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# The Effect of Noise Exposure on Cognitive Performance and Brain Activity Patterns

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## ABSTRACT

It seems qualitative measurements of subjective reactions are not appropriate indicators to assess the effect of noise on cognitive performance. In this study, quantitative and combined indicators were applied to study the effect of noise on cognitive performance. A total of 54 young subjects were included in this experimental study. The participants' mental workload and attention were evaluated under different levels of noise exposure including, background noise, 75, 85 and 95 dBA noise levels. The study subject's EEG signals were recorded for 10 minutes while they were performing the IVA test. The EEG signals were used to estimate the relative power of their brain frequency bands.

Results revealed that mental workload and visual/auditory attention is significantly reduced when the participants are exposed to noise at 95 dBA level ($P < 0.05$). Results also showed that with the rise in noise levels, the relative power of the Alpha band increases while the relative power of the Beta band decreases as compared to background noise. The most prominent change in the relative power of the Alpha and Beta bands occurs in the occipital and frontal regions of the brain respectively.

The application of new indicators, including brain signal analysis and power spectral density analysis, is strongly recommended in the assessment of cognitive performance during noise exposure. Further studies are suggested regarding the effects of other psychoacoustic parameters such as tonality, noise pitch (treble or bass) at extended exposure levels.

**Keywords:** Noise; Cognitive Performance; Attention; Brain Activity; Electroencephalogram

## INTRODUCTION

The influence of noise on human cognitive performance and brain activity has been often neglected (Basner et *al*, 2014). Noise has different negative effects ranging from interference with cognitive processing to damaging mental and physical health (Stanefeld and Matheson, 2003). In any vital industry, optimizing human performance is a key factor in accident prevention. Noise is one aspect of the work environment that affects workplace safety. Workers in vital occupational roles require high levels of cognitive skill and they need to maintain effective performance while exposed to higher levels of noise than Threshold Limit Values (TLV). Studies show that noise causes cognitive impairment and oxidative stress in the brain (Wang et *al*, 2016). Previous studies have suggested that the Limbic system in the brain is involved in emotional activities, The Amygdala and the Hippocampus are two of the main parts within the Limbic system that receives sensory information directly and indirectly from the central auditory system. Auditory stimulation itself can directly or indirectly affect these areas.

The active process of cognitive selection is called attention (Jones, 2006). Attention plays a significant role in daily activities such as physical movements, emotional responses and perceptual and cognitive functions. Noise can affect performance either by impairing information processing or causing changes in strategic responses. In particular, noise increases the level of general alertness or activation and attention. The scope of cognitive and mental function is diverse, encompassing reaction time, attention, memory, intelligence and concentration. Altered cognitive function leads to human error and subsequently increases accidents. This can ultimately lead to reduced performance and productivity. Noise as a sensory stimulus increases arousal which is believed to cause a reduction in the breadth of attention. In other words, loud noise causes alterations in the performance of attentional functions.

Exposure to noise above 85 dBA intensity leads to many adverse auditory and non-auditory effects. Cognitive theory suggests that the brain is highly involved in emotions. Basic emotions use specific cortical and sub-cortical systems within the brain and are different from the brain's electrical and metabolic activities. Therefore, EEG is one of the most effective and common methods of brain imaging used for Brain activity processing relating to human stress including noise (Choi et *al*, 2015). EEG signals measure all fluctuations in the electrical fields resulting from nerve activity in millisecond resolutions. EEG signals are usually evaluated in multiple frequency bands to determine their relationship with stresses. These bands include the Alpha (8-12.5 Hz), Theta (4-8 Hz), Delta (1-4 Hz) and Beta (12.5-30 Hz) bands. A reduction in the power of the Alpha band along with a rise in the power of the Theta and Beta bands is an indicator of neurological disorders. Therefore, EEG can be a great tool not just for detecting stressors in the environment but also for predicting the negative effects of noise exposure.

## MATERIAL AND METHODS

The experiment was conducted upon University students ranged in 23-33 age-group, normal hearing, no prior cardiovascular disorders, no alcohol and caffeine consumption 12 hours before testing, a BMI index of 18-28, no hypersensitivity to noise and no sleep disorders. This experimental study was conducted in an acoustically insulated, climate-controlled room (H = 3 m, L = 3.5 m and W = 2.5 m). A total of 54 participants, including 27 males and 27 females, took part in this study. Study subjects were divided into 3 groups, each with 9 males and 9 females. All study groups were exposed to background noise (45 dBA), and three different noise levels (including 75, 85 and 95 dBA). Table 1 shows the experimental design in detail.

