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Exposure to whole Body Vibration (WBV) and prevalence of MSDs amongst haulage operators of underground coal mines of Punjab, Pakistan.

Madiha Ijaz[1] and Momna Sajid[2]

[1]College of Earth and Environmental Sciences, University of the Punjab, Lahore, Pakistan.
[2]Fatima Memorial College of Medicine and Dentistry, Lahore, Pakistan.
**Corresponding author's email: madihab65@gmail.com*
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Abstract

To measure exposure to whole-body-vibration (WBV) and musculoskeletal-disorders (MSDs) amongst haulage operators of underground mines, present research was conducted. 100 workers from 20 mines were surveyed using Standard Nordic Musculoskeletal Questionnaire. Their 8-hours exposure to WBV was measured by fixing tri-axial seat pad accelerometer (equipped with a control panel to record vibration exposure). IBM SPSS, 26 was used to get Multivariate-Logistic-Regression-Analyses. The mean value of age was 42.2389 years, working hours/day 9.56, and working months/year 8.82. The operators with BMI 25-34 category were having alarming pain in neck with OR 7.79 (95% CI 1.14-53.59). Values of frequency-weighted root mean square acceleration and vibration dose along three (X/Y/Z) axes has been measured. The crest factor of highly exposed group (N=82) were crossing limits, categorizing all workers "high risk" by ISO 2631-1. The operators of mines are being exposed to WBV and MSDs, effecting their social lifestyle. Intervention is required to reduce risk.

Keywords: WBV; underground coal mines; haulage operators; occupational safety; socioeconomic issues.

1. Introduction

Mining industry of Pakistan is vital for economic boost. It not only adds a value to GDP growth (Janjuhah et al., 2021) but also shares burden of unemployment by hiring a large bulk of population to meet rising demand of coal production (Mohsin et al., 2021). In this connection, underground coal mines of Punjab are of great significance. Coal is extracted manually and workers are exposed to different occupational health and safety hazards (Ijaz et al., 2020; Yeoman et al., 2020). Musculoskeletal disorders (MSDs) are top among them. These are the disorders which involve tear, tendon, displacement, rupture or any acute/chronic malfunctioning of muscles, bones and joints of workers (Yamalik, 2006). Exposure to body vibration is a common source of such MSDs. Whole Body Vibration (WBV) is type of vibration in which workers' entire body is exposed to vibration prompting pain or discomfort in entire body (Duarte et al., 2020). It triggers disruption in musculo-skeleton of workers. In underground mines, there are different stages at which workers are exposed to vibration during machinery operation.

Like many other industries, mining of minerals is responsible for making its workers' bodies exposed to vibration of the machinery they operate on, on daily basis (Aye and Heyns, 2011). In underground mines of our study area, coal is transported by haulages to the surface dumping sites. Operators of these haulages are commonly exposed to WBV. Haulage is a machinery which runs on track in wings of underground mines. Haulage operator run it through active faces to collect extracted coal. A worker operates it throughout the work shift. Despite the, mechanization of underground mines, haulage operation is still there with different problems (Ghasvareh et al., 2019).

Workers of different occupations (mining as top among them) are exposed to vibration (segmental or whole body) while operating delivery objects, earthen heavy machinery, and engines of different installations (Krajnak, 2018). The whole-body-vibration (WBV) is defined as a vibration being transmitted throughout the body of human on contact with the vibration emitting engine (Smith and Leggat, 2005). Different standards have been introduced to make intervention in this occupational exposure to whole body vibration.

International Organization for Standardization (ISO) sets 2631-1 and 2631-5 standards for prediction of risk level from vibration exposure. There are several studies available in which health hazards related to WBV are predicted in accordance with these standards (De la Hoz-Torres et al., 2022). A study endorsed the effectiveness of 2631-1 for high risk prediction from load-haul-dump. Another study (Marin et al., 2017) monitored risk of whole body vibration (complying with ISO 2631-1) stemming from vehicle operation in open-pit mines. Both 2631-1 and 2631-5 hold validity for defied parameters of WBV caused by various machinery operations, and are applied to monitor WBV exposure in different industries, e.g., construction, agriculture, mining and forestry (Tekin, 2022; Podlaha et al., 2023). According to the criteria (to describe acceleration amplitude in ISO 2631-1), frequency range between 0.5 to 80 Hz is "critical range" (Lu and Lin, 2020). Despite strict compliances, workers are exposed to vibrations (either segmental or whole body) while operating vibration producing engines.

