Original Article

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Exposure to whole body vibration in heavy mine vehicle drivers and its association with upper limbs musculoskeletal disorders

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Abstract
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Background: Vibration as one of the harmful physical factors is relatively present in a wide range of jobs. Musculoskeletal disorders (MSDs) are among the most prevailing complaints of workers encountering occupational factors for example vibration. Therefore, this study was conducted to investigate vibration and its association with the MSDs in upper limbs of heavy mine vehicles drivers.
Materials and Methods: This cross-sectional study was conducted, on heavy mine vehicles of Gol-Gohar Sirjan Centre, Sirjan, Iran. In general, 288 drivers with 92 vehicles were working at the mine site. SVAN958 vibration meters and the Nordic Musculoskeletal Questionnaire were used to measure whole body vibration and upper limb MSDs, respectively. Finally, the data were analysed using SPSS.
Results: The highest average equilibrated acceleration was in graders (2.179 m/s^2) and drills had the lowest average acceleration (0.479 m/s^2). Prevalence of MSDs within past 12 months showed a significant difference in the neck ($P = 0.044$) and elbow ($P = 0.023$) between case and control group. The whole body vibration variable was associated with MSDs in the neck ($P = 0.020$) and wrist/hands ($P = 0.030$), and with increase in vibration the MSDs showed a 59% increase in neck and 72% in wrist/hands. In multivariate analysis, the whole body vibration variable had a significant relation with MSDs in wrist/hand ($P = 0.027$) and caused an 83% increase in the risk of MSDs per each unit in wrist/hand.
Conclusions: The prevalence of disorders in studies with short duration is probably not quite visible; however, by increasing the working experience with these vehicles which have higher vibration than standard rates, the chance of developing MSDs increases.

Keyword: Vibration, Musculoskeletal Disorders, Exposure, Vehicles

Introduction

Vibration is defined as oscillatory movements of a medium and refers to those movements or vibrations that recur in anticipated times (1). Vibration, as a harmful physical factor, is relatively present in a wide range of jobs. This phenomenon can especially be seen more often in industrial settings (2-4). The important factor in the relation of vibration of materials and the human body (with regard to the health issues) is that energy of vibrating waves can be dangerous when in direct contact with organs (2). Whenever the natural frequency of a

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machine or a building and the external frequency unite, resonance happens causing maximum movement of the vibrating system that can inflict serious damages to the system (1). Musculoskeletal disorders (MSDs) are one of the most prevailing complaints of workers in the workplaces. Many different factors including age, gender, smoking, and metabolic disorders can cause MSDs, but its relevance to job is mostly associated with ergonomic issues and physical factors within the workplace. Poor body posture, routine and static jobs, over-powering the muscles, poor climatic conditions of workplace and vibration are some of these factors. Whole body vibration (WBV) can cause backache, prostate disorders, hemorrhoid, and heart disorders (5). Currently, exposure to WBV is a major risk factor of MSDs in spinal column among professional drivers, who are usually diagnosed with undesirable low-back pain (LBP) and spine disc herniation (6). The epidemiologic records have shown that professional drivers are relatively more prone to LBP and the other sorts of spinal disorders (7).

According to the NIOSH is work-related musculoskeletal disorders the second rank in terms of frequency, severity, and the likelihood of progression of the disease is associated with own work. Every year, 1.1 million people in Great Britain suffer from musculoskeletal injuries. According to the Social Security Organization of Tehran Medical Commission, 14.4 percent of disability due to various diseases is related to MSDs (8).

