A Simple, Cost-effective, and Novel Method for Determining the Efficiency of Industrial and Commercial Noise-Canceling Earmuffs

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Abstract

Context: There are several ways to assess the noise reducing efficiency of earmuffs, but they usually involve using human participants and/or specialized equipment. Objective: The current study was designed to develop a less labor-intensive, cost-effective, participant-free first-pass method for measuring the efficiency of earmuffs. Methods: We evaluated the noise-cancelling ability of five different types of earmuffs (3M: Optime 98, Optime 105; iDEA USA V201; Tronsmart Encore S6; Bose QuietComfort 35) under laboratory and field conditions. We compared our results to the microphone-in-real-ear (MIRE) method. Lastly, a survey of college-aged students was also conducted to determine which earmuffs were the most comfortable and provided the best fit. Results: Of the five earmuffs studied, the Optime 98 and Bose earmuffs were most effective at reducing noise levels in both the laboratory and field. These earmuffs also received the highest scores for comfort, fit, and perceived ability to reduce noise, with Bose being slightly more preferred than Optime 98. The MIRE method provided the same overall results as the laboratory and field tests. Conclusion: Our method for evaluating the noise-canceling ability of earmuffs could be used to supplement more complicated testing procedures as a first-pass method.

Keywords: Noise, noise-canceling earmuffs, microphone-in-real-ear, traffic

INTRODUCTION

Earmuffs—a type of hearing protection device (HPD)—generally provide greater protection from sound than earplugs, are easier to fit to a person’s head, tend to be more durable, and are typically designed so that one size fits most.[1] However, previous studies acknowledge that improper fit of earmuffs can decrease their noise-canceling ability, especially when the earmuffs are ill-fitting due to eyewear.[2] Earmuffs can also vary with respect to the muff material being used, the depth of the dome, and the force exerted by the headband that clamps the muffs onto the head. Disadvantages of earmuffs include their higher price, and in high temperature work areas, they can be more uncomfortable to wear.[1]

There are several well-known ways to measure the sound attenuation of HPDs. The gold standard method is real-ear attenuation at threshold (REAT); this method has been previously well documented.[1-4] REAT is considered the gold standard method because it accounts for ear physiology to provide an estimation of hearing protection provided by the fit of HPDs. During REAT, subjects rate the noise-cancelling ability of different HPDs. A major limitation of REAT is the subjective nature of the test, as it relies on human participants to determine when they can no longer hear sound levels coming from a microphone. Because of this, REAT is very time consuming and results are dependent upon the ability of participants to hear the sounds being studied.[5] Another popular method for measuring sound attenuation is the microphone-in-real-ear (MIRE) technique, which has been employed both in laboratory and in the field (f-
Both REAT and MIRE require human subjects, which make studies more laborious, time-consuming, and expensive, and additional approval for human-subjects research would be required. Further, these methods generally require very low background sound levels and test chambers for the participants to sit in during measurements, and these facilities may not be readily available to researchers. Thus, for this study we are proposing a simpler, less expensive way to measure sound reductions of one type of HPD—earmuffs—without the need for human participants or specific low-sound chamber environments. Our method can easily offer a first-pass way to measure sound reduction before using these more sophisticated, complicated set-ups and engaging in time-consuming and potentially expensive human subjects research. This could be particularly useful when several HPDs are to be compared to each other to determine the most appropriate device for a specific application, occupation, research study, or sound source. This method could also be used for a curious observer, rather than a dedicated researcher, that wants to find the best earmuff for their specific intended use. Thus, we don’t envision this technique as being a substitute for REAT or MIRE, but rather as an aid in the selection of appropriate HPD when the justification of different HPDs are needed or warranted before engaging with human participants.

