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ORIGINAL ARTICLE

The Impact of Ergonomic Interventions on the Whole Body Vibration of Mining Machinery Drivers in Sarcheshmeh Copper Complex

SAEED GHANEH[1*], YASER SAHRANAVARD[2], MASOUMEH KARAMI[3], ZOHREH KARAMI[4]

[1] *Ph.D. Student in Ergonomics, Department of Occupational Health Engineering, School of Public Health, Tehran University of Medical Sciences, Tehran, Iran. Tehran, Enghelab Square, Poursina Street, School of Public Health, second floor, Department of Occupational Health Engineering, Postal code: 8915173160, Tel: 09127035993, Fax: 02166462267;*

[2] *M.Sc. Student in Occupational Health Engineering, Department of Occupational Health Engineering, International Campus, Shahid Sadoughi University of Medical Sciences, Yazd, Iran;*

[3] *M.Sc. Student in Ergonomics, Department of Ergonomics, School of Public Health, Shahid Sadoughi University of Medical Sciences, Yazd, Iran;*

[4] *Department of Occupational Therapy, School of Rehabilitation Sciences, Shiraz University of Medical Sciences, Shiraz, Iran*

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ABSTRACT

The existence of mechanical vibrations inside and around the industrial machinery and the constant exposure of the operators to these vibrations, increase the risk of musculoskeletal disorders in the operators and gradually affect their general health. The research is an attempt to investigate the effects of ergonomic interventions on the whole body vibration (WBV) of heavy machinery drivers in Sarcheshmeh Copper Complex in southern Iran. To evaluate the drivers' exposure to WBV, a total number of 25 drivers, out of 45 drivers working in the complex, were selected. The vibration level was measured for each operator before and after the intervention using Bruel & Kjaer 4447 HAVS – Hand-Arm and Whole Body Vibration Meter. The measurements were conducted simultaneously in three axes (X, Y, and Z) in accordance with ISO 2631-1:1997. The obtained results were compared with the occupational exposure limits, recommended by the Iranian the Ministry of Health and Medical Education (MoHME) of Iran, as a national standard. The data analysis was done by the independent t-test in SPSS software version 19. The obtained results revealed that prior to the intervention; the highest exposure to WBV was in the z axis, which was the main axis of vibration entry into the drivers' body. The results also showed that the equivalent acceleration of all vehicles exceeded the permissible limits (0.65 m/s2). The mean and maximum exposure levels were 0.66 and 0.56 m/s2 before the interventions and 0.88 and 0.63m/s2 after the interventions, which were significantly different ($P<0.001$). The application of engineering and administrative interventions, such as seat replacement, modification of the suspension system, work pace control, and training the operators to properly control the vehicle, can play a meaningful role in reducing the exposure to the vibration from heavy mining machinery.

KEYWORDS: *Whole-body vibration, Mining machines, Ergonomics, Intervention*

INTRODUCTION

Vibration is considered to be one of the physical stresses of workplaces and is present in many industries, machines, equipment, and tools. The negative effects of vibrations have recently kept an uptrend due to the industrialization and

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**** Corresponding Author: Saeed Ghaneh***
Email: saeedghaneh@yahoo.com

increasing production growth, and its impact is reflected in production quality, labor efficiency, productivity, employees' health, and comfort. Therefore, attempts should make to avoid exposure to these undesirable vibrations as much as possible. Human beings in their daily life are somehow exposed to vibrations, which is inevitable. The effect of mechanical vibrations on the human body is called human vibrations, which is investigated from two aspects of whole-body vibration (WBV) and hand-arm vibration. The WBV is transmitted through the surface to all parts of the body (e.g., legs, seat, and back). For instance, a person, who drives a vehicle, is exposed to the WBV through the seat and backrest. Exposure to the WBV can cause permanent physical or nervous system injuries [1].

Health damage may include back pain, spinal cord injuries, damage to the central nervous system, circulatory and urinary systems [2, 3]. Having contact with WBV even for at least half of the working hours may lead to a higher prevalence of musculoskeletal disorders among the workers [4, 5]. Ergonomic risk factors of human vibration could be external and/or individual. The external factors are vibration frequency, acceleration, arrival, vibration arrival area, exposure time, and work experience. The individual factors are body posture, tensile strength, and individual and inherent characteristics. To control these ergonomic risk factors, an ergonomic intervention should be done with respect to the priority of control measures.

