

Assessment of Effects of Concomitant Exposure to Sound, Heat, and Physical Workload Changes on Physiological Parameters in Five Different Combination Modes, a Controlled Laboratory Study

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Abstract: Exposure to sound, heat, and increased physical workload can change physiological parameters. This study was conducted to evaluate the effect of concomitant exposure to sound, heat, and physical workload changes on physiological parameters in controlled laboratory conditions. This experimental cross-sectional study was conducted in 35 male university students with a mean age of 25.75 years and a mean BMI of 22.69 kg/m². Systolic and diastolic blood pressure and heart rate were measured after 15 min rest in the laboratory, 5 and 10 min after starting the experiment, and then after 20 min in controlled laboratory conditions in five combination modes. The combination modes were (Sound: 65 dB, WBGT: 22°C, Speed: 1.7, Slope: 10%), (Sound: 65 dB, WBGT: 22°C, Speed: 3.4, Slope: 14%), (Sound: 95 dB, WBGT: 22°C, Speed: 1.7, Slope: 10%), (Sound: 65 dB, WBGT: 32°C, Speed: 1.7, Slope: 10%), and (Sound: 95 dB, WBGT: 32°C, Speed: 3.4, Slope: 14%). Mixed model analysis and paired *t*-test were applied for analysis. The results showed that the mean physiological parameters (Systolic and diastolic blood pressure and heart rate) increased when different combination modes worsened (Sound from 65 to 95 dB, WBGT from 22°C to 32°C, speed from 1.7 to 3.4, and slope from 10% to 14%, and when sound: 95 dB, WBGT: 32°C, Speed: 3.4, and Slope: 14%). Moreover, the mean changes of systolic and diastolic blood pressure were significant in all conditions when compared with the reference condition (Sound: 65 dB, WBGT: 22°C, Speed: 1.7, and Slope: 10%). The mean heart rate changes were also significant except for exposure to the second condition (Sound: 65 dB, WBGT: 22°C, Speed: 3.4, Slope: 14%) and the third condition (Sound: 95 dB, WBGT: 22°C, Speed: 1.7, Slope: 10%). Exposure to hazardous levels of sound, heat, and workload has adverse effects on physiological parameters. Concomitant exposure to all three hazards has a synergistic effect and increases the adverse effect.

Keywords: Concomitant exposure; sound; heat; physical workload; physiological parameters



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1 Introduction

There are different occupational factors in the industry that expose workers to physical, chemical, ergonomic, biological, and psychological hazards [1]. Physical factors are an important group of occupational hazards [2–4]. Noise, defined as unwanted sound, is regarded as an industrial challenge in recent years following industrialization [5] and is associated with harmful consequences [6]. Totally, sound pollution as a harmful physical element could lead to increased oxygen consumption, elevated heart rate and blood pressure, reduced number of blood vessels, EEG changes, constriction of blood vessels, and increased intravascular blood pressure [7]. Lusk et al. [8] in a study entitled “acute effect of noise on blood pressure and heart rate” showed a significant direct association between systolic and diastolic blood pressure changes and heart rate and sound pollution.

Heat is another physical factor of the work environment, which is known as an environmental and occupational hazard [9]. Exposure to high temperatures is common in workers working in hot environments and is associated with numerous physiological effects [10]. In environments with a high heat stress, in addition to the environmental heat, the heat produced by physical activity results in the accumulation of heat in the body and elevation of core body temperature, causing physiological effects and heat tension [11]. Studies have shown that exposure to excessive heat has direct and indirect effects on metabolism, body temperature, heart rate, blood pressure, occupational errors and accidents, mental and psychological problems, and productivity in workers [12]. Canadian health office has estimated that the rate of heat-related death will increase from 20 cases in 2001 to 300 cases in 2020 [13]. Therefore, heat exposure should be scientifically analyzed as an important cause of mortality and morbidity. As mentioned earlier, two hazardous factors of the work environment, i.e., sound and heat, may affect the workers’ performance and physiological factors.

Workload ability can also affect the worker’s performance and physiologic parameters. Workload has always been considered an important factor in the personal performance in complex systems [14]. According to Varley’s study, workload is the relationship between the demands of a task and available resources [15]. The aim of workload assessment is to determine the effect of the demands that a task produces in the operator or a group of operational workers [16]. Moreover, workload is considered a risk factor for cardiovascular diseases. Many studies have demonstrated an association between workload and blood pressure as a possible mechanism for the relationship between cardiovascular disease and workload [17]. A study showed a significant association between systolic and diastolic blood pressure, heart rate, and cortisol level with workload variety in men [18]. Therefore, occupational and health factors of the workplace have an important effect on productivity and physiologic parameters. Since previous studies only addressed the independent effect of each of these hazardous factors alone and no study has evaluated their combined effect, the aim of this study was to examine the effect of concurrent exposure to hazardous and non-hazardous levels of sound, heat, and physical workload changes on physiological factors (blood pressure and heart rate) under controlled laboratory condition.