This study aims to measure haulage operators' exposure to whole body vibration and the prevalence of MSDs. Second aim of this study is to survey socioeconomic profile of these workers.

2. Materials and methodology

In District Chakwal, underground coal mines operate actively. We selected 20 mines for our study. Selecting 5 workers form each mine, we closed our sample at 100 operators. Before start of our study, we conducted a meeting with workers from all nearby mines, explained the purpose and process of study, and sought their consent to participate in study. At demand, we ensured their anonymity.

2.1 Standard Nordic Musculoskeletal Questionnaire (NMSDQ)

To survey the prevalence of MSDs among haulage operators, we used modified form of NMDQ. The NMSDQ has been reported reliable with high validity by many researchers (Dawson et al., 2009; Kahraman et al., 2016). Traditionally, it has 4 main sections. First is on respondent's personal information, second about occurrence of pain, third is about frequency (in last 7 days/last three months/last 6 months/last 12 months. It also contained a separate body image with 9 anatomical localizations based on potential risks of MSDs. The frequency of pain was asked in last section and the options for it ranged from 1 to 5 with 1 for weekly, and 5 for once in a year.

2.2 Measurements of whole-body-vibration-exposure

For the measurements, we followed ISO 2631-1 guidelines which suggest measurements to be taken at interface of worker and source of vibration (De la Hoz-Torres et al., 2019). In this study, measurements were taken at the operator seat by fixing tri-axial seat pad (4447 by Bruel and Kjaer) accelerometer - equipped with a control panel to record vibration exposure-, called vibration analyser. This accelerometer was fixed to the seat with help of adhesive tape. All measurements were taken in repetitive cycle of time (going down to the active face of coal mining and coming back with the haulage). Thus, all the cycles were recorded during 8-hour shift of one haulage operator. The mean of all measured values was calculated to write level of exposure of one operator during his 8-hor shift of haulage driving. The recommended value for WBV is 10.0 mV $(ms^{-2})^{-1}$ (Chaudhary et al., 2019).

2.3 Calculations of WBV and health risk

Operators' exposure to WBV was measured in compliance with ISO 2631-1 guidelines which suggest that impact of multidirectional vibration should be measured by evaluating sum of vector of X-axis, Y-axis and Z-axis (Eger et al., 2013). Thus, acceleration value of frequency-weighted root-mean-square (rms), and value of vibration exposure dose, referred as (VDV), were measured along Z- axes, Y-axis, and X-axis. Crest factor which is measurement of ratio of peak value to the rms value, for the span of measurement, was obtained to check existence of transient vibration. Similarly, the frequency-weighted rms acceleration (A(8)) for 8-hours, and Vibration dose Value (VDV) for 8 hours were calculated and compared with the ISO-guidelines 2631-1 Health Guidance Caution Zone (HGCZ). According to these guidelines, for A(8) the limits range from 0.45 m/s^2 to 0.90 m/s^2, and for VDV (8), the limits range from 8.5 $m/s^{1.75}$ to 17 $m/s^{1.75}$ respectively (De la Hoz-Torres et al., 2019).

2.4 Equations of frequency-weighted rms acceleration, a_w calculation

The frequency-weighted rms acceleration values (a_w) in three orthogonal axis were obtained with help of equation 1- given as under;

$$a_w = \sqrt{\frac{1}{T}\int_0^T a_w^2(t)dt} \text{ , ---------------- (1)}$$

Here a_w = frequency-weighted rms acceleration in m s^{-2}, a_w (t) = frequency-weighted rms acceleration at time t in m s^{-2}, T = measurement duration.

The exposure value of rms -A(8) was calculated using equation 2.

$$A(8) = a_{wd}\sqrt{\frac{T}{8}} \text{ , ---------------- (2)}$$

Here A(8) = daily frequency-weighted rms acceleration in m s^{-2}, *awd* = frequency-weighted rms acceleration along dominant axis in m s^{-2}, a_w = frequency-weighted rms acceleration in m s^{-2}, T = measurement duration.

