Original Article

Investigating the Psychoacoustic Characteristics of Absorbents used in Common Earmuffs: A Laboratory Study

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Abstract

Introduction: In addition to having auditory effects, sound also has nonauditory effects. Acoustic Annoyance is one of the nonauditory effects of sounds which are construed as psychoacoustic characteristics. The study at hand was undertaken to investigate the psychoacoustic characteristics of absorbents used in common earmuffs. **Materials and Methods:** In this study, four earmuffs prevalent in industries were used. The psychoacoustic characteristics of loudness and sharpness were measured and analyzed in sound levels of 75, 85, and 95 dB using an impedance tube and Va-Lab 4 software with and without absorbers. The results were analyzed with SPSS-26 software. **Results:** Results showed that the highest and the lowest increase in loudness were attributed to the EM-101 and the EM-104, respectively. In addition, with the increase in the sound level, the loudness increased. Furthermore, in 85 dB, there was no significant relationship between loudness and earmuff absorber only in the case of the earmuff EM-103. Furthermore, the highest and the lowest increase in sharpness were, respectively, attributed to the EM-101 and the EM-103. Only in the samples of EM-103 and EM-104 earmuffs at the level of 75 dB, there was no significant relationship between sharpness and earmuff absorber. **Conclusion:** Earmuffs used in industries showed different performances against the loudness and sharpness of the sound. In other words, the quality and the structure of earmuff absorber play noteworthy roles in decreasing the qualitative parameters of sound.

Keywords: Impedance tube, loudness, psychoacoustic, sharpness

INTRODUCTION

Noise is an unwanted and unpleasant sound, which in addition to auditory effects, has nonauditory effects on individuals. The most prevalent auditory effect of noise is hearing loss, and based on previous studies, sleep disturbance and high blood pressure are among the nonauditory effects of noise.[1-3] Furthermore, recent studies have shown that noise could affect individuals' mental health and 6% of the workers' absences at work are caused by mental problems.[4-6] A similar discussable individual in acoustics, is the analysis of nonauditory effects such as noise annoyance, which is a mental reaction to noise.[7] In this regard, the elimination of the sound source, the substitution of quieter equipment, engineering control, administrative controls, and the use of personal protective equipment are among the ways to control and reduce noise exposure.[8]

Qualitative and quantitative parameters are used to study noise in workplaces. Quantitative parameters, such as sound pressure level, are not able to describe an individual's perception and feeling of sound.[9] For example, it has been observed, the sound level does not exceed the standard rate in some workplaces, but people do not have enough comfort.[10] Therefore, in addition to reducing the quantitative parameters, it is necessary to consider the qualitative parameters of the sound. Sound quality parameters are considered psychoacoustic indicators. Psychoacoustics is the study of psychology and physics; it studies the subjective perception of human beings from sound and links sound characteristics to the listener's perception and understanding.[11,12]

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There are various psychoacoustic indicators, including loudness and sharpness. An important noise quality parameter is loudness, based on which sound could be measured from "quiet" to "loud."[13,14] Loudness has been defined as the "magnitude of an auditory sensation."[15] The unit for noise loudness is "Sone." One Sone is equal to the sound intensity level of 40 dB in a frequency of 1 kHz, and Zwicker was the first to put forth a method of measuring noise loudness.[16] Another noise quality parameter is sharpness, which is a sensation quantity dependent on frequency. Noise sharpness causes a sharp or shrill sensation, and its unit is "acum." One acum is equal to the sound intensity level of 60 dB in a frequency of 1 kHz.[17] Bismarck and Aures have proposed the measuring method of noise sharpness.[13]

As mentioned above, one of the most commonplace ways of preventing hearing loss is using earmuffs.[18] In this line, attending to the maximum functionality of this equipment while building them is important.[19,20] In previous studies that have been conducted on the absorbers of protective devices, structural parameters such as transmission loss and the type of earmuff model have been investigated, which aimed to improve the performance of protective devices by reducing the sound that reaches people's ears.[18,21] In addition to this, several studies have been conducted regarding the quality parameters of sound. For instance, the results of a study showed that to improve the sound quality of the car, the absorber plays an efficient role in reducing the loudness of the sound.[22] Lashgari and Arab demonstrated in a study on a tractor that qualitative parameters can affect brain activities.[9] In another study undertaken by Li and Huang, results proved that loudness and sharpness are effective causes of noise annoyance.[23] Yi and Cho's study held that fabric material and its sound characteristic correlated with loudness and sharpness.[24] Following the rustling sounds of fabrics, Cho, *et al*. Found that psychoacoustic parameters correlated with each individual's psychological and physiological responses.[25]

According to the studies conducted regarding psychoacoustic characteristics and their effects on different people, it was necessary to investigate this issue in the case of hearing protection devices, and accordingly, the use of the study results by the manufacturing companies. Therefore, this study was conducted to investigate the psychoacoustic characteristics of the absorbents used in common earmuffs.

