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Original Article

Whole-body Vibration Exposure of Drill Operators in Iron Ore Mines and Role of Machine-Related, Individual, and Rock-Related Factors

Dhanjee Kumar Chaudhary [1], Ashis Bhattacherjee [1,*], Aditya Kumar Patra [1], Nearkasen Chau [2,3]

[1] Department of Mining Engineering, Indian Institute of Technology, Kharagpur, India
[2] National Institute for Health and Medical Research (Inserm), U1178, Paris, France
[3] University Paris-SudU and University Paris Descartes, UMR-S1178, Paris, France

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ABSTRACT

Background: This study aimed to assess the whole-body vibration (WBV) exposure among large blast hole drill machine operators with regard to the International Organization for Standardization (ISO) recommended threshold values and its association with machine- and rock-related factors and workers' individual characteristics.

Methods: The study population included 28 drill machine operators who had worked in four opencast iron ore mines in eastern India. The study protocol comprised the following: measurements of WBV exposure [frequency weighted root mean square (RMS) acceleration (m/s^2)], machine-related data (manufacturer of machine, age of machine, seat height, thickness, and rest height) collected from mine management offices, measurements of rock hardness, uniaxial compressive strength and density, and workers' characteristics via face-to-face interviews.

Results: More than 90% of the operators were exposed to a higher level WBV than the ISO upper limit and only 3.6% between the lower and upper limits, mainly in the vertical axis. Bivariate correlations revealed that potential predictors of total WBV exposure were: machine manufacturer ($r = 0.453$, $p = 0.015$), age of drill ($r = 0.533$, $p = 0.003$), and hardness of rock ($r = 0.561$, $p = 0.002$). The stepwise multiple regression model revealed that the potential predictors are age of operator (regression coefficient $\beta = -0.052$, standard error SE = 0.023), manufacturer ($\beta = 1.093$, SE = 0.227), rock hardness ($\beta = 0.045$, SE = 0.018), uniaxial compressive strength ($\beta = 0.027$, SE = 0.009), and density ($\beta = -1.135$, SE = 0.235).

Conclusion: Prevention should include using appropriate machines to handle rock hardness, rock uniaxial compressive strength and density, and seat improvement using ergonomic approaches such as including a suspension system.

1. Introduction

A feature of a machine is that when it oscillates due to external and internal forces, these are transmitted to workers' bodies through the part in contact with the vibrating surface, such as the handle of a machine (known as "hand–arm vibration"), surface of a piece of equipment, or seat of a mobile machine (known as "whole-body vibration", WBV). Occupational exposure to WBV has generated many health concerns and related medical and socioeconomic consequences in most industrialized countries. It is recognized as a potential risk factor for musculoskeletal disorders (MSDs) in the workplace [1,2]. Several epidemiological investigations reported the role of long-term exposure to WBV in the occurrence of low back pain and early degeneration of the lumbar spine, including intervertebral disc disorders [3–5]. Some studies indicated that lower back pain, a common disorder, is more prevalent in professional drivers than in control groups unexposed to WBV [6–8], but the authors concluded that not a single study satisfied the criterion

* Corresponding author. Department of Mining Engineering, Indian Institute of Technology, Kharagpur 721302, India.
E-mail address: ashisb2006@gmail.com (A. Bhattacherjee).

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to draw any conclusion about the specific health effects of WBV. Recently, studies have investigated the prevalence of MSDs among professional drivers of industrial machines and vehicles which have contributed to the understanding of the risk of back symptoms and disorders of lumbar spine [2,9–20]. A number of earlier studies have demonstrated that operators in construction stone quarry [21], locomotive [22], forklift [23], crane [24], transportation [25], and load–haul–dump (LHD) [9,26] are exposed to high levels of WBV. High levels of WBV exposure were recorded from all-terrain vehicles [27–30], farm tractors [31], professional drivers [13], heavy vehicle operators [32], and agricultural quad bikes [33].

Opencast mines are associated with high level of mechanization that includes deployment of heavy earth moving machinery for production and ancillary processes. Vibration sources in opencast iron ore mines include machines such as drills, shovels, road headers, rock breakers, bulldozers, and heavy duty dumpers. The operators of such machines are therefore expected to be subjected to high exposure to WBV. Moreover, trucks and buses operate on public roads which are paved. However, the heavy machinery in mines operate under unpaved and undulated natural surfaces with the potential of high WBV exposure. In India, the number of miners regularly exposed to WBV ranges from 1.80 lakhs to 18 lakhs and they are at risk of WBV related health consequences [34]. To date a few studies on mining industries have reported high daily WBV exposure experienced by heavy equipment operators, especially those working with load–haul–dump mining vehicles [9,26]. An earlier study involving seven LHD vehicles used in mining reported that four LHD operators experienced vibration levels within the Health Guidance Caution Zones (HGCZ) limits established in ISO 2631-1 while the remaining three operators experienced vibration levels above the HGCZ [9]. In another study it was found that 50% of the LHD operators are exposed to WBV level above the HGCZ. WBV exposure levels previously reported for LHD vehicle operators of two underground mines do suggest vibration frequencies are in a range that is harmful to human health [26]. One survey conducted in several opencast mines in India found that operators of heavy earth moving machinery were subjected to WBV exposure that exceeds the ISO 2631-1 standard and therefore the workers are at a greater health risk of WBV exposure [34]. An Australian study on 36 drivers and passengers in mining vehicles reported 80%, 75%, and 50% of workers complaining of musculoskeletal disorders, low back pain, and neck pain, respectively [35].