Among the engineering controls can be pointed to the vibration damping at source, proper maintenance of equipment, timely repairs, insulation and isolation, and change and replacement of the parts of devices and machines. When engineering controls are not available due to the high costs or lack of required technologies, it is necessary to switch to another control programs, such as changing cabins or isolating the chamber with absorbents", supervision on the purchase of suitable equipment and avoiding the purchase of equipment with non-standard vibration, selecting the right manpower, reducing staff exposure, improving the machinery cabin workstation, and improving job postures, rotating jobs, performing properly the occupational examinations, and using appropriate personal protective equipment such as shoes and gloves [6]. Barkhordari et al. (2008), in a study on the personnel of Gol Gohar Mine (in Sirjan County, southern Iran), found the highest vibration levels in the grader cars (2.179 m/s2) and the backhoe loaders (1.738 m/s2), respectively. Drill cars with an acceleration of 0.479 m/s2 had the lowest total body-mass acceleration among all models, and the vibration in most of the heavy-duty cars was much higher than the permissible limits and even higher than the levels of care. This revealed the need for the corrective measures, such as implementing suspension systems, correcting seat position, and management controls [7]. Ismell et al. (2010) conducted a study on train passengers and reported that the daily exposure to vibration and the level of vibration dose were 0.3749 and 1.2513 m/s2, respectively. In addition, when the subject is exposed to vibration and passengers' journeys increase, the WBV absorbed by the human body will also increase [8]. Nasiri et al. in a study on the drivers of Tehran and Suburbs Bus Company concluded that the total acceleration values in the Ikarus buses (0.78 m/s2) was more than Shahab buses (0.71 m/s2) and both were more than MAN buses (0.70 m/s2), which exceeded the drivers' daily exposure permissible limit. The results showed that the type (place of its engine and type of vibration isolation) and the age of the buses are two factors affecting the amount of the vibration transmitted to the drivers [9].

In a study by Maleki et al. on tractor drivers, it was shown that the average values of acceleration vectors on the tractors and the drivers' body was significantly different ($p<0.001$) so that with the increase of the driver's mass, the average acceleration vector on his body declined. For example, the driver with a mass of 55 Kg had the highest average acceleration (9.8 m/s2) and the driver with a mass of 100 Kg had the lowest average acceleration (3.3 m/s2). After comparing the acceleration average values on the body of different drivers with the international standards, the level of comfort of the drivers, who drove with JDI model 3140 and the Universal model 651 tractors, was assessed to be extremely disturbing [10]. According to a study by Goglia Waldo et al. (2006), the vibration levels in all working conditions of tractor drivers in X and Y directions were much higher than Z-direction [11]. People who drive for more than half of their working hours suffer from lumbar problems three times more than the non-driver population [12].

Spinal disorders in professional drivers are due to psychological, physical and ergonomic stressors [13, 14]. The vibration is a physical stressor and lumbar damage and other musculoskeletal disorders in the shoulder and neck can result from the vibration transmitted from the driver's seat to the different parts of the body [15-17]. Further studies found that drivers' low back pain (LBP) is related to the intensity of vibration [18-25] and applying ergonomic interventions can reduce the exposure and physiological responses [26-30]. Johanning et al. (2006) studied the factors of seating design as a confounder of the locomotive operators' exposure to WBV and reported the meaningful influences on WBV exposure [24]. Yassierli (2017) could be able to reduce the LBrelated sick leave due to WBV exposure among the nickel mining operators by implementing ergonomic programs, including the LBP training and macroergonomic interventions [29]. Mining and transportation of minerals in the Sarcheshmeh Copper Mine involve employing many heavy-duty types of machinery, such as mining trucks, which need to pass mainly on newly excavated rough surfaces. The vibrations caused by the motor of these vehicles and their movements on rough surfaces eventually entail significant vibrations to be transmitted through the seats to the whole body of the operators. The ergonomic and seating conditions are important and possible modifying factors in the overall risk assessment of WBV exposure [31, 32]. These are also important for musculoskeletal health in occupational medicine [33].

