ORIGINAL ARTICLE

A Novel Effect of White Noise on Auditory and Visual Attention using Biomedical Signals on Petrochemical Control Room Operators

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ABSTRACT

Background: Shift work causes sleep disorder and drowsiness and thus reduces consciousness, attention, and increases human error.

Aim: The aim of the study was whether or not white noise can affect cognitive performance, and the changes could be estimated using Electro-Dermal Activity (EDA) and Heart Rate Variability (HRV) in the petrochemical control room staff.

Method: The subjects were exposed to white noise at two pressure levels of 65dB(*A*) and 73dB(*A*) while their auditory and visual attention were evaluated by Integrated Visual and Auditory (IVA) test. Moreover, to evaluate the effect of white noise on physiological parameters, HRV and EDA methods were used. Subsequently, the Generalized Estimating Equations (GEE) were used to analyze the data.

Results: The findings showed that white noiseat pressure level of 73 dB could have a significant positive effect on auditory (B=8.8, p=0.001) and visual attention (B=7.03, p=0.001). In addition, cognitive performance changes due to white noise could be estimated by EDA and HRV.

Conclusion: White noise at pressure level of 73 dB can have a significant positive effect on auditory and visual attention. Moreover, cognitive changes in operators can be estimated by EDA and HRV.

Keywords: Auditoryattention,Electro-Dermal Activity, Heart Rate Variability, Visual attention, White Noise.

INTRODUCTION

Research studies have shown that shift work has a negative impact on important cognitive performance, such as information processing, memory, and attention. On the other hand, studying the effects of shift work on cognitive performanceis complicated; since cognitive performance impairment can be affected by sleep disorders, circadian cycles, and other factors [1,2]. Shift work causes sleep disorder and drowsiness, which can reduce consciousness, attention, and increase human error[3]. This fact has been well understood and confirmed that noise influences cognitive performance under different circumstances[4].Some research studies have shown that environmental noise can have a negative effect on the cognitive process[5]; however, listening to white noise shows the opposite result[6,7].

Recent studies on the effect of white noise on cognitive performance have shown that white noise can lead to increased attention, accuracy, memory, and consciousness of individuals and improve their cognitive performance[7,8]. In addition, different sound characteristics have a different impact on human performance[9,10]. Drowsiness has a considerable effect on the Autonomic Nervous System (ANS). The Heart Rate Variability (HRV) spectral analysis is a non-invasive method for quantitative evaluation of ANS system dynamics[11,12].

Electro-Dermal Activity (EDA) is a method for measuring changes in the electrical conductivity ofthe skin, which is a precise method for measuring the sympathetic system activity. The relationship between HRV, heart autoimmune neuropathy, and cognitive performance has already been confirmed[13]. The EDA activity is the most useful indicator of changes in sympathetic stimulation that can detect cognitive performance; since it is the only independent psychological variable that does not affect parasympathetic activity[14]. The EDA is closely related to cognitive performance and is widely used as a sensitive indicator of cognitive performance and sympathetic activity[15].The EDA activity index has a similar trend with vigilance indicators and it can be a supplement to the HRV to evaluate cognitive performance[16].

Process industries, especially petrochemicals, gas have always been prone to dangerous incidents, particularly explosions and terrible fires around the world over the past decades. Damage to people and equipment in such accident indicate the dangerous nature of these industries[17,18]. The Performance of the petrochemical control room operators is very important in maintaining the safety of the process; therefore, the employees of this department need to be alert and well-functioning[19].

Although the night shift staffs' vigilance and proper performance in the control room of the petrochemical industry are important, the effect of white noise on their auditory and visual attention has not been studied. Therefore, the aim of this study is whether or not white noise can affect the cognitive performance of the petrochemical control room staff and these changes can be estimated using the HRV and EDA.

MATERIALS AND METHOD

Participants and Design: This interventional study was conducted on 30 male participants. All the studied participants were the control room operators of a petrochemical complex located in southern Iran. All the operators who didn't use sedative and stimulant drugs didn't smoke, didn't have psychiatric diseases and sleep disorders were included in the study. Consuming caffeine was limited for the objective of the study. Thus, 3 operators were excluded from the total 33 operators. The work schedule of the participants included seven-night shifts, seven-day shifts, and seven-day rest. The day shift started at 07:00 and ended at 19:00, while the night shift started at 19:00 and ended at 07:00. The participants completed a demographic questionnaire to examine the significant variables. The participants complete all questionnaires 30 minutes before beginning the test.

White Noise: White noise is a random signal including the equal intensity at different frequencies, giving it a constant power spectral density[8].

