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Letter to the Editor

Reply to “Critical examination of the article: Impulse noise injury prediction based on the cochlear energy”

In this Letter, we respond to the issues raised by Price et al. (2017) about our paper, Zagadou et al. (2016) on the improvements to the Auditory Hazard Assessment Algorithm for Humans developed by Price and Kalb (AHAAH-PK). Our overall efforts included (1) the reconstruction of AHAAH-PK in MATLAB/Simulink codes (AHAAH-M), (2) verification of the AHAAH-M calculations against published benchmark results of AHAAH-PK (ARL, 2016), (3) modification of model parameters and behavior based on literature data guidance to produce an improved model (AHAAH-M-NEW), (4) replication of the historical US Army Blast Overpressure Project (BOP) Walk-up Study (WS) tests to collect eardrum data using acoustical test fixtures (ATFs) as model input to circumvent the need to model the hearing protector devices (HPDs), and (5) validation of AHAAH-M-NEW and development of dose-response curves using the WS and small arms data.

In Price et al. (2017), the authors expressed a number of disagreements with our findings. In their opinion, AHAAH-M does not fully replicate AHAAH-PK, the improvements made to the model are not needed, the test replication of WS is not accurate enough, and the lack of understanding of the AHAAH-PK results. Price et al. have long been asserting that AHAAH-PK is validated and does not need change, a position we disagree with as shown by our research.

The formulation based on a mammalian auditory system is the strength of AHAAH-PK, but the model was developed mostly using cat data and the details of its translation to humans have not been independently validated while many critical controversies continue to linger, as documented in the latest panel review by the American Institute of Biological Sciences (Wightman et al., 2010). AHAAH-PK has been incorporated as an analysis options in MIL-STD-1474E, a US Military System Acquisition Guidance, but AHAAH-PK has not been accepted as a US Impulse Noise Medical Standard, primarily because of its many unresolved controversies. If AHAAH-PK is being considered as an ANSI standard as mentioned by Price et al., it is crucial that the model be subjected to rigorous IV&V, but that has never been carried out because the model source code is not available to the public. Our main objective is to contribute to the continuing research and dialogue to help understand the mechanisms of auditory damage. The issues raised by Price et al. can be grouped in five categories as addressed below in turn.

1. The problem of non-monotonic response or dose-response inversion

Contrary to Price's claims, the dose response inversion of the AHAAH-PK is a serious shortcoming that can lead to dangerous predictions as illustrated below.

To illustrate the danger of the auditory risk unit (ARU) dose-inversion behavior, calculations were performed using AHAAH-PK with the WS 1-m test data. During the 1-m test series, the only parameter that changed was the C4 charge weight from level 1 to 7 (L1-L7) with everything else kept the same. Using the recorded waveforms for each level, AHAAH-PK calculations were performed to predict the hazards for increasing number of shots (N). Fig. 1 shows the change of the calculated ARU with level and N, with ARU = 500 taken as the injury threshold, and where the abscissa also indicates the increase of C4 charge weight used with level. For N = 1 and 5, AHAAH-PK predicts all conditions are safe, and the ARU dose-response behavior is clearly seen with L4 being the most injurious condition. When N increases to 10, AHAAH-PK predicts L2-L4 will be injurious while L1 and L5-L7 will be safe. Furthermore, when N is increased to 15, AHAAH-PK predicts only L7 is safe while all other levels are injurious. In other words, keeping the standoff at 1 m with everything else the same but only increasing the charge weight, AHAAH-PK shows that for 15 shots with 2.47-lb C4 (producing 194.5 dB at L7) the exposure is safe, but with 0.05-lb C4 (177.3 dB at L1) the exposure will be injurious. For AHAAH-PK to become an ANSI standard, this non-monotonic issue needs to be addressed rigorously. This problem was corrected in AHAAH-M-NEW.

Contrary to the claim by Price et al. (2017), data do not support the dose-response inversion. The reference to Fig. 4 from Chan et al. (2001) does not validate the dose-response inversion behavior of AHAAH-PK. The referenced figure rather shows the unsatisfactory correlation of the WS data with the empirical MIL-STD-1474D dose metric (p-value ~ 0.444). We attributed the wide scatter of the last two 1-m test data points to the significant drop-off in the number of volunteers from 65 to 24 and 41, respectively at L5 and L6 when N reached 100. In fact, for N = 6 with 62 subjects used, the injury data shows no dose-inversion behavior from L1-L7. Furthermore, Fig. 8 in Chan et al. (2001) shows that an excellent fit can be obtained with minimal data scatter if a best-fit regression is applied to the coefficients of the MIL-STD-1474D dose metric (p-

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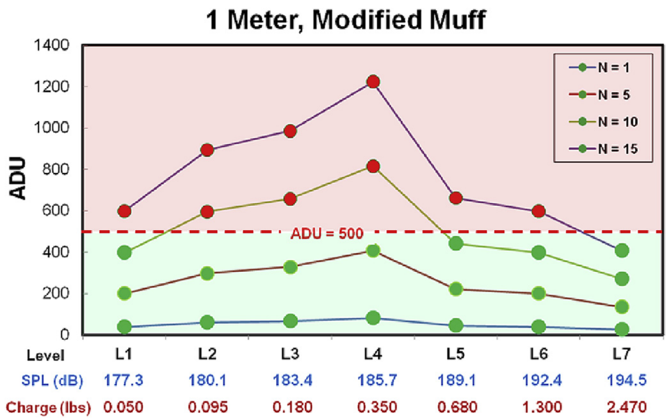

Fig. 1. Danger of ARU dose-response inversion for 1-m test illustrated by ARU vs. exposure level for increasing N. AHAAH-PK predicts 15 shots at L7 (194.5 dB) is safe vs. unsafe at L1 (177.3 dB) with everything else the same.

value = 0.906), where the apparent "dose-inversion" behavior mentioned by Price et al. (2017) disappeared. This shows that the ARU-inversion behavior of AHAAH-PK is an indication of its weak biomechanical basis. Smoorenburg (2001) attributed this model behavior to the over compressive nature of AHAAH-PK in clipping low-frequency intense noise through the ME.

