

The Influence of Conventional Earmuff Sound Absorbers on Psychoacoustic Factors: A Laboratory Study

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Abstract

Aim: Traditional indicators used for evaluating hearing protectors do not capture their impact on psychoacoustic parameters. Therefore, this study aimed to analyze commonly used absorbers in earmuffs and their influence on psychoacoustic indicators, specifically focusing on roughness and fluctuating strength. **Methods:** This intermittent and descriptive-analytic study involved measuring psychoacoustic indicators at sound pressure levels (SPLs) of 75, 85, and 95 dB using white noise and an impedance tube for single- and double-layered absorbers. SPSS software was used for statistical analyses, including reporting descriptive statistics (mean and standard deviation) for quantitative data. The effects of the absorber on psychoacoustic parameters were examined using the independent statistical test. **Results:** The study findings revealed that the average values of roughness and fluctuating strength parameters decreased across all four absorbers as sound pressure intensity increased. The statistical test results indicated that there were no significant differences in psychoacoustic parameters among the absorbers at the three pressure levels tested, regardless of the presence or absence of an absorber (all $P > 0.05$). However, the statistical test showed a significant difference ($P = 0.032$) for the roughness parameter among the four absorbers at 95 dB level. In addition, for the fluctuating strength parameter, significant differences were observed among the four absorbers at 75 dB level ($P = 0.036$) and 95 dB level ($P = 0.003$). **Conclusion:** Controlling noise to reduce psychoacoustic parameters such as roughness and fluctuating strength at SPL above 85 dB can be achieved effectively using earmuffs equipped with single-layered absorbers compared to those with double-layered absorbers.

Keywords: Ear protective devices, fluctuating strength, impedance tube, psychoacoustic, roughness

INTRODUCTION

Noise, as defined, refers to unwanted and unpleasant sounds that can disrupt human activities and create instability. The issue of noise pollution is primarily caused by human activities and has become a significant problem for individuals in both workplaces and daily life.^[1] Recent studies have provided alarming statistics, indicating that approximately 22 million workers in the USA are currently exposed to noise, with a history of noise exposure reported by 25% of these individuals. Similar findings have also been reported in countries such as Canada, Australia, and members of the European Union.^[2,3]

Given the widespread prevalence of noise exposure and concerns about its physical, physiological, mental, and psychological effects, extensive research has been conducted in recent years. Studies have revealed that besides temporary or permanent hearing impairments resulting from noise exposure, other adverse effects include increased blood pressure,

anxiety, cardiovascular diseases, and disruptions in endocrine function.^[4] In addition, noise exposure has been associated with annoyance, elevated stress levels, sleep disturbances, and cognitive impairments, as evidenced by various studies.^[5,6]

Consequently, the importance of controlling noise exposure in workplaces has become paramount, leading to the development and implementation of numerous control methods. The National Institute for Occupational Safety and Health recommends five

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How to cite this article: Khaki M, Asady H, Pourabdian S, Khorshidikia S, Forouharmajd F. The influence of conventional earmuff sound absorbers on psychoacoustic factors: A laboratory study. *Int J Env Health Eng* 2025;14:27.

Received: 01-01-2024,

Revised: 30-04-2024,

Accepted: 08-05-2024,

Published: 29-07-2025

Access this article online

Quick Response Code:



Website:
<https://journals.lww.com/IJEH>

DOI:
10.4103/ijehe.ijehe_1_24

primary control measures for noise exposure: elimination, substitution, engineering controls, administrative controls, and personal protective equipment (PPE). It is worth noting that the effectiveness of these measures decreases from elimination to PPE.^[7,8] However, due to the current state of work environments, the emphasis is placed on the use of PPE, specifically in terms of mitigating noise exposure. Employing hearing protection programs in workplaces and for individuals exposed to noise is considered an economically viable approach. Commonly used PPE for noise control includes earmuffs and earplugs, either used individually or in combination. When selecting appropriate PPE, several factors need to be considered, such as the equipment's noise reduction capabilities, ease of use, available budget, and the environmental and organizational context.^[9]

