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Abstract

Construction work requires the combined use of eye and hearing protection. Earmuff specifications don't address the impact of eye protection on earmuff performance. This study used earmuff noise insertion loss (NIL) and a discomfort rating to assess the impact of using 6 different types of protective eyewear on the performance of 3 different earmuffs, where 15 subjects were exposed to noise from 4 power-tools while adopting 5 neck postures. Earmuff, protective eyewear and posture had a significant effect (5%) on earmuff NIL while only the first two were significant (5%) for the discomfort rating.

Within the boundaries of this study, researchers were able to identify the eyewear that least impacted earmuff performance, the earmuff with the best performance when used together with eye protection, the set of earmuff x eyewear combinations that were found more comfortable, and the combinations that were least affected by neck posture.

Key Findings (Considering all earmuffs used had NRR of 25 dB)

1) The method used in this study to assess earmuff Noise Insertion Loss can be applied in the implementation of a conformity assessment protocol to test earmuff performance when used alone or together with protective eyewear.
2) Considering the 5 different brands and models of protective eyewear evaluated in this study, the 3M GoggleGear™ Safety Goggle with headband was found to pose the least consistent negative impact on earmuff performance, with an average associated Noise Insertion Loss above 30 dBA.
3) Considering the three different brands and models of earmuffs evaluated in this study, the 3M Peltor™ Optime™ 98 Over-the-Head earmuff was found to provide the highest performance measured as Noise Insertion Loss regardless of the protective eyewear used, with an average Noise Insertion Loss above 30 dBA.
4) Considering the 18 different earmuff x protective eyewear combinations evaluated in this study that are listed below:

Protective Eyewear / Earmuff	Elvex Go-Specs II™ Foam Lined Spectacle, with Elastic Fabric Strap System	Elvex Go-Specs II™ Foam Lined Spectacle, with Temples	3M GoggleGear™ Safety Goggles with Temples	3M GoggleGear™ Safety Goggles with Headband	Pyramex I-Force SB7080SDT Eyewear with Temples	Pyramex I-Force SB7080SDT Eyewear with Elastic Strap
3M Peltor™ Optime™ 98 Over-the-Head earmuff	Combination 1	Combination 2	Combination 3	Combination 4	Combination 5	Combination 6
Howard Leight QM24+ Quiet Muff	Combination 7	Combination 8	Combination 9	Combination 10	Combination 11	Combination 12
Elvex ValueMuff™- HB-25	Combination 13	Combination 14	Combination 15	Combination 16	Combination 17	Combination 18

Combinations 1, 2, 3, 4, 5, 6, 8, 10, 13, 14, 16, 17 and 18 provided an average Noise Insertion Loss greater than 18 dBA (NRR of 25 dB – 7 dB as mandated by OSHA) and were deemed fairly comfortable by the subjects that participated in this study.

5) Considering the three different brands and models of earmuffs evaluated in this study, the 3M Peltor™ Optime™ 98 Over-the-Head earmuff and the Elvex ValueMuff™- HB-25 earmuff were the most robust earmuffs in terms of performance with respect to neck posture, with average Noise Insertion Loss estimates above 26 dBA.

Introduction

Approximately 30 million people in the United States are occupationally exposed to hazardous noise levels (OSHA, 2010). Most of the work done in construction requires the continuous use of eye protection for jobs that are frequently associated with high noise levels. Even though earmuffs are often used in combination with eye protection, none of the evaluations included in the conformity assessment process for hearing protection devices (HPDs) to date include a specific assessment of the impact of eye protection use on earmuff performance (Cohen et al., 2010).

On the other hand, OSHA requires that employers select HPDs based on their Noise Reduction Rating (NRR) values when workers are exposed to noise at or above an 8-hr TWA of 90 dBA and mandates the use of HPDs for employees who have developed noise induced hearing and are exposed to an 8-hr TWA equal or greater than 85 dBA (29 CFR §1910.95). Moreover, OSHA currently requires that the NRR value be reduced by 7 dB to estimate its true value in the A scale. Furthermore, the Industrial Hygiene profession backed among other agencies by OSHA, AIHA, ACGIH, and NIOSH recommend the use of a de-rating factor of 25% to account for less than optimum fit of earmuffs. Despite the results of past research studies showing that eye protection has a negative effect, 3 to 7 dB, on earmuffs' performance (Berger, 2000), no requirements or recommendations have been proposed to reduce HPDs NRR to account for the effect that eye protection has on their performance.

Moreover, the Committee on the Certification of Personal Protective Technologies (Cohen et al. 2010) also recommends fitting the specific HPD to the worker as a critically important component of the effectiveness of hearing protection devices. Although this fitting process can in fact more accurately estimate the performance of HPDs for a give worker, it does not specifically take into account the use of eye protection as a potential source of HPD performance variability.

This small study proposed an applied, quantitative and more realistic approach to assess the impact of using protective eyewear on the performance of earmuffs. The effect of 2 different types of protective eyewear (3 safety glasses and 3 safety goggles) on the performance of three different earmuffs with the same NRR (25 dB) was evaluated through: a) a qualitative comfort and effectiveness rating, and b) the quantitative effect protective eyewear had on earmuff's Noise Insertion Loss, NIL. The methodology used in this small study represented an innovative approach towards collecting earmuff performance data while subjects were exposed to noise with sound pressure levels quite above their correspondent frequency hearing thresholds, coming from four real life power tools automatically operated in a continuous mode, while study participants adopted 5 different neck postures.

Objectives

This small research study had the following objectives:

1. To evaluate the feasibility of using Noise Insertion Loss in the development of a conformity assessment protocol to test earmuff performance when used together with protective eyewear.

2. To identify, within the scope of brands and models of earmuffs and protective eyewear evaluated in this study, the protective eyewear with the least negative impact on earmuff performance.
3. To identify, within the scope of brands and models of earmuffs and protective eyewear evaluated in this study, the earmuff that was least affected by the use of protective eyewear.
4. To qualitatively identify the most comfortable combination of earmuff x protective eyewear evaluated in this study.
5. To identify the combination of earmuff x protective eyewear, within the scope of brands and models of earmuffs and protective eyewear evaluated in this study, that was least affected by worker's neck posture.

Methods

This small study used an applied and quantitative approach to assess the impact of using protective eyewear on earmuffs' performance, where 15 study subjects were actually exposed to noise coming from 4 power tools used in construction (power sander, chipping hammer, miter saw, and a grinder), that were remotely operated all at the same time while subjects were standing up approximately 4 feet away from each tool. A total of 3 earmuffs of different brands and models (NRR = 25 dB) described in Table 1 and 2 different types of protective eyewear (3 safety glasses of different brand and models and 3 safety goggles of different brand and models) also described in Table 1 were evaluated in this small study. In each of the 18 earmuff and protective eyewear combinations, the earmuffs' noise insertion loss (NIL) measurements were taken (with and without protective eyewear) while subjects remained standing with their heads in 5 different postures, as shown in Figure 1 and described as follows:

- While subjects maintained their neck in neutral posture (0 degrees) looking straight forward
- While subjects flexed their neck looking downwards 30 degrees with respect to the vertical plane.
- While subjects extended their neck looking upwards 30 degrees with respect to the vertical plane
- While subjects twisted their neck to their right side 90 degrees
- While subjects twisted their neck to their left side 90 degrees

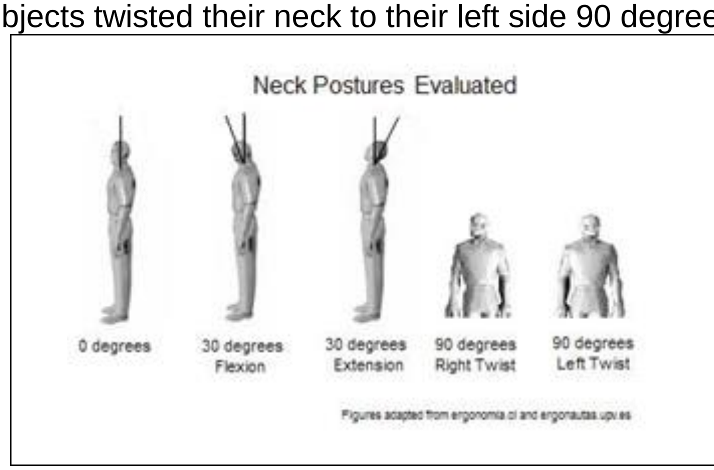

Figure 1: Neck postures evaluated

Neck posture was included in this study in order to evaluate the robustness of each earmuff x protective eyewear combination to different body postures.

Fifteen study subjects (8 female, 7 male) were recruited through the word of mouth from the general University community, including faculty, students, maintenance and facilities employees, and administrative staff. Interested potential subjects received a detailed explanation of all study procedures and a copy of the written informed consent (approved UPR IRB protocol # A3390113) for their review. Once written informed consent was given by study subjects, they were trained on earmuff and safety eyewear donning practices, had their head anthropometric measurements taken, and systematically got acquainted with all 18 possible earmuff x protective eyewear combinations evaluated (each located in a separate and numbered box). Subjects were then trained on how to control and adopt the neck postures that were evaluated in the study, as well as on the procedures (quantitative data collection and qualitative comfort/effectiveness data collection) that followed during the data collection session. The average time taken by the training session was 45 minutes.

The data collection session immediately followed subjects' training session and lasted approximately one hour and a half for each subject. All subjects were evaluated for each of the 18 earmuff x protective eyewear combinations (3 earmuffs and 6 protective eyewear) in each of the 5 postures described above, totaling 90 experimental conditions per subject. Each earmuff x eyewear combination was presented in random order to each subject, where noise exposure was measured in each of the 5 postures in a random order for 8 seconds in three different configurations in the following order: a) protective eyewear only, b) earmuff and protective eyewear, and c) earmuff only. In addition, there was approximately a 10 second interval between each of these three configurations totaling an approximate 3 minutes for gathering the data in each of the 18 earmuff x protective eyewear combinations. Moreover, there was an approximate 2-minute interval between consecutive combinations, where subjects rested and made a preliminary qualitative assessment of the earmuff x eyewear combination just evaluated by assigning a numeric rating from 0 to 10 to that combination (any continuous number from 0 to 10). For the preliminary qualitative assessment, subjects were asked to write down their rating taking into account the whole earmuff x eyewear combination, looking at the interaction that the eyewear had with the earmuff. Moreover, for the numeric rating, 0 was to be associated with a very uncomfortable and poorly protective combination (noise wise); and 10 should be associated with a very comfortable and better protective combination (noise wise). Moreover, subjects were told that this was just a preliminary assessment for them to use as a reference for the qualitative evaluation to be done at the end of their participation. The quantitative data collection lasted approximately 90 minutes (one and a half hour) for each subject. During the length of the entire study, each of the 18 earmuff x protective eyewear combinations was located in a separate and numbered box, and all brand and model information for earmuff and eyewear was covered with tape.