2 Methods

This cross-sectional, experimental, interventional study was conducted in 35 male students under controlled climate, physical activity, and sound pressure level conditions in the thermal tension room of the School of Public Health, Shiraz University of Medical Sciences. After a public announcement, the study samples were selected from men with a normal BMI ($18.5 < \text{BMI} < 25 \text{ kg/m}^2$) and a normal hearing status on a primary audiometry (hearing loss $< 25 \text{ dB}$) [19]. All participants underwent cardiovascular, clinical, para-clinical, and ophthalmic evaluations by an occupational medicine specialist. The participants were required to have a plenty of rest and avoid coffee, caffeine, and alcohol within 12 h before the test. The inclusion criteria were general health, lack of cardiovascular diseases and blood pressure-related diseases in the person or their family; lack of pulmonary and neuromuscular diseases; negative history of diabetes, seizures, epilepsy, musculoskeletal disorders, hearing loss, or asthma; and

willingness to participate in the study. Patients were excluded if they took drugs affecting blood pressure or heart rate, smoked, or exercised professionally. The study was stopped in case of profound fatigue, including a heart rate > 180 beats/s and a core temperature above 39°C [20].

2.1 Assessment Tool

The participant's mental health status was assessed by the General Health Questionnaire (GHQ). This questionnaire was first developed by Goldberg in 1972. This questionnaire has 28 questions in four small tests, each containing seven questions (questions 1–7, 8–14, 15–21, and 22–28 are related to somatic symptoms, anxiety and insomnia, social dysfunction, and depression, respectively). A total score of 23 or higher indicates a high level of mental stress. This self-administered questionnaire was completed by the participants. This questionnaire has been widely used in domestic and international studies and its reliability and validity have been confirmed [21].

2.2 Temperature, Sound, and Workload Condition

A thermal tension room was used to provide the required temperature. The wet-bulb globe temperature (WBGT) was measured according to the following formula:

$$\text{WBGT} = 0.7T_w + 0.3T_g$$

where WBGT is wet-bulb globe temperature, T_w is natural wet-bulb temperature (in Celsius), and T_g is globe thermometer temperature (in Celsius) [22].

In this study, the Cassella WBGT meter (England) was used to increase the reliability of the wet globe temperature. In addition, a wet and a wet globe thermometer were used to measure the temperature in the room. The CELL 420 (England) and TES (Taiwan) sound level meters were used for sound pressure level measurement. Because a work environment sound sample was required to conduct the study under laboratory conditions, the most common sound in the industry was played using the Goldwave software with two 500-watt speakers located beside and behind the participants at 1.5 m. During the measurement, produced level of noise exposure kept constant in the laboratory [23].

To produce physical workload, a treadmill (Turbo, Taiwan) was used in the room for 10 min, from minute 11 to minute 20. Blood pressure and heart rate were measured digitally (Beurer BC16, Germany). To control the effects of confounders (light and ergonomic workstation) and to provide equal conditions, a brightness of 500 lux was maintained throughout the study using halogen and fluorescent lamps. In addition, tables and chairs with a standard height and appropriate footrests were prepared for participants.

In the beginning of the study, the participants received information about the study and signed informed consent forms. Before blood pressure and heart rate measurement, the objectives of the study were presented to the participants to decrease their stress and prevent bias. The participants were also asked to take plenty of rest the night before the study and avoid caffeine, alcohol, coffee, and high-fat meals for about 12 h before the test. To control the effect of clothes on heart rate, blood pressure, and body temperature, all subjects wore light clothes, comfortable pants, and white uniforms. After 15 min rest in the supine position on the examination bed, systolic and diastolic blood pressure and heart rate were measured using an automatic wrist blood pressure monitor in the sitting position in a calm environment. The left wrist was used for measurements with hand in the heart level. The measurements were repeated for three times and their average was recorded.