**Table 1: Experimental design of the study**

| Study group | Students (N=54) | Background Noise (dBA) | Exposure Noise (dBA) |
|---|---|---|---|
| 1 | 18 | 45 | 75 |
| 2 | 18 | 45 | 85 |
| 3 | 18 | 45 | 95 |

The study protocol for each subject included a 10-minute relaxing phase before testing, followed by the Integrated Visual and Auditory Continuous Performance (IVA) test which was accompanied by background noise while EEG signals were being recorded. After a 30-minute rest, the subject was exposed to noise for 15 minutes, and at the 16th-minute mark, while the subject was being exposed to various noise levels, the IVA test was initiated, and EEG signals were once again recorded (Figure 1).

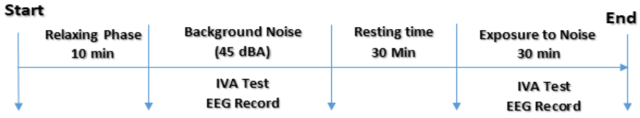

**Figure 1: Study protocols timing**

In this study, the used noise was recorded in a household appliance factory using a B and K PULSE Multi-Analyzer System Type 3560. The recorded noise was then analyzed using a B & K Sound Level Meter Type 2238. To modify the noise and obtain steady noise at 75, 85 and 95 dBA levels, the Gold Wave software version 4.26 was used. Finally, the noise was replayed using two Genius HF-2020 speakers situated on either side of the test table.

A NASA-TLX questionnaire is a well-known tool for evaluating mental workload. This multi-dimensional method assigns an overall score for mental load. Integrated Visual and Auditory test, which was designed by Stanford et al., is part of the Continuous Performance Tests (CPTs) and used to evaluate auditory/visual attention (Standford and Turner, 2007). It consists of a 13-minute continuous auditory and visual test that evaluates two factors of response control and attention.

The EEG signals were recorded from 16 Ag/AgCl electrodes mounted in an elastic cap with the amplifier bandpass set to 1 – 40 Hz at a sampling rate of 250 Hz. The electrodes were placed at the frontal (Fp1, Fp2, F3, F4, F7 and F8), temporal (T3 and T4), central (Cz, C3 and C4), parietal (Pz, P3 and P4) and occipital (O1 and O2) regions. The reference electrode was the left mastoid. Impedance was maintained at below 10 KΩ during the experiment.

Statistical analysis of the mental workload and attention data was carried out using the SPSS 22 software solution. Before performing t-tests, data distribution norms were checked using the Kolmogorov–Smirnov test. A *p*-value of less than 0.05 was considered statistically significant. The Generalized Estimating Equations (GEE) statistical method was applied for data analysis.

## RESULTS AND OBSERVATIONS

**Demographic Characteristics of Participants:** Table 2 displays the study demographic characteristics. A total of 56 individuals, 27 males and 27 females, were enrolled in the study. Average and standard deviation of age and Body Mass Index (BMI) was 26.56 ± 2.45 and 23.81 ± 1.43, respectively.

**Table 2: Participants Demographic factor**

| Characteristic | M | SD | Max | Min |
|---|---|---|---|---|
| Age (Year) | 26 | 2.45 | 33 | 23 |
| Weight (Kg) | 56 | 6.24 | 72 | 54 |
| Height (Cm) | 154 | 5.12 | 160 | 150 |
| BMI |  | 1.47 | 27 | 20 |

**Effect of Noise levels on Mental Workload**: Figure 3 illustrates the effects of various noise levels on average overall mental workload compared to background noise (45 dBA) for study.

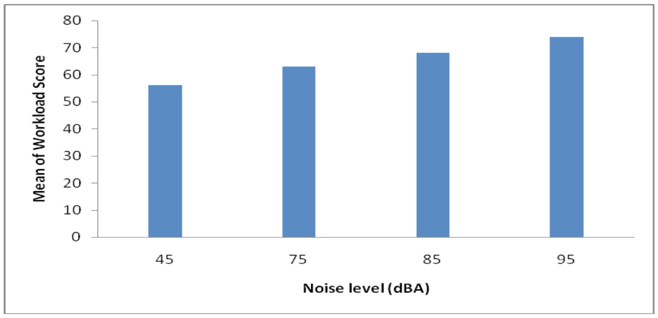

**Figure 3: The effect of noise levels on mental workload. Background noise = 45dB (A)**

The results show that 75 and 85 dBA noise levels, as compared to just background noise, does not follow a particular trend and does not cause a considerable change in the average mental workload (P > 0.05). At 70 dBA level, compared to just background noise, the mental workload had decreased while at 85 dBA it had increased. At 95 dBA level, compared to just background noise, the increase in mental workload was statistically significant (P = 0.03).

