ASSESSMENT OF THE EFFECTS OF VARIOUS PERSONAL PROTECTIVE EQUIPMENT (PPE) AND APPAREL IN THE PERFORMANCE OF EARMUFFS

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ABSTRACT

Hearing protectors have been used extensively to mitigate the risk of occupational noise-induced hearing loss (ONIHL) but the rate of workers compensation claims for noise-induced hearing loss in Australia has remained relatively stable in the period of 2006 to 2010. One factor which may be related to this unchanged rate of ONIHL is that workers may not be receiving the expected level of protection from their hearing protectors.

Earmuffs are frequently selected as the preferred hearing protector due to their robustness and ease of use. However, earmuffs are often worn with other PPE, where compatibility issues between PPE are commonly reported.

The study investigated the effects of a range of PPE and apparel on the level of protection achieved by headband earmuffs (3M™ Peltor™ X4A and X5A). It also evaluated the influence of different models of industrial safety helmets in the performance of helmet mounted earmuffs (3M X4P3 and X5P3). Measurements of Personal Attenuation Rating (PAR) were taken for 28 test subjects with the use of field microphone-in-real-ear (F-MIRE) system. Each person was tested with combinations of headband earmuffs and various PPE including safety glasses, goggles, reusable respirator, nonwoven hood, hairnet, fleece beanie, golf style cap and three models of industrial helmets.

The paired t-test revealed a reduction in PAR of up to 7 dB when safety glasses were worn with headband earmuffs. The straps and buckles of the reusable respirator also affected the PAR by up to 8 dB. The use of a fleece beanie under the headband earmuff resulted in a reduction of 12 dB of attenuation. The PARs achieved for the helmet mounted earmuffs were not affected by the differences between the models of industrial safety helmets. Understanding the significance of the effects of other PPE in the level of protection provided by earmuffs can assist end users and occupational health and safety professionals in the selection of the most appropriate hearing protector.

INTRODUCTION

Assessing the level of protection provided by hearing protection devices (HPDs) has historically been done by measurement of the attenuation provided by a specific HPD using the real ear attenuation at threshold (REAT) methodology as the "gold standard." This process uses a panel of test subjects and measures the occluded and unoccluded noise levels detected by each member of the panel across a range of frequencies. The pooled data are then used to calculate a representative value for the overall attenuation provided by the device. In the case of AS/NZS 1270, the value is called the Sound Level Conversion 80 or SLC_{80} – a calculated value indicating the attenuation expected to be achieved by at least ~80% of the test population wearing the tested HPD in the same manner as did the test subjects. All of this testing has taken place in specialised acoustic rooms with appropriate noise emission and measurement equipment.

There are many studies that show that this lab-acquired REAT data often gives an inadequate prediction of real-world attenuation for groups of users. Even though AS/NZS 1270 test method provides a somewhat better group indication, it still doesn't give a good indication for the individual attenuation with potential variations of 20dB or more (Gauger & Berger 2004).

Recent advances in miniature microphones and computer software are now allowing various methods to be used in the field, without the expense, size and bulk of the physical room and equipment needed for traditional REAT testing. Variants of this method such as use of circumaural earphones and loudness balancing are now possible in the field. Another approach is called field microphone-in-real-ear (F-MIRE), and this methodology is used by the 3M™ E-A-Rfit™ system. This objective method uses small dual-element microphones with associated proprietary technology and probed earplugs or ear muffs to measure the

Personal Attenuation Rating (PAR) of the individual test subject using the HPD, all in a very short timeframe (<10 sec per measurement).

The PAR for specific ear muffs can thus be quickly determined on an individual in this way. In the real world, however, use of ear muffs is often associated with simultaneous use of other personal protective equipment or apparel that can have a degrading effect on the PAR achieved. Equipment like safety glasses, goggles, hair nets, caps and beanies can all interfere to some degree with the seal of the ear muffs on the head of the wearer. Helmet-mounted ear muffs are another case, with the size of the helmet and the quality of the seal of the ear muff cushions on an individual's head both potentially having an effect on the PAR achieved.

This study looks at the effect of several different types of PPE and apparel on the PAR achieved by a panel of test subjects when wearing either the 3M™ Peltor™ X4A or the X5A ear muffs with a headband configuration. The PAR was also measured when using the 3M™ Peltor™ X4P3E and X5P3E helmet mounted ear muffs fitted to three different industrial safety helmets to investigate the effect on the PAR between individuals and with different helmets.

