HSE IJ

Iranian Journal of Health, Safety & Environment, Vol.6, No.1, pp.1198-1205

Whole-Body Vibration Exposure Study in Intercity Mini-Bus Drivers-The Risk of Musculoskeletal Disorders

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Received: 12 Agu. 2017, Revised: 11 Feb. 2018, Accepted:18 May 2018

ABSTRACT

Exposure to Whole Body Vibration (WBV) is one of the most important risk factors for musculoskeletal disorders (MSDs), which drivers are likely to report non-specific health complaints. The purpose of this study was to investigate the association between whole body vibrations with musculoskeletal disorders among intercity mini-buses drivers.
80 intercity mini-bus drivers were participated in this study. The values of the frequency-weighted Root Mean Square (RMS), Vibration Dose Values (VDV) and Crest Factor (CF) was measured using the SVAN-958 and the SV39A/L accelerometer, in accordance with ISO 2631-1. ANOVA, Post-hoc analysis, and correlation tests were used to analyze the obtained data using SPSS 23.
This study show that the overall equivalent acceleration $A_{eq}(T)$ difference in various studied models of minibuses was significant (P<0.01), so that the mini-buses model 2011 have the lowest acceleration (0.88 m/s^2), whereas the 2009 model have the highest value (0.96 m/s^2). POST hoc analysis and Bonferroni method show that there was a significant difference between three models of the mini-buses (P<0.01-F=4.90). Also, there was a significant correlation between pain in different areas of the body with values of exposure daily vibration, expressed in terms of 8-h, respectively (P<0.001).
There was sufficient evidence to prove the relationships of whole body vibration with MSDs. In addition, the lifetime of minibuses production is introduced as one of the effective factors in transmitting vibration to drivers.

Key words: Upper Extremity, Musculoskeletal Disorders, Mini-Bus, Overall Equivalent Acceleration, Vibration Dose Value, Crest Factor

INTRODUCTON

Work-related musculoskeletal disorders (WRMSDs) due to the work environment is defined as poor and inappropriate functioning of joints, muscles, tendons, nerves and bones which can be induced by deficient and non-ergonomic postures, repetitive tasks, environmental factors, contact stress, etc.[1,3]. As a result of these disorders, absence of work is increased which give a rise to the financial expenditure of employers [4].

Increasing human dependency on the car for work and recreation and increasing the sitting time during driving is highly correlated with high risk of low back pain and absenteeism [5]. As a result, musculoskeletal disorders among public-vehicles drivers has become very common and drivers come across with higher prevalence of these disorders than other occupational groups [6]. The most common musculoskeletal discomfort in drivers is low back pain (7). Long-term sit-ups of drivers alone are not related to the risk of low back pain, but despite of factors such as vibration and inappropriate postures, the risk of back pain has been increased fourfold [8]. Vibration in vehicles, especially buses and urbane transport vehicles, is considered as one of the most important factors in the development of diseases and musculoskeletal disorders [9,10]. The whole body vibration can be transmitted from various contact points such as seats siting area and seats back to the body of drivers and passengers. The transmitted vibrational energy to the body can affect the comfort of the vehicle's driver and lead to musculoskeletal and hygienic disorders [11–13]. The back pain and hernia of inter-vertebral disc are the major consequences of whole-body vibration that bus drivers exposed throughout driving [14-16]. In addition to musculoskeletal disorders, body-transmitted vibration leads to central nervous system impairment and effects adversely the blood circulation and urine, blurred vision, reduces attention and concentration, and damages the auditory system (17,18).

The amount of damages caused by vibration in the body depend on the amplitude, speed, acceleration, and energy of transmitted vibration through the body [19,20]. Vibration at frequencies below 0.5 HZ can lead to motion impairment, nausea, vomiting and pale [21,22]. Also, it is demonstrated that in vibrations up to 12 Hz frequency, the incidence of local and temporary diseases is evident, while in vibrations ranging from 2 to 20 Hz at acceleration of $1\ {}^{m}/_{s^2}$ subjects experience a variety of complications such as dizziness, inability to perform manual and skillful activities and imbalances [23,24].

