Real-ear attenuation of hearing protection in young children

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ABSTRACT

Much attention has been focused in the past decade on the possibility that children and adolescents 6-19 years of age may experience noise-induced hearing loss (NIHL) due in part to high-level sound exposure during recreational, hobby, and employment activities. One of the strategies that is utilized to reduce the potential of experiencing NIHL is to wear hearing protection (earplugs and/or earmuffs) when exposed to hazardous noise levels. Currently, many parents rely upon adult-sized hearing protectors for use by their children and even though performance on adults has been measured since the 1950s, the effectiveness of smaller-sized products for children is unknown. This paper examines the feasibility of conducting standardized real-ear-attenuation-at-threshold (REAT) measurements with children of 5–10 years of age, and presents the results achieved with three types of hearing protectors (slow-recovery foam and premolded three-flange earplugs, and earmuffs) measured according to ANSI S12.6-2008. The Method A and B procedures were modified so that rather than the subject (child), the inexperienced parent served as the person inserting the hearing protector. Attenuation metrics are reported in terms of the Noise Reduction Rating (NRR) and 1/3 octave-band attenuation values for each protector. Differences between the three fitting conditions; Trained Parent (Method A), Untrained Parent (Method B) and Expert fit are highlighted. Values are also compared to those found for similar protectors fitted on adults.

INTRODUCTION

Concern regarding the prevalence of noise-induced hearing loss (NIHL) in U.S. children and adolescents aged 6 to 19 years has been expressed in the past decade (Niskar et al. 2001; Henderson et al. 2011). The World Health Organization has also reported a world-wide concern regarding the risk of NIHL for children (WHO 1997). Evidence of a notched high-frequency hearing loss suggestive of NIHL is not a recent or emerging health concern. In fact, Loch (1943) first described the incidence and permanency of 4-kHz tonal dips in adolescents from Baltimore, Maryland. These studies suggest that hazardous noise exposures from recreational, hobby, and employment activities may contribute to the risk of NIHL in this population.

One of the intervention strategies that is utilized to reduce the potential of experiencing NIHL for both adults and children is to advise the wearing of hearing protection (earplugs and/or earmuffs) when exposed to hazardous noise levels. Hearing protection devices (HPD) are labeled with laboratory-based real-ear-attenuation-at-threshold (REAT) measurements obtained on adults and tested in accordance with U. S. or similar International standards (ANSI S3.19-1974; ANSI, S12.6-2008; ISO 4869-1:1990; ISO 4869-5:2006).

Currently, many parents rely upon adult-sized hearing protectors for use by their children and, even if smaller-sized products are fit, the effectiveness of hearing protectors for children is unknown. Though performance on adults has been measured since the 1950s, there are no standards or guidelines established with respect to laboratory attenuation measurements obtained on young children or adolescents. In clinical practice, it has been generally assumed that the same degree of sound protection is afforded to young ears as compared to adult ears.

This study examines the feasibility of conducting standardized REAT measurements with children of 5–10 years of age, and presents the results achieved with three types of hearing protectors (slow-recovery foam and premolded three-flange earplugs, and earmuffs) measured according to ANSI S12.6-2008.

STUDY PARTICIPANTS

Human subject participation and consent was obtained after research approval by the Institutional Review Board at the University of Northern Colorado. Child participants ranging in age from 5-10 years were recruited for this study and were accompanied by one parent participant. Child participants were excluded from the study if they exhibited physical features or disabilities, such as those resulting from birth defects, ear surgery, or personal adornments that would adversely affect the fitting of the hearing protectors. Eligible child participants were subsequently screened with otoscopy for earcanals which were free from conditions that would affect the fit of the hearing protector (such as excessive cerumen, irritation, or infection). Acceptance criteria for the child participants included the following; pure-tone air conduction hearing threshold less than or equal to 15 dB HL at the octave-band center frequencies from 125 to 8,000 Hz as measured by a standard audiometer and the ability to understand and speak English and generally follow verbal instructions to ensure study cooperation. Child participants were excluded from the study if 1/3 octave-band thresholds of hearing measured in the sound field of the test room, averaged across two determinations, were more than 3 dB below the octave-band ambient noise levels at any test frequency from 125 to 8,000 Hz.

Adult (parent) participants were over the age of 18 years and also had earcanals free from conditions that would affect the fit of a hearing protector. Parent participants were able to understand, read and speak English. "Inexperienced" parent participants were required to meet the qualifications for inexperience subjects specified in ANSI S12.6 - 2008. All participants received rest periods, nourishment rewards during the rest periods, and monetary rewards upon completion of all test conditions.

