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Occupational Vibration in Urban Bus and Influence on Driver's Lower Limbs: a review

M. Cvetković [1], J. Santos Baptista[2], M. A. Pires Vaz[3]

[1]Department of Occupational Safety, Faculty of Occupational Safety of the University of Niš, Niš, Serbia (marko.cvetkovic.33@gmail.com) ORCID 0000-0003-4425-8575; [2]Department of Mining Engineering, Faculty of Engineering University of Porto, Porto, Portugal (jsbap@fe.up.pt) ORCID 0000-0002-8524-5503; [3]Department of Mechanical Engineering, Faculty of Engineering University of Porto, Porto, Portugal (gmavaz@fe.up.pt) ORCID 0000-0002-6347-9608

Abstract

Whole-body vibration occurs in many occupational activities, promoting discomfort in working environment and inducing a variety of psychophysical changes where consequences as a permanent dysfunction of certain parts of the organism may occur. The main goal of this review article is to find research works with the most reliable results relating whole-body vibrations in buses and, to compare them with the results of drivers' lower limbs musculoskeletal disorders, which occurs as a result of many years exposure. PRISMA Statement Methodology was used and thereby 32 scientific databases were searched through where 3996 articles were found, of which 5 were included in this review. As leading standards for whole-body vibration analysis, ISO 2631-1 and ISO 2631-5 standards were considered. Furthermore, works including the European Directive 2002/ 44/ EC, where a daily action exposure to the whole-body vibrations is determined were also considered. All the results presented in this paper were compared with the aforesaid standards. Implementing the research methodology on the available databases, considering the problem of the impact of the vibration on the lower limbs, the found papers did not contain any information about the described problem.

Author Keywords. Whole-Body Vibration, Exposure, Bus Driver, Lower Limb.

Type: Review Article

1. Introduction

It is worldly accepted that occupational activities where workers are exposed to whole-body vibrations, can cause discomfort, reducing worker/operator efficiency and, at the same time, deteriorates their health (Barreira et al. 2015). The presence of the whole-body vibration problems can be found in many professions, whereas particularly high-risk groups where might be highlight the drivers of construction machinery, agricultural machinery, heavy trucks and buses (Sekulić et al. 2013). Research proved that vibrations, namely whole-body vibrations affect the exposed workers. After prolonged exposure, might lead to functional disorders and changes in the tissues. Can also cause different musculoskeletal disorders, such as pain in the lower back, the disease of spine, shoulders, head and neck, as well as mental illnesses (mental fatigue, tiredness, tension), sleep disorders, etc. (Alperovitch-Najenson et al. 2010; Blood et al. 2011; Blood et al. 2015; Kim et al 2005; Paddan et al. 1998; Picu et al. 2010; Sekulić et al. 2013; Thamsuwan et al. 2013).

In terms of the reduction of exposure to vibrations, thus reducing the risk of appearing the disease, the European Union published Directive 2002/44/EC (European Union, 2002) about the limitations of daily exposure. It should be noted that the used values, were adapted from International Organization for Standardization (ISO) 2631-1 (ISO 2631-1, 1997) where the values of Average Weighted Vibration (AW) and Vibration Dose Value (VDV), are approximately equal to the aforementioned Directive. ISO subsequently issued a new standard, ISO 2631-5 (ISO 2631-5, 2004), where the used principle was the continuous collection of raw data in a triaxle exposure to whole-body vibration. These data are further processed to obtain daily vibrations exposure in the lumbar spine and are presented as Static Compressive Dose (Sed).

For an easier comparison, the data are presented in Table 1, where an eight-hour exposure to vibrations is valid for each value. Alongside defined limit vibration dose values, presented in Table 1, ISO (ISO 2631-1, 1997) described recommendation of comfort reactions to vibratory environments. Average Weighted Vibration was defined for fairly uncomfortable response on vibration from 0.5 m.s^{-2} to 1 m.s^{-2} and uncomfortable response from 0.8 m.s^{-2} to 1.6 m.s^{-2}.

However, after searching and screening different scientific sources, it might be get the impression that, while conducting new measurements and experiments, it is recommended the use ISO 2631-1 (ISO 2631-1, 1997) instead ISO 2631-5 standard (ISO 2631-5, 2004). It needs to be noticed that these standards (ISO 2631-1, 1997; ISO 2631-5, 2004) support different procedures and different working criteria. Nevertheless, the use of the two standards can be considered as a recommendation (when measuring vibration) to a better understanding of vibration problems and its consequences for the workers 's health (Blood, 2011). The vibration disease is of chronic type, with a permanent evolution that reaches firstly a reversible functional character, but later it gains an organic character and becomes irreversible (Tamrin et al. 2007).