White noise can be accepted as a sound, which is artificially produced by combining all audible frequencies in equal intensity[6]. Natural sounds including river flow, sea wave, waterfall, streaming water, and the sound of the rain were provided giving them a constant power spectral density by cool edit pro 2.1 software as a 1/3 octave band in (*A*) network with constant power per 1 Hz frequency band across the entire sound spectrum over large frequency span. As it is recommended, 1/3 octave band was used to increase the precision of sound frequency analysis. The SPL of the applied white noise was measured to satisfy the steady state sound. Therefore, the variation of the SPL was less than 5 dB.

Some of these sounds were combined in binary (waterfall with the sound of rain and stream of the river with waterfall) and their play time was determined in the test environment for 40 minutes. It was replayed in the sound lab and analyzed by the sound analyzer in order to verify the soundness of the produced white noise. The sound level meter used in this research was the B&K 2238, which acts according to IEC-61672 standard. It is also according to ANSI-S1.4-1983- Type1. The tests guaranteed the quality of the applied sound. The study was conducted with SPL of 65 dB(*A*) as Background noise and 73 dB(*A*).

Cognitive Tests: The Integrated Visual and Auditory (IVA) Continuous Performance Test (CPT) is a screening tool used to assist in the screening of an individual's attention. It can also be used to monitor the effectiveness of neurofeedback training or medication. Like all CPT's the IVA is designed to be mildly boring and demanding of sustained attention producing errors of inattention (omission) and impulsivity (commission).This is a computerized test and needs 13 minutes to be performed[20]**.**

Heart Rate Variability (HRV): The HRV is the physiological phenomenon of variation in the time interval between heartbeats[21]. To remove noise and motion artifacts, Electrocardiogram (ECG) signals were analyzed in the frequency range 0.05-40 HZ. The frequency spectral density method was used to analyze the HRV data. A Blackman window (length of 1000 points) was applied to each segment.

First, Fast Fourier Transform (FFT) analysis of the wave decomposition was performed in terms of frequency distribution, and then the average power density under the curve was calculated. Low-Frequency (LF) Index was calculated in the range of 0.045-0.15 HZ, High-Frequency (HF) 0.15-0.4 HZ.

Since the cardiac data of many people are heavily influenced by individual differences, the cardiac responses of the operators were compared with each other and the comparison was not made between the individual[13,22]. Average Heart Rate (HR)/HRV parameters and LF/HF ratio were compared in two levels of white noise with baseline conditions.

Electro-dermal activity (EDA): To get the highest signal dynamics; the frequency of 0.0004 Hz was cut. Although the skin guidance level refers to the tonic EDA, the SCL index was calculated as the mean tonic EDA over the course of 8 minutes. A Blackman window (length of 1000 points) was applied to each segment.

First, Fast Fourier Transform (FFT) analysis of the wave decomposition was performed in terms of frequency distribution, and then the mean power of the frequency spectrum was calculated below the curve. The EDA power index was calculated by combining power in the range of 0.045 to 0.25 Hz[23,24]. Finally, the mean SCL index was compared in two levels of white noise with baseline conditions. In this study, for each run; 8 min of EDA were collected while the subject was performing the IVA, to compute SCL and HRV.

Sleep Quality (Pittsburgh Sleep Quality Index): The PSQI was used to measure the sleep quality of the participants. Buysse et al. The range of overall score obtained from the questionnaire is 0-21; while the overall score of 5 shows a significant undesirable quality of sleep and sleep disorder. Farrahi et al.[25] reported a sensitivity of 100% and Cronbach alpha of 0.89 for the Persian version of this questionnaire which was used in this study[26].

Morningness-Eveningness Questionnaire Type: Researchers Horne and Ostberg developed the Morningness-Eveningness Questionnaire (MEQ) that is a self-assessment questionnaire in 1976. It aims at measuring mainly whether a person's circadian rhythm (biological clock) produces peak alertness in the morning, in the evening, or in between. The internal consistency of this questionnaire has been reported to be 0.85 in research studies[27].

Demographic Characteristics Questionnaire: The participants completed the demographic questionnaire, including age, gender, marital status, educational level, work experience, average working hours per day, and type of work system[28].

Experimental Design: The standard method (ISO 9612-2009) was used to measure the noise level in the control room. Four speakers (Samsong, Koran) were positioned around the room to evenly distribute the noise level in it. It was tested to be sure that each study subject receives a noise level of 65 dB(*A*) for Background noise and 73 dB(*A*).

