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The Influences of Individual Sensitivity, Sound Frequency, and Sound Pressure Level on Cognitive Performances of Students

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ABSTRACT

Low-frequency noise is annoying even at lower levels and affects cognitive functions of individuals. Some individual differences, such as sensitivity, can reduce or increase the effects of noise on cognitive performance. This study investigated the effect of noise sensitivity on cognitive performance in the presence of low-frequency noise. In this experimental study, 120 fourth-year seniors in the field of health sciences year from Hamadan University of Medical Sciences, Iran were selected through purposive sampling (60 students with high sensitivity and 60 students with low sensitivity). All the participants were exposed for 40 min to the noise levels of 50, 60, and 70 dB at the frequencies of 125 and 250 Hz, during which, the cognitive performance of the subjects was examined using the Integrative Visual-Auditory Continuous Performance Test (IVA CPT). Data were analyzed by independent t-test, and ANOVA test in SPSS 20.0 software. The low-frequency noise negatively affected the components of cognitive performance so that with increasing the sound pressure level (SPL) from 50 to 70 dB and from 125 to 250 Hz ($P<0.05$), the components of cognitive performance decreased. The results also showed that in female subjects with high sensitivity, cognitive performance components were more affected than the male subjects with low sensitivity ($P<0.05$). The components of attention and work quality reduced with increasing SPL, and this negative effect of low-frequency noise was higher in women with high sensitivity.

KEYWORDS: *Low-frequency noise, Individual sensitivity, Cognitive performances*

INTRODUCTION

Low-frequency noise has been defined as a broadband noise (BBN) within the frequency range of 10 to 250 Hz [1-3]. Low-frequency noise, in addition to the industrial places, is found in public environments.

The use of new techniques, especially new digital techniques, has reduced the level of noise in industries. However, more use of new devices and technologies in public environments, such as ventilation systems, compressors, computers, printers, etc., is associated with the emission of annoying low-frequency noise.

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Low-frequency noise is generally generated from different sources, such as ventilation systems, pumps, compressors, diesel engines, gas turbines, and transport vehicles. It is therefore expected that these sounds be found in various industrial units, such as the control room as well as in residential areas and offices [2-4].

Among the many reported symptoms of low-frequency noise exposure, irritability and headache have the most correlation with reduced work capacity [5]. The most important effects of low-frequency noise on human health include fatigue, difficulty in focus, and feeling pressure on the head and eyelids. Many new occupations require special precision during information processing and may face unforeseen circumstances. Noise has different effects on human, e.g. low-frequency noise affects cognitive performance of individuals.

There are complex and multidimensional relationships between exposure to low-frequency noise and cognitive performance [6]. Griefahn and Robens in 2010 declared that low-frequency noise has adverse effects on cognitive performances of people [7]. Taylor et al. (2004) claimed that noise exposure improves the cognitive performance [8]. Due to these contradictions in relation to the effects of noise on cognitive performance, the inverted U-hypothesis was introduced to explain the relationship between noise exposure and individual cognitive performance [9]. Although many studies have been conducted to understand the effects of low-frequency noise on cognitive performance, conclusive and consistent results have not yet been obtained and the results are contradictory [2,10-11]. In general, these differences can be associated with the different sensitivity of individuals to noise and particularly, to low-frequency sound levels [12].

The present study investigated the effect of low-frequency noise, at the intensities common in industries, on cognitive performance of students with an emphasis on the role of the individuals' sensitivity. For this purpose, Integrative Visual And Auditory Continuous Performance Test (IVA CPT) was conducted during exposure to different sound pressure levels (SPLs) of 50, 60, and 70 dB and at two frequencies of 125 and 250 Hz.

MATERIALS AND METHODS

A written consent was obtained from the study group. The purpose of the study was explained to the participants and they were enrolled voluntarily.

Participants: In this experimental study, the research population consisted of all students of Hamadan University of Medical Sciences, Iran. Overall, 120 fourth-year seniors in health sciences were selected randomly through purposive sampling (60 students with high sensitivity and 60 students with low sensitivity). The study was conducted in 20117.