We calculated CF, VDV and VDV 8 using equations 3, 4, and 5 in combination with equation 2.

$$CF = \max(a^{w(t)}) \text{ ,...............(3)}$$

Here CF = crest factor, max (a_w (t)) = maximum instantaneous peak value of the rms acceleration at time t, a_w = frequency-weighted rms acceleration.

$$VDV = \sqrt[4]{\int_0^T a_w^4(t)dt} \text{ , -------------- (4)}$$

Here VDV = vibration dose value, a_w = frequency-weighted rms acceleration, and t is times at measurement of a_w, T = measurement duration.

The daily VDV exposure, noted *VDV*(8), for 8 hours of a work shift per day, was obtained by putting values in equation (2), following the ISO 2631-1 guidelines:

$$VDV(8) = K_z \times VDV_d \sqrt[4]{\frac{T_0}{T}} \text{ , -------(5)}$$

Where VDV_d = vibration dose value in dominant axis, expressed in m $s^{-1.75}$, T0 = reference duration of 8 h, T = measurement duration, K_z = scaling factor for health for dominant axis (here *z* axis) = 1.

2.5 Methods to analyze data statistically

To get statistically analyzed results from the data collected on independent variable (vibration exposure from haulage operation) and dependent variable (miscellaneous occupational and personal factors), both IBM SPSS, 26, and R programming were used. The mean values with variance and range of different variables (occupational, personal and socioeconomic) were calculated. To check the risk factors associated with MSDs in spine, neck, upper limb, and lower limb, Multivariate Regression Analyses along with Odd Ratios with 95% CI were applied and their validity was checked using Omnibus test (X^2) (Sharpe, 2015).

3. Results

3.1 Personal and occupational information of workers

In this section, a combination of personal and occupational information was gathered. questions about work routine, experience, and socio-economic profile were asked. To calculate their BMIs, we measured participants' heights and weights. Means of these and many other miscellaneous factors were calculated and mentioned in table 1. Their average income was in category 2, implying for 41,000 to 60,000 per month. History of accident other than workplace. Number of workers with MSDs was 78. There were very minimal facilities to get access to basic health facilities and child schooling. Half of the respondents were having no national identity.

Table 1. Mean values different factors of workers

variables	mean	Sd	var	range
Age	42.2389	7.823	49.896	38(27,59)
BMI	22.897	2.486	7.1602	26(21,30)
Working hours/day	9.5596	1.535	2.358	11(8,14)
Working months/year	8.8205	1.863	3.472	9(4,13)
Number of workers reporting MSD pain	0.7866	0.4100	0.1681	1(0,1)
Work experience (years)	8.3247	4.3088	18.566	23(2,25)
Monthly income (PKR)	1.9900	.6675	0.230	2(1,3)
Part time job	.1662	.3133	0.098	1(0,1)
Smoking	.200	.3290	0.200	1(0,1)
Liquor	.1600	.3374	0.175	1(0,1)
Having CNIC	.4900	.59224	0.242	1(0,1)
Education	.1100	.31315	0.098	1(0,1)
Number of workers exposed to high vibration	.8200	.30025	0.090	1(0,1)
Access to basic health facility	0.0033	0.05769	0.003	1(0,1)
Offspring education	0.0050	0.07059	0.005	1(0,1)
Break duration/day	1.897	0.4963	0.246	2(1,3)

3.2 Measurement of the whole body vibration of respondents

To evaluate workers' exposure to whole body vibration, we calculated frequency-weighted rms acceleration, vibration dose value, and crest factor. Based on the threshold limits (according to ISO 2631-1 guidelines), we categorized the respondents into two groups. Details are coded in table 2. The mean value of VDV (8) was 18.21 (with 11.64 and 24.07 values of upper and lower bound respectively) for the operators being exposed to vibration. Whereas, the mean VDV (8) was 12.33 for the operators working at relatively safe range (labelled as non-exposed group of 18 workers).

For the evaluation of the risk factor associated to workers' exposure to whole body vibration, we calculated percentage of their daily frequency-weighted RMS acceleration (A(8)) as well as their daily vibration-dose value (VDV (8)) vis-à-vis the ISO 2631-1 guidelines. Table 3 narrates the percentage of risk level.