In the Gruber's study on 1448 bus drivers, they found a significant statistical difference in the consequences of WBV such as gastrointestinal, venous, musculoskeletal, and respiratory disorders between the case and the control group (9). In a study on tractor drivers, it was observed that the effects of WBV become intensified through long work hours and bad sitting behaviours (10). Also, Mohammadi et al. showed that WBV had the greatest effect on neck pain in truck drivers (5). Another study that was conducted in Sweden indicated that having contact with WBV at least during half of work hours was associated with a high rate of MSDs among workers (11). The rate of backache and neck pain among locomotive drivers due to contact with WBV was two times as much as the control group (12). The results of Rob and Mansfield study showed that rate of MSDs within past 12 months and a week were 39% and 12% for shoulders, 34% and 11% for the neck, and 9% and 1% for elbow, respectively (13). Another study in India showed that rate of MSDs among mine truck drivers were 85% for back, 30% for shoulders, and 37.5% for neck (14). According to above mentioned cases and the fact that side effects of vibration can cause disruption in individuals' normal activities, impair their daily life, and harm their health, and that in our country a wide range of people working in industrial sectors like mines are prone to this hazardous factor, it is necessary to execute some actions in order to control and improve work conditions and to check people's health who are in direct contact with vibration. Therefore, this study intended to investigate vibration and its association with upper limbs MSDs in heavy vehicles mine drivers of Gol Gohar Sirjan site, Sirjan, Iran.

Material and Methods

This cross-sectional study was conducted on drivers of heavy mine vehicles of Gol Gohar Sirjan centre in 2014-2015. A total number of 288 drivers and 92 vehicles, in 4 work-shifts (8-hours each) were working on the site. Seventy-two of drivers were excluded from the study due to their MSDs, records of inflammatory metabolic diseases, spinal trauma, inherited disorders, less than one-year driving experience, and unwillingness to cooperate. The control group (n = 216) who had no long-term exposure to vibration were selected randomly from the Gol Gohar Sirjan office staff. All participants were male. In the current study, the vibrations of 7 different kinds of vehicles were analysed (Table 1).

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A calibrated SVAN 958 vibration meter and SV 39 A/L whole body disc sensor (with a 10 $^{mV}/_{ms^{-2}}$ sensitivity rate) was used in order to measure WBV. By considering work cycle of each vehicle and associated sub-cycles, vibration was measured in a way that covered all levels of work cycles to each vehicle. Measurement of WBV was based on (ISO) 2631-1-(1997) standard related factors such as duration of measurement and location of sensor were considered according to this standard (15). The position of whole body vibrometer sensor disc on the seat is shown in figure 1. All measurements were conducted within normal working conditions of vehicles so that through getting a mean from achieved values from each cycle, eradicate the effects of present interferences like road surface, type of tires, etc. as far as possible. Due to 8-hours shifts in the site, the comparisons were carried out with regard to 8-hour exposure limit value and 8-hour action limit value presented by ISO 2631 (1997) (R2004). Upper limb MSDs were assessed by the Nordic Musculoskeletal Questionnaire (NMQ) in case and control groups (16). This questionnaire has been used to study the MSDs caused by vibration as well (13, 17, 18). The NMQ provides useful and reliable information about the symptoms of MSDs, which can be used for more profound observations and/or decision making on corrective measures. In addition, current questionnaire provides information about whether during the past 12 months, there were any problem or pain in 9 anatomic areas and whether these problems resulted in any work leaving or inability and if there were any problem or pain during past 7 days for any of these areas (16, 19). In addition, a demographic questionnaire and medical records of staff were used to provide information about age, previous employment records, employment history in this industry, daily working hours, smoking, etc. Finally, the data were analyzed by SPSS (version 20.0, IBM Corporation, Armonk, NY, USA). Inclusion criteria were 1) men with 2) at least one year of work experience and having 3) physical and mental health. Exclusion criteria were 1) history of accident, 2) having diabetes and any rheumatologic problem 3) work not being static and repetitive 4) not carrying heavy loads and unsuitable workplace ambient conditions. In addition to descriptive statistics, analytic tests were also used including t-test, one-way ANOVA to compare means, chi-square to compare the prevalence, and Pearson correlation and logistic regression to examine the relationship between MSDs during the past 12 months with restriction and other variables. In all statistical tests significant range of $P < 0.050$ was adopted.