The focus of this current study was to develop a basic technique that can be used to easily calculate and compare the percent sound reduction of several brands of earmuffs and compare those results to a more sophisticated technique. The earmuffs selected for this work included both industrial and recreational earmuffs to demonstrate versatility. In addition, we tested both passive and active sound-reducing earmuffs to assess how sound-canceling ability may influence sound reduction percentages. Briefly, five unique earmuffs (two industrial and three recreational) were evaluated when eight different pre-recorded soundtracks were played in a quiet laboratory setting. We then took the best overall sound reducing earmuffs into the field where we tested for sound reduction at three settings differing in sound sources. Additionally, we thought it was important to evaluate whether the earmuffs differed in their fit level and comfort and perceived ability to reduce noise levels, and we conducted a short survey of 30 college students and asked them to evaluate the muffs based on these three factors. Fit and comfort are important factors to consider if these muffs are to be used in occupational or environmental studies because research has suggested that poor design can decrease use of hearing protection devices due to employees’ discomfort and inability to perform work-related tasks while wearing the devices.[5] Lastly, we validated our method against a popular method for measurement of noise reduction, MIRE.

**METHODS**

**Pre-recorded soundtracks**

Eight pre-recorded soundtracks were obtained from the AudioBlocks website, which contains access to a library including more than 100,000 unique and continuously-updated soundtracks (https://www.audioblocks.com/). The soundtracks were selected based upon their length, which was approximately two to four minutes for consistency between track lengths, and the track’s representation of common sounds found in city environments. For this work, the selected tracks were: 1) City Traffic Heavy (2 min 0 sec); 2) City Center Walking Crowd (3 min 7 sec); 3) City Crossroads Traffic (2 min 11 sec); 4) City Background Ambience (3 min 0 sec); 5) City Bus Station Traffic Pedestrians Bus Traffic (2 min 0 sec); 6) Morning Birds Ambience (2 min 9 sec); 7) Student Outdoor Crowd (2 min 54 sec); and 8) Dog Barking on Sidewalk of Busy Street (3 min 55 sec).

**Earmuff selection**

Five unique earmuffs were assessed for this work. Two earmuffs were meant for occupational sound reduction: Optime 98 (3M, St. Paul, MN) and Optime 105 (3M). Both earmuffs can be purchased online and are relatively inexpensive, costing approximately $15. The remaining three earmuffs were recreational, meaning they are most likely to be used for daily or home sound reduction and for listening to music, and ranged in price from $60 to $300. The three recreational earmuffs selected were Tronsmart (Encore S6, Shenzhen, China), iDEA USA (Atomix V201, Chino, CA), and Bose (QuietComfort 35, Framingham, MA) earmuffs. Upon doing an online search, there were many recreational sound-reducing earmuffs available. Our selections for these muff:s were based on ease for online purchase and positive online reviews and ratings. Further, the Bose earmuffs were rated in 2016 as the best overall active noise-canceling wireless earmuff to date based on a popular review website (CNET—Technology News),[6] which is the world’s leader in technology product reviews. Both occupational earmuffs used passive noise canceling by physically blocking sound with the earmuff design. This was in contrast to the recreational earmuffs which used both passive and active noise canceling by creating sound waves with the same amplitude and opposite phase of the ambient sound to cancel out the waves. The recreational earmuffs were tested both with and without the active noise-canceling (ANC) function enabled for comparison. Four of five earmuffs were “over ear” style, while the Optime 105 earmuffs were “behind-the-head” style.
Measuring the sound reduction in a laboratory environment

A laboratory located in a quiet setting was selected for the location to complete this portion of the work. The baseline sound pressure level (SPL) (Sper Scientific, Model # 850013, Scottsdale, AZ) of the laboratory space was recorded for 15 minutes prior to playing any soundtrack to assess the background sound level of the laboratory. Then, SPL measurements of each of the eight soundtracks were individually obtained over a span of 15 minutes by playing each soundtrack on repeat approximately five times. This gave us the SPL of the soundtrack with no sound reduction or interference. The microphone was directly facing the speakers for every trial. Next, the SPL meter microphone was sandwiched between the earmuffs and tightly secured with labeling tape. The microphone was again directly facing the speakers during each trial. We ensured a tight fit around the microphone to get the best and most accurate SPL reduction for each earmuff tested. Once the microphone was completely secure, each soundtrack was played again for 15 minutes for each of the five earmuff types. For the three earmuffs that could reduce sound both actively and passively, both sound reduction methods (i.e. active and passive, and passive alone) were tested for each soundtrack. The soundtracks were played from computer speakers located six inches from the SPL meter, with the location of the speakers and SPL meter marked so the distance was consistent between all trial runs. In total, this experimental design resulted in one baseline reading of the background SPL levels in the laboratory setting, eight background soundtrack readings without the earmuffs, and 64 soundtrack readings with the earmuffs. The volume was put on the maximum setting for the computer speakers to ensure it would be consistent throughout the entire experiment, and this setting was never altered during the course of the experiment. SPL measurements were recorded by the meter twice per second on fast response mode. The SPL meter had a working range of 30 to 130dB and was operated on an A-weighting scale.