Many factors may influence the WBV exposure level of heavy earth moving equipment operators. This can broadly be categorized into: (1) machine related factors that include vehicle type and design, age and condition of vehicle, vehicle suspension systems, seat type and design, cab layout, position and design, vehicle or machine speed, lighting and visibility; and (2) personal factors such as drivers' age, body mass index (BMI), living style, and health status. In addition to this a job-associated factor can also be thought of which includes road condition, task design, work organization, and working condition [35–38]. Previous studies on professional drivers of forklift trucks, forestry machines, mobile cranes, trucks, tractors, subway trains, and harvesters have shown that their WBV exposure was influenced by a number of personal and physical factors including posture, workplace and vehicle characteristics (road condition, suspension systems, seat type, load, and maintenance of vehicle) as well as driving experience, driving speed, and body mass index [26,33,36–40]. The results of an earlier study on WBV exposure by the truck operators indicated that among several factors such as seat type, driver experience, road condition, truck type, and truck mileage, only the truck type and road condition are the factors that significantly influence the WBV exposure level [38]. It was suggested that the role of seat, driver experience and truck age on WBV should be explored. In the case of WBV exposure of urban taxi drivers, a study hypothesized driving speed, manufacturer, engine size, engine age, seat cushion, body weight, and age of operator as the predictive parameters [37]. It was reported that driving speed is the major parameter that influences WBV level. Engine size, wheel base, and tire width were also suggested to influence the WBV level. Notwithstanding the above studies, the research on various factors that predict the WBV exposure level is limited.

Of all the machinery in mines, the drill machines used for drilling holes for production blasts are different from others due to: (1) limited mobility; and (2) high energy operations where holes are drilled into natural strata which are very hard. In addition to machine-related and personal factors, the rock-related parameters such as hardness, uniaxial compressive strength, and density of rock significantly influences the WBV level. The drill machine is therefore a unique machine as far as WBV exposure from its operators is concerned. Depending on geo-mechanical characteristics of the strata, the operation requires high power drilling which involves a high level of vibration of machine as well as operator. However, no investigation has been carried out either on WBV exposure level of drill operators or the influence of rock-related parameters on WBV exposure in opencast mines. The present study aimed at assessing the WBV exposure (in reference to the threshold values recommended by the ISO 2631-1 (1997) [41]) and determining which factors related to machine, rock, and individual (manufacturer of machine, age of drill machine, height of seat, thickness of seat pad, height of seat rest; hardness, uniaxial compressive strength, and density of rock; operator's age, weight, height, and drilling experience) that predicted the WBV exposure levels experienced by the drill machine operators in the opencast iron ore mines in India.

2. Materials and methods

2.1. Study sites

The study was conducted during May–November 2013 in four opencast iron ore mines located in eastern India. All these mines are operated by the same company and have the same infrastructure and service facilities required for large sized and fully mechanized opencast mines. These mines supply iron ore to integrated steel plants. The method of mining is top slicing with deep hole drilling and blasting. The height of the benches is 10 m in overburden and ore with bench width more than or equal to the bench height. Down-the-hole method of drilling is being practiced with 6 inch (150 mm) diameter drills. Loading was being carried out with a combination of shovel, hydraulic excavator, and front end loaders of 2.7–4.6 m^3 capacity. Ore/waste was transported with 35–85-tonne rear discharge dumpers. Slurry explosives and nonel detonators were used for blasting. The spacing and burden in overburden/ore benches varied from 5 m to 6 m. The study mines have the same occupational, safety, and health practices.

The study protocol included: (1) face-to-face interview using a questionnaire to record personal factors including operator's age, weight, height, and drilling experience; (2) collection of drill machine-related data (manufacturer, age of drill machine, height of seat and seat rest, and thickness of seat pad) from mine office; (3) collection of rock samples from drilling sites and laboratory test for the hardness, uniaxial compressive strength, and density of rock; and (4) measurement of WBV exposure.

2.2. Participants

The study population included all 32 blast-hole drill machine operators who were working in the four mines. Among the 32