Original Article

Journal of Occupational Health and Epidemiology
Journal Homepage: https://johe.rums.ac.ir/
JOHE
Rafsanjan University of Medical Sciences

The Effect of Co-Exposure to Heat Stress and Whole-Body Vibration on Auditory-Visual Attention and Reaction Time in a Laboratory Setting

Elham Akhlaghi Pirposhteh[1], Mohammad Javad Jafari[2], Somayeh Farhang Dehghan[3], Zahra Salehzadeh[4], Saeid Ghaffari[5*]

1. Ph.D. Student in Occupational Health Engineering, Dept. of Occupational Health Engineering, Faculty of Medical Sciences, Tarbiat Modares University, Tehran, Iran.
2. Professor, Safety Promotion and Injury Prevention Research Center (SPIPRC), Shahid Beheshti University of Medical Sciences, Tehran, Iran.
3. Associate Prof., Environmental and Occupational Hazards Control Research Center, School of Public Health and Safety, Shahid Beheshti University of Medical Sciences, Tehran, Iran.
4. Bachelor of Software Engineering, Islamic Azad University, Islamshahr, Iran
5. M.Sc. in Occupational Health Engineering, School of Public Health and Safety, Shahid Beheshti University of Medical Science, Daneshjoo Blvd, Velenjak, Shahid Chamran Highway, Tehran, Iran.

CrossMark

Citation: Akhlaghi Pirposhteh E, Jafari MJ, Farhang Dehghan S, Salehzadeh Z, Ghaffari S. The Effect of Co-Exposure to Heat Stress and Whole-Body Vibration on Auditory-Visual Attention and Reaction Time in a Laboratory Setting. J Occup Health Epidemiol. 2024;13(1):49-60.

Article Info

*** Corresponding author:**
Saeid Ghaffari,
E-mail:
saeedghafary20@gmail.com

Article history
Received: Aug 2023
Accepted: Jan 2024

doi 10. 61186/johe.13.1.49

Print ISSN: 2251-8096
Online ISSN: 2252-0902

Peer review under responsibility of Journal of Occupational Health and Epidemiology

Abstract

Background: WBV and heat stress are important hazardous agents, which can affect the people's cognitive function. The present study aimted to explore the effect of co-exposure to heat stress and WBV on auditory-visual attention and reaction time in a laboratory setting.

Materials & Methods: The present study was conducted on 32 consenting male students chosen from the university in accordance with the inclusion criteria. The participants were required to complete the General Health Questionnaire (GHQ-28) in order to determine their state of health. The Ishihara color blind test was performed afterward. Heat stress exposure was exerted at a WBGT index of 22, 29, and 34 °C, with 22 °C as the control condition. WBV was applied at 0.53, 0.81, and 1.12 m/s2, as well as a no WBV exposure condition (the control), making a total of 12 different exposure modes. The reaction times and auditory-visual attention of the subjects were measured via the IVA test. Further, the individuals' heart rate was recorded by a digital heart rate monitor.

Results: Elevation of WBV acceleration and WBGT from 29°C to 34°C independently caused a significant reduction in auditory-visual attention, as well as a significant rise in reaction times. Co-exposure to WBV and heat stress significantly affected auditory-visual attention and reaction time ($p<0.001$).

Conclusions: According to the results, WBV and heat stress are two influential factors on cognitive performance which can reduce concentration and attention devoted to work.

Keywords: Heat Stress, Vibration, Cognitive Test, Attention, Reaction Times

Introduction

In industrial environments, workers are exposed to various harmful occupational hazards, which may be physical, chemical, mechanical, or even ergonomic. Prolonged exposure to these harmful agents can have detrimental effects on the workforce (1). One of these harmful physical agents is vibration. Workers in various fields such as control rooms of casting plants, power station generator operators, and drivers are daily exposed to different types of vibrations throughout their work. Research on Malaysian drivers has shown that exposure to whole-body vibration causes changes in body chemistry and metabolism and may lead to fatigue complications plus changes in mental function (2).

Whole-body vibration (WBV) is a common type of vibration especially important at low frequencies. This type of vibration can be exerted while sitting or standing, and prolonged exposure to it at above Threshold Limit Values (TLV) can cause physiological disorders (5). Research has revealed that exposure to vibration can have various impacts on cognitive performance. Reduced performance caused by exposure to vibration during tasks requiring visual attention or hand control indicates the role of vibration in causing mental fatigue (6). Furthermore, previous research has shown that exposure to vibration can increase mental load (1). From an environmental perspective, vibration, through its effect on visual attention and the disruption of tasks involved with tools or controlling devices, prevents performing vital work, or disrupts the performance of the individual. These effects precisely depend on frequency as well as the resonance effect in the vibrating object. Exposure to vibration can reduce speed in tasks requiring precise hand-eye coordination (7).

Considering the geographical location of Iran (close to the equator), and the heat producing processes involved in many industries, heat is an especially problematic harmful physical agent. In a review study by Kovats et al. entilted Heat as an Important Cause of Death (8), they showed that heat can have negative effects on production efficiency, comfort level, and worker health, besides causing occupational disorders and accidents (9). Heat stress in warm environments occurs when the body is unable to dispose of the excessive external heat (environmental conditions) or excessive internal heat (metabolism). Working in warm environments puts the body at risk of heat stress, which can be accompanied by various mental or physical side effects. The initial mental response to heat includes increased excitability, irritability, aggression, mood changes, and depression. Physical response to heat stress includes increased heart rate, sweating, water and electrolyte imbalance , as well as changes in skin blood flow (10). The combination of mental and physical responses to heat stress manifests itself in the form of reduced performance, lower skill during tasks, faster onset of fatigue, loss of focus, and the resulting increase in errors and mistakes (11).

Under heat stress conditions, dehydration due to sweating can affect cognitive performance (12). Certain studies have shown that dehydration can lower performance in fundamental cognitive functions such as short-term memory and working memory. This reduction in performance correlates with the level of dehydration. A significant reduction in cognitive performance is observed when dehydration reaches 2% loss in body weight (13). Heat stress can affect the individual’s cognitive and behavioral performance through causing discomfort, mental fatigue, anxiety, and loss of consciousness. The effect of heat stress on cognitive performance depends on the type of cognitive task. There is a direct relationship between the internal temperature of the body and the effect of heat stress on cognitive performance. The role of individual differences in response to heat stress is well understood (8).