Measuring sound reduction in field environments

For this experiment, we wanted to assess whether the earmuffs behaved differently when removed from a controlled laboratory setting. The three earmuffs that were the most effective at reducing sound levels in the laboratory setting were tested in field settings between June and July 2018 at three diverse locations around Syracuse, NY. As the soundtracks from the laboratory experiments were focused on environmental sounds, the field locations were chosen to obtain a mix of urban and rural sound measurements. The first location chosen was Marshall Street. Marshall Street is at the center of Syracuse University’s campus with many restaurants, a hospital, parking garages, and bus stops located nearby. The second location chosen was Onondaga Lake Park, which is an urban park with two major interstates running adjacent to it. The last location was a commonly used research field site in Heiberg Memorial Forest referred to as the Tully Field Site. This location represents the most rural and quietest site for this work.

To assess the ability of the sound reducing earmuffs to reduce sound levels at these field locations, two identical SPL meters were used to simultaneously measure the SPL with and without the earmuffs; the meters were pre-calibrated (REED R8090 Sound Level Calibrator) to ensure that similar readings were given between them. Further, the SPL meter used with the earmuffs for assessing sound reduction was kept consistent at all the locations. In contrast to the laboratory studies, in which sound levels did not fluctuate during the course of the experiments, two SPL meters were needed in the field locations as the sound levels greatly changed over time. Similar to the laboratory experiments, SPL measurements were obtained for approximately 15 minutes for each earmuff at each of the three field locations. The two SPL meters were tested for consistency with each other by collecting sound measurements for approximately five minutes in between earmuff tests.

Survey of comfort and efficiency

A survey of 30 college students was conducted to assess whether certain characteristics of the three sound-reducing earmuffs used in the field tests differed. The characteristics we were interested in were comfort, fit, perceived sound-reducing ability, and which earmuff they would most likely purchase for their own personal use. The survey was administered using a ten-point Likert scale, with 1 being the worst and 10 being the best. This study was approved by Syracuse University’s Institutional Review Board.

Measurement of the sound reduction with the MIRE method

To validate that our method was a comparable to established methods, the three earmuffs compared in the survey were used in a second study involving seven human subjects in the same quiet laboratory environment as previously mentioned in our laboratory experiment. Two identical noise dosimeters (Quest Technologies Noise Pro DL) were utilized, with one microphone being placed inside the right earmuff while worn by the participant and the second microphone being placed directly outside the earmuff. While participants were wearing the earmuffs, one loop of the “City Traffic Heavy” soundtrack was played on maximum volume from computer speakers; meanwhile, the noise inside and outside the earmuff was recorded. This soundtrack was chosen because it was the most representative of typical ambient and traffic noise in an urban environment. Care was taken to ensure that the distance between the speakers and the participants remained the same for each experiment. The percent difference between these two time-series averages was then calculated. Dosimeters had a working range of 65 to 114dB and operated on an A-weighting scale. Measurements were
recorded once per second on fast response mode. This study was approved by the Syracuse University’s Institutional Review Board.

**Statistical analysis**

Percent sound reduction was calculated using the formula for percent difference, where the difference between background soundtrack SPL and the SPL with earmuffs applied was divided by the background soundtrack SPL. Sound-level data obtained in the laboratory were analyzed for differences across the different earmuff types using a one-way analysis of variance (ANOVA). Paired t-tests were completed for the ANC versus non-ANC earmuff experiments to assess differences between the SPL meters. All statistics were computed in RStudio (version 1.1.463).

