REVIEW ARTICLE

Review of Measurement Methods for Hearing Protector Attenuation

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ABSTRACT

The attenuation degree labelled on hearing protectors is based on internationally set standards. The attenuation is measurement in laboratories using methodology of real-ear attenuation at threshold (REAT), microphone in-real ear (MIRE) and acoustics test feature (ATF). The measured attenuation gap from the actual workplace is a problematic predicament. The conceptual review of how far these methods affect the gap could embark future researches. Therefore, a conceptual review of the conducted methodologies according to standards for attenuation which include Noise Reduction Rating (NRR) and Single Number Rating (SNR) are discussed in this paper. 23 papers from ProQuest, EBSCOhost and Google Scholar databases are chronologically reviewed. Summarily, the improved attenuation measurement methods will help close the gap between laboratory data and field performance and subsequently will better prevent Noise-Induced Hearing Loss. Most of the latest findings after year 2010 were in agreement with the studies in 2000 to 2009.

Keywords: ANSI 12.6, EPA 40 CFR 211, Hearing protection device attenuation, ISO 4869, Laboratory standard

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INTRODUCTION

Since 1974, United States (US) Environmental Protection Agency (EPA) came out with EPA 40 CFR 211 of hearing protectors. Through the act, all hearing protectors or henceforth the hearing protective devices (HPD) sold in US must be labelled accordingly. The field study started in 1974 when the EPA first commenced. The EPA 40 CFR 211 1979 (1) was reviewed back in 1996 by Berger & Royster (8) considering issues raised in 1986 until 1989 when a few researches on HPD attenuation effectiveness were done (2-6).

The research done in 1986 (7) was reinvestigated in 1996 by Royster on the effectiveness of HPD at the workplace, since the worries on the continuously occurring Noise-Induced Hearing Loss (NIHL) was raised. Consequently, the study group made recommendation to EPA regarding the non-importance of less than 3 dB attenuation difference between HPD. Another recommendation was made for a possibility study on usage of laboratory data to estimate the field performance. Researcher has also developed a laboratory-based standard to yield field performance estimates of the HPD (8).

Another group reviewed and reinvestigated the current HPD labelling standard and requirement which main purpose was to study the procedure effectiveness of standard attenuation measurement (9). At that time, the research study chose the method from American National Standard International of ANSI S12.6 (10) and not on other equivalent standards. They investigated on the electroacoustic and psychoacoustic procedures. Among the recommended modifications were the sample size, fitting procedure, subject selection, supervision, training, and number of trial for closer estimation to field attenuation. Furthermore, there was an extensive study of attenuation measurement laboratory protocol using the Real-Ear Attenuation at Threshold (REAT). They also produced a lot of research outcomes regarding HPD attenuation. They also mentioned that for any new attenuation method, the group derived a specific power of measurement for the minimum and maximum value of calculated attenuation (9). Additionally, another researcher discussed on the proper wear of HPD based on Occupational Safety and Health Act 1970 (11) and its latesttechnologies in 1997 (12). Besides, Berger revisited

his own work in 1996 (8) during another related study in 1998 (13).

Another study had focused on the issues of subject fit (SF), as per recommended on the lowering of NRR by 25% for earmuff or 50% for slow recovery foam ear plugs or 75 % for all other earplugs (14). The 75% reduced NRR category was not representing the real world REAT of HPD. In other words, it was found that there was difference in subject-fit procedures between ISO and equivalent ANSI implementation. Regarding the difference found, the studied ISO 4869 (10) which was equivalent to ANSI S12.6-1997 Method B (15) procedures did not include naive subject on the training and HPD usage. Thus, it was noted that in ISO 4869-1 (16), HPD use was uncontrolled. Furthermore, in Method B test subjects adjust HPD insertion or fitting for a better earplug seals on ear. Therefore, ISO 4869-1 produced higher estimates on field attenuation while most attenuation values obtained from Method B were higher than the former at workplaces. Apart from that, this interlaboratory study conducted in the US published findings that source of variation on the measured attenuation came from measurement standards, procedures, experimental subjects, experimenter, facility and instrumentation, headband force measurement, and HPD itself (17).

