

Evaluation of the Effect of Noise on the Rate of Errors and Speed of Work by the Ergonomic Test of Two-Hand Co-Ordination

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ABSTRACT

Background: Among the most important and effective factors affecting the efficiency of the human workforce are accuracy, promptness, and ability. In the context of promoting levels and quality of productivity, the aim of this study was to investigate the effects of exposure to noise on the rate of errors, speed of work, and capability in performing manual activities.

Methods: This experimental study was conducted on 96 students (52 female and 44 male) of the Isfahan Medical Science University with the average and standard deviations of age, height, and weight of 22.81 (3.04) years, 171.67 (8.51) cm, and 65.05 (13.13) kg, respectively. Sampling was conducted with a randomized block design. Along with controlling for intervening factors, a combination of sound pressure levels [65 dB (A), 85 dB (A), and 95 dB (A)] and exposure times (0, 20, and 40) were used for evaluation of precision and speed of action of the participants, in the ergonomic test of two-hand coordination. Data was analyzed by SPSS18 software using a descriptive and analytical statistical method by analysis of covariance (ANCOVA) repeated measures.

Results: The results of this study showed that increasing sound pressure level from 65 to 95 dB in network 'A' increased the speed of work ($P < 0.05$). Increase in the exposure time (0 to 40 min of exposure) and gender showed no significant differences statistically in speed of work ($P > 0.05$). Male participants got annoyed from the noise more than females. Also, increase in sound pressure level increased the rate of error ($P < 0.05$).

Conclusions: According to the results of this research, increasing the sound pressure level decreased efficiency and increased the errors and in exposure to sounds less than 85 dB in the beginning, the efficiency decreased initially and then increased in a mild slope.

Keywords: Ergonomics, noise, rate of error, speed of work, two-hand coordination.

INTRODUCTION

Different factors are effective in the growth and development of productivity of the workforce in a system. The most important effective factors in productivity are efficiency of individuals,

accuracy, and speed of work, and also capability of executing the activities that are by themselves affected by environmental factors.^[1] Workers are continually in collaboration with environmental factors in different industrial settings. These factors affect their health, convenience, and execution morale. Effects on the capabilities and performances of people cause great anxiety, as reduction in productivity of the worker causes loss of profits for any company or industry.^[2] Sound is one of the most important environmental factors existing in industry due to the existence of machineries with different revolutions per unit of time and also various mechanical motions.^[3] Sound is probably the most prevalent occupational and environmental danger.^[4] Research has shown that in occupational situations that require fast reactions and with the effects that sound has on physical abilities, sensing powers, and concentration, and on the potentials in processing environmental information, it increases the rate of errors and accidents.^[5,6] Exposure to sounds louder than the standard causes disturbance in vocal communications and in understanding warning signs, and this could affect the safety and performance of individuals by affecting concentration and increasing risks related to health, inducing early fatigue in people, increasing errors, reducing efficiency and production quality, and so on.^[7] According to studies on the workers of small or medium companies by Kim *et al.*, the risks for reported accidents is more for workers who are exposed to noise.^[8] It is estimated that over 600 million people in the world are exposed to sounds higher than the acceptable standard in their working places.^[9] Emergence of disorders in cognitive activities such as learning, memorizing, and other personal behaviors^[10-12] followed by reducing efficiency of the person, especially in intellectual activities is the one of effects of noise on individuals.^[13] In this respect, Torre *et al.* showed in a research study that mental health score in people who are exposed to high environmental noise (sounds higher than 95 dB) is low.^[14] In his research, Hagler and Goines has stated that noise could make alterations in performance and social behaviors of employees, such as increasing the rate of error, accidents, reducing concentration, memory, and the ability to solve problems, misuse of medicines, disappointment, and hopelessness.^[15] According to the theory of H.W. Henric, one of the

main reasons for accidents is unsafe actions that lead to increasing the potential for accidents. The theory of Henric, known as the domino theory, identifies accidents to be due to the continuity of unsafe actions by individuals, and unsafe actions to be due to a set of factors such as environmental factors (like noise). Although human beings have been accustomed to noise and are in concordance with noisy environments, noise is indeed a tiring element, reducing the capacity of human beings to work both in intellectual occupations or even in physical and simple activities.^[16]

Hence, in the context of the hygienic and occupational issues in the workplace and the importance of productivity of the workforce, the present research was done with the aim to determine the effects of noise at different times on the rate of errors, speed of work, and ability in doing manual work, *in vitro*.