The effects of vibration can disrupt people's normal activities and even affect their daily lives and health. Therefore, it is necessary to take measures to control and improve the working conditions and health status of persons exposed to vibration. In the country of Iran, a wide range of people in industries, especially mines, are exposed to this harmful agent. Therefore, it is necessary to take measures to control and improve the working conditions and health status of people exposed to vibration. The present study was designed to investigate the effect of ergonomic interventions to reduce the WBV in the drivers of heavy mining machines in Sarcheshmeh Copper Complex.

MATERIALS AND METHODS

This study was conducted on 25 male heavy vehicle drivers in Sarcheshmeh Copper Mine. To assess the exposure of the operators to WBV, Bruel & Kjaer 4447 HAVS – Hand-Arm and Whole Body Vibration Meter with the sensitivity of 10 mv/g and the whole-body three-axis disk sensor, B&K Type 4524-B, were used (Fig. 1). The device is able to measure simultaneously the Root Mean Square (RMS) of frequency weighted accelerations and the vibration dose value of three axes (X, Y, and Z) for each operator.

Fig.1. WBV vibration meter model 4447 manufactured by Brüel & Kjær Company.

The WBV measurements in the frequency weighted values were done according to ISO 2631-1:1997, including the frequency weighting filter of Wd for X and Y directions and Wk for the vertical axis (Z direction) within the frequency range of 0.5-80 Hz. With respect to the working cycle of each vehicle and its associated sub-cycles, the vibration measurement was carried out such that it covers all stages of each vehicle cycle.

Vibration measurements included whole-body vibration at the operator's seat level and below the operator's foot in the cabin floor by locating the seat pad accelerometer at the seat/operator interface and at 1/3 octave according to ISO 2631-1. By balancing the measurements made in each cycle, all measurements were performed under the normal working conditions of the vehicles to minimize the impact of confounders, such as road surface, tire type, etc. Given that the path and speed (40 Km/h) were the same for all vehicles, the vibration measurements were done on a round trip, which took about 65 minutes on average from the start of the vehicle until its return and stop, as a representative of the whole shift work.

To predict the human health risk, the frequency weighted acceleration (RMS) values in the X, Y and Z axes (ax, ay, and az) were summed up to calculate the equivalent acceleration (Aeq) using the following equation:

$$A_{eq} = \sqrt{(1.4a_x)^2 + (1.4a_y)^2 + (a_z)^2}$$

In general, the WBV measurements were performed in two phases. In phase 1, the WBV was measured prior to the ergonomic interventions and compared with the permissible occupational exposure limits recommended by the Ministry of Health and Medical Education of Iran [34]. In phase 2, Due to the high level of exposure of drivers to human vibrations compared to the occupational exposure limit, it was decided to reduce the received vibration level to below the permitted level by performing ergonomic interventions. The interventions included formulating a tire pressure balancing program to balance the pressure of tires at the beginning and end of each shift, paving traffic routes, especially in tailings dump routes to smooth and widen the useful road surface (large soil particles, due to incomplete explosion, increase the vibration acceleration, especially in X and Y axes during the loading operation of the vehicles by shawl machine. the vibration could be reduced by managing explosion and leveling the loading locations), modifying the suspension system, improving the drivers' seat to attenuate the vibration transmission to the drivers' body (because drivers' seats are usually unacceptable in terms of the various adjustment and comfort criteria). This would be possible by using the seats with adjustable features and air cushion (replacing the foam of both seat and backrest and making the backrest angle and seat height adjustable to better fit to the driver's anthropometric features), replacing the worn-out vehicles with the new ones, controlling the work pace, training the operators how to control properly the vehicles and developing job instructions to reduce the unauthorized vibration levels to acceptable limits. The measured values of the pre- and post-intervention steps were analyzed using the independent t-test in SPSS software, version 19.

RESULTS

The drivers were 35/4 ± 16/29 years old on average with a work experience of 8.3 ± 74.3, all of whom were involved in a shift-based work program. Figure 2 shows the resultant value of the vibration exposure values in three axes in the pre-intervention step compared to the occupational exposure limit in the population under study. According to the figure, the exposure is mostly higher than the standard limit.