Considering that the control room sound was tested at 65 dB(*A*), it was assumed that white noise, which is equivalent to background noise, could affect the cognitive functions. Therefore, one of the interventions was applied to background noise.

Stages of noise exposure for the participants were as follows: First, the participants did not expose to white noise and completed the IVA test; this stage was considered as the baseline. In the second stage, the participants were exposed to white noise at SPL of 73 dB(*A*) for 40 minutes and then again performed the IVA test. In the third stage, before the exposure to the SPL of 65 dB(*A*), the participants had rest for an hour and then they were exposed for 40 minutes to SPL of 65 dB(*A*) and then they performed the IVA test. All IVA tests were performed in three stages of the study in a non-sound room. In the second and third stages of the study, the participant's white noise was exposed to constant power per 1 Hz frequency band across the entire sound spectrum over a large frequency span. Finally, the results of the three stages of the IVA test were compared.

A sound level meter (B&K, UK) was applied to measure the pressure of broadcasted sound several times to ensure its uniform playback. The assessment should be done when the level of alertness was at the lowest level; therefore, the test was performed on the night shift workers at 2:00-5:00. The environment was in thermal comfort conditions at 23 ± 2 °C and relative humidity of 35% (Generaltools, Germany).

Statistical Analysis: The Generalized Estimating Equations (GEE) test was used to examine the effect of white noise on the attention of auditory and visual types by adjusting the effect of sleep quality, circadian cycle, age, work experience, and marital status. According to this study, each person experienced three situations; the generalized estimating equations test considers the correlation of measurements in the analysis. SPSS version 23.0 was used to analyze the data and the significant level was considered to be less than 0.05 (e. g., $p< 0.05$). As previously mentioned, the GEE is a type of regression considering the relationship between repetitive observations of a sample[29].

RESULTS

Thirty male operators working in a petrochemical complex participated In this study. The mean age and standard deviation were 36.7±4.1 years. Table 1 shows the participants' individual information. Examining the effect of demographic variables including age, marriage, work experience, sleep quality, and circadian cycle on auditory attention types showed that none of the mentioned parameters affected significantly the auditory attention and visual attention types using multivariable linear regression.

The results of comparing the interventions with the baseline conditions indicated that white noise affected significantly the auditory attention at SPL of 73 dB(*A*) ($B = 8.8$, $p = 0.001$). Also, the effect of white noise on auditory Selective Attentionexpressed that white noise affected significantly the auditory Selective Attentionat SPL of 73 dB(*A*) ($B = 17.73$, $p = 0.001$) (Table 2).

Figure 1 shows the mean score of the IVA test on attention types. As Figure 1 shows, the participants' cognitive performance increased at 73 dB(*A*).

The effect of white noise on visual attention showed that white noise at SPL 73 dB(*A*) had a positive significant effect ($B = 7.03$, $p = 0.001$). Considering the test and comparing it with the baseline (pre-intervention) conditions in the visual Selective Attention, it was observed that the white noise atSPL of 73 dB(*A*) had a positivesignificant effect ($B = 8.26$, $p = 0.001$) (Table 2).

Figure 2 shows the mean score of the IVA test on visual attention types. As Figure 2 indicates, there is a significant increase in the cognitive performance of the participants in the white noise at SPL of 73 dB(*A*).

The results of the GEE test of the operators' physiological indices in baseline and exposure conditions with noises at pressure levels of 65dB(*A*) and 73dB(*A*) are shown in Table 3. The results show that HR ($B = 8.66$; $p = 0.001$), LF/HF ($B = 0.047$; $p = 0.002$) and EDA have a positive and significant increase in terms of 73 dB(A) noise conditions.

Table 1: General characteristic of study population.

Variable	Mean ± SD
Age (years)	36.7 ±4.4
Work experience (years)	10.9 ± 3.8
BMI	25.2 ± 2.3
PSQI (Sleep quality score)	4.61 ± 1.61
MEQ	N (%)
morning type	6 (20%)
interstitial type	20 (66.3%)
evening type	4 (13.7%)

Note: Total number of participants: *N* = 30; BMI = body mass index; MEQ = Morningness-Eveningness Questionnaire; PSQI = Pittsburgh Sleep Quality questionnaire.

Table 2: Comparing the effect of white noise at sound pressure levelof 73 dB(*A*) and 65 dB(*A*) with baseline conditions on auditory and visual attention types.