METHODS

Subjects

This interventional study was done in 2012 in the School of Health of the Esfahan Medical Science University, on 96 students (52 female and 44 male) with an average (standard deviation) age of 22.81 (3.04) years, height 171.67 (8.51) cm, and weight 65.05 (13.13) kg. The subjects were selected from students at different education levels, according to four-person random block sampling method. Inclusion criteria included individuals tending to co-operate in the research and physically healthy people, especially with no history of musculoskeletal disorders of the upper body and also people with healthy organs of hearing and vision. The subjects were given an explanation of the study, a consent form to sign, and a questionnaire for obtaining demographic information and ensuring no musculoskeletal disorder in them by enquiring with the participants. To ensure the hearing sense in the participants (having a loss in hearing of less than 25 dB), an audiometric screen test was performed. Visual intensity in participants was also evaluated by the Snellen chart. The participants were divided into four groups, each consisting of 24 people (one group as the control group and the other three groups exposed to sound pressure level of 65, 85,

and 95 dB in the 'A' network). The sample size was 74 people with a confidence interval of 95% and power factor of 80%. Due to the possibility that some participants might leave the test, the number of participants was increased by 30%, to get a total of 96 students. The test was done in an acoustic room to control the interventional variables and providing similar conditions for the participants. The illumination intensity in the testing area was 591 lux. Tables and chairs with suitable height and suitable footstools were prepared for the participants, and inside the acoustic room, the thermal condition was controlled (wet bulb globe temperature: $20 + 1^{\circ}\text{C}$).

Preparation of laboratory conditions

The sound made from a centrifugal fan with a wide frequency band was recorded by a voice recorder, (model: Denpa Digital HR-F24) and was adjusted and amplified by Gold Wave software. The specifications of sound pressure level at different frequencies were determined [Figure 1] during recording and playing by a noise analyzer (model: B and K type: 2231). Three speakers with 500 watt of power were used, 1.5 m away (two at the sides and one at the back) from the test participant [Figure 2]. The sound pressure levels were controlled beside each participant during the test every five minutes. The sound pressure levels were adjusted by using a sound level meter (model: B and K type 1625) and the speaker volume was adjusted at three different levels of 65, 85, and 95 dB in the 'A' network.

Experimental design

To begin, the participant went to the test room and rested for 15 minutes. During this time, a relevant question was asked about the discomfort of the participant due to the noise, according to ISO 15666 standards,^[17] with respect to a specific grading with 10 numbers (from '0' as the least discomfort to '10' as the state of maximum discomfort), and the response of the participant was recorded. Then the methodology of the test with the measuring device for the ergonomic test of hand coordination was instructed verbally to the participants. The ergonomic test for coordination of the hands is one of the evaluation methods for manual skills^[18] [Figure 3]. This test is used for measuring the moving abilities of two hands in coordination manner, precision in working, speed of

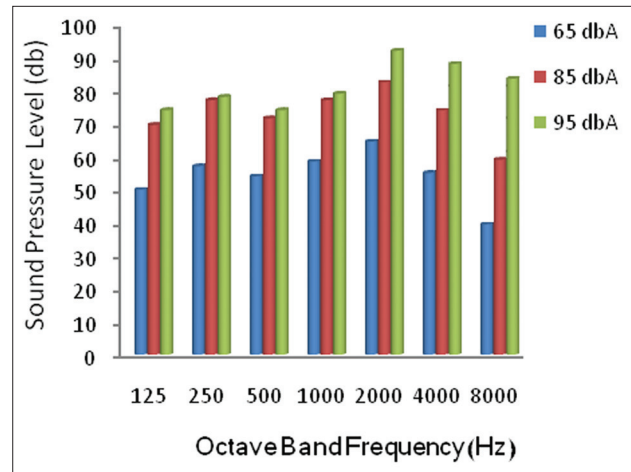


Figure 1: Specifications of sound pressure levels at different frequencies, in three different levels

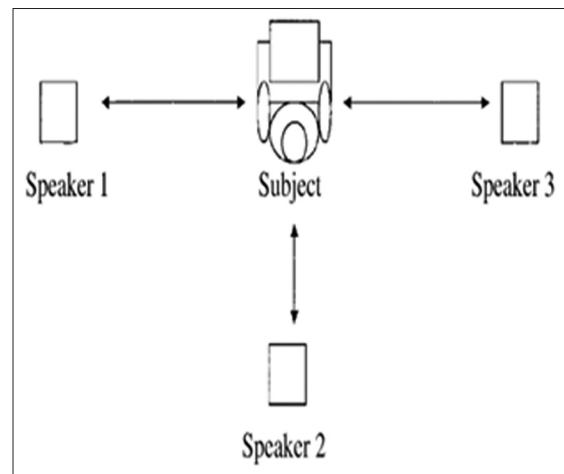


Figure 2: Place for deploying the participants during intervention with different sound pressure levels due to noise, according to ISO15666 standards in the studied groups (Before and after confronting with noise)

