Original Article

Correlation between Reduced Work Speed and Noise Annoyance Due to Exposure to Low-Frequency Noises

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Abstract

Aim: Low-frequency sounds are generated from many sources in both the occupational and nonoccupational environments. Hence, the aim of this study was to investigate the effect of low-frequency noise (LFN) on the working speed and the rate of annoyance of the subjects under study. **Materials and Methods:** This cross-sectional/interventional study was performed in the sound and vibration laboratory of Isfahan University of Medical Sciences in 2019. Simple random sampling was used to select the subjects. In this study, the working speed of the subjects was evaluated using mental arithmetic test and the rate of the perceived annoyance was measured using ISO 15666 in Likert format (0–11) due to exposure to noise sources. Mann–Whitney U-test was used to analyze the data. **Results:** There was a significant statistical difference in the rate of the individuals' working speed Between 0 and 90 min at the frequency of 125 Hz and the sound level of 95 dB ($P = 0.029$). There was a statistically significant difference between the frequencies of 125 and 1000 Hz at the sound pressure level of 85 dB and the 45 min time ($P = 0.001$) and 90 min ($P = 0.001$) as well as at the 95 dB sound pressure level at 45 min ($P = 001$) and 90 min ($P = 0.001$). **Conclusion:** The results of the present study showed that increasing sound pressure levels and the exposure time in both LFN and high-frequency noises, increased the working speed and the amount of perceived annoyance in individuals.

Keywords: Annoyance, low-frequency noise, sound pressure level, speed, time

Introduction

Low-frequency noise (LFN) is usually defined as a broadband noise with the dominant content of 10-250 Hz or 20-250 Hz frequencies.[1] In general, LFN is generated by many sources such as pumps, compressors, fans, air conditioners, air and road transport, boilers as well as some home appliances such as washing machines, hair dryers, and refrigerators. In addition to these sources, which are human resources, some natural events such as wind, earthquake, and lightning also have LFN.[2] Hence, LFN exposure is not only limited to working in certain industries but can also be present in many leisure activities and environmental conditions such as transport.[3] Since some studies have shown that similar to the high-frequency noise, LFN can also cause a number of health damages.[4] Therefore, the World Health Organization has devoted special attention to LFN as an environmental problem.[5] The LFNs are associated with the effects such as headaches, unusual fatigue, lack of concentration, anger, and pressure on the eardrum, mental annoyance, and sleep disturbances.[6] These effects are also more pronounced in the sensitive subjects to the LFN than in nonsensitive subjects.[7] Some studies have shown that some reactions to exposure to LFN such as fatigue, headache, anger, and the concentration problems from exposure have a greater impact on reducing the performance capacity of individuals.[8,9] On the other hand, the LFNs of human resources cause more physiological responses such as stress and feelings of irritation due to the negative attitude of people towards the occupational noise sources.[10,11] Many studies have been conducted to determine the effects of LFN on individuals but no consistent results have so far been reported.[2,12] For instance, one study demonstrated that LFN reduces the time required to perform mathematical calculations in noise-sensitive individuals.

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Furthermore, another study has shown an increase in the time to perform mathematical calculations during exposure to LFN.[13,14] Some studies have shown that LFN causes higher performance errors than high-frequency noise.[15,16] Exposure to LFN can also alter the speed of mental analysis.[14]

Since the new working conditions require a person to be very careful while working, process a lot of information and make decisions, it seems that users will need to perform processes with great care and concentration and high information processing while dealing with LFN.[17] On the other hand, other studies have shown that LFNs can also cause mental annoyance in individuals.[4,14] Other studies have shown that annoyance can impair mental functioning of individuals.[16,18] Thus, regarding the importance of this issue about the effect of LFN on mental analyses and performance in the present study, the effect of LFNs with sound pressure levels of 75, 85, and 95 dB on the working speed and annoyance of individuals were analyzed during the mathematical calculations.

Methods Statistical Population and Inclusion Criteria

This cross-sectional/interventional study was performed in in the Sound and Vibration Laboratory of the Faculty of Health in 2019. One of the inclusion criteria was hearing health (hearing loss of <25 dB). In this study, audiometric test was used to assess the hearing health of individuals. Moreover, lack of sensitivity and irritation to the LFNs was another inclusion criterion to the study. Sensitivity and irritation were also measured using standard questionnaires. Ultimately, out of 21 volunteers participating in the study, 13 male and female students of Isfahan University of Medical Sciences with low sensitivity and irritation to LFNs and with hearing health were included in this study. It should be noted that the subjects were simple randomly selected in this study.