2. Problem of model parameters

Our examination of the model has found that it is built on a mixture of cat and chinchilla data. These model parameters can be obtained from the AHAAH-PK's coefficient file (MAN.COE).

2.1. Head size variable

The head size in AHAAH-PK is similar to that of a cat, not human. Contrary to the assertion by Price et al. (2017), the correction of the human head size is needed to provide the correct diffraction properties of the head. In AHAAH-PK, the acoustic resistance and inductance provided in MAN.COE are the parameters associated with the diffraction field around the head. These two parameters can be related to the head size as done by Bauer (1967); Giguere and Woodland (1994) in the development of network models that AHAAH-PK is based on. The head size was corrected in AHAAH-M-NEW from a rodent to a human head.

2.2. The stapes displacement problem

Price et al. (2017) chose to discard the importance of using model parameters matching key human data. As described in Zagadou et al. (2016), an extensive effort was made to correct the parameters based on the latest literature. Parametric sensitivity analysis also showed that the AHAAH-PK behavior is very sensitive to these key parameters, including the human head size, stapes area and annular ligament (AL) dimensions, and cochlear input impedance (CII).

First, a typographical error is acknowledged for the stapes area expressed in MKS in Table 2 of Zagadou et al. (2016), but all results presented were performed using the correct CGS units as required in AHAAH-PK. The correct stapes area values for 'current AHAAH' and 'improved AHAAH' in Table 2 of Zagadou et al. (2016) are 2.1e-6 and 3.2e-6 m^2, respectively.

Contrary to arguments made by Price et al. (2017), the values of critical parameters in AHAAH-PK are not those of humans, and this is an important issue. Price et al. (2017) argued that an effective stapes area of 2.1 mm^2 was used in place of the true area. However, the fact that several critical parameters of AHAAH-PK are similar to those of cat or chinchilla cast doubts, especially for a model that was originally a cat model. In particular, 1) the stapes area of 2.1 mm^2 happens to be equal to that of chinchillas (Vrettakos et al., 1988); 2) the CII, one of the most important parameters in auditory sound transmission, was assigned a value of 264 acoustic GΩ MKS which is similar to that of cats (200 acoustic GΩ MKS) (Lynch et al., 1982) and is way outside of the range of human values of 6–60 acoustic GΩ MKS as measured by several research groups (Aibara et al., 2001; Merchant et al., 1996); 3) the AL width in AHAAH-PK is similar to the maximum displacement as set by the cat's AL clipping properties (Guinan and Peake, 1967); and 4) the head circumference of 25 cm is similar to that of a cat.

Accurately specifying the stapes footplate area is critical because it affects not only the ME properties but also the CII, which determines how much power enters the cochlea. An incorrect value for the CII in the model means that the variables calculated inside the cochlea, including the basilar membrane displacement which determines the ARU, are also erroneous. Setting the correct human AL width makes the ME less compressive and contributes to the elimination of the dose-response inversion problem.

2.3. Acoustic reflex (AR) modeling and ME muscle latency

Contrary to the claim by Price et al. (2017), the AR model in AHAAH-PK remains to be validated. The AR model in AHAAH-PK is too simple given the complexity of the AR mechanism, and the model still needs improvement and validation where much data are still needed. The whole idea of warned vs. unwarned response is even a greater controversy that has no concurrence from the research community. The AR latency of 9 ms in AHAAH-PK for unwarned response does not fix this problem. The AR is presently being investigated by expert audiologists to determine whether it is sufficiently prevalent to be included in damage risk criteria and hazard assessments for impulse noise (Flamme et al., 2015) (G. Flamme, personal communication, August 26, 2016).

3. Problem of the non-use of the AHAAH model

3.1. AHAAH-M outputs match AHAAH-PK outputs

Contrary to the assertion by Price et al. (2017), we successfully reconstructed AHAAH-PK adequately in AHAAH-M. The AHAAH-M ARU results match all benchmark cases published by Price (2007). Using the available waveforms provided by AHAAH-PK as input, the ARU-values were obtained by running the waveforms through AHAAH-M and comparing the ARU per impulse for both the 'warned'(W) and 'unwarned' (U) conditions to the published cases in Price (2007). For the M60 machine gun firing 7.62 mm at 155 dB peak pressure level (PPL) the ARU-values were 16.6 vs. 16.6 (W) and 118 vs. 118.2 (U), respectively; for the Belgian FNC rifle firing 5.56 mm at 158 dB PPL, 156.8 vs. 156.8 (W); for the German G3 rifle at 161 dB PPL 178.3 vs. 178.3 (W); and for M72 LAW at 161 dB PPL 105 vs. 105.1 (W) and 516 vs. 516.5 (U); at 179 dB PPL 920 vs. 920.2 (W) and 4217 vs. 4217 (U).

AHAAH-M also produced practically identical ARU-values for all the BOP WS waveforms as AHAAH-PK. The calculations were performed using WS undermuff data as input. As shown in Fig. 2, the ARU-values agreed in all cases between AHAAH-M and AHAAH-PK. Based on these results AHAAH-M and AHAAH-PK are essentially identical.