METHOD

A total of 28 adults, including 12 female and 16 males, were tested with a set of PPE and apparel as shown in Table 1. The test subjects were given brief verbal and visual instructions on how to properly fit and adjust the earmuffs prior to the beginning of the tests but they were not assisted by the testers during the actual tests. All subjects were office-based employees and most of them had little or no previous experience with the use of earmuffs. Each subject was tested with four models of earmuffs starting with the headband models X4A and X5A, followed by the helmet-mounted models X4P3 and X5P3. The headband earmuffs X4A and X5A were tested with the same set of PPE or apparel and the helmet-mounted earmuffs X4P3 and X5P3 were tested with three different brands of industrial safety helmets.

Table 1: Combinations of 3M Earmuffs and PPE/Apparel

Category	Devices description	Earmuffs	
Respirator	3M™ 7500 half face piece	X4A	X5A
Eyewear	3M™ SecureFit™ (thin frame)	X4A	X5A
	3M™ SX 2000™ (medium frame)	X4A	X5A
	3M™ Virtua™ (thick frame)	X4A	X5A
	3M™ Lexa™ (thick adjustable frame)	X4A	X5A
	3M™ Fahrenheit™ goggles (thick straps)	X4A	X5A
Apparel	Nonwoven hood (white)	X4A	X5A
	Hairnet (blue)	X4A	X5A
	Golf style cap	X4A	X5A
	Fleece Beanie	X4A	X5A
Combinations	7500 + SecureFit™ + hairnet	X4A	X5A
	7500 + SecureFit™	X4A	X5A
	7500 + Fahrenheit™	X4A	X5A
Industrial Safety Helmets	3M™ G2000 (P3K attachment)	X4P3	X5P3
	MSA V-Guard (P3E attachment)	X4P3	X5P3
	Protector HC600 (P3G attachment)	X4P3	X5P3

The test method utilised for the assessment of the earmuffs is F-MIRE, as mentioned above. F-MIRE is also is also referred as objective fit test method as it doesn't rely on measuring the person's hearing thresholds. The 3M™ EARfit™ Dual Ear Validation system used in this study is one example of a commercially available F-MIRE system. It comprises a pair of dual-element microphones illustrated in Figure 1. The external microphones measure the test noise emitted by a standard speaker while the internal microphone measures the noise underneath the earmuffs. The dual-element microphones were connected to ear cushion probes that were specifically designed to fit the 3M X-Series earmuffs as illustrated in Figure 2 and Figure 3.

Measurements of the PARs were taken using EARfit™software v5.1.14.0 in a laboratory environment with no particular attention to the background noise.

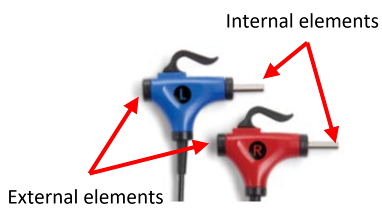

Figure 1: 3M™ EARfit™ Dual-Element microphones

Figure 2: 3M™ Peltor™ X-Series earmuffs test probes

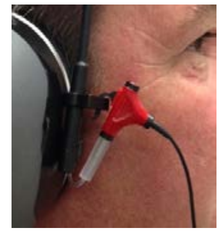

Figure 3: Dual-element microphone attached to the earmuff test probe

The F-MIRE results for all earmuffs were compared with their respective AS/NZS 1270 REAT results. Paired t-tests were used to analyse the changes in PARs when the earmuffs were worn with other PPE and apparel. Finally, analysis of variance (ANOVA) was utilised to determine whether the differences in the design of the industrial safety helmets assessed in this study have any significant influence in the performance of the X4P3 and X5P3 earmuffs.

RESULTS AND DISCUSSIONS

Comparison between AS/NZS 1270 REAT and F-MIRE

The F-MIRE results were compared with existing AS/NZS 1270 test reports provided by Michael & Associates Inc., an independent laboratory accredited by the American Association for Laboratory Accreditation (A2LA) to conduct attenuation tests according to AS/NZS 1270. This test method requires the selection of test subjects inexperienced in the use of hearing protectors and does not allow them to receive any assistance for the correct fitting of hearing protectors apart from what is provided on the packaging instructions.

Considerations should be made when comparing REAT SLC_{80} and F-MIRE PAR as they have their own variabilities and computational differences. The uncertainty of the PAR value is a result of three factors: variation within subject fitting, differences between REAT and F-MIRE test methods and noise spectrum uncertainty. However, PAR has been developed to estimate individual attenuation ratings and thus it doesn't take into account variations between subjects as SLC_{80} does. Having said that, one standard deviation was subtracted from the PAR_{50} to encompass the variability between subjects and compare PAR_{84} with SLC_{80}. The PAR_{84} values for the assessed earmuffs is listed in the middle column of Table 2.