While traditional indicators like single number rating (SNR) and noise reduction rating (NRR) provide information about the noise reduction capabilities of hearing protectors,^[10] they do not account for the changes in psychoacoustic factors resulting from the utilization of such equipment.^[11,12] It has been recognized that noise effects are not solely determined by physical parameters like sound pressure level (SPL) but also by psychoacoustic indicators such as sharpness, roughness, fluctuating strength, and overall sound level. The term "psychoacoustics" is generally defined as the study of listeners' responses to sounds. More specifically, psychoacoustics looks for statistical and causal relationships between certain physical properties of sounds and certain properties of human responses. Same as the physical parameters of sound like SPL (dB) psychoacoustic has its own parameters for calculation and measurements, most practical of them are loudness, sharpness, roughness, fluctuation, strength, and tonality. For instance, studies have shown that psychoacoustic parameters significantly influence noise annoyance levels in classrooms, as well as students' learning and attention.^[13] Similarly, research conducted in intensive care units has highlighted the importance of psychoacoustic evaluation alongside SPL control in regulating the impacts of noise exposure.^[14]

Since SNR and NRR primarily convey information about changes in sound pressure intensity, they fail to provide users with insights regarding alterations in psychoacoustic factors resulting from the use of hearing protection equipment. Therefore, it is necessary to calculate these parameters in sound measuring devices or psychoacoustic calculations. Thus, the objective of this study is to analyze the effects of common absorbers found in earmuffs on two psychoacoustic indicators: roughness and frequency power. By examining these effects, we aim to enhance our understanding of how these absorbers influence noise perception and contribute to the overall effectiveness of hearing protection equipment.

MATERIALS AND METHODS

Choosing the earmuffs under scrutiny

This study is intermittent and descriptive-analytic in nature and took place in a sound and vibration laboratory at the Medical

University of Isfahan's Health Faculty in 2021. To undertake this study and to select the commonly used earmuffs, 30 shops selling personal protection equipment in different parts of the city were analyzed and four models of widely and commonly used earmuffs were chosen based on the sale rate of these shops. The specifications of these earmuffs are recorded in Table 1.

Methods of measuring psychoacoustic features

To go through with this study, an acoustic impedance tube, a 3 cm-wide pipe with an overall length of 157/2 cm, 2 half-inch microphones manufactured by China's BSWA Co., LabVIEW application (v. 2012), and also an MC-3642 acoustic analysis card made by the USA's National Instrument Co. were utilized. To measure the psychoacoustic parameters under study, initially, the two microphones were calibrated using a B and K Calibrator Model 4230, at a frequency of 1000 Hz and SPL of 94 dB. Subsequently, the calibration of the acoustic impedance tube was done by placing a BSWA standard absorber into the tube alongside measuring the absorption coefficients and absorber transmission loss in a 780–6640 Hz frequency range; a comparison between these measurements and the standard graph provided by BSWA was undertaken for the standard model in use, which was accepted after making sure that it was in accordance with the graph in precision and authenticity.

The standard foam calibration of an acoustic impedance tube with 2.5 cm thickness and 30 cm diameter is used to measure the effect of the absorbers in the earmuffs under scrutiny with regard to psychoacoustic features such as roughness (it describes the human perception of temporal variations of sounds. This metric is measured in asper) and fluctuation strength (fluctuation strength is similar to roughness except it quantifies subjective perception of slower [up to 20 Hz] amplitude modulation of a sound in vacil). In this case, first, the foams in the earmuffs were taken out, on which the necessary excisions to reach the standard were done. Foams with a thickness of 1.25 cm were chosen for earmuffs in which double-layered foams were to be used, making a general thickness of 2.5 cm. A digital coulis was used for higher precision in dimensions and to analyze every aspect of the foams under study.