Inclusion and exclusion criteria: The ***i***nclusion criteria were age range of 20 to 30 years, no medication use affecting consciousness at the time of testing, no color blindness, having normal hearing, no history of cardiovascular diseases, no respiratory problems, and no sleep disorders. After final selection of the subjects, all of the tests were explained completely to them. Based on previous studies, the sample size was estimated to be 120 people [13].

Study design: IVA CPT was used to measure the cognitive performance of the subjects. This tool is one of the continuous performance tests, which was first introduced in 1956, and quickly became popular [14]. The test has different types. In the present study, its numeric version was used that measures hearing attention items in addition to the items of visual attention. It consists of three target motivators for the visual part and five target motivators for auditory part.

During the test, the subjects should click after hearing and seeing the target stimulus. The test lasts for about 10 min and measures the types of attention, reaction time, and concentration. Visual reaction time, auditory reaction time, visual selective attention, auditory selective attention, visual intermittent attention, auditory intermittent attention, visual continuous attention, auditory continuous attention, visual focused attention, auditory focused attention, visual divided attention, auditory divided attention, visual vigilance, auditory vigilance, visual speed, and auditory speed were the variables we measured during the test.

The Persian version of this test has a reliability coefficient (Cronbach's alpha) of 0.93 [15]. This cognitive test was performed when the subjects were being exposed to the sound pressure levels of 50, 60, and 70 dB (as common noise levels in workplaces).

The sensitivity to low-frequency noise was determined by a questionnaire, which was based on ISO 15666 [16]. The reliability coefficient of this questionnaire was determined through ''Test re-Test'', which was 0.89. Based on the questionnaire, the subjects were divided into two groups with high sensitivity and low sensitivity to the low-frequency noise. The questionnaire consists of three questions and each question has five response grading scales from totally agree (1) to totally disagree (5). In this regard, the subjects with scores higher than or equal to 9 were classified into the high-sensitivity group or LFN+, and the rest were classified into the group with low sensitivity or LFN- [4,17]. Noise Generation Program was used to generate sounds at the considered frequencies. This tool is strong software for generating noise at different frequencies, especially at low-frequency sound levels. During the noise broadcast, SPL was measured near the ears of the individuals and their seats. The measurements were done using a noise level meter (SVANTEK 971 model, made in Poland -America) based on the IEC 61672 standard. This device can analyze the sound levels at either 1:1 or 1: 3-octave bands. Spherical speakers with an SWA-100 amplifier were used to amplify low-frequency noise that was similar to workplace noise. The research was conducted in an ergonomic laboratory, 4x5 m in size, designed for such research. The equivalent noise level in the chamber is lower than 30 dB when its door is closed. The inner surfaces of the test area, including walls and ceiling, were made from plaster and its floor from stone, which were similar to the real environment. The average of Noise Reduction Coefficient (NRC) for each of the used materials was determined in the central frequencies of 1000, 2000, 500, and 250 Hz in accordance with the following equation:

$$NRC = \frac{a250 * a500 * a1000 * a2000}{4} \text{ i or } \alpha \quad (1)$$

The NRC of the entire test environment was obtained according to the following equation:

$$\frac{\sum si\ \alpha i}{\sum S} = \alpha \quad (2)$$

Where;
Si= Absorbent surface area (m^2).
Iα = Absorption coefficient of each absorbent.
S= Total area of the test environment.

The NRC value for the whole test environment was equal to 0.60, which was similar to the real environment. The subjects were investigated under all of the mentioned noise levels. After each step, the groups were changed to remove the effect of sequential exposure to noise. Upon entering the laboratory room, subjects rested for 15 min until their body returned to the normal cycle.

After completing the questionnaire of sensitivity to low-frequency noise, each subject was exposed to the noise levels under the test environment for 40 min. The cognitive performance tests lasted 10 min, and each subject responded to the questions within 30-40 min. There was a 20 min break between each stage, during which, the participants were served with a sweet beverage to prevent hypoglycemia and distortion of results.