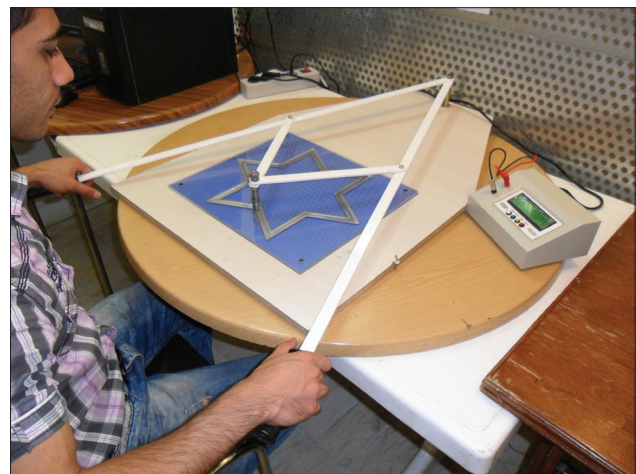


Figure 3: Ergonomic test of two-hand coordination

action, driving, and other relevant skills.^[19,20] After instructions, the test of co-ordination of the hands was performed individually by each participant. Then the recorded sound was played with the sound pressure levels of 65, 85, and 95 dB in the 'A' network. Depending on the code (65 dB (A), 85 dB (A), or 95 dB (A)), each person was exposed to the sound for 40 minutes and during the 40 minutes of exposure to the sound, the co-ordination test of the hands was done thrice; first test at time '0', that is, before any exposure, second test at 20 minutes after start of the test, and the third test at 40th minute after exposure to the noise. The testing time and the number of errors by the participant during the test were recorded by an impulse indicator connected to the measuring device. After the 40-minute test, the participant was asked again about the discomfort due to the noise and the score regarding his/her response was recorded. SPSS18 was used to analyze the data. Average and standard deviation indexes were used to describe the data, and the analysis between increase in the sound pressure level, performance time, and measured errors in the test regarding co-ordination of the hands was done by the use of the covariance test with repetition.

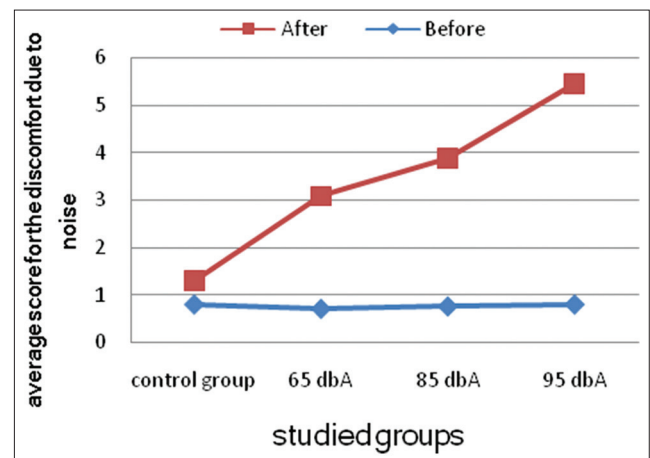
RESULTS

The average and standard deviation for body mass index (BMI) of the participating people in the test was 21.92 (3.22) kg/m². The youngest person was 18 and the oldest was 38 years old; 86.6% of the participants were single and 13.4% were married.