An important cognitive function in this regard is “attention”. This function is vital in collecting information and enables the individual to consistently perform a task for extended periods. Attention helps the individual maintain attention and selective attention, while making consistent attempts at a task despite varying environmental conditions. Attention is the cognitive ability to focus on a specific task or special aspects thereof (sustained attention) as well as the allocation of mental resources between different tasks or special aspects of tasks (divided attention) while suppressing automatic responses (14).

Another cognitive function evaluated in the present study is reaction time. Reaction time is the time it takes to understand conditions until processing them, i.e., about 10 to 12 hundredth of a second in a healthy individual (15). The attention parameter can be quantified through calculating the number of mistakes made by the individual during the test. Lower mistakes correlate with higher attention. Other factors such as the reaction time for correct answers as well as changes in this reaction time will be evaluated as well (16).

Given the above, it can be concluded that each of these stressors (heat and vibration) can in turn affect cognitive and physical performance. Co-exposure to both of these agents will probably intensify their cognitive effects. This is important, since WBV and heat stress are present in almost all industrial and occupational environments and many workers, whether in transportation, agriculture, forestry, or roadwork, undergo co-exposure to these harmful occupational agents. It is therefore necessary to evaluate the effects of co-exposure to WBV and heat stress on cognitive performance in a controlled environment. Literature review indicates many studies on the effects of independent exposure to heat or WBV on cognitive performance. However, very few studies have dealt with the effects of co-exposure to these harmful physical agents (heat stress and WBV) on cognitive performance, a strong point of the present study compared to the previous research (7, 13, 12). Thus, the present study was conducted to evaluate the effect of co-exposure to heat stress and whole-body vibration on auditory-visual attention and reaction time in a laboratory setting.

Materials and Methods

This intervention-experimental study evaluated the effect of co-exposure to heat stress and whole-body vibration on auditory-visual attention and reaction time of 32 male university students in a simulated environment inside a laboratory. Conventional sampling method was used. Subjects entered the study voluntarily during a call made by the researcher. Next, the researcher selected the subjects with the inclusion criteria of the study among the volunteers' students. The medical record filled by each student upon entering the university was used. Since previous studies have shown that responses to vibration depend on age, all participants were chosen from the same age range. Inclusion criteria were healthy subjects within the age range of 20-29, being able bodied with no disability involving the hands (from the tip of the fingers to the shoulders), not being addicted to alcohol or other drugs, not suffering from diabetes or high blood pressure, and not having any underlying disorders such as respiratory illnesses, sleep disorders, or any other issues in brain or muscles. Subjects not willing to continue participation could leave the study if they wished. Any participant who used medication that could affect resistance to heat (amphetamines, phenothiazine, and barbiturates) was also excluded from the study.

Written consent forms were taken from the participants before performing any test. The participants also completed the consent forms approved by the faculty ethics committee (FEC). Then, the participants were familiarized with the method by which computerized cognitive performance tests are done as well as the laboratory environment. As another ethical principle, the information was kept confidential.

The participants were required to complete the General Health Questionnaire (GHQ-28) in order to determine their state of health. This questionnaire is based on self-reporting and used to distinguish cases of mental disorder. It can also determine the possibility of the existence of a mental disorder in the subjects (17). Malakouti et al. determined the validity and reliability of the Persian version of this questionnaire (18). In this questionnaire, the total score of a person ranges between 0 and 84 with a score above 22 being indicative of a disorder (13). According to the results, the mean and standard deviation of the GHQ scores obtained from those who met the inclusion criteria were 16.12± 4.31. Those scoring above 22 were not enrolled in the study (17). Since all subjects had a score of lower than 22, they had no general health problem.

Subsequently, the Ishihara color blind test, a color comprehension test designed to determine red-green color blindness, was performed. The reliability and validity of Ishihara color blind test were evaluated by Salvia et al. (19). All participants were required to undergo this test and any participant with trouble determining color was excluded from the study. The ISO 8996 standard (20) was used to estimate the metabolism and workload of the participants. According to the tables provided in this standard, the metabolic cost of carrying out a light task while seated (cognitive tests done on a computer) was considered equal to 0.4 kcal/m. In general, the rate of metabolism for sedentary and sitting activities was considered equal to 1.2 met at the level of administrative work.

Characteristics of Laboratory room: Two adjacent rooms were used to carry out this design. One of them was the laboratory, i.e. the main location for the tests, while the other room was the researcher's location. A view of the experimental room and the way the participants perform the tests are displayed in Fig. 1. The dimensions of laboratory room were 4.6 meters long, 2.3 meters wide, and 3.3 meters high. An intercom system was placed on the table about 10 cm from the monitor to facilitate communication between the subject and the researcher. A closed-circuit camera was installed in a location where it could cover all angles with its feed being projected in the control room.

The room was illuminated by fluorescent lamps kept constant during all experiments. In order to evaluate and measure the light intensity, the INS DX-200 lux meter was employed. The average brightness of the test table was 320 lux. In the laboratory, two conventional electric heaters and a fan electric heater were used to create the required thermal conditions for the experiment. These heaters were placed on both sides (left and right) of the subjects on the table surface and behind them on the floor at a distance of at least 2 meters. In addition, a fumigator was utilized to maintain the relative humidity of the environment in a stable state (50%).

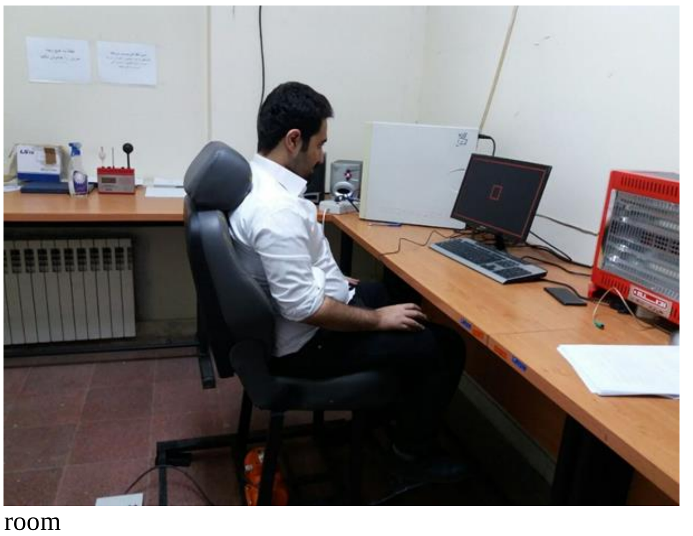

Fig. 1. A view of the experimental room

Experimental conditions: After the final selection of those who met the inclusion criteria, all the tests were fully explained to the participants and they were familiarized with the test methods. In the present study, the demographic information of the participants (age, height, weight, education, and marital status) was collected using worksheets designed by the researcher. The participants were asked to come to the test location at a specific date. Further, they were instructed to have a full 8-hour sleep the night before and refrain from consuming tea, coffee, chocolate, or other caffeinated drinks. The participants were also asked to wear light summer clothing (Clo Value = 0.6). Thus, no correction was made on the wet bulb globe temperature (WBGT) index. The WBGT index was used to measure heat stress.

