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Original Article

# Experimental study of exposure to human vibration and its relationship with physical performance in mining equipment operators

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## ABSTRACT

**Background and Objectives:** Exposure to vibration is one of the occupational agents that causes a variety of health effects. The aim of this study was to determine the association between exposure to human vibration and physical performance of mining drivers.

**Methods:** In the present study, 65 drivers working in one of the Iron Ore mines, were asked to complete the standard questionnaire for assessing the level of disability of the arm, shoulder and hand (DASH). Exposure to human vibration was measured using Svantek 106 vibrometer. Drivers' physical performance was assessed based on grip strength, Pegboard dexterity, and monofilament finger sensory tests. Data were analyzed using SPSS 21 software.

**Results:** The average vibration acceleration whole body (WBV) and hand-arm (HAV) were 1.00±0.23 and 2.46±0.68 $m/s^2$ respectively. There was a significant relationship between exposure to HAV and the grip strength and hand dexterity ($p<0.05$). According to the DASH score, 56.9% of drivers had mild and 43.1% had moderate upper limb disability. The results of multiple regression model with a coefficient of determination of 0.207 showed that the WBV in the presence of other predictor variables had a significant effect on DASH score ($p<0.05$).

**Conclusion:** In mining truck drivers, WBV exposure was higher and HAV exposure was lower than the national exposure limits. The results confirmed that WBV caused by mining trucks is the most important risk factor affecting the level of drivers' disability.

**Keywords:** Physical performance, human vibration, disability, mining truck, drivers

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## Extended Abstract



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## Background and Objectives

Heavy mining equipment produces a lot of vibration, and consequently, their operators are exposed to this physically harmful factor [3]. Full-body vibration is a risk factor for musculoskeletal disorders. The vibration transmitted to the operators' hands of heavy vehicles has a significant effect on the grip strength, hand performance, and vibration of operators' hands (tremors) [4-6]. One of the considerable points from a safety perspective is the fall of operators while grabbing and dropping the handles of mining equipment, which occurs in large numbers every year. Based on the reports, the disorder of balance due to full-body vibration, reduced grip strength, and sensory disturbances of drivers' hands are the reasons for the fall of the drivers during getting in or out of the car [10]. Although, previous studies have highlighted the importance of exposure to vibration. Comprehensive empirical studies on the extent of exposure to human vibration and its effects on the health of mining equipment operators are found in a limited way. In this regard, this study was designed to experimentally investigate the relationship between the exposure level to human vibration and the physical performance of mining equipment operators.

## Methods

This cross-sectional study was carried out in the summer of 2020 in one of the iron ore mines of Kurdistan province with the participation of 65 professional operators of various mining vehicles. The subjects were selected using random sampling.

$$n = \frac{(\sigma_1^2 + \sigma_2^2)(z_{1-\frac{\alpha}{2}} + z_{1-\beta})^2}{(\mu_1 - \mu_2)^2}$$

Which σ1, σ2, Variance, μ1, and μ2 are obtained mean by the internal similar studies. The reliability and test power of this test were 95% and 80%, respectively. The sample size was determined to be 65 vibration of the whole body and $a_{HTV}$ is acceleration equivalent to hand-arm vibration. Acceleration people by substituting different values. The inclusion criteria were non-smoking, at least one year of work experience, lack of history of musculoskeletal, sensory-neurovascular disease due to non-occupational reasons, and no history of driving accidents. Exclusion criteria were lack of adequate rest, nutrition, and ergonomically unsuitable driving seats.

It should be noted that to compare the effects of vibration exposure, 45 people in the administrative department of the mine were selected as a control group, who were similar to the drivers in terms of demographic characteristics and study criteria. All drivers completed the consent form to participate in the study. First, a questionnaire containing demographic information was distributed among eligible drivers. Then, physical function tests were performed. The approximate time for the tests was 15-20 minutes for each driver [15]. The drivers' exposure to hand-arm and full-body vibration was measured for 15 minutes [15].

### Measuring human vibration

Based on ISO 5349 and ISO 2631 standards using a radiometer, model 106 from Svantek, Poland, and according to the hours of exposure, drivers' exposure to hand-arm and full-body vibration was measured in three X, Y, and Z axes. The vibration was evaluated by the sum of weight acceleration resulting from the three axes through equations 1 and 2 for full-body and hand-arm vibration, respectively [16, 17].

$$a_{WBV} = \sqrt{(1.4a_x)^2+(1.4a_y)^2+(a_z)^2} \quad (1$$

$$a_{HTV} = \sqrt{(a_x)^2+(a_y)^2+(a_z)^2} \quad (2$$

$a_x$, $a_y$, and $a_z$ are the effective acceleration rate for separate axes. $a_{WBV}$ is acceleration equivalent to the equivalent to vibration at 8 hours exposure was determined using Equation