Independent Variable	73 dB(*A*)			65 dB(*A*)		
Comparing statistical parameter	*B*[*]	*SE*	*p*	*B*	*SE*	*p*
Auditory Attention	8.80	2.63	0.001	-1.70	0.35	0.061
Auditory Selective Attention	17.73	3.28	0.001	-2.30	0.67	0.068
Auditory Divided Attention	10.10	1.92	0.001	-5.20	0.60	0.089
Auditory Moving Attention	8.40	1.34	0.001	-3.66	0.48	0.074
Visual Attention	7.03	2.14	0.001	-1.20	0.27	0.064
Visual Selective Attention	8.26	1.97	0.001	-3.33	0.76	0.061
Visual Divided Attention	8.33	1.90	0.001	-4.46	0.51	0.071
Visual Moving Attention	8.80	1.36	0.001	-4.83	0.87	0.079

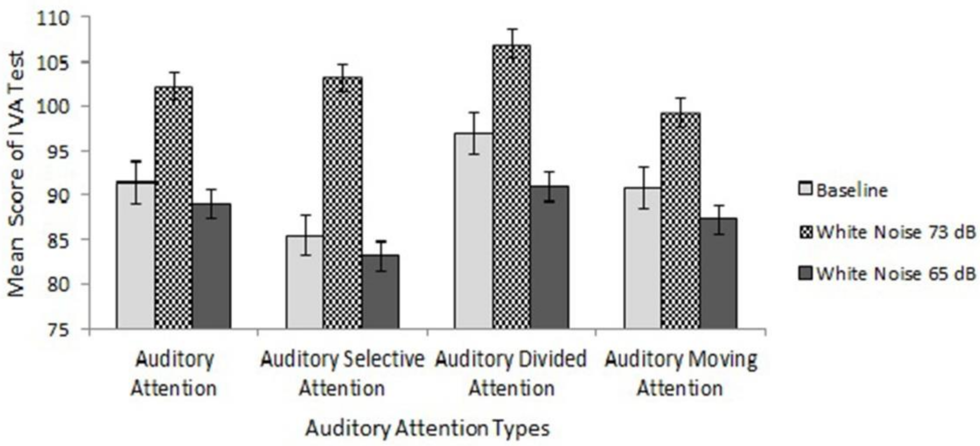
Note: Total number of participants: *N* = 30.Values significant at $p< 0.05$.
[*]Effect

Table 3:Effect of white noise at two pressure levels with baseline conditions on biomedical signals.

Independent Variable	**73 dB(*A*)**			**65 dB(*A*)**		
Comparing statistical parameter	***B****	***SE***	***p***	***B***	***SE***	***p***
HR	8.66	1.18	0.001	-3.51	.58	0.071
HRV	-0.06	0.009	0.001	.006	.010	0.578
LF/HF	0.047	0.01	0.002	-0.02	0.01	0.062
EDA	75.05	16.12	0.001	-7.27	5.61	0.195

Note: Total number of participants: $N = 30$. HR = Heart Rate; HRV = Heart Rate Variability; LF = Low Frequency; HF = High Frequency; EDA = Elector Dermal Activity; Values significant at $p< 0.05$.
*Effect size of intervention.

Fig. 1: Mean score of Integrated Visual and Auditory (IVA) on auditory attention types



Note: The results show that when the participants were exposed to white noise at sound pressure level (SPL) of 73 dB(*A*), their score was significantly higher than the SPL of 65 dB(*A*). Low variance of the estimates indicates the precise measurement of the variables in this study

Fig. 2: Mean score of Integrated Visual and Auditory (IVA) on visual attention types
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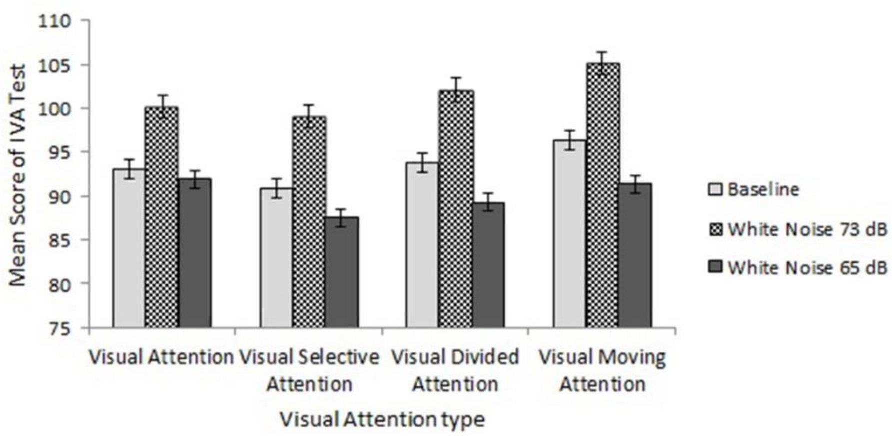

