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The simultaneous exposure to heat and whole-body vibration on some motor skill functions of city taxi drivers

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Keywords: Combined exposure; heat; whole-body vibration; body balance; grip strength; city drivers

Abstract

Background: *Driving requires sensory-motor abilities in unpredictable and complex driving scenarios. This experimental study aimed to investigate the combined effects of exposure to whole-body vibration and heat on motor skill functions of city taxi drivers.* **Methods:** *This study was conducted using a driving simulator on 30 male taxi drivers. The drivers were exposed to five exposure conditions set by a single or combined exposure of two air temperatures (24 and 30 °C) and two vibration levels (0.5, 1 m/s^2). Motor skill functions, including body balance, hand grip strength, and perceived fatigue, were measured using a force plate, dynamometer, and Borg CR-10 questionnaire.* **Results:** *The separate exposure to heat did not modify balance and hand grip strength, but its combined exposure to vibration affected balance and grip strength. The effect sizes of heat, vibration, and heat + vibration on balance were respectively 0.003, 0.23, and 0.441. Vibration exposure made the most significant mean differences in hand grip strength compared with the other scenarios. The separate effect of heat on drivers' perceived fatigue was comparable to vibration. The combined exposure to heat and vibration aggravated the perceived fatigue associated with exposure to heat and vibration alone.* **Conclusion:** *Vibration mainly affects the driver's postural equilibrium, handgrip strength, and fatigue. The heat exposure alone did not have any remarkable effects on the balance responses and handgrip strength; however, it significantly increased the drivers' perceived fatigue. Exposure to heat can aggravate the effects of vibration on motor skills with a synergistic interaction.*

1. Introduction

Using vehicles as taxis in urban life is integral to the lifestyle and a source of drivers' whole-body vibration (WBV) [1]. The vibrations transmitted from the road surface to the vehicle get in touch with the driver through the foot, seat, and backrest [2]. Exposure to WBV can cause health problems in

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the cardiovascular, respiratory, gastrointestinal, spinal, and peripheral nervous systems, and it may also cause a disturbance to the vision and hearing systems [3, 4]. Hence, long-term exposure to whole-body vibration in taxi drivers can cause adverse effects such as reduced perception, annoyance, disturbance of vision and delicate motor tasks, spinal cord injury, and damage to the digestive and reproductive systems. It can reduce blood flow to the lower back and causes cell damage and local fatigue [5], which may cause low back pain [6] and postural imbalance [7].

It should be noted that motor skills are defined as the fundamental movement characteristics of humans and are very important in job performance. Strength, endurance, and speed are primary skills, while mobility and coordination are complementary. In this regard, Savage et al. mentioned that human balance disturbance is one of the most common complications of WBV exposure, which sometimes leads to falls [7]. A fall accident is a non-traffic-related occupational injury, especially at high vibration frequencies, due to body imbalance of drivers [4]. Human postural equilibrium or balance is essential for human motor skills and is very important for daily activities [8] so standing and walking depend on it [4]. Balance is a complex process achieved from the integrated information of visual, vestibular, and somatosensory systems [9]. When these sensory systems are disturbed, the body's balance control mechanisms change and the balance decreases [10]. Studies have shown that vibration can reduce the balance by interfering with the proprioceptive system [4, 11, 12]. It should be noted that the force plate used to measure balance will be able to record the horizontal and vertical reaction forces. The center of pressure (COP) coordinates are determined, and sway from the pressure center is recorded as COP displacement [13].

Handgrip strength is an essential characteristic of the hand in different activities, especially driving, and reduced strength can indicate muscle fatigue due to exposure to vibration. Widia and Dawal showed strong relationships between muscle activity, grip strength, interval time and vibration level. Muscle activity and ratio decrease of grip strength increase as the vibration level and exposure duration increase [14]. Drivers require high motor-sensory skills. Hence, proper handgrip strength and suitable postural stability are essential for safe driving [4].

The dissatisfaction levels of extreme air temperature have even some veto power over the existing outdoor noise levels from traffic loads during driving. Due to the nature of taxi driving in outdoor areas, drivers are exposed to heat stress in the warm seasons, aggravated by global warming [15]. Spaul et al. have shown combined exposure to heat and WBV can even reduce the effectiveness of body cooling mechanisms [16, 17]. Exposure to heat and whole-body vibration (WBV) may be the risk factors for drivers' physical and mental fatigue, which can result in poor performance or *postural* instability [18, 19]. Son et al. showed that workers' balance ability is affected by physical workload and heat exposure [20].

The related literature emphasized the interactions among environmental factors and recommended more detailed research. It can be seen that exposure to any of the physical factors alone can affect the physical and mental performance of drivers [21]. There are limited studies on the combined effects of vibration and heat exposure during driving activities, especially among taxi drivers. This study empirically investigated the effects of separate and combined exposure to vibration and heat on some motor skills among taxi drivers under simulated driving conditions.