The sensitivity to LFN was assessed by a questionnaire according to the ISO 15666 standard. The questionnaire consisted of three questions and each question had five rating scales ranging from "entirely agreed" to "entirely disagree." Individuals with a score ≥"9" were classified into the high-sensitivity group to the LFNs and the rest were considered in the low-sensitivity group. The noise irritation was also assessed by a numerical scale in accordance with ISO 15666.[19] People with the irritation, rating ≤5, were divided into the group with no irritation to the LFN.

Study plan

After entering the laboratory, the subjects performed the tests at the times "zero" (resting and unexposed), 45 and 90 min (noise exposure modes). Sinusoidal noises at three frequencies equal to the 125, 250, and 1000 Hz and three pressure levels of 75, 85, and 95 dB were used as the noise sources. Because of the three frequencies and the three sound pressure levels, each individual was exposed the total 9 times in 9 different days to different noises, each time with 125 Hz of noise with 75, 85, and 95 dB sound pressure levels, as well as 250 Hz with 75, 85 and 95 dB sound pressure levels, and 1000 Hz with 75, 85, and 95 dB. The fatigue of individuals was also measured at 30, 60, and 90 min (noise exposure modes). Meanwhile, all the subjects were exposed to the same conditions when exposed to noise for the homogeneity of the intervening factors. (the processor card used in this study (DAQ) was made by National Instrument (USA).) was used to generate the noise. A calibrated microphone was installed to measure the sound level in the person's hearing area to measure the sound level heard by the person and transmit it to the Lab View software. Furthermore, for more reliability, the sound level in the individual's hearing area was measured using a calibrated sound level meter. In this way, the sound pressure was adjusted to the desired level. The mental arithmetic test as well as the annoyance test was performed on the subjects to measure their working speed and mental annoyance.

Speed test

Mental Arithmetic Test was performed by the subjects. The test was written as 15 numerical fractions with a two-digit number denominator and a single-digit denominator with two decimal places. In order to achieve the time required to perform the mentioned 15 divisions, a pilot study was performed on 12 individuals and based on the results of the pilot study, the time of 3 min was chosen as the duration of the numerical calculations. In order to measure the speed of the work done by the participants, the number of the fulfilled divisions up to two decimal places was used to measure the working speed regardless of the correct or incorrect answers.

Annoyance test

Furthermore, the level of annoyance perceived by ISO 15666 was measured on a 0-10 Likert scale (by 0 demonstrating no sense of annoyance and 10 indicating maximum sense of annoyance).[20] This questionnaire has been used in studies conducted on the Iranian population.[12]

Fatigue test

The test was evaluated in the Likert scale ranging from 0 to 10 (0 indicating no fatigue, while 10 indicates maximum fatigue). This questionnaire has been used in studies conducted on the Iranian population.[21]

Statistical analysis

The obtained Information was analyzed using the IBM Co. Armonk city, New York, USA. In the descriptive statistics section, the mean and standard deviation were used for the quantitative data and the percentage was used for the qualitative data. Mann–Whitney U-test was used to investigate the relationship between independent variables and two dependent variables. $P < 0.05$ was considered as the significant level.

Results

Demographic conditions

In terms of gender, out of the subjects, 7 (53.8%) were female and 6 (46.2%) were male. The mean age of the subjects was 24.84 years with a standard deviation of 3.28 years. The level of education indicated 8 people (61.5%) with master's degree and the rest (38.5%) had bachelor's degree. Furthermore, 100% of the subjects were single in terms of marital status.

Results of the fatigue test

Comparison of subjects' perceived irritation at 30, 60, and 90 min at any of the frequencies and sound pressure levels showed no statistically significant difference.

Results of the speed test

Comparison of working speed between frequencies of 250 and 1000 Hz at 95 dB sound level and the time of 90 min ($P = 0.025$) showed a significant statistical difference [Table 1].

There was no statistically significant difference between the rates of working speed in any of the sound pressure levels. In general, it was observed that increasing the sound pressure level at different frequencies increases the working speed [Table 2]. There was a significant difference between the rate of working speed of the subjects between 0 and 90 min at 125 Hz and 95 dB sound levels ($P = 0.029$). Moreover, the statistical significant difference was observed at 1000 Hz frequency between 0 and 45 min and 75 dB sound pressure level ($P = 0.049$), between 0 and 90 min at 85 dB sound level ($P = 0.018$), and in the sound pressure level of 95 dB between 0 and 45 min ($P = 0.033$) and between 0 and 90 min ($P = 0.005$). In general, it was observed that increasing the exposure time at different frequencies increases the working speed [Table 3].