Table 1: Earmuffs evaluated in the current study

Earmuff Code in Experiment	Earmuff Brand	Earmuff Model	Earmuff Photo
1	3M	Peltor™ Optime™ 98 Over-the-Head Earmuffs	
2	Howard Leight	QM24+ Quiet Muff	
3	Elvex	ValueMuff™, HB-25	

For each of the 90 experimental conditions, the effect of the protective eyewear on earmuff performance was estimated by subtracting NIL for the earmuff and protective eyewear from the NIL for the earmuff only. NIL for the earmuff only was calculated by subtracting noise exposure measured for the earmuff only from the noise exposure with protective eyewear only. Similarly, NIL for the earmuff x protective eyewear combination was calculated by subtracting noise exposure measured for the earmuff and protective eyewear from the noise exposure with protective eyewear only.
Noise exposure measurements were taken with a technology developed and used in two other studies by this study's principal investigator. This technology uses binaural microphones connected to a digital recorder, where sound data was collected in the digital recorder and then post processed in a LabView program developed for this purpose. The binaural microphones were inserted in the entrance of the ear canals of each subject, and were connected to the digital recorder through very thin wires that minimized potential compromises to the cushion-to-circumaural-flesh seal between the earmuff cushion and the subject's head. In order to eliminate carrying seal leak effects from one measurement to the next, subjects were asked to don the earmuffs before each new measurement was taken.

Table 2: Protective Eyewear evaluated in the current study

Protective Eyewear Code in Experiment	Protective Eyewear Brand	Protective Eyewear Model	Protective Eyewear Photo
1	Elvex	Go-Specs II™ Foam Lined Spectacle, Clear Lens with Elastic Fabric Strap System	
2	Elvex	Go-Specs II™ Foam Lined Spectacle, Clear Lens with Temples	
3	3M	GoggleGear™ Safety Goggles, Clear Lens, Temples (S,M,L)	
4	3M	GoggleGear™ Safety Goggles, Clear Lens, Headband (S,M,L)	
5	Pyramex	I-Force SB7080SDT Eyewear with Temples	
6	Pyramex	I-Force SB7080SDT Eyewear with Elastic Strap	

Once the quantitative data collection was concluded, each subject had approximately 40 minutes to qualitatively order the 18 earmuff x protective eyewear combinations evaluated from most uncomfortable and least protective to most comfortable and most protective with respect to each other. During this 40-minute qualitative data collection session, subjects were exposed to the same noise sources as in the quantitative data collection session, and were allowed, under the supervision of the study PI, to retry each of the 18 earmuff x protective eyewear combinations, each placed inside a numbered card box, as many times as they felt necessary to be able to order these 18 combinations according to the instructions. For this part of the study, using the preliminary rating subjects had given for each combination during the quantitative session, they used a large horizontal table surface were they ordered the 18 numbered card boxes, each with a specific earmuff x protective eyewear combination, in ascending order of comfort and noise protection. In case subjects found that two or more earmuff x eyewear combinations had the same comfort/protection level, they were allowed to place up to two earmuff x protective eyewear combinations boxes in the same relative order. In other words, in the beginning of this qualitative evaluation, each of the 18 earmuff x protective eyewear combinations were located inside their respective numbered box and the boxes where displayed in a line in ascending order according to their respective numbers. A the end of the evaluation, each of the 18 earmuff x protective eyewear combinations were still located inside their respective numbered box but the boxes had been relocated along the original line according to their relative comfort and noise protection. The more to the left the numbered box was, the more uncomfortable and least protective was that combination. Conversely, the more to the right the numbered box was, the more comfortable and protective was that combination.

Results

The data collected from this small study was subjected to a variety of detailed analyses using Minitab in order to collect information as to respond to the objectives set forth in this project. The different analyses performed are described in detailed with their respective discussion in Appendix 2. This section describes the summary results obtained from these analyses as well as provides a discussion on the main findings from this study.

Quantitative Noise Insertion Loss Data

Pertaining to NIL, earmuff, protective eyewear, and posture had all a significant impact (5% level) in determining participants' noise exposure. Table 3 shows the average Noise Insertion Loss results for each earmuff tested in this study when used by itself without any type of protective eyewear.

Table 3: Summary NIL data for all Earmuffs Evaluated without Protective Eyewear

Earmuff Brand and Model n=450 for each earmuff	Average Noise Insertion Loss [dBA]	Standard Deviation NIL [dBA]
3M Peltor™ Optime™ 98	35.5	4.5
Howard Leight QM24+ Quiet Muff	27.6	4.3
Elvex ValueMuff™, HB-25	32.0	3.7

As show in Table 3, all three earmuffs evaluated in the study had average NIL estimates above the expected 18 dBA (25 dB – 7 dB = 18 dBA), while all three muffs had Noise Reduction Rating (NRR) specifications of 25 dB. When evaluated with the 6 different types of protective eyewear used in this study, their average performance is reduced but it is still above the expected 18 dBA, as seen in Table 4.

As show in Table 4, all three earmuffs evaluated in the study with the six types of protective eyewear also had average NIL estimates above the expected 18 dBA (25 dB – 7 dB = 18 dBA).

Tables 3 and 4 indicate that all three earmuffs evaluated in this study (NRR=25 dB) yield average performances measured as Noise Insertion Loss that are above their correspondent nominal expected performances of 18 dBA.

When the collected data is evaluated taking into account extreme values observed as in the Box Plot displayed in Figure 2, however, it becomes clear that although all three earmuffs have the same NRR specifications, they perform differently when used together with protective eyewear. The coding identification for earmuffs and protective eyewear in Figure 2 is described in Tables 1 and 2 respectively.

As it can be observed in Figure 2, from the three earmuff models evaluated in this study, the only earmuffs that had at least 75% of the measured performance above their expected performance (25-7=18 dBA) were the 3M Peltor™ Optime™ 98 and the Elvex ValueMuff™, HB-25. Furthermore, the 3M Peltor™ Optime™ 98 earmuff had a clearly better performance among the three models evaluated. In addition, from Figure 2, we can clearly see that the goggle like protective eyewear (with elastic straps or headbands) was associated with a better earmuff performance independent of earmuff type. Moreover, from Figure 2 we can see that from the 6 types of protective eyewear evaluated in this study, the 3M GoggleGear™ Safety Goggles with Headband was the only protective eyewear associated with an earmuff performance with at least 75% of the measured data above the expected performance (25-7=18 dBA).

Table 4: NIL data in dBA for all Earmuffs Evaluated together with Protective Eyewear

Protective Eyewear	Earmuff					
	3M Peltor™ Optime™ 98		Howard Leight QM24+ Quiet Muff		Elvex ValueMuff™ HB-25	
	Mean-NIL	Std Dev-NIL	Mean-NIL	Std Dev-NIL	Mean-NIL	Std Dev-NIL
Elvex Go-Specs II™with Elastic Fabric Strap System	32.3	5.2	25.5	4.2	31.1	4.3
Elvex Go-Specs II™ with Temples	29.6	6.1	21.2	4.2	24.8	4.5
3M GoggleGear™ Safety Goggles with Temples	32.0	4.8	23.0	3.8	26.5	4.1
3M GoggleGear™ Safety Goggles with Headband	34.7	4.9	26.7	4.1	32.2	3.4
Pyramex I-Force SB7080SDT Eyewear with Temples	25.5	6.1	20.1	5.0	24.0	5.8
Pyramex I-Force SB7080SDT Eyewear with Elastic Strap	29.7	4.4	23.0	3.7	29.1	3.6

Note: n=75 for each earmuff x protective eyewear combination

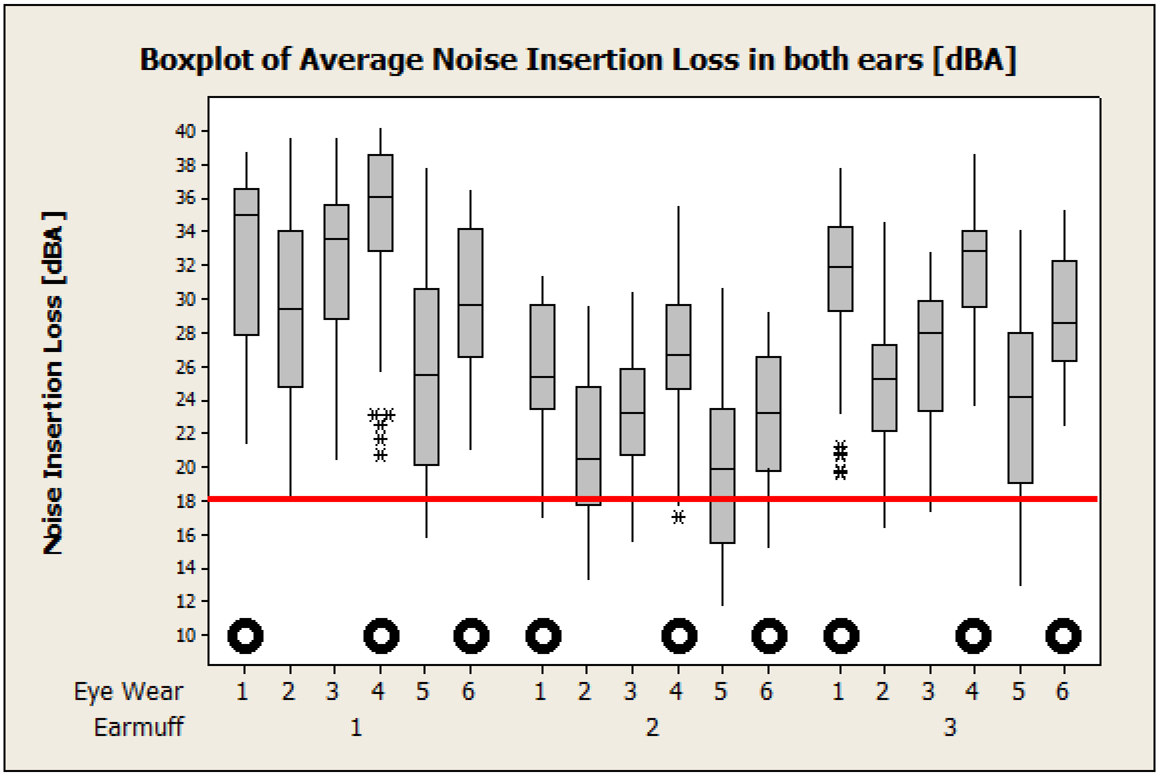

Figure 2: Boxplot of Average NIL for each Earmuff x Protective Eyewear Combination
Notes: Protective Eyewear with elastic strap or headband are marked on top of code
n=75 for each earmuff x protective eyewear combination

Furthermore from Figure 2, we can also see that 3M GoggleGear™ Safety Goggles with Temples was among the protective eyewear evaluated in this study, the only safety glass like protective eyewear associated with an earmuff performance with at least 75% of the measured data above the expected performance (25-7=18 dBA). Finally from Figure 2, we can observe that among the protective eyewear evaluated in this study, Pyramex I-Force SB7080SDT Eyewear with Temples was the type of protective eyewear associated with the lowest earmuff performance independent of earmuff type.