**RESULTS**

**Laboratory experiment**

Overall, the soundtrack SPL ranged from 68.8 to 78.2 dBA. The loudest track played was City Background Ambient, which was 78.2 ± 3.0 dBA, and the quietest track played was Dog Barking, which was 68.8 ± 4.8 dBA. The variability in the SPL for the tracks was very minimal, suggesting each track had a fairly consistent SPL. The noise levels presented by the eight soundtracks were consistent with environmental SPL in urban environments. [7]

The percent difference, used as a measure of noise-canceling ability for each earmuff, is reported in Table 1 for the eight soundtracks. For the active-canceling earmuffs, percent reductions in both the passive and active-canceling modes are reported. The lowest-performing earmuffs were the Tronsmart and iDEA USA earmuffs, both in passive-noise-canceling mode, which reduced sound levels at an average of 18.8 ± 9.5% and 18.6 ± 9.1%, respectively. The Optime 98 muffs and Bose earmuffs, when in active-canceling mode, reduced the sound levels to the greatest extent, with an average percent reduction of 30.8 ± 5.6% and 35.1 ± 13.2%, respectively. Overall, when the active noise-canceling function was enabled, it was able to reduce sound to a much greater extent than when it was disabled. These two earmuffs, in addition to the iDEA USA earmuffs, were selected for further field experiments.

We compared SPL measurements between the baseline levels in the laboratory without the soundtracks and without the earmuffs (i.e., baseline), when the soundtracks were playing without the earmuffs (i.e., background), and when the soundtracks were playing using the earmuff interventions. Regardless of the soundtrack being played, similar trends were observed for the earmuffs. In general, the 3M Optime 98 and the Bose QuietComfort 35 earmuffs were the most effective at reducing sound levels. However, we found that they did so in different manners. Both industrial earmuffs from 3M, which utilized only passive canceling, reduced sound levels with the lowest standard deviation, showing a consistent and stable reduction in sound levels regardless of how the sound levels varied with the soundtracks. This was in contrast to the recreational earmuffs, which reduced sound levels following the same increases and decreases in sound levels as the soundtracks, culminating in a higher standard deviation between data points. An example of these trends can be seen for one loop of City Traffic Heavy, which is the soundtrack most representative of heavy downtown traffic noise, in Figure 1. The three earmuffs that went on for further testing in the field are shown for purposes of clarity.

**Field experiment**

Two pre-calibrated SPL meters were tested simultaneously between each field experiment with the earmuffs to ensure that the output from the meters agreed with one another before securing the earmuffs around one of them in a
modified field MIRE method, similar to that utilized for the laboratory experiments. Each recording was taken five times in the field. We found high correlation between the two meters at Marshall Street ($R^2 = 0.83$), which represented our most urban location with high foot, car, and bus traffic. The correlation coefficient was less at Onondaga Lake Park, with a correlation coefficient of 0.64. The average correlation coefficient was lowest at the Tully Field Site ($R^2 = 0.43$), our most rural location. Low correlation between meters in a single test at Tully led us to complete a Bonferroni outlier test; however, the $P$-value was greater than 0.05, which did not allow us to reject the data point.

The baseline sound levels at Marshall Street, Onondaga Lake Park, and Tully Field Site were $62.8 \pm 2.0$ dBA, $56.6 \pm 4.8$ dBA, and $43.4 \pm 3.7$ dBA, respectively. Sound-reducing

![Figure 1: Sound levels over one loop of City Traffic Heavy soundtrack for the baseline soundtrack and the three earmuffs (Optime 98, IDEA USA, Bose) as compared to the laboratory background noise. IDEA USA and Bose are reported with the ANC function enabled. ANC, active noise cancelling](image-url)
ability of the earmuffs was evaluated by percent difference. We found that even though the earmuffs were tested in a more uncontrollable setting, they still performed similarly in the field as they did in the laboratory [Table 2]. We found that the 3M Optime 98 and Bose with ANC enabled were able to reduce the highest percentage of sound in the field, with the Optime 98 earmuffs reducing sound levels 26.4 ± 3.9%, 42.5 ± 2.8%, and 20.9 ± 9.7% at Marshall Street, Onondaga Lake Park, and Tully Field Site, respectively. The Bose, when operating with both passive and active noise canceling, reduced sound levels by 35.9 ± 2.0% at Marshall Street, 48.0 ± 2.4% at Onondaga Lake Park, and 38.5 ± 1.8% at the Tully Field Site. A similar trend of greater sound reduction when using both active and passive noise canceling was also observed for the iDEA USA earmuffs, but to a much lesser extent.

