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Enhancing Hearing Protection: Evaluating Innovative Training Modalities for Optimal Fitting Outcomes

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Abstract

Background: *Measuring the effectiveness of training in properly fitting hearing protection devices (HPDs) is crucial, as it directly influences their attenuation. We assessed an earplug's personal attenuation ratings (PAR) following various intervention modalities.* **Methods:** *The sample consisted of 52 adults without experience using hearing protection devices (HPD). The Personal Attenuation Rating (PAR) was evaluated through real-ear attenuation at threshold (REAT) and microphone-in real-ear (MIRE) measurements after participants fitted the HPD as they saw fit. Participants were then randomly assigned to groups and given instructions on HPD fitting as follows: (G1) individual in-person demonstration; (G2) package reading; (G3) video; (G4) no intervention. PAR was subsequently reassessed. Data analysis was conducted using ANOVA and the Fisher Exact test.* **Results:** *Pre-intervention assessments showed no significant differences between the groups using either method. After training, G1, G2, and G3 significantly increased the PAR compared to G4, through both processes. The comparison of PAR post and pre-intervention revealed significant differences for G1, G2, and G3 (REAT) as well as for G1 and G3 (MIRE), in contrast to G4. Regarding "pass" and "fail" outcomes through MIRE, G1, G2, and G3 had more "pass" results after the intervention, compared to G4.* **Conclusions:** *Intervention, regardless of modality, effectively improved correct earplug HPD fitting, evidenced by increased PAR and higher rates of individuals achieving sufficient attenuation. Individual in-person demonstrations and video instructions proved to be the most effective training modalities.*

1. Introduction

Noise-induced hearing loss (NIHL) is a global public health issue with high prevalence and significant health impacts [1, 2]. In 2019, 7 million (4.76–10.06) years lived with disability, which was attributed to occupational noise exposure, highlighting the need to promote measures to reduce noise exposure [1]. The adverse effects of noise exposure extend beyond hearing; they may also contribute to increased blood pressure, cardiovascular diseases, stress, sleep disturbances, cognitive dysfunctions, and more [3-6]. Workers in construction, mining, the military, agriculture, public services, transportation, industry, and music are among the populations most at risk for noise-related hearing changes [3, 4, 7]. NIHL is irreversible. Therefore, prevention is the best strategy to avoid the adverse effects of noise exposure [3, 4]. Measures such as monitoring and reducing noise exposure, using hearing

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protection devices (HPDs), assessing hearing regularly, and providing health education should be taken to prevent NIHL [2, 3].

Noise mitigation in the workplace should follow the control hierarchy: first, eliminate noise at the source, then utilize individual hearing protection devices (HPD). Although HPDs are integral to preventing hearing loss, their incorrect use can reduce noise attenuation due to poor fitting, inadequate wearing time, or degradation [7]. A systematic review found that training in proper HPD use can decrease noise exposure by ensuring adequate attenuation, which is crucial for preventing NIHL [8]. Workers need guidance and training for effective HPD use in their work environments, making ongoing health education vital [3]. Additionally, studies indicate that laboratory-measured HPD attenuation exceeds that in daily environments, necessitating individual calculations based on fit and variability [10, 12].

Field attenuation estimation systems currently provide the most accurate assessments of personal attenuation rating (PAR) to determine if necessary attenuation is achieved [8]. Standard systems include real-ear attenuation at threshold (REAT) and microphone in the real ear (MIRE). HPD fitting significantly impacts device attenuation [13-16], yet studies comparing educational interventions for fitting and their attenuation effects are limited. This research evaluates and compares the PAR of an insert earplug HPD after various intervention modalities.

2. Methods

2.1. Study Design

This randomized controlled trial (RCT) involves a convenience sample of 52 university students of both sexes, with a mean age of 23.52 ± 3.76 years, who had no prior knowledge of fitting HPDs. The exclusion criteria included previous HPD use, visually inspected changes in the external auditory canal, a history of ear infections and/or otologic surgeries, and auditory complaints. When applicable, individuals were referred to the institution's otorhinolaryngology service. The institution's research ethics committee approved this study under evaluation report no. 114/13. All participants received guidance and explanations about the study and signed an informed consent form before beginning any procedures.

2.2. Procedures

Initially, all participants completed a brief clinical questionnaire addressing their health history and auditory complaints. Then, they underwent an otoscopy (using a Mini 3000 otoscope by Heine) to identify any abnormalities that could interfere with the subsequent procedures. REAT and MIRE were used to obtain the PAR of the insert earplug HPD (model 1100 by 3M).