Figure 1: Position of vibrometer sensors on the seat

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Results

Evaluation of vehicles acceleration and its comparison with standard showed that the mean equilibrated acceleration of all trucks, bulldozers and graders exceeded the 8-hours exposure limit and mean equilibrated acceleration of shovel, mechanical digger, loader, and drills were less than 8-hours exposure limit. The comparison showed that mean equilibrated acceleration of all vehicles exceeded the 8-hour action limit. Table 1 illustrates the mean values, standard deviation, overall equilibrated acceleration of all vehicles, and the results of comparison between these values with 8-hour exposure limit and action limit standards.

Table 1: Frequency, mean, standard deviation, equilibrated acceleration in all vehicles and comparison with 8-hours action limit and exposure limit ($\mathbf{m}/_{\mathbf{s^2}}$)

Machine	N (%)	M (SD)	P *EL	P **AL	Status
New truck 100 ton	5 (5.4%)	1.412 (0.151)	0.001	< 0.001	Exceed EL Exceed AL
KOMATSO truck 100 ton	15 (16.3%)	1.004 (0.122)	0.001	< 0.001	Exceed EL Exceed AL
Old truck 100 ton	11 (11.9%)	1.320 (0.279)	< 0.001	< 0.001	Exceed EL Exceed AL
EUCLID 85 ton	5 (5.4%)	1.173 (0.062)	< 0.001	< 0.001	Exceed EL Exceed AL
KOMATSO truck 35 ton	17 (18.4%)	1.133 (0.126)	< 0.001	< 0.001	Exceed EL Exceed AL
Shovel	7 (7.6%)	0.657 (0.138)	0.007	0.024	Less EL Exceed AL
Mechanical digger	9 (9.7%)	0.537 (0.188)	0.001	0.569	Less EL Exceed AL
Loader	2 (2.17%)	0.867 (0.088)	0.975	0.107	Less EL Exceed AL
Grader	4 (4.3%)	2.179 (0.489)	0.013	0.006	Exceed EL Exceed AL
Bulldozer	12 (13.04%)	1.738 (0.3)	< 0.001	< 0.001	Exceed EL Exceed AL
Drill	5 (5.43%)	0.479 (0.146)	0.004	0.769	Less EL Less AL

*Exposure limit (8-hours exposure limit According to ISO 2631 (1997) (R2004) = 0.87 $m/_{s^2}$)
**Action limit (8-hours action limit According to ISO 2631 (1997) (R2004) = 0.5 $m/_{s^2}$)
AL: Action limit; EL: Exposure limit; SD: Standard deviation

Comparison of demographic variables and factors that affect MSDs in case and control group showed a significant difference between age (P = 0.005), work experience (P = 0.001), work experience within 10 years (P < 0.001), exercise (P = 0.014) and alcohol consumption (P = 0.030). However, 6 cases used alcohol and non-occupational disease records were associated with those cases that did not cause a musculoskeletal problem in the individual and these diseases were not related to their jobs. Table 2 illustrates demographic variables and effective factors on MSDs in both case and control groups.

The upper limb MSDs within past 12 months were compared in case and control groups (Table 3) and prevalence of MSDs of neck (P = 0.044) and elbow (P = 0.023) were significantly higher in case group. Overall, the prevalence of disorders in cases (40.2% in the neck; 28.2% in shoulders; 4.6% in elbows; and 9.72% in wrist/hand) was greater than the control group.