Different Conditions designed plus the coding for each exposure of subjects are presented in Table 1. The twelve different conditions were designed for the experiment. A total of twelve different conditions were designed for the test including three different conditions of heat stress exposure (Control conditions, TLV of occupational exposure in those who are acclimated, levels exceeding TLV) and four different conditions for WBV exposure (control condition, vibration with an acceleration of 0, 0.53, 0.81, and 1.12 m/s2).

Table 1. Different Conditions designed and the coding for each exposure

Run	Exposure code	Exposure	
		Heat stress (°C)	Whole body Vibration(m/s^2)
1	WBGT22-WBV 0	22	0
2	WBGT22-WBV0.53	22	0.53
3	WBGT22-WBV0.81	22	0.81
4	WBGT22-WBV1.12	22	1.12
5	WBGT29-WBV0	29	0
6	WBGT29-WBV0.53	29	0.53
7	WBGT29-WBV0.81	29	0.81
8	WBGT29-WBV1.12	29	1.12
9	WBGT34-WBV0	34	0
10	WBGT34-WBV0.53	34	0.53
11	WBGT34-WBV0.81	34	0.81
12	WBGT34-WBV1.12	34	1.12

According to Table 1, the run No. 1 (WBGT=22 oC, WBV=0) was considered as the background condition for the individual and combined exposure modes to WBGT and WBV. The runs No. 1-4 and runs No. 1, 5, and 9 constituted the control conditions for the individual exposure to WBV and WBGT, respectively. The 32 participants were randomly assigned into doing three runs (2-12) and running No. 1 as background condition.

Formula 1.

Total number of experiments=32 Subjects*4 different exposure modes = 128

Before each subject entered the room, the exposure conditions of that subject in the laboratory room were prepared. The subject then entered the room. Thirty minutes before the start of the test, the subjects were exposed to the condition, after which the test began. The test lasted 30 minutes. Thus, in general, each subject had one hour of exposure in each test. To avoid interference between samples, each test was performed on a separate day for each subject. Further, due to the ethical issues of exposure to heat, each test was performed once for each subject.

WBV Exposure Conditions: In the present study, in order to analyze cognitive performance while being exposed to WBV, a vibration simulation device) SVAN 958, SVANTEK) was used, with a vibrating motor, capable of creating vibrations along the x, y or z axes at different frequencies and intensities in the form of sine waves or random waves. The participants were exposed to vibration for 30 minutes. Since the aim of the study was to evaluate the whole-body vibration, the vibrometer was placed in the seat. The vibration intensity used in the present study was chosen after considering ranges suggested by other researchers (7), within the frequency range of 3-7 Hz, and at low acceleration (0.53) for regular consumer vehicles, medium acceleration (0.81) for public transportation vehicles, and high acceleration (1.12) m/s2 for heavy transportation vehicles exerted by the vibrating motor and connected to the legs of the WBV simulation chair. The back of the chair and the leg resting area were both adjustable ensuring maximum comfort for the participant. Each participant underwent one experiment condition per day to prevent the negative effects of vibration exposure on physiological and cognitive function from passing over to the next experiment. In order to prevent succession in performing the test, the 0.53, 0.81, and 1.12 m/s2 acceleration were randomly assigned to each subject.

According to the general conditions, ISO-2631 standard has proposed the general method of measuring the vibration of the seat surface to evaluate the vibration in sitting people; the installation of accelerometers was done according to the guidelines of the ISO-2631 standard. Accelerations in three axes were measured on the seat surface of the chair according to the recommendations of the ISO-2631 standard.

The measurement was performed by a three-axis accelerometer simultaneously on the surface of the seat. During the measurement, in order not to interfere with individual characteristics in all measurements, a stable person with a weight of 78 kg and a height of 175 cm was employed.

To ensure the calibration of the vibration generated by the simulator, the vibration acceleration created for each experiment condition was measured using a Human-response vibration meter model 4447 made by Bruel & Kjar, Denmark (with a mean reliability of ±0.02) based on the ISO 2631 standard (21). The aforementioned device was calibrated before measurement.

Heat Stress Exposure Conditions: Heat stress was exerted at three WBGT index levels of 22, 29, and 34 °C according to the ISO 7234 standard (22) with the WBGT index of 22 °C as the laboratory control conditions. In order to measure WBGT index, a WBGT meter model QUESTEMPO10 made in the USA was applied. The measurement range of this device was -5 to +70 °C with a measurement accuracy of ±0.1 °C. The WBGT index of 22 °C was considered the background laboratory condition representing conditions with no heat stress.

The device was calibrated before each measurement. To calibrate this device, a special calibrator was used. The calibrator was connected to the WBGT meter. According to the catalog, the device must show certain numbers for this mode. If these numbers are correct, the device is calibrated.

Analyzing Cognitive Performance: The cognitive functions being analyzed include auditory-visual attention and reaction time, measured at different WBV accelerations and three WBGT index levels via the collection of software tests from the Integrated Visual and Auditory (IVA) continuous performance test (CPT). This tool is a continuous auditory and visual test evaluating two main factors, i.e. reaction time and attention. The IVA test also determines the reaction time duration of the subject regarding to auditory or visual stimuli. Overall, 22 IVA subscales help detect problems in response prevention, lack of focus, tolerance and attention and overall, the duration of response. This test takes about 30 minutes to complete (along with the training section). The main task in this test involves responding or refraining from responding (respond prevention) to 500 test stimuli. Each stimulant is only presented for one and a half seconds. Therefore, the test requires sustained attention. The validity of the test in the re-test method indicates that the 22 IVA scales have a direct positive relationship (46%-88%). Overall, based on the findings, this test has an adequate as well as high validity and reliability in evaluating attention, accuracy, as well as detecting attention deficit hyperactivity disorder (ADHD) (23).