SLC_{80} and PAR values are also derived from different noise spectra and weightings. Whilst PAR values are derived from the NIOSH 100 noise spectra and can be directly subtracted from A-weighted sound levels, SLC_{80} is derived from the South Australia 615 noise spectra and is intended for subtraction from C-weighted sound levels. The median C-A value for industrial noises is about 2.5 dB, so that much should be subtracted from the SLC_{80} when it is used with dBA (Waugh R, 1976 and 1984). The SLC_{80} (dBA) values are listed in the right column of Table 2.

The differences observed between PAR_{84} and SLC_{80} values varied between 1-5 dB. This is a reasonable range of variation considering the differences in the REAT and F-MIRE subject test panels. The PAR values could also have been affected by the learning factor. Some test subjects might have improved their fitting techniques over the tests sequence, achieving higher PAR results. The learning factor could have affected X5A and X5P3 more noticeably as these earmuffs were tested after X4 and X4P3, respectively.

Table 2: Comparison between REAT SLC_{80} and F-MIRE PAR_{84} ratings

Earmuff model	F-MIRE PAR_{84} (dB)	REAT SLC_{80} (dBA)
X4A headband	30	29
X5A headband	36	33
X4P3 helmet mounted	24	25
X5P3 helmet mounted	34	29

Figure 4 to Figure 7 show the overall one-third octave-band (OB) data presented at OB centre frequencies for REAT and F-MIRE for the earmuffs without any interfering PPE. In these charts, mean values were used for each frequency in order to establish a direct comparison between the average OB data from both test methods. The charts in Figure 4 to Figure 7, showed similar trends for REAT and F-MIRE for all earmuffs with the largest discrepancies being 10 dB at 4000 Hz for X5P3, 8 dB at 500 Hz for X5A, 6 dB at 4000Hz for X4P3 and 5 dB at 1000 Hz for X4A. Having said that, the individual frequency variations observed in the OB analysis did not affect the calculation of the overall PAR and the ability of F-MIRE to predict REAT values.