2. Methods

2.1 Subjects

In this experimental study, 30 healthy male taxi drivers participated voluntarily, and a clear explanation of the testing process was given to them. Eligible drivers filled out a demographic questionnaire which included age, height, weight, history of the disease, and the Pittsburgh Sleep Quality Index (PSQI) questionnaire assessing sleep quality over a 1-month time interval. The mean±SD of age and BMI of the participants were 34.56±5.93 years and 22.57±2.06 kg/m^2, respectively.

The drivers had not engaged in any possible medications related to motor skills. The drivers had to get at least 7 hours of sleep the night before each session and not use caffeine or other stimulants.

All participants were paid to ensure their motivation. The Hamadan University of Medical Sciences Ethics Committee approved this study (Code: IR.UMSHA.REC.1400.036.). All drivers were informed of the research, and consent forms were obtained. The inclusion criteria for volunteers to make the study as accurate as possible are as follows:

- Drivers should not be older than 45 years;
- Weight was kept in the range of 75 to 85 as it can interfere with the received vibration levels;
- The Pittsburgh Sleep Quality Index questionnaire score should be below 6;
- Drivers should be healthy and be in the standard BMI range (18-23);
- Drivers should not use specific drugs or caffeine, or any other stimulants;
- Drivers should not have sleep problems and have at least 7 hours a day;
- Drivers should not suffer from daltonism (Ishihara test) and have correct visual acuity (visual acuity score=20/20) using the visual screening device (Optec 5000/5000P Series).

2.2 Experimental design

The research was performed using a within-subjects design, where all drivers were considered their controls. A repeated-measures design was conducted to investigate the effect of exposure of 30 minutes to heat or WBV in different scenarios. As shown in Figure 1, the drivers exposed for 30 minutes to five different scenarios on separate days under simulated driving conditions: (i) heat exposure (air temperature: 30 °C, WBV acceleration: 0 m/s^2), (ii) WBV_1 exposure (air temperature: 24 °C, WBV acceleration: 0.5 m/s^2), (iii) WBV_2 exposure (air temperature: 24 °C, WBV acceleration: 1 m/s^2), (iv) combined heat and WBV_1 (air temperature: 30 °C, WBV acceleration: 0.5 m/s^2), and (v) combined heat and WBV_2 (air temperature: 30 °C, WBV acceleration: 1 m/s^2). The WBV intensities of 0.5 and 1 m/s^2 were selected based on ISO 2,631 exposure limit recommendation. They were also chosen according to the real data obtained from taxi drivers exposed to WBV in fields. The grip strength and balance test and Borg scale fatigue were tested before and after each scenario. Different scenarios were performed randomly for each driver to eliminate the sequence effect. Moreover, the interval between each experiment was two days to eliminate the effects of previous exposure.

2.3 Driving simulation condition

The simulated driving system was derived from city car driving software (v1.5.9.2) that simulates visual driving. It was linked to a vibration simulator (Car racing VR-Sarisa model) with Xbox 360 controller. This car simulator works with a pneumatic system mechanism, and it can produce vibration in different adjustable acceleration and frequency spectrums. It is powered by two air compressors that can generate vibrations in different regulated frequencies and accelerations. The vibration was set at two levels of 0.5 m/s^2 and 1 m/s^2 and monitored continuously by a vibration meter (SVANTEK, SV106A). Table 1 shows the vibration acceleration values of the driving simulator system. The vibration of vehicles such as the studied taxi car frequently varies from 1 to 50 Hz, and the most noticeable vibrations occur on the Z-axis [22, 23]. It should be noted that the output frequency of the driving simulator was 5 to 20 Hz.

The driving simulator was located in the air-conditions simulator chamber shown in Figure 2. Air-conditions simulator chamber can able to provide different air temperature conditions. The chamber's dimensions are 4 × 3.5 × 2.7 m (L×W×H), and is made of pre-made injected polyurethane panels with a density of 40 kg / m3, and is covered with alloy sheets that produce -25 to 50 °C air temperature condition in the chamber. The WBGT-meter (CASELLA -HB3279-03) was used to monitor air temperature, and it got constant at 30 °C and 24 °C. The digital light meter (INS-DX-200) and Sound-level meter (LUTRON SL-4011 (Were used to keep brightness and background noise at the optimal limit of 300 Lux and 50 to 55 dB, respectively.

2.4 Motor skill functions measurement

For measuring body balance, Subjects' COP was measured in ML and AP axes in two different vision conditions, including Eyes-Open (EO) and