Note: Comparing the three conditions of the participants showed that white noise at sound pressure level (SPL) of 73 dB(*A*) created an increase in the score of visual attention types. Error bars (whiskers) indicate an acceptable precision of measuring the variables

DISCUSSION

The aim of this study was to evaluate the effect of white noise on visual and auditory attention and its evaluation with cognitive IVA test and biomedical signals of HR/HRV and EDA before and after the intervention. The results showed that white noise at a level of 73 dB can have a significant positive effect on visual and auditory attention (Table 2) and improve cognitive performance of the participants. In addition, the cognitive performance changes of operators exposed to white noise at a level of 73 dB can be estimated using the HRV and EDA.

In this study, given that 66% of the participants had a moderate circadian cycle, the round-the-clock cycle had no significant effect on auditoryand visual attention[30,31]. The participants in this study were on average 36.7 years old. This age group was not affected by sleep disorders, and no significant relationship was found between age and quality of sleep and auditory and visual attention. These results were consistent with studies by other researchers[32,33].The study confirmed the previously published papers indicating that the participants' BMI did not significantly affect the cognitive performance due to the average 25.2 of BMI and moderate circadian cycles[34,35].

The researchers showed that EDA and HRV could potentially be used to develop tools to assess and predict the cognitive performance of people who are forced to shift work and awake at night due to their occupation and, although they need full vigilance to carry out their duties[14,16]. During the deprivation of sleep, EDA is sensitive to both the circadian rhythms and sympathetic stimulation of the skin[24]. It was observed that the EDA has a similar trend with respect to vigilance and attention indicators. The study shows that the EDA and HRV indices can be used to evaluate the effect of white noise on visual and auditory attention[13].

A study on the effect of environmental noise as a stimulant in creativity showed that the sound at the pressure level 73dB compared to low noise (50dB) increases the performance of creative activities. The present study showed that white noise at a pressure level of 73 dB improves visual and auditory attention[36,37]. Another study on the effect of white noise on students' attention showed that exposure to white noise at a 78 dB pressure level improves the performance of careless children. The results of this study showed that different types of attention can be improved with the white noise effect at a pressure level of 73 dB[6,10].

The results of the study on students' cognitive performance, which were subjected to four levels of intensity (45, 75, 85, and 95 dB) with sound quality of low frequency, medium and high frequency, showed that the sub-average sound (75dB-8000HZ) reduced their reaction time and improved their performance which is consistent with the result of this study[38,39]. As the findings of this study show, sound features in terms of intensity and frequency can affect cognitive performance.

In the present study, which the moderate-intensity and white noise were used, it was observed that moderate-intensity white noise could have a significant positive effect on visual and auditory attention[40]. Based on the results of the present study and other researchers, white noise with more intensity than the background noise could improve cognitive performance, including individuals' attention[41].

The results of this study can be used in places where people's vigilance, attention, and precision are of great importance, such as control rooms for oil, gas, petrochemical, refinery, power plants, and nuclear industry. Moreover, the results can be a way to prevent human errors and accidents caused by these industries and high-risk occupations.

Limitations of the study: One of the limitations of this study is the impossibility of examining the neuro-chemical effects of white noise, depression, fatigue, and workload on cognitive performance of the participants. However, the intervention of the two levels of white noise in the petrochemical control room in southern Iran and the assessment of this effect by biomedical signals (HR/HRV and EDA) and measurement of visual and auditory attention can be one of the strengths of this study.

CONCLUSIONS

From a theoretical point of view, the findings are in accordance with the authors' suggestions, and white noise with more intensity than background noise can improve the auditory and visual aspects of the night-shift operator in control rooms. In addition, the hypothesis of white noise influence on improving cognitive performance in field conditions has been confirmed and these changes resulting from white noise can be estimated by the EDA and HR/HRV.

Nevertheless, white noise may have effects on the perceptual or neuropsychological levels, or they may directly affect the neuro-chemical levels, which will alter the level of dopamine release and affect cognitive performance. Therefore, more research studies are required regarding the specific nervous mechanisms responsible for these effects.

Ethics approval and consent to participate: We obtained permission from the personnel keeping these records. Confidentiality of our participants was maintained. Our study was approved by the Ethics Committee of the School of Public Health and Safety, ShahidBeheshti University of Medical Sciences.

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Conflict of Interests: The authors have no conflicts of interest to declare for this study.

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