In Table 1, the vibration dose values (VDV) measured based on the exposure limit index in three directions of X, Y, and Z before and after the interventions are presented and compared. Before the interventions, the maximum VDV was 0.34 $m/s^{1.75}$ measured in the Z direction and the lowest value was 0.23 $m/s^{1.75}$ measured in the Y direction. After the intervention, the highest and lowest values were reported from the Z and X axes, respectively. The acceleration value in the Y-axis showed an increase of 0.02 $m/s^{1.75}$ after the interventions, but not exceed the standard limit. As the table suggests, the mean values of VDV in X and Zdirections are significantly different ($p<0.001$) in pre- and post- interventions, all of which are below the ISO action value (8.5 $m/s^{1.75}$).

Table 2 represents the mean and standard deviation of the equivalent acceleration (Aeq) before and after the interventions. The difference between the Aeq mean values before and after the interventions are statistically significant ($p<0.001$) and all of them are above the ISO acceptable value (0.5 m/s2). Figure 3 shows the results of the vibration exposure after the interventions in comparison to the standard limit in the sample under the study. In all cases, the exposure limit is less than the recommended limit.

DISCUSSION

Prolonged exposure to vibration can increase the risk of occupational health problems. Based on the obtained results, the whole body vibration exposure was high among the heavy machinery drivers of Sarcheshmeh Copper Mine (before the interventions). The highest exposure was in the Z-axis and the lowest in the Y axis. The results comply with the findings of the existing studies [22-24]. Kumar et al. (2001) studied the vibration intensity of tractors and the drivers' health and found that the vibration acceleration values were higher than the 'health guidance caution zone' [22].

Similar studies [23, 24] showed that Z axis is the most important way of entering vibration into the body. The result also confirmed the output of the study [25] on the examination of the WBV in the transport industry, in which it is stated that the acceleration values in the Z-axis are always more prominent than the other axes.

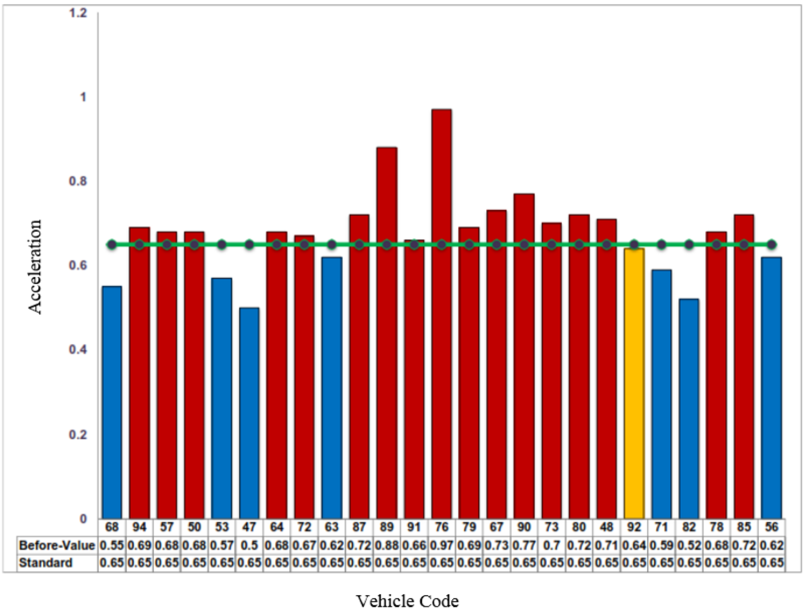

Fig 2. Resultant of the vibration exposure values in three axes in the pre-intervention step compared to the standard limit

Table 1. VDV values in each direction before/after the interventions based on the exposure limit value

in $m/s^{1.75}$

VDV	N	Acceleration Direction								
		X			Y			Z		
		M	SD	p-value	M	SD	p-value	M	SD	p-value
Pre-intervention	25	0.24	0.06	0.001	0.23	0.06	0.65	0.34	0.08	0.001
Post-intervention	25	0.22	0.05		0.25	0.16		0.32	0.07	

Table 2. Mean and standard deviation of A_{eq} (m/s^2) before and after intervention in drivers

Body vibration	N	M	SD	Min	Max	p-value
Pre-intervention (m/s^2)	25	0.66	0.08	0.50	0.88	0.001
Post-intervention (m/s^2)	25	0.56	0.05	0.50	0.63	