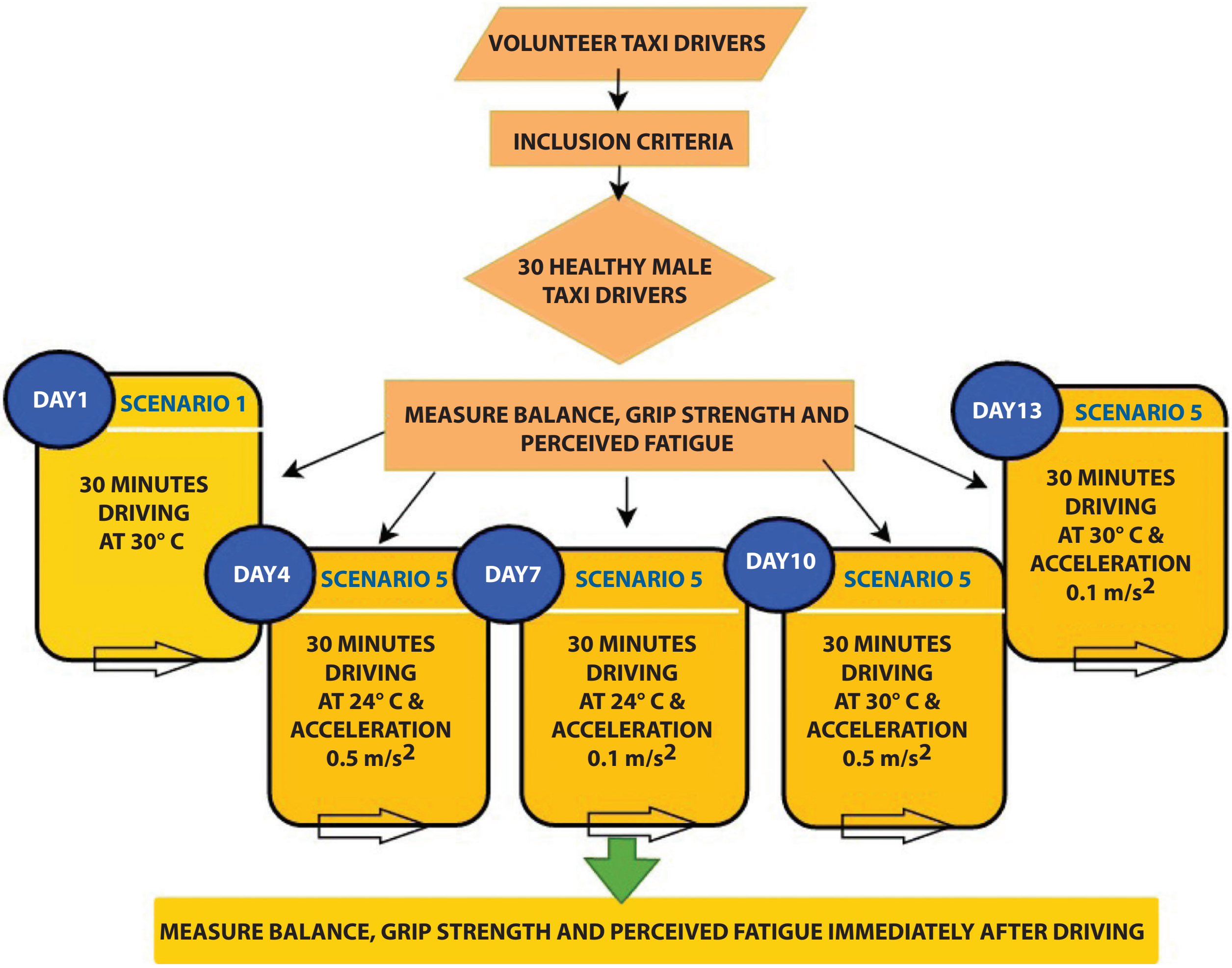

Figure 1. Diagram of the study experiment setup.

Table 1. Characteristics of vibration accelerations induced by the driving simulator.

Condition (1)	x	y	z	sum	Condition (2)	x	y	z	sum
a_{rms} (m/s^2)	0.01	0.09	0.49	0.50	a_{rms} (m/s^2)	0.08	0.11	0.98	1.00
$MTVV^a$	0.11	0.28	2.17		$MTVV^a$	0.30	0.57	2.21	
a_{peak}	0.23	0.47	2.71		a_{peak}	0.82	1.35	4.81	
VDV^b (m/s$^{1.75}$)	0.24	0.85	4.88		VDV^b (m/s$^{1.75}$)	3.66	12.82	73.20	

a= the maximum transient vibration value, calculated at a one-second interval.
b= the fourth power vibration dose value.