The IVA test is comprised of four stages, including warm up, training, main test, and cooling down. The warmup stage is separated into two parts: first, a one-minute visual warm-up and second, a one-minute auditory warm-up. One hundred items are presented in each of these parts. Afterward, the training section begins. At this stage, auditory and visual stimuli are presented in combination, taking 1.5 minutes. Further, the main, secondary, auditory, and visual stimuli are presented in combination in the main test stage. The cooling down stage is the same as the warm-up stage. The participants first perform the test for 2 minutes as a training period to learn the process completely (1).

The distribution normality of quantitative data was determined using the Kolmogorov–Smirnov test. The SPSS v.20 was employed for data analysis. Descriptive data are presented as mean ± standard deviation (SD). Homogeneity ANOVA was performed. In order to analyze the independent and co-exposure effects of WBV plus heat stress on auditory-visual attention and reaction time, the one-way analysis of variance (ANOVA) and univariate ANOVA were used. A significance level of 0.05 was considered in all tests.

Results

The demographic information of the participants was collected via the completed questionnaires (Table 2). According to the tests performed, all participants had an acceptable general health score and none of them was colorblind. According to the results, the mean age of the participants was 22.19±2.56 and their mean Body Mass Index (BMI) was 24.20±2.31 kg/m2. The results of measuring the participants' demographic variables are presented in Table 2. Considering education, 26 participants (81.25%) were undergrad students while six of them (18.75%) were postgrad students. All participants were male, single and between 20 and 29 years of age.

Table 2. Demographic characteristics of subjects

Variable	Group	No.	Percentage (%)
Age (Year)	18-22	20	62.5
	23-26	8	25
	27-29	4	12.5
BMI (kg/m^2)	Underweight (<18.5)	1	3.13
	Normal (18.5-24.9)	25	78.12
	Overweight (25-29.9)	4	12.5
	Obese (>30)	2	6.25

*BMI = Body Mass Index

Individual Exposure to Whole-Body Vibration: Tables 3 and 4 present the results of the analysis of the effect of individual exposure to whole-body vibration on auditory-visual attention and reaction time among the participants. ANOVA test statistical analysis results (Table 3) demonstrated a significant difference between the exposure groups in auditory-visual attention (P < 0.001). The lowest levels of auditory attention and reaction time were seen at vibration acceleration of 0.53 m/s2 and the lowest level of visual attention was observed at vibration acceleration of 0.81 m/s2. In addition, the highest level of auditory-visual attention was related to baseline condition (acceleration of 0 m/s2 and WBGT=22 °C). The maximum level of reaction time was seen with vibration acceleration of 1.2 m/s2.

Table 3. Results of one-way analysis of variance regarding individual exposure to whole body vibration

Variable	Vibration acceleration(m/s^2)	Mean	Std. deviation	F	P-value
Auditory attention score	0	105.04	4.95	10.02	.001
	0.53	96.91	5.28		
	0.81	97.77	3.45		
	1.12	102.00	4.69		
Visual attention score	0	106.32	5.08	4.60	0.007
	0.53	100.83	3.80		
	0.81	100.33	7.24		
	1.12	102.75	4.11		
Reaction time (Milliseconds)	0	394.92	37.01	1.59	0.205
	0.53	366.33	40.53		
	0.81	392.00	48.67		
	1.12	401.75	39.36		

Table 4 reports the results of univariate ANOVA for determining the effect size of individual exposure to vibration on the level of auditory-visual attention and reaction time. In order to determine the significance of each variable and their role in the regression model, the column STANDARDIZED COEFFICIENTS (BETA/B) is shown. A variable with the larger standardized coefficient will play a more effective role in predicting the dependent variable. According to Table 4, exposure to the vibration acceleration of 1.12 m/s2 compared to the baseline conditions (acceleration of 0 m/s2 and WBGT=22 °C), had the highest significant effect on the auditory attention score (B=-8.123 P = 0.001), so that the chance the auditory attention score of people exposed to the acceleration of 1.12 m/s2 would decline compared to the baseline condition of 12.8 m/s2. Additionally, the highest significant effect size was seen on visual attention score (B=-5.987, P=0.004) and reaction time (B=-28.587, P=0.049) with vibration acceleration of 1.12 m/s2 compared to the baseline conditions.

Table 4. The results of the univariate analysis of variance test regarding individual exposure to whole-body vibration

Variable	Vibration acceleration(m/s^2)	B	95% Confidence Interval		P-value
			Upper Bound	Lower Bound	
Auditory attention score	0.53	-3.04	-8.23	2.15	0.245
	0.81	-7.26	-11.01	-3.51	**0.001**
	1.12	**-8.12**	-11.51	-4.73	**0.001**
Visual attention score	0.53	-3.57	-9.22	2.08	0.210
	0.81	-5.48	-10.06	-1.90	**0.005**
	1.12	**-5.98**	-9.17	-1.80	**0.004**
Reaction time (Milliseconds)	0.53	6.83	-36.80	50.46	0.754
	0.81	-2.92	-34.42	28.58	0.853
	1.12	**-28.58**	-57.04	-0.12	**0.049**

Individual Exposure to Heat Stress: Table 5 reveals the results of studying the effect of heat stress on the participants' auditory-visual attention and reaction time. The results of Table 5 are related to the conditions of WBV=0, that is tests No. 9, 5, and 1 in Table 1, including 44 tests. The lowest level of auditory-visual attention was related to WBGT=29 °C and the lowest level of reaction time was linked to the highest level of heat stress (WBGT=34 °C). The highest levels of auditory-visual attention and reaction time were both seen in the baseline condition (WBGT=22 °C). The results suggest that elevating the level of heat stress can lower auditory-visual attention and reaction time. The results of the statistical analysis of ANOVA test showed a significant difference between the exposure groups in auditory-visual attention (P < 0.001).

