# The Influence of Noise Exposure at Different Loudness Levels on EEG Index and Types of Attention

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## Abstract

**Bachground:** Noise is one of the most important harmful factors in the environment. There are limited studies on the effect of noise loudness on brain signals and attention. The main objective of this study was to investigate the relationship between exposure to different loudness levels with brain index, types of attention, and subjective evaluation. **Methods:** Four noises with different loudness levels were generated. Sixty-four male students participated in this study. Each subject performed the integrated visual and auditory continuous performance test (IVA-2) test before and during exposure to noise loudness signals while their electroencephalography was recorded. Finally, the alpha-to-gamma ratio (AGR), five types of attention, and the subjective evaluation results were examined. **Results:** During exposure to loudness levels, the AGR and types of attention decreased while the NASA-Tax Load Index (NASA-TLX) scores increased. The noise exposure at lower loudness levels (65 and 75 phon) leads to greater attention dysfunction than at higher loudness. The AGR was significantly changed during exposure to 65 and 75 phon and audio stimuli. This significant change was observed in exposure at all loudness levels except 85 phon and visual stimuli. The divided and sustained attention changed significantly during exposure to all loudness levels and visual stimuli. The AGR had a significant inverse correlation with the total score of NASA-TLX during noise exposure. **Conclusions:** These results can lead to the design of methods to control the psychological effects of noise at specific frequencies (250 and 4000 Hz) and can prevent non-auditory damage to human cognitive performance in industrial and urban environments.

**Keywords:** *Attention, electroencephalograph, loudness, psychoacoustic*

## Introduction

Noise pollution is an important and unavoidable health issue in public and occupational environments.[1] It can have serious physiological and psychological effects on human health and well-being, including annoyance, sleep disorders, cognitive disorders, mental disorders, and hearing loss. However, its psychological effects have received little attention.[2,3] Noise can disrupt workers' focus and attention and reduce productivity.[4] Since hearing loss due to noise exposure has been among the main concerns in occupational health and safety, noise is usually characterized by physical quantities such as sound pressure level (SPL) and frequency. In recent decades, the psychological effects of noise, including noise comfort, have been considered an essential measure for determining the quality of life. The physical quantities of noise, such as SPL, are insufficient to show the subjects' emotions and auditory perception. In such cases, applying sound quality or psychoacoustic criteria in such cases seems more logical.[5–7] Psychoacoustics determines the functional relationships between the physical properties of noise and auditory sensory phenomena.[8]

Psychoacoustic is a science that describes how humans perceive sound. The studies of these scientists led to methods for determining the objective quantity of human-perceived sounds.[9] According to ISO532-1, loudness is one of the important noise characteristics in psychoacoustics.[10] Loudness is related to human perception of the volume of sound expressed. It is measured in sone, corresponding to a sound of 40 decibels per ton of 1 kHz. The loudness perception is a function of the SPL and frequency, and it is calculated based on the following equation 1.[9,11]



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Equation 1 $N = \int_{0}^{24Bark} N'dz$

According to equation 1, the loudness (N) is calculated by integrating the specific loudness (N´) along the 24 critical bands. The specific loudness (N´) is a function of the critical bandwidth measured in Bark (unit).[9,11]

Exposure to harmful noise increases mental workload (MWL), leading to a detrimental effect on human cognitive function. In human–system interaction, various aspects of cognitive function, including working memory, perception, attention, decision-making, and learning, are important because they affect the mental performance of the operator.[12] Attention is one of the important components of cognitive function. Attention is a criterion for filtering out distractions and focusing on work-related issues. The criterion of attention has been defined as the ability to achieve certainty and confidence in a person's perception.[13] This parameter can be classified into five categories: sustained, divided, alternating, focus, and selective.[13–15]

In general, the effects of various factors on cognitive performance (such as attention) can be examined via subjective evaluation, measuring performance indicators, and psycho-physiological methods.[16–18] Subjective evaluation is the self-reporting of subjects, which includes scoring levels of fatigue, anxiety, mental effort, and etc. In this method, questionnaires are usually completed by the subject after a certain time, followed by extracting the relevant final score. NASA-Tax Load Index index and subjective rating scale are examples of this method. Performance indicators are based on techniques that record an individual's ability to perform the desired task. In addition, Psycho-physiological measurements are the most objective indicators for assessing MWL and performance.[19] One of the most functional methods of psycho-physiological measurement is electroencephalography (EEG). Electroencephalography is a technique that records the electrical activity of the brain. With its help, the behaviors related to the brain can be analyzed based on the characteristics of the EEGs.[20] Various brain indicators are used to assess a person's performance. One of these indicators to examine attention is the ratio between the alpha wave's absolute power to the gamma wave's absolute power. Fahimi *et al*. applied AGR (alpha–gamma ratio) as an indicator of mental attention.[21]

Understanding the relationship between psychoacoustic and individuals' cognitive performance is essential in creating a safe environment for doing work. Few studies have examined the effect of noise exposure at various loudness levels while applying visual and audio stimuli on the brain and cognitive indicators of attention. Also, few studies have examined the relationship between the brain index of attention, types of attention, and mental indicators. Thus, understanding the effect of psychological aspects of noise on the attention parameter is a challenge. The main objective of this study was to investigate the influence of noise on the biological attention index, performance indices of different types of attention, and subjective evaluation considering noise loudness levels and applying audio and visual stimuli during the IVA test.