Finally, drivers suffering from musculoskeletal disorders not only lose their performance, but also may face with an early retirement or abandonment of experienced staff and impose heavy burdens on society. The present study was conducted to evaluate the level of exposure to whole body vibration and determine the prevalence musculoskeletal disorders in the intercity minibus drivers of Tehran-Bumehen road.

MATERIALS AND METHODS

In this descriptive study, 80 drivers of Hyundai Cruise Mini-Buses in the Tehran-Bumehen road were selected. The number of tested samples from the previous studies (which the mean and standard deviations of the overall acceleration on buses were reported to be 0.73 and 0.11 m/s², respectively) is considered as follows (p=0.05)[25]:

$$n = \frac{(z_{1-\alpha/2} + z_{1-\beta})^2 \times s^2}{d^2} \qquad (1)$$

Following criteria were excluded from the study including fresh fractures, all types of diseases related to gallstones and kidney stones, and acute back pain. All participants gave written informed consent to participate in this study. The study was approved by the Human Ethics Committee of the university according to the Declaration of Helsinki. The selected minibuses are categorized based on the year of construction in three models (2009-2010-2011).

In order to increase the accuracy and eliminate the interfering factors, the test was conducted in the Tehran-Bumehen road with normal traffic load and geographic conditions, while the buses included standard number of passengers. The total travel time on this road was achieved about 55±5 minutes. Also, before starting the test and measuring the vibration, the apparent appearance of the vehicle's tires and its outer surface, the standard height and width of tires and their pressure were examined based on the tire and apparent apparatus inspection standards [26,2**7]**. All selected minibuses had a rim and rubber size of 16 and a width of 716 mm.

Whole-body vibration self-administered questionnaire

An initial assessment of the risk factors caused by whole body vibration was performed in the participated subjects, using self-reported questionnaire [28]. The questionnaire consisted of 4 sections (individual profile, work experience, medical history and symptoms of musculoskeletal disorders and diseases in other parts of the body), each of which examines the symptoms of musculoskeletal disorders and diseases caused by vibration in various parts of the body. In the third section of the questionnaire, the subjects are evaluated for the presence of musculoskeletal disorders such as pain in the lower back, neck and shoulders in the course of last 7 days and 12 months. In the fourth section, the presence of diseases in different parts of the body was recorded.

Vibration measurement and daily exposure to vibration

The SVAN958 was used to measure the entire body's vibration, whereas the SV39 A/L accelerometer model of SVANTEK Company with nominal sensitivity of $10\ {}^{mv}/_{ms^2}$ were used for acceleration measurement [22,29]. The values of the frequency-weighted Root Mean Square (RMS) acceleration of vibration, Vibration Dose Values (VDV) and Crest Factor (CF) are measured in accordance with ISO 2631 in three directions x, y and z, by placing the accelerometer in the center of seat siting area under the standard conditions. Measuring the whole body vibration in these mini-buses was carried out during the working hours of the day and at different times of the week. Also according to the recommended standards, the minimum measurement time in this study was considered 20 minutes [30,31].

The primary index for evaluating vibration is the root mean square (RMS) or overall effective acceleration. But in some situations, for example, when the crest factor (CF)[1] is greater than 9, the evaluation of human response to vibration using the frequency-weighted RMS acceleration of vibration ($a_{w,rms}$) is not enough and human health can be significantly affected by

[1] **Crest factor (CF)** is defined as the ratio of peak value to rms value of a current waveform.