From the exposed group, 100% (N=82) were at level of high health risk in connection with their daily frequency-weighted RMS acceleration. Whereas from the non-exposed group, only 39.3% were at this level of risk and 59.7% were at risk on moderate scale. The moderate scale was determined following the classification of ISO 2631-1 guidelines.

3.3 Multivariate Logistic Regression Analysis

For the workers who were found working above permissible limits, we analyzed their reporting on MSDS and their socioeconomic profile. A logistic regression with CI 95% was drawn and coded in table 4. This table finds Odd Ratios (ORs with CI 95%) of different categories of age, BMI, years of experience, break duration etc.

According to table (4), workers with working for 13-16 hours per day were having highest value of OR 95% CI 2.648(0.701-10.002) for spine. BMI (kg/m^2) range 25-30 got the highest OR value 7.799(1.135-53.587) for pain in neck. Among workers with experience 11-20 years, the OR was highest (1.435 with CI 0.415-4.964) for lower limb.

Table 2. Workers' categorization based on the level of exposure to WBV

Parameter		Frequency-weighted rms acceleration, m s^{-2}				Crest factor			Vibration dose value, m s$^{-1.75}$			
		a wx	*awy*	*awz*	*A*(8)	CF_x	CF_y	CF_z	VDV_x	VDV_y	VDV_z	*VDV*(8)
Haulage operators with measurements above	Mean	2.07	1.79	2.35	2.02	8.97	8.92	11.80	3.99	2.90	5.95	18.21
	Median	1.15	1.06	1.88	1.88	8.00	7.68	11.07	3.23	2.67	5.35	16.84
	SD	0.24	0.17	0.38	0.38	2.39	2.27	3.50	0.62	0.52	1.04	3.11
permissible level (*N* = 82)	Minimum	1.23	0.77	1.93	1.80	6.22	6.11	5.90	2.25	2.45	3.82	11.64
	Maximum	2.11	1.91	2.55	2.66	15.90	16.04	18.87	5.03	5.07	8.01	24.07
Haulage operators with measurements within permissible level (*N* = 18)	Mean	0.61	0.40	0.92	0.92	6.57	6.53	09.89	3.21	2.05	5.91	12.33
	Median	0.47	0.40	0.91	0.91	7.31	6.83	11.66	2.44	2.18	5.25	12.57
	SD	0.09	0.06	0.12	0.12	1.43	1.39	2.78	0.59	0.70	1.30	1.87
	Minimum	0.40	0.39	0.69	0.69	4.06	3.31	5.97	1.91	1.59	3.73	9.00
	Maximum	0.75	0.47	1.17	1.17	8.98	8.63	13.88	4.77	5.00	10.82	15.81

Note: CF*x*, CF*y*, CF*z* = crest factor in *all three respective axes (x,y,z)*; *A*(8) = daily frequency-weighted rms acceleration; *VDV*(8) = daily vibration dose value; a_{wx}, a_{wy}, a_{wz} = frequency-weighted rms acceleration in *x, y, z* axes respectively; *N* = number of operators; VDV_x, VDV_y, VDV_z = vibration dose value in *x, y, z* axes respectively; *SD* = standard deviation.

Table 3. Workers' percentage in ISO marked categories of health risks

Haulage operator	WBV	% of workers having moderate health risk	% of workers having high health risk
Exposed group (N=82)	*A*(8), m s^{-2}	0	100
	VDV(8), m s$^{-1.75}$	26.5	84.5
Non-exposed group (N=18)	*A*(8), m s^{-2}	59.7	39.3
	VDV(8), m s$^{-1.75}$	70.2	29.8

Table 4. Multivariate Logistic analysis for occupational and socioeconomic risk factors significant for MSDs among vibration exposed group. (N=82).