Therefore, of the spread of vibrations through the Human organism tissues and the consequence of the involuntary nervous system functioning, the impact of vibrations can be relatively reflected in the body where the above-mentioned diseases consequently occur. Moreover, the effect of vibrations can also cause positive effects on the organism. Different studies indicate that under longer influence of vibrations there are improvements of the strength and muscle power, which means better muscle performance (Avelar et al. 2013; Pel et al. 2009; Yu et al. 2014), improving the blood circulation (Yu et al. 2015) and increasing bone density (Schneider et al. 2015). These authors refers to literature which states that "vibration training" can lead to positive results in the treatment of sarcopenia, osteoporosis and metabolic syndrome, and that they were also used in physical therapy, the fitness industry, professional sports, rehabilitation and beauty and wellness applications.

	European Union Directive 2002/44/EC		**ISO 2631 – 5**	
	AW (m.s^{-2})	VDV (m.s^{-2})	Sed (MPa)	Probability of an adverse health effect
Action limit	0.5	9.1	0.5	Moderate
Exposure limit	1.15	21	0.8	High

Table 1: Daily (8h) action and exposure limits for a whole-body vibration

As the main objective of this review article, a question was raised "How does whole-body vibrations affect bus drivers' lower limbs?". The obtained results will illustrate the impact of vehicle vibration on lower limbs musculoskeletal disorders. Establishing the outcomes of the review paper, as a future work, the prevention measures need to be performed.

2. Materials and Methods

Following defined research problem, as the very next step, inclusion/exclusion criteria were established to reject all the articles that do not fulfil the following principles: 1) be written in English, 2) title and abstract should be in accordance with the main goal of this study and 3) papers to which content could be accessed, 4) the articles must be related to the analysis of the vibration exposure of driver's lower limbs. Subsequently, the computer research was limited to studies published between January 1, 2007, and October 1, 2017 (additional articles were involved (research was performed before above-mentioned period from the references of the selected articles) (Figure 1)).

This search included 32 scientific databases: ACM Digital Library, ACS Journals, AHA Journals, AIP Journals, ASME Digital Library, BioMed Central Journals, CE Database (ASCE), Directory of Open Access Journals, Emerald Fulltext, Highwire Press, Informaworld (Taylor and Francis), Ingenta, IOP Journals, MetaPress, Oxford Journals, SAGE Journals Online, SciELO, Science Magazine, ScienceDirect, Scitation, Wiley Online Library, Academic Search Complete, CiteSeerX, Current Contents, Inspec, MEDLINE, PubMed, ScienceDirect, SCOPUS, SourceOECD, TRIS Online, Web of Science. The used keywords were a combination of "Bus driver" with: "Vibration" + "Whole-body vibration"; "Vibration" + "Transmissibility" + "Seat"; "Whole-body vibration" + "Transmissibility" + "Seat"; "Vibration" + "Exposure"; "Whole-body vibration" + "Exposure"; "Vibration" + "Road type". Were also used the following key-words: "Bus" + "ISO 2631"; "Whole-body vibration" + "Lower limbs.

Following the previously described criteria (inclusion/exclusion) as well as detailed analysis of each article selected in this step (Figure 1), articles which provide the most information about the specified problem were selected.

3. Results

Figure 1 presents the PRISMA Statement flow diagram and defined the research methodology. The computer search through databases (established in the methodology) produced a total of 3996 records (of which 3980 were recognized by searching the database and 16 papers were found through other papers, namely by searching their references). Following the analysis and the application of these exclusion/inclusion criteria, 60 papers were considered acceptable. The present paper includes 5 papers which are presented in this review paper, including the results of vibration measurements, methodologies, device types and positions of the same ones were represented in Table 2 and Table 3. Exclusion criteria were defined to provide to eliminate any selected paper which was not considering the negative influence of the vibration on the professional bus drivers lower limbs. Following the originally based exclusion criteria, the papers did not provide any information on this topic. Based on that, the extension criteria required to be expended. The new exclusion criteria were to eliminate the paper which not contains the information of the measurements of the vibration floor of the buses.

After a detailed analysis of multiple databases, the desired results were not reached, i.e., no articles were found that addressed the topic as a whole. However, in some papers, the knee problem was emphasized, but the majority of the provided results are based on questionnaires (Tamrin et al. 2007). As the questionnaires were not supported by medical examinations, they only showed consistency in musculoskeletal pain in the drivers' lower limbs.