Statistical analyses: The data were analyzed using multivariate ANOVA and independent t-test in SPSS software (Ver. 20, Chicago, IL, USA), developed by IBM.

RESULT

The average ±standard deviation of the subjects' age was 23.94±3.25, with a minimum of 20 years and a maximum of 30 years. The subjects' gender did not have a uniform distribution. Approximately, 85% of the participants were single and the rest were married. Most of the participants (80%) were undergraduates. Tables 1 and 2 demonstrate the mean and standard deviation of the variables based on the sensitivity and noise frequency levels, respectively. Table 3 presents the effect of three variables of frequency, sound pressure level (SPL), and personal sensitivity on cognitive performance. The individuals' cognitive performance decreased with increasing SPL. In addition, the reduction of auditory components was statistically significant ($P<0.05$). While the visual-auditory components, including vigilance and speed improved significantly, but there was no significant decrease in the visual components of attention ($P<0.05$).

Moreover, the visual-auditory components of the reaction time improved with increasing SPL so that the reaction time to the corresponding stimuli decreased with increasing the SPL. The sensitivity to low-frequency noise can further decrease the components of cognitive performance. There was also found a significant difference between the groups with high and low sensitivity ($P<0.05$) in terms of attention auditory components and the visual-auditory components of vigilance and reaction time. In the subjects with high sensitivity, the reaction time was lower and the speed was higher than those with low sensitivity ($P<0.05$) (Table 3). This phenomenon may reduce the types of attention in people with high sensitivity. The reduction of visual attention components in two groups was not statistically significant ($P>0.05$). However, there was a decrease in the subjects with high sensitivity, descriptively. Table 3 also shows the integrative effect of these variables on the participants' cognitive performance. The integrative effect of noise frequency and sensitivity on participants' cognitive performance was insignificant in all cases.

Likewise, the integrative effect of noise frequency and sound pressure level was also insignificant in all cases. Similar results were found for the integrative effects of noise frequency, sound pressure level, and individuals' sensitivity. However, the integrative effect of individuals' sensitivity and sound pressure level was significant in some cases, i.e. auditory reaction time, visual reaction time, auditory selective attention, and auditory vigilance; however, in most cases these effects were not high enough to be considered significant. We aimed at addressing the effects of individual sensitivity to noise, noise frequency, and sound pressure level on the components of the participants' cognitive performance.

Table 1. Components of cognitive performance (mean ± SD) in the subjects with high and low sensitivity

Variable	Sensitivity	
	High	Low
Visual reaction time	21.97 (3.35)	23.22 (3.56)
Auditory reaction time	17.35 (3.89)	24.14 (4.05)
Visual selective attention	22.12 (4.05)	24.53 (3.13)
Auditory selective attention	22.13 (5.15)	26.98 (4.53)
Visual intermittent attention	21.78 (4.61)	23.62 (4.48)
Auditory intermittent attention	22.01 (3.13)	27.04 (4.41)
Visual continuous attention	20.95 (5.65)	21.11 (6.66)
Auditory continuous attention	21.46 (3.39)	26.12 (6.51)
Visual focused attention	24.38 (4.19)	25.15 (4.12)
Auditory focused attention	19.64(3.64)	28.12 (3.07)
Visual divided attention	431.01 (82.06)	528.13 (83.19)
Auditory divided attention	442.33 (81.38)	574.35 (81.79)
Visual vigilance	21.92 (3.48)	23.65 (2.86)
Auditory vigilance	21.01 (2.90)	24.42 (2.17)
Visual speed	29.86 (4.17)	22.62 (3.17)
Auditory speed	28.66 (4.62)	24.44 (3.12)

Table 2. Components of cognitive performance (mean ± standard error) by frequency