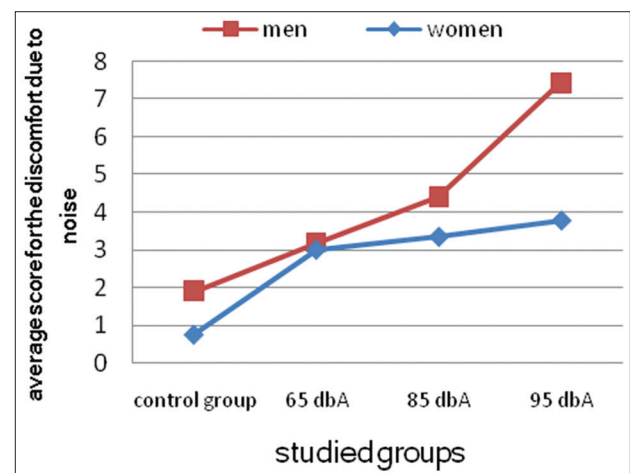
The participants were studying in different fields in the school of health, including occupational health (36.3%), environmental health (23.4%), public health, and other fields of study. The level of education of most participants was bachelor degree (87.6%). The obtained results show that the discomfort due to noise considerably increased after exposure to it at a sound pressure level of 95 dB (A) [Graph 1]. Also, the results showed that discomfort due to exposure to noise has statistical significance with gender ($P < 0.05$). After categorizing the participants for the gender, it was found that the effect of sound pressure level was more on men than women and men get annoyed due to the noise more than women [Graph 2].

Regarding the evaluation of manual skills, rate of errors, and working speed of the participants, measurements were done by using the test for co-ordination of both hands. Table 1 shows the time obtained by the test and the rate of errors made.

According to the data obtained from the test regarding co-ordination between the hands, it was found that increasing the exposure time in this test (0-40 min) and gender (being a male or female) does not statistically provide significant differences in the speed of activities ($P > 0.05$), but increase in sound pressure level from 65 dB to 95 dB in the 'A' network caused increase in the speed of work ($P < 0.05$). In calculating the rate of errors in the test for co-ordination of the hands with increase in the exposure time, no significant differences



Graph 1: Comparison of the average score for the discomfort



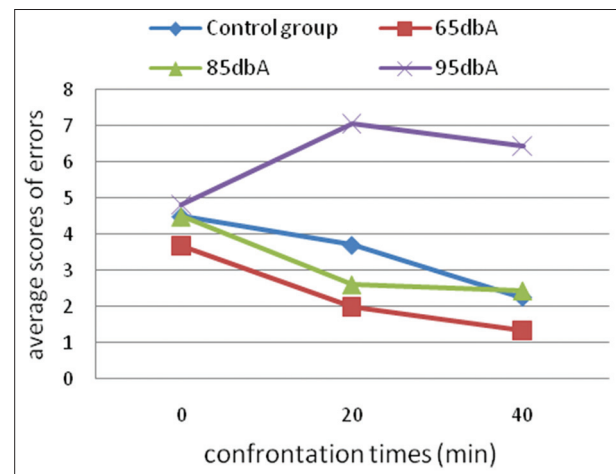
Graph 2: Comparison of the average score for the discomfort due to noise, according to ISO15666 standards in men and women (After confronting with noise)

were observed ($P > 0.05$), but by increasing the sound pressure level, a significant difference was observed ($P < 0.05$) [Table 2].

DISCUSSION

In addition to controlling for intervening factors, a combination of the factors of sound pressure level and duration of exposure to noise was used in the present research for the relevant tests. The findings of this study showed that average scores regarding discomfort before and after exposure to noise have significant relation with sound pressure levels. Of course, it is to be noted that as discomfort due to noise in this research was considered only at the beginning and at the end of the research, the effects of increasing discomfort due to noise could not be considered as only limited to sound pressure levels, but other reasons such as fatigue could affect discomfort and uneasiness due to relatively long-term confrontation with noise. The findings also showed that discomfort due to exposure to noise has statistical significance for gender. Various results have been recorded concerning correlation of gender and discomfort. The research by Enmarker showed also that the rate of discomfort does not have significant differences between men and women,^[21] whereas Kjellberg *et al.* stated that the intensity of discomfort in men is higher than women.^[22] This statement is in conformity with the present research. The findings showed that increase in sound pressure level could have a

negative effect on the rate of accuracy in human beings; in other words, it reduces the efficiency of a person by increasing errors in doing the assigned work [Graph 3]. Comparing the rate of errors of the control group with other groups shows that the rate of error at sound pressure level of 95 dB in 'A' network is the highest at any exposure time, but it decreases initially and then gradually increases for 65 dB or 85 dB levels at any time. This result is in conformity with the studies made by Khan and Smith, who showed that sound may first have positive effects on performance, but in course of time with exposure to sound, this effect weakens.^[23,24] The increase or decrease in the rate of error could be justified by the Yerkes and Dodson law. Yerkes and Dodson were



Graph 3: Comparison of the average scores of errors and increasing confrontation times of studied groups