A real example of interdependence between road type, vehicle speed and vibration can be observed when driving at higher speeds (>83.4 (± 7.4) km/h), where the increase in vibration exceeds the standard's limits (0.51 (± 0.04)) (Lewis et al. 2012). Further, it is possible to see that the r.m.s. (root mean square) acceleration for each axis is different for different city buses types or, when they travel on cobblestones or asphalt at the same average speed (Okunribido et al. 2007).

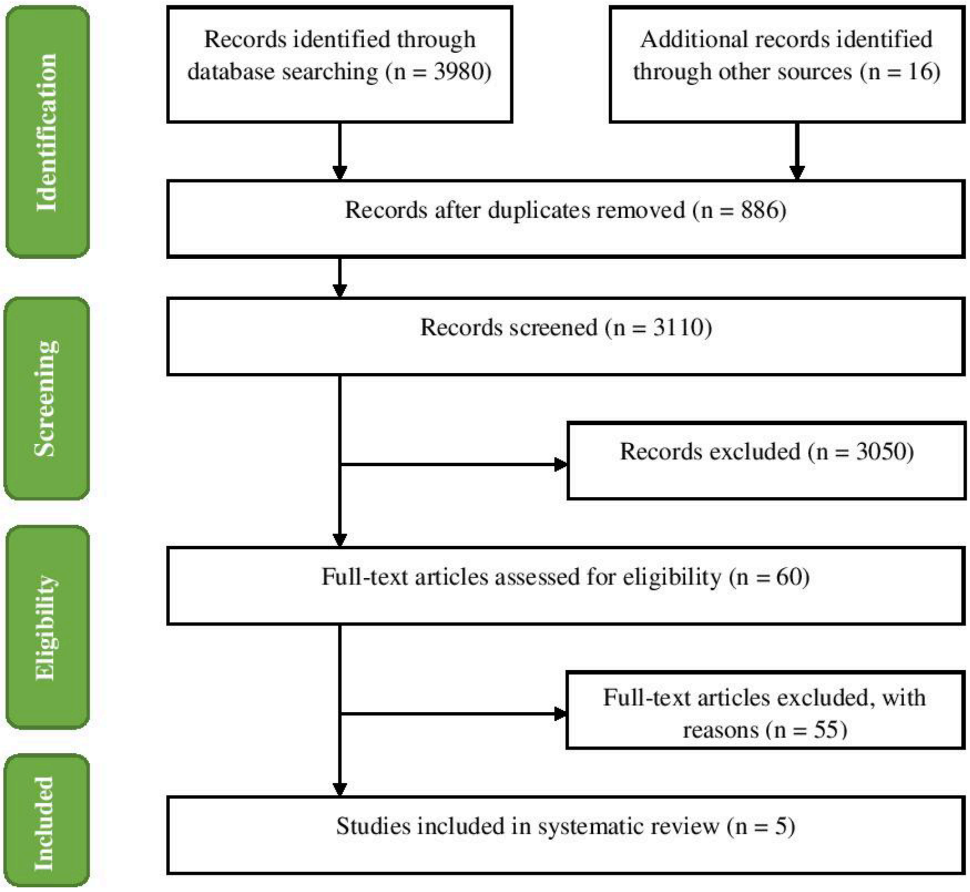

Figure 1: PRISMA Flow Diagram

In the Table 2 can be seen the type of each device and the method of the data collecting and its analyzing.

Author	Country	Standard	Device	Position of device	Data analysis	N. of buses	Time
Thamsuwan et al. (2013)	United States	ISO 2631-1 ISO 2631-5	ICP accelerometer (model 356B40; PCB Piezotronics; Depew, NY)	Seat pan and bus floor	JMP Statistical Discovery Software (version 8.0; SAS Institute; Cary; SC)	2 buses	8h
Lewis et al. (2012)	United States	ISO 2631-1 ISO 2631-5	ICP accelerometer (model 356B40; PCB Piezotronics, Depew, NY, USA)	Seat pan and bus floor	JMP Statistical Discovery Software (Version 8; SAS Institute, Cary, NC, USA)	1 bus	8h
Blood and Johnson (2012)	United States	ISO 2631-1	ICP accelerometer (model 356B40; PCB Piezotronics; Depew, NY)	Seat pan and bus floor	LabVIEW version 7.1; National Instruments; Austin, TX	N.A.	8h
Jonsson et al. (2015)	United States	ISO 2631-1 ISO 2631-5	ICP accelerometer (model 356B41, PCB Piezotronics, Depew, NY)	Seat pan and bus floor	Statistical software (JMP, SAS Institute, Cary, SC)	2 buses	8h
Blood et al. (2015)	United States	ISO 2631-1 ISO 2631-5	ICP accelerometer (Model 356B40, frequency range 0.5 – 1,000 Hz, PCB Piezotronics, Inc., Depew, NY)	Seat pan and bus floor	JMP Statistical Discovery Software (Version 10.0, SAS Institute, Cary, SC)	N.A.	8h