EXPERIMENTAL METHOD

The measurement of REAT is a psychoacoustic test method that relies upon subjective auditory responses from listeners for determining the attenuation of a hearing protector. Auditory thresholds are determined using both an occluded (with hearing protector in place) and unoccluded (without hearing protector in place) test conditions using one-third octave-band noise as the stimulus (ANSI S12.6-2008). Two distinct methods were used in this study for measuring attenuation, Method A: trained-subject fit (which also corresponds to ISO 4869-1:1990), and Method B: inexperienced-subject fit (corresponding to ISO/TS 4869-5:2006). In the U. S., REAT is also be measured via the ANSI S3.19-1974 experimenter-fit procedure as is required for testing to conform to U. S. Environmental Protection Agency hearing protector labeling requirements (EPA 1979).

For this study, REAT testing was sequentially completed with each child participant for three experimental conditions; Method B "inexperienced-subject fit" by an untrained parent, Method A "experienced-subject fit" by a trained parent and "experimenter-subject fit" or expert fit accomplished by the first author who directly fit the child participants. For the untrained-parent condition (Method B), the parent was given the hearing protection device and instructed to follow only the package directions for fitting her/his child with the hearing protector(s). For the trained parent condition (Method A), the parent was given detailed hearing protector fit instructions by the experimenter in accordance with the instructions that were provided with the product. Parents were permitted to fit themselves with the hearing protector to practice their technique. Deviation from the ANSI S12.6 standard Method-A protocol occurred in terms of eliminating the use of fitting noise during parent training due to the lack of auditory feedback to the parent while fitting a child. All participants were fit binaurally.

REAT testing was conducted in a double-walled acoustic test booth. Consistency of head position and orientation was maintained using a plumb bob referenced to the nose of the seated subject. The sound-field test environment was calibrated to ANSI 12.6 and ambient sound levels of the test suite did not exceed those permitted in that same standard. All threshold measurements were obtained using a Grason-Stadler (GSI 61™) audiometer calibrated to ANSI S3.6-2004. The audiometer served as the noise generator with one-third octave band filtering at center frequencies of 125, 250, 500, 1,000, 2,000, 4,000 and 8,000 Hz. Thresholds were measured using a modified Hughson-Westlake test procedure and a 2 dB step size. For each experimental condition, repeat measures of the unoccluded and occluded thresholds were obtained and counter-balanced. Randomization of the hearing protector fitting condition (e.g. untrained parent, trained parent or expert) was not possible due to the influence of one type of training on any subsequent measures.

Three common types of hearing protectors were evaluated; slow-recovery small-sized foam earplugs, youth-sized premolded three-flange earplugs (smaller flanges) and child-sized earmuffs (with standard adult-sized earmuff cups but a smaller headband sized for children's heads). A new pair of foam earplugs was used for each test condition. New pairs of three-flange earplugs and earmuffs were provided to each child participant and the same HPD was reused for each experimental condition. The experimenter returned the earmuff headband to manufacturer shipping position out of sight of the parent participant between trials.

ANALYSIS

Threshold data were organized by HPD type and tabulated in an Excel spreadsheet. Descriptive statistics were applied to calculate the means and standard deviations of the REAT data for each octave-band tested and experimental condition; trained parent (Method A), untrained parent (Method B) and expert. The NRR was calculated using the following equation:

$$NRR = 107.9\,dBC - 10\log\sum_{f=125}^{8000} 10^{0.1(L_{Af} - APV_{f98})} - 3\,dB$$

where L_{Af} is the A-weighted octave band level at frequency f of a pink noise spectrum with an overall level of 107.9 dBC and APV_{f98} is the mean attenuation value minus two standard deviations at frequency f (two standard deviations provides for 98%

protection in a normal distribution) (Franks et al. 1994). The NRR was also calculated with a minus one-standard-deviation correction (providing for 84 % protection in a normal distribution).

RESULTS

Twenty-six children with a mean age of 8 (and ranging from 5–10 years of age) participated in the study. Fifty-four percent (n=14) were female and reflected the preferred gender balance recommended by ANSI S12.6. All children were able to complete the full study with the exception of one male subject who expressed an aversion to having earplugs inserted into his earcanals. Subsequent discussion with the parent revealed that this subject had a traumatic experience several months prior in which a bee was trapped in his earcanal and stung him repeatedly.

Figures 1-3 reveal the mean and standard deviation one-third octave band attenuation values and calculated NRRs (with both a 2-SD and a 1-SD computation) for each of the three experimental conditions for each hearing protector evaluated. Laboratory data obtained on adult subjects using comparable hearing protectors are also provided for the EPA label test (per ANSI S3.19) and Method B (inexperienced subject-fit). The label test data include attenuation measured at 3 and 6 kHz.