## Subjects and Methods

This experimental study was conducted in the following four stages. All experimental parts of the study were performed in a standard acoustic room.

### Phase 1: Generating noise according to proposed psychoacoustic parameters

The sound comfort limit equals 70 dB in the industrial environment for maintaining mental performance. According to the The sound comfort limit equals 70 dB in the industrial environment for maintaining mental performance limit for 15 minutes, the maximum SPL was considered equal to 97 dB (care limit).[22] So, four noises with different loudness levels of 5.66–45.3 (65–95 phon) were generated using a Test Tone Generator program (Esser Audio Co, Germany) in the frequency range of 250 to 8000 Hz, and the SPL of 60–97 dB. The generated noise samples were broadcasted using a BSWA microphone (calibrated at 1 kHz and 114 dB) and a Tesco speaker. The broadcasted noise level was evaluated using sound quality and Va-lab4 software.

### Phase 2: Study subjects selection and preparation for tests

64 healthy male students aged 20–35 years old participated in this study. Because in most industries, men are more employed than women, only the gender of men was used in this study. A valid and efficient[23] General Health Questionnaire was used to select healthy subjects. The Weinstein questionnaire was also used to determine the sound sensitivity of all chosen subjects. The validity and reliability of Weinstein's sound sensitivity test were studied before by Ali Mohammadi *et al*.[24] The audiometry test was applied to both ears of the subject. A hearing loss of less than 25 dB in the 125 to 8000 Hz frequency range was considered an inclusion criterion for the normal auditory threshold. In addition, each subject's blood pressure and heart rate were measured in the acoustic room and compared with normal values in the age range of 20 to 35 years. Generally, the inclusion criteria for this study were: having a normal auditory threshold, having normal heart rate and blood pressure, having physical and mental health based on the results of the GHQ questionnaire, having no sensitivity to sound, no use of psychiatric medicines, alcohol, and drugs, no sleep disorders, and completion of the consent form.

### Phase 3: Experimental tests

The following three methods of EEG, IVA test, and subjective evaluation were used to determine the effect of noise at different loudness levels on brain index, performance status, and types of attention.

- Electroencephalography: Brain signals were recorded with the g-Nautilus electroencephalograph (g. tec company) before and during exposure to each noise. Brain waves were recorded according to the international 10-20 standard using 19 electrodes (Fp1, Fp2, F7, F3, F4, Fz, F8, T7, C3, Cz, C4, T8, P7, P3, Pz, P4, P8, O1, O2). The sampling frequency was 512 Hz, and the right earlobe was considered the reference electrode. An EOG electrode was also used to remove ocular artifacts. The artifacts created by body and muscle movements, eye movements, blinking, urban noise, etc., were removed at the preprocessing stage. First, this process was carried out using a 0.5-40 Hz band-passage filter. Then, other artifacts were removed using MATLAB software, EEGLAB Toolbox, and independent component analysis (ICA). In addition, ocular artifacts were identified by EOG. The *Z*-score normalization method was applied to extract the feature. The EEG signals were converted to the frequency domain by the Fast Fourier Transform method. The ratio of alpha to gamma power (AGR) extracted from Fp1, and Fp2 electrodes [equation 2][21] was used in the present study.

Equation 2 $AGR = \alpha / \gamma$

- IVA test: The integrated visual and auditory continuous performance test (IVA-2) version was used in this study. The total testing time was about 20 minutes, while the main testing was about 12 minutes. In this test, 250 visual and 250 auditory stimuli appear randomly on a computer monitor. At each stage, whenever a subject sees or hears the number 1, he/she must press the mouse key, and whenever he/she sees or hears the number 2, he/she must not react. Five auditory and visual attention types were extracted focus, sustained, selective, alternating, and divided. Previous studies have shown that this test has a sensitivity of 92% and a predictive power of 89%[25,26]
- Subjective evaluation: The NASA-TLX questionnaire was used for subjective evaluation. This questionnaire considers six dimensions, including mental, physical, temporal, performance, effort, and frustration, to determine the perceptual aspects of workload. The total score of the individual's mental load (from 0 to100) is calculated numerically. The validity and reliability of this questionnaire were confirmed in past studies. It's Cronbach's alpha was reported to be 0.83.[27]