**The Effect of Noise levels on Visual and Auditory Attention**: Figure 4 presents the average and standard deviation for the visual and auditory attention score at various levels of noise compared to background noise (45 dBA). The results show that the changes in visual and auditory attention under exposure to various noise levels are very similar in pattern. At 85 dBA levels, average attention scores are reduced, as compared to just background noise, but this is not statistically significant (P > 0.05). But at 95 dBA levels, average attention scores are reduced considerably compared to background noise; this was statistically significant (P < 0.05).

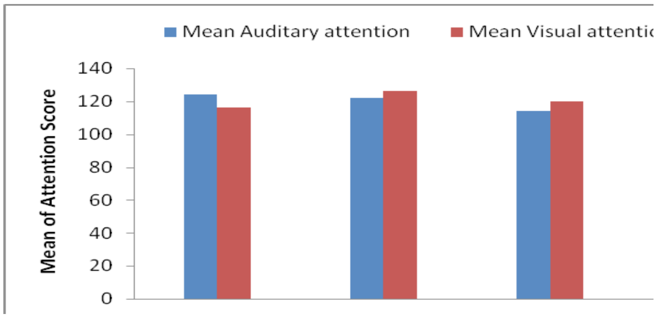

**Figure 4: The effect of noise levels on visual and auditory attention**

**The Effect of Noise levels on EEG Fluctuations:** The Kolmogorov-Smirnov test results indicated that the data were distributed normally. Therefore, the t-test was used in this part.

The relative power of the intended brain frequency bands was used to analyse brain signals during exposure to various noise levels relative to background noise (45 dBA). The considered frequency bands include the Delta (1-4 Hz), Theta (4-8 Hz), Alpha (8-12.5 Hz), Beta (12.5-30 Hz) and Gamma (30 Hz upwards) bands. The results show that among the mentioned frequency bands, the Alpha and Beta bands undergo considerable changes, as relative to just background noise, and are being affected by noise. Based on Table 3, going from 75 dBA to 95 dBA noise level causes a statistically significant average variation in the relative power of the Alpha band for the Fp1, F4, P3, O1 and O2 regions of the brain (P< 0 .05). Again, based on Table 3, at 95 dBA, the largest variation in the relative power of the Alpha band is observed for the O1 region of the brain (P < 0.001).

**Table 3: Average variation in the relative power of the Alpha band during noise exposure to background noise (45 dBA)**

| Noise level (dBA) | 75 |  | 85 |  | 95 |  |
|---|---|---|---|---|---|---|
| **Brain-part** | **t-value** | **p-value** | **t-value** | **p-value** | **t-value** | **p-value** |
| FP 1 | 0.130 | 0.907 | 0.017 | 0.997 | 3.254 | 0.011 |
| F3 | 1.41 | 0.183 | -0.978 | 0.351 | -2.554 | 0.027 |
| F4 | -0.833 | 0.427 | 0.074 | 0.953 | 2.450 | 0.032 |
| F7 | 2.442 | 0.023 | 2.289 | 0.042 | -0.752 | 0.472 |
| C4 | 1.544 | 0.149 | 2.803 | 0.019 | -0.646 | 0.538 |
| P3 | 0.367 | 0.729 | 2.067 | 0.063 | 2.451 | 0.033 |
| O1 | -0.028 | 0.990 | -1.343 | 0.206 | 5.885 | 0.007 |
| O3 | 0.413 | 0.696 | -2.849 | 0.018 | 2.253 | 0.045 |

A significant reduction in the relative power of the Alpha band was only observed for the F3 region (P<0.05), though a slight reduction was observed for the C4, F7 and F3 regions of the brain also. The most affected areas of the brain when exposed to noise seems to be the Occipital, Prefrontal, Frontal and Parietal regions of the brain as illustrated in topographic image (Figure 5A).