In 2003, a few researchers from US with EPA background gave individual talks on the HPD attenuation. Alice H. Suter elucidated a few measurement were available; and Europe uses SNR and HML, Canada and Australia use Class Systems while US use the NRR (18). The NRR used in US was emphasized due to regulation promulgation (19). Alice highlighted most HPD user generally working at industries believes higher NRR value gives higher protection, not knowing the protection did not specify according to the occurring noise hazard's TWA and specific ear, and that there is overestimation of noise reduction in real-world use. She also noted on the unavailability of data in hearing conservation effectiveness and relevance of instruction to derate NRR value (18). Another speaker talked on the laboratory study conduction to get precise attenuation data using existing standards (20) and researcher named Franks reviewed existing standards (21) including ISO-4869 (10), ANSI S12.6-1997 Method A and B (14), CSA Z94.2-02 (22) and EPA 40 CFR Part 211 (1).

The method of real-ear at attenuation threshold (REAT) is measured based on thresholddifference between the occlusion and unocclusion via a HPD use (3). The microphone in real- ear (MIRE) measured a sound pressure level at the eardrum by a tiny microphone placed in the ear and compared between occluded and unoccluded ear in which termed as insertion loss (IL) (25). An acoustic test fixture (ATF) is HPD attenuation made on dummy head normally for a high level of noise (3).

MATERIALS AND METHODS

In this paper, the solutions towards real world attenuation represented by noise attenuation in research studies were reviewed. The critical review (23) was used to understand the contribution of studied methodology in attenuation measurement conducted using laboratory procedure. This review is written in the narrative and chronological form for an update of recent studies on highlights the device attenuation and its methodology conceptualization. The agreement of latest researches review to the early studies sought on a few database. The field study, qualitative study, the prevalence of hearing loss related to HPD was excluded for this review. All the reviewed papers were published in English language. The review topic has included ISO 4869-1 revised in year 1990 (16), ISO 11904-1 revised in year 2002 (24), attenuation methods (25), objective or subjective or non-acoustic type (25), guidelines on accuracy, fitting, and precision or measurement uncertainty (27).

An extensive research of literature was made, its quality critically evaluated and a few keywords used for the review process. Using the keywords of ISO 4869, hearing protectors' attenuation, laboratory standard, EPA 40 CFR 211, and ANSI S12.6, 30 articles were screened but only 23 papers were reviewed. The reviewed papers were published in diverse journals retrieved on ProQuest Health & Medical Complete and EBSCO Discovery Service that searchable in Google Scholar too. 23 papers were chosen by including results which related to the HPD attenuation testing in laboratory. The studies are closely related to the effect such as subject, fitting, training, instruction, interlaboratory, tester and HPD type. The studies are also based on the raised issue of adequate protection level (8,23,32,52,53). Besides, the methods developed and applied on standards of attenuation measurements (9,13,20) are concurrently studied. Additionally, a few other articles of the latest publication related to the review topic were also included in this paper.

The review highlighted a few methods used by the researchers in their various HPD attenuation measurement studies. The attenuation value studied and recommendation to the updated standardization was synthesized. This section is mainly about the research findings in2010 until 2018. During these years, the study contexts were focusing on the matter of estimating a HPD attenuation laboratory calculated value close to its equivalent field setting at the workplace. Then, the recommendation made by those study and findings agreementwith its earlier investigations was explained. The published works since 1990 were mainly about retrospective studies of its earlier investigation about the gap value between manufacturer label and real world attenuation of a HPD with different settings. The earlier

research has begun in 1986 and the studies conducted until 1989. Table I is used to classify the attenuation measurement, the attenuation related matters that have been studied, and the attenuation values obtained. Table I also highlights a few recommendations made for otherinvestigations.

ATTENUATION ESTIMATION

Recently, a study conducted by manipulating the HPD fitting. The researcher identified the presence of NIHL's association with frequency of exposed noise when HPD worn (28). On the other hand, an inter-laboratory study conducted by a group of researchers. The inter-laboratory study included four laboratories to conduct tests. The laboratories compared its Subject Fit attenuation result with American National Standard Institute (ANSI) data (29). The finding of the inter-laboratory study included an amount of 2 dB average difference calculated without any significant difference between the four laboratories' data observed. They suggested further investigations on the study participant's experience and test administrator and the fit-test psychometric tasks (30).

Field (F)-MIRE study conducted in the year of 2016 as the measuring method of HPD attenuation at workplace. The manufacturers' attenuation value obtained using F-MIRE was higher than the field attenuation across all frequencies compared to the measured in the workplaces. The researcher proposed that HPD usage, cleaning, storing and training for effective placement denoted as all the contributing factors to difference of attenuation between labelled and on-job (31).