Following the calibration of the needed devices and tools and providing the necessary dimensions of the foams under study, the measurement of psychoacoustic indicators in SPL of 75, 85, and 95 dB took place, along with the emission of white noise (created by VA-Lab2 software) into the acoustic impedance tube as the sound source using the Moore method and the Monaural-1 state through the VA-Lab4 software. This software is based on LabVIEW program designed by the National Instrument of America. Measurements in this state were done both in the presence of absorbers and in their absence. To increase precision and minimize errors in measurements, 30 tests were undertaken in each state and for every absorber. Each sample was undertaken three times so that a total number of 90 tests have been done. Some tests were happened for single- and doubled-layered absorbers randomly.

Data analysis

According to the information recorded in the SPSS software used for this analysis is developed by IBM Corporation, headquartered in (Armonk, New York, United States.) in the descriptive section and for the existing quantitative data, the average number and standard deviation were reported. To examine the effects of the absorber under scrutiny on the psychoacoustic parameters, the independent *t*-test was utilized. To analyze the discrepancy with regard to the parameters under study in relation to the four foams under scrutiny, the ANCOVA model and the least significant difference (LSD) *post hoc* test were used. In all the tests, the equal averages more than the significance level of 0.05 were disregarded.

RESULTS

The study findings indicate that the average values of the roughness and fluctuating strength parameters decrease for all four absorbers as the sound pressure intensity increases. Absorber number 1 showed the highest average roughness value of 111.51 asper and a fluctuating power of 0.38 vacil at 75 dB when the absorber was present in the acoustic impedance tube. Similar patterns were observed for the other absorbers. Tables 2-5 show more detailed information. All of the results are demonstrated in Tables 1-7.

DISCUSSION

The *t*-test results showed that there were no significant differences in the studied psychoacoustic parameters among the absorbers at the three pressure levels, both with and without the presence of an absorber ($P > 0.05$). To further analyze the differences among the four absorbers at the three pressure levels, the ANCOVA test and *post hoc* test LSD were employed, focusing on the psychoacoustic parameters. The results of the test indicated a statistically significant difference ($P = 0.032$) in the roughness parameter among the four absorbers at 95 dB when the parameter was balanced in the presence of an absorber. If a tone (e.g. 1 kHz sine) is 100% amplitude modulated, our sensation depends on the modulation frequency. The first sensation experienced is fluctuation strength, where the individual loudness modulations are audible. This experience peaks at 4 Hz. Once the modulation frequency reaches 15 Hz, the sensation of roughness begins to appear. The LSD *post hoc* test results revealed that the differences in the roughness parameter between absorbers 1 and 2 ($P = 0.048$) and 1 and 4 ($P = 0.20$) were statistically significant. Table 6 shows more information. The comparative results of the fluctuation strength variable in different earmuff absorbers and different levels of SPL are presented in Table 7. In the 75 dB SPL, the LSD *post hoc* test results showed that the differences between absorbers 1 and 3 ($P = 0.028$) and absorbers 2 and 3 ($P = 0.008$) were statistically significant. Furthermore,

Table 1: Specifications of the earmuffs under scrutiny

Brand	Country	Earmuff model	Number of absorber's layers	Absorber kind	NRR as designated by the manufacturer (dB)	Absorber number
Tasco	USA	2550	1	Foam	25	1
Akhavan	Iran	Venus-740	1	Foam	60	2
3M	USA	Optime 98	2	Foam-Foam	25	3
Parkson	USA	EP10751	2	Foam-Foam	34	4

NRR: Noise reduction rating

Table 2: Descriptive statistic of the psychoacoustic parameters in the different stimulus sound pressure levels (dB) and also in the presence and absence of absorber 1