In general, each subject was asked to get enough sleep the night before the test and avoid consuming caffeine, alcohol, and painkillers that may affect the EEG. The sound source was placed in the center of the acoustic room to ensure that each participant was equidistant from the sound source. In the first stage, the subject performed an IVA test in the background noise conditions of 30 dB (no broadcasting noise) while the subject's EEG was recorded. In the end, the subject was required to complete a NASA-TLX questionnaire. The subject was then rested for 30 minutes. The sounds of nature were played to enhance the individual's relaxation during resting time. This sound was the artwork "Sound of Nature", recorded by Dr. Arnd Stein in 2011 and includes the sound of birds, the sea, rivers, forests, and rain.[28]

Finally, the same steps were repeated this time in exposure to the noise at a certain loudness level. Figure 1 shows an overview of the test steps.

### Phase 4: Data analysis

Statistical data analysis was carried out using SPSS 20 software. The paired samples *t*-test was used to determine the relationship between the variables before and during noise exposure. The Pearson Correlation Coefficient was used for the correlation between the variables. A significance level of 0.05 was also considered. All graphs were drawn using Origin software.

### Ethical statement

The study was conducted according to the guidelines of the Declaration of Iran and approved by the Ethics Committee of Shahid Beheshti University of Medical Sciences (IR. SBMU.PHNS.REC.1399.111).

## Results

### Generated noises

Four noise samples at different loudness levels were generated in the 5.66-45.3 sone range. Each subject was exposed to only one of these noises at a time. Table 1 shows the identifier for each noise and the loudness specifications in terms of phon and sone units.

### The effect of noise at different loudness levels on brain signals

The results revealed that exposure to noise with both auditory and visual stimuli applied during IVA-2 test decreased AGR

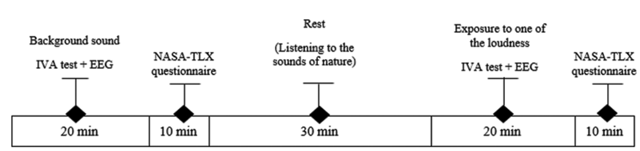


**Figure 1: Steps of the test procedure**

**Table 1: Codes and specifications of four-generated noise with different loudness levels**

| Test code | Loudness (Sone) | Loudness (Phon) | Frequency (Hz) |
|---|---|---|---|
| F250-L65 | 5.66 | 65 | 250 |
| F4000-L75 | 11.3 | 75 | 4000 |
| F8000-L85 | 22.6 | 85 | 8000 |
| F500-L95 | 45.3 | 95 | 500 |

during exposure to all noise loudness levels. The most significant decrease was observed when the subjects were exposed to F250-L65, and F4000-L75 sounds with auditory stimuli (71% and 73%, respectively). It was also observed that applying visual stimuli and exposure to F250-L65 and F4000-L75 sounds caused a further decrease in the AGR (77% and 75%, respectively). Moreover, it was found that exposure to F250-L65, F4000-L75, and F500-L95 sounds along with visual stimuli during the IVA test decreased AGR more than when audio stimuli were applied [Figure 2].

The statistical tests also revealed that applying audio stimuli along with noise exposure changed AGR significantly during exposure to noise at loudness levels of 65 and 75 phon. The results also showed that exposure to noise at all tested loudness levels (except for F8000-L85 sound) along with visual stimuli in the IVA-2 test changed AGR significantly [Table 2].

## The effect of noise at different loudness levels on types of attention

### *Applying audio stimuli along with noise exposure*

Figure 3 shows that when audio stimuli are applied in the IVA test along with noise exposure, all types of attention decrease compared to pre-exposure. The results also showed that noise exposure at a loudness level of F250-L65 and F4000-L75 could significantly reduce attention types. Exposure to F250-L65 and F500-L95 sound led to the greatest decrease in selective (72%) and alternating (32%) attention, respectively. However, the F4000-L75 and F8000-L85 sounds caused the greatest decrease in focus attention (71% and 29%, respectively) [Figure 3]. According to Table 3, focus attention changed significantly during exposure to all four types of noise. Exposure to noise at loudness levels of 65, 75, and 95 phon along with audio stimuli, changed the selective and divided attention significantly. There was also a significant difference in alternating attention when exposed to all sounds and sustained attention when exposed to all sounds except 85 phon along with audio stimuli [Table 3].