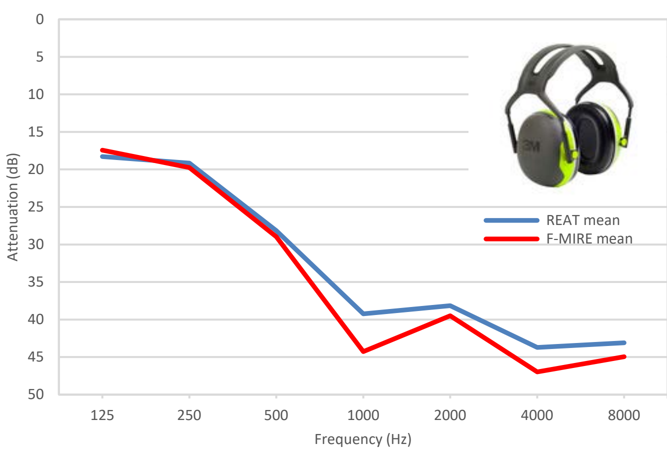

Figure 4: Comparison between REAT and F-MIRE for X4A earmuff

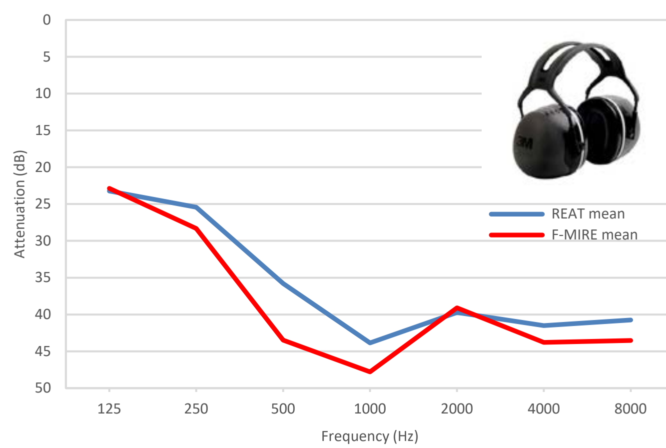

Figure 5: Comparison between REAT and F-MIRE for X5A earmuff

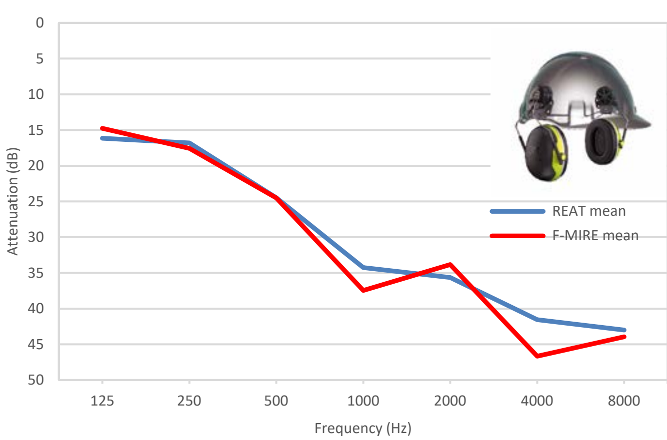

Figure 6: Comparison between REAT and F-MIRE for X4P3 earmuff

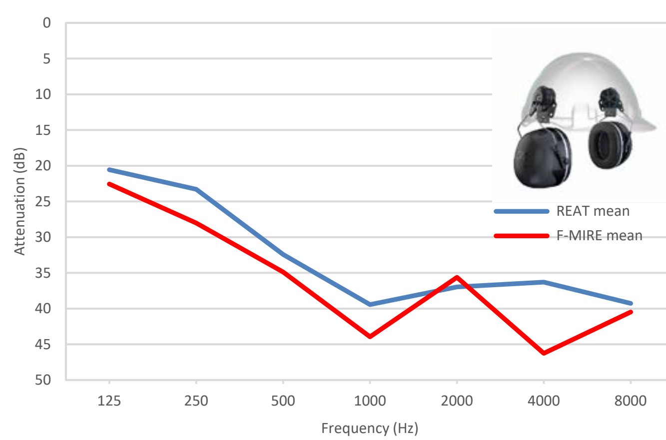

Figure 7: Comparison between REAT and F-MIRE for X5P3 earmuff

In addition to the OB analysis, REAT and F-MIRE individual attenuation data were plotted against each other as showed in Figure 8 in order to evaluate the equivalency of these two test methods. Each model of earmuff was tested by 16 subjects totalising 64 data points in the chart. The bold line crossing the centre of the chart represents a perfect relationship between REAT and F-MIRE where the difference between them is zero, whilst the dashed lines at ±10 dB indicate the limits where the F-MIRE would be divergent from REAT by more than 10 dB. When all data were analysed together, the cluster was slightly off set above the *x=y* line which could be associated on differences between the subject test panels utilised for REAT and F-MIRE. Further investigation would be necessary for a more definitive explanation for this slight under prediction trend. Having said that, 94% of the values fell within the specified range of ±10 dB, demonstrating consistency with Berger et al, (2011), where the authors obtained 97%-98% of a total of 80 data for earplugs within the same specified range.

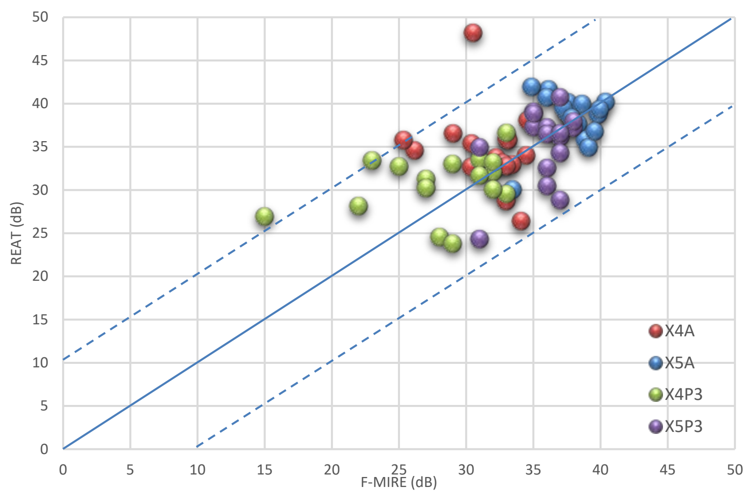

Figure 8: Scatter Plot chart for F-MIRE versus REAT for four models of earmuff

Effects of Eyewear

It is well known that the use of safety glasses and goggles are likely to affect the noise attenuation when worn with earmuff. Previous investigation have been conducted by Lemstad and Kluge (2004) utilised F-MIRE and reported significant increase (5-8 dB) in the attenuation provided by the earmuffs when the workers were asked to remove their safety glasses. Brueck L (2009) utilised microphone in real ear (MIRE) to measure SNR on four subjects wearing safety glasses with earmuffs. Brueck found differences between 3.5-8.5 dB for safety glasses and as much as 10 dB of reduction for large goggles. More recently, Wells et al. (2013) used REAT on ten subjects and reported loss in the NRR between 2-11 dB depending on the thickness of the temple frames and the model of the earmuff.

The charts on Figure 9 and Figure 10 shows the degraded PAR values for four models of safety glasses and one goggles. The thickness of the safety glasses frame have a clear influence in the reduction of the PAR. 3M SecureFit has the slimmest design of all and showed the least impact in the PAR (3 dB) for both X4A and X5A earmuffs. On the other hand, 3M Lexa, with a thick adjustable frame, presented reductions of 7 dB and 6dB for X4A and X5A respectively. The effects observed for 3M Fahrenheit goggles were 6 dB and 5 dB for X4A and X5A which was no different from other safety glasses with thick frames.