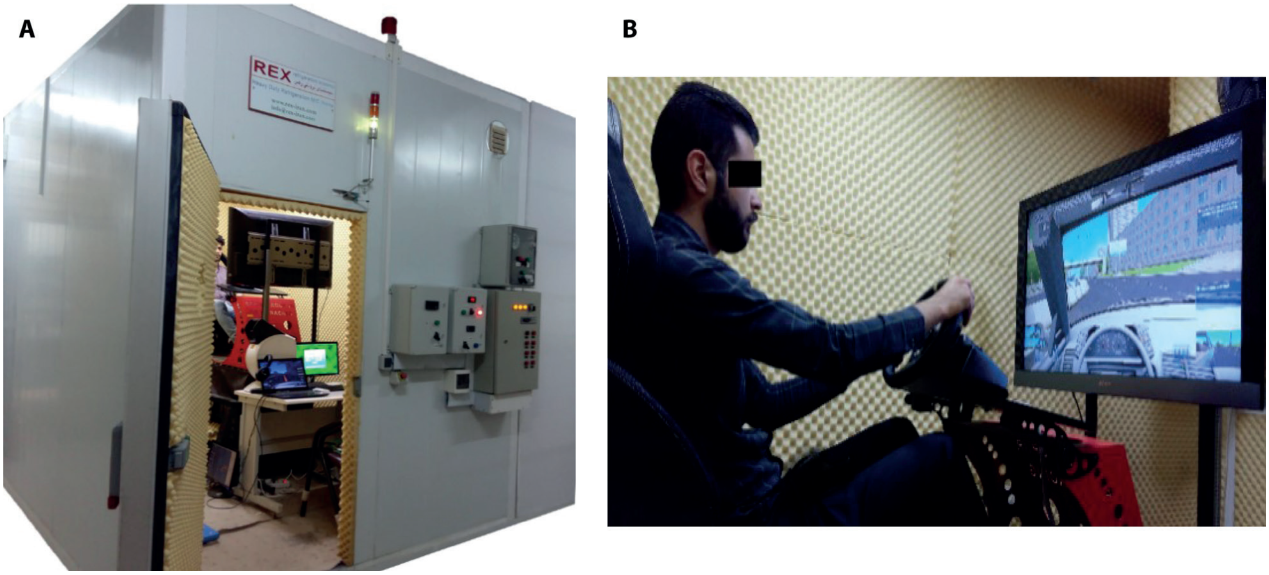

Figure 2. The air-condition simulator chamber (a) and the driving simulator (b).

Eyes-Closed (EC), before and after exposure in each session. The force plate is placed on a rigid surface to prevent unwanted movements. The subjects stood barefoot in a Romberg position (stand straight and motionless with hands to the sides of the body and in a neutral position) on the Kistler 9286BA force platform (Winterthur, Switzerland) for 30 seconds while they were looking at a specific target at a distance of one meter from their eyes height [24]. Body balance was measured three times with open eyes and three times with closed eyes, and an average of these was reported. The stand location on the force plate must be the same for everyone, so a T-shaped sheet was installed on the force plate, and people stood on the marked area. The force plate was connected to Kistler 9865 amplifier, and recorded data were transformed to BioWare software (Software for Data Acquisition of Force Plates) by an analogue to digital converter Kistler 5691A Data Logger. The sampling frequency was 100 Hz, and to increase the measurement accuracy, 10s first data were deleted, and the 20s final data were extracted. Finally, 4,000 coordinate points of COP (2,000 point x, 2,000 point y) were used to calculate the root-mean-square of COP anterior-posterior (y)/ medial-lateral (x) displacement by using formulas in excel [12]{Cornelius, 1994 #12;Pollard, 2017 #28}. Many parameters can be calculated from formulas to describe the balance, all of which are suggestive [11]. A graph of the COP displacement recorded by the BioWare software in different directions is shown in Figure 4.

Jamar hydraulic hand dynamometer was used to measure hand grip strength before and after each scenario. The mean score of handgrip strength was obtained by three times measured. Each time, a dynamometer fitting the anatomy of the individual's hand was calibrated to 0. The volunteers had to keep the upper arm close to the body, at a 90-degree angle, grabbing the dynamometer for a few seconds with maximum force. The kilogram number on the dynamometer indicates gripe strength [25, 26].

Finally, the Borg scale (CR-10) was used to determine the perceived fatigue of the drivers [27, 28]. Each of the numbers on this scale expresses a degree of perceived fatigue such that a value of zero means nothing at all, a matter of five means moderate fatigue, and a value of 10 means unbearable fatigue. Fatigue perceived by the individual was used to assess fatigue before and after each scenario.

2.5 Statistical analysis

After confirming the normality of the data by using the Kolmogorov-Smirnov test, paired sample

T-test was used to determine the effects of exposure in different scenarios. When Mauchly's test rejected the Sphericity Assumed, a Greenhouse-Geisser correction was used to obtain p-values. The repeated measure ANOVA was employed to compare the scenarios in pairs and to report effect size (ES). LSD post hoc test was used to compare the means between groups in pair scenarios. All statistical analyses were performed using the SPSS 22 package.

3. Results

The comparison between the root-mean-square (RMS) of COP in anterior-posterior (AP) and Medial-Lateral (ML) displacement before and after different exposure and vision conditions by paired t-test is shown in Table 2. In the open eyes condition, there were significant mean differences in COP-AP and COP–ML in all exposure conditions except for heat and WBV_1 scenarios. In the closed eyes condition, the significant displacement increment of COP-AP and COP-ML were observed in all scenarios, except for the heating scenario (p=0.24 and p=0.64). Generally, it was observed that WBV_2 and heat +WBV_2 had more significant effects on drivers' body balance compared with the other conditions.

Table 2 also shows the effect sizes of COP-AP and COP–ML RMS data in all exposure conditions. The heat exposure scenario cannot affect balance lonely. Still, the combined exposure to heat with WBV1 and WBV2 can affect the displacement increment of COP more effectively than the single WBV exposure scenario.