Annoyance test results

Comparison of subjects' perceived annoyance between the frequencies of 125 and 250 Hz at 95 dB sound pressure level and the time of 45 min ($P = 0.038$) showed a significant difference. There was a statistical significant difference between the frequencies of 125 and 1000 Hz at 85 dB sound pressure level and the times of 45 min ($P = 0.001$) and 90 min ($P = 0.001$) as well as at 95 dB sound pressure level at the times of 45 min (001) and 90 min ($P = 0.001$). In addition, there was a statistical significant difference between the frequencies of 250 and 1000 Hz at the sound pressure level of 85 dB at 45 min ($P = 0.001$) and 90 min ($P = 0.001$) and at the sound pressure level of 95 dB at 45 min ($P = 0.001$) and 90 min ($P = 0.001$) [Table 1]. Comparison of the subjects' perceived annoyance at a constant frequency and time and different sound pressure levels in some cases showed a statistically significant difference. In general, the results showed that with increasing sound pressure level, people become more annoyed [Table 2].

The results also showed that people become more annoyed with increasing exposure time [Table 3].

Discussion

Totally, few studies have been conducted to compare the effect of high-frequency noises with LFNs on the working speed and the degree of annoyance of individuals. One study showed the effect of LFN on the increase working speed in individuals,[14] but the results of another study showed the decrease in the working speed.[22] Concerning the annoyance,

Table 1: Comparison of speed and annoyance scores in sound pressure level and constant time and different frequencies

Time		0 (min)				45 (min)				90 (min)			
SPL*	Frequency (Hz)	Speed		Annoyance		Speed		Annoyance		Speed		Annoyance	
		Mean rank	P	Mean rank	P	Mean rank	P	Mean rank	P	Mean rank	P	Mean rank	P
75 dB (A)	125	12.35	0.422	13.92	0.611	12.42	0.431	15.50	0.167	12.12	0.313	16.23	0.065
	250	14.65		13.08		14.58		11.50		14.88		10.77	
	125	13.85	0.811	12.92	0.575	12.62	0.522	13.69	0.894	12.88	0.659	14.81	0.373
	1000	13.15		14.08		14.38		13.31		14.12		12.19	
	250	15.31	0.204	12.62	0.348	13.77	0.841	11.69	0.215	14.19	0.605	11.08	0.098
	1000	11.69		14.38		13.23		15.31		12.81		15.92	
85 dB (A)	125	13.38	0.937	13.62	0.902	12.54	0.503	12.77	0.617	11.58	0.173	13.85	0.813
	250	13.62		13.38		14.46		14.23		15.42		13.15	
	125	12.54	0.509	13.65	0.870	12.27	0.385	8.46	0.001	10.96	0.068	7.85	0.001
	1000	14.46		13.35		14.73		18.54		16.04		19.15	
	250	12.81	0.637	13.58	0.935	12.88	0.662	8.69	0.001	12.31	0.368	8.15	0.001
	1000	14.19		13.42		14.12		18.31		14.69		18.85	
95 dB (A)	125	12.15	0.348	13.58	0.945	11.85	0.236	10.46	0.038	14.23	0.590	10.73	0.060
	250	14.85		13.42		15.15		16.54		12.77		16.27	
	125	12.58	0.521	14.58	0.253	10.85	0.051	7.54	0.001	11.69	0.102	7.12	0.001
	1000	14.42		12.42		16.15		19.46		15.31		19.88	
	250	13.96	0.744	14.54	0.270	12.27	0.331	8.04	0.001	10.77	0.025	7.27	0.001
	1000	13.04		12.46		14.73		18.96		16.23		19.73	

*Sound pressure level

Table 2: Comparison of speed and annoyance scores in frequency and constant time and different sound pressure levels