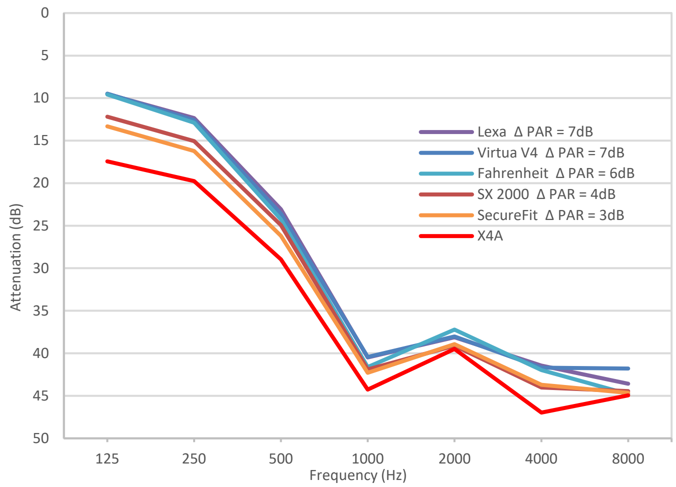

Figure 9: Effects of safety glasses and goggles when worn with X4A earmuff

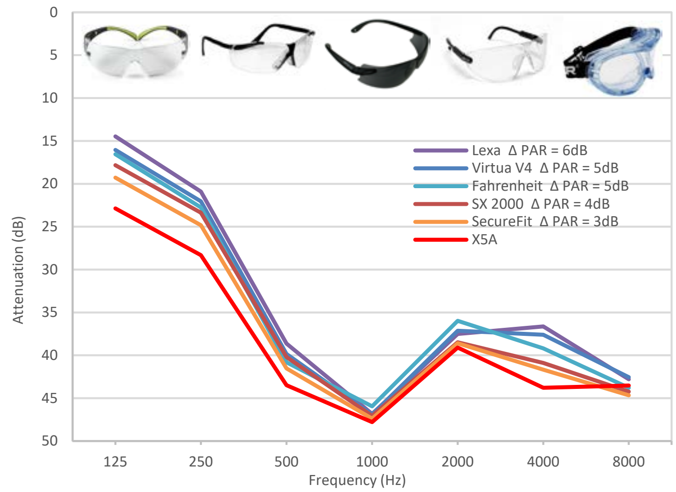

Figure 10: Effects of safety glasses and goggles when worn with X5A earmuff

Effects of apparel

Figure 11 and Figure 12 show the reduction of the PAR provided by different types of apparel. The white nonwoven hood had minimal influence in the PAR (1 dB). However, all the other apparels had significant effects on the PAR when worn underneath the earmuffs. Even the thin translucent hairnet provided a reduction of 4 dB for both X4A and X5A. Some subjects used the hairnet above the ears and others preferred to have them covering the ears. Since these two set ups are commonly found in the food and health care industries, the testers did not influence the subjects' preferences in order to have a more realistic approach. Wells et al. (2013) reported a loss of 7 dB as a result of the use of a similar hairnet under the Model 1000 earmuff. Golf style caps and fleece beanies are commonly used in several workplaces especially in outdoor environments where workers are subject to hot or cold climates but in some cases it may be part of the worker's uniform (e.g. military and law enforcement). Examples of industries where caps and beanies can be easily found are manufacturing, warehouses, food industries (chill rooms), transportation, airports, construction sites, etc. Cap reduced the PAR by 9 dB when worn underneath X4A and 6dB when worn with X5A. The fleece beanie was used folded over the ears and provided the most drastic reduction in the PARs, 13 dB for X4A and 12dB for X5A.