### *Applying visual stimuli along with noise exposure*

According to Figure 4, with visual stimuli applied in IVA-2, all types of attention selected in this study decreased during exposure to all noise loudness levels compared to their value before exposure. Exposure to F250-L65 and F4000-L75 noises caused a greater reduction in various attention types. With visual stimuli applied, exposure to F250-L65, F8000-L85, and F500-L95 caused a greater decrease in sustained attention (79%, 44%, and 45%, respectively). In exposure to F4000-L75 sound with visual stimuli, a more significant reduction was observed for alternating attention (77%) [Figure 4]. According to Table 3, with visual stimuli, a significant difference in focus

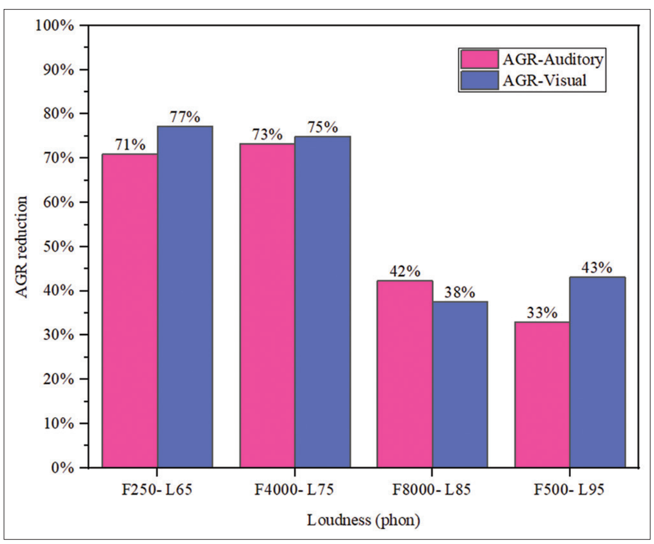


**Figure 2: The reduction of AGR during noise exposure at different loudness levels, along with auditory and visual stimuli applied in the IVA test**

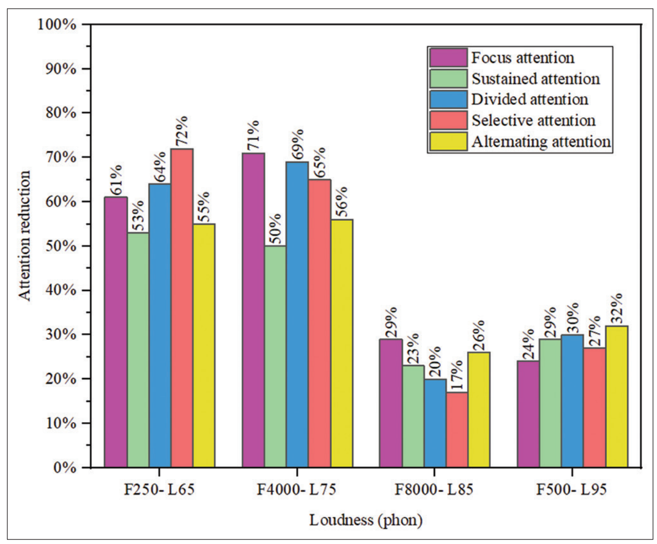


**Figure 3: The reduction in various types of attention during noise exposure at different loudness levels along with auditory stimuli applied in the IVA test**

**Table 2: AGR values before and during exposure to noise at different loudness levels with auditory and visual stimuli applied during IVA-2 test**

| Loudness | Auditory stimuli | | | Visual stimuli | | |
|---|---|---|---|---|---|---|
| | Pre-Exp | Dur-Exp | *P* | Pre-Exp | Dur-Exp | *P* |
| F250-L65 | -0.0171±0.001 | -0.06±0.002 | <0.001 | -0.0173±0.001 | -0.075±0.003 | <0.001 |
| F4000-L75 | -0.0172±0.002 | -0.066±0.001 | <0.001 | -0.00170±0.002 | -0.068±0.002 | <0.001 |
| F8000-L85 | -0.0174±0.003 | -0.03±0.001 | 0.07 | -0.0170±0.003 | -0.028±0.002 | 0.08 |
| F500-L95 | -0.017±0.002 | -0.025±0.003 | 0.5 | -0.019±0.002 | -0.031±0.001 | 0.04 |

Pre-Exp=before exposure to noise, Dur-Exp=during exposure to noise attention was observed when the subjects were exposed to all noise loudness levels (except 95 phon). Under the same condition, the divided and sustained attention significantly changed during exposure to noise at all four loudness levels. This significant difference was observed during exposure to all four types of noise except 95 phon for alternating and 85 phon for selective attention [Table 3].

### The effect of noise at different loudness levels on subjective evaluation

In general, during exposure to all four types of loudness, the score of each dimension of the NASA-TLX questionnaire and the total score compared to non-exposure conditions increased. However, this increase was more in the exposure to loudness of 65 and 75 phon [Figure 5].