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$$3.A(8) = \sqrt{\frac{1}{T_0}\sum_{I=1}^{n} a_i^2\ T_i} \qquad (3$$

*$T_i$ is the total exposure time (hr), and $T_0$ is considered limited time (8 hr).*

***Measuring the physical performance of drivers***

*The dominant grip strength of the drivers was measured using the hand dynamometer, model Jamar. In this test, the operators place the elbow at a 90-degree angle on a flat surface. It enters the maximum force (kg) 3 times in 10-second intervals by grabbing the dynamometer handle. An average of 3 measurements were recorded. Studies have shown that Jamar hydraulic dynamometer is the gold standard with good and excellent relative reliability (ICC between 0.90 and 0.95) to measure the grip strength [18]. The skill and agility test of the hands was performed by Pegboard measuring instrument model 32020A with a reliability of 0.76 to 0.89. This test consists of a wooden plate with 25 holes in two rows parallel to each other, short metal rods, pins, metal, and hollow washers. These small pieces should be placed in the appropriate areas. The test is scored based on the number of tests performed in a specified period, and it can be used to assess the level of agility and assembly skills [19]. The level of sensory-neurological disorders was determined using a monofilament kit test with a reliability of 0.62 to 0.99. For this purpose, monofilaments with different numbers (1.65-6.65) were used. The monofilaments are stretched from 1.65 on the surface skin of all the fingers and 3 palm areas of both hands, and the person responds with each touch of the monofilament. If the higher monofilament number is not felt, the test is performed [21].*

***Determining the disabilities of the arms, shoulders, and hands***

*Determining the level of physical disability of drivers was measured by a validated questionnaire assessing the level of disability of the arms, shoulders, and hands (DASH). This questionnaire was translated by the researcher and evaluated by experts to check the validity. The original version was in the English language. The translation-re-translation method was used. After the final translation, the content validity ratio (CVR) and content validity index (CVI) was used to assess the content validity of the questionnaire. The rate of CVR and CVI were 0.74 and 0.9, respectively. The Cronbach's alpha coefficient was used to evaluate the reliability of the questionnaire, which was calculated to be 0.75. The DASH questionnaire consists of 20 items related to performing specific activities by hand. Each item has five options and a range score between 1 and 5. In a classification of upper limb disability, a score less than 24.99 indicates a mild problem, a score between 25 and 49.99 indicates a moderate problem, a score between 50 and 74.99 indicates a severe problem, and a score of 75 or higher indicates disability in the upper limb [22].*

***Statistical analysis***

*Collecting data were analyzed using SPSS 21 software. The mean comparison test, Pearson correlation coefficient, and multiple regression model was used to analyze the risk factors affecting the DASH score of drivers.*

## ***Findings***

*The average age and work experience of drivers were 42.59±9.62 (21-65 years) and 14.27±8.02 (1-39 years), respectively. The results showed that the average acceleration of full-body vibration was equal to 8 hours for mining vehicles drivers, which was more than the recommended permissible level and the mean acceleration of vibration on the z-axis was the highest (Table 1). The mean score of the DASH questionnaire was 27.23±7.13 (20-47), which showed the severity of disability in the moderate range. 37 operators (56.9%) had mild problems, and the rest (43.1%) were in the middle problem class of the upper limbs. The results of the physical performance of operators (Table 2) showed that the average grip strength of the dominant hand in*

*operators was 32.1±8.2 kg, which had a significant difference with the control group (45±1.5) ($p<0.05$). In addition, the results of the agility test showed a significant difference between the agility of drivers' hands in all stages (right hand, left hand, both hands simultaneously, and assembling) with the corresponding values in the control group ($p<0.05$).*


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The results of the monofilament test showed that all the examined subjects (100%) were in the normal range in terms of finger sensory test.

**Table 1.** Level of occupational exposure of mining vehicles drivers to human vibration

| | X axis | | Y axis | | Z axis | | Equivalent | |
|---|---|---|---|---|---|---|---|---|
| Acceleration | Rang | Mean (S | Rang | Mean (S | Rang | Mean (S | Rang | Mean (Sd |
| Body ($m/s^2$) | 0.83-0.18 | 0.38 (0.1 | 0.19-1.19 | 0.34 (0.1 | 0.41-1.23 | 0.67 (0.2 | 0.57-1.62 | 1.00 (0.23 |
| Hand-arm ($m/s^2$ | 0.78-3.98 | 1.38 (0.4 | 0.90-2.94 | 1.48 (0.4 | 0.59-1.12 | 1.37 (0.3 | 1.53-4.84 | 2.46 (0.68 |