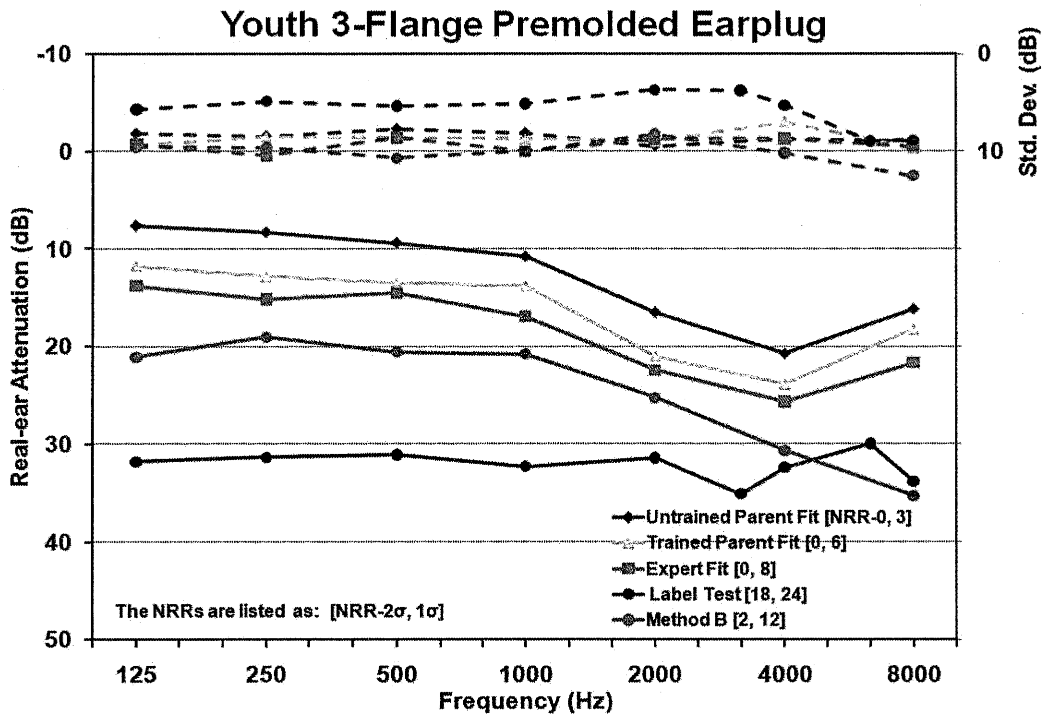

Figure 1: Mean attenuation (left axis) and std. dev. (dashed lines, right axis) for children (n-25) fit with 3-flange earplugs and calculated NRRs in brackets with both 2 and 1 standard deviation(s) compared to adult laboratory data