MATERIALS AND METHODS

This experimental study took place at the sound and vibration laboratory of the Medical University of Isfahan in 2021. In this study, an ISO 10534-2 impedance tube using the transfer function method,[26] a BSWA MC3642 (by National Instrument USA) sound analysis card for analyzing the digital frequency, a 4230 microphone calibrator (B&K Co. in Denmark) for calibration of microphones and Va-Lab4 was utilized. To carry out this study, four common earmuffs models known in the country's industries were measured. Then, based on the impedance tube cross-section, the EM-101 earmuff absorber with a density of 30 $\frac{kg}{m^s}$, EM-102 absorber with a density of 27.6 $\frac{kg}{m^s}$, EM-103 absorber with a density of 18.63 $\frac{kg}{m^s}$, and EM-104 absorber with a density of 23.6 $\frac{kg}{m^s}$ were prepared with a width of 1.2 cm.

The impedance tube has two parts with a section of 3 cm. On each piece, there are designated three microphone ports. On the middle part of the tube is a port set for absorbers and on one end exists the sound source. The measurement frequency range of the impedance tube was 780–6640 Hz. As was mentioned earlier, the Va-Lab4 was used to measure these indices. It needs to be mentioned that this software, connected to a sound analysis card and amplifier, could turn a computer into a well-equipped device for measuring and analyzing sound, as well as several educational purposes. Furthermore, in Lashgari and Arab's study, the same software was used to measure the noise annoyance parameters.[9]

Before the initiation of the experiment, the calibration of the impedance tube was done using a standard BSWA Technology foam, and the calibration of the microphones was done using a B and K 4230 calibrator, in a frequency of 1 kHz and a sound level of 94 dB.

The common sound levels of industries are 75 dB, 85 dB, and 95 dB.[27] As a result of adjusting the Va-Lab4 software, white noise was disseminated by the sound source in three sound levels of 75 dB, 85 dB, and 95 dB through the impedance tube. The measurement of loudness and sharpness took place by Va-Lab4, switching on the loudness function and Monaural-1 and using the Moore method. Figure 1 shows a view of the system and earmuffs.

Each sound indices in each sound level were tested 30 times with and without an absorber in the impedance tube. Loudness and sharpness within a frequency spectrum of a 1/3 octave band were measured using a sound analysis card and the software Va-Lab4, and the resulting data were shown on the software screen.

The statistical analysis of data was done through the statistical package for the social science-26 (SPSS- 26) (IBM., Armonk.

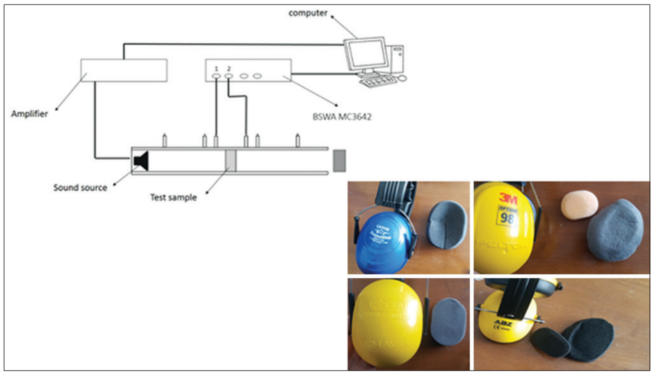

Figure 1: Impedance tube design and 4 model earmuffs

New York, USA). First, the normality of qualitative variants was tested using the Shapiro–Wilk test. The mean index (± standard deviation) was used to describe the qualitative data, and the independent *t*-test was used to identify the significant relationship between the variable. In this test, the mean difference of the dependent variants (loudness and sharpness) was evaluated in two groups with and without absorbers. Furthermore, Spearman's correlation test was used to check the relationship between sound levels and psychoacoustic indices. The significance level was considered to be $P < 0.05$.

RESULTS

Mean loudness and sharpness values were obtained. The mean value and standard deviation for loudness without absorbers in sound levels of 75 dB, 85 dB, and 95 dB were, respectively, 17.48 ± 0.55, 25.26 ± 0.48, and 44.21 ± 1.39. Furthermore, the mean value and standard deviation for sharpness without absorbers in sound levels of 75 dB, 85 dB, and 95 dB were, respectively, 1.56 ± 0.02, 1.62 ± 0.00, and 1.57 ± 0.00.