FACTORS	NECK	Spine	Lower limb	Upper Limb
	OR (95% CI)	**OR (95% CI)**	**OR (95% CI)**	**OR (95% CI)**
AGE(YAERS)				
25-34	0.056(0.002-1.657)	1.597(0.450-5.666)	1.624(0.437-5.519)	0.706(0.175-2.845)
35-44	0.018(0.001-0.521)	2.408(0.655-8.852)	0.589(0.168-2.065)	0.895(0.215-3.721)
45-54	0.032(0.001-0.996)	2.525(0.613-10.393)	1.172(0.296-4.644)	0.464(0.098-2.182)
BMI (KG/M^2)				
15-24	0.996(0.414-2.400)	0.714(0.310-1.648)	1.381(0.581-3.283)	0.794(0.313-2.013)
25-34	7.799(1.135-53.587)	1.587(0.350-7.201)	0.539(0.096-2.983)	1.219(0.235-6.316)
MONTHLY INCOME				
20,000-40,000	3.184(0.917-11.062)	0.670(0.196-2.289)	1.222(0.362-4.130)	1.130(0.303-4.215)
4,1000-60,000	0.416(0.099-1.743)	0.710(0.180-2.805)	0.674(0.167-2.717)	1.852(0.406-8.446)
PART TIME JOB				
YES	0.029(0.003-0.273)	0.301(0.119-0.763)	0.733(0.329-1.631)	1.377(0.564-3.363)
NO	24.007(3.66-31.89)	3.320(1.311-8.409)	1.364(0.613-3.036)	0.726(0.297-1.774)
WORK SITE RESIDENCE				
OFF WORK SITE	1.020(0.377-2.758)	0.763(0.296-1.966)	0.747(0.285-1.958)	1.868(0.646-5.397)
ON WORK SITE	0.981(0.363-2.652)	1.310(0.509-3.374)	1.338(0.511-3.507)	0.535(0.185-1.547)
HISTORY OF ACCIDENT				
YES	2.335(0.764-7.135)	0.784(0.303-2.030)	2.121(0.798-5.640)	1.434(0.481-4.256)
NO	0.428(0.140-1.309)	1.275(0.493-3.301)	0.471(0.177-1.253)	0.699(0.235-2.077)
SMOKING				
YES	5.843(1.787-19.105)	0.459(0.182-1.155)	0.800(0.342-1.871)	1.054(0.415-2.675)
NO	0.171(0.052-0.560)	2.181(0.866-5.494)	1.251(0.535-2.927)	0.949(0.374-2.410)
DURATION OF BREAK TIME (MINUTES)				

15	1.179(0.231-6.014)	0.828(0.178-3.844)	0.222(0.044-1.113)	3.046(0.521-17.805)
30	0.795(0.188-3.359)	0.769(0.199-2.969)	0.404(0.100-1.635)	1.994(0.416-9.564)
45	0.848(0.166-4.323)	1.210(0.260-5.628)	4.505(0.899-22.583)	0.328(0.056-1.919)
WORKING EXPERIENCE (YEARS)				
<=10	0.183(0.048-0.706)	1.115(0.320-3.889)	1.093(0.303-3.937)	1.044(0.269-4.044)
11- 20	0.278(0.075-1.031)	1.146(0.334-3.934)	1.435(0.415-4.964)	0.829(0.219-3.142)
>20	5.450(1.417-20.954)	0.897(0.257-3.129)	0.915(0.254-3.298)	0.958(0.247-3.711)
WORKING HOURS/DAY				
8-10	0.039(0.001-1.205)	0.378(0.100-1.426)	0.722(0.197-2.646)	1.948(0.454-8.365)
11-13	1.475(0.648-3.356)	0.669(0.310-1.446)	0.723(0.328-1.594)	1.606(0.678-3.802)
14- 16	0.039(0.001-1.205)	2.648(0.701-10.002)	1.365(0.378-5.076)	0.513(0.120-2.204)

4. Discussion

In this study, we monitored haulage operators' exposure to whole body vibration (WBV) during their work shift at underground coal mines. Also, we surveyed the prevalence of musculoskeletal diseases among them using Standard Nordic Musculoskeletal Questionnaire (SNMQ). Based on the observation, data of workers was divided into two groups; first with very risky exposure to WBV, and second with moderate to no risky exposure to WBV.A detailed analysis was drawn on values of whole-body-vibration, prevalence of consequent diseases and the socioeconomic profile of all workers (N=100).