Table 5 shows the average NIL measured along with its standard deviation for each posture evaluated for each of the three earmuffs evaluated and independent of the protective eyewear evaluated in this study. Furthermore, Figure 3 shows Boxplots for the NIL measured for each neck posture categorized by the type of earmuff used.

Table 5: Summary NIL data in dBA for all 5 neck postures evaluated

		Earmuff 1		Earmuff 2		Earmuff 3	
Neck Posture	N	Mean	StDev	Mean	StDev	Mean	StDev
Extension	180	33.8	5.3	26.0	4.9	30.2	4.8
Flexion	180	32.9	6.2	25.5	5.4	29.8	5.2
Left Turn	180	32.8	6.2	25.6	5.3	30.0	5.4
Neutral	180	33.5	5.7	25.8	5.0	30.1	4.9
Right Turn	180	32.5	5.9	24.3	4.4	29.7	4.8

Note: Earmuff codes described in Table 1

From Table 5 and Figure 3, although there is a small effect of posture on the average NIL, such effect is considerably smaller than the measured effects for the type of earmuff and the type of protective eyewear. From the data collected, the effect of posture on the performance of the earmuffs evaluated in this study was considered negligible.

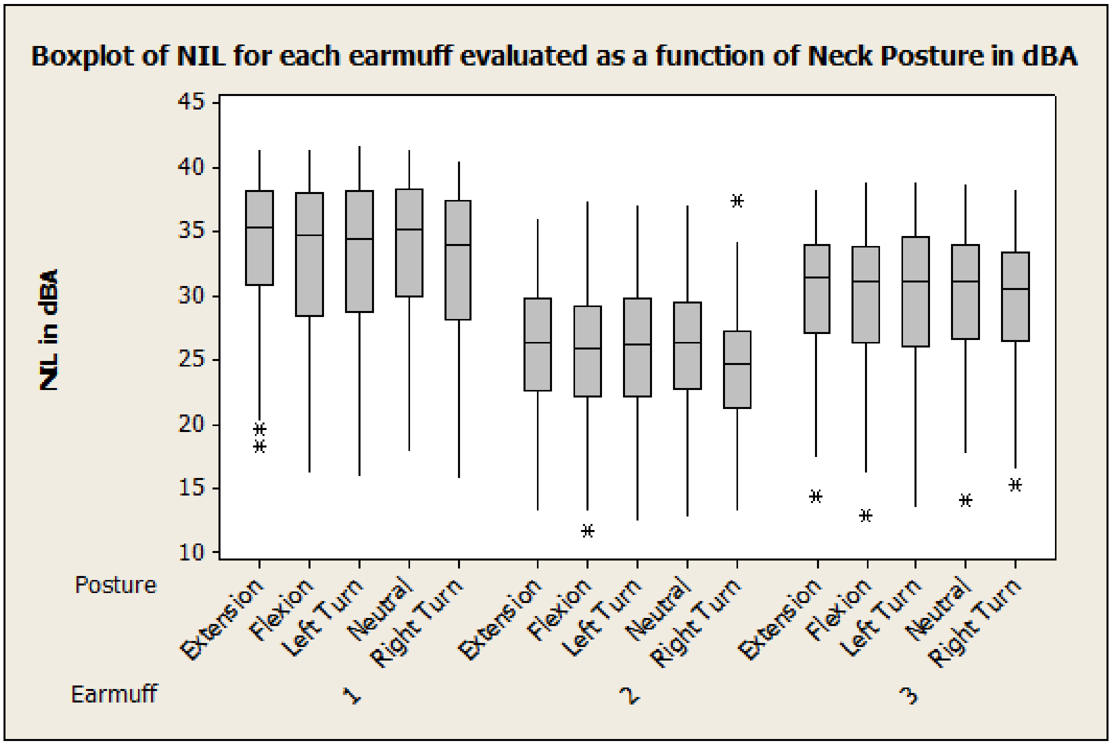

Figure 3: Boxplot for NIL data by Earmuff for each Neck Posture evaluated

Note: Earmuff coding is described in Table 1

Qualitative Discomfort Rating Data

Provided that instructions given to participants requested them to rate each earmuff x eyewear combination according to subjective perception of the combination' combined comfort AND noise protection abilities, it is only relevant to assess subjects ratings on the earmuff x eyewear combination, and not on the different earmuffs nor protective eyewear independently. Each participant's discomfort ratings were standardized as to be comparable with the discomfort ratings from the other participants, and Figure 4 shows a Boxplot for the Discomfort Rating for each earmuff x eyewear combination evaluated in this study grouped by the type of earmuff evaluated.

As it can be observed in Figure 4, those combinations with earmuff # 1 (3M Peltor™ Optime™ 98) were associated with the lowest discomfort ratings obtained in this study, while those with earmuff # 2 (Howard Leight QM24+ Quiet Muff) were associated with the highest discomfort ratings obtained. Even though the boxplots in Figure 4 show a significant variability in the ratings for almost all combinations, when we look at the combinations' medians we can see a different tendency for each earmuff group and more specifically those combinations with earmuff # 1 present a lower overall median discomfort rating.

On the other hand, when the Discomfort Rating data is displayed in a Boxplot grouped by protective eyewear, as observed in Figure 5, those combinations with protective eyewear # 5 (Pyramex I-Force SB7080SDT Eyewear with Temples) were associated with the lowest overall discomfort rating (3rd Quartile values) as compared to the combinations with other protective eyewear.