Then, the participants were directed to the heat tension room and exposed to the sound level and heat tension for about 10 min in the sitting position. After 5 and 10 min, their systolic and diastolic blood pressure and heart rate were measured three times and the average readings were recorded. While the subjects were exposed to sound and heat stress, they used the treadmill for about 10 min, starting from minute 11, and their blood pressure and heart rate were measured after 20 min. All participants were

exposed to different conditions mentioned in [Tab. 1](#) at an interval of 1 to 2 days using a crossover method with random sequence allocation of work conditions. It is noticeable to mention that in order to. In summary, participants were directed to the test room with specified level and tension days for about 10 min in setting position. Systolic and diastolic blood pressure and heart rate of the subjects were measured and recorded after 5 to 10 min of resting. At the next step, participants were asked to go on a treadmill for 20 min. At the end of the procedure the indexes were measured again. The participants were exposed to the 5 conditions based on a cross-over design with random sequence allocation of work conditions.

Table 1: Combination of conditions designed for exposure to environmental factors [24–26]

Condition	Sound pressure level (A decibel)	Wet-bulb temperature (Celsius)	Physical workload change
1	65*	22*	Speed: 1.7, Slope: 10%
2	65*	22*	Speed: 3.4, Slope: 14%
3	95*	22*	Speed: 1.7, Slope: 10%
4	65*	32*	Speed: 1.7, Slope: 10%
5	95*	32*	Speed: 3.4, Slope: 14%

*Hazardless condition.

To conduct analysis, Linear Mixed Model and student paired *t*-test were used. Data was analyzed by SPSS (Version 19). Before the analysis was started, test of normality was conducted for all quantitative variables.

3 Results

In the present study, the effect of concurrent exposure to sound, heat and physical workload changes on physiological parameters was assessed in 35 students of Shiraz University of Medical Sciences. The demographic characteristics of the participants are shown in [Tab. 2](#).

Table 2: Demographic characteristics of participants (n = 35)

Age (year) Mean ± SD	Weight (kg) Mean ± SD	Height (cm) Mean ± SD	General health score Mean ± SD
25.75 ± 2.52	64.52 ± 5.22	168.72 ± 7.42	18.32 ± 2.81

[Tabs. 3](#) and [4](#) show the mean and standard deviation of systolic and diastolic blood pressure before and after the exposure as compared to the reference exposure group (hazardless sound and heat, speed of 1.7 and slope of 10). Accordingly, there was an increase in the mean systolic and diastolic blood. The results of post hoc comparison showed significant differences between all conditions and the reference condition ($p < 0.005$). Moreover, comparison of the mean measurements showed that the greatest effect on the systolic and diastolic blood pressure was related to condition $1 < 2 < 3 < 4 < 5$ ([Tabs. 3](#) and [4](#)).

[Tab. 5](#) shows the mean and standard deviation of the heart rate before and after the exposure as compared to the reference condition (hazardless sound and heat, speed of 1.7 and slope of 10). Accordingly, there was an increase in the mean heart rate. The results of post hoc comparison showed significant differences between all conditions and the reference condition, except for (speed of 3.4, slope of 14, hazardless sound, and hazardless heat) and (speed of 1.7, slope of 10, hazardous sound, hazardless heat) ($p < 0.005$). Moreover, comparison of the mean measurements showed that the greatest effect on the systolic and diastolic blood pressure was related to condition $1 < 2 < 3 < 4 < 5$ ([Tab. 5](#)).

Table 3: Systolic blood pressure changes before and after exposure and comparison with reference condition

Exposure condition (N = 35)	Mean and SD of systolic BP changes before and after exposure	Increase in systolic BP compared with reference condition	Level of significance*
1 Reference condition (hazardless sound, hazardless heat, speed 1.7, slope 10)	9.93 ± 2.9	–	–
2 Hazardless sound, hazardless heat, speed 3.4, slope 14	65.83 ± 13.9	11.56	<0.001
3 Hazardous sound, hazardless heat, speed 1.7, slope 10	43.32 ± 14.11	12.34	<0.001
4 Hazardless sound, hazardous heat, speed 1.7, slope 10	78.96 ± 15.12	13.68	<0.001
5 Hazardous sound, hazardous heat, speed 3.4, slope 14	25.58 ± 19.7	17.18	
Comparison of groups**			<0.005

*Paired *t* test.

** ANCOVA.

Table 4: Diastolic blood pressure changes before and after exposure and comparison with reference condition

Exposure condition (N = 35)	Mean and SD of diastolic BP changes before and after exposure	Increase in diastolic BP compared with reference condition	Level of significance*
1 Reference condition (hazardless sound, hazardless heat, speed 1.7, slope 10)	125.53 ± 0.6	–	–
2 Hazardless sound, hazardless heat, speed 3.4, slope 14	40.26 ± 4.5	2.81	0.005
3 Hazardous sound, hazardless heat, speed 1.7, slope 10	43.04 ± 6.6	6.31	<0.001
4 Hazardless sound, hazardous heat, speed 1.7, slope 10	75.21 ± 6.5	6.62	<0.001
5 Hazardous sound, hazardous heat, speed 3.4, slope 14	65.37 ± 7.7	7.53	<0.001
Comparison of groups**			0.002

*Paired *t* test.