B & K - Bruel & Kjaer Sound & Vibration Measurement

Table 2: Standards, equipment and procedures

Table 3 presents measurements results of acceleration A (8) and Sed (MPa). From them it can be conclude that, in general, the measurements were within the limits defined in the standards (Blood et al. 2011; Lewis et al. 2012; Thamsuwan et al. 2013). The differences in the three axes are not significant, although there are considerable deviations depending on the roads' conditions and routes on which a bus is traveling (Blood et al. 2011; Blood et al. 2015; Jonsson et al. 2015; Lewis et al. 2012; Thamsuwan et al. 2013). Seat Effective Amplitude Transmissibility (SEAT) in different road types of bus circulating in paths with deferent characteristics. However, they do not provide elements in relation to the type of pavement, stating only that most of the route's pavement was built with asphalt (Blood et al. 2015; Jonsson et al. 2015). In addition, they do not demonstrate or present elements that allow a direct relationship between the type of road and / or the condition of the pavement and the SEAT (Barreira et al. 2015).

Author	Road type	Axis	A(8)	Sed(Mpa)	SEAT (%)
Thamsuwan et al. (2013)	Smooth freeway	X	0.16 (±0,01)	0.09 (±0,01)	90.0 (±2.5)
		Y	0.18 (±0,01)	0.17 (±0,01)	
		Z	0.42 (±0,02)	0.24 (±0,01)	
	Rough freeway	X	0.19 (±0,01)	0.11 (±0,01)	86.0 (±2.6)
		Y	0.21 (±0,01)	0.18 (±0,02)	
		Z	0.53 (±0,02)	0.32 (±0,01)	
	City streets	X	0.20 (±0,01)	0.12 (±0,02)	88.0 (±2.6)
		Y	0.19 (±0,01)	0.22 (±0,05)	
		Z	0.39 (±0,01)	0.32 (±0,02)	
	Speed humps	X	0.24 (±0,01)	0.12 (±0,01)	106.0 (±2.6)
		Y	0.26 (±0,01)	0.20 (±0,01)	
		Z	0.39 (±0,02)	0.41 (±0,05)	
Lewis and Johnson (2012)	Freeway	X	0.16 (±0.06)	0.42 (±0.05)*	101.7 (±1.30)
		Y	0.17 (±0.02)		
		Z	0.51 (±0.04)		
	City street	X	0.20 (±0.05)	0.71 (±0.21)*	106.9 (±1.68)
		Y	0.21 (±0.02)		
		Z	0.47 (±0.04)		
	Speed humps	X	0.25 (±0.06)	0.58 (±0.2)*	122.8 (±3.04)
		Y	0.28 (±0.02)		
		Z	0.46 (±0.08)		
Blood and Johnson (2012)	City streets	X	0.14 (±0.01)	0.45 (±0.03)*	90.4 (±72.5)
		Y	0.11 (±0.01)		
		Z	0.36 (±0.01)		
	Speed humps	X	0.17 (±0.01)	0.42 (±0.03)*	92.3 (±73.4)
		Y	0.15 (±0.01)		
		Z	0.36 (±0.01)		
	New freeway	X	0.11 (±0.01)	0.29 (±0.03)*	83.6 (±73.8)
		Y	0.11 (±0.01)		
		Z	0.43 (±0.01)		
	Old freeway	X	0.13 (±0.01)	0.30 (±0.03)*	
		Y	0.12 (±0.01)		
		Z	0.51 (±0.01)		
Jonsson et al. (2015)	-	X	0.17	-	96
		Y	0.19	-	
		Z	0.32	-	
Blood et al. (2015)	City Streets	X	0.18 (±0.01)	-	-
		Y	0.13 (±0.00)	-	
		Z	0.37(±0.01)	-	
	Freeway	X	0.20 (±0.01)	-	-
		Y	0.14 (±0.00)	-	
		Z	0.37 (±0.01)	-	
	Rough Road	X	0.22 (±0.01)	-	-
		Y	0.16 (±0.00)	-	
		Z	0.42 (±0.01)	-	

*- average value

Table 3: Compilation of studies evaluating whole-body vibration exposure in urban bus drivers

For a bus traveling on different road types, the deviations of the x and z axes are not significant, while the deviations on the y axis are different with an rms acceleration ranging from 0.0847 to 0.2089 m.s-2 (Tamrin et al. 2007). Thus, it can be found that the values of r.m.s. acceleration are in the range of 0.213-1.087 m.s-2 for x axis, 0.325-0.968 m.s-2 for y axis, while for z axis the are 0.563-1.894 m.s-2. The mean value of the acceleration Aw is in the range from 0.787 to 2.782 m.s-2 (Picu et al. 2010). The results are directly connected not only to the road surface, but also to the characteristics of the buses themselves, its engine position and speed.