crest factor. Therefore, the evaluation using the root mean square acceleration method may result in less health risk calculation than in reality. In such a situation, the use of a vibration dose value (VDV) indicator is recommended to provide a healthy range based on the vibration dose rate indicator. Exposure limits for health effects provided by this standard provide a precautionary approach to the chart in which at its higher "risk area and probable health effects" and at the lower part, there is a situation where health effects are not specifically observed. $a_{wr.m.s}$, $VDV\left({}^{m}/_{s^{1.75}}\right)$ and CF can be expressed respectively:

$$a_{wr.m.s} = \sqrt{\frac{1}{T}\int_0^T a_w^2(t)dt} \qquad (1)$$

$$VDV\left({}^{m}/_{s^{1.75}}\right) = \sqrt[4]{\int_0^T [a_w(t)]^4\, dt} \qquad (2)$$

$$CF = \frac{a_w(t)_{max}}{a_{w,rms}} \qquad (3)$$

Where, $a_{w,rms}$ is the frequency-weighted RMS acceleration of vibration, T is the time measurement, $a_w(t)$ is the frequency-weighted acceleration of vibration at time t and $VDV$is the vibration dose value.

The total equivalent acceleration ($A_{eq}(T)$) is calculated by combing the frequency distributed RMS accelerations through x, y, and z axis (a_x، a_y، a_z) as follows:

$$A_{eq}(T) = \sqrt{(1.4\, a_x)^2 + \left(1.4\, a_y\right)^2 + (a_z)^2} \qquad (4)$$

In ISO 2631-1 standard [29], knowing the sampling time and the corresponding values, it is possible to obtain the required driving time to reach the upper and lower limits of the health warning area by the following equations:

$$t_{(s)} = \frac{(17)^4 \times (T_m)}{(VDV)^4} \qquad (5\}$$

$$t_{(s)} = \frac{(8.5)^4 \times (T_m)}{(VDV)^4} \qquad (6)$$

In this equations, $t_{(s)}$ **is** driving time per second to reach the upper limit of the vibration dose $17{}^{m}/_{s^{1.75}}$, in which the maximum health damage caused by the whole body vibration occurs at this level. Whereas, the lower limit of the health alert zone (the entire body vibration allowed limit) occurs at $8.5{}^{m}/_{s^{1.75}}$. Also, *VDV* is vibration dose value (${}^{m}/_{s^{1.75}}$) **and** T_m **is** the measured time in seconds.

Data analysis

The obtained data were analyzed using SPSS 23 software. Descriptive statistics (i.e., mean, standard deviation, minimum and maximum) for the measured data were calculated. ANOVA test was used to determine the difference of the overall equivalent acceleration between different models of the mini-buses. In addition, to determine which models were different from each other, POST hoc analysis and Bonferroni method were used. Pearson and Spearman correlation tests were used to specify the relationship between WMSDs with driver's transmitted vibration. The significant required level for tests was considered 95%.

RESULTS

Totally, 80 drivers from the intercity minibuses on the Tehran-Bumehen road were participated in this study. The mean and standard deviation (M±SD) for age, height and weight of drivers were 42.8±8.88 years, 1.74±0.17 meters and 81.6±14.8 kg, respectively. The history of driving in the public transport section for participants was 15.9±8.89 years. 49 of drivers (61.3%) had a BMI greater than 25, which can be interpreted as they were over weighted. The level of education among the drivers of the studied minibuses was at three levels of: 36 primaries (45%), 15 diplomas (18.55%) and 29 university educated (36.25%). In addition, 63 (78.75%) and 17 (21.25%) of participants were married and single, respectively. Meanwhile, 58 of participants (72.5%) were smoking.

The frequency of prevalence of musculoskeletal disorders over the past 12 months for the right, left and both sides of the body organs of the drivers (elbow, hand/wrist, hips, knees and feet) is presented in Fig. 1. Also, 52 out of 80 drivers (65%) surveyed in this study were felt pain from lower back area. This is the most common symptom of pain among the organs of drivers.