To monitor operators' exposure to WBV, we calculated daily frequency-weighted rms acceleration (A(8)) in a_{wx}, a_{wy}, a_{wz} , crest factors, and daily vibration dose value (VDV (8) as VDV_x, VDV_y, $VDV)_z$, for all three respective orthogonal axes. The mean values of all these measurements show that in highly-exposed group of operators, the highest crest factor is for *z* axis, and the highest VDV is also for z axis. This is because the workers have to operate haulage in standing position. For the group of operators with less exposure to WBV, these values were also high for the z axis. Some other studies find the high magnitude of z axis among drivers of heavy engines or earth moving machinery (Kim et al., 2016; Akinnuli et al., 2018). We compared the situation of workers' exposure of WBV with guidelines of ISO 2631-1, and calculated level of risk. All (100%) of the workers from exposed group were having high level of risk. On the contrary, from the less exposed group, only 39% were at this high level of risk.

Workers were relatively young. However, their BMI were high as majority of the operators was obese. During logistic regression analysis of BMI categories with prevalence of MSDs, we get high odd ratios (ORs) with maximum confidence intervals (CI) for workers falling in high category (26 kg/m^2- 34 kg/m^2) of BMI. There are studies finding the same relation (Emkani et al., 2016; Akinnuli et al., 2018). Likewise, duration of daily and annual work-shift is also significant for these sampled haulage operators. They were spending more than 8 hours/day with maximum break of 45 minutes/shift, at their respective mines. The OR (CI95%) value for pain in upper and lower limb was high for workers spending 14 to 16 hours per day at the workplace. There are studies which prove relationship between duration of shift/day, and the exposure to WBV resulting into prevalence of MSDs (Cann et al., 2004; Johnson et al., 2018).

Among workers (N=82) exposed to whole body vibration, reporting of pain in neck, spine, upper limb and lower limb was classified according to groups of age, experience, working hours, break duration etc. Workers with age groups above 30 reported pain in maximum body parts which proved significance of age in causing pain. The study establishes the same results (Senthanar and Bigelow, 2018). Number of years of experience did also influence reporting of pain in workers' limbs. Its prevalence was common among workers with great number years of experience. Based on the analysis of logistic regression models, the ORs (CI95%) proved association of every studied occupational and personal factor with discomfort in upper and lower extremities of workers. These ratios varied with variation in classification of each factor, e.g., age groups, work stages, number of working hours/day, duration of break/shift, etc. It was high in all parts of upper limbs of workers with history of accident.

The odd ratios hold high values for certain socioeconomic factors. Income and access to basic health facilities were the factors able to influence reporting in pain of different limbs of workers. The group with least income sources reported high prevalence of pain in many body parts. And the group with least access to health facilities reported largely about pain. The factor of residence at worksite and level of education was also found strongly associated with pain in neck, upper extremity and lower extremity.

5. Conclusion

The present study infers that haulage operating puts its workers at high risk of Whole Body Vibration (WBV), and the consequent musculoskeletal diseases. Among highly exposed groups, the value of vibration magnitude was maximum along *z* axis, when measured in compliance with the ISO 2631-1 guidelines. All participant of this highly exposed group were having high values of A (8), VDV, VDV(8), and crest factor. While surveying the prevalence of WHB-induced-MSDs, pain in neck, spine, upper limb and lower limb was asked. This prevalence was compared among categories of workers with respect of age, BMI, experience, duration of shift, etc. pain in spine was prevailing the most, followed by lower limb, neck and upper limb. It is probably due to the high degree of risk level from exposure to vibration stemming from haulage operation, notwithstanding other occupational and socioeconomic factors. Although the sample size includes only 100 workers, still the study is believed to provide useful information about prevalence of health risks induced by haulage operation in underground coal mines of Punjab, Pakistan

Authors' Contribution

Madiha Ijaz proposed the main concept, conducted study, designed statistical analysis methods and wrote initial draft of the paper. Momina Sajid helped in collection of filed data, prepared results, and did proof read of the manuscript.

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Declarations

Ethical Approval and consent to participate

The current study was approved by the Bioethical Clearance Committee of University of the Punjab.

Competing interest

All authors declare that they have no competing interests for this research titled Association between Whole Body Vibration (WBV) and prevalence of MSDs amongst haulage operators of underground coal mines of Punjab, Pakistan.

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