Psychoacoustic parameters	Stimulus SPL (dB)					
	75		85		95	
	With	Without	With	Without	With	Without
Roughness (asper)						
Mean	111.51	109.96	96.54	93.33	82.17	81.45
SD	19.20	17.95	3.48	11.55	2.64	7.13
95% LB	104.35	103.25	95.24	89.02	81.18	78.79
95% UB	118.68	116.66	97.84	97.64	83.16	84.11
Minimum	82.98	89.65	87.44	79.25	76.23	70.99
Maximum	172.09	129.53	99.25	126.56	85.91	101.36
Fluctuation strength (vacil)						
Mean	0.38	0.37	0.32	0.31	0.26	0.26
SD	0.07	0.09	0.02	0.04	0.008	0.01
95% CI*	0.35–0.4	0.33–0.4	0.31–0.33	0.20–0.33	0.25–0.26	0.26–0.27
Minimum	0.29	0.26	0.30	0.26	0.25	0.24
Maximum	0.58	0.54	0.36	0.42	0.28	0.29

*95% CI for mean (LB–UB). CI: Confidence interval, SD: Standard deviation, LB: Lower bound, UB: Upper bound, SPL: Sound pressure level

Table 3: Descriptive statistic of the psychoacoustic parameters in the different stimulus sound pressure levels (dB) and also in the presence and absence of absorber 2

Psychoacoustic parameters	Stimulus SPL (dB)					
	75		85		95	
	With	Without	With	Without	With	Without
Roughness (asper)						
Mean	112.73	108.20	93.05	93.46	82.26	75.56
SD	21.24	22.18	7.61	10.53	6.87	6.96
95% LB	104.80	99.92	90.21	89.53	79.70	72.97
95% UB	120.66	116.88	95.89	97.39	84.83	78.17
Minimum	81.95	76.80	81.20	77.56	71.91	65.26
Maximum	171.51	169.64	115.97	133.53	94.54	88.58
Fluctuation strength (vacil)						
Mean	0.38	0.37	0.32	0.32	0.28	0.25
SD	0.07	0.07	0.02	0.03	0.02	0.02
95% LB	0.36	0.34	0.31	0.30	0.27	0.25
95% UB	0.40	0.39	0.33	0.33	0.29	0.26
Minimum	0.27	0.26	0.27	0.26	0.24	0.22
Maximum	0.57	0.57	0.39	0.45	0.32	0.30

CI: Confidence interval, SD: Standard deviation, LB: Lower bound, UB: Upper bound, SPL: Sound pressure level

Table 4: Descriptive statistic of the psychoacoustic parameters in the different stimulus sound pressure levels (dB) and also in the presence and absence of absorber 3

Psychoacoustic parameters	Stimulus SPL (dB)					
	75		85		95	
	With	Without	With	Without	With	Without
Roughness (asper)						
Mean	93.60	89.80	87.43	84.96	80.79	78.20
SD	11.13	13.91	7.30	6.40	6.35	4.93
95% LB	89.45	84.60	84.70	82.57	78.42	76.36
95% UB	97.76	94.99	90.15	87.35	83.16	80.04
Minimum	78.11	72.18	74.72	71.01	67.66	70.39
Maximum	113.62	123.80	106.59	98.25	94.66	90.74
Fluctuation strength (vacil)						
Mean	0.32	0.30	0.30	0.29	0.27	0.27
SD	0.03	0.04	0.02	0.02	0.02	0.01
95% LB	0.30	0.29	0.29	0.28	0.27	0.26
95% UB	0.32	0.32	0.31	0.30	0.28	0.27
Minimum	0.26	0.24	0.25	0.24	0.23	0.23
Maximum	0.38	0.41	0.36	0.33	0.32	0.30

CI: Confidence interval, SD: Standard deviation, LB: Lower bound, UB: Upper bound, SPL: Sound pressure level

in the 95 dB pressure level, the differences between absorbers 1 and 2 ($P = 0.001$), 1 and 3 ($P = 0.026$), and 2 and 4 ($P = 0.029$) were statistically significant.