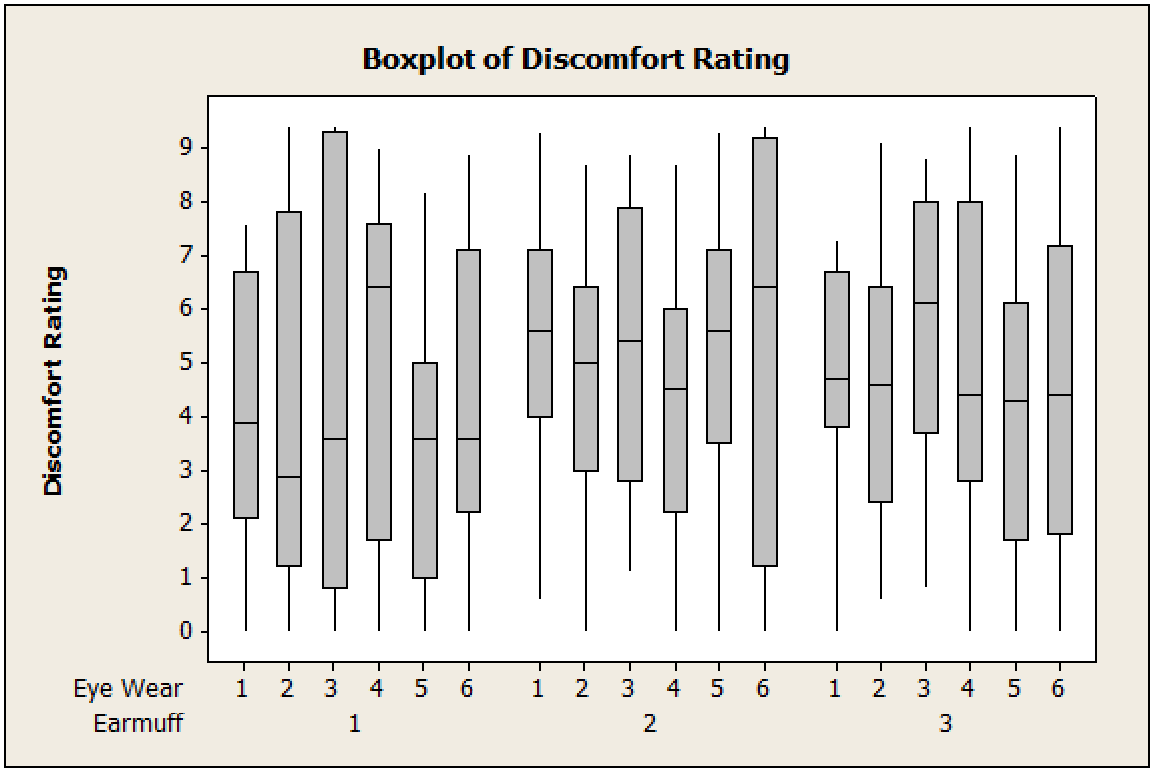

Figure 4: Boxplot of Discomfort Rating grouped by Earmuff

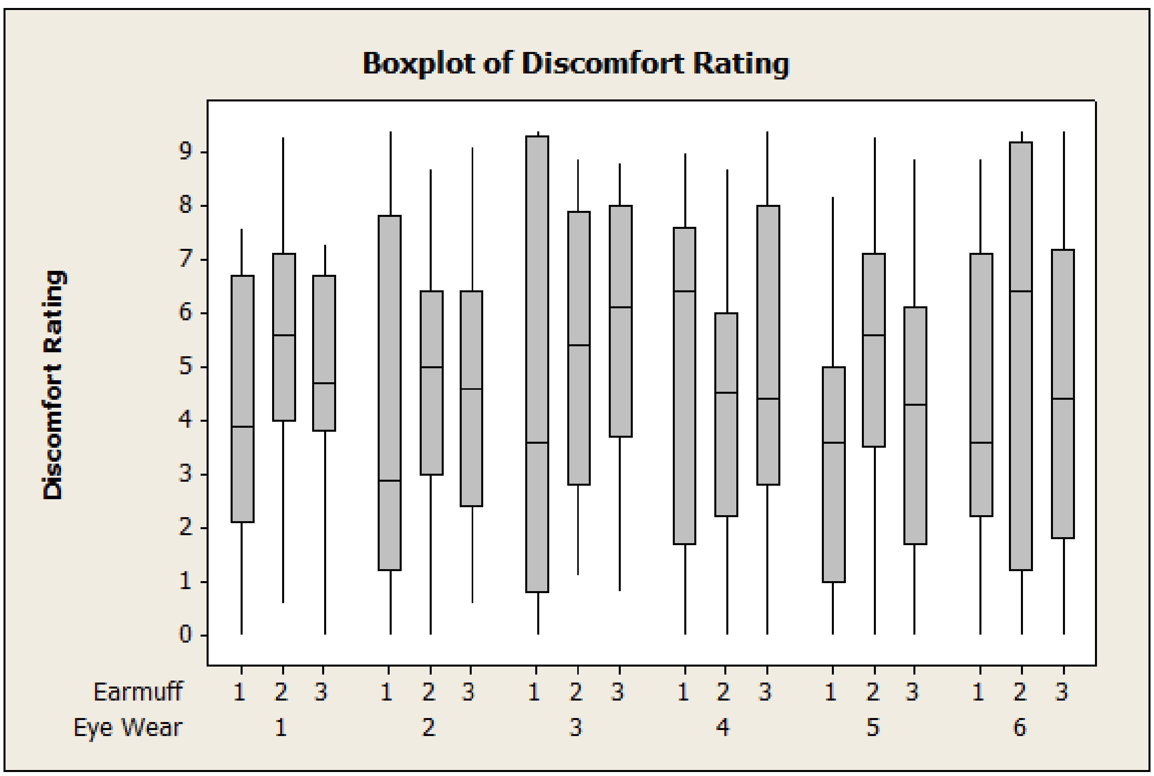

Figure 5: Boxplot of Discomfort Rating grouped by Protective Eyewear

Now, when the quantitative data from Figures 2 is compared with the qualitative data in Figure 4, we can see that participants were able to identify clearly the best earmuff using the instructed discomfort rating, whereas for protective eyewear, the worst eyewear in terms of negative effects on earmuff performance was associated with the smallest discomfort rating. It is our strong believe that even though subjects were instructed to rate each combination based on comfort and degree of noise protection, comfort played a higher role and importance in their subjective response. Since protective eyewear # 5 has wide and straight hard temples, it was most likely deemed by subjects as very comfortable since it held part of the pressure exerted from the earmuffs on subjects' head and did not compressed their temples as much as the other safety glasses. One of the main reasons for collecting a discomfort response and comparing to the quantitative NIL response was to identify a specific combination between eyewear and earmuff that has both good noise protection and small discomfort. By closely examining Figures 2 and 4 with the objective of picking one single combination from all 18 evaluated to recommend for use, we can see that combination 2 (3M Peltor™ Optime™ 98 earmuff with Pyramex I-Force SB7080SDT Eyewear with Temples) was associated with a fairly high noise protection at the same time as being associated with the smallest median discomfort rating. Other combinations such as: earmuff 1 with protective eyewear 1, 3, 4, 5, and 6; b) earmuff 2 with protective eyewear 2 and 4; and c) earmuff 3 with protective eyewear 1, 2, 3, 5 and 6 provided an average noise protection greater than 18 dBA (NRR of 25 dB – 7 dB) and were deemed fairly comfortable by the subjects that participated in this study.

Accomplishments as well as Relevance and Practical Application of Study Results

Although this project was a pilot study and the initial steps in larger and more comprehensive research effort, results obtained from this research project have demonstrated that the proposed Noise Insertion Loss method can be used to conduct conformity assessments to earmuffs alone and to earmuffs when interacting with protective eyewear.

The proposed NIL method of assessing hearing protection performance in many ways complements the already existent methods described in the literature. It actually allows the user to assess hearing protection in real life scenarios, with realistic noise levels and interactions between hearing protection and protection eyewear, as well as between the combination hearing and eye protection and the power tool used by the worker.

Specifically with the brands and models of earmuff and protective eyewear evaluated in this study, as described in detailed in the results section of this report, we were able to:

- To identify protective eyewear # 4 as the one posing the least consistent negative impact on earmuff performance.
- To identify earmuff # 1 as the one with the highest NIL regardless of the protective eyewear used.
- To qualitatively identify a group of comfortable combinations of earmuff x protective eyewear among those evaluated in this study.
- To identify the combinations of earmuff x protective eyewear that were least affected by worker's neck posture, and
- To evaluate, understand and prove the feasibility of using Noise Insertion Loss in the development of a conformity assessment protocol to test earmuff performance when used together with protective eyewear.

Changes/problems that resulted in deviation from the methods

Very few changes were made to the study methods.

1. For the data collection section, we had to reduce the duration of each trial from 10 seconds to 8 seconds in order to increase the expected life of the retrofitted chipping tool in the chipping hammer. Even with this modification, we still had to fabricate 5 tools to run the entire set of 15 subjects.
2. In order to keep the data collection section lasting as long as we original anticipated and to control any potentially inflated variability from an excessive number of donning during

the experiment, we changed the randomization structure of the experimental matrix. In the experimental scheme used for this study, instead of having the order of the 90 experimental conditions independently randomized for each subject, the order of the 18 earmuff x protective eyewear combinations was randomly determined and within each combination the order of each of the 5 postures within that earmuff x protective eyewear combination was selected in random order.

3. Instead of using a hammer drill, we ended up using a power grinder in its place due to the complexity of maintaining a constant noise source. This modification resulted in a better safety for the participants and did not significantly alter the noise signature that was anticipated in the proposal of the study.
4. We decided to take the abrasive wheel out of the portable grinder, the circular blade out of the circular area, and the sanding belt from the belt sander in order to enhance the safety of participants. The noise generated by the tools was not altered individual by presence or absence of their specific work tool. This measure significantly increased the safety of everybody participating in the study.

Future funding plans

Several ideas have emerged during the data collection and data analysis phases of this pilot study:

1. We intend to contact the manufacturers of the protective eyewear evaluated in this study and offer insight in how to modify their product as to decrease discomfort or to decrease the negative effect on earmuff attenuation. All the goggles evaluated in this study were expected to have very little effect on the performance of any earmuff, but this was not what we found for protective eyewear # 1 and # 6. Eyewear # 4 had a marked difference in its design compared to the other two goggles, and it was the general type of elastic band and most importantly the location of buckle to tighten or loosen the elastic band around the users head. While the buckle in eyewear #4 is located in the back of the head, in goggles # 1 and # 6 it is located on the right hand side basically at a level that makes a great interference with any of the earmuffs used. We understand that by changing the type of elastic band and relocating the buckle to the back of the head , goggles 1 and 6 will significantly improve in terms of their negative effect on earmuff performance. On the other hand, some subjects complained about fogging inside their goggles, which we believe we can also work and support the manufacturers in improving their product. Finally on this topic, our methodology can be used to improve the design of temples such as those used in eyewear # 5. Our intentions are to contact the manufacturers and request funding to expand our study to all their other models of protective eyewear.
2. Similarly to the above idea, we want to contact the manufacturers of earmuffs and request funding to expand this study to a larger pool of earmuffs with a larger number of subjects, because we believe our methodology can be beneficial for manufacturers in improving their products.
3. We currently have a doctoral student starting her studies who participated in the data collection and analysis for this current study, who showed interest in continuing the research work as her doctoral dissertation, where one of the objectives was to develop a conformity assessment protocol for earmuffs when they interact with eye protection.
4. We will also, together with the above mentioned doctoral student write a proposal looking for NIOSH funding to expand the study through a Mentored Research Scientist Development Award, K01 type grant. Furthermore, once we have published

this study and the results of her doctoral work, our plans are to submit a R01 grant to then evaluate most of the available combinations of eye protection x earmuffs available in the American market.

5. The data base created with studies such as this can be used for many other purposes. We also want to expand a pilot study conducted by this study PI on the Noise Insertion Loss of commercially available earmuffs and include most of the earmuffs that have been included in the NIOSH compendium of Hearing Protection. The methodology proposed in this study can also be used to develop a conformity assessment for earmuffs when used alone.

List of presentations/publications.

As of now, we have not published or presented the work conducted in this pilot study. Our first presentation will be on the Research Forum on Health Education, organized by the University of Puerto Rico and to be held early next year, for which an abstract has already been submitted. Our intentions are to write and submit at least one peer reviewed publication, as well as present this work in the AIHCe 2015 and the 2015 Brazilian Conference of Occupational Hygiene.

Dissemination plan

In our attempt to disseminate these study findings, we will contact the manufacturers and provide them with a copy of this study report if we obtain their commitment that accurate study findings will be published on their websites. In addition, if CPWR agrees, we hope to generate an online flyer to be posted on CPWR's website provided as well as on our School website. Finally, the results from this study will be made part of our course on Control of Physiscal Hazards offered to our industrial hygiene masters students.

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Appendix 1

Quantitative measurement protocol

This small study proposed an applied, quantitative and more realistic approach to assess the impact of using protective eyewear on the performance of earmuffs. Earmuff performance was evaluated through quantitative Noise Insertion Loss, NIL, with and without protective eyewear. The proposed methodology represented an innovative approach towards collecting earmuff performance data while subjects were exposed to noise coming from real life power tools, with sound pressure levels way above subjects' correspondent frequency hearing thresholds.

This methodology was originally developed and validated to monitor noise exposure in motorcycle drivers and uses a digital recorder (Figure 2) connected to binaural microphones located in the entrance of each ear's auditory canal, as depicted in Figure 1. The binaural microphones used are manufactured by Sound Professionals, master series, part number # MS-TFB-2. The published frequency response for the binaural microphones used in this study is shown in Figure 3. The digital recorder used in this study is a 24 bit wave/MP3recorder manufactured by Rolland, brand Edirol, model R-09.