We also wanted to compare the noise cancelling ability between active and passive noise cancelling in the earmuffs that had the ability to use active noise cancelling. To do this, a paired t-test was conducted for each pair of earmuffs that had both active and passive noise-canceling abilities. T-tests were performed for data collected in the laboratory as well as in the field. All means were statistically different from one another (P<0.05), indicating that the percent noise reduction when the active noise cancelling function was enabled was statistically different from the noise reduction when only passive noise cancelling was applied.

### Survey of comfort and efficiency

A sample of 30 college-aged students were asked to complete a survey and compare three pairs of sound reducing earmuffs (3M Optime 98, iDEA USA, Bose) on four categories: comfort, fit around their head, their perceived sound-reducing ability, and their preferred earmuffs for personal purchase and use [Table 3]. Participants briefly wore each pair of earmuffs and completed the survey in a quiet environment with low ambient noise levels and assigned a score between 1 and 10 to each category, with 1 being the worst and 10 being the best. Across all these categories the Bose ANC earmuffs scored the highest, suggesting that they were the earmuffs that were the most comfortable to wear, fit the best, and were perceived to reduce ambient sound levels the best. However, the Optime 98 muffsn had similar scores for the best perceived ability to reduce sound levels. The iDEA USA earmuffs received the second highest score in the comfort category, with the Optime 98 muffns ranked as the least comfortable of the three tested. The iDEA USA earmuffs received the lowest score from participants in two of three categories, including the lowest score across the entire survey for perceived noise-canceling ability, indicating that these earmuffs were the worst performing and would not be advised compared to the Bose and Optime 98.

Additionally, participants were asked to choose their favorite earmuffs, representing the pair they would be most likely to buy; 14 participants selected the Bose (47%), 12 participants selected 3M Optime 98 (40%), and 4 participants selected iDEA USA (13%). This distribution further supports that the Bose earmuffs are the preferred muffns among college-aged students, although the 3M Optime 98 were comparable. Several participants noted that they would prefer the Optime 98 earmuffs for outdoor use, such as yardwork. Several other participants noted that eyeglasses affected the quality of fit of the earmuffs, which led them to choose the Bose earmuffs as their favorite due to their adjustability.

### MIRE experiment

A sample of seven college-aged students were recruited to participate in this portion of the study. The subjects were asked to wear three pairs of noise-canceling earmuffs (Optime 98, iDEA USA, Bose) while one loop of the “City Traffic Heavy” soundtrack was played in a quiet
laboratory environment. ANC mode was enabled for the iDEA USA and Bose earmuffs. One dosimeter microphone was placed inside the right earmuff, and the second dosimeter microphone was placed directly outside the earmuff. The percent sound reduction was calculated by comparing the percent difference between the two time-series averages. Overall, it was found that the results of the MIRE method study followed the same trends as the previous laboratory and field experiments. The Optime 98 and Bose earmuffs were the most effective at reducing noise with percent noise reduction values of 26.5 ± 1.1% and 27.4 ± 1.3%, respectively. Additionally, it was found that the iDEA USA earmuffs were not as effective at reducing noise, with an average reduction of 22.0 ± 3.0%. These results support the results of our novel, modified MIRE method and are also in line with the results of our survey.

**DISCUSSION**

The objectives of this study were twofold: to develop a basic technique that can be used to easily calculate and compare the sound reduction of several brands of earmuffs, and then compare those results to a more sophisticated technique that requires human participants.

Our technique involves initial analysis in a quiet laboratory environment of the noise-canceling efficiency of five brands of industrial and recreational earmuffs, both with and without ANC functions enabled, when available. We were able to identify significant differences between the brands of earmuffs in this test. Our second objective was to compare the results of our novel method to results of a more sophisticated technique, MIRE. By utilizing the same laboratory environment for MIRE testing as was used for our method, we achieved the same results, with the Optime 98 and Bose Quiet Comfort 35 with ANC function enabled achieving the highest levels of noise canceling.