HPD attenuation from MIRE compared to REAT through a study made in the year of 2015. The objective of this study aimedto know effect of HPD insertion training on both the MIRE and REAT methods. The HPD attenuation value compared among total of 80 trained and untrained male subjects. The experimenter trained and guided the usage of HPD on each subject and then compared to a control group that did not receive any training. Higher attenuation observed among the trained group subjects at 500, 1000, 2000 and 4000 Hz in both MIRE-objective and REAT-subjective methods (32).

In 2013, a study conducted to establish the comparable occlusion effect between the REAT and the MIRE or F-MIRE . The equivalent attenuation result for each mentioned methods from a subject are REAT, Noise Reduction and Insertion Loss measurement thatshowed similar trend of occlusion effect across all tested frequencies (33).

A research output on attenuation consistency published in 2012. During the study, researcher found dissimilarity

Table I: The attenuation measurement methods studied and the proposed suggestions from study in 2010 to 2018

Method	Purpose/Setting (laboratory/ field)	Limitation/Result	Preferred Recommendation	Author, Year
Simulation	Attenuation at different frequencies	sound control, repeat previous study at different frequencies		Ziayi et al. 2018 (27)
REAT	Four lab results compared to single REAT (American National Standard Institution - ANSI)			Byrne et al. 2017 (29)
MIRE	Safety eyewear effect in fitting of HPD	Personal Attenuation Rating (PAR), 2 dB difference	Training efficacy available among both premolded and foamable earplug	Biabani et al.2017(39)
F-MIRE	Manufacturer versus on job	NRR, low variability	F-MIRE is applicable for test while workers work normally	Rocha et al. 2016 (30)
F-MIRE	Premolded earplug versus foamable earplug	Significant difference		Murphy et al. 2016 (41)
MIRE, REAT	Frequencies 500 Hz, 1kHz, 2kHz, 4kHz	No significant difference		Samelli 2015 (31)
Analysis	Predict pressure level at ear	Acoustically electrical diagram, energy flow paths	Training gave higher attenuation value compared to untrained fitting published a HPD simulator	Kalb 2013 (42)
MIRE, REAT, EA*	Occlusion effect among methods	IL & NR, Similar occlusion effect	REAT more practicable to measure threshold value, MIRE more practicable to calculate high level pink noise data	Nelisse 2013(32)
REAT, MIRE, F-MIRE	Custom earplug versus non-custom earplug	PAR*, attenuation consistency is higher on custom earplug	Training produce better attenuation consistency	Tufts et al. 2012 (33)
REAT	Four different HPD vs REAT data	Standard deviation of REAT is higher	Attenuation correction factors of physiological noise and bone conduction was considered. Four HPD is practicable to make real attenuation prediction.	de Almeida et al. 2011 (34)
REAT	Proposed the uncertainty prediction model of HPD attenuation	SNR 84% dB NRR SF, both 0.6 uncertainties		Lima 2010 (35)

*Electroacoustic

of attenuation consistency between the custom and non-custom earplug type. Researcher observed the HPD attenuation more consistent using custom earplug compared to the non-custom type. The training of earplug fitting affected the consistency in both earplug types (34). The study of MIRE- Insertion Loss (IL) made in 2011 denoted as an alternative to the Noise Reduction Rating number (NRR) (35).

In 2010, researchers considered the measurement parameters, the equipment factors or errors and the test subject as the uncertainty sources in method implementation of ANSI S12.6 and ISO 4869-1. In this study, results taken from randomly selected 12th subjects out of 7 tests at 4 frequencies that equal to 28 thresholds tests on each subject. They highlighted result of the 4.7 dB uncertainty found at 4 kHz that its greatest influence camefrom subject response contributed 99.65% towards all tested error sources (36).