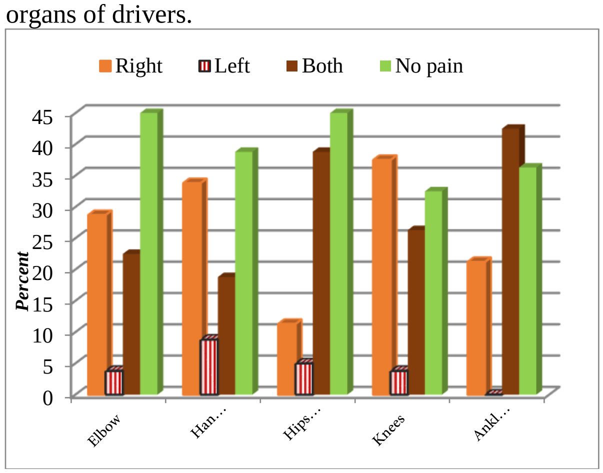

Fig. 1: Prevalence of reported WRMSD in mini-bus drivers.

As shown in Table 1, Pain in the lower back, neck and upper back/shoulders was the main reasons for absenteeism of drivers during the last 12 months, respectively.

The results of the measurement values of the frequency weighted accelerated RMS for each axis and the overall equivalent acceleration in the studied mini-buses (models 2009, 2010, and 2011) are shown in Table 2. According to these data, the overall vibrational equivalent acceleration in the studied mini-buses undergoes a downward trend, so that the mini-buses model 2011 have the lowest acceleration (0.88 m/s^2), whereas the 2009 model have the highest value (0.96 m/s^2).

On the other hand, ANOVA test used to compare the overall equivalent acceleration difference between various mini-buses. The results showed that the overall acceleration difference in various studied models of minibuses was significant (P<0.01). POST hoc analysis and Bonferroni method were used to find out which mini-buses had a significant difference, where it was found that there was a significant difference between different models of the minibuses (P<0.01-F=4.90).

Table 1: The prevalence of musculoskeletal disorders in the past 7 days and the percentage of people who have lost their jobs and work-related activities due to musculoskeletal disorders in the last 12 months, among minibus drivers.

Body organs	The prevalence of musculoskeletal disorders in the last 7 days (%)	Percentage of survivors of work and daily activities in the last 12 months (%)
Elbow	11.75	1.25
Neck	36.25	13.75
Shoulders	30.50	12.50
Hand/wrist	12.50	--
Hips/thighs	27.50	3.75
Upper back	37.45	13.25
Lower back	47.75	16.25
Knee	29.25	8.75
Leg	28.25	2.50

The results of Vibration Dose Values (VDV) and Crest Factor CF values are presented in Tables 3 and 4, respectively. As shown in these tables, VDV and CF values are decreased. In other words, the vibration peak increases significantly with an increase in the year of construction (car life) and produces more impact vibration and ultimately results in more damage to the organs of the body due to the vibration wave.

Table 2: RMS and total equivalent acceleration in mini-buses drivers.

Model	N	RMS and the overall equivalent acceleration						$A_{eq}(T)$ (m/s^2)
		X		Y		Z		
		M±SD	Min-Max	M±SD	Min-Max	M±SD	Min-Max	
2009	34	0.38±0.03	0.37-0.41	0.35±0.06	0.31-0.40	0.63±0.07	0.57-0.68	0.92
2010	28	0.33±0.02	0.30-0.36	0.27±0.04	0.25-0.31	0.59±0.04	0.49-0.64	0.87
2011	18	0.27±0.05	0.22-0.29	0.25±0.05	0.20-0.31	0.57±0.05	0.49-0.62	0.72

Table 3: The whole body vibration dose rate in each axis among mini-buses drivers.