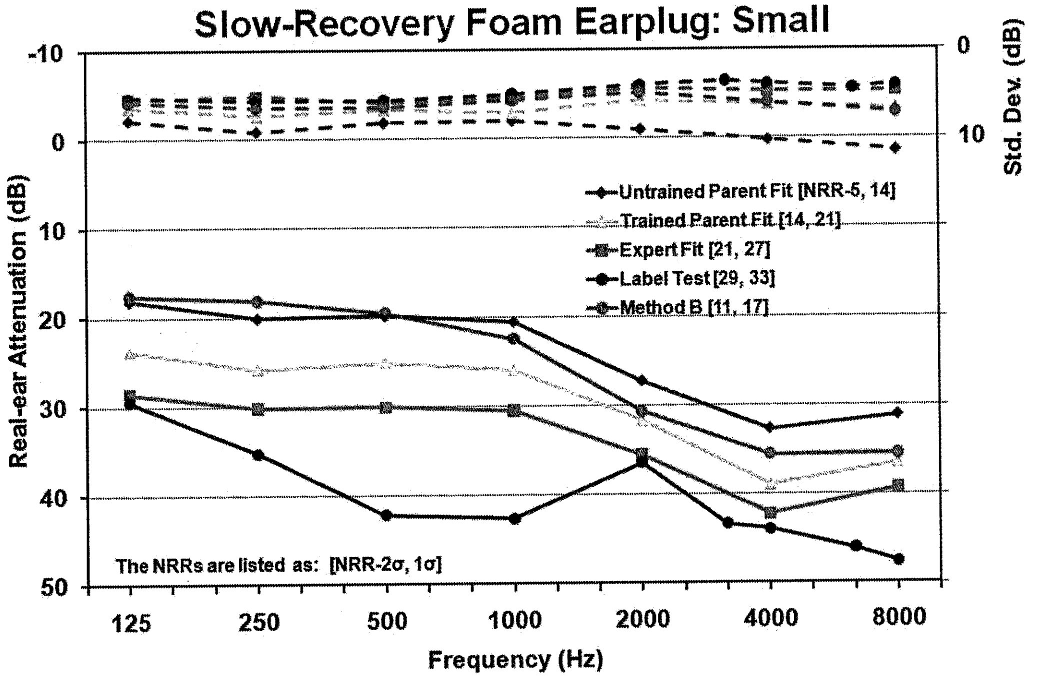

Figure 2: Mean attenuation (left axis) and std. dev. (dashed lines, right axis) for children (n-25) fit with slow recovery foam earplugs and calculated NRRs in brackets with both 2 and 1 standard deviation(s) compared to adult laboratory data

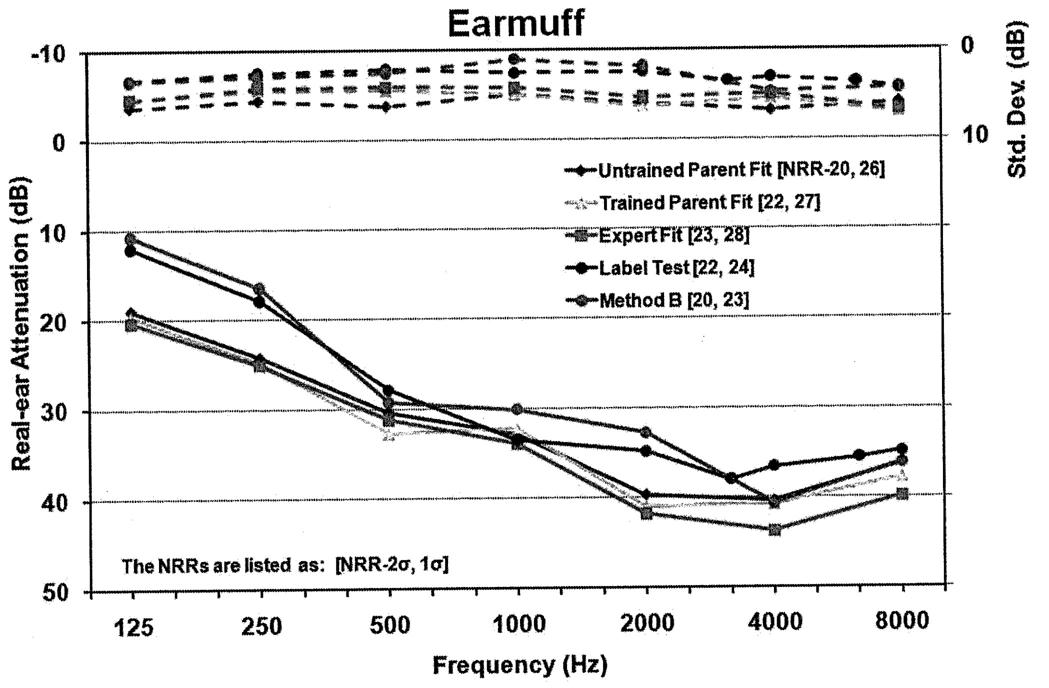

Figure 3: Mean attenuation (left axis) and std. dev. (dashed lines, right axis) for children (n-26) fit with child-sized earmuffs and calculated NRRs in brackets with both 2 and 1 standard deviation(s) compared to adult laboratory data with a comparable earmuff

In terms of experimental findings with earplugs, parent training and fitting experience contributes to greater attenuation for children. This is consistent with the training effects reported for adults in the literature (see ANSI S12.6). For both earplug styles evaluated on children, the expert fit provided the greatest degree of attenuation, followed by trained parent (Method A) when compared to untrained parent (Method B). Approximately 5 dB more attenuation was achieved across frequency when parents were trained on the earplug insertion and fitting, however attenuation did not achieve expert-fit levels. For all fitting conditions, attenuation was greater for the 3-flange earplug when measured on adults in the laboratory label test as opposed to children. Variability for the 3-flange earplug attenuation was lowest for adult laboratory label test data and generally consistent across frequency for all other fitting conditions in both children and adults.