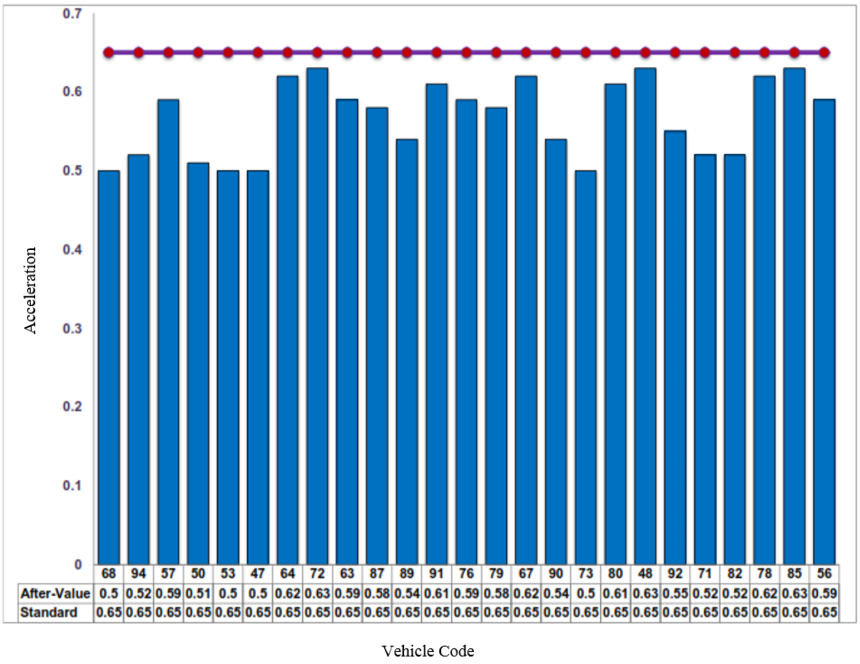

Fig. 3. Vibration exposure in post-intervention in comparison with the standard limit in the sample under study

In addition, the significant difference in the body vibration values before and after interventions in the present study showed that the ergonomic interventions could attenuate the whole body vibration below the standard exposure limit.

These results are in line with the studies on the use of ergonomic interventions to control the exposure to the vibration from the equipment. As such, Tiemessen et al. (2007) studied the vibration from forestry machinery, carpentry, tractors, and trucks [26]. Langer et al. (2012) worked on reducing WBV exposure in backhoe loaders by the education of the operators on eco-driving and vibration avoidance. They reported an average reduction of 22.5% in the WBV exposure and concluded that the operators' education will improve the occupational health and save fuel [27]. Blood et al. (2012) investigated the effect of task exposure and tire configuration in WBV received by heavy equipment operators and recommended the use of tires with basket chains over the ladder chains [28]. Johanning et al. (2006), by the ergonomic design of seats could be able to reduce meaningfully the WBV exposure in locomotive drivers [24]. Yassierli (2017) reported a reduced LBP sick leaves by implementing LBP-based training and macroergonomic programs [29]. Similar to the effect of the interventions in present study, Deboli et al. (2017) suggested using specific suspension systems along the horizontal and lateral axes to reduce the rolling and pitching influential effects on the seat accelerations along wth these directions [30].

CONCLUSION

It is concluded that the engineering and administrative ergonomic controls and interventions (such as the development of a program for adjusting the inflation rate of tires, the pavement of the routs, especially tailings dump routs, modification of the suspension system, replacement of worn-out vehicles with the new machines, work pace control, operators' training to properly control the vehicles, and especially ergonomic and seating modifications) can reduce the WBV exposure in heavy machinery drivers, reduce their work-related complaints, and enhance the quality of their working life and productivity. The seating posture, awkward positioning and seat/cab adjustment features were also evaluated to be important in the WBV exposure risk. The important role of the driver's posture leading to musculoskeletal problems has been emphasized in the previous studies. In this study, no postural measurements were taken to provide additional information on WBV exposure and postural risks. However, it is assumed that the operators in the relaxed seating position without twisting and bending of the spine would be at a lower risk of longitudinal spinal cord injury. It is recommended that in future studies, the real-time postural risks and the impact of each ergonomic intervention on heavy machinery drivers are investigated, separately and compare with each other to reach a clear understanding about their effects and maybe their priorities.

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