In open eyes condition, the effect sizes of heat, WBV_2, and heat+WBV_2 on COP-AP were 0.003, 0.23, and 0.441, respectively. The effect sizes of heat, WBV_2, and heat+WBV_2 on COP-ML were 0.01, 0.04, and 0.54, respectively. These responses are the same about closed eye conditions.

The combined effects of heat and vibration were more than the sum of these separated effects. Table 3 shows the significant differences for RMS data of COP in all directions and all exposure scenarios and open and closed eyes vision conditions.

Table 4 also shows the pairwise comparison of RMS data of COP in EO (AP and ML directions) and EC (AP and ML direction) in different exposure conditions.

The mean differences in hand grip strength in all scenarios are shown in Table 5.

A significant reduction in grip strength after exposure in all scenarios except in heat and WBV_1 scenarios (p=0.08 and p=0.13, respectively). Based on the acquired effect size, WBV_2 scenario makes the greatest mean differences in hand grip strength compared with the other scenarios. It is also observed that the effect sizes of heat, WBV_2, and heat+WBV_2 on hand grip strength are 0.004, 0.012, and 0.019, respectively. It can be stated that exposure to heat has increased the effect of vibration on hand grip strength. As shown in Tables 4 and 5, it can also be seen the separate effect sizes of exposure whole-body vibration on drivers' postural equilibrium and grip strength were considerable compared with the heat exposure in the domain of the studied scenarios.

The effects of different scenarios on the perceived fatigue scores were presented in Table 6. The results showed that all drivers experienced fatigue in all scenarios ($p<0.001$). According to the acquired effect size, the combined scenarios (Heat+WBV_1=0.73, Heat+WBV_2=0.98) have more effect on perceived fatigue than the single exposure scenarios (Heat=0.31, WBV_1=0.21, WBV_2= 0.55).

As shown in Table 6, the separate effect sizes of exposure to heat on drivers' perceived fatigue was comparable to vibration at the domain of the studied scenarios. Moreover, the effect of exposure to heat on the perceived fatigue was considerable compared the hand grip strength at the domain of the studied scenarios.

4. Discussion

Occupational exposure to environmental factors can act in quite complex ways to produce their combined effects on body responses. It is observed that the studies about the separate and combined effects of occupational exposure to environmental factors have become very important.

This study confirmed that separate exposure of drivers to vibration caused a significantly increased COP displacement in the different directions. Some

Table 2. The significant mean difference of COP in (AP) and (ML) directions in all exposure conditions.

	Eyes Open						Eyes Closed					
	AP(y)			ML(x)			AP(y)			ML(x)		
Scenarios	**Mean±SD**	**Sig**	**ES**	**Mean±SD**	**Sig**	**ES**	**Mean±SD**	**Sig**	**ES**	**Mean±SD**	**Sig**	**ES**
Heat	0.24±1.13	0.23	0.003	-.03±0.84	0.80	0.010	-0.22±1.04	0.24	0.006	0.09±1.11	0.64	0.004
WBV_1	0.12±0.93	0.48	0.036	0.23±0.93	0.21	0.113	0.32±0.66	**0.013***	0.021	0.47±0.92	**<0.01***	0.170
WBV_2	0.65±0.91	**<0.01***	0.230	0.41±0.75	**0.04***	0.04	0.51±0.95	**0.02***	0.213	0.64±0.70	**<0.01***	0.574
Heat $_+$ WBV_1	0.48±0.85	**0.04***	0.078	0.35±0.91	**0.04***	0.252	0.47±0.65	**<0.01***	0.115	0.47±1.00	**<0.01***	0.413
Heat$_+$ WBV_2	1.13±0.78	**<0.01***	0.441	0.62±0.89	**<0.01***	0.54	1.03±0.95	**<0.01***	0.268	0.92±0.79	**<0.01***	0.668

[a] *Mean: The difference between COP in different directions before and after each exposure condition.*

[b] **: indicates statistically significant.*

[C] *WBV: whole body vibration (at two acceleration levels; WBV1: 0.5 m/s^2 and WBV2:1 m/s^2).*

Table 3. The significant differences for RMS data of COP in all directions and in all exposure scenarios.

Directions	Mean Difference	SD	F	p
COP-AP	-0.378	0.38	-13.23	< 0.001*
COP-ML	-0.447	0.77	-7.72	< 0.001*

research revealed that whole-body vibration exposure can impair human body balance [4, 29, 30]. This impairment actually can reduce the function of central postural control mechanisms, especially at the high vibration acceleration [31]. Yung et al. demonstrated that the single exposure to low to high levels of vibration may increment to some extent in human postural sway [32].

The separate exposure to heat has no significant reduction effect on body balance in any direction and vision condition, however, the combined exposure to heat and vibration can affect on body postural stability more effectively than the single WBV exposure scenario. The acquired effect sizes data showed that the combined effects of heat and vibration on body balances were more than the sum of these separated effects. It can be said that the synergist effects can be seen in the interaction of heat and vibration on the body balance. Previous studies on the combined effects of vibration and heat on body balance were not found. However, Golhosseini et al. determined simultaneous exposure to WBV and noise can increase the equilibrium effects more than a single exposure to WBV [33]. Raffler et al. also showed WBV and awkward posture have more effect than single factor exposure on low back pain [5]. It is also observed that combined exposure to vibration and noise can make disturbance on visual cognitive process [34].