Table 1: Speed rate and error rate in case and control groups

Test for coordination of both hands	Duration of confrontation (minute)	Control group	Case group			P value
			65 dB (A)	85 dB (A)	95 dB (A)	
Speed rate (seconds)	0	71.94 (18.57)*	77.88 (29.83)	79 (26.32)	76.18 (18.47)	0.749
	20	56.87 (16.75)	68.43 (22.4)	59.66 (19.3)	54.23 (16.61)	0.06
	40	45.34 (12.4)	59.82 (17.37)	41.15 (9.11)	34.17 (5.23)	0.000
Error rate	0	4.5 (3.21)	3.7 (4.27)	4.5 (2.02)	4.83 (2.08)	0.622
	20	3.7 (2.05)	2 (2.48)	2.62 (3.68)	7.08 (6.06)	0.000
	40	2.25 (1.96)	1.34 (1.46)	2.45 (1.91)	6.46 (2.34)	0.000

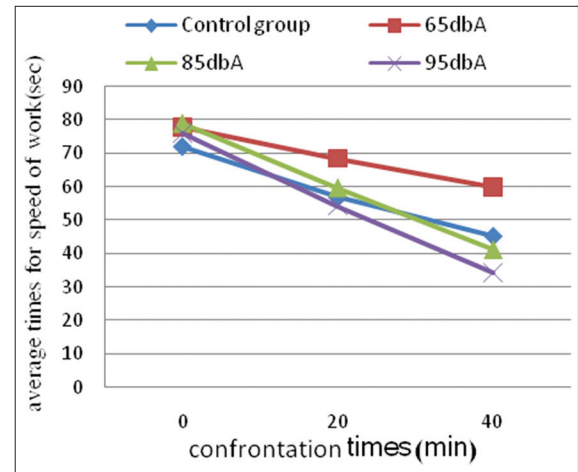
*Average (standard deviation)

Table 2: Effects of sound pressure level on speed of work and rate of errors

	Error rate (accuracy)			Time (speed rate)		
	F	df	P value	F	df	P value
Time (0, 20 and 40 min)	1.443	(2 and 88)	0.242	0.269	(2 and 88)	0.765
Sound pressure level	4.513	(6 and 176)	0.000	3.343	(6 and 176)	0.04

two management theoreticians who presented the relation of stress and performance as the Yerkes and Dodson law. This law states that when stress is optimized, performance will be at its highest level. When stress is low or very high, performance is low, and only when stress is at an intermediate level and is optimized, the performance is at its maximum.^[25] According to this, it could be said that the sound played at sound pressure levels of 65 dB (A) and 85 dB (A) could create optimized stress in participants, in comparison with the control group and at the beginning of exposure to noise. This could reduce the number of errors after playing the sound, but by increasing the time of exposure, performance gradually weakens and the rate of making errors in participants increases. As the test of hand coordination is simple in nature, the sound pressure of 65 dB (A) and 85 dB (A) could improve efficiency in the tests in the beginning. One of the considerable points of this study is that by comparing the measured time for the control group and the other experimental groups [Graph 4], it was seen that the speed of action of an individual has a significant difference with increase in the sound pressure level ($P < 0.05$).

By increasing the sound pressure to 95 dB, the speed of work will get a steeper slope. One of the factors in increase in the slope in sound pressure level at 95 dB with passage of confrontation time could be the attempt of the person for faster completion of the test and being relieved of the pressure from loud noise, in which case the rate of error increases and the attention of the person decreases. This study fully confirms the effect of noise on efficiency (speed and accuracy of the individual) and is completely in conformity with the studies by Muzammil^[26] and Naravane.^[27-29] Noise at a high pressure level causes the exposed people to have a change in their strategies for accuracy, attention, and speed of work to overcome the noise. This however imposes a pressure on them in addition to their main duties. Due to this pressure, the safety of people in the working environment will be at risk and in case observing safety and protective measures and appropriate controls are not observed, the efficiency of the individual as well as productivity in industry will witness a significant decrease.^[30-33] The results of this research could provide the necessary basis for improving the conditions in workshops, factories,



Graph 4: Comparison of the average times for speed of work and sound confrontation times in studied groups

education centers, and so on to prevent creation of annoyance and related problems.

CONCLUSIONS

According to the results obtained in this study, by increasing the sound pressure level, performances and errors are definitely affected. This is in conformity with previous studies in this regard. At the sound pressure level of 95 dB, the efficiency decreased and rate of mistakes increased, and in exposure to sounds less than 85 dB at the initial period, performance increased and with the passage of time of confrontation, the performance gradually reduced.

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