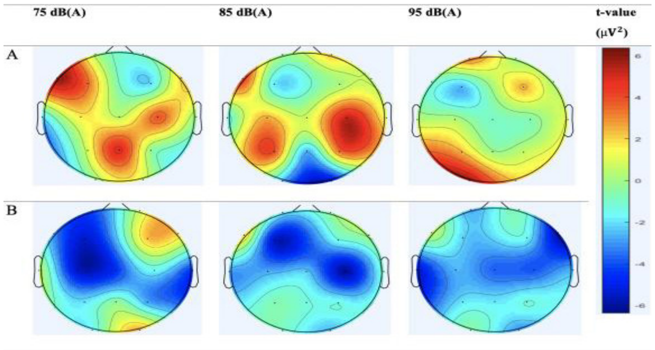

**Figure 5: Topographical mapping of frequency bands' relative power during exposure to noise as relative to background noise (45 dBA)**

Table 4 demonstrates average variation in the relative power of the Beta band during exposure to various noise levels relative to background noise. The results show a reduction in the relative power of the Beta band in all channels as a result of exposure to 75, 85 and 95 dBA noise, although this reduction was most prominent at 95 dBA.

Based on table 4, this reduction is statistically significant ($P < 0.05$) and the order by which it occurs, and the affected areas are as follows: F8-T3-C4-Cz-O2-Fp1-T4-F3-C3. No significant effect was observed in the other areas of the brain under study ($P > 0.05$). Also, based on figure 5b, the reduction in the relative power of the beta band as a result of the increase in the level of noise occurs in the Frontal, Temporal, Occipital and Central lobes.

## DISCUSSION

The results of this study showed that as a stressor, noise affects cognitive performance and brain signals, and, also that noise pressure level is an important factor regarding impairment of cognitive function and power spectral density of the brain as in agreement with the proposal that a relationship exists between low performance and high levels noise (Irgens-Hansen et *al*, 2015). Some studies have used qualitative measurements including subjective responses for the evaluation of the effects of noise exposure on cognitive function. In this study, however, quantitative indicators were used in combination, including the evaluation of mental workload, evaluation of auditory/visual attention and brain signals analysis.

This method is suggested to overcome the limitations in physiological evaluation techniques (Choi et al, 2015) as Share and others who also suggested that to improve cognitive and mental stress evaluation, a combination of these tools should be used (Al-Shargie et *al*, 2015). In previous studies, the effects of noise exposure on heartbeat and blood pressure at 95 dBA were compared to 75 and 85 dBA (Kristel-Boneh et al, 1995). The effects of high levels of noise exposure on cognitive performance can be amended to the Poulton arousal model which states that noise exposure increases cognitive performance at first, but thereafter the negative effects of noise exposure on cognitive function begin to show (Poulton, 1981). The results in the present study can be explainable using arousal theory. This theory states that the level of central nervous system activity regulates human response to stimuli and it can be said that when arousal is high or low, or in other words, in both low stress and high-stress situations, performance is reduced (Yerkes and Dodson, 1908).

**Table 4: Average variation in the relative power of the Alpha band during noise exposure to background noise (45 dBA)**

| **Noise level (dBA)** | **75** | | **85** | | **95** | |
|---|---|---|---|---|---|---|
| **Brain-part** | **t-value** | **p-value** | **t-value** | **p-value** | **t-value** | **p-value** |
| FP 1 | -1.440 | 0.176 | -1.449 | 0.174 | -2.743 | 0.0147 |
| F3 | -1.886 | 0.084 | -4.470 | 0.007 | -2.255 | 0.0390 |
| F8 | 0.694 | 0.507 | 0.055 | 0.968 | -6.106 | 0.070 |
| T3 | 0.694 | 0.824 | -2.297 | 0.042 | -5.654 | 0.009 |
| T4 | 0.241 | 0.147 | -0.846 | 0.420 | -2.750 | 0.021 |
| C3 | -1.554 | 0.079 | -2.208 | 0.048 | -2.680 | 0.023 |
| C4 | -1.940 | 0.592 | -4.885 | 0.007 | -4.023 | 0.009 |
| O2 | -0.562 | 0.387 | -2.043 | 0.064 | -3.107 | 0.015 |
| CZ | 0.907 | 0.146 | -1.853 | 0.089 | -3.832 | 0.008 |
| PZ | -0.161 | 0.886 | -1.025 | 0.329 | -1.980 | 0.073 |

There were conflicting results regarding the effects of noise on cognitive function in previous studies. Some studies determined that noise had improved cognitive function (Hoskin et *al*, 2014), while others had concluded that noise had reduced cognitive function (Staal, 2004). This is part of the reason why, in this study, quantitative measurements were used in combination. The results of the present study reveal that the reduction of cognitive function and brain signals was only significant when exposed to noise at 95 dB level and not at 75 or 85 dBA. This could be due to other psychoacoustic factors such as noise pitch, tonality, exposure duration, and noise type. The importance of noise pitch and its effects on cognitive function and brain activity has been emphasized in other studies. The study showed the complexity of brain activity increases at midrange frequencies, showing the effects of the change in frequency on brain activity (Allaberdy and Jafari, 2016).