DISCUSSION

The simulation model to obtain the hearing protection level provided by worn earphone at workplace tested recently (28). Besides, the recommendations of subject's experience using HPD, subject fit and tester's instruction to use HPD (30) agreed with Murphy's and co-researchers work (37) and with Berger and Royster (8). In ANSI S12.6 Method B, naive subject used continuously for its next Method A. However, in this study Method B of ANSI S12.6-1997 Revision 2002 implemented that only newly-trained naive subjects used in both methods. The researcher noted that when the subjects learn to fit the HPD, that habit contributed erroneous values to the result of either test conducted within subject, between subject, or inter-laboratory. Thus, erroneous values affected the standard deviation for individual frequencies and A-weighted attenuation of Method A and Method B experiments. Using the proposed subject number, for Method A of within subject no any significant difference suggested. Besides, the test on between subjects tested using three to twelve subjects suggested the need to get 6 dB attenuation differences. The study also suggested that an inter-laboratory test should include 12 to 132 subjects to get about -0.1 to 3.0 dB attenuation difference. The result of Method B within subject attenuation showed no significant difference. The result of attenuation difference in between subject of 6 dBshowed, and suggested using five to nineteen subjects for reproducibility. The result of interlaboratory test showed -0.1 to 3.0 dB attenuation difference, and suggested using nine to 28 subjects for reproducibility (37).

Besides that, an evaluation study conducted on the actual HPD attenuation (Noise Reduction) using MIRE (37). The relative strengthening of the unobtrusive sound field caused by the ear canal and pinna resonance and the effect of the presence of the head called transfer function of open ear (TFOE) which, if added to the noise reduction (NR) equalto insertion loss (IL). Basically, MIRE procedures considered the TFOE measurement (3,5,6,26,39). TFOE value reinvestigated in 2017, and its results (39) agreed to those previous researches' finding (3,5,6,26,39).

In 2016, a study mentioned that the labeled attenuation value by HPD's manufacturer represented the higher number across all frequency (31). From a study in 2015, researcher denoted that the training to wear a HPD give effect to increase the obtained amount of attenuation (32).

Nelisse and co-researchers' work as mentioned earlier (33) agreed to the work of other researchers, and in addition looked into the bone-conduction matter (40,41). In 2012, a group of researchers mentioned that the ear-plug HPD attenuation' consistency affected by the training. Furthermore, the custom and non-custom earplug type showed different value on attenuation consistency range (34).
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53 In 2010, the low understanding on sources of errors value causedresearchers to face difficulties in quantifying the measurement uncertainty. Proposed model for uncertainty calculation for HPD attenuation measurement (36) agreed to the earlier findings on the hearing protection level (2,4,9). Table I shows some of the knowledge contributions of the reviewed studies conducted between the year 2010 until 2018 within a few criteria. The criteria are method, purpose or setting in laboratory limitation or result, and recommendation if any. Besides, the measured attenuation name that used by the researchers in their studies are shown in Table I too.
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19 Based on Table I, the five earliest studies investigated the REAT attenuation (34,35) with three of it compared to data from MIRE (31-33). Next, attenuation studies on F- MIRE method made (30-32,39,41,42), followed by a simulation study (28) recently.
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28 Initially since 2010, REAT method investigated but later the MIRE method investigated too with criteria as shown in Table I. Shortly, the latest finding from researchers are described in this paper. The latest HPD attenuation researches conducted based on theearlier researches made in 1986 to 1989 (2-4,6) and in year 1996 (9). The studies focused to find understanding on factors contributing to non-effective HPD rating number made in the years of 1990's(8,9,13,17,44,45) followed by attenuation value studies for real job environment presentation in years of 2000's (25,26,37,40,46-52). The chronological of studies between latter and former research highlighted showed most of latest research findings (25,26,37,40,46-52) agreed with the previous

studies (8,9,13,17,44,45). For example, fitting training and experience affect HPD the attenuation value increment.
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MIRE attenuation classified as objective method whiles the REAT as the subjective method (37). The advantage of MIRE over REAT mentioned such as on the simultaneous occlusion effect during measurement is less time consuming.MIRE known as an objective method that not consider the human response during test like the REAT (33). The real world optimum attenuation estimation using both MIRE and REAT method remains unsolved (1,2,4,14,53). Even though the attenuation number is not the only consideration in selecting a HPD (8,54), because workplace performance is affected by various real world factors (54), but researches which attempt to idealize attenuation number with real world performance and its results were continuously studied.

CONCLUSION

Several studies have documented that educational program plays a crucial role in reducing parenting stress among parents of children with ASD. This systematic review provides an important opportunity to advance our understanding of the effectiveness of the educational program for reducing parent stress and improving coping mechanism among parents of children with Autism Spectrum Disorder. Future experimental studies and mix method design with large sample size can be recommended to provide scientific evidence regarding the effectiveness of an educational program. Furthermore, cohort studies which include multi-year follow-up can be used to assess the long term effectiveness of an educational program.

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