To investigate the distribution of earmuff absorbent psychoacoustic parameters, mean values were obtained for each parameter of four earmuff models. Table 1 shows the mean value and standard deviation for the loudness and sharpness of earmuffs. The loudness of the sound at the sound level of 75 dB ranged from 11.53 sone (EM-101) to 16.04 sone (EM-104). Furthermore, the loudness of the sound at the sound levels of 85 dB and 95 dB ranged from 18.00 sone (EM-101) to 26.16 sone (EM-104) and 30.86 sone (EM-101) to 40.76 sone (EM-104) in order. In addition, the measurement results showed sharpness the highest and lowest reductions in sound levels at 75 dB and 85 dB are related to the earmuff absorbers EM-101 and EM-103, respectively. Furthermore, the sharpness of the sound at the sound level of 95 dB ranged from 1.36 acum (EM-101) to 1.58 acum (EM-104).

The absorbent role of earmuffs on psychoacoustic parameters was investigated. In fact, the mean loudness and sharpness of the sound in two groups with absorber and without absorber, at the sound levels of 75 dB, 85 dB, and 95 dB, were examined with the independent Samples *t*-test at a 95% confidence interval. Only in the EM-103 earmuff absorber sample at the sound level of 85 dB, there is no significant relationship between loudness and earmuff absorber. The $P = 0.056$ ($P > 0.05$). Furthermore, only in the samples of EM-103 and EM-104 earmuff absorbers at the level of 75 dB, no significant relationship between sharpness and earmuff absorber was found ($P > 0.05$). More details are mentioned in Tables 2 and 3.

The results of Spearman's correlation test showed a significant relationship between sound level and loudness (Spearman's $r = 0.94$, $P < 0.001$). In other words, with the increase of the sound level, the loudness of the sound in the impedance tube has increased, but there was no significant correlation between the sound level and the sharpness of the sound in the impedance tube (Spearman's $r = 0.13$, $P = 0.206$).

DISCUSSION

According to a number of authors, the quantitative noise indices such as sound intensity level could not evaluate the comfort of workers.[10,11] Hence, studying qualitative indices (psychoacoustic) sounds essential. Bearing in mind that one of the ways of preventing hearing loss is using earmuffs, four models of the most common earmuffs were selected to study the psychoacoustic characteristic of the built-in absorbers. Within this study, the psychoacoustic characteristics of the absorbents used in common earmuffs were investigated.

Due to the fact that the sound levels of 75 dB, 85 dB, and 95 dB are known to be common levels in industries,[27] these levels were used in this study as well. To compare the noise indices of loudness and sharpness within these sound levels, the average amount of each index was measured for the earmuff of the aforementioned four models.

Psychoacoustic parameters of absorbent samples are given in Table 1. The results showed that the EM-101 earmuff absorber showed the lowest mean value for the loudness and sharpness of the sound in all measured levels. In other words, it performs better in terms of loudness and sharpness than other phones under review.

Furthermore, results showed that with an increase in sound level, the loudness escalates too. In other words, loudness indices had a positive relation with the sound level. Within the study of Yi and Cho, which focused on the psychoacoustic

Table 1: Descriptive statistics of psychoacoustic parameters of earmuff absorbent samples

Earmuff absorbent sample	Psychoacoustic parameters	Sound levels		
		75 dB	85 dB	95 dB
EM-101	Loudness (sone)	11.53±0.60	18.00±0.42	30.86±5.88
	Sharpness (acum)	1.35±0.04	1.36±0.00	1.36±0.08
EM-102	Loudness (sone)	14.57±0.60	24.47±0.27	38.89±0.67
	Sharpness (acum)	1.51±0.03	1.57±0.00	1.56±0.00
EM-103	Loudness (sone)	15.27±0.41	25.05±0.37	40.09±0.57
	Sharpness (acum)	1.56±0.01	1.58±0.00	1.57±0.00
EM-104	Loudness (sone)	16.04±0.61	26.16±0.73	40.76±1.57
	Sharpness (acum)	1.55±0.02	1.58±0.01	1.58±0.00

Table 2: Comparison of the with-absorber and without-absorber group loudness mean values at different sound levels

Earmuff absorbent sample	Sound levels (dB)	Mean±SD	*P*	95% CI	
				Minimum	Maximum
EM-101	75	−5.94±014	0.001	−6.24	−5.64
	85	−7.26±0.11	0.001	−7.49	−7.02
	95	−13.35±1.10	0.001	−15.60	−11.10
EM-102	75	−2.91±0.14	0.001	−3.20	−2.61
	85	−0.79±0.10	0.001	−1.00	−0.59
	95	−5.32±0.28	0.001	−5.89	−4.75
EM-103	75	−2.21±0.12	0.001	−2.64	−1.95
	85	−0.21±0.11	0.056	−0.44	−0.00
	95	−4.12±0.27	0.001	−4.67	−3.56
EM-104	75	−1.44±0.15	0.001	−1.74	−1.14
	85	0.89±0.16	0.001	0.57	1.21
	95	−3.44±0.38	0.001	−4.21	−2.67