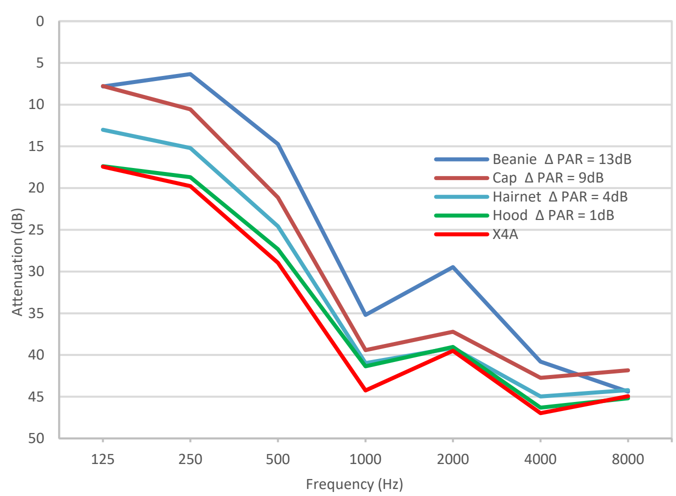

Figure 11: Effects of different types of apparel when worn under the X4A earmuff

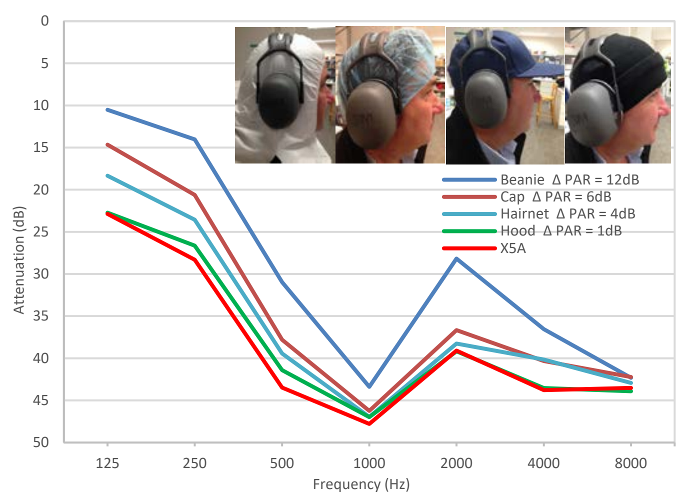

Figure 12: Effects of different types of apparel when worn under the X5A earmuff

Effects of the 3M 7500 half face piece respirator

Respiratory protection in commonly used in combination with earmuffs and other hearing protectors in several industries including mining, smelter, oil and gas, construction, food industry and work tasks such as grinding, welding, blasting and spraying. There is a wide range of styles of respirators in the market but for the purpose of this study, 3M 7500 reusable half face respirator was selected due to its likelihood to interfere in the attenuation provided by earmuffs. The 7500 respirator has adjustable straps which allow the wearers to adjust the height of the face piece and achieve appropriate face fitting. However, when the respirator is in use, plastic buckles are positioned right above the wearer's ears. As a result of that, the buckles and folded straps interfered in the seal of the earmuff cushions reducing the attenuation of X4A and X5A earmuffs in 8 dB and 5 dB respectively. Figure 13 and Figure 14 shows the degraded attenuation of X4A and X5A caused by the 7500 respirators across the frequencies spectrum.

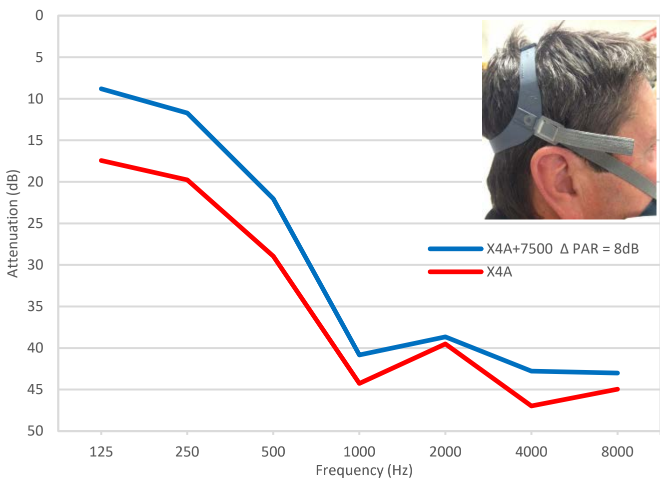

Figure 13: Effects of 7500 respirator when worn with X4A earmuff

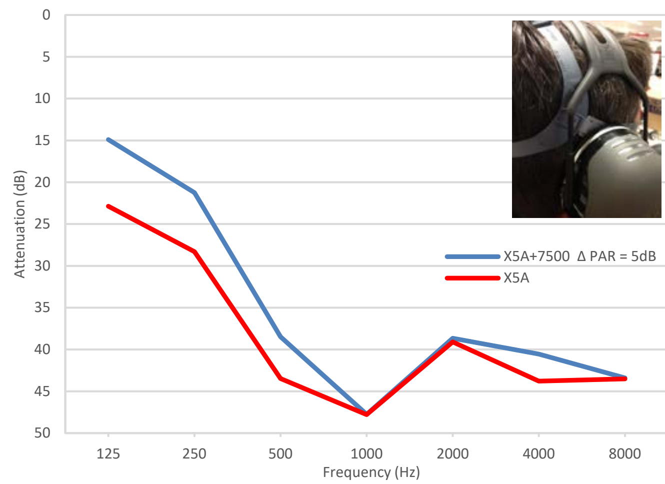

Figure 14: Effects of 7500 respirator when worn with X5A earmuff

Effects of the different combinations of respirator, goggles, safety glasses and hairnet

Some workplaces and work tasks require the use of respiratory protection combined with eye and hearing protection. Therefore, the combination of 7500 respirator with SecureFit safety glasses and one Fahrenheit goggles were included in the scope of this study. Both combinations provided approximately 10 dB of reduction in the PAR for X4A and X5A earmuffs. The inclusion of the blue hairnet with 7500 and safety glasses did not show any further loss in the attenuation.

