Whole Body Vibration in Open Pit Mining - A short review

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ABSTRACT: The main objective of this study was to synthesize scientific knowledge in order to characterize Whole Body Vibration (WBV) in open pit mining: sources, measurements methodologies and main effects on health. A review based on PRISMA Statement was done. Inclusion criteria were research on WBV in mining, published after 1990 and written in English. Thirty-three studies were included in the review. Rock drills, shovels and dumpers are strongly present in this industry. They are potential sources of workers exposure to WBV. All bibliography followed methodological recommendations of ISO 2631-1:1997. For WBV characterization routine works, individual tasks, occurrence records, pavement features, were topics considered. Dumper is the equipment that can be the more dangerous; it has the highest Root Mean Square (RMS) acceleration values. Back pain is the main complaint in workers due to WBV exposure.

1 INTRODUCTION

All risk categories are present in mining environment (Donoghue 2004). Consequently, mining is classified as high risk activity and it is being the target of numerous studies, always aiming to eliminate/reduce accidents and prevent occupational diseases. In open pit mining, production is based on the extraction and processing of rocks. It includes fundamental operations such as drilling, charging and blasting, loading, transport and crushing (Matos & Ramos 2010). These operations are carried out with equipment that generates vibrations which workers are exposed. Rock drills, shovels and dumpers are common equipment in this industry, and potential sources of Whole-Body Vibration (WBV) (Aye & Heyns 2011; Leduc, Eger *et al.* 2011; Kunimatsu & Pathak 2012).

According some authors (Bovenzi 1996; Pope, Magnusson *et al.* 1998; Pope, Wilder *et al.* 1999; Cann, Salmoni *et al.* 2003; McPhee 2004) there are a strong connection between exposure to WBV and low back pain. It is important and interesting to companies and professionals to reduce this exposure and consequently workers complaints.

This article intends to be a synthesis of scientific knowledge on WBV in open pit mining. The main objective is to present the most recent and relevant scientific information available in order to characterize the jobs in this workplace, measurement methodologies and the main known effects on workers' health.

2 RESEARCH METHODOLOGY

A literature review was carried out based on PRISMA® Statement (Preferred Reporting Items for Systematic Reviews and Meta-Analysis).

Searches were conducted in data bases such as Web of Knowledge (which include Current Contents Connect, Derwent Inovation Index, Essential Science Indicators, Journal Citation Reports, Web of Science + Proceedings), Scopus and Academic Search Complete, and scientific journals such as Annual Reviews, EBSCO Electronic Journals Service, Elsevier (ScienceDirect), Springer, Taylor & Francis and Wiley InterScience. Articles from other sources, like references of the articles selected in the first stage of the systematic review, were not excluded.

The keywords used were: occupational vibration, whole-body vibration, hand arm vibration, mining, extractive industry, mining equipment, open cast mining. These words were combined with different Boolean operators, searching on title, abstract and keywords.

The exclusion criteria were:

- Language: The review was restricted to studies published in the English language;
- Publication date: Articles published before 1990 were excluded (this date was set out because it was intended to cover older equipment still in use in the industry);
- Subject (relevance to the purpose of the review): For inclusion, the study should deal with occupational vibration in mining.

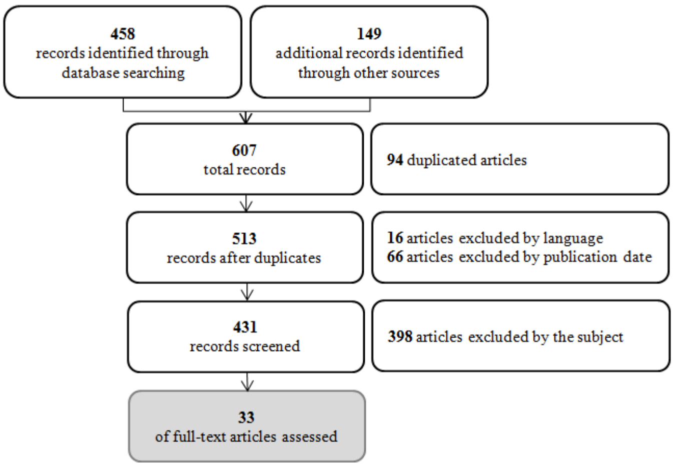
All identified studies were screened initially by title and abstract, and then more carefully in full text.