SD: Standard deviation, CI: Confidence interval

Table 3: Comparison of the with-absorber and without-absorber group sharpness mean values at different sound levels

Earmuff absorbent sample	Sound levels (dB)	Mean±SD	*P*	95% CI	
				Minimum	Maximum
EM-101	75	−0.211±0.009	0.001	−0.230	−0.191
	85	−0.0258±0.001	0.001	−0.262	−0.255
	95	−0.181±0.014	0.001	−0.211	−0.150
EM-102	75	−0.052±0.007	0.001	−0.067	−0.036
	85	−0.050±0.002	0.001	−0.054	−0.046
	95	0.009±0.001	0.001	0.012	0.007
EM-103	75	0.001±0.005	0.863	−0.010	0.012
	85	−0.037±0.001	0.001	−0.040	0.034
	95	0.004±0.001	0.001	−0.007	−0.000
EM-104	75	−0.010±0.007	0.161	−0.024	−0.004
	85	−0.041±0.002	0.001	−0.046	−0.036
	95	−0.009±0.001	0.001	−0.006	−0.011

SD: Standard deviation, CI: Confidence interval

characteristic of fabrics and their comparison with the physical parameters using the Zwicker method, the results revealed that loudness had a positive relation with the sound level.[24] In another study, by analyzing the fundamental differences every fabric material could bring about on sound parameters, Kim, *et al*. maintained that loudness was in a positive relation with the sound level.[28] Although the aim of the present study and the two-mentioned studies were different, all three studies pointed to the increase in loudness at high levels compared to low levels.

One of the findings of this study was the relationship between earmuff absorbent and loudness. For this aim, the loudness indices of two groups with absorber and without absorber were measured. The results showed that there is a significant relationship between the earmuff absorber and the loudness, except for the EM-103 model earmuff absorber at the level of 85 dB. In other words, one could claim that using an earmuff could have an effective role in decreasing noise loudness and subsequently, decrease the risk of noise annoyance for an individual.

Comparing the sharpness in two groups with absorber and without absorber, it could be claimed that there is a significant relationship between earmuff absorber and sharpness, and it is only in the earmuffs absorbers EM-103 and EM-104 that no significant relationship was observed at 75 dB.

Furthermore, the findings of this study indicated that the elevation of sound level had caused no alteration in the sharpness. This is quite in line with the study done by Yi and Cho, within which they maintained that sharpness is not in relationship with the overall sound intensity.[24] By analyzing the relationship between sound parameters and the fabric's mechanical characteristics using the Zwicker model, Jin and Cho stated that sharpness is not under the influence of sound level intensity, which is also what the study at hand claims.[29] In general, the results of the studies showed that sharpness is not related to sound level.

The findings of this study could be of vital importance in designing absorbers. As a matter of fact, manufacturers could satisfy the consumer by evaluating and controlling the qualitative, as well as quantitative parameters, and hence be able to witness a rise in their product sales. Due to the current situation, it was not possible in this study to scrutinize all of the earmuffs with different widths that exist in the market. It is suggested to study more absorbers in future studies. Furthermore, due to the type of software measurement, it was not possible to analyze the sound indices in one-third octave band frequency. It is recommended to use several similar software and more facilities to analyze various frequencies. Furthermore, sufficient information was not available regarding the earmuff absorber materials. Future studies could measure psychoacoustic parameters using sufficient information about earmuff absorbers. In addition, it is suggested that when the individual confronts noise (with and without earmuffs), the relationship between psychoacoustic parameters and the individual's mental perception be scrutinized and closely studied.

CONCLUSION

This study was conducted to investigate the psychoacoustic characteristics of absorbents used in common earmuffs. Earmuffs used in industries showed different performances against the loudness and sharpness of the sound. Probably, the density and structure of the earmuff have a vital role in the relationship between absorbing and reducing loudness and sharpness. Due to the lack of knowledge of the authors about the structure of the absorbents used in earmuffs, it is not possible to express this issue with certainty. To identify its related factors, further investigation is needed in future studies. In addition, with the increase in sound level, the level of loudness increased, but there was no change in the level of sharpness. This information about psychoacoustic characteristics could aid manufacturers in the design and manufacture of materials used in earmuffs, as well as raising awareness about the qualitative parameters of sound.

Ethics code

The ethics code was IR.MUI.RESEARCH.REC.1399.569.

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Conflicts of interest

There are no conflicts of interest.

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