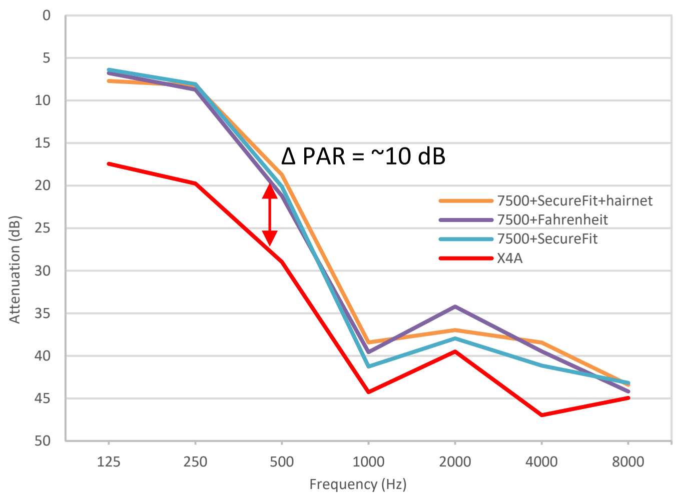

Figure 15: Effects of 7500 respirator, safety glasses, goggles and hairnet when worn with X4A earmuff

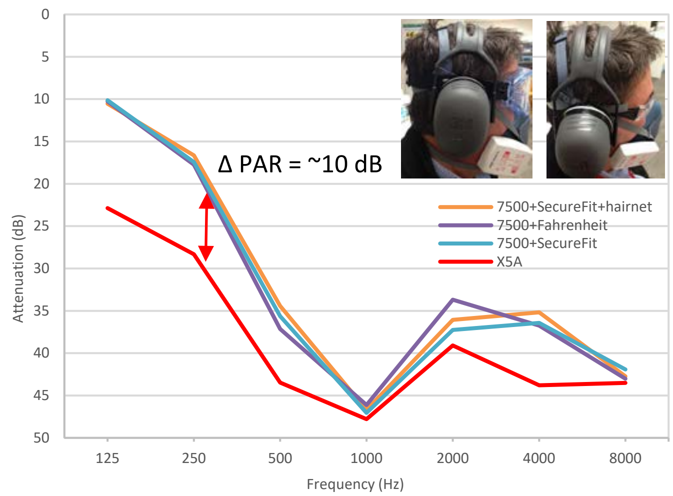

Figure 16: Effects of 7500 respirator, safety glasses, goggles and hairnet when worn with X5A earmuff

Significance of industrial safety helmets

Helmet mounted earmuffs can be designed to fit a wide variety of industrial safety helmets. However, due to the costs and practicalities associated with the AS/NZS 1270 testing, they are usually tested with one or two models of safety helmets that should be indicated on the product packaging with following statement from the standard: "These earmuffs were tested in combination with the following industrial safety helmets and may give different levels of protection if fitted to different helmets: (list helmets)."

In Europe, the EN 352.3:2002 established specific requirements for the headband force of supplementary combinations based on the headband force measured for a basic combination. If the headband force of supplementary combination cannot meet requirements of this standard, then it should be submitted for a new attenuation testing.

In order to assess the influence of industrial safety helmets in the performance of earmuffs, three models of helmets commonly found in the Australian market were tested in combination with X4P3 and X5P3 earmuffs.

The charts in Figure 17 and Figure 18 shows the OB results for X4P3 and X5P3 respectively. The OB analysis indicated a maximum variation of 3 dB at 1000Hz for X4P3 and 3 dB at 500Hz for X5P3 suggesting that the model of the safety helmet does not have a significant influence on the OB results. The ANOVA conducted for the three models of safety helmets provided *p*-values >0.05 for both X4P3 and X5P3 confirming that the differences associated with the helmets were not statistically significant for the overall PAR values with 95% confidence.