Model	N	Vibration dose rate on each axis (VDV) $(m/s^{1.75})$					
		X		Y		Z	
		M±SD	Min-Max	M±SD	Min-Max	M±SD	Min-Max
2009	34	4.80±0.55	4.31-5.41	4.70±0.70	3.80-5.88	8.10±0.25	7.65-8.45
2010	28	4.65±0.65	3.30-5.81	4.03±0.60	3.29-5.19	7.85±0.70	6.12-8.19
2011	18	3.96±0.90	2.80-4.75	4.04±0.40	3.67-4.35	6.75±0.55	5.29-7.47

Table 4: Crest factor (CF) in mini-buses drivers.

Model	N	Crest factor in each axis (dimensionless)					
		X		Y		Z	
		M±SD	Min-Max	M±SD	Min-Max	M±SD	Min-Max
2009	34	8.45±0.60	7.72-8.90	8.08±0.73	7.70-9.30	8.32±0.40	8.03-8.65
2010	28	8.85±0.70	8.42-9.65	8.25±0.68	7.29-8.81	8.85±0.70	7.85-9.00
2011	18	7.45±0.90	6.70-8.05	8.14±0.56	7.91-9.19	7.56±0.50	7.11-8.19

In addition to 8 hours of work, the drivers of Tehran-Bumehen minibuses typically had an extra 2-3 hours of daily work and the rest time of the drivers were low and about 1 hour in an intermittent between driving hours. Comparison of the values of A_{eq}(T) between the studied mini-buses and the exposure action value (EAV), which has been set to 0.5 m/s^2 for 8 hours of work in accordance with the EU Physical Factor construction (Vibration), indicates that the 8-hour exposure of drivers in all minibuses are much more than it was expected to be.

Among the studied drivers, there was a significant relationship between age and pain in the elbow, arm/wrist, waist, hip/thigh and leg/ankles, as well as between the driving record in the transport sector with elbow pain, hand/wrist and upper back limb (p<0/05). However, no significant correlation between age with knee pain and also between work record with pain in hip/tight, knee and leg/ankle is observed. Also, among all drivers of the studied mini-buses, there was no significant relationship between the pain of various organs of the body with regular exercise, smoking, education and marriage (p≥0.05). Also, there was no significant correlation between body mass index (BMI) and pain in different organs of the drivers' body (p≥0.05).

Pearson correlation and Spearman tests showed a significant correlation between pain in different areas of the body with transmitted vibration to the drivers. Among various organs, pain in the lower back, upper lumbar/shoulders and neck region had the most significant correlation with vibration (Table 5).

Table 5: Association between WRMSD and equivalent vibration magnitude (m/s^2) in previous 12 months.

variable	Equivalent vibration magnitude (RMS acceleration)	
	Correlation coefficient	P-value
Elbow	0.23	0.033
Neck	0.56	.0001*
Upper back/shoulders	0.57	.0001*
Hand/wrist	0.24	0.029
Hips/thighs	0.47	.0001*
Lower back	0.67	.0001*
Knees	0.48	.0001*
Ankles/feet	0.29	0.038

Significance *P≤0.001

DISCUSSION

In this study, the values of frequency weighted Root Mean Square (RMS) accelerations in each axis and A_{eq} (T) with Caution Health Zone based on the ISO-2631 standard is determined and compared in order to obtain the allowable range of exposure to the whole body vibration [30]. This study demonstrated that the frequency weighted RMS accelerations in X and Y axes are below the health alert zone (a_{rms} <0.46) in all three mini-buses, while in the Z axis, which is accountable for the maximum value for RMS acceleration, the frequency weighted RMS acceleration is within the health alert area ($0.46 < a_{rms} < 0.93$) (Table 2). Since the health effects are not clearly documented or objectively reported for the contacts in the warning sub-zone, as well as the fact that to this day the threshold has not been considered as effective for contact with vibration, therefore contact with vibration in the health alert area must not be considered as a riskless (31,32). Contact with whole body vibration in the area of health warning can create potential health risks that should be addressed to these risks and safety and occupational health measurements must be taken into account to prevent harmful health effects on drivers [34,35].