The results of univariate ANOVA for determining the effect size of individual exposure to heat stress on the level of auditory-visual attention and reaction time are outlined in Table 6. According to this table, exposure to

WBGT=34 °C compared to baseline conditions (acceleration of 0 m/s2 and WBGT=22 °C), had the highest significant effect on the auditory attention score (B=-6.707, P=0.001). So that the chance the auditory attention score of people exposed to WBGT=34 °C would decline compared to the score of people exposed to the background is 6.7 times. Furthermore, the highest significant effect size on visual attention score was seen with WBGT=34 °C compared to baseline conditions (B=-8.653, P=0.001), and the highest significant effect size on reaction time was observed with WBGT=29 °C compared to baseline conditions (B=-33.170, P=0.109).

Table 5. Results of one-way analysis of variance regarding individual exposure to heat stress

Variable	WBGT (ºC)			F	P-value
Mean (Std. Deviation)	**22**	**29**	**34**		
Auditory attention score	**105.04 (4.95)**	**98.33 (5.15)**	**99.00 (5.71)**	**9.04**	**.001**
Visual attention score	**106.32 (5.08)**	**97.66 (3.81)**	**98.75 (6.23)**	**16.80**	**.001**
Reaction time (Milliseconds)	**394.92 (37.01)**	**379.20 (37.73)**	**361.75 (40.87)**	**1.78**	**.181**

*WBGT= wet bulb globe temperature

Table 6. The results of the Univariate Analysis of Variance test regarding individual exposure to heat stress

Variable	WBGT (ºC)	B	95% Confidence Interval		P-value
			Upper Bound	**Lower Bound**	
Auditory attention score	29	-6.04	-11.56	-0.51	0.033
	34	**-6.70**	-10.05	-3.35	**0.001**
Visual attention score	29	-7.57	-12.77	-2.36	0.005
	34	**-8.65**	-11.81	-5.49	**0.001**
Reaction time (milliseconds)	29	**-33.17**	-74.01	7.67	**0.109**
	34	-15.72	-40.48	9.04	0.207

*WBGT= wet bulb globe temperature

Co-Exposure to Heat Stress and Whole-Body Vibration: Table 7 presents the results of analyzing the Co-effects of different levels of WBV and heat stress on the participants' auditory-visual attention and reaction time. A significant difference was seen between the average of different exposure modes for auditory-visual attention (P < 0.001). This significant difference in exposure to WBGT=34 °C and WBV=1.2 m/s2 has the highest significant effect on the auditory-visual attention score. However, there was no significant difference between the average of different exposure modes for reaction time (P > 0.001).

Table 7. Results of one-way analysis of variance regarding co-exposure to heat stress and whole-body vibration

Variable	Exposure code	Mean	Std. deviation	F	P-value
Auditory attention score	WBGT22-WBV 0	105.04	4.95	5.59	**0.001**
	WBGT22-WBV0.53	96.90	5.76		
	WBGT22-WBV0.81	97.63	3.23		
	WBGT22-WBV1.12	102.00	4.69		
	WBGT29-WBV0	98.33	5.15		
	WBGT29-WBV0.53	99.20	5.65		
	WBGT29-WBV0.81	93.83	2.92		
	WBGT29-WBV1.12	100.20	4.76		
	WBGT34-WBV0	99.00	5.71		
	WBGT34-WBV0.53	96.60	4.39		
	WBGT34-WBV0.81	94.00	3.67		
	WBGT34-WBV1.12	92.89	3.31		
Visual attention score	WBGT22-WBV 0	106.32	5.08	6.22	**0.001**
	WBGT22-WBV0.53	100.40	3.94		
	WBGT22-WBV0.81	100.81	6.63		
	WBGT22-WBV1.12	102.75	4.11		
	WBGT29-WBV0	97.66	3.811		
	WBGT29-WBV0.53	105.50	4.22		
	WBGT29-WBV0.81	94.83	4.79		
	WBGT29-WBV1.12	102.40	4.33		
	WBGT34-WBV0	98.75	6.23		
	WBGT34-WBV0.53	100.20	3.76		
	WBGT34-WBV0.81	95.20	6.22		
	WBGT34-WBV1.12	93.62	4.57		

Reaction time (Milliseconds)	WBGT22-WBV 0	394.92	37.01	1.42	0.184
	WBGT22-WBV0.53	364.80	43.41		
	WBGT22-WBV0.81	388.72	45.22		
	WBGT22-WBV1.12	401.75	39.36		
	WBGT29-WBV0	379.20	37.73		
	WBGT29-WBV0.53	369.30	45.61		
	WBGT29-WBV0.81	380.16	21.51		
	WBGT29-WBV1.12	343.00	29.22		
	WBGT34-WBV0	361.75	40.87		
	WBGT34-WBV0.53	380.00	18.39		
	WBGT34-WBV0.81	362.40	46.67		
	WBGT34-WBV1.12	350.21	35.42		

Table 8 lists the results of univariate ANOVA related to determining the effect size of exposure to WBV and heat stress on the level of auditory-visual attention and reaction time. Based on this table, combined exposure with WBGT =34 °C and WBV=1.2 m/s2 had the highest significant effect on the score of auditory-visual attention and reaction time compared to other exposure modes and the baseline conditions, where the chance that the auditory attention score of people exposed to the acceleration of 1.2 m/s2 and WBGT =34 °C would diminish compared to baseline condition is 12.01 times. This chance for visual attention score is 12.61 and for reaction time is 64.39 (P=0.001).