The results of this study indicate that the presence of an absorber can lead to a significant reduction in two psychoacoustic indicators, specifically roughness and fluctuating strength. These findings align with a previous study conducted by Zuccherini Martello *et al.*,^[15] which also demonstrated that materials and sound-absorbing devices used in building facades can increase psychoacoustic parameters such as roughness. Another study by Wang supports the present study’s findings, showing that the use of noise control methods, including

acoustic absorbing materials, can improve the psychoacoustic state, decrease parameters like roughness and fluctuating strength, and reduce noise annoyance.^[16]

The results indicate that the average roughness parameter decreases less for double-layered absorbers compared to single-layered absorbers at 75 dB and 85 dB pressure levels. Using more and better double-layered absorbers, with the same width as single-layered absorbers, can impact psychoacoustic parameters such as roughness and lead to a decrease in this parameter. Roughness, as a psychoacoustic parameter, is considered a factor of noise annoyance due to frequency modulation^[17] and does not correlate strongly with SPL.^[15]

Table 5: Descriptive statistic of the psychoacoustic parameters in the different stimulus sound pressure levels (dB) and also in the presence and absence of absorber 4

Psychoacoustic parameters	Stimulus SPL (dB)					
	75		85		95	
	With	Without	With	Without	With	Without
Roughness (asper)						
Mean	101.50	98.13	92.32	90.59	93.96	92.34
SD	18.09	16.70	15.94	14.03	14.20	10.57
95% LB	94.75	91.90	86.37	85.83	88.66	88.40
95% UB	108.25	104.37	98.27	95.83	99.27	96.29
Minimum	69.04	69.66	69.14	70.54	70.84	66.17
Maximum	145.41	136.06	122.20	116.45	120.30	112.02
Fluctuation strength (vacil)						
Mean	0.34	0.33	0.31	0.31	0.27	0.26
SD	0.06	0.05	0.06	0.04	0.02	0.03
95% LB	0.32	0.31	0.29	0.29	0.27	0.26
95% UB	0.36	0.35	0.33	0.32	0.28	0.28
Minimum	0.23	0.23	0.23	0.24	0.24	0.22
Maximum	0.48	0.45	0.41	0.39	0.31	0.32

CI: Confidence interval, SD: Standard deviation, LB: Lower bound, UB: Upper bound, SPL: Sound pressure level

Table 6: The output of the ANCOVA test for comparison of the effect of four different absorbers on the roughness (asper) in the three sound pressure level

SPL (dB)	Absorber number	Mean (asper)	SE	95% CI		F	P
				Lower	Upper		
75	1	106.11	2.572	101.01	111.20	1.363	0.258
	2	108.45	2.546	103.41	113.50		
	3	101.09	2.636	95.87	106.31		
	4	103.66	2.513	98.68	108.63		
85	1	95.06	1.430	92.23	97.89	1.869	0.139
	2	91.51	1.431	88.67	94.34		
	3	90.42	1.466	87.52	93.33		
	4	92.31	1.419	89.50	95.12		
95	1	82.44	1.301	79.86	85.02	3.029	0.032
	2	86.26	1.410	83.47	89.05		
	3	83.12	1.339	80.47	85.77		
	4	87.33	1.582	84.19	90.46		

Bold numbers=significant P values (P < 0.05). CI: Confidence Interval, SPL: Sound pressure level, SE: Standard error

Table 7: The output of the ANCOVA test for comparison of the effect of four different absorbers on the fluctuation strength (vacil) in the three sound pressure level

SPL (dB)	Absorber number	Mean (vacil)	SE	95% CI		F	P*
				Lower	Upper		
75	1	0.36	0.009	0.34	0.37	2.944	0.036
	2	0.36	0.009	0.34	0.38		
	3	0.33	0.009	0.31	0.34		
	4	0.34	0.009	0.32	0.36		
85	1	0.31	0.005	0.30	0.32	0.575	0.633
	2	0.30	0.005	0.29	0.31		
	3	0.30	0.005	0.29	0.31		
	4	0.30	0.005	0.29	0.31		
95	1	0.25	0.003	0.25	0.26	5.057	0.003
	2	0.27	0.003	0.26	0.28		
	3	0.26	0.003	0.26	0.27		
	4	0.26	0.003	0.25	0.27		

*The significance level was set at $\alpha = 0.05$. P-values less than 0.05 are considered statistically significant. Bold numbers=Significant P values (P < 0.05). CI: Confidence Interval, SPL: Sound pressure level, SE: Standard error

Therefore, controlling roughness through absorbers, which are effective in absorbing acoustic energy and reducing SPL, is an economical and important method for managing sound roughness and perceived noise annoyance.