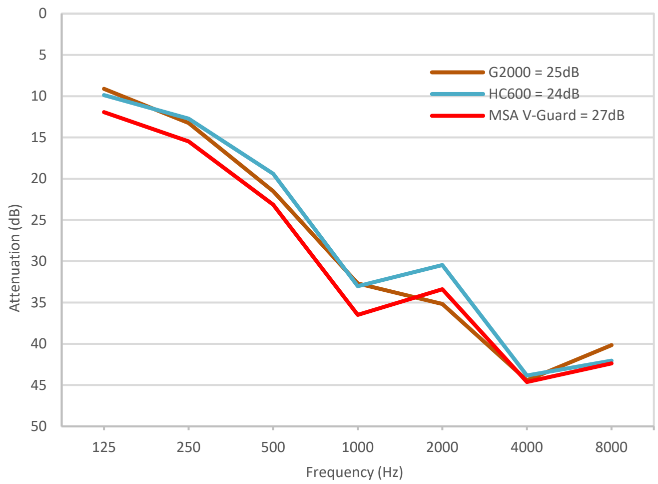

Figure 17: F-MIRE Octave Band results for X4P3 earmuff attached on industrial safety helmets

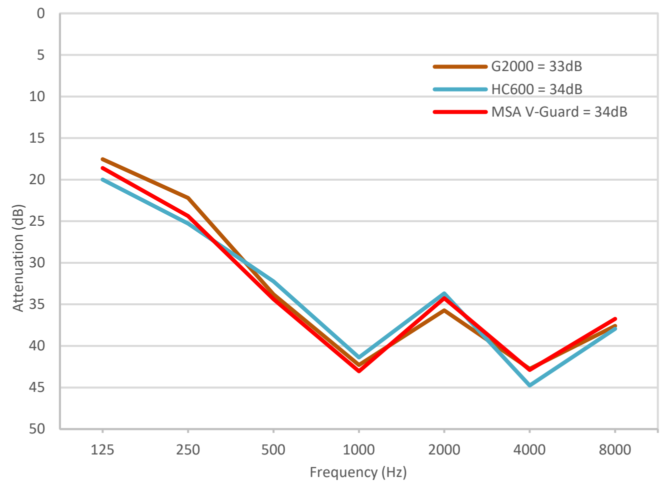

Figure 18: F-MIRE Octave Band results for X5P3 earmuff attached on industrial safety helmets

CONCLUSIONS

Suitability of the F-MIRE to predict REAT ratings

The comparison of PAR_{84} and SLC_{80} was reasonable, within 1 to 5 dB. The fitting of the F-MIRE test subjects versus the REAT laboratory subjects certainly had an influence in this result.

When the PAR values were compared to the AS/NZS 1270 individual data, 94% out of 64 values fell within an interval of ±10 dB. This result indicate that there is a good fit or equivalency between F-MIRE and REAT. The overall results suggested that F-MIRE has a trend to slightly lower than REAT results. However, this trend could be associated with the fact that the comparison was based in different subject test panels. Further investigation would be necessary to reach a more definitive explanation for this observation.

Performance of earmuffs when worn with other PPE and apparel

Earmuffs are often selected as the preferred type of hearing protector due to ease-of-use and durability. On the other hand, earmuffs are more susceptible than earplugs to the interference and compatibility issues provided by other PPE when worn with earmuffs.

This study provided quantitative information about the degradation of attenuation caused by a range of PPE and apparel. This information is relevant to wearers and occupational health and safety professionals involved in the selection of hearing protectors as part of the control measures for noise exposure.

The reduction of the PAR caused by the use of safety glasses worn underneath the ear cushions varied between 3 dB to 7 dB depending on the thickness of the safety glasses temple frames. The degraded attenuations may still be sufficient to maintain the noise exposures within what is considered safe levels (below 85 dB for an 8-hr shift). However, wearers and professionals involved in the specification of PPE should be aware about the potential effects of eyewear on the performance of the earmuffs and take into consideration characteristics of the design of these PPE (e.g. thickness of temple frames, width of straps or presence of buckles) in the selection of the most appropriate combination of eyewear and earmuff.

Respirators are also commonly worn underneath earmuffs and similarly to eyewear, the harness design, the thickness of straps and the positioning of buckles can affect the attenuation of the earmuffs. The 3M 7500 half face respirator reduced the attenuation of X4A and X5A in 8 dB and 5 dB respectively. The reduction of attenuation can be aggravated by another 3-5 dB when 7500 respirator is worn in combination with eyewear.

When hairnet, cap and beanie were worn with earmuffs, they reduced the attenuation in 4 dB (hairnet), 6-9 dB (golf style cap) and 12-13 dB (fleece beanie). Once again, wearers and professionals involved in the selection of PPE should consider these effects in their risk assessment in order to determine whether earmuffs are suitable to maintain the workers exposure at safe levels or if additional controls or other styles of hearing protectors are necessary.

Some helmet mounted earmuffs can be attached to a wide range of industrial safety helmet models although it is unreasonable to test all possible combinations of earmuffs and helmets to AS/NZS 1270. In this study, three models of industrial safety helmets were assessed with the intention to verify the influence of these safety helmets on the attenuation of the X4P3 and X5P3 earmuffs. The PAR differences amongst the models of safety helmet were not statistically significant, suggesting that the design of these helmets have no significant influence in the level of protection provided by the earmuffs.

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