, D., Hamernik, R., 2012. The use of kurtosis measurement in the assessment of potential noise trauma. In: Le Prell, C.G., Henderson, D., Fay, R.R., Popper, A.N. (Eds.), Noise-induced Hearing Loss: Scientific Advances. Springer, New York, pp. 41–56, 49.

Kardous, C.A., 2013. Development and Validation Testing of an Impulse Noise Meter. Cincinnati, OH, Engineering and Physicals Hazards Branch. Division of Applied Research and Technology, NIOSH. www.cdc.gov/niosh/surveyreports/pdfs/349-11a.pdf.

Kardous, C.A., Willson, R.D., 2004. Limitations of using dosimeters in impulse noise environments. J. Occup. Environ. Hyg. 1 (7), 456–462.

Lobarinas, E., et al., 2016. Differential effects of suppressors on hazardous sound pressure levels generated by AR-15 rifles: considerations for recreational shooters, law enforcement, and the military. Int. J. Audiol. 55 (Suppl. 1), S59–S71.

Masterson, E.A., Sweeney, M.H., Deddens, J.A., Themann, C.L., Wall, D.K., 2014. Prevalence of workers with shifts in hearing by industry a comparison of OSHA and NIOSH hearing shift criteria. J. Occup. Environ. Med. 56 (4), 446–455.

Murphy, W.J., Khan, A., Shaw, P.B., 2009. An Analysis of the Blast Overpressure Study Data Comparing Three Exposure Criteria Cincinnati, OH. National Institute for Occupational Safety and Health, pp. 1–61. www.cdc.gov/niosh/surveyreports/pdfs/309-05h.pdf.

National Institute for Occupational Safety and Health, 1998. Occupational Noise Exposure, Revised Criteria 1998. DHHS, Cincinnati, OH, pp. 1–105. www.cdc.gov/niosh/docs/98-126/.

Price, G.R., 2007a. Predicting mechanical damage to the organ of Corti. Hear. Res. 226 (1–2), 5–13.

Price, G.R., 2007b. Validation of the auditory hazard assessment algorithm for the human with impulse noise data. J. Acoust. Soc. Am. 122 (5), 2786–2802.

Price, G.R., Kalb, J.T., 1991a. Insights into hazard from intense impulses from a mathematical-model of the ear. J. Acoust. Soc. Am. 90 (1), 219–227.

Price, G.R., Kalb, J.T., 1991b. A New approach to a damage risk criterion for weapons impulses. Scand. Audiol. 21–37.

Zhao, Y.M., Qiu, W., Zeng, L., Chen, S.S., Cheng, X.R., Davis, R.I., Hamernik, R.P., 2010. Application of the kurtosis statistic to the evaluation of the risk of hearing loss in workers exposed to high-level complex noise. Ear Hear. 31 (4), 527–532.