A significant difference of the body balance in open and closed eyes vision conditions so that it can be indicated the role of sight in body balance. It should be noted that, the acceleration of 1 m/s^2 can upset a person's proper balance, but acceleration of 0.5 m/s^2, has no direct significant effect on balance, but when vision as sensory ability is eliminated, the same low vibration level (acceleration 0.5 m/s^2) can also upset the balance. Black et al. also indicated that visual sensory impairment is associated with body imbalance and falls [35].

The mean differences in perceived fatigue among drivers in all scenarios were statistically significant ($p<0.001$). In accordance with the current finding, Fujii et al. demonstrated that activity at high air temperatures can increase fatigue [19]. Moreover, Ferreira-Souza et al. mentioned that exposure to vibration can induce fatigue among drivers [36]. The results confirmed that the synergism interaction also occurs in the driver's perceived fatigue at simultaneous exposure to heat and vibration so that the size effect of heat and WBV on the fatigue is greater than the sum of each factor. The finding represented that the separate effect size of exposure to heat on drivers' perceived fatigue was very considerable in the domain of the studied scenarios. Heat stress, as a physical stressor, can affect the body's physiological responses, and the resulting consequences appear as fatigue over time.

The separate effect of exposure to heat is not significant on grip strength. However, in the combined exposure condition, the effect of vibration on grip strength was aggravated. The low acceleration level of vibration could not also statistically affect the handgrip strength, but the combined exposure to heat were significant ($p<0.001$). It should be noted that the low grip strength can indicate muscle fatigue [37] resulting a decline in physical function [21]. Albert et al. reported that the physical function is an important task in a driving vehicle and lack of this is associated with unsafe driving [38].

The main limitation of this study is the short-term exposure as compared with actual working hours of driving activities. More studies in the field seem necessary to fully validate this finding in the long-term exposure of drivers. Moreover, the interaction of this physical factors on some psychophysiological responses of the city taxi drivers can be studied using the advanced clinical methods in future. It should also be noted that the findings are limited to the experiment configurations of air temperatures and vibration levels as the most common real exposure levels of drivers.

Occupational health program should be carried out to help prevent adverse health effects among taxi

Table 4. Pairwise comparisons of COP in (AP) and (ML) directions in all exposure conditions.

			Heat		WBV1		WBV2		Heat+ WBV1		Heat+ WBV2	
Vision	**Direction**	**Scenarios**	**Δ Mean**	**Sig.**	**Δ Mean**	**Sig.**	**Δ Mean**	**Sig.**	**Δ Mean**	**Sig.**	**Δ Mean**	**Sig.**
Eyes-Open	(AP)	Heat	-	-	0.33	1	-0.32	1	-0.2	1	0.78*	0.041*
		WBV1	-0.33	1	-	-	-0.65	0.16	-0.55	0.23	-1.11	<0.001*
		WBV2	0.32	1	0.65	0.165	-	-	0.122	1	-0.45	0.03
		Heat+ WBV1	0.2	1	0.53	0.23	-0.122	1	-	-	-0.57	0.04
		Heat+ WBV2	0.78	0.04	1.11	<0.001*	0.45	0.03	0.57	0.04	-	-
	(ML)	Heat	-	-	-0.155	1	-0.51	0.22	-0.37	0.22	-0.65	0.18
		WBV1	0.155	0.12	-	-	0.35	0.79	0.21	1	-0.5	0.13
		WBV2	0.51	0.21	0.35	0.79	-	-	0.14	1	-0.14	1
		Heat+ WBV1	0.37	0.54	021	1	-0.14	1	-	-	-0.28	0.45
		Heat+ WBV2	0.65	<0.001*	0.5	0.13	0.145	1	0.28	0.45	-	-
Eyes-Closed	**(AP)**	Heat	-	-	0.55	0. 01*	0.71	0.01*	-0.51	0. 01*	-1.24	<0.001*
		WBV1	0.55	0.01	-	-	0.158	0.14	0.37	0.71	-0.69	<0.001*
		WBV2	0.71	0.001	0.158	0.14	-	-	0.195	0.25	-0.53	<0.001*
		Heat+ WBV1	0.516	0.012	-0.03	0.71	-0.195	0.255	-	-	-0.73	<0.001*
		heat+ WBV2	1.24	<0.001*	0.69	<0.001*	0.53	<0.001*	0.73	<0.001*	-	-
	(ML)	Heat	-	-	-0.26	1	-0.616	0.06	0.247	0.44	-0.83	0.01
		WBV1	0.26	1	-	-	-0.34	0.48	-0.36	1.62	-0.56	0.21
		WBV2	-0.616	0.006	0.34	0.48	-	-	0.24	0.44	-0.217	0.92
		Heat+ WBV1	0.369	0.62	0.1	1	-0.24	0.117	-	-	-0.46	0.11
		Heat+ WBV2	0.88	<0.001*	0.56	0.21	0.21	0.92	0.46	0.11	-	-

*Δ Mean: The difference between COP in different directions before and after each exposure condition; *: indicates statistically significant differences.*
WBV: whole body vibration (at two acceleration levels; WBV1: 0.5 m/s^2 and WBV2:1 m/s^2).