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Table 2: Describe the demographic variables and factors affecting MSDs in case and control groups

Variable		Case Mean (SD)	Control Mean (SD)	P
Age (year)		34.29 (7.85)	32.34 (6.50)	∗0.005
Work experience (year)		4.4 (3.19)	5.98 (5.40)	∗0.001
Daily working hours (hour)		8.56 (1.38)	8.44 (0.85)	0.260
Height (cm)		175.55 (7.07)	175.45 (8.4)	0.890
Weight (kg)		78.88 (11.26)	77.28 (11.67)	0.150
BMI		25.60 (3.36)	25.09 (3.64)	0.130
Work experience, last 10 years (year)		6.67 (4.74)	2.004 (2.91)	∗< 0.001
		Frequency (percent)	**Frequency (percent)**	**P**
Exercise	Yes	114 (52.8)	140 (64.8)	∗0.014
	No	102 (47.2)	76 (35.2)	
Smoking	No	190 (88)	199 (92.1)	0.056
	Casual	18 (8.3)	16 (7.4)	
	Regular	8 (3.7)	1 (0.5)	
Alcohol consumption	Yes	6 (2.8)	0 (0)	∗0.030
	No	210 (97.2)	216 (100)	

∗ Significant
SD: Standard deviation; BMI: Body mass index

There was a significant difference between case group and control group in MSDs with restriction within past 12 months in the neck (P = 0.001) and wrist/hands (P = 0.040). This prevalence was 17.59% in neck; 6.48% in shoulders; 3.24% in elbows; 9.72% in wrist/hands in cases (Table 3). With respect to MSDs within past 7 days, there was also a significant difference in the neck (P = 0.018) and wrist/hands (P = 0.005), between the case and control groups, but the difference was not significant in shoulders (P = 0.280) and elbows (P = 0.450). The prevalence of these disorders was 16.2% for neck 9.72% for shoulders; 6.48% for elbows; and 9.7% for wrist/hands (Table 3).

Table 3: Frequency of musculoskeletal disorders based on upper limbs in cases and control groups

Organs	Status	Musculoskeletal disorder during the past 12 months			Musculoskeletal disorder during the past 12 months with restriction			Musculoskeletal disorder during the past 7 days		
		Case	Control	P-value	Case	Control	P-value	Case	Control	P
Neck	Yes	87	66	∗0.044	38	16	∗0.001	35	18	∗0.018
	No	129	150		178	200		181	198	
Shoulders	Yes	61	55	0.587	14	20	0.28	21	17	0.611
	No	155	161		202	196		195	199	
Elbows	Yes	33	17	∗0.023	10	7	0.45	14	6	0.107
	No	183	199		206	209		202	210	
Hand/wrist	Yes	59	43	0.089	21	10	∗0.04	21	6	∗0.005
	No	157	173		195	206		195	210	

* Significant

According to the explanations mentioned in the methods, the MSDs with restriction within past 12 months are the most prevalent MSDs, and we investigated their relationship with various variables including WBV, age, work experience, body mass index (BMI), smoking, and exercise, using logistic regression test. The associated odds ratio (OR) and P-value are shown in table 4. In univariate tests, WBV as the main variable in this study, associated

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with MSDs in the neck (P = 0.020) and wrist/hands (P = 0.030), and the MSDs showed a 59% increase in neck and 72% in wrist/hands for each unit increase in the vibration. Work experience had a significant relationship with MSDs in elbows (P = 0.009) (per month) and increase in work experience increased the rate of MSDs in elbows by 0.8%. Smoking had a significant relationship with MSDs in the neck (P = 0.003) and wrist/hands (P = 0.016) as well. In addition, in smokers, the rate of MSDs increased by 136% for neck and 125% for wrist/hand.

In multivariate analysis, the relation between variables including vibration, age, work experience, BMI, smoking, and exercise, and MSDs with restriction within past 12 months was examined and results are shown in table 4. Comparing vibration, age, work experience, BMI, smoking, and exercise variables together, vibration had a significant relation with MSDs in wrist/hand (P = 0.027). Examining the odds ratio of vibration values with MSDs in different body areas showed that the increase in vibration range (per unit) caused an increase in the risk of MSDs in wrist/hand by 83%. Smoking had a significant association with MSDs in wrist/hand (P = 0.031) and neck (P = 0.009) such that the risk of MSDs for smokers was 114% for neck and 110% for wrist/hand compared to non-smokers. Work experience had also a significant relation with MSDs in the elbow (P = 0.013) and an increase in work experience (for each month) caused an increase in MSDs in the elbow by 1.3%.