To minimize annoyance and reduce sound roughness, both above the standard level (85 dB) and below it, using double-layered absorbers may yield more favorable results compared to earmuffs with single-layered acoustic absorbers. It is worth noting that both types of earmuffs (single or double layered) result in a significant decrease in roughness.

According to the Zwicker and Fastl model, psychoacoustic annoyance encompasses four parameters: loudness, sharpness, roughness, and frequency fluctuation strength.^[18-20] There

is a direct relationship between psychoacoustic annoyance and these four parameters. In this study, the second analyzed parameter was fluctuation power. Similar to roughness, the difference in this parameter among various absorbers at an SPL of 95 dB was statistically significant, with single-layered foams performing more efficiently than double-layered ones. However, at 75 dB and 85 dB SPL, the average fluctuating strength was higher in single-layered absorbers. This suggests that similar to roughness, there are differences in the reduction of this psychoacoustic parameter when exposed to different acoustic absorbers, with the difference being more pronounced at 95 dB. Hence, it can be claimed that single-layered absorbers are more effective in controlling fluctuating strength compared

to double-layered absorbers. In other words, the performance of various absorbers in controlling and reducing the frequency power parameter, particularly at SPL higher than the standard bounds (85 dB), would not differ significantly.

This study is subject to several limitations. First, it is unable to measure other psychoacoustic parameters such as loudness and sharpness, thereby restricting the scope of the analysis to specific parameters. In addition, the study does not encompass an examination of absorbers' performance on psychoacoustic parameters at higher pressure levels, limiting the understanding of their effectiveness in such conditions. Moreover, due to financial constraints, the investigation could not encompass a comprehensive exploration of all available earmuffs in the market. Another limitation lies in the relatively small sample size used in the study, which may impact the generalizability of the findings. Acknowledging these limitations is crucial in interpreting the results, and future research should aim to address these constraints to provide a more comprehensive understanding of the topic at hand. Furthermore, it is worth considering a comparison between different materials for earmuffs in future studies.

CONCLUSION

The study findings demonstrated that the presence of an absorber in an environment has been shown to enhance the levels of roughness and fluctuating strength psychoacoustic parameters. Moreover, when it comes to psychoacoustic parameters at lower pressure levels of 75 and 85 dB, double-layered absorbers exhibit greater effectiveness in reducing yields compared to single-layered absorbers. However, at 95 dB, single-layered absorbers outperform double-layered absorbers in terms of yield reduction. Therefore, it can be concluded that if the objective of noise control is to diminish the psychoacoustic parameters of roughness and fluctuating strength at pressure levels exceeding 85 dB, earmuffs equipped with single-layered absorbers would yield superior performance compared to those with double-layered absorbers.

Acknowledgments

This article was extracted from the thesis written by Mahshid Khaki, a student of Occupational Health and Safety Engineering.

Financial support and sponsorship

This study is a research project approved and financially supported by the Isfahan University of Medical Sciences as a Master's Thesis, Grant number: #399706.

Ethics code

This study was also approved by the Ethics Committee of Isfahan University of Medical Sciences, No. IR.MUI.RESEARCH.REC.1399.570.

Conflicts of interest

There are no conflicts of interest.

Authors' contributions

Mahshid Khaki: Data collection and Writing original draft;

Hadi Asady: Validation, Writing review and editing; Samane Khorshidikia: Data analysis and Methodology; Siamak Pourabdian: Validation, Writing review and editing; Farhad Forouharmajd: Conceptualization, Investigation, Writing review and editing.

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