The NRRs achieved with slow-recovery foam were higher than those obtained with 3-flange earplugs in children, and it is evident that minimal protection was provided for some children when using the youth-sized flanged earplugs. Interestingly, the slow-recovery foam earplug results for untrained parents (Method B) were essentially identical for 125-1,000 Hz to Method B (inexperienced subject-fit) attenuation measured on adults, though this was not true for the 3-flange earplug. Variability with the slow-recovery foam earplugs was generally comparable for both children and adults with the exception of untrained parents (Method B), especially for the higher frequencies (4 and 8 kHz), where greater variability in excess of 10 dB was evident. Both trained-parent (Method A) and expert-fit testing revealed greater attenuation at all frequencies for children as opposed to adult Method B (inexperienced subject-fit) data. REAT measured in children never approximated adult label-test values for any test frequency when fit with either of the earplugs in this study.

For children, earmuffs generally provide a consistent degree of attenuation regardless of training and fitting experience. In fact, the untrained and trained parent conditions achieved NRRs equal to or exceeding the label-test and Method-B (inexperienced subject-fit) values obtained on adults. Variability was also lower with earmuffs as compared to earplugs; however variability was slightly greater in children than in adults. In our subjects, approximately 10 dB more attenuation was achieved by children than adults for the lowest frequencies (125 and 250 Hz) and approximately 5 dB more attenuation at 2,000 Hz. Parents routinely spontaneously expressed a preference for earmuffs over earplugs in terms of ease of use with children.

DISCUSSION

REAT testing with children is feasible and reliable. There are challenges when working with this young population in terms of maintaining interest and attention. Providing frequent rest periods and changing the response paradigm from button-pushing to hand-raising to verbal responses to auditory stimuli proved helpful. It was impossible to maintain head position/orientation throughout the testing as the children repositioned themselves in the chair frequently. The examiner was able to call a child's attention back to the proper orientation through voice-over through the test speakers. For the younger children, visual reinforcement with lighted toys above the test speaker was also useful for re-positioning the head. The examiners will need to be familiar with behavioural audiometry and experienced with pediatric hearing testing paradigms.

Test-retest reliability with children does not appear to be a major concern for REAT measurements. Stuart et al. (1991) reported that the pure-tone test/retest reliability in children does not have a statistically significant difference when compared to the test/retest reliability in adults for behavioral diagnostic testing. These authors state that test/retest reliability becomes a factor when the threshold results obtained are 10 to 15 dB different than previous testing (Stuart et al. 1991) when using a 5 dB step size. The variability for all three types of hearing protection was less than 10 dB and consequently appears to suggest good test/retest reliability for REAT measurements with children.

Relevant to the 3-flange earplug results, the experimenter noted that for the five children who obtained particularly low values of attenuation, the youth-sized flanged earplugs were unable to properly accommodate their earcanals or, in one case, were small enough that even the largest flange could not fully fill and seal the canal. As a result of this, a subsequent experiment is planned to further investigate the fit of an alternative 3-flange earplug on these children. Foam earplugs were routinely not deeply inserted into the earcanals due to very small earcanal apertures; however substantial attenuation was still achieved. It may be inappropriate to judge the adequacy of slow-recovery foam attenuation merely on the basis of visual appearance when worn by children.

Training of parents was felt to be inadequate when referencing the current manufacturer instructions. These instructions were all designed to instruct adults to insert the hearing protector in their own ears and not in a child's ear. There is a need to modify the instructions to specifically reference the different approaches to insertion necessary with children. Changes to consider include the best direction to manipulate the pinna to expand the aperture of the earcanal, the recommended hand to use for insertion of the earplug, the positioning of the adult in reference to the ear for improved visualization, and the proper insertion technique. Many parents expressed concern that the earplug would harm the child's eardrum if they inserted it improperly. Therefore, parents also need some anatomical orientation and reassurance regarding this low-risk occurrence. Despite these limitations, training with existing materials does improve the attenuation achieved when parents fit the HPDs.

Children also need training regarding their role in the fitting, auditory and physical expectations and communication with the HPD inserted. It was interesting to note that children often spontaneously reported the occlusion effect after binaural earplug insertions. Children also provided unsolicited verbal feedback to the parent regarding the adequacy of the HPD fit. It may be useful to encourage children to do this if fitting instructions are specifically created for parents and children in the future.

The clinical assumption that HPD attenuation is equivalent between children and adults requires further investigation. The results of this study suggest that earplug attenuation is less than reported for adults and fit training is critical. However, for earmuffs, NRRs are generally equivalent to adult label-test values and, surprisingly, octave-band attenuation values for children exceed adult laboratory values. It may be necessary to consider distinct laboratory testing and labelling for HPDs worn by children. In summary, it is feasible to conduct reliable REAT testing in children to assess the degree of attenuation provided by HPDs in this population and, based on our initial test results with one model of earmuff (with a headband sized for children's heads) it appears that earmuffs can provide effective levels of protection for children wearing them.

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