Table 4: Association of different variables with upper limb musculoskeletal disorders with restriction in the past 12 months

Organs			Variable					
			Vibration	Age	Work experience	BMI	Smoking	Exercise
Neck	Crude	P	*0.024	0.24	0.332	0.986	*0.003	0.507
		CI %95	1.06-2.38	0.98-1.06	0.99-1.01	0.92-1.08	1.35-4.12	0.67-2.2
		OR	1.593	1.022	0.997	1.001	2.363	1.221
	Adjusted	P	0.139	0.126	0.112	0.854	*0.009	0.315
		CI %95	0.89-2.2	0.99-1.09	0.99-1.001	0.91-1.08	1.2-3.82	0.74-2.55
		OR	1.404	1.04	0.994	0.992	2.145	1.373
Shoulders	Crude	P	0.708	0.129	0.402	0.986	0.185	0.714
		CI %95	0.52-1.54	0.99-1.08	0.99-1.01	0.92-1.12	0.79-3.33	0.55-2.35
		OR	0.903	1.034	1.002	1.021	1.626	1.144
	Adjusted	P	0.433	0.167	0.726	0.687	0.226	0.627
		CI %95	0.43-1.43	0.98-1.11	0.99-1.006	0.92-1.13	0.75-3.29	0.57-2.52
		OR	0.788	1.044	0.999	1.021	1.575	1.202
Elbows	Crude	P	0.725	0.285	*0.009	0.906	0.07	0.614
		CI %95	0.56-2.3	0.97-1.09	1.002-1.01	0.88-1.16	0.94-5.04	0.47-3.58
		OR	1.135	1.033	1.008	1.008	2.172	1.298
	Adjusted	P	0.369	0.277	*0.013	0.866	0.1	0.546
		CI %95	0.67-2.89	0.85-1.05	1.003-1.02	0.87-1.16	0.87-4.86	0.48-3.96
		OR	1.397	0.945	1.013	1.012	2.059	1.383
Hand/wrist	Crude	P	*0.036	0.329	0.12	0.611	*0.016	0.401
		CI %95	1.04-2.85	0.97-1.07	0.99-1.01	0.87-1.08	1.16-4.37	0.35-1.52
		OR	1.723	1.023	1.004	0.973	2.257	0.731
	Adjusted	P	*0.027	0.359	0.069	0.496	*0.031	0.548
		CI %95	1.07-3.13	0.9-1.04	0.99-1.015	0.86-1.076	1.07-4.14	0.37-1.69
		OR	1.830	0.968	1.007	0.962	2.106	0.792

∗ Significant
OR: Odds ratio; BMI: Body mass index

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Discussion

Because of limited studies about health consequences of occupational exposure to vibration of mine heavy machines, it seems quite important to conduct such studies in Iran and other parts of the world. This study has tried to take into consideration all mine vehicles, with respect to their vibration and various aspects of drivers exposure to vibration.

Results showed the average acceleration for graders and bulldozers were much higher than other vehicles. In a study by Hasheminejad et al. (20) the average acceleration in bulldozers and graders were higher than other machines that are consistent with the results of this study. In the study of Hasheminejad et al. shovels had the lowest average acceleration among the studied vehicles, and in the current study, shovel had a similar status and the machines had the lowest average vibration. Since the vehicles investigated in the current study were more diverse, lowest vibration acceleration was observed in drills and mechanical digger.

The comparison of average acceleration with 8-hour exposure limit showed that average acceleration in all vehicles were higher than the standard value and only shovels, mechanical diggers, loaders, and drills had average accelerations lower than the standard value. Our results are similar to and Hakimi et al. (21) study and Hasheminejad et al. (20) study.

The prevalence of MSDs was studied in three time spans, which were past 12 months, past 12 months with restriction, and past 7 days.