Table 4 shows a significant difference before and during exposure to F250-L65 and F4000-L75 in all questionnaire dimensions. There was also a significant difference before and during exposure to F8000-L85 for all dimensions except physical and temporal. For F500-L95, there was a significant difference in all dimensions except physical and performance.

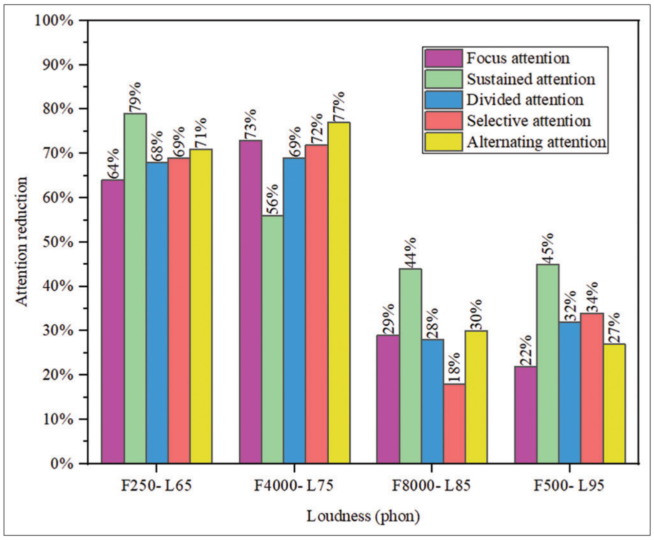


Figure 4: The reduction in various types of attention during noise exposure at different loudness levels along with visual stimuli applied in IVA test

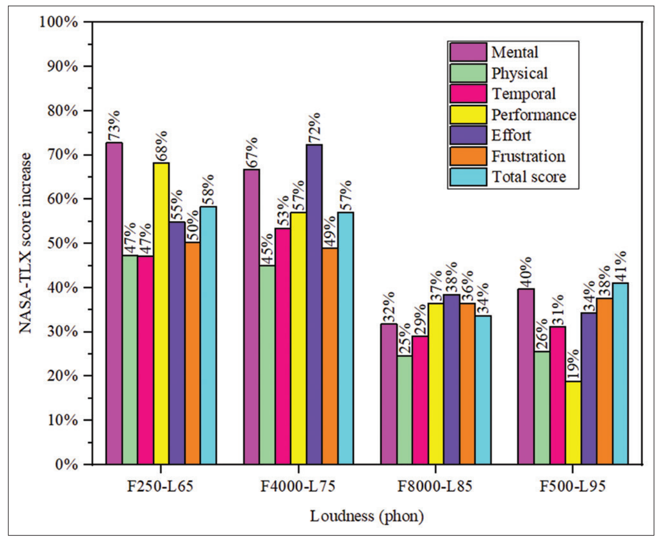


Figure 5: The increase of NASA TLX dimensions scores during noise exposure at different loudness levels

**Table 3. The effect of noise at different loudness levels along with audio and visual stimuli on types of attention**

| Stimuli | Attention | F250-L65 | | F4000-L75 | | F8000-L85 | | F500-L95 | |
|---|---|---|---|---|---|---|---|---|---|
| | | Pre-Exp | Dur-Exp | Pre-Exp | Dur-Exp | Pre-Exp | Dur-Exp | Pre-Exp | Dur-Exp |
| Audio | Focus | 99.6±2.3 | 61.8±3.1 | 100.6±5.2 | 58.7±4.4 | 98.7±3.1 | 76.7±1.7 | 99.9±1.9 | 80.4±2.9 |
| | | *P*=0.007 | | *P*=0.004 | | *P*=0.023 | | *P*=0.04 | |
| | Selective | 98.9±3.1 | 57.3±2.7 | 100±5.4 | 59.8±1.5 | 97.5±1.1 | 84.2±0.5 | 99.4±2.5 | 76.5±3.1 |
| | | *P* <0.001 | | *P* <0.001 | | *P*=0.31 | | *P*=0.03 | |
| | Sustained | 102.1±4.8 | 69.1±1.9 | 103.5±3.1 | 69±1.01 | 102.8±3.1 | 83.4±1.6 | 100.7±4.2 | 77.2±1.2 |
| | | *P*=0.007 | | *P*=0.01 | | *P*=0.07 | | *P*=0.04 | |
| | Alternating | 103±2.9 | 66.6±3.6 | 104.5±3.8 | 67±1.2 | 101.5±2.2 | 80.7±1.7 | 102.7±5.9 | 78.1±2.5 |
| | | *P*=0.02 | | *P*=0.001 | | *P*=0.04 | | *P*=0.04 | |
| | Divided | 101.5±3.8 | 67.7±1.6 | 104.8±2.3 | 64.5±0.7 | 103.9±2.7 | 88.6±1.5 | 105.5±2.4 | 85±1.9 |
| | | *P*=0.029 | | *P*=0.001 | | *P*=0.053 | | *P*=0.03 | |
| visual | Focus | 98.4±1.3 | 60.6±1.5 | 99.3±4.2 | 58.5±1.3 | 99.7±2.1 | 76.5±2.1 | 98.4±2.9 | 81.9±1.8 |
| | | *P*=0.039 | | *P*=0.026 | | *P*=0.04 | | *P*=0.12 | |
| | Selective | 98.1±2.1 | 58.3±1.1 | 99.5±3.4 | 57.7±2.6 | 100.2±2.1 | 83.4±3.3 | 99.4±1.5 | 72.6±2.4 |
| | | *P*=0.006 | | *P*=0.004 | | *P*=0. 22 | | *P*=0.026 | |
| | Sustained | 101.1±2.5 | 59.2±2.9 | 102.5±2.1 | 66.2±2.01 | 101.8±2.1 | 71±1.4 | 103.7±2.2 | 69±2.6 |
| | | *P*=0.001 | | *P*=0.006 | | *P*=0.015 | | *P*=0.037 | |
| | Alternating | 102±1.9 | 60.5+1.6 | 103.5±2.2 | 59+3.2 | 105.3±3.2 | 78.4+1.8 | 104.7±3.1 | 80.7+2.5 |
| | | *P*=0.05 | | *P*=0.001 | | *P*=0.04 | | *P*=0.061 | |
| | Divided | 105.5±3.5 | 66±3.6 | 105.1±2.3 | 64.8±0.7 | 104.9±2.1 | 85.6±2.5 | 103.5±2.9 | 82±1.9 |
| | | *P*=0.029 | | *P*=0.001 | | *P*=0.013 | | *P*=0.017 | |