This study demonstrated that the Bose earmuffs, in addition to the 3M Optime 98 muff, were the most effective at reducing laboratory and field-based sound levels; however, the consistency of noise canceling is important to mention. The 3M earmuffs had a very low standard deviation throughout the time series both in the laboratory and in the field, suggesting that they are best at reducing sound levels with little variation, while the Bose earmuffs had a high standard deviation throughout the time series, suggesting that they are more variable in their ability to reduce sound levels but on average reduce sound to a larger extent. This is due to the active noise canceling function necessary for the Bose, as sound waves designed to cancel out outside noise cannot maintain a constant noise reduction and fluctuate based on their surrounding environment.

It is also important to note that the industrial and recreational earmuffs are designed to cancel out different types of noise. Industrial earmuffs, designed for use in loud factories and near heavy machinery were more effective at reducing traffic noise (City Background Ambient, Marshall Street) than conversational noise (Dog Barking, Onondaga Lake Park). This may be due to their intended use, which is so the wearer can hear people working near them but not the loud noises that may cause hearing damage. In contrast, the recreational earmuffs were still effective at reducing traffic noise (City Background Ambient, Marshall Street), but they were much more effective than the industrial earmuffs at reducing quieter sounds (Dog Barking, Onondaga Lake Park).

Based upon the experimental data, the 3M Optime 98 and Bose earmuffs were most appealing to the college students who participated in the survey. One limitation of the survey, however, was that participants had different activities in mind that did not necessarily fall in line with their occupation when selecting the most appealing brand of muff. For example, some participants noted that if they were mowing a lawn or using loud yard equipment, they would choose to purchase the 3M earmuffs. Several participants also noted that eyewear use negatively impacted the fit of the muff, causing their scores for comfort and fit to be reduced. This is mirrored in the literature, where studies have suggested that proper employee training and individual testing of the fit and efficiency of hearing protection must be considered when choosing and evaluating noise-canceling earmuffs. Other participants noted that they would be more likely to purchase the Bose earmuffs for daily use, but their price was a major limitation when deciding to do so. Those who chose the iDEA USA as their favorite earmuffs seemed to be more concerned about the fit of the muffs rather than their comfort or noise-canceling ability.

There are several limitations to this study. First, we could have been more cautious in ensuring the muffs securely covered the microphone of the SPL meter. However, our results were very consistent, so we do not think that was a major problem in our study, and our results were consistent with the more sophisticated MIRE technique. Additionally, we conducted our field study during the summer months, when it was very warm outside. Although we stayed within the operating limits of the muffs, the SPL meters were in direct sunlight for some of the experiments and could have possibly overheated, resulting from the meters being exposed to direct sunlight. We attribute the temperature to a possible reason why some of the correlation coefficients were very low on particularly sunny, hot days. We also observed that nine measurements were near the SPL meters’ limit of detection of 30 dBA (SPL < 40 dBA), which could have been avoided with a different control site being selected. Another limitation of this study was not taking into account sound frequencies during either the laboratory or the field-based studies. It has been previously shown that different hearing protection devices are better at reducing sound levels at different frequencies. It has also been previously shown that the MIRE method is vulnerable to error at high frequencies and the REAT method is vulnerable to error at low frequencies due to physiological masking. Additionally,
the dosimeters for the MIRE method had a limit of detection of 65 dBA, which may have caused our percent noise reduction values for the Optime and Bose earmuffs to be lower than the actual reduction experienced by the participants. While the results for the MIRE test still support the results from our novel, modified MIRE method, additional studies should be conducted to confirm that the amount of noise reduction was consistent with the laboratory and field results when human subjects were involved.

There are also several advantages to this work. We were successful in designing a first-pass method for evaluation of the noise canceling ability of earmuffs, which can shorten the initial analysis time and the cost of earmuff evaluation. Our initial analyses allowed us to identify the best-performing pairs of earmuffs, which were selected for further testing in the field. Furthermore, we were able to identify significant differences between SPL with and without the muffs at three field locations that contained different levels of traffic. With two brands of earmuffs clearly being the most successful in laboratory, field, survey and MIRE test results, we confirmed that our technique could be a suitable substitute for MIRE when time and resources are limited.