By comparing the A_{eq} (T) values with the health alert area, it can be stated that in the 2009 mini-bus models, exposure to whole body vibration was higher than the health alert area (A_{eq} $(T) > 0.93$), which poses a health hazard for likely drivers in this area, while is located in the health alert area ($0.46 < a_{RMS} < 0.93$) for the models 2010 and 2011 (Refer to table 2). These findings are consistent with the results of the previous studies which investigated the exposure of drivers to vibration and the presence of physical stress in drivers (36,37). In a study titled "work conditions and health conditions of drivers", it was found that the average level of vibration of the whole body of drivers on the highways and smooth and rugged roads was not higher than the limit value, which was in contradiction with findings of present study (38). Many studies have shown that prolonged exposure to vibration can increase the risk of occupational health (39,40). Considering that the 8-hour exposure of drivers in all mini-buses is more than practical, and since in the calculation of Vibration dose values (VDV) over time, shocks and vibration impacts are of great importance, then the amount of Vibration dose values (VDV) can be considered as the best criterion for assessing the driver's comfort [41].

In many studies, the longevity and type of vehicle (position of the motor) are two major factors in the generation of sound and vibration. Considering that all the mini-buses of this study were of the same type, the lifetime of the mini-buses was obtained as one of the most influential variables at the transmitted vibration to body of drivers. So that, with an increase in the life of the mini-buses, the amount of vibration increases which is in agreement with the previous studies performed to compare the value of whole body vibration in drivers of old and new similar trucks [42].

Among the various organs of the body, pain and discomfort in the lower back, upper back/shoulders and neck had the highest correlation coefficient with vibration (P≤0.001). The results were consistent with the findings of other studies associated with vibration and WRMSDs correlation. In many of these studies, there was a significant relationship between vibration and pain in the regions of the lower back, neck and shoulders [43–45].

Therefore, due to a higher driving time than the lower boundary of the health alert zone (which is the initial limit for harmful effects on health), there is a need to pay attention in changing the daily schedule of drivers to reduce their exposure to vibration and increase the rest time which can be used effectively to reduce the harmful effects of health. On the other hand, the lack of attention to the issue of periodic inspections and repair of mini-buses, the use of worn-out and low-quality replacement parts, lack of timely adjustment of the engine and its inappropriate performance, and ignoring the situation of vehicle insulations can increase the transmitted vibration to the driver and passengers, periodically, which will eventually lead to an increase in the health and safety hazards.

CONCLUSIONS

This study showed that inter-city bus drivers are subjected to various risk factors which develop the work-related musculoskeletal disorders (MSDs). To reduce the health effects of vibration on drivers and passengers, ergonomic examinations, driver training for proper seat adjustment, occupational safety and occupational safety management using the engineering tools, and reducing the daily working hours of drivers to maintain their health and safety must be taken into account.

Various factors such as lack of attention to seat features, prolonged sitting and psychological characteristics (such as stress, anxiety, and fatigue) were the limitations of this study. In addition, the study did not record the load intensity of each manual lifting performed by the mini-bus drivers, which can limit the understanding relationship between the manual lifting and risk of MSDs.

ETHICAL ISSUES

Ethical issues such as plagiarism have been observed by the authors. Also, this study was approved by the regional ethical committee, Iran University of Medical Sciences, Tehran, Iran.

CONFLICT OF INTEREST

The Authors declare no conflicts of interest concerning this article.

AUTHORS' CONTRIBUTION

In this article Shahram Vosoughi was the supervisor and the corresponding author. Other authors' equally help to collect and analyze the data as well as to write this article.

FUNDING/SUPPORTS

This work is financially supported by the occupational health research center, Iran University of Medical Sciences (Code Project: 29648; 2017/4/4).

ACKNOWLEDEMENT

The authors are grateful for all supports of occupational health research center, Iran University of Medical Sciences, Tehran, Iran.

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