Table 8. The results of the Univariate Analysis of Variance test regarding co-exposure to heat stress and whole-body vibration

Variable	Exposure code	B	95% Confidence Interval for Mean		P-value
			Lower Bound	Upper Bound	
Auditory Attention Score	WBGT34–WBV1.12	-12.01	-16.23	-7.35	**0.001**
	WBGT34–WBV0.81	-11.04	-15.74	-6.33	**0.001**
	WBGT34-WBV0.53	-8.44	-13.14	-3.73	**0.001**
	WBGT34-WBV0	-6.04	-11.21	-.867	**0.023**
	WBGT29-WBV1.12	-4.84	-9.54	-.134	**0.044**
	WBGT29-WBV0.81	-11.20	-15.57	-6.84	**0.001**
	WBGT29-WBV0.53	-5.84	-9.43	-2.24	**0.002**
	WBGT29–WBV0	-6.70	-9.84	-3.56	**0.001**
	WBGT22-WBV1.12	-3.04	-8.21	2.13	0.246
	WBGT22-WBV0.81	-7.404	-10.87	-3.92	**0.001**
	WBGT22-WBV0.53	-8.140	-11.73	-4.54	**0.001**
Visual Attention Score	WBGT34–WBV1.12	-12.61	-16.38	-7.16	**0.001**
	WBGT34–WBV0.81	-11.12	-15.88	-6.35	**0.001**
	WBGT34-WBV0.53	-6.12	-10.88	-1.35	**0.012**
	WBGT34-WBV0	-7.57	-12.80	-2.33	**0.005**
	WBGT29-WBV1.12	-3.92	-8.68	0.84	0.106
	WBGT29-WBV0.81	-11.48	-15.90	-7.06	**0.001**
	WBGT29-WBV0.53	-.82	-4.45	2.81	0.655
	WBGT29–WBV0	-8.65	-11.83	-5.47	**0.001**
	WBGT22-WBV1.12	-3.57	-8.80	1.66	0.179
	WBGT22-WBV0.81	-5.50	-9.02	-1.98	**0.003**
	WBGT22-WBV0.53	-5.92	-9.55	-2.28	**0.002**
Reaction Time (Milliseconds)	WBGT34–WBV1.12	-39.64	-75.91	-16.12	**0.001**
	WBGT34–WBV0.81	-32.52	-70.34	5.30	0.091
	WBGT34-WBV0.53	-14.92	-52.74	22.90	0.435
	WBGT34-WBV0	-33.17	-74.75	8.41	0.117
	WBGT29-WBV1.12	-51.92	-89.74	-14.09	**0.008**
	WBGT29-WBV0.81	-14.75	-49.85	20.35	0.406
	WBGT29-WBV0.53	-25.62	-54.51	3.27	0.082
	WBGT29–WBV0	-15.72	-40.93	9.49	0.219
	WBGT22-WBV1.12	6.83	-34.75	48.41	0.745
	WBGT22-WBV0.81	-6.19	-34.13	21.74	0.661
	WBGT22-WBV0.53	-30.12	-59.01	-1.22	**0.041**

Discussion

Effect of Exposure to Heat Stress and Whole-Body Vibration on Auditory-Visual Attention: According to the results of the present study, exposure to WBV reduced auditory-visual attention among participants in the study. The WBV of 1.2 m/s2 had the highest significant effect on the auditory-visual attention score. This reduction was significant for both auditory and visual attention (P<0.001). In a study by El Falou et al. (2003), the effect of vibration on drivers during long driving periods was evaluated. Their results were obtained via the target pursuit cognitive test, revealing that increasing exposure duration resulted in higher error rates in the performance of individuals (24), being consistent with the results of the present study. Khani et al. (2012) noted that increasing WBV acceleration caused a reduction in the number of correct answers (P=0.01) and an increase in the number of wrong answers (P=0.01). It seems that higher vibration acceleration would intensify mental stress in the subject and reduce optimal performance during exposure to vibration (25), being in line with the results of the present study. Khan et al. (2007) looked at the effect of vibration on the reading performance of an operator in a mobile driving environment. Their results revealed that vibration can negatively affect the reading ability of subjects and reduce their cognitive performance (26). Newell et al. (2007) stated that exposure to vibration and unsuitable posture disrupt the focus of subjects while performing the reaction time test (6). Niazmand-Aghdam et al. showed that co-exposure to road traffic noise and WBV resulted in lower auditory-visual attention level scores (1). Zamanian et al. (2014) argued that WBV can disrupt sustained attention while affecting the speed and focus required for information processing in humans (27).

The results of the experiments in the present study indicated that compared to the control conditions (22 °C), elevation of WBGT caused a statistically significant reduction in mean auditory-visual attention among the participants (P<0.001). Naserpur et al. (2014) evaluated the cognitive performance of students during exposure to heat using CPT. They stated that the highest percentage of attention among the participants (99.67%) was observed at a WBGT of 22 °C, while a reduction in attention was observed at the highest and lowest limits of TLV for occupational exposure. They concluded that the cognitive performance of subjects exposed to various levels of heat stress improves if they are acclimated to heat and when being within TLV for occupational exposure. However, exposure to heat stress above TLV for occupational exposure disrupts the cognitive and mental performance of subjects (29).

Mazlomi et al. (2016) examined the effects of heat exposure on cognitive performance and blood hormone levels among a casting plant's workers. The effect of heat on the workers' reaction time, focus, and attention was evaluated using a three stage (preliminary, experimental, and main) Stroop Color and Word Test (SCWT) conducted both before the start of the work shift and during the work shift. According to their results, exposure to heat stress can lead to changes in stress hormone levels in the blood and negatively affect cognitive as well as mental performance. Their study concluded that higher stress hormones in the blood due to extreme heat exposure would result in increased human error, which in turn leads to more occupational accidents, reduced efficiency, and lower worker performance (30).

Hancock et al. (2007) carried out a study to analyze human performance under heat stress conditions. Their results indicated that heat stress would limit work capacity and increase the probability of occupational injuries. Additionally, cognitive performance, decision-making, and work performance were disrupted under both heat stress and cold stress conditions, though the effects of heat were far more influential and increased the probability of errors and mistakes in the work environment (31). McMorris et al. conducted a study to evaluate the effects of heat stress on working memory, reaction time, and changes in mood. They found that heat stress could affect cortisol and adrenaline levels in the blood, considerably affecting the subjects' performance test results. This means that noradrenaline concentration in the blood can be used as a measure for evaluating heat stress exposure in individuals (32).

The present study results found that in groups with similar heat stress exposure modes, increasing WBV acceleration would lower the subjects' mean auditory-visual attention. At each of the WBV intensities, increasing WBGT resulted in lower mean auditory-visual attention among the subjects. Further, a significant difference was seen between different exposure modes for auditory-visual attention. This significant difference in exposure to WBGT=34 °C and WBV=1.2 m/s2 had the highest significant effect on the auditory-visual attention score. Thus, it can be concluded that the effects of WBV and heat stress on auditory-visual attention are dependent on each other. Thus, it can be stated that the changes in auditory-visual attention observed among the subjects is due to simultaneous exposure to both stressors.