Variable	Frequency	
	125 Hz	250 Hz
Visual reaction time	422.12 (109.13)	578.36 (98.32)
Auditory reaction time	446.63 (108.69)	533.56 (101.12)
Visual selective attention	22.18 (4.56)	22.01 (2.89)
Auditory selective attention	27.68 (4.51)	20.90 (3.65)
Visual intermittent attention	22.86 (3.13)	22.11 (3.33)
Auditory intermittent attention	27.24 (3.36)	19.84 (2.85)
Visual continuous attention	23.77 (4.14)	23.30 (3.39)
Auditory continuous attention	22.41 (4.56)	21.97 (5.56)
Visual focused attention	21.83 (6.66)	21.66 (5.51)
Auditory focused attention	22.01 (4.65)	21.16 (6.13)
Visual divided attention	24.71 (6.65)	24.92 (6.66)
Auditory divided attention	24.63 (5.95)	17.54 (3.93)
Visual vigilance	22.19 (5.55)	21.72 (5.94)
Auditory vigilance	21.93 (5.89)	21.53 (6.31)
Visual speed	21.87 (3.63)	22.63 (5.65)
Auditory speed	24.73 (6.65)	26.91 (5.69)

Table 3. Individual and integrative effects of noise frequency, sound pressure level, and participants' sensitivity on the components of cognitive performance

Variable	Effect of						
	Se	Fr	SPL	Se*Fr	Se*SPL	SPL* Fr	Se*Fr*SPL
Auditory reaction time	0.000	0.820	0.000	0.986	0.000	0.998	0.846
Visual reaction time	0.000	0.599	0.000	0.918	0.038	0.855	0.901
Auditory selective attention	0.000	0.670	0.033	0.401	0.043	0.521	0.725
Visual selective attention	0.031	0.000	0.183	0.962	0.335	0.582	0.491
Auditory intermittent attention	0.004	0.023	0.002	0.198	0.435	0.975	0.764
Auditory continuous attention	0.089	0.354	0.000	0.572	0.448	0.917	0.837
Visual intermittent attention	0.168	0.000	0.525	0.548	0.233	0.555	0.818
Visual continuous attention	0.492	0.473	0.000	0.883	0.706	0.479	0.947
Auditory focused attention	0.001	0.452	0.000	0.725	0.274	0.784	0.880
Auditory divided attention	0.016	0.081	0.000	0.373	0.177	0.787	0.944
Visual focused attention	0.001	0.452	0.000	0.725	0.274	0.784	0.880
Visual divided attention	0.011	0.202	0.000	0.588	0.937	0.865	0.790
Auditory vigilance	0.131	0.032	0.166	0.217	0.002	0.416	0.448
Visual vigilance	0.448	0.448	0.000	0.506	0.541	0.813	0.649
Auditory speed	0.220	0.601	0.197	0.873	0.100	0.868	0.860
Visual speed	0.600	0.737	0.000	0.737	0.662	0.980	0.945

Se: sensitivity, Fr: frequency, SPL: sound pressure level

Table 4. Components of cognitive performances (mean ± standard error) by gender

Variable	**gender**		**P-value**
	Women	**Men**	
Visual reaction time	21.97 (3.35)	23.32(3.56)	0.000
Auditory reaction time	17.35 (3.89)	24.14 (4.05)	0.000
Visual Selective Attention	22.12 (4.05)	26.53 (3.13)	0.000
Auditory selective attention	22.13 (5.15)	28.98 (4.53)	0.000
Visual intermittent attention	18.78 (4.61)	23.66 (4.48)	0.000
Auditory Intermittent attention	20.01 (3.13)	27.84 (4.41)	0.000
Visual Continuous Attention	19.95 (5.65)	23.71 (6.66)	0.000
Auditory continuous attention	21.46 (3.39)	25.32 (6.51)	0.000
Visual focused attention	24.38(4.19)	25.15 (4.12)	0.000
Auditory focused attention	19.64 (3.64)	28.12 (3.07)	0.000
Visual divided attention	551.01 (82.06)	478.33 (83.19)	0.001
Auditory divided attention	582.33 (81.38)	464.35 (81.79)	0.000
Visual vigilance	22.92 (3.48)	23.65 (2.86)	0.139
Auditory vigilance	21.11 (2.90)	24.42 (2.17)	0.104
Visual speed	24.86 (6.17)	25.62 (5.17)	0.339
Auditory speed	25.66 (5.22)	27.44 (4.12)	0.191

The participants were selected randomly from the students at Hamadan University of Medical Sciences, Iran. The study was performed in an acoustic chamber designed for conducting such research. Both individual sensitivity and sound pressure level had a significant effect on the components of cognitive performance, while the effect of noise frequency was not significant on almost all types of cognitive performance.