** ANCOVA.

Table 5: Diastolic heart rate changes before and after exposure and comparison with reference condition

Exposure condition (N = 35)	Mean and SD of heart rate changes before and after exposure	Increase in heart rate compared with reference condition	Level of significance*
1 Reference condition (hazardless sound, hazardless heat, speed 1.7, slope 10)	53.41 ± 3.5	–	–
2 Hazardless sound, hazardless heat, speed 3.4, slope 14	90.43 ± 3.5	0.375	0.806
3 Hazardous sound, hazardless heat, speed 1.7, slope 10	68 ± 5.6	2.15	0.159
4 Hazardless sound, hazardous heat, speed 1.7, slope 10	75.58 ± 6.6	3.21	0.036
5 Hazardous sound, hazardous heat, speed 3.4, slope 14	56.91 ± 10.5	7.03	<0.001
Comparison of groups**			0.002

*Paired *t* test.

** ANCOVA.

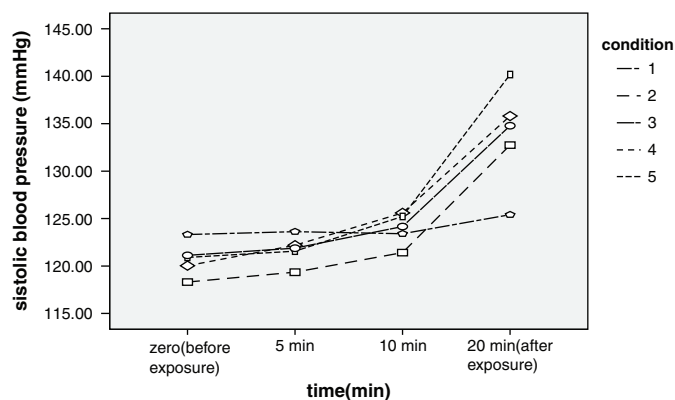


Figure 1: Systolic BP changes in different exposure condition

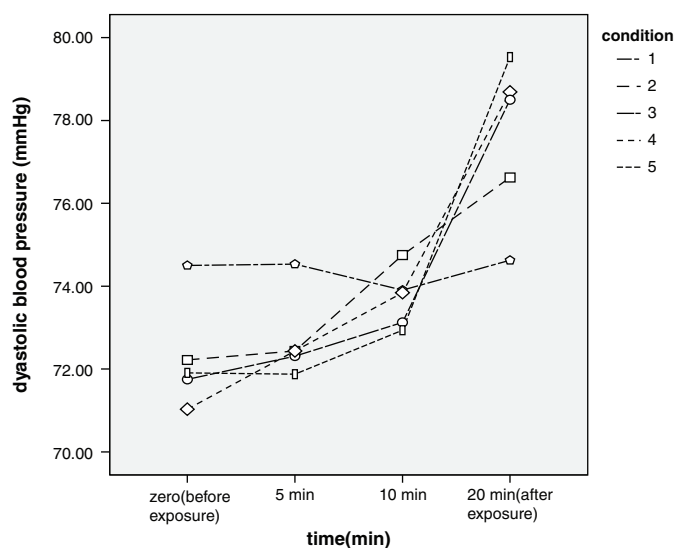


Figure 2: Diastolic BP changes in different exposure conditions

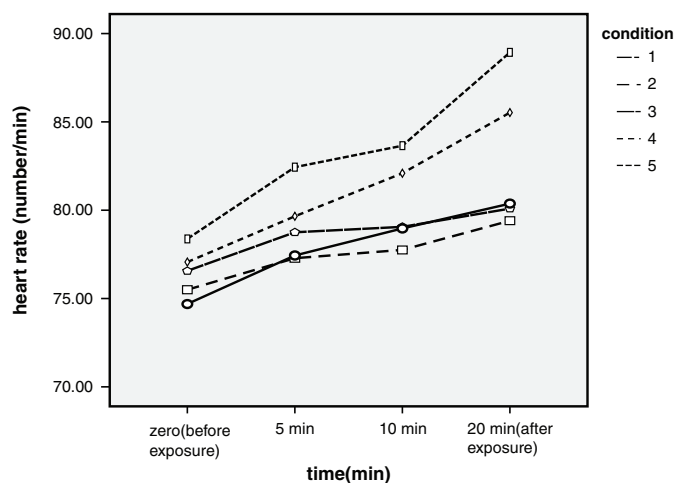


Figure 3: Hear rate changes in different exposure conditions

Figs. 1–3 show the mean changes of systolic and diastolic blood pressure and heart rate before, during, and after exposure. Accordingly, an increase in blood pressure and heart rate was seen in all condition except for the reference condition.