Effect of Exposure to Heat Stress and Whole-Body Vibration on Reaction time: The present study results revealed that exposure to WBV caused a significant increase in the reaction times of participants (P<0.001). The differences in mean reaction time observed between the no vibration condition and low vibration condition (0.53 m/s2), no vibration condition and medium vibration condition (0.81 m/s2), as well as between medium vibration condition (0.81 m/s2) and high vibration condition (1.12 m/s2) were statistically significant (P<0.001). Additionally, increasing WBV acceleration resulted in a significant rise in reaction time among the subjects. The rise in reaction time may be due to the effect of vibration on eyesight as the subjects lose the ability to quickly identify the correct response and need to spend more time finding it.

Schust et al. (2006) also stated that elevation of the vibration acceleration exerted by the seat onto the drivers along different axes resulted in their increased reaction time (33). In line with the findings of the present study, Newell et al. argued that exposure to vibration can disrupt the focus of subjects during testing and increase their reaction time (6).

Based on the results, increasing WBGT compared to the control conditions (22 °C) caused a significant increase in mean reaction times of the subjects ($P<0.001$). Naserpur et al. (2014) evaluated the cognitive performance of students during exposure to heat stress using the continuous performance test (CPT). They found that elevation of WBGT from 22 °C to 33 °C increased the reaction time of the subjects. Further, a significant difference was observed between reaction time under a WBGT of 33 °C and other levels of heat stress (29). In another study by Lieberman et al. (2005), it was found that heat stress negatively affected cognitive performance (reduced efficiency and reaction time). In their study, reaction time was considered simple cognitive tests, while attention was considered complicated cognitive tests, with all cognitive functions witnessing a significant reduction (34). Mazloumi et al. (2017) evaluated the effects of heat stress on selective attention and reaction time in a warm industry. Their results indicated that heat stress can increase reaction time and selective attention in subjects (30), being consistent with the presents study results.

Literature review demonstrates that many studies have been conducted on the effects of independent exposure to heat or WBV on cognitive performance. Nevertheless, very few studies have dealt with the effects of co-exposure to these harmful physical agents (heat stress and WBV) on cognitive performance, i.e. a strong point of the present study compared to previous research. The present study results indicated that in groups with similar WBV exposure, increasing WBGT resulted in higher mean reaction time in the subjects. The highest significant effect size on reaction time was seen in the co-exposure to WBGT=34 °C and WBV=1.2 m/s2. At each WBV intensity, elevation of WBGT compared to the control conditions resulted in higher reaction times. Furthermore, a significant difference was seen between different exposure modes for reaction times. This significant difference in exposure to WBGT=34 °C and WBV=1.2 m/s2 had the highest significant effect on the reaction times.

Notable limitations of the presents study include the relatively small sample size as well as low exposure durations due to ethical considerations. Further, conducting tests in a laboratory setting has been due to the presence of many interfering factors in the field. Evaluation of long-term effects of WBV exposure (chronic) and the employment of female sample populations are suggested. It is recommended to apply Electrocardiography and Electroencephalography for analyzing the effects of vibration on cognitive functions (via brain waves) (35) for future studies.

Conclusion

Exposure to WBV caused a significant reduction in the subjects' auditory-visual attention. Augmentation of WBGT from 29 °C to 34 °C also caused a significant reduction in their auditory-visual attention. There was a significant difference between the individual and co-exposure groups with heat stress and WBV in auditory-visual attention and reaction time. According to the results, heat stress and WBV are two effective factors in mental performance which can reduce accuracy and fatigue when doing work. Therefore, it is essential to pay attention to cognitive issues to reduce errors and accidents.

Acknowledgement

The author highly appreciates the subjects for their participation and making this project possible.

Conflict of interest: None declared.

Funding

This research received no external funding

Ethical Considerations

All ethical considerations were followed in this study. Written consent forms were taken from the participants before performing any test.

Code of Ethics

Ethical approval for this study was obtained from School of Public Health and Safety at work - Shahid Beheshti University of Medical Sciences (IR.SBMU.PHNS.REC.1396.97).

Authors' Contributions

Presentation of the idea and initial plan: Ghafari, Jafari. Data collection: Ghaffari, Salehzadeh, Akhlaghi. Analysis and interpretation of data: Ghaffari, Akhlaghi, Jafari, Farhang, Salehzadeh. All the authors participated in the initial writing of the article or its revision, and all accept the responsibility for the accuracy and correctness of the contents of the present article with the final approval of this article.