2.2.1. REAT

Hearing thresholds were measured in a free field with the ear occluded (with HPD) and not occluded (without HPD), using a warble tone as sound stimuli. The free-field pure-tone audiometry used the following equipment: audiometer model AC-40 (Interacoustics); two-channel amplifier model FF-70 (Acústica Orlandi); and sound field system model SO200P (Acústica Orlandi).

The participant was instructed to remain still with their head at a 0° azimuth angle toward the loudspeaker, 60 cm away from it, and was asked to signal to the evaluator whenever they heard the sound stimulus. The difference between the two measures was calculated for each frequency. The PAR was then obtained through a detailed calculation that included the attenuation values obtained across all frequency bands specified in the method [17].

2.2.2. MIRE

The MIRE utilised the E-A-Rfit Validation System™ by 3M™, specifically designed to obtain the PAR of 3M™ HPDs. This equipment consists of a loudspeaker connected to a pair of microphones. The E-A-Rfit™ software, version 3M.4.4.17.0, manages all evaluation procedures. The loudspeaker generates white noise at 100 dB SPL. One of the microphones connects to the HPD explicitly designed for this purpose and is inserted into the external auditory canal (internal microphone). At the same time, the other is positioned near the participant's outer ear (external microphone). The software automatically calculates the difference in intensities captured by each microphone (internal and external) for each ear separately, providing the PAR.

The software also compares the PAR for each ear. It considers the lower attenuation value to classify the individual as "passed" (sufficient protection) or "failed" (insufficient protection), based on the subtraction of the noise exposure level (100 dBA) and a variation value. The latter, automatically calculated by the software, includes a combination of user fit variation, the user's noise spectrum, and the mean variation itself [18]. The cutoff value for sufficient protection was set at 85 dBA, meaning that the PAR plus the variation should achieve a minimum of 15 dB (as calculated by the software). Moreover, the equipment adopts the lower PAR of the two ears as the binaural PAR. The participant was instructed to keep their head at a 0° azimuth angle toward the loudspeaker, 60 cm away from it, and remain still.

The REAT and MIRE evaluations were conducted in an acoustically treated booth: free ear (without HPD) (stage 1); occluded ear (with HPD) before intervention (stage 2); and occluded ear (with HPD) after intervention (stage 3). Hearing thresholds were initially obtained with the free ear (stage 1 – only REAT). Then, participants were instructed to fit the HPD in both ears as they deemed most appropriate, and a new evaluation was conducted using MIRE and REAT (stage 2). Next, participants were randomly assigned to one of four groups (G1, G2, G3, or G4).

The first three groups received educational intervention with standardised instructions on the correct HPD fitting, while G4 (control group) received no intervention (Table 1).

After the intervention (or lack thereof, in the case of G4), participants were instructed to fit the HPD again, and a new evaluation was performed using MIRE and REAT (stage 3). The analysis considered the differences in PAR (stages 2 and 3)—i.e.,

Table 1. Classification of the groups according to the modality of intervention for the fitting of hearing protection devices (HPD).

Groups	Interventions	Procedures
Group 1 (G1)	Oral instructions with an individual hands-on demonstration	The researcher provided standardized demonstrations of the correct HPD fitting.
Group 2 (G2)	Reading the packaging	The participant read the HPD manufacturer's instructions on the packaging, with images and explanatory phrases.
Group 3 (G3)	Video with oral instructions and demonstration	The researcher provided standardized instructions and demonstrations in an explanatory video on the correct HPD fitting.
Group 4 (G4)	Control Group	The REAT is subjective, in a free field with an audiometer to assess hearing thresholds with the ear occluded (with HPD) and not occluded (without HPD). The difference between the two measures is the PAR of the HPD. The MIRE, in turn, is objective, measuring sound pressure levels (SPL) using two microphones simultaneously – one internal microphone connected to the HPD, inserted in the ear canal, and one external microphone positioned near the outer ear. The equipment automatically calculates the difference (PAR) between the intensities captured by the two microphones [12]. Furthermore, the effectiveness of training for the correct did not receive any type of instructions on the correct HPD use.

Table 2. Comparison between groups for the mean personal attenuation levels (PAR) pre- and post-intervention and for the differences in personal attenuation levels (PAR) between the pre- and post-intervention stages using the REAT method.

Situation	Group	N	Mean PAR	SD	ANOVA p-value	Tukey
Before	G1	13	15.48	12.11	0.619	-
	G2	13	20.13	12.37		
	G3	13	18.35	10.32		
	G4	13	20.50	7.09		
After	G1	13	30.95	11.99	0.001*	A
	G2	13	34.63	8.31		A
	G3	13	36.09	5.43		A
	G4	13	21.87	10.60		B
Difference in PAR before and after intervention	G1	13	15.47	11.99	<0.001*	A
	G2	13	14.50	8.31		A
	G3	13	17.74	5.43		A
	G4	13	1.37	10.60		B

post-intervention PAR pre-intervention PAR—obtained in the two evaluations for each method.