### Correlation ($R^2$) between AGR with different attention types and subjective evaluation

It was found that before exposure to noise with audio stimuli, AGR had a direct statistically significant relationship with focus and sustained attention. However, a significant direct correlation for focus, sustained, and divided attention was observed in noise exposure situations. The AGR directly correlated with alternating and divided attention in the visual stimuli and before the noise exposure situation. This relationship was observed during exposure to noise and all types of attention except divided attention [Table 5].

Regarding the correlation between AGR and the questionnaire's dimensions, it was found that there is a statistically significant inverse relationship between AGR and the mental and performance dimensions before noise exposure. In addition, the AGR index with mental, temporal, performance, effort parameters, and total score of the questionnaire had a significant inverse relationship during exposure to noise [Table 6].

## Discussion

Most previous studies have neglected to examine cognitive function in exposure to psychoacoustic factors such as loudness. Also, some studies have used only qualitative measurements, including subjective responses, to assess the effects of exposure to psychoacoustic parameters on cognitive function. In this study, three different methods, including evaluation of MWL, evaluation of attention along with visual and audio stimuli, and brain signals, were used to study the effect of sounds with different loudness levels on cognitive function. Shargie *et al*. also stated that it is necessary to use a combination of tools to improve the assessment of mental and cognitive stress.[29]

In general, exposure to noise at different loudness levels compared to pre-exposure conditions in all three methods of brain indicators, types of attention in the IVA test, and NASA-TLX questionnaire showed mental dysfunction and decreased attention. Therefore, AGR and various types of attention decreased, and the score of the NASA-TLX questionnaire increased. The results obtained by Patricia

**Table 4: The effect of noise at different loudness levels on the score of the NASA-TLX questionnaire's dimensions**

| Attention | F250-L65 | | F4000-L75 | | F8000-L85 | | F500-L95 | |
|---|---|---|---|---|---|---|---|---|
| | Pre-Exp | Dur-Exp | Pre-Exp | Dur-Exp | Pre-Exp | Dur-Exp | Pre-Exp | Dur-Exp |
| Mental | 38.1±1.9 | 65.9±1.3 | 40.2±0.4 | 68.7±1.1 | 39.4±3.2 | 51.8±0.9 | 39.4±2.4 | 55±0.2 |
| | *P*<0.001 | | *P*=0.001 | | *P*=0.02 | | *P*=0.01 | |
| Physical | 18.7±0.5 | 27.6±0.1 | 19.5±1.4 | 25.4±1.1 | 18.7±0.8 | 23.4±0.9 | 19.5±0.4 | 25.7±1.2 |
| | *P*=0.002 | | *P* <0.001 | | *P*=0.35 | | *P*=0.47 | |
| Temporal | 37.7±1.25 | 52.6±2.6 | 37.2±1.7 | 55.6±0.4 | 38.7±1.5 | 50±1.9 | 38.1±1.8 | 50±1.6 |
| | *P* <0.001 | | *P*=0.003 | | *P*=0. 1 | | *P*=0.04 | |
| Performance | 43.1±1.9 | 72.5±1.4 | 44±0.9 | 70.6±1.3 | 44.4±1.8 | 53.7±1.8 | 43.1±1.5 | 51.2±4.3 |
| | *P* <0.001 | | *P*=0.002 | | *P*=0.03 | | *P*=0.23 | |
| effort | 41.4±0.2 | 62.5±2.4 | 41.6±1.8 | 70±1.1 | 42.8±3.5 | 59.4±2.6 | 41.7±2.1 | 58.7±1.8 |
| | *P*=0.031 | | *P* <0.001 | | *P*=0.03 | | *P*=0.031 | |
| Frustration | 27.4±1.2 | 41±1.5 | 27.4±0.1 | 40.7±2.9 | 26.7±2.1 | 29±0.6 | 26.8±1.6 | 29.2±0.6 |
| | *P* <0.001 | | *P*=0.01 | | *P*=0.02 | | *P*=0.04 | |
| Total score | 34.4±0.2 | 54.4±1.1 | 34.2±0.3 | 53.7±0.9 | 34.9±0.7 | 46.9±0.5 | 34.2±0.4 | 48.3±0.9 |
| | *P* <0.001 | | *P* <0.001 | | *P*=0.013 | | *P*=0.012 | |