Another effective parameter regarding noise and performance is noise tonality as it was observed that performance was reduced with increasing noise tone strengths (Lee et al, 2017). Type of noise is also important when evaluating the effects of noise on cognitive function. Studies have shown that the effect of fluctuating noise on cognitive function is higher than steady noise (Kjellberg, 1990). Steady noise was the only type used in our study. Also, exposure times used were rather short, which may result in a reduced effect of noise on performance and brain signals when exposed to lower than TLV noise. The lesser effect of lower than TLV noise (45, 75 and 85 dBA) on performance and brain activity may also be due to non-psychoacoustic parameters as scope and diversity are influential in the methods used for cognitive function evaluation (Koelega and Brinkman, 1986). Simplicity or complexity of the task is another example as a complex task causes a greater cognitive dysfunction when compared to simple tasks. Personal characteristics may also be a factor when subjects are exposed to noise. As some may experience reduced cognitive function while others may not, and some may even show increased cognitive function (Koelega and Brinkman, 1986). These factors may not be as influential in the present study as the students were prescreened for mental disorders, cardiovascular disorders and behavioral abnormalities before selection. Many aspects of brain function and behavior can only be discussed in terms of neurons communicating with each other. All cognitive processes in the brain are carried out through neuronal activity such as synapses and spikes. Orientation and executive function which are involved in the processing of attention are specifically undermined to enable information processing. The disruption of attention likely occurs in students whenever there is a need for sustained attention.

In this study, Brain signal analysis disclosed that the Alpha and Beta frequency bands were affected by noise. With an increase in noise levels, the relative power of the Alpha and increased while the relative power of the Beta band decreased. Topographical mapping of the scalp shows that all four lobes of the brain are usually affected by noise, but this is more pronounced in the frontal and occipital lobes, which is consistent with the results of other studies (Tseng et *al*, 2013). Other conclusions can be made from this study regarding the relationship between visual / auditory attention and the relative power of the Alpha and Beta bands. In this regard, it can be said that with increasing noise levels, participants' auditory / visual attention score went down while the relative power of the Alpha and Beta bands increased and decreased respectively. Topographical mapping of the scalp indicates that the area responsible for attention processing is located in the frontal, temporal and occipital regions of the brain which is consistent with the results of Liz et *al* (2014). Therefore, the results of this study suggest that when one is exposed to various noise levels, mental workload, visual / auditory attention and the relative power of the frequency bands follow a similar trend. In studies that pertain to brain signals and cognitive performance, attention to artifacts such as eye and body movement, electrical interference, impedance fluctuations, sleep disorders, personality characteristics, age, sex and race are all important, and this has been reiterated in various studies (Rabat et *al*, 2006). The benefits of using the NASA TLX and IVA +Plus tests along with EEG signal recording in the psychological and neuro-physiological evaluation include the ease of administration, non-invasiveness, short evaluation times and low cost. It is suggested that in future studies on the evaluation of the effects of noise, other psychoacoustic parameters such as noise pitch, tonality and also extended periods of exposure be considered. It is also suggested that more than 16 channels be used for the EEG recordings for better and more detailed evaluations of the various brain regions.

## CONCLUSION

In conclusion, noise levels seem not to have the appropriate sensitivity at levels below 85 dBA on cognitive performance. Therefore, other psychoacoustic parameters that influence cognitive function, including noise pitch and tonality are suggested for future research. Scalp topographic mapping indicates that the frontal and occipital regions along with the Alpha and Beta frequency bands are most affected by exposure to noise considering the influence of task complexity, personality characteristics, the effects of other psychoacoustic parameters on cognitive and neuro-physiological functions, applying new methods such as the use of brain 2-way signals along with power spectral density in the evaluation of environmental and occupational stress, especially in the case of noise exposure is suggested. It can thus be concluded that the evaluation of mental workload, auditory / visual attention and brain signals in combination can be considered as a useful indicator for the assessment of the effects of noise exposure on cognitive performance.

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