The results of previous studies about the effect of noise on human cognitive functions are contradictory and do not show a logical relationship. For example, some studies confirm that noise levels ranging from 50 to 110 dB decrease cognitive performance, while some other studies argue that noise has no effect on mental performance [18, 19]. There are also studies that claim sound improves the speed and accuracy of individuals in mathematical mental processing tests [20-21]. Moreover, cognitive performance in relation to the mathematical test was not affected by the sound pressure level under 60-95 dB. However, the components of cognitive function decreased with increasing sound level in the mentioned range [22-23]. However, the sound pressure levels tested by the two previously mentioned studies slightly differ from that of the present study and comparison of the results should be made with caution. In the present study, there was a significant relationship between sensitivity to low-frequency sound levels and reduced cognitive performance. This may cause a significant decrease in the components of auditory attention with increasing SPL. The motivation theory can be cited in terms of the effect of noise sensitivity on cognitive performance. According to the motivation theory, exposure to noise in highly sensitive individuals leads to high levels of stimulation, which can increase the speed and reaction time, resulting in lower cognitive performance [24].

On the effect of noise on the components of cognitive performance and the role of individuals' sensitivity to noise, Hebb DO motivation theory could be cited. According to the theory, noise sensitive people exhibit high levels of stimulation and excitement in exposure to noise. This increases the speed and reduces reaction time, resulting in a lower cognitive performance [24]. According to Rookamp theory (in confirmation of HEB theory), in noise-sensitive people, the reaction of sympathetic activity (such as, increased heart rate, increased respiration, and narrowing of the blood vessels) is increased further than those with high tolerance to noise [25]. The SPLs, louder than 70 dB (generally and regardless of frequency), reduces various types of attention components. This result is consistent with another study. Since deep mental process requires longer processing time, the corresponding memory is more affected by stressors, such as louder sound levels [26]. The reaction time for the target stimuli decreased significantly with the increase of SPL (*P*<0.05). In general, loud noise levels can reduce the response time. It can also be due to the sensitivity of people to low-frequency noise levels. In a similar study it was found that the attention and focus variables in the exposure of noise were significantly different from that in quiet conditions (*P*<0.05) [13]. According to studies, at the exposure of loud noise, individuals' reaction time becomes shorter compared to relatively quiet conditions. People tend to get rid of uncomfortable noise as quickly as possible [27]. This finding is consistent with the result of the present study. Table 4 shows the comparison of cognitive functions by gender. According to the significance level, the results of the present study showed that in females, the components of cognitive performance are more affected than males and this difference was significant (*P*<0.05). These findings are inconsistent with the results of another study [15]. The difference may be attributed to the types of environmental noise, which have different effects on the exposed people as well as the individuals' sensitivity. In the present study, the sensitivity of the subjects was studied by gender [28]. In general, the reaction time was mostly influenced by the individuals' sensitivity and sound pressure level. Treble noise led to an increase in the reaction time. We can generalize the results of this study to the maximum compatibility theory [29] and the theory of compensatory quest model [30]. Generally, these two theories imply that the quantitative performance (reduced reaction time and increased speed) is improved with increasing environmental stimuli to specific ranges in different phases.

CONCLUSION

Individual differences, especially noise sensitivity, are an effective factor in the effect of noise on individual performance. Therefore, in people with high sensitivity, the presence of noise could lead to lower efficiency than those with low sensitivity. In workplaces, where exposure to noise is more than usual, industrial managers can increase work efficiency by selecting the workers, who are more tolerant of noise, and this will increase efficiency and productivity and, consequently, reduce occupational accidents. It is recommended to consider individual sensitivity in implementing noise control programs, so that the priority is with those workers with more sensitive to noise.

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