**Table 5: Correlation between AGR and types of attention along with audio and visual stimuli (indicates significance at *P*<0.05 Level**)**

| Brain Index | Exposure status | Attention | | | | |
|---|---|---|---|---|---|---|
| | | Focus | Selective | Sustained | Alternating | Divided |
| AGR-Auditory | Pre-exp | 0.13** | 0.05 | 0.25** | 0.15 | 0.03 |
| | Exp | 0.34** | 0.01 | 0.41** | 0.01 | 0.25** |
| AGR- Visual | Pre-exp | 0.16 | 0.11 | 0.04 | 0.06** | 0.57** |
| | Exp | 0.24** | 0.21** | 0.41** | 0.46** | 0.05 |

**Table 6: Correlation between AGR and NASA-TLX questionnaire's dimensions (indicates significance at *P*<0.05 Level**)**

| Brain Index | Exposure status | Dimension | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Mental | Physical | Temporal | Performance | Effort | Frustration | NASA score |
| AGR | Pre-exp | -0.27** | 0.12 | -0.17 | -0.35** | -0.21 | -0.17 | -0.07 |
| | Exp | -0.26** | -0.075 | -0.36** | -0.26** | -0.44** | -0.003 | -0.56** |

Tassi *et al*. showed that exposure to sound disrupts the attention processes and therefore reduces the level of consciousness,[30] which was in line with the results of this study. Jafari *et al*. found that applying audio and visual stimuli with increasing sound levels reduced attention compared to the background noise of the environment.[31] Impairment of attention due to sound exposure was similar to the results of the present study. However, unlike Jafari *et al*., this study showed that SPL alone is not a sufficient criterion for assessing cognitive impairment, and noise at lower loudness can cause impaired attention. Eakins stated that neuroticism scores had a positive correlation coefficient with subjective MWL measured by the NASA-TLX in-office noise exposure. This meant that when the neuroticism scores increased, the subject's MWL also increased under noisy office conditions.[32]

Exposure to F250-L65, F4000-L75, and F500-L95 noise caused a more significant decrease in visual attention than auditory attention. The applying visual stimuli and exposure to F250-L65 and F4000-L75 noise compared to applying audio stimuli caused a further decrease in all types of attention except selective and divided, respectively. These conditions were observed when exposed to F8000-L85 in attention types except focused attention and F500-L95 in sustained and divided attention. Therefore, performance and attention seemed more affected by exposure to noise while applying visual stimuli than audio stimuli. This factor may be because the person needs to transfer attention between two different stimuli to respond to a visual stimulus when exposed to noise. In this regard, Ersin *et al*. stated that performing tasks with dual attention sources, including visual and auditory stimuli increases the perceptual load of the individual and reduces performance compared to performing each task separately.[33] Fernandes *et al*. found that sound as a disruptive factor can reduce reading and writing performance and sustained attention.[34]