3 RESULTS AND DISCUSSION

3.1 *Research results*

Literature search has produced 607 potentially relevant papers. Following screening process steps shown in Figure 1. Thirty-three articles were included in the review. Most of them were discarded due to violating the inclusion criteria, although many duplicates were also excluded.

Figure 1. Flow diagram of studies selected for review.



3.2 *Sources of vibration in mining*

Classes of equipment and their open pit mining operations (WBV producers) were studied (Table 1).

Table 1. Equipment and operations associated with WBV.

Machine	Activity
Rock drill	Positioning Drilling Travelling
Shovel	Trenching/excavating Swinging and loading Travelling
Dumper	Travelling Loaded by shovel Unloading

Kunimatsu and Pathak (2012)

3.2.1 *Rock drills*

Rock drills are, according to several authors, the equipments that produce lower Root Mean Squared (RMS) acceleration values over the occupational exposure. Howard, Sesek *et al.* (2009) reached an acceleration of 0,30 $m{\cdot}s^{-2}$ and Van Niekerk, Heyns *et al.* (2000) 0,16 $m{\cdot}s^{-2}$ on vertical axis (zz). According to these authors, at this workplace, the operator will be safeguarded from the risk of exposure to WBV. These studies were the only ones to analyze WBV in rock drills.

3.2.2 *Shovels*

Due to its flexibility, low-cost operations, maintainability and multifaceted operating capability, shovels are widely used in surface mines (Frimpong, Galecki *et al.* 2011).

The studies aiming the characterization of WBV exposure in shovels, in open pit mining, found very different values for RMS. Some studies point to WBV values below 0.5 $m.s^{-2}$ (Howard, Sesek *et al.* 2009; Aye & Heyns 2011; Dentoni & Massacci 2013). However, authors like Vanerkar, Kulkarni *et al.* (2008) call attention to the risk conditions that may be subject these workers, with WBV values reaching 2.3 $m.s^{-2}$. The same happens with the predominant axis, there is no a clear definition. The vertical (zz) and the longitudinal (xx) are presented as the main axis according Aye & Heyns (2011) and Dentoni & Massacci (2013).

Thus, the discrepant characterization of exposure to WBV in these equipments is notorious. This is probably due to the multiple operations carried by shovel, which lead to different situations.

3.2.3 *Dumpers*

Dumpers are strong vehicles widely used in open pit mining environments to transport large quantities of rock to crushing plants or dump locations. Their capacity range is from 7 to 350 tonnes (Mandal & Srivastava 2010; Eger, Stevenson *et al.* 2011).

The majority of studies analyzed (Van Niekerk, Heyns *et al.* 2000; Kumar 2004; Eger, Stevenson *et al.* 2008a; Howard, Sesek *et al.* 2009; Mandal & Srivastava 2010; Smets, Eger *et al.* 2010) assigns to these machines considerable vibration values, above 0.5 $m.s^{-2}$. The predominant axis is the vertical (zz). The dominant frequencies are set below 4 Hz.

3.2.4 *Synthesis*

Table 2 shows the analyzed studies towards the characterization of WBV exposure in rock drills, shovels and dumpers in open pit mines. It is focused the RMS acceleration value, main axis and dominant frequencies.

In open pit mines, in terms of WBV exposure were highlighted by its relevance, rock drills, shovels and dumpers (Howard, Sesek *et al.* 2009).

Rock drill workers had the lowest exposition to WBV (only office workers are below). They are followed by the Shovels and Dumpers operators by increasing degree of risk. This ranking is consistent with the values collected in this review. Thus the dumper will be the workplace targeted for priority intervention.

Table 2. Summary of studies characterizing exposure to WBV in rock drilling, shovel and dumper in open pit mining.