**Table 2.** Results of physical performance test of hands of mining vehicles drivers

| Physical performance index | Mean (Sd) | | p-value |
|---|---|---|---|
| | Case group | Control group | |
| Grip strength of dominant hand (kg) | 32.1 (8.2) | 45.0 (1.5) | 0.001 |
| Right-hand agility | 14.1 (1.9) | 16.2 (2.4) | 0.001 |
| Left-hand agility | 13.1 (6.5) | 15.2 (1.4) | 0.001 |
| Agility of both hands simultaneously | 11.1 (1.4) | 25.3 (2.2) | 0.001 |
| Assembly activity | 6.7 (3.0) | 7.1 (6.0) | 0.001 |

There was a significant negative relationship between exposure to hand-arm vibration and mean grip strength of hands ($p<0.05$ and $r=-0.224$). There was also a significant negative relationship between exposure to hand-arm vibration and agility strength of both hands ($p<0.05$ and $r=-0.167$). There was a significant relationship between age and DASH score ($p<0.05$ and $r=0.176$). There was also a significant relationship between work experience and DASH score ($p<0.05$ and $r=0.164$). There was no significant relationship between exposure to hand-arm vibration and DASH score ($p<0.05$ and $r=0.07$). There was also a significant relationship between body vibration and DASH score ($p<0.05$ and $r=0.396$).

**Regression model of DASH score prediction**

The results showed that full-body vibration had a significant effect on DASH score in the presence of other predictor variables ($p<0.05$). The coefficient of determination of the regression prediction model is 0.207, which indicates that the variables predict about 20% of the changes in the DASH score. The results of the best-developed model have been presented in Table 3.

**Table 3.** Multiple regression model of DASH score prediction in operators of mining vehicles

| Model variables | Non-standard | | Standard | t | p-value |
|---|---|---|---|---|---|
| | B | Std.Error | Beta | | |
| Constant | 10.703 | 9.257 | - | 1.156 | 0.253 |
| Whole body vibration | 12.121 | 3.594 | 0.407 | 3.372 | 0.001 |
| Hand-arm vibration | -0.548 | 1.253 | -0.053 | -0.437 | 0.663 |
| Work experience | 0.002 | 0.162 | 0.003 | 0.015 | 0.988 |
| Age | 0.126 | 0.130 | 0.162 | 0.969 | 0.337 |
| Body mass index | 0.023 | 0.285 | 0.010 | 0.082 | 0.935 |


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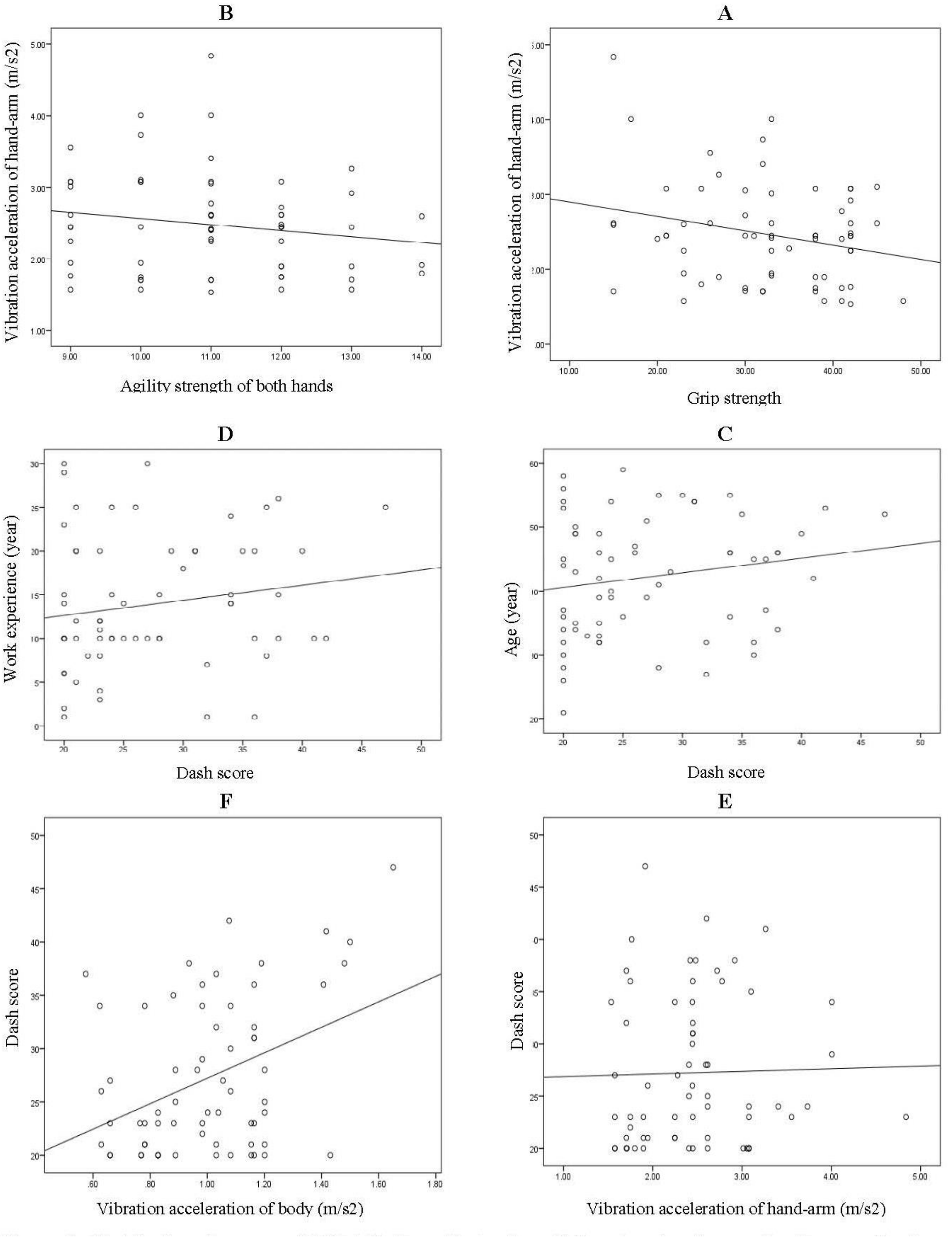