2.3. Data Analysis

Quantitative results were presented as mean ± standard deviation (SD) and analysed using one-way analysis of variance (ANOVA) and Tukey's post-hoc test. The Fisher Exact test was used for qualitative data (MiniTab 18 and Jamovi 0. 19.3 software). All analyses considered a significance level of $p \leq 0.05$.

3. Results

Fifty-two university students (40 women and 12 men) were recruited, with a mean age of 23.36 (± 3.76), minimum 18 and maximum 50, with no difference between groups (p-value 0.814). No significant difference was found comparing PARs between groups before the intervention. However, G1, G2, and G3 differed significantly from G4 after the intervention. The comparison between the groups for the differences in PARs using the REAT (post-intervention PAR minus pre-intervention PAR) showed that G1, G2, and G3 were statistically different from G4 (Table 2).

The mean PARs of the groups before the intervention were not significantly different. However, they were significantly different after the intervention, with G4 having the lowest mean PAR. The comparison of the groups' PAR differences using the MIRE (post-intervention PAR minus pre-intervention PAR) found that G1 and G3 were statistically different from G4 (Table 3).

The "pass/fail" performance before and after intervention (Table 4) was statistically different between the groups. The qualitative results showed that G1, G2, and G3 differed in performance from G4 (G1 – 15% to 54%; G2 – 31% to 62%; G3 – 31% to 62%; G4 – 24% to 15%), that is, all three groups increased their "pass" results, but G4 did not.

4. Discussion

This RCT aimed to evaluate and compare the PARs of insert HPDs obtained after different intervention modalities (in-person demonstration, package reading, and video) and to compare these modalities with the absence of intervention. The four participating groups did not differ in terms of mean age or prior knowledge of HPD use, aiming to minimize potential confounding variables in the results [11]. Moreover, individuals were randomly

Table 3. Comparison between the groups for the mean personal attenuation levels (PAR) pre- and post-intervention and for the differences in personal attenuation levels (PAR) between the pre- and post-intervention stages using the MIRE method.

Situation	Group	N	Mean PAR	SD	ANOVA p-value	Tukey
Before	G1	13	11.85	5.00	0.462	-
	G2	13	14.31	5.77		
	G3	13	14.46	6.31		
	G4	13	11.85	5.46		
After	G1	13	20.31	6.38	<0.001*	A
	G2	13	18.23	6.38		A
	G3	13	20.77	6.54		A
	G4	13	10.85	5.62		B
Difference in PAR before and after intervention	G1	13	8.46	6.38	<0.001*	A
	G2	13	3.92	6.38		AB
	G3	13	6.31	6.54		A
	G4	13	-1.00	5.62		B

Table 4. Frequency of pre- and post-intervention results classified according to the "Pass" or "Fail" criteria by group.

Group	Before Pass / Fail	After Pass / Fail
G1	2 / 11	7 / 6
G2	4 / 9	8 / 5
G3	4 / 9	8 / 5
G4	3 / 10	2 / 11
Fisher Exact test p-value	<0.025*	

allocated into the groups. For both methods (REAT and MIRE), the results of this study showed differences between the groups (G1, G2, and G3 compared to G4) after the intervention, indicating that the three groups that underwent some form of intervention increased their PAR. However, there were no significant differences among them. It was also found that the four groups did not have different PARs before the intervention. Hence, the attenuation was similar at the beginning of the study, and none of them stood out in the correct HPD fitting.

The comparison of differences in PAR (post-intervention minus pre-intervention) between the groups also reveals significant differences for both methods. For the REAT, G1, G2, and G3 (mean values of 15.4, 14.5, and 17.7, respectively) differed from G4 (mean value of 1.3). For the MIRE, G1 and G3 (mean values of 8.4 and 6.3, respectively) differed from G4 (mean value of -1). This indicates that groups G1 (in-person demonstration) and G3 (video) achieved the best post-intervention performances.

The performance of the control group (G4) regarding the differences in PAR before and after the intervention demonstrates that little to no change in HPD fitting was achieved without intervention. In contrast, the performance of the other groups showed higher PAR after the intervention, indicating that all approaches were practical (with a particular emphasis on the in-person and video methods) compared to the absence of instructions. This underscores the importance of training for the proper HPD fitting.