4. Discussion

It is well known that each human body part has a distinct oscillation frequency. So, matching the frequencies of interfering vibrations with the tissue natural frequencies, organs normal functions may be disturbing. The whole-body vibration can cause different musculoskeletal disorders and cause pain in the lower back, neck, shoulders and arms among other.

In contrast, the whole-body vibrations are used in modern medicine for training and rehabilitation, increasing muscle tone and circulation, improving bone and neuromuscular functions, knee flexion, better muscle performances, speed up recovery period (after long period of exercise or similar) among others (Martinez-Pardo et al. 2014; Pel et al. 2009; Torvinen et al. 2002; Yu et al. 2014). For this purpose, vibrating platforms are used on which a subject stands and through the changing of frequency (0-50 Hz) (Yu et al. 2015), the oscillation amplitude (0 - 9 mm) and angles of the knee (30^0, 60^0, 90^0) (Avelar et al. 2013; Ritzmann et al. 2013), the above described positive results are obtained. During the bus ride, the angles over 90° are predicted.

According to the above described use of vibrations Yu et al. (2015) state that an angle of 90° provides better flexibility of the knee, and the r.m.s. results show the value of 0.904 ± 0.454 $m.s^{-2}$. Each of the studies included a period of a few months (Avelar et al. 2013; Pel et al. 2009; Torvinen et al. 2002; Yu et al. 2014; Yu et al. 2015) with the recommended frequency of 20 - 50 Hz for the favorable development of the muscles (Yu et al. 2014), however, a frequency of 50 Hz can cause muscle aches (Yu et al. 2014).

On the other hand, many years of exposure to whole-body vibrations can cause musculoskeletal problems, such as spinal diseases, particularly in the lower back, shoulders, neck and head. Comparting the vibration platform (Avelar et al. 2013) with the floor of the bus, can been realized that r.m.s. acceleration is significantly higher in the platform. Barreira et al. (2015), presented the floor r.m.s. values for various routes of the bus and the scope ranges are from 0.545 to 0.723 $m.s^{-2}$. Values pointed out by different authors (see above) as being within the range that provides positive results. However, it should be noticed that these results of floor vibration contradict the values of European Parliament and Council of the European Union (2002) directive recommendations. Therefore, more studies are necessary in order to verify the real influence of vibrations on the driver's lower limbs.

Additionally, the driver's lower limbs are exposed to higher values in relation to other parts of the body and, therefore, there may be the possibility of musculoskeletal disorders in lower limb system. Considering only vibration influence on driver's lower limb, their weight is significantly lower than in the whole-body, but the length of exposure to vibrations of higher frequency values is greater, especially in the case of professional drivers, which can be over 20 years (Barreira et al. 2015; Thamsuwan et al. 2012).

In addition to such a statement, with drivers' age, certain changes should be expected in the joints and musculoskeletal system. In future research, attention should be paid to additional issues as vibrations analysis on bus floor, as well as their impact on driver's lower limbs.

5. Conclusions

The outcomes of this review can be analyzed considering, firstly that the articles found present measurement data as accurate and reliable as possible. The intention was to create buses vibrating 'image' of to be used in the analysis of its consequences on the driver's lower limbs. The desired results did not occur, because works dealing with research on the impact of whole-body vibrations on lower limbs and disorders of musculoskeletal system were not found. Tamrin et al. (2007) state the knee pain as a consequence, but the results were obtained by a questionnaire.

The increase of vibrations in bus driver's seat depends on several factors of which the position of the bus engine, road surface and moving speed, seat ability to absorb vibrations, are often referred. From the analyzed work results, vibrations cause pain in the lower back, spine, neck and shoulders (Alperovitch-Najenson et al. 2010; Blood et al. 2011; Blood et al. 2015; Paddan et al. 1998; Kim et al. 2005; Picu et al. 2010; Sekulić et al. 2013; Thamsuwan et al. 2013) on