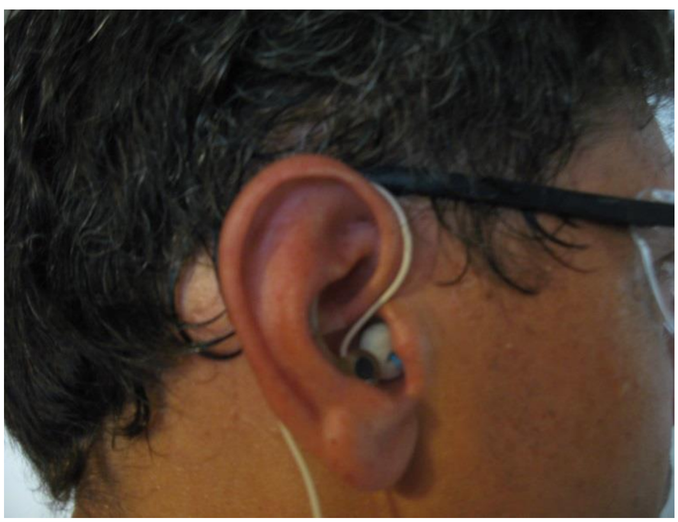

Figure 1: Binaural microphones as they were placed in the entrance of subjects' ear canal

As depicted in Figure 2, the digital recorder captures sound data for each ear that is post processed into noise data by a LabView program developed by NIOSH Hearing Conservation Laboratory for this particular application. Processed noise data can be viewed as total noise in linear and A scale, in octave bands or in third octave bands from 20 to 20,000 Hertz. The two great advantages of this technology over commercially available and affordable personal noise dosimeters is that: 1) the microphone can be placed in the entrance of subjects' ear canal allowing the investigator to evaluate earmuff noise insertion loss; and b) the investigator can characterize subject noise exposure down to third octave band frequencies.

Figure 2: Portable digital recorder used in this study

For each experimental condition, the effect of the protective eyewear on earmuff performance was estimated by subtracting NIL for the earmuff and protective eyewear from the NIL for the earmuff only. NIL for the earmuff only was calculated by subtracting noise exposure measured for the earmuff only from the noise exposure with no earmuff. Similarly, NIL for the earmuff x protective eyewear combination was calculated by subtracting noise exposure measured for the earmuff and protective eyewear from the noise exposure with no earmuff.

The noise measuring equipment used in this study was calibrated before and after each subject's participation with a Quest QC 10 calibrator where the calibrator's microphone insert tip was retrofitted to tightly fit both binaural microphones (one at a time) for calibration. The binaural microphones were inserted in the entrance of the ear canals of each subject as depicted in Figure 1, and were connected to the digital recorder through very thin wires that minimize potential compromises to the cushion-to-circumaural-flesh seal between the earmuff cushion and the subject's head (See Figures 1 and 2). In order to eliminate carrying seal leak effects from one experimental condition to the next, subjects were asked to don the earmuffs before each new measurement was taken.

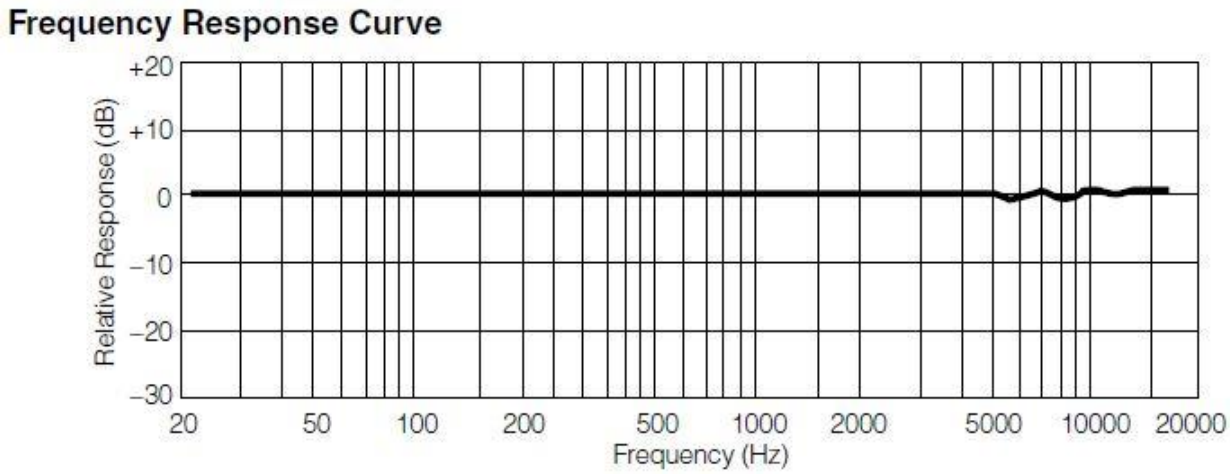

Figure 3: Frequency response curve for the Sound Professionals binaural microphones used in the study

Appendix 2

Detailed Statistical Analysis Conducted as Originally Proposed

1) Analysis of Variance

Analysis of Variance was conducted on the data for the average (both ears) A-weighted Noise Insertion Loss when earmuffs and protective eyewear were worn together. Subjects were blocked and main factors used in the analysis of variance were: a) earmuff; b) protective eyewear; and c) posture. Interaction effects were evaluated for all two-way interactions between the three main factors. The ANOVA table extracted from Minitab is shown in Table 1.

Table 1: Results of Analysis of Variance Conducted on Earmuff NIL data

General Factorial Regression: A-Weight-Av versus Subject (blocks), Earmuff, Eyewear, and Posture

Factor Information

Factor	Levels	Values
Earmuff	3	1, 2, 3
Eye Wear	6	1, 2, 3, 4, 5, 6
Posture	5	Extension, Flexion, Left Turn, Neutral, Right Turn

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	103	41218.3	400.18	47.83	0.000
Blocks	14	17849.5	1274.96	152.39	0.000
Linear	11	22277.8	2025.25	242.07	0.000
Earmuff	2	12547.2	6273.59	749.87	0.000
Eye Wear	5	9467.5	1893.50	226.32	0.000
Posture	4	263.1	65.78	7.86	0.000
2-Way Interactions	38	1067.0	28.08	3.36	0.000
Earmuff*Eye Wear	10	910.8	91.08	10.89	0.000
Earmuff*Posture	8	57.8	7.22	0.86	0.547
Eye Wear*Posture	20	98.5	4.93	0.59	0.923
3-Way Interactions	40	24.0	0.60	0.07	1.000
Earmuff*Eye Wear*Posture	40	24.0	0.60	0.07	1.000
Error	1246	10424.4	8.37		
Total	1349	51642.7			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
2.89245	79.81%	78.15%	76.30%

In order to use the ANOVA results, assumptions were checked to confirm that no major deviations from the general ANOVA assumptions occurred with the collected data. Figure 1 shows a 4 plot output from Minitab where we can observe that the residuals of the ANOVA model do not deviate from the expected normal behavior (Normal probability plot and histogram of residuals) and there are no evidence of specific concerning patterns when the ANOVA model residuals are plotted against their fitted values or their observation order.

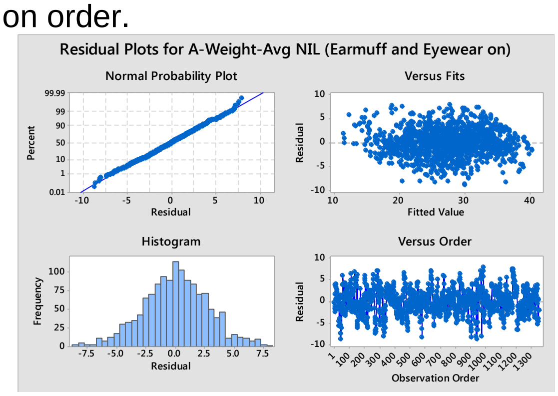

Figure 1: Residuals Plots for the ANOVA performed on average A-weighted Noise Insertion Loss Data when Earmuffs and Eyewear are worn together

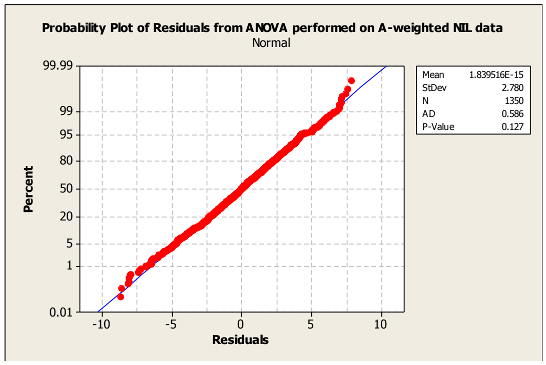

Figure 2: Normal Probability Plot performed on ANOVA Model Residuals for performed on average A-weighted Noise Insertion Loss Data when Earmuffs and Eyewear are worn together

Moreover, in Figure 2, we can observe an additional Normal Probability Plot performed on the ANOVA model residuals where there is no reason to believe that the data is not of Normal behavior.

Another important assumption that was checked was constant variance among the different evaluation groups in the model. This ANOVA model evaluated 90 different data groups or classes (3 earmuffs x 6 protective eyewear x 5 postures). Figure 3 shows a test for equal variances performed in Minitab for the data where there is no statistical evidence to believe that the evaluated groups had different variances.

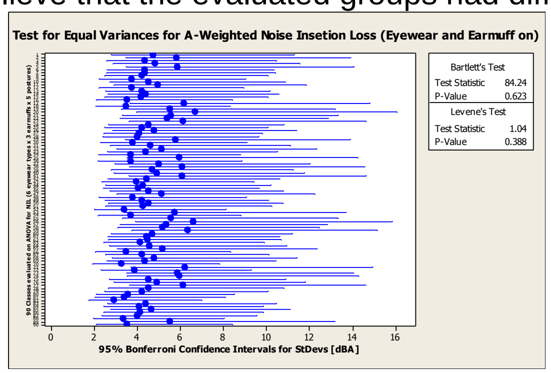

Figure 3: Test of Equal Variances between all study classes for data on average A-weighted Noise Insertion Loss Data when Earmuffs and Eyewear are worn together NIL Data

When we look at the ANOVA model residual data versus Earmuff and Protective Eyewear as depicted in Figures 4 and 5 respectively, we can observe that there was no visual difference in terms of variability of residuals with respect to the different types of earmuffs used or the different protective eyewear evaluated.