The in-person instruction method is often the most used to train workers [9]. It includes guidance on noise exposure levels, desired attenuation levels, and demonstration of the correct HPD fitting, which has proven effective in increasing PAR in previous studies [19, 20]. A study with 321 recruits in training with the United States Navy, randomly assigned to three groups, examined the effectiveness of different training modalities (video, in-person with a specialized professional, and video combined with in-person training). The study concluded that all methods were effective, with the most significant emphasis on training by a specialized professional [21]. Kim et al. (2019) conducted in-person training for workers annually over 4 years [22]. Using the MIRE, they observed that the PAR improved after each training session, with increasingly better results each year, highlighting the importance of long-term training [20, 23].

The analysis of "pass/fail" results automatically provided by the MIRE found that the approval rates increased by over 30% only for G1, G2, and G3. Thus, it is evident that not only is the PAR higher after training, but also the rate of individuals achieving the target PAR (with sufficient attenuation for protection) increases. These findings are consistent with those obtained by Takada et al. (2020) and Federman et al. (2020) and emphasize the importance of training for the proper HPD fitting to provide the necessary attenuation to reduce noise exposure and prevent NIHL [10, 21]. Nonetheless, some individuals, even among those who underwent training, did not reach the target PAR (G1 46%, G2 38%, G3 38%, G4 85%). In the case of G4, the failure rate can be attributed to the absence of training. However, for the other groups, several variables may contribute to this outcome, such as the need for additional training, the shape and geometry of the ear (which may make this HPD type unsuitable for the individual), and so forth [10, 24, 25].

Previous studies reported similar findings. Their authors noted that the recommendation for a specific HPD type should consider anatomical differences among individuals [21, 26].

Regarding the intervention modalities, our results indicate that video instruction was as effective as in-person training, suggesting that this approach should be increasingly explored, as it requires fewer financial resources and is easily reproducible. It eliminates the constant need for a specialized professional, allowing workers to consult the instructional material whenever necessary. Joseph et al. (2007) observed an increase in the mean PAR, measured by the REAT, after training with audiovisual material on the correct HPD use, followed by in-person training (either individually or in groups) [9]. Thus, the option of using audiovisual materials can complement in-person training.

Studies evaluating the effectiveness of interventions using audiovisual resources are still scarce. However, technological advancements noticeably increase the importance of such strategies to disseminate information and promote health. Other areas of healthcare have already studied and applied this strategy in various contexts. For example, Razera et al. (2016) compared the training of caregivers of children on postoperative care through in-person instructions and video, finding better knowledge retention when acquired via video than via in-person instructions [27].

The limitations of this study include the evaluation method, which did not simulate a real work environment, as participants remained seated and motionless. This setup does not assess whether the PAR decreases throughout the day.

Although the study design (i.e. RCT) is a factor that improves its internal validity, as it has the potential to provide the highest-quality evidence for assessing interventions, the setting and the individuals studied are not similar to the occupational environment, which may limit the generalisation of the findings. However, the controlled laboratory environment reduces the influence of several variables, seeking to isolate the intervention per se. RCTs are difficult to perform in real-world settings because of the presence of many stakeholders and social interaction between participants [8].

Tikka et al. [8] and Morata et al. [28] highlighted this difficulty in their Cochrane systematic reviews. The authors emphasized that, due to the challenges of randomization in the workplace [28] and the need for interventions to prevent occupational hearing loss [8], both reviews chose to include controlled before-and-after studies. In Morata et al.'s review [28], the authors considered including uncontrolled before-and-after studies; however, the absence of a "control group" would complicate determining whether the observed effects could be attributed to the intervention. As a final consideration of this review, more RCT studies were recommended to support the evidence. Therefore, given the scarcity of RCTs in this area and the low to moderate quality of evidence regarding interventions involving hearing loss prevention (including training for appropriate use of the HPDs) [8], we chose to conduct an RCT study, but within the laboratory. Future studies should evaluate the possibility of carrying out a similar methodology, assessing the effectiveness of instructions and HPD use during occupational activities in environments closer to the real world. Situations such as the concomitant use of personal protective equipment and adverse working conditions, among others, make the use of HPD more complex. Potential strengths of this study include the randomization of individuals across the four groups, which reduces the possibility of bias, the inclusion of participants with no prior knowledge of HPDs, and the inclusion of a control group that did not receive any intervention. This is particularly noteworthy since many studies have excluded a control group [9, 10, 21].

5. Conclusion

Our findings highlight that the intervention (regardless of the modality) for properly fitting insert HPDs effectively increased the PAR and the rates of individuals achieving sufficient attenuation. Training through individual demonstration and video instructions proved to be the most effective modalities.

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Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

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