**CONCLUSIONS**

For this study, we developed a first-pass method to evaluate the efficiency of noise-canceling earmuffs in both a laboratory and field setting. To do this, we tested our method using five different noise-reducing earmuffs, eight soundtracks, and two distinct field locations. We found our method to be comparable to a more sophisticated method (MIRE). Our method is novel and easy to conduct and requires no human participants or sophisticated equipment, making it easy to use for both researchers and consumers.

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**Conflicts of interest**

There are no conflicts of interest.

**References**

1. Canadian Centre for Occupational Health and Safety [Internet]. Government of Canada [updated2019 Mar-03]. Available from: https://www.ccohs.ca (accessed 1 October 2019).
2. Biabani A, Aliabadi M, Golmohammadi R, Farhadian M. Individual fit testing of hearing protection devices based on microphone in real ear. Saf Health Work [Internet]. 2017:8:364-70. Available from: https://www.sciencedirect.com/science/article/pii/S2093791117301749 (accessed 1 October 2019).
3. Neitzel R, Somers S, Seixas N. Variability of real-world hearing protector attenuation measurements. Ann Occup Hyg 2006;50:679-91. Available from: https://academic.oup.com/annhyg/article/50/7/679/317809/Variability-of-RealWorldHearingProtector (accessed 1 October 2019).
4. Berger EH, Voix J, Kieper RW. Methods of developing and validating a field-mire approach for measuring hearing protector attenuation. 2007; Available from: http://espace2.etsmtl.ca/id/eprint/5757/ (accessed 1 October 2019).
5. Berger EH. Preferred methods for measuring hearing protection attenuation. In: The 2005 Congress and Exposition on Noise Control Engineering [Internet]. Rio de Janeiro, Brazil: 2005. p. 1–10. Available from: http://multimedia.3m.com/mws/media/8932070F/preferred-methods-for-measuring-hearing-protector-attenuation.pdf (accessed 1 October 2019).
6. CNET [Internet]. CBS Interactive [updated2018 Jun-01]. Available from: https://www.cnet.com/reviews/bose-quietcomfort-35-review (accessed 1 October 2019).
7. Fiedler PEK, Zannin PHT. Evaluation of noise pollution in urban traffic hubs—Noise maps and measurements. Environ Impact Assess Rev 2015;51:1-9. Available from: https://www.sciencedirect.com/science/article/pii/S0195925514001024 (accessed 1 October 2019).
8. Canetto P. Hearing protectors: topicality and research needs. Int J Occup Saf Ergon 2009;15:141-53. Available from: https://www.tandfonline.com/doi/full/10.1080/10803548.2009.11076795 (accessed 1 October 2019).
9. Verbeek JH, Kateman E, Morata TC, Dreschler WA, Mischke C. Interventions to prevent occupational noise-induced hearing loss. In: Verbeek JH, editor. Cochrane Database of Systematic Reviews. Chichester, UK: John Wiley & Sons, Ltd; 2012. Available from: http://doi.wiley.com/10.1002/14651858.CD006396.pub3 (accessed 1 October 2019).
10. Alam N, Sinha V, Jalvi R, Gurnani D, Barot D, Suryanarayan A. Comparative study of attenuation measurement of hearing protection devices by real ear attenuation at threshold method. Indian J Otol 2013;19:127. Available from: http://www.indianjotol.org/text.asp?2013/19/3/127/117477 (accessed 1 October 2019).
11. Berger EH. Preferred methods for measuring hearing protector attenuation In Inter-Noise And Noise-Con Congress and Conference Proceedings 2005:3:4342-41.
12. de Almeida-Agurto D, Gerges SNY, Arenas JP. MIRE-IL methodology applied to measuring the noise attenuation of earmuff hearing protectors. Appl Acoust 2011;72:451-7. Available from: https://www.sciencedirect.com/science/article/pii/S0003682x11000223 (accessed 1 October 2019).