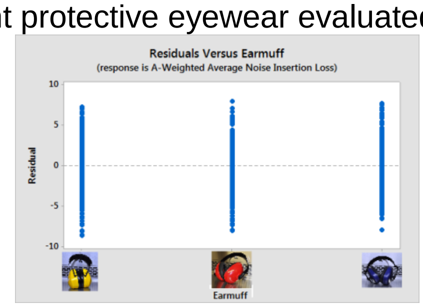

Figure 4: ANOVA model residual data plotted versus the Earmuffs evaluated in the study

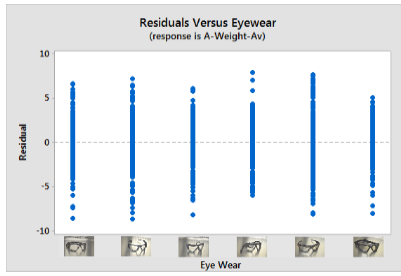

Figure 5: ANOVA model residual data plotted versus the different types of Protective Eyewear evaluated in the study

Having cleared the assumptions for the primary Analysis of Variance, we can say from Table 1 that all main factors in the model had a significant effect (5% level) in the data, as well as the interaction between earmuff and protective eyewear had a significant effect (5% level) in the data. As expected, subjects also had a significant effect in the data reason why blocking subjects was an appropriate strategy. Furthermore, Figure 6 shows the effects that each main factor had on the average A-weighted NIL data when earmuffs and protective eyewear were worn together.

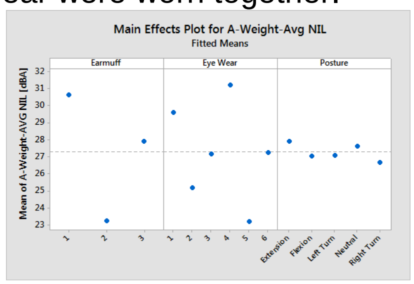

Figure 6: Main Effects Plot for average A-weighted NIL data when earmuffs and protective eyewear are worn together

As it can be seen in Figure 6, earmuff and eyewear had a much greater significant effect than posture in the NIL data. Earmuff # 2 was associated with the smallest average Noise Insertion Loss and Earmuff # 1 was associated with the largest average NIL as it can be further observed in Figure 7 with the 95% Confidence Intervals for the average A-weighted NIL.

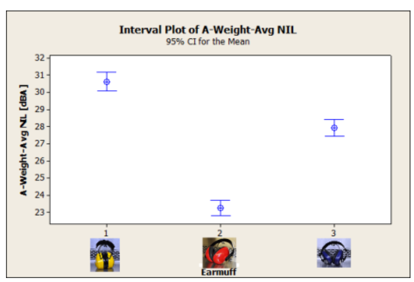

Figure 7: 95% Confidence Intervals for A-Weighted Average NIL versus Earmuffs

From Figure 6, we can also observe that protective eyewear 4 and 5 were associated with the highest and lowest earmuff noise insertion loss respectively as depicted in Figure 8 with the 95% confidence intervals for the NIL in dBA versus eyewear.

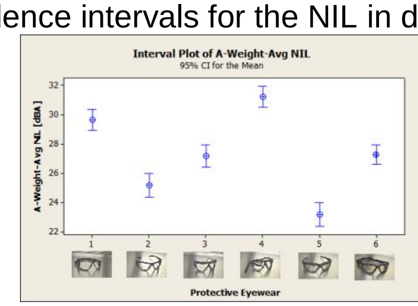

Figure 8: 95% Confidence Intervals for A-Weighted Average NIL versus Protective Eyewear

Even though posture was a significant factor, the actual effect it had on the A-weighted average NIL as depicted in Figure 6 is visually less than any other factor evaluated in this study. As depicted in Figure 9, the only earmuff that had its performance a little affected by posture was earmuff # 2. In other words, earmuffs # 1 and # 3 were more robust in their performance with respect to posture than earmuff # 2.

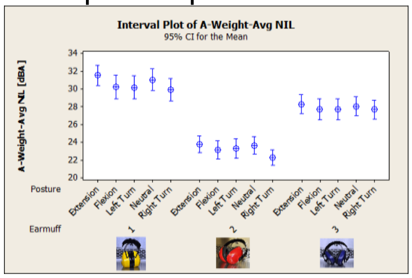

Figure 9: 95% Confidence Interval for A-weighted Avg NIL versus Posture by Earmuff

2) 95% Confidence Interval for the Average Discomfort rating of each earmuff x protective eyewear combination.

Standardized discomfort ratings were calculated based on the qualitative response provided by each subject with the reordering of the combinations from most uncomfortable least protective combination to the most comfortable most protective combination. From the order provided by each participant, each numbered box location was divided by the highest location selected by that subject in order to standardize the relative location in a scale from 0 to 1. This scale was then transformed in a discomfort rating where 0 was no at all uncomfortable and 10 most uncomfortable. This qualitative data was processed into 95% Confidence Intervals for the Average Discomfort Rating by each earmuff x protective eyewear combination, which are shown in Figure 10.

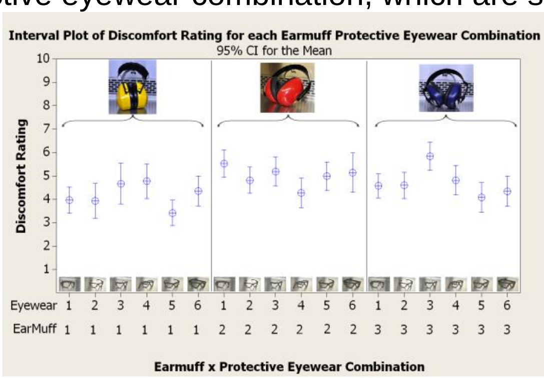

Figure 10: 95% confidence interval for the average discomfort rating of each earmuff x protective eyewear combination.

As it can be observed from Figure 10, Earmuff 1 and Protective Eyewear 5 seemed to be the least uncomfortable (most comfortable) combination for the subjects participating in this study, while Earmuff 3 and Protective Eyewear 3 seemed to be the most uncomfortable combination. Moreover, Figure 11 corroborates this finding showing the results of the Analysis of Means performed on the Discomfort Rating data from the study.

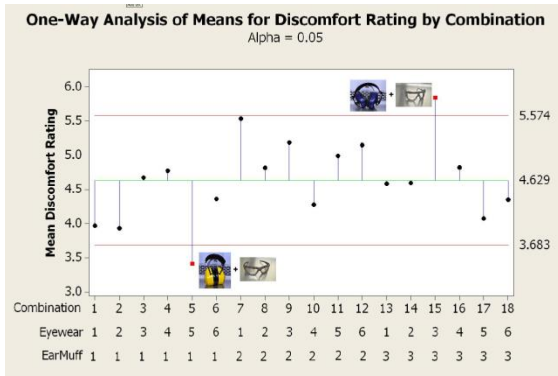

Figure 11: One-Way Analysis of Means for Discomfort Rating by Combination

There are two combinations that clearly have statistically different discomfort ratings from the rest, combination 5 (earmuff 1 x eyewear 5) with the smaller average discomfort rating; and combination 15 (earmuff 3 x eyewear 3) with the greater average discomfort rating.

3) 95% confidence intervals for the average effect of each correctly sized and fitted protective eyewear on the NIL of earmuffs 1, 2 and 3, in each of the 5 neck postures evaluated

The 95% confidence intervals for the average effect of each correctly sized and fitted protective eyewear on the NIL of earmuffs 1, 2 and 3, in each of the 5 neck postures evaluated, are shown in Figures 12, 13 and 14 respectively. Confidence intervals not containing "zero" represent evidence of a significant effect, positive or negative, on earmuff performance imposed by protective eyewear or neck posture.

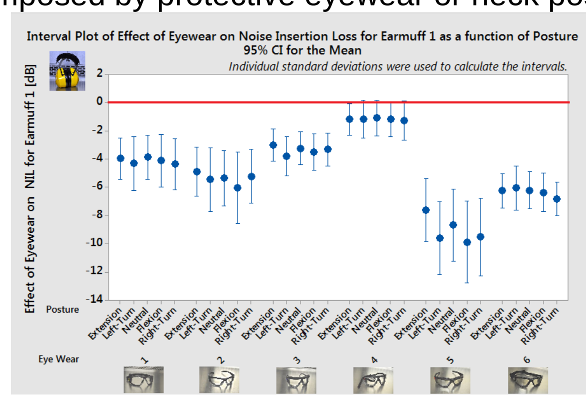

Figure 12: The 95% confidence intervals for the average effect of each correctly sized and fitted protective eyewear on the Noise Insertion Loss of Earmuff 1, in each of the 5 neck postures evaluated

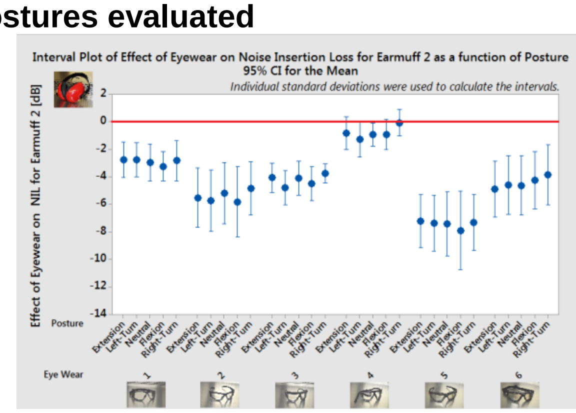

Figure 13: The 95% confidence intervals for the average effect of each correctly sized and fitted protective eyewear on the Noise Insertion Loss of Earmuff 2, in each of the 5 neck postures evaluated.