Time		0 (min)				45 (min)				90 (min)			
Frequency	SPL	Speed		Annoyance		Speed		Annoyance		Speed		Annoyance	
		Mean rank	*P*	Mean rank	*P*	Mean rank	*P*	Mean rank	*P*	Mean rank	*P*	Mean rank	*P*
125 (Hz)	75	14.23	0.619	11.35	0.870	14.04	0.707	14.81	0.366	14.31	0.576	15.42	0.190
	85	12.77		11.65		12.96		12.19		12.69		11.58	
	75	14.31	0.582	12.85	0.526	14.00	0.723	15.35	0.204	12.42	0.432	15.58	0.159
	95	12.69		14.15		13.00		11.65		14.58		11.42	
	85	13.19	0.833	13.08	0.682	13.31	0.894	13.85	0.810	11.35	0.126	14.00	0.732
	95	13.81		13.92		13.69		13.15		15.65		13.00	
250 (Hz)	75	15.31	0.214	13.08	0.611	14.85	0.333	12.04	0.317	14.23	0.587	11.85	0.261
	85	11.69		13.92		12.15		14.96		12.77		15.15	
	75	14.04	0.706	12.58	0.327	13.69	0.886	10.35	0.032	14.35	0.532	9.81	0.013
	95	12.96		14.42		13.31		16.65		12.65		17.19	
	85	12.08	0.321	13.00	0.628	12.23	0.358	11.31	0.130	13.69	0.888	10.81	0.065
	95	14.92		14.00		14.77		15.69		13.31		16.19	
1000 (Hz)	75	13.46	0.978	14.08	0.575	13.81	0.822	9.81	0.012	12.46	0.427	8.35	0.001
	85	13.54		12.92		13.19		17.19		14.54		18.65	
	75	13.23	0.853	14.54	0.270	12.23	0.317	7.88	0.001	11.23	0.053	7.23	0.001
	95	13.77		12.46		14.77		19.12		15.77		19.77	
	85	13.42	0.958	14.00	0.547	12.08	0.263	9.19	0.004	12.15	0.192	8.69	0.001
	95	13.58		13.00		14.92		17.81		14.85		18.31	

SPL: Sound pressure level

Table 3: Comparison of speed and annoyance scores in frequency and constant sound pressure level and different times

SPL		75 dB (A)				85 dB (A)				95 dB (A)			
Frequency	Time (min)	Speed		Annoyance		Speed		Annoyance		Speed		Annoyance	
		Mean rank	*P*	Mean rank	*P*	Mean rank	*P*	Mean rank	*P*	Mean rank	*P*	Mean rank	*P*
125 (Hz)	0	12.46	0.469	7.65	0.001	12.27	0.399	8.46	0.001	11.77	0.233	9.08	0.002
	45	14.54		19.35		14.73		18.54		15.23		17.92	
	0	12.42	0.456	7.58	0.001	12.42	0.463	7.85	0.001	10.35	0.029	7.54	0.001
	90	14.58		19.42		14.58		19.15		16.65		19.46	
	45	13.46	0.978	10.04	0.018	13.69	0.895	10.54	0.045	11.62	0.175	10.62	0.050
	90	13.54		16.96		13.31		16.46		15.38		16.38	
250 (Hz)	0	12.31	0.390	8.65	0.001	11.38	0.145	7.81	0.001	12.04	0.293	7.42	0.001
	45	14.69		18.35		15.62		19.19		14.96		19.58	
	0	12.00	0.277	7.92	0.001	10.96	0.078	7.23	0.001	12.27	0.383	7.08	0.001
	90	15.00		19.08		16.04		19.77		14.73		19.92	
	45	13.31	0.883	11.46	0.166	12.38	0.411	10.62	0.049	13.92	0.757	10.42	0.036
	90	13.69		15.54		14.62		16.38		13.08		16.58	
1000 (Hz)	0	10.69	0.049	7.35	0.001	11.46	0.157	7.00	0.001	10.58	0.033	7.00	0.001
	45	16.31		19.65		15.54		20.00		16.42		20.00	
	0	11.19	0.108	7.04	0.001	10.15	0.018	7.00	0.001	9.85	0.005	7.00	0.001
	90	15.81		19.96		16.85		20.00		17.15		20.00	
	45	13.77	0.843	10.69	0.056	12.50	0.445	8.38	0.001	12.54	0.307	9.54	0.007
	90	13.23		16.31		14.50		18.62		14.46		17.46	

SPL: Sound pressure level

a study showed that high-frequency noise had a fewer effect on the increasing annoyance than the LFNs.[23] On the other, a study has shown higher effect of high-frequency noise as compared to the low-frequency.[24]

The factors such as sound pressure level, sound frequency bandwidth, type of study plan, and the demography of study subjects can influence the sound-induced effects.[25,26] And are expected to vary with the sound pressure level of the observed effects in each case.[12,27,28] The effects of changes in sound pressure level, frequency, and exposure time was investigated in this study on the working speed and the rate annoyance.

Regarding the sound pressure levels, and since 75, 85, and 95 dB levels are commonly recognized as common sound pressure levels in the industry.[29] And also, considering the OSHA standard, i.e., OSHA (PEL: 90-dBA for 8-hour exposure and exchange rate: 5 dB),[30] the sound pressure levels of 75, 85, and 95 dB were used in this study to evaluate the effects. Furthermore, in correctly realize the effects of LFN (considering more knowledge of the effects of high-frequency noise), the effects of LFN with 125 and 250 Hz were compared with regards to the exposure to 1000 Hz. In order to evaluate the effect of working time and speed as well as the rate of annoyance were measured before the exposure (time "zero"), 45 and 90 min after the exposure.