Results of the current study showed that prevalence of MSDs in the cases was significantly different with control subjects in the neck ($P = 0.001$) and wrist/hand parts ($P = 0.040$). Previous studies have shown some factors that might be related to MSDs including age, smoking, inflammatory disorders, diabetes, anthropometry, gender, anatomical differences, alcohol abuse, personality, psychological disorders, and neuromuscular and metabolic diseases (22). Also, anthropometric characteristics were not found to be significant, but probably they might be of great importance in a vehicle with limited space problem (22). In this study the relationship between age, BMI, smoking, and exercise and exposure to WBV and MSDs with restrictions in the past 12 months was investigated by using univariate and multivariate tests. Neck disorders had a significant relationship with WBV ($P = 0.020$) and smoking ($P = 0.003$). In a study by Mohammadi et al. (5) WBV had a significant relation with neck disorders as well, but there was no relation between smoking and neck disorders. They reported that WBV exposure increased the risk of pain in the neck by 2.33% (5), while in the present study the increase in the WBV (for each unit) increased the neck disorders by 59.3% that was significantly higher. This difference can be related to more powerful vehicles that can generate stronger vibration in Gol Gohar mine. The relationship between smoking and MSDs can point out those drivers who smoke while driving adopt a specific posture that can be effective in disorders. However, more research is needed to investigate this issue. The rate of neck disorders within past 12 months was 40.3% in this study, and for professional truck drivers, it was 34% in Rob and Mansfield’s study (13). Now, there is sufficient data that indicates the relationship between WBV exposure and MSDs of neck and shoulders (23). In this study, neck and shoulder MSDs had a significant relationship with WBV, which confirms previous studies. Results of continuous surveillance and control showed that the prevalence of musculoskeletal problems associated with working was 6% in the neck and 9.3% in shoulders during past 12 months in the Swedish professional drivers (22), that is much lower than the prevalence of MSDs in Gol Gohar heavy vehicle Drivers. The vast range of MSDs in the current study can be associated with duration of exposure to underlying factors such as vibration. Probably one of the causes of neck and shoulder MSDs

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can be hand-arm vibration because in these machines, high-level vibration is transmitted to the driver through the steering wheel and levers that is a different cause from other studies.

In multivariate logistic regression analysis, only smoking was significantly associated with neck disorders (P = 0.009). In the study by Mohammadi et al., BMI and smoking had no significant relationship with neck disorders, but WBV had the greatest impact on neck disorders, and after that, driving experience and age had great impact (5). In addition, the rate of self-reporting MSDs in the neck and upper limbs differs from reports of 14% to 46% in European countries (24). Also in this study, the rate of MSDs in the neck and upper limbs including shoulders, elbows, and wrist/hands were close to these values. Drivers exposure to WBV potentially goes along with other MSDs risk factors, and that was the reason of difficulty in identifying a particular risk factor for incidence of MSDs (24).

In this study, vibration, along with other variables, had a significant role in causing MSDs, in such a way that vibration had a significant relation with neck, elbows, and wrist/hand disorders within past 12 months. In addition, vibration had a significant relation with MSDs with restriction within past 12 months. In the studying of vibration without considering other variables, it turned out that this variable had a significant relation with MSDs with/without restriction in neck and elbow within past 12 months. According to above-mentioned results, vibration could be considered as a significant and major physical factor that causes MSDs. Also in a study conducted by Mohammadi et al., this fact was confirmed that vibration had the greatest impact on creating disorders in the neck (5). Although there is a direct relationship between WBV and MSDs because other factors also affect MSDs so vibration may be considered as one of the causes of MSDs.

Conclusion

Results showed that prevalence of MSDs in upper limbs in those working with these vehicles is considerable. Probably the prevalence of disorders in the studies with a short time span is not quite visible. However, by increasing the experience of driving heavy vehicles which have higher vibration than standard rates, the chance of incidence of MSDs increases. Therefore, appropriate controlling measures should be taken in order to decrease the exposure of people to vibration and more screening measures should be used to find people prone to or people affected with MSDs.

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