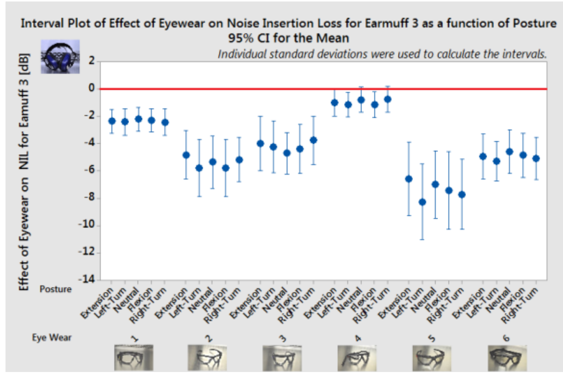

Figure 14: The 95% confidence intervals for the average effect of each correctly sized and fitted protective eyewear on the Noise Insertion Loss of Earmuff 3, in each of the 5 neck postures evaluated

4) Neck Posture Independent Center Octave Frequency (125 Hz through 8000 Hz) Average Effect of each evaluated protective eyewear on the Noise Insertion Loss of each evaluated earmuff.

The average effect of each protective eyewear on the NIL of each earmuff, independent of neck posture, was plotted as a function of center octave frequencies from 125 Hz through 8000 Hz, and it can be observed in Figure 15, where each row represents one type of protective eyewear and each column represents one type of earmuff evaluated in this study.

What can be observed from Figure 15 is that Protective Eyewear # 4 had a much smaller negative effect on the NIL of any of the three earmuffs evaluated across the entire frequency spectrum. In addition, the effect from Protective Eyewear # 4 to all three earmuffs had a much smaller variability across the entire frequency spectrum evaluated, and therefore we consider Protective Eyewear # 4 to be a more robust and earmuff–friendly eyewear than the other 5 models evaluated in this study. Conversely from Figure 15, Protective Eyewear # 5 had in general the larger measured negative effect on any of the earmuffs evaluated, with the larger variability irrespective to the noise frequency evaluated.

In order to compare the data from all protective eyewear evaluated in this study with all three earmuffs with the results reported in the literature for the effect of safety glasses on the attenuation at threshold of three other earmuffs (Berger, 2000), the frequency dependent effects on earmuff noise insertion loss from the current study had their signal inverted and were plotted in the same scale as the data described in Berger, 2000. Figure 16 shows the comparison between the results from the current study and the results reported in the literature as indicated above.

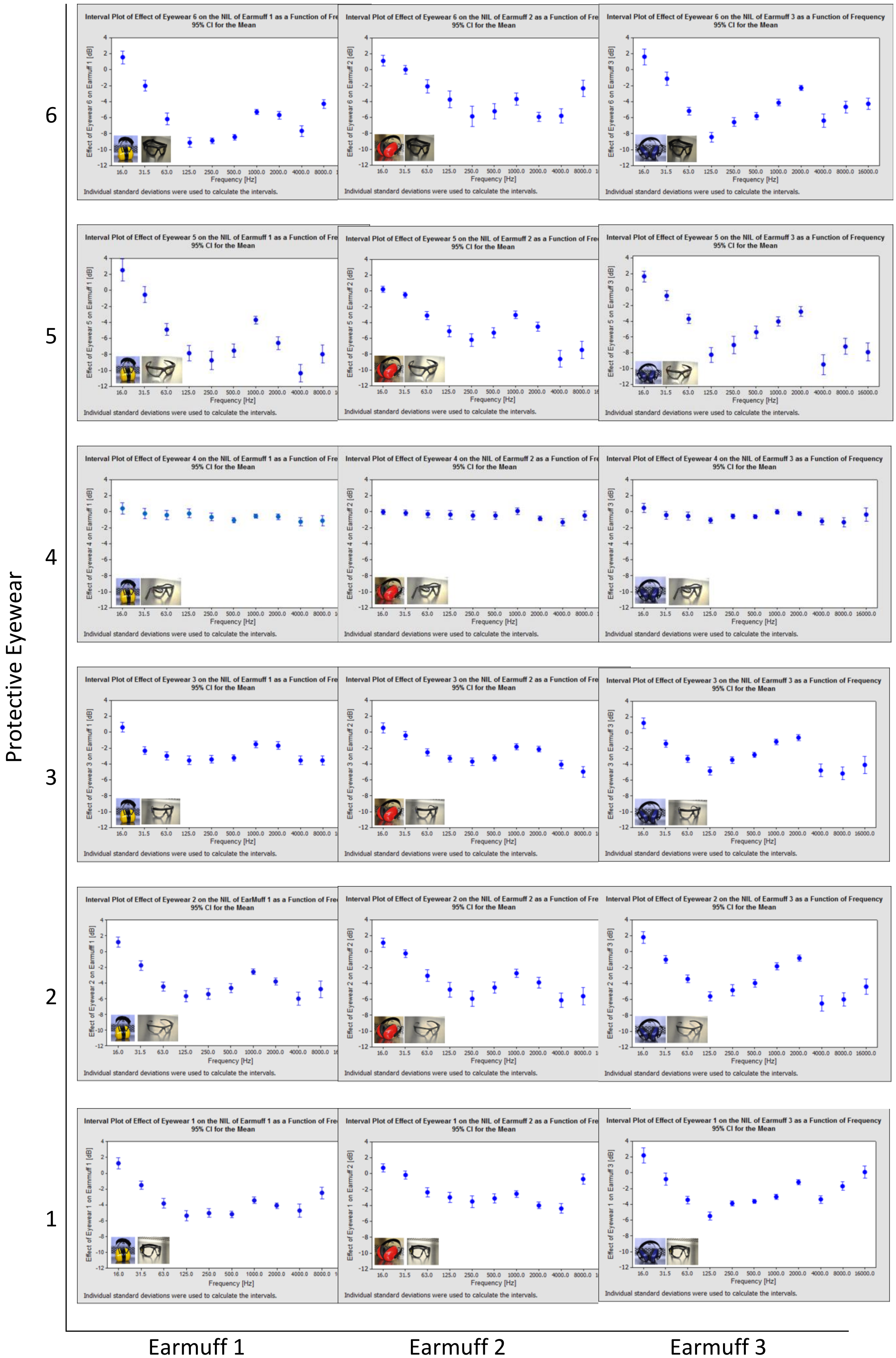

Figure 15: Neck Posture Independent Center Octave Frequency Average Effect of each evaluated protective eyewear on the Noise Insertion Loss of each evaluated earmuff

As it can be observed in Figure 16, there are some similarities between the results obtained from the current study with the results reported in Berger 2000. The differences between overall reported results may be due to the fact that noise exposure in the current study was not at threshold of hearing, nor it was monotonic. It is very important to note that depending on the protective eyewear used, the loss in earmuff performance can both be significantly greater than the average and way more variable depending on individual head anthropometry.

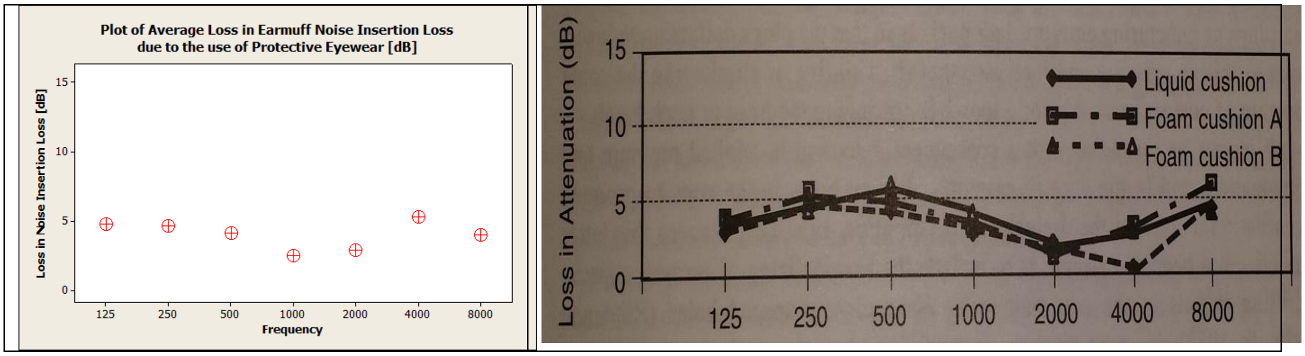

Figure 16: Comparison of current study data with results reported in Berger 2000 for frequency dependent loss in earmuff performance in dB

5) T-tests on the differences for each earmuff NIL with and without all protective eyewear evaluated in octave center frequencies from 125 Hz through 8000 Hz

Table 2: T-tests results on the effect of each protective eyewear evaluated on each earmuff evaluated

Earmuff	Eyewear	2-Tail T test on the Effect of Protective Eyewear on Earmuff's NIL in dB						
		125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz
1	1	**	**	**	*	**	**	*
1	2	**	**	**	*	**	**	**
1	3	**	*	*	*	*	**	*
1	4		*	*	*	*	*	*
1	5	**	**	**	**	**	**	**
1	6	**	**	**	**	**	**	**
2	1	*	*	*	*	**	**	*
2	2	**	**	**	*	**	**	**
2	3	*	**	*	*	*	**	**
2	4			*		*	*	
2	5	**	**	**	*	**	**	**
2	6	*	**	**	*	**	**	*
3	1	**	**	**	*	*	*	*
3	2	**	**	**	*	*	**	**
3	3	**	**	*	*	*	**	**
3	4	*	*	*			*	*
3	5	**	**	**	**	*	**	**
3	6	**	**	**	**	*	**	**

* Means that average effect of specific eyewear on specific earmuff was significantly greater (5% level) than 0 dB

** Means that average effect of specific eyewear on specific earmuff was significantly greater (5% level) than 3 db

Note: Empty cells means no significant effect on that frequency, and ** implies that the mean effect is also greater than 0 dB

From Table 2, we can corroborate what was said from Figure 15 regarding the small effect that protective eyewear # 4 had on all earmuffs across the frequency spectrum evaluated with respect to the other eyewear studies. Moreover, we can also see that protective eyewear # 5 had the greater effect across the frequency spectrum on all earmuffs evaluated.

Furthermore, results from this study were compared to results reported in the literature for difference in noise attenuation at threshold due to eye glasses (Nixon and Knoblack, 1974; Fletcher and Loeb, 1964; and Webster and Rubin, 1962). Table 3 shows a summary of the frequency dependent percentage of combinations where the protective eyewear had a significant effect on the earmuff (5% level) in the current study entitled CPWR study and in the results reported by Nixon and Knoblack in 1974, by Fletcher and Loeb in 1964, and by Webster and Rubin in 1962.

Table 3: Comparison between results from CPWR study and results reported in the literature.