Machine	Authors (year)	RMS [$m.s^{-2}$]	Main axis	Dominant frequencies

				[Hz]
Rock drill	Howard, Sesek *et al.* (2009)	0,30	-	-
	Van Niekerk, Heyns *et al.* (2000)	0,16	z	-
Shovel	Dentoni & Massacci (2013)	0,52-0,97	x	-
	Kunimatsu & Pathak (2012)	0,5-2,3	-	-
	Aye & Heyns (2011)	0,21-0,51 0,25-0,39	z x	-
	Howard, Sesek *et al.* (2009)	0,45	-	-
Dumper	Smets, Eger *et al.* (2010)	0,80	-	2 – 4
	Mandal & Srivastava (2010)	1,10	z	-
	Howard, Sesek *et al.* (2009)	0,58	-	-
	Eger, Stevenson *et al.* (2008a)	0,77	z	1,0-1,25 (x) 1-1,25 (y) 3,15 – 4 (z)
	Kumar (2004)	0,37-11,73	z	2 – 4
	Van Niekerk, Heyns *et al.* (2000)	0,75	z	-

3.3 *Methodologies applied to the measurement of vibrations transmitted to the whole body*

In the equipment under consideration the contact points between the worker and the machine are, par excellence, feet and seat (Kunimatsu and Pathak 2012). The vibration transmitted to the hand-arm through contact with the controls of vehicles or the steering wheel is not relevant (Hill, Langis *et al.* 2001; Donoghue 2004; Gallagher and Mayton 2007; Kunimatsu and Pathak 2012). However, these workers are exposed to impact shocks (Eger, Stevenson *et al.* 2011).

The bibliography, focused on WBV, follows almost consensually, the ISO standard 2631-1:1997 - Mechanical vibration and shock - Evaluation of human exposure to whole-body vibration - Part 1: General requirements (ISO 1997). Besides being followed methodological principles for the measurement of vibration, are also followed the calculation methods of required parameters to evaluate vibration exposure. One of the methodological recommendations of ISO 2631-1:1997 that should be emphasized in this work is the measurement and analysis of vibration exposure separately, taking into account the existence of several periods with different characteristics (Chapter 5.5 Duration of measurement).

Typically, a mining environment involves well defined operations with short duration, associated with different vibration amplitudes. Thus, measurements should be made for each operation and the result obtained from the combination of these.

The most striking example is the dumper. In these, worker exposure to vibration changes considerably with the task. Usually a work cycle includes tasks such as unloaded travel, loading, loaded travel and dumping (Smets, Eger *et al.* 2010).

Salmoni, Cann *et al.* (2010) and (Smets, Eger *et al.* 2010) said the expected, that the waiting times (standby) are those where the vibration exposure is lower as opposed to transport tasks (movement of the vehicle loaded and unloaded) where the vibration values are higher. Different authors warn that, for the determination of daily exposure to WBV, all tasks should be considered as well as its duration time.

For this reason, some studies, together with the measurement of vibration levels, followed visually the operations, noting the time period of the tasks and any observations which may have influence in the results (Salmoni, Cann *et al.* 2010; Smets, Eger *et al.* 2010; Leduc, Eger *et al.* 2011). Other authors recorded the operations in video (Eger, Stevenson *et al.* 2008b; Torma-Krajewski, Wiehagen *et al.* 2009; Salmoni, Cann *et al.* 2010).

Another very important aspect of this activity is a strong correlation between the features and conditions in which the work is developed and the resulting exposure to WBV (Kunimatsu and Pathak 2012). The vibration suffered by workers when operating with vehicles depend on, among others, the external excitation force, the mass of the vehicle and environmental factors such as the condition of the pavement, the characteristics of the material handled, operations organization and worker experience (Mandal & Srivastava 2010; Frimpong, Galecki *et al.* 2011). As expected, exposure to WBV does not depend on the type of operation (raw material), but from the working conditions and the type of equipment used as stated by the authors as Vanerkar, Kulkarni *et al.* (2008).

Equipment for determining the vibrations are triaxial accelerometers. The accelerometer is normally placed in a rounded surface rubber which is fixed with tape to the operator's seat. By the bibliography, the vibration measured is often the one that is transmitted through the seat, to the seated body as a whole. The vibration transmitted through the feet and the seat backrest is not normally considered (Leduc, Eger *et al.* 2011).