***Figure 1.*** *Distribution diagrams; A) Distribution of grip strength based on hand-arm vibration acceleration; B) Agility of both hands based on hand-arm vibration acceleration; C) DASH score distribution by age; D) DASH score distribution based on work experience; E) DASH score distribution based on hand-arm vibration acceleration; F) DASH score distribution based on the vibration acceleration of the whole body*

## *Discussion*

*The results showed that the average acceleration of full-body vibration was equal to 8 hours for mining vehicles drivers, which was more than the recommended permissible level. The result is following the findings of Emkani et al. [7] and Hashemi Nezhad et al. [9]. In this study, mild*


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*disability was observed in 56.9% of the subjects, and the rest had moderate upper limb disability. The study by Taghizadeh et al. also showed that 58% of bus drivers had mild problems in the upper limb [22]. Inability to work and job fatigue is among the causes of occupational accidents. According to the results of previous studies, drivers' fatigue after a period of driving can cause their cognitive dysfunction and increase the chance of accidents by increasing the probability of error [2, 23]. The results also showed that drivers' disability in the upper limbs also increases with aging and increase of work experience; the results are following the study of Obelenis et al. [24]. The pressure on the ligaments and joints increases with aging, based on physiological changes and reduction of body mass and access limits. On the other hand, muscle mass decreases with aging, and the internal load on the body (due to the application of force) will increase. This issue has been considered in previous studies [25-27]. The mean grip strength in drivers was significantly lower than in the control group ($p<0.05$). There was a linear- inverse correlation between exposures to hand-arm vibration with grip strength. The results of a previous study also showed that grip strength decreases with increasing exposure to vibration [28]. The results of the prediction regression model of DASH score showed a significant effect of full body vibration on DASH score. Prolonged exposure to full-body vibration has different effects on the human physiological system. The findings of the studies have shown that exposure to vibration is directly associated with musculoskeletal disorders [30, 31], and musculoskeletal disorders are one of the factors affecting the inability of people [32, 33]. Regarding drivers, the findings of previous studies indicate an association between exposure to full-body vibration and musculoskeletal disorders, which confirm the results of this study [7, 22].*

*Since this study was carried out in the field concerning exposure in real conditions, it was not possible to distinguish the effects of exposure to different levels of vibration. Repeating this study in a laboratory simulated setting may report favorable results. In addition, it is suggested to study upper limb disabilities using clinical and objective methods.*

## Conclusion

*In drivers of mining vehicles, the full-body vibration level was higher, and the hand-arm vibration level was lower than the national permissible level. The results showed a decrease in physical performance among drivers compared to the control group. There was a significant relationship between exposure to hand-arm vibration and physical function. The results of the regression model showed the effect of full-body vibration caused by mining vehicles on the level of disability of operators in the presence of other predictor variables. To prevent the effects of vibration in long-term exposure due to the occupational nature of operators, the providing and implementation of care methods, health period examinations and monitoring, and possible control technical measures should be considered by occupational health authorities.*


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