The results of this study showed that exposure to both the LFN and high-frequency noises compared to the state of nonexposure to these frequencies increased the working speed of individuals, although the observed differences were not statistically significant. However, it was observed that exposure to high-frequency noises has more effects on the working speed of individuals as compared to that of the LFNs. This result was consistent with the results of other study.[22] The result of the studies demonstrated that exposure to the high-frequency noises has a greater impact on speeding up the work than the LFNs. On the other hand, the results of some other studies were contrary to the findings of this study, in which the results of the study of Bengtsson *et al*., as well as the study of Kazempour *et al*. showed that LFNs increase the working speed of individuals as compared to the high-frequency noises.[14,31] It seems that the reasons such as the presence of people sensitive to LFN and the high exposure time in the Bengtsson study, and the reason for the low sound pressure level in the Kazempour study have caused contradictions in the findings. Since exposure to noise causes mental stress and more irritation in exposed people,[32] in response to this stressor as a defensive reaction, the exposed individuals in such conditions like to speeds up their work and release themselves from the stressful situations.[13]

The results of the present study indicated that high-frequency noises cause more mental annoyance than the LFNs in individuals. This finding was consistent with the results of a study that high-frequency noises were more annoying than the LFNs.[24] However, a study by Leventhall *et al*. showed that the exposure to LFN causes more mental annoyance in the subjects compared to the high-frequency noises.[23]

It seems that the reason for the inconsistency of the results of this study with that of Leventhall's study includes the presence of noise-sensitive individuals, as well as the type of sound used in the study. According to the findings of this study, it seems that a higher to reach a definite level of annoyance, a higher sound pressure level is required for the LFNs as compared to the high-frequency noises.[33]

Another affecting parameter in the rate of mental annoyance is the sound pressure level. The results of this study showed that the level of annoyance of the individuals in LFN and high-frequency noises increases with increasing the sound pressure level. This finding was consistent with results achieved from other studies.[34,35] However, the results of the present study demonstrated that high-frequency noises cause more annoyance in the people compared to LFNs at the same sound pressure level. These results were not consistent with the study by Persson *et al*. as well as the results of the study by Leventhall *et al*., which showed that LFN causes more annoyance in individuals compared to high-frequency noises at the same sound pressure level.[23,36] The reasons for the inconsistency can be found in the low sound pressure levels used in the Persson study and the type of study plan in the Leventhall study. In general, all noise effects are dependent on the sound pressure level of the noise exposure and it is expected that with increasing sound pressure level the effects will usually increase as well.[16] Exposure to levels above 80 dB affects the endocrine glands and increases the secretion of cortisol.[37] In such conditions, as the level of this hormone in the blood is increased, it is expected that the blood pressure will rise and eventually increase the stress in the person and that the increase in stress can cause annoyance.[38] As a result, exposure to higher sound pressure levels may increase the annoyance.

Increasing the exposure time to low and high-frequency noises can also increase the amount of annoyance. This finding was consistent with the results of other studies.[33,34] Studies have shown that exposure to noise can cause symptoms such as tinnitus and pressure on the tympanic membrane.

Furthermore, it has been observed that the aforementioned symptoms sound pressure level with increasing the exposure time,.[34,39] On the other hand, tinnitus can lead to annoyance in individuals.[34] In addition, the study by Borsky *et al*. showed that the increased exposure time to noise can act as a irritation factor in individuals, which is seen in individuals with the feelings of irritation and annoyance.[40] The increased exposure time can also increase blood pressure and followed by the increasing mental annoyance.[35] In such conditions, it seems that increasing the exposure time to noise through various mechanisms such as tinnitus, feeling pressure on the tympanic membrane, as well as causing dissatisfaction and irritation, can cause annoyance in the individuals. Since our study was conducted under laboratory conditions, the relevance of its results to actual work situations should be carefully evaluated.

Conclusion

Exposure to all the different noises (LFN and high-frequency noises) increases the working speed in the individuals. In addition, the effect of high-frequency noises on the working speed was greater than that of the LFNs. Moreover, the speed of work increases with increasing sound pressure level and exposure time for both the LFN and high-frequency noise. Concerning the annoyance LFNs annoyance have a fewer effect on the amount of annoyance experienced in individuals as compared to the high-frequency noises. This effect has direct relations with the sound pressure level and duration of exposure to both the LFN and high-frequency noises.

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Conflicts of interest

There are no conflicts of interest.

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