Other parameters analyzed in WBV studies are:

– machines characteristics (Kumar 2004; Howard, Sesek *et al.* 2009; Eger, Stevenson *et al.* 2011; Dentoni & Massacci 2013);
– operations that the equipment performs (Kumar 2004; Eger, Stevenson *et al.* 2008; Salmoni, Cann *et al.* 2010; Smets, Eger *et al.* 2010; Leduc, Eger *et al.* 2011);
– work routines (Torma-Krajewski, Wiehagen *et al.* 2009; Smets, Eger *et al.* 2010);
– pavement conditions (Mayton, Amirouche *et al.* 2005; Howard, Sesek *et al.* 2009; Salmoni, Cann *et al.* 2010; Dentoni & Massacci 2013);
– position and seat features (Mayton, Amirouche *et al.* 2005);

– vibration type (continuous, intermittent, impact) and its direction and source (Leduc, Eger *et al.* 2011);
– number of times that performs the task or all work cycle per day, average duration of the task or work cycle (Mandal & Srivastava 2010; Smets, Eger *et al.* 2010);

Simultaneously, other important information are collected as e.g. demographic information, medical and occupational historic and lifestyle (Eger, Stevenson *et al.* 2008; Mandal & Srivastava 2010; Smets, Eger *et al.* 2010; Eger, Stevenson *et al.* 2011; Leduc, Eger *et al.* 2011).

3.4 *Main effects of whole-body vibrations*

Establish direct relations between WBV exposure and its effects are not easy. Magnusson, Pope *et al.* (1998) reported difficulties in establishing a clear relationship between exposure and effect, mainly due to the high number of factors influencing the risk associated with exposure to WBV. Mansfield (2004) suggests a holistic and cautious approach. The effect of exposure to WBV most often reported in the literature is the back pain. This relation is established in several epidemiological studies (Teschke, Nicol *et al.* 1999; Lings & Leboeuf-Yde 2000; Gallais & Griffin 2006; Gallagher & Mayton 2007). However, the same type of complaints occurs in most work activities, and is demonstrably influenced by human degenerative process associated with age, so it is not easy to establish a direct causal link. Other reported symptoms are sciatic pain, low back pain and widespread pain in the back, and may be associated illnesses such as herniated discs and early degeneration of the spine (Teschke, Nicol *et al.* 1999; Gallagher & Mayton 2007; Eger, Stevenson *et al.* 2011).

In the particular case of heavy equipment operators, which include mine workers, epidemiological studies try to associate back pain and the operation of vehicles. Truck drivers, shovels and dumpers are at high risk, because are exposed to WBV with values often higher than those recommended. It is also accepted that the risk of musculoskeletal injuries increased with increasing time of exposure (Teschke, Nicol *et al.* 1999; Bovenzi, Rui *et al.* 2006; Gallagher & Mayton 2007).

Teschke, Nicol *et al.* (1999) and Gallais & Griffin (2006), with their analyzes of epidemiological studies on exposure to WBV in drivers, concluded that there were several competing factors for the appearance of back pain. Age, working postures, materials handling and "heavy" work, smoking, falls or other events that cause pain, stress and work pressure, physical condition and morphology of the body, including weight, height are some of the examples reported. In other words, confirmed the large number of confounding factors related to this problem.

In fact, the adoption of postures is a very important aspect regarding to drivers health. This is an additional factor of physical load in the column that, together with exposure to vibration, is a source of back pain reported by professional drivers (Teschke, Nicol *et al.* 1999; Bovenzi, Rui *et al.* 2006).

4 CONCLUSIONS

Rock drills, shovels and dumpers are strongly present in open pit mining. They are potential sources of workers exposure to WBV. The dumper is the one with higher values of WBV, followed by the shovel and finally by the rock drill, which is the least dangerous to workers health. The WBV are typically measured with the operator seated and through the seat. The tasks within a work cycle are detailed with timing and recording occurrences that may influence. The machine characteristics, the operator tasks, work routines, pavement conditions, vibration type, seat characteristics are topics that should be included in an exposure to WBV study. It is not proved a direct causal relationship between the drive a mining vehicle and the appearance of back pain. However there is evidence that the most frequent complaint among workers is back pain.

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