4 Discussion

Although there are different hazardous factors in the work environment and people spend a significant amount of time in the workplace, few studies have addressed concurrent exposure to hazardous factors. Therefore, the aim of this study was to evaluate the effect of concurrent exposure to heat, sound, and physical workload change on physiological parameters (blood pressure and heart rate).

We noted an increase in the mean systolic and diastolic BP before and after exposure in the second condition (hazardless sound, hazardless heat, speed 3.4, slope 14). Moreover, there was a significant difference in the systolic and diastolic blood pressure after exposure to the second condition as compared to the reference condition (hazardless sound, hazardless heat, speed 1.7, slope 10), indicating the effect of workload on blood pressure. This finding is consistent with the results of a study by Naravane in 2009 who investigated the relationship between blood pressure and daily workload [24]. However, there was no significant difference in the mean heart rate changes before and after exposure between the second and the first (reference) condition, which is not consistent with the results of a study by Ramsey et al. [25]. The reason for this inconsistency may be differences in the exposure time, age range of the participants, sample size, slope, or speed.

Regarding the effect of sound, there was an increase in the mean SBP and DBP after exposure to the third condition (hazardous sound, hazardless heat, speed 1.7, and slope 10) and the difference with the first (reference) condition was significant. This finding is in line with the results of studies conducted by Tomei et al. [26], Lusk et al. [8], Vogt et al. [27], but inconsistent with the results reported by Zamanian et al. [28–30], Rizi et al. [31], and Kalantari [32] reported an inverse association in this regard.

The mean heart rate increased after exposure to hazardous sound, but its difference with the reference condition was not significant. This finding is consistent with the results of studies by Zamanian et al. [28–30] and Chang et al. [33]. However, Rizi's et al. [31] reported different results in this regard. It is difficult to draw a definite conclusion on the association of sound and physiological parameters. The differences in the results may be due to differences in the type of sound, sound pressure level, type and complexity of the activity, exposure time, and sample size.

As for thermal stress, with an increase in the temperature as compared to the reference condition (condition 4: Hazardless sound, hazardous heat, speed 1.7, slope 10), a significant increase was observed in the systolic and diastolic BP, which is consistent with the results of a study by Ising et al. [34] and Singhal et al. [35]. However, Brothers et al. [36] and Malakouti et al. [37] reported contradictory results.

The mean heart rate increased significantly after heat exposure as compared to the reference condition, which is consistent with the results of studies by Schneider who showed an increase in the cardiac output and heart rate following exposure to thermal stress [11] while Zamanian reported different results in workers in a steel factory [30]. The reason for different results may be differences in the temperature and heat, complexity and type of activity, sample size, and exposure time.

Finally, the mean systolic and diastolic blood pressure and heart rate increased at different time points after exposure to hazardous levels of sound and heat, speed of 3.4, and slope of 14 with a significant difference when compared to exposure to the reference condition, indicating that concurrent exposure to the three environmental factors has a synergistic effect on the systolic and diastolic blood pressure and heart rate.

In studies similar to our study, due to the small sample size and lack of access to vital information, it is very difficult to determine the effect of multiple hazardous factors. However, considering the variety of occupational hazardous factors, one of the advantages of this study was assessment of physiological parameters in people exposed to different levels of sound, heat, and workload, and evaluation of concurrent exposure to multiple environmental factors in five different combination modes.

5 Conclusion

The results of this study showed an increase in the systolic and diastolic BP and heart rate after exposure to any condition as compared to the reference condition. Moreover, the effect of a concurrent exposure to all three factors was greater than the effect of exposure to each factor alone. The effect of heat alone was greater than the effect of sound alone, and the effect of sound alone was greater than the effect of workload changes on the blood pressure and heart rate. Our results showed a combination of hazardous sound and heat and increased workload had a synergistic effect of physiological parameters.

Finally, this study was conducted in men under laboratory conditions. It is suggested to conduct similar studies in different sound, heat, and workload conditions with attention to the effect of confounding factors on physiological responses. Our findings highlight the importance of engineering and management interventions to reduce hazardous factors to increase productivity and promote the workers' health.

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Conflicts of Interest: The authors declare that they have no conflicts of interest to report regarding the present study.

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