The result was shown that noise exposure at loudness levels of 65 and 75 phon had a more significant decrease in attention than at other loudness levels. Considering the lower loudness levels of this noise sample, it seems that higher loudness does not always cause more disturbance, and noise with lower loudness can be more annoying and disruptive. An important issue with these types of noise is their frequency, which was 250 and 4000 Hz, respectively. Regarding noise with a frequency of 250 Hz, it can be said that noise with a low-frequency range usually does not cause the risk of hearing loss. In these cases, the SPL on the A-weighted scale is generally low (less than 85 dB). However, many mental effects, such as mental stress, dissatisfaction, and discomfort, appear in exposure to these types of noise.[35] In this regard, the results of the study of Monteiro *et al*. showed that exposure to noise at 68 dB caused disturbances in the performance and attention of participants. Participants also experienced higher discomfort, stress, and disturbing perception in this situation.[36] Pawlaczyk-Łuszczyńska *et al*. stated that exposure to low-frequency sounds could adversely affect visual function, concentration, and continuous and selective attention.[37] Leventhal believed low-frequency sound was an important factor in disturbance and mental disorders.[38] Huang *et al*. stated that low-frequency noise causes more disturbance and annoyance than other frequencies.[39] According to the results, it is clear that the effects of low-frequency sounds and their relation to mental dysfunction and annoyance have been accepted as a specific issue. However, the remarkable point in the present study is that in exposure to the psychological aspects of noise, such as loudness, sounds at low frequencies seem louder and more annoying to people than other frequencies.

In the present study, a significant disturbance in the subject's attention was observed at a frequency of 4000 Hz. Various studies have discussed physical damage caused by sound at this frequency.[40,41] Generally, the basilar membrane at 4000 Hz is usually affected by noise due to sound conduction from the ear bones. Organs of Corti are more sensitive to specific frequencies, and experiments have shown that the ear is most vulnerable at 4096 Hz frequency. Factors associated with the maximum sensitivity in the 4000 Hz region may be related to the vasoconstriction of stria cells, the reflection of sound energy in the cochlea, and the resonant characteristics of the outer ear.[42,43] Therefore, it seems that in addition to physical dysfunction, there is more mental dysfunction at this frequency. It can be said that the person pays more attention to the disruptive noise due to the high sensitivity at this frequency. Therefore, more dysfunction and mental fatigue can lead to the onset of physical harm. Guang Li *et al*. found that the average alpha wave power (APEEG) as an annoyance index among the exposure to sounds with frequencies of 160, 500, and 4000 Hz has the highest value at a frequency of 4000 Hz.[44] Beheshti *et al*. revealed that reaction time decreased with the rise in frequency from 500 to 4000 Hz.[45]

It was also found that when audio stimuli are applied along with noise exposure, the AGR significantly correlates with the focus, sustained, and divided attention. As for visual stimuli, this correlation was observed with all attention except divided attention. In addition, a significant correlation was observed during exposure to noise between AGR and the dimensions of mental, temporal, performance, effort, and total score of the NASA-TLX questionnaire. Therefore, attention disorder due to exposure to different loudness levels of noise can be examined directly from the AGR. The study of Guang Li *et al*. investigated the relationship between annoyance brain indices, including the relative APEEG of alpha and theta waves, with the results of the subjective ranking of individuals for annoyance related to 70 dB sound. It was found that the mental annoyance caused by noise could be directly estimated through the brain indicators mentioned in the forehead area.[44]

This study examined the effects of exposure to psychological aspects of sound, such as loudness. It was observed that noise at higher loudness levels does not necessarily cause more disturbance. In addition to the sound loudness, special attention should be paid to the frequency of the noise loudness. The results showed that the noise with lower loudness, but at frequencies of 250 and 4000 Hz, can cause more disruption to the person's performance. The evaluation of brain activity and performance aspects of individuals, such as attention, can help us to investigate the performance disturbance and the non-auditory effects of noise exposure on human brain activity. These results could lead to the designing of a global standard protocol to prevent the non-auditory effects of psychological aspects of sound on human cognitive performance in industrial and urban environments. Another advantage of these results is monitoring hearing protection in industrial centers to determine the qualified individuals and employees who work in these centers. In this study, a limited number of laboratory conditions were examined due to the time and facilities available. So, evaluating more conditions and different scenarios in future studies is necessary. In addition, it is necessary to produce sounds at different loudness levels with frequencies of 250 and 4000 Hz and analyze their effect on the brain waves, functional aspects, and subjective evaluation of individuals.

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### Ethical statement

The study proposal was approved by the Ethics Committee of Shahid Beheshti University of Medical Sciences (IR. SBMU.PHNS.REC.9942) prior to its execution.

### Author Contributions

Concepts: MJ J and Z M; Design: MJ J and Z M.; Definition of intellectual content: MJ J, Z M, A Kh, AS J, A A; Literature search: Z M.; Experimental studies: MJ J and Z M.; Data acquisition: MJ J, Z M, A Kh, AS J, A A; supervision, MJ J.; Data analysis: MJ J, Z M, A Kh, AS J, A A, M P.; Manuscript preparation: Z M.; Manuscript editing: MJ J, Z M, A Kh, AS J, A A, M P.; Manuscript review: MJ J, Z M, A Kh, AS J, A A, M P.; All authors have read and agreed to the published version of the manuscript.

### Conflicts of interest

There are no conflicts of interest.

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