A Calculational Procedure for Incorporating Hearing Protector Variability in Health Hazard Assessments with the AHAAH Model

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The Problem

One of the critical issues in health hazard assessment (HHA) is the uncertainty associated with the attenuation that hearing protective devices (HPDs) will actually provide as worn in the field (Berger & Royster, 1996). In addition to the inherent differences in attenuation attributable to design are the effects of user interactions. Assuming that the HPD is comfortable enough to be worn, there is still the question of the user's ability to obtain and maintain a good fit while on the job. When attitudes toward the wearing of hearing protection are not the most positive, HPDs, as actually used, may in fact provide almost no attenuation (ANSI, 1997).

At the same time, it is impractical to assume the worst case (hearing protectors do nothing) when system effectiveness depends on their successful use. This is the situation when weapon impulses are concerned. Virtually all impulse-producing weapons are hazardous to the unprotected ear. Furthermore, there is no technological "fix" that will eliminate the problem without also totally defeating the purpose of the weapon. In this case, HPDs are an integral part of the weapon system, and their proper use is critical.

How then should we make allowance for the attenuation provided by HPDs to assure that the 95 percentile ear is in fact protected? Even when HPDs are properly designed and used, there is still an inherent variability in the attenuation they provide. A variety of methods is used currently. The current standard used in the U.S. (MIL STD-1474D) simply ignores the issue. It makes only a single-valued attenuation allowance for all forms of single hearing protection and an additional value for all forms of double protection (in all cases regardless of actual attenuation achieved) and makes no allowance for variability. When A-weighted energy is used as a metric, it is possible to determine the attenuation provided by a protector, but such a procedure still needs to address the question of differences between users and the use of the protectors. A common procedure is to reduce the measured attenuation by some number of standard deviations, with the exact number being debated along with the procedure through which attenuation should be measured. There is the additional problem that even if the A-weighted energy can be established under the protector, it correlates very poorly with hearing loss at high intensities (Price, 2003).

More recently, the question of attenuation and how to allow for it has become more complicated. The new non-linear HPDs are deliberately designed to vary their attenuation as a function of level, so no single value or set of values will accurately reflect their performance at all levels. In addition, there is the fact that the ear itself becomes non-linear at very high levels, effectively peak clipping the displacement waveforms at the stapes (Price, 1974; Price & Kalb, 1991). The size and effect of the ear's conductive non-linearity depends on the waveform that actually penetrates the HPD which in turn is a function of the attenuation provided by the protector.

Clearly, the problem of making allowance for HPD attenuation is complicated. Moreover, it is an important issue because it is a relatively large effect. The measured attenuations can vary over many decibels as a function of frequency, and the variance associated with measured attenuations is often 10 dB or higher and varies as a function of frequency. In critical applications at very high levels a single decibel makes the difference between passing or failing a system under going test. Present methods of dealing with HPD attenuation and rating hazard clearly have their shortcomings and an improved approach addressing these issues would be desirable.

The AHAAH method

The Auditory Hazard Assessment Algorithm for the Human (AHAAH) has been shown to be far more accurate than existing systems for rating hazard for the human ear (Price, 2003) and has been proposed for use as the standard upon which to base HHAs (Price & Kalb, 1998, 2000). In it, a mathematical model of the ear processes the digitized waveform to calculate the hazard for the ear. The waveform that actually reaches the ear can be measured or estimated by several methods, which would include free field recording, recording under a protector on a subject or a manikin as well as calculation from a free field recording passed through a mathematical model of the hearing protector or through a digital filter reproducing the attenuation characteristics of the HPD in question. The AHAAH model has the advantage of including the high-level non-linearity of the middle ear as part of its analysis. The question that this paper addresses is how one can properly make allowance for variability in HPD attenuation so that the prediction of safety for the 95 percentile ear can be maintained, without the error of over-predicting hazard and reducing system performance.

In HHAs, the expectation is that the 95 percentile (most susceptible) ear will be protected. Therefore, the fundamental structure of AHAAH was designed to predict hazard for the 95 percentile ear, given the waveform entering the ear from the free field, at the ear canal entrance, or at the eardrum.

In its development, the model was originally created to predict hazard for the median ear (Kalb & Price, 2003). To arrive at 95 percentile susceptibility, AHAAH assumes that susceptibility is normally distributed, with a standard deviation of 6 dB. It argues further, that a susceptible ear is like a normal ear except that it is effectively being driven harder. By coupling these two concepts, the model achieves the prediction for the 95 percentile ear by artificially raising the SPL on the test impulse by 10 dB (1.64 standard deviations) and doing the hazard calculation. As noted earlier, the AHAAH method has proved to be highly effective in predicting hazard from both protected and unprotected ears (Price, 2003).

If we now presume that hearing protector fit is uncorrelated with susceptibility, we are faced with predicting the joint probability of susceptibility and the uncorrelated variation in attenuation from a hearing protector. Traditional statistical arguments suggest that variances in such cases should add. Thus, if the standard deviation for fit were 8 dB, for the ear wearing the hearing protector, the two variances should sum with the result that the variance for the protected 95 percentile ear would be 100 (36+64 =100) and the new standard deviation for the ear's susceptibility would be 10.0 dB with the 95 percentile ear effectively being driven 16.4 dB harder than the median ear.

To illustrate the effects of the application of this procedure, we have applied it to data from the Army's Albuquerque studies (Johnson, 1998, 1994). In those studies, the pressures were recorded on the subjects with microphones at the ear canal entrance under the muff. Adding the HPD calculation as outlined results in an estimated hazard, for those impulses 1.6 to 1.9 times higher than with the median protector.
This translates into about a halving of the allowable number of rounds.

This procedure can be used with the present versions of AHAAH model (through use of the calibration algorithms); but the program should be revised to include this feature.

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