References

1. Niazmand-Aghdam N, Ranjbarian M, Khodakarim S, Mohammadian F, Farhang Dehghan S. Effect of combined exposure to traffic noise and whole body vibration on attention and response control in men. Iran Occup Health. 2020;17(1):807-22.
2. Firdaus M, Rahayu S, Minhat M, Fukumi M, Ito T. Effect of vibration towards driving fatigue and development of regression model based on vibration. Paper presented at: The Proceedings of Design & Systems Conference; 2017 Sep 13-15; Shimonoseki, Japan.
3. Rafieepour A, Nasiri P, Giahi O, Monazzam Esmaeilpour MR, Zakerian A, Mohammadian F. Investigation of the change in the acceleration of whole body vibration in a simulated environment on individuals reaction time and mental performance. J Health Saf Work. 2017;7(4):343-52.
4. Davies HW, Wang F, Du BB, Viventi R, Johnson PW. Exposure to whole-body vibration in commercial heavy-truck driving in on-and off-road conditions: effect of seat choice. Ann Work Expo Health. 2022;66(1):69-78.
5. Ebrahimi H. Investigation of noise and vibration exposure of Tehran’s bus drivers. Tehran: Tehran Univesity of Medical Sciences. 2009.
6. Newell GS, Mansfield NJ. Evaluation of reaction time performance and subjective workload during whole-body vibration exposure while seated in upright and twisted postures with and without armrests. Int J Ind Ergon. 2008;38(5-6):499-508.
7. Kubo M, Terauchi F, Aoki H, Matsuoka Y. An investigation into a synthetic vibration model for humans:: An investigation into a mechanical vibration human model constructed according to the relations between the physical, psychological and physiological reactions of humans exposed to vibration. Int J Ind Ergon. 2001;27(4):219-32.
8. Kovats RS, Hajat S. Heat stress and public health: a critical review. Annu Rev Public Health. 2008;29:41-55.
9. Akhlaghi Pirposhte E, Jafari MJ, Farhang Dehghan S, Khodakarim S, Hajifathali A. Investigating the relationship between heat stress and workers’ blood parameters in a foundry. J Mil Med. 2019;21(6):618-27.
10. Jafari MJ, Pirposhteh EA, Dehghan SF, Khodakarim S, Jafari M. Relationship between heat stress exposure and some immunological parameters among foundry workers. Int J Biometeorol. 2020;64(5):853-61.
11. Ljungberg JK, Neely G. Stress, subjective experience and cognitive performance during exposure to noise and vibration. J Environ Psychol. 2007;27(1):44-54.
12. Golbabaei F, Mazloumi A, Mamhood Khani S, Kazemi Z, Hosseini M, Abbasinia M, et al. The effects of heat stress on selective attention and reaction time among workers of a hot industry: application of computerized version of stroop test. J Health Saf work. 2015;5(1):1-10.
13. Mohebian Z, Farhang Dehghan S, Dehghan H. Evaluation of the combined effects of heat and lighting on the level of attention and reaction time: climate chamber experiments in Iran. ScientificWorldJournal. 2018;2018:5171582.
14. Schlittmeier SJ, Feil A, Liebl A, Hellbr CK JR. The impact of road traffic noise on cognitive performance in attention-based tasks depends on noise level even within moderate-level ranges. Noise Health. 2015;17(76):148-57.
15. Mohebian Z, Mehrifar Y, Dehghan H, Habibi E, Yadegarfar G. Investigating the combined effects of heat and lighting on students reaction time in laboratory condition. J Occup Hyg Eng. 2016;3(3):40-6.
16. Tinius TP. The Integrated Visual and Auditory Continuous Performance Test as a Neuropsychological Measure. Arch Clin Neuropsychol. 2003;18(5):439-54.
17. Willmott SA, Boardman JA, Henshaw CA, Jones PW. Understanding General Health Questionnaire (GHQ–28) score and its threshold. Soc Psychiatry Psychiatr Epidemiol. 2004;39(8):613-7.
18. Malakouti SK, Fatollahi P, Mirabzadeh A, Zandi T. Reliability, validity and factor structure of the GHQ-28 used among elderly Iranians. Int Psychogeriatr. 2007;19(4):623-34.
19. Salvia J, Ysseldyke J. An analysis of the reliability and validity of the Ishihara color plates with mentally retarded males. Percept Mot Skills. 1971;33(1):243-6.
20. Giedraityte L, Holmér I, Gavhed D. Validation of methods for determination of metabolic rate in the Edholm scale and ISO 8996. Int J Occup Saf Ergon. 2001;7(2):135-48.
21. International Organization for Standardization. ISO 2631-2:2003. Mechanical vibration and shock: Evaluation of human exposure to whole-body vibration. Part 2: Vibration in buildings (1 Hz to 80 Hz). . Available from: https://www.iso.org/standard/23012.html
22. International Organization for Standardization. ISO 7243:1989. Hot environments — Estimation of the heat stress on working man, based on the WBGT-index (wet bulb globe temperature). Available from: https://www.iso.org/standard/13895.html
23. Tollander H. The integrated visual and auditory continuous performance test: Does the comprehension scale discriminate ADHD. [PhD thesis]. Forest Grove, Oregon, United States: Pacific University; 2011.
24. El Falou W, Duchêne J, Grabisch M, Hewson D, Langeron Y, Lino F. Evaluation of driver discomfort during long-duration car driving. Appl Ergon. 2003;34(3):249-55.
25. Khani Jazani R, Saremi M, Kavousi A, Monazam MR, Abedi M. The effect of whole-body vibration on vehicle driver's reaction time and mental and physiological workload. Ann Mil Health Sci Res. 2013;10(4):e67643.
26. Khan IA, Mallick Z, Khan ZA. A study on the combined effect of noise and vibration on operators’

performance of a readability task in a mobile driving environment. Int J Occup Saf Ergon. 2007;13(2):127-36.

27. Zamanian Z, Nikravesh A, Monazzam MR, Hassanzadeh J, Fararouei M. Short-term exposure with vibration and its effect on attention. J Environ Health Sci Eng. 2014;12(1):135.
28. Mohebian Z, Dehghan H, Habibi E. Studying the effect of heat stress on attention and reaction time in a laboratory setting. J Health Saf Work. 2017;7(3):233-44.
29. Jafari MJ, Naserpour M, Monazzam MR, Saremi M, Pouragha Shahneshin HR, Jam Bar Sang S. Evaluation of Students' Cognitive Performance While Exposed to Heat Using Continues Performance Test. J Occup Hyg Eng. 2014;1(2):1-9.
30. Mazlomi A, Golbabaei F, Farhang Dehghan S, Abbasinia M, Mahmoud Khani S, Ansari M, et al. The influence of occupational heat exposure on cognitive performance and blood level of stress hormones: A field study report. Int J Occup Saf Ergon. 2017;23(3):431-9.
31. Hancock PA, Ross JM, Szalma JL. A meta-analysis of performance response under thermal stressors. Hum Factors. 2007;49(5):851-77.
32. McMorris T, Swain J, Smith M, Corbett J, Delves S, Sale C, et al. Heat stress, plasma concentrations of adrenaline, noradrenaline, 5-hydroxytryptamine and cortisol, mood state and cognitive performance. Int J Psychophysiol. 2006;61(2):204-15.
33. Schust M, Blüthner R, Seidel H. Examination of perceptions (intensity, seat comfort, effort) and reaction times (brake and accelerator) during low-frequency vibration in x-or y-direction and biaxial (xy-) vibration of driver seats with activated and deactivated suspension. J Sound Vib. 2006;298(3):606-26.
34. Lieberman HR, Bathalon GP, Falco CM, Kramer FM, Morgan CA 3rd, Niro P. Severe decrements in cognition function and mood induced by sleep loss, heat, dehydration, and undernutrition during simulated combat. Biol Psychiatry. 2005;57(4):422-9.
35. Hajra SG, Xi P, Law A. A comparison of ECG and EEG metrics for in-flight monitoring of helicopter pilot workload. In: The 2020 IEEE International Conference on Systems, Man, and Cybernetics (SMC). 2020 Oct 11-14; Toronto, ON, Canada. P.4012-9.