	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz
CPWR Study	89%	94%	100%	89%	94%	100%	94%
Literature Results	100%	100%	100%	60%	0%	60%	80%

As it can be observed in Table 3, there are some great differences between past results and the results reported from this study, specifically in the frequencies of 1000 Hz, 2000 Hz, and 4000 Hz. These differences can be associated with several hypothesized reasons:

a) reported studies did not report on different eye glasses, which may mean that all models were considered with the same potential effect or that just one model was used in these studies;

b) considering earmuff noise insertion loss a surrogate estimate of actual quantitatively measured earmuff attenuation, the method of measuring attenuation in the reported studies closely followed the American National Standards Institute (ANSI) Method for the measurements of Real Ear Attenuation of Ear Protectors at Threshold in which subjects determine the amount of protection provided by the earmuff in a specified sound field which is by the nature of the method monotonic. The current study had subjects exposed to real life noise coming from power tools commonly used in construction with a combined frequency spectrum with correspondent sound pressure levels diametrically different from that used in past studies.

c) Eye glasses and earmuffs evaluated in past studies were not the same brands and models of protective eyewear and earmuffs evaluated in this current study, and from what has been observed from the data collected in the current study, both factors are significant in determining the effect of protective eyewear on the earmuff.

Moreover, if the results on the effect of eyewear on earmuff attenuation reported on past studies, Figure 17, are averaged per noise frequency and plotted against 95% Confidence Intervals for the effects of protective eyewear on earmuffs' noise insertion loss shown in Figure 18, we also see discrepancies that are most likely due to the same reasons stated just above.

DIFFERENCES IN ATTENUATION OF EARMUFFS WORN WITH AND WITHOUT EYEGLASSES (IN DECIBELS)

TEST			EARMUFF		
FREQUENCY	V*	W*	X**	Y**	Z**
125	6.1***	3.1	9	6	0
250	7.0	7.5	9	7	0
500	6.1	6.7	5	4	-1
1000	0.9	4.6	5	2	0
2000	8.7	5.1	0	0	-1
3000	7.2	-1.0	-	-	-
4000	11.8	7.0	5	5	0
6000	8.2	11.4	12	5	0
8000	4.7	9.3	-	-	-

*FLETCHER AND LOEB
**WEBSTER AND RUBIN
***POSITIVE ENTRIES INDICATE AMOUNT OF ATTENUATION LOSS DUE TO THE EYEGLASSES

Figure 17: Differences in attenuation of earmuffs worn with and without eyeglasses, in dB from Nixon, C. W., and Knoblach, W. C. (1974)

It is important to note that while the reported data in past studies is done in a way that the effect of eye glasses on earmuffs' attenuation is displayed with positive sign but it is understood it represents a negative effect, the effect data in the current study is reported with its correspondent sign. Therefore, in Figure 18, the average values calculated from Figure 17 were plotted with a negative sign so as to compare with the results from the current study.

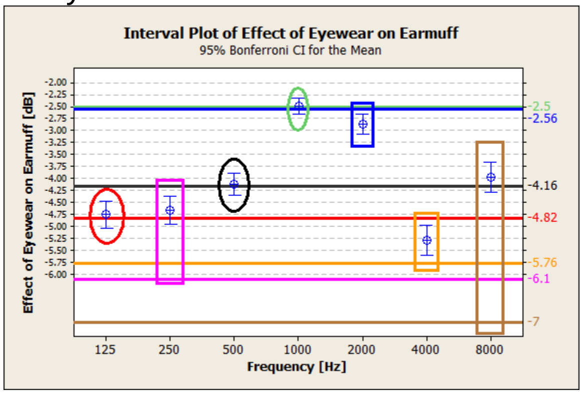

Figure 18: 95% Confidence Intervals for the frequency dependent effect of protective eyewear on earmuff from current study compared with average effects of eye glasses on earmuffs' attenuation reported in past studies

6) Correlation analysis between earmuff x protective eyewear quantitative NIL with qualitative rating

Figure 19 shows a comparison between the two response variables (quantitative NIL and discomfort rating) by earmuff and by protective eyewear.

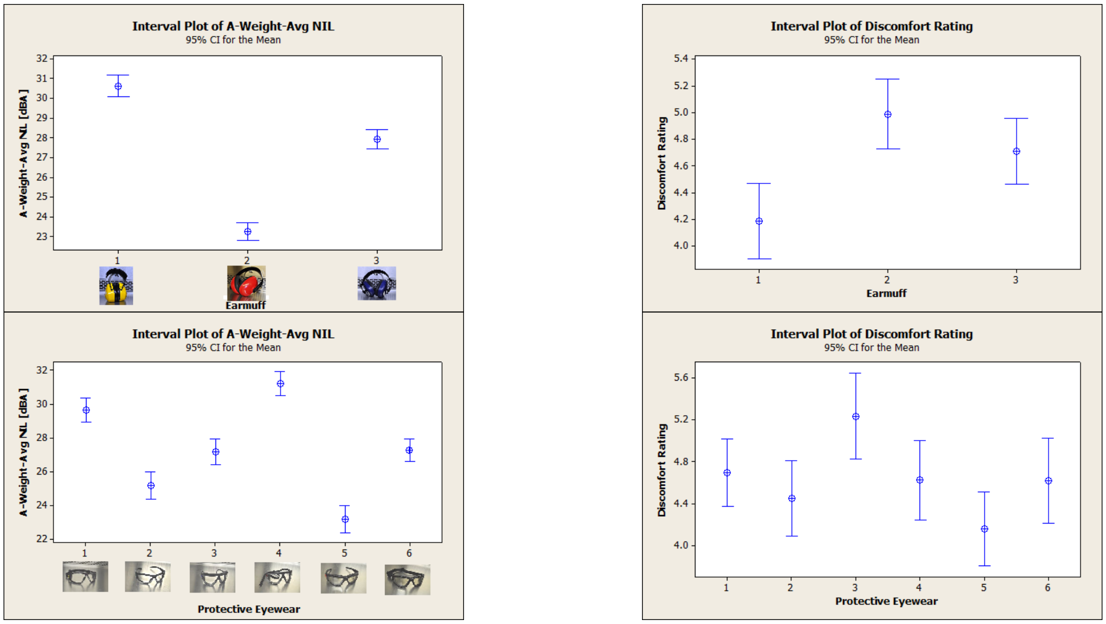

Figure 19: Comparison between the two response variables (quantitative NIL and discomfort rating) by earmuff and by protective eyewear

As it can be observed in the top two plots in Figure 19, participants were able to identify clearly the best earmuff using the instructed discomfort rating, whereas for protective eyewear, the worst eyewear in terms of negative effects on earmuff performance was associated with the smallest discomfort rating. It is our strong believe that even though subjects were instructed to rate each combination based on discomfort and degree of noise protection, discomfort played a higher role and importance in their subjective response. Since protective eyewear # 5 has wide and straight hard temples, it was deemed by subjects as very comfortable since it held part of the pressure exerted from the earmuffs on subjects' head and did not compressed their temples as much as the other safety glasses. Protective eyewear # 4, on the other hand, even though had the least effect on earmuff NIL, it is a goggle and it fogged for some of the subjects, being associated with a higher discomfort rating than some of the other protective eyewear.

One of the main reasons for collecting a discomfort response and comparing to the quantitative NIL response is to identify a specific combination between eyewear and earmuff that has both good noise protection and small discomfort. Figure 20 compares the analysis of means for discomfort rating presented above in Figure 11 with the analysis of means for the protective eyewear x earmuff combination noise insertion loss.

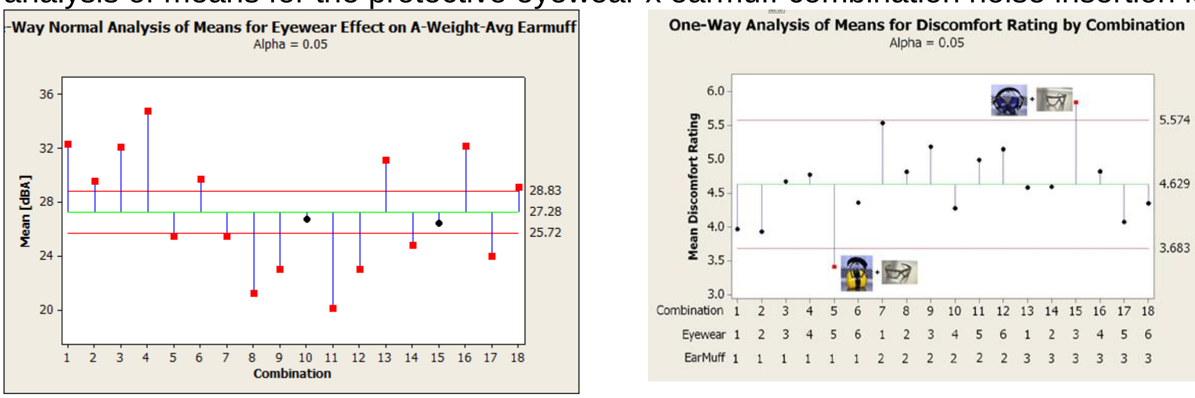

Figure 20: Comparison between the ANOM for both response variables evaluated in the study.

When both plots in Figure 20 are closely examined, we can see that the least discomfort combination (# 5) does not provide as a good noise protection as some other combinations. On the other hand, we can observe that many of the combinations with a significantly higher mean NIL fall within the non-significantly different discomfort ratings whose means fall between ratings of 3.683 and 5.574. In practice the way to choose the appropriate combination would be to select a combination with a significantly higher NIL and at the same time a non-significant but lower discomfort rating. Another important aspect of this process would be to select a combination that has a noise insertion loss that would be at least equivalent to the attenuation of its correspondent earmuff in the A weighting scale (NRR – 7 dB, by CFR 1910.95 Appendix B).

With the stated above in mind, and considering the specific brands and models of protective eyewear and earmuffs evaluated in this study, combinations 1, 2, 3, 4, 5, 6, 8, 10, 13, 14, 16, 17 and 18 provide an average noise protection greater than 18 dBA (NRR of 25 dB – 7 dB) and were deemed fairly comfortable by the subjects that participated in this study. Further refining from these combinations should be done taking into account the other analysis reported earlier: a) robustness with respect to posture, b) main effects of earmuff and protective eyewear, and certainly c) frequency dependent NIL of these combinations and the specific workplace noise signature.