Table 5. The significant mean differences of handgrip strength in all exposure conditions.

Exposure conditions	Mean±Std.	Sig.	Effect size
Heat	1.83±2.42	0.08	0.004
WBV_1	0.76±2.23	0.137	0.00
WBV_2	2.73±2.09	<0.001*	0.012
Heat+ WBV_1	2.13±1.75	<0.001*	0.008
Heat+ WBV_2	3.3±2.11	<0.001*	0.019

*Mean: The difference between COP in different directions before and after each exposure condition; *: indicates statistically significant WBV: whole body vibration (at two acceleration levels; WBV1: 0.5 m/s² and WBV2:1 m/s²).*

Table 6. The significant mean differences of perceived fatigue in all exposure conditions.

Exposure conditions	Mean± Std.	Sig.	Effect Size
Heat	2.97±.77	<0.001*	0.31
WBV_1	1.4±1.38	<0.001*	0.21
WBV_2	4.4±.99	<0.001*	0.55
Heat+ WBV_1	4.16±.80	<0.001*	0.73
Heat+ WBV_2	6.17±1.27	<0.001*	0.98

*Mean: The difference between COP in different directions before and after each exposure condition; *: indicates statistically significant WBV: whole body vibration (at two acceleration levels; WBV1: 0.5 m/s² and WBV2:1 m/s²).*

drivers. The mechanical vibration transmitted from car seat to drivers must be reduced using preventive maintenance as much as possible. Instructing drivers regarding adverse health effects of environmental factors while driving is also necessary.

5. CONCLUSION

It is confirmed that the separate exposure of drivers to vibration have main effect and the separate exposure to heat have crossed effect on driver's postural equilibrium. The heat exposure alone cannot lead to remarkable effects on the balance responses; however, it can increase the effect of vibration on the balance. The combined effects of exposure to heat and vibration represented synergist interactions on balance or equilibrium, as an essential functional skill of drivers. The separate effect of exposure to heat is not significant on grip strength, however, the effect of vibration on grip strength was aggravated during simultaneous exposure to heat. The findings also represented that the separate effect size of exposure to heat on drivers' 'erceived fatigue was very considerable at the domain of the studied scenarios. It is recommended that future studies focus on the validation of this experimental design in field.

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REFERENCES

1. Duarte MLM, de Melo GC. Influence of pavement type and speed on whole body vibration (WBV) levels measured on passenger vehicles. *J Braz Soc Mech Sci Eng.* 2018;40(3):1-12.
2. Nassiri P, Koohpaei A, Zeraati H, Shalkouhi PJ. Train passengers comfort with regard to whole-body vibration. *J Low Freq Noise V A.* 2011;30(2):125-36.

3. Shi W, Li M, Guo J, Zhai K. Evaluation of road service performance based on human perception of vibration while driving vehicle. *J Adv Transp*. 2020. Doi: https://doi.org/10.1155/2020/8825355
4. Mani R, Milosavljevic S, Sullivan SJ. The effect of occupational whole-body vibration on standing balance: A systematic review. *Int J Ind Ergon.* 2010;40(6):698-709.
5. Raffler N, Rissler J, Ellegast R, Schikowsky C, Kraus T, Ochsmann E. Combined exposures of whole-body vibration and awkward posture: a cross sectional investigation among occupational drivers by means of simultaneous field measurements. *Ergonomics*. 2017; 60(11):1564-75.
6. Bovenzi M, Schust M, Mauro M. An overview of low back pain and occupational exposures to whole-body vibration and mechanical shocks. *Med Lav*. 2017;14;108(6):419-433.
7. Savage R, Billing D, Furnell A, Netto K, Aisbett B. Whole-body vibration and occupational physical performance: a review. *Int Arch Occup Environ Health*. 2016;89(2):181-97.
8. Lord SR, Clark RD, Webster IW. Postural stability and associated physiological factors in a population of aged persons. *J Gerontol*. 1991;46(3):M69-M76.
9. Johansson R, Magnusson M. Human postural dynamics. *Crit Rev Biomed Eng*. 1991;18(6):413-37.
10. Vouriot A, Gauchard GC, Chau N, et al. Sensorial organisation favouring higher visual contribution is a risk factor of falls in an occupational setting. *Neurosci Res*. 2004;48(3):239-47.
11. Cornelius KM, Redfern MS, Steiner LJ. Postural stability after whole-body vibration exposure. *Int J Ind Ergon*. 1994;13(4):343-51.
12. Pollard J, Porter W, Mayton A, Xu X, Weston E. The effect of vibration exposure during haul truck operation on grip strength, touch sensation, and balance. *Int J Ind Ergon*. 2017;57:23-31.
13. Prieto TE, Myklebust JB, Hoffmann RG, Lovett EG, Myklebust BM. Measures of postural steadiness: differences between healthy young and elderly adults. *IEEE Trans Biomed Eng*. 1996;43(9):956-66.
14. Widia M, Dawal SZ. The Effect of Vibration on Muscle Activity and Grip Strength Using an Electric Drill. *Adv Electron Forum*. 2013;10:318-323.
15. Makowiec-Dąbrowska T, Gadzicka E, Jadwiga Siedlecka, et al. Climate conditions and work-related fatigue among professional drivers. *Int J Biometeorol*. 2019;63(2):121-8.
16. Spaul W, Spear R, Greenleaf J. Thermoregulatory responses to heat and vibration in men. *Aviat Space Environ Med*. 1986;57(11):1082-7.
17. Kjellstrom T, Freyberg C, Lemke B, Otto M, Briggs D. Estimating population heat exposure and impacts on working people in conjunction with climate change. *Int J Biometeorol*. 2018;62(3):291-306.
18. Troxel WM, Helmus TC, Tsang F, Price CC. Evaluating the impact of Whole-Body Vibration (WBV) on fatigue and the implications for driver safety. *Rand Health Q*. 2016;5(4):10-20.
19. Fujii H, Fukuda S, Narumi D, Ihara T, Watanabe Y. Fatigue and sleep under large summer temperature differences. *Environ Res*. 2015;138:17-21.
20. Son SY, Tokizawa K, Yasuda A, Sawada CI. Physiological responses and balance ability are affected by physical workload and heat exposure in workers. *Extreme Physiol Med*. 2015;4:25-29.
21. Bohannon RW. Muscle strength: clinical and prognostic value of handgrip dynamometry. *Curr Opin Clin Nutr Metab Care*. 2015;18(5):465-70.
22. Mansfield N. Vibration and shock in vehicles: new challenges, new methods, new solutions. 1st International Comfort Congress, Salerno, Italy, 7-8 June 2017.
23. Zeng X, Kociolek AM, Khan MI, Milosavljevic S, Bath B, Trask C. Whole body vibration exposure patterns in Canadian prairie farmers. *Ergonomics*. 2017; 60(8):1064-73.
24. Lê T-T, Kapoula Z. Role of ocular convergence in the Romberg quotient. *Gait Posture*. 2008;27(3):493-500.
25. Ramlagan S, Peltzer K, Phaswana-Mafuya N. Hand grip strength and associated factors in non-institutionalised men and women 50 years and older in South Africa. *BMC Res Notes*. 2014;7(1):8.
26. Thuresson M, Äng B, Linder J, Harms-Ringdahl K. Intra-rater reliability of electromyographic recordings and subjective evaluation of neck muscle fatigue among helicopter pilots. *J Electromyogr Kinesiol*. 2005; 15(3):323-31.
27. Borg G. An introduction to Borg's RPE-scale: Mouvement Publications; 1985.
28. Borg E. On perceived exertion and its measurement: Psykologiska institutionen; 2007.
29. Lu SY, Liu CC, Lee CL, Lin YH. Vertical vibration frequency and sitting posture effects on muscular loads and body balance. *Int J Ind Ergon.* 2019;74:102860.
30. Ahuja S, Davis J, Wade LR, editors. Postural stability of commercial truck drivers: Impact of extended durations of whole-body vibration. *Proc Hum Factors Ergon Soc Annu Meet.* 2005: SAGE Publications Sage CA: Los Angeles, CA.
31. Le Clair K, Riach C. Postural stability measures: what to measure and for how long. *Clin Biomech*. 1996;11(3):176-8.
32. Yung M, Tennant LM, Milosavljevic S, Trask C. The multisystem effects of simulated agricultural whole body vibration on acute sensorimotor, physical, and cognitive performance. *Ann Work Expo Health*. 2018;62(7):884-98.
33. Golhosseini SMJ, Aliabadi M, Golmohammadi R, al. Combined effects of exposure to noise and vibration on human postural equilibrium under simulated driving conditions. *Sound Vib*. 2022;56(1):37-49.
34. Niazmand-Aghdam N, Ranjbarian M, Khodakarim S, Mohammadian F, Dehghan SF. The effects of

combined exposure to road traffic noise and whole body vibration on types of attention among men. *Med Lav*. 2021;112(5):360.
35. Black A, Wood J. Vision and falls. *Clin Exp Optom*. 2005;88(4):212-22.
36. Ferreira-Souza L, Gama M, Coelho-Oliveira A, Sá-Caputo D, Bernardo-Filho M. Could Whole-body vibration lead the professional drivers to fatigue? A Narrative Review. *Ergonomics*. 2021;11:272.
37. Little MA, Johnson Jr BR. Grip strength, muscle fatigue, and body composition in nomadic Turkana pastoralists. *Am J Phys Anthropol.* 1986;69(3):335-44.
38. Albert G, Lotan T, Weiss P, Shiftan Y. The challenge of safe driving among elderly drivers. *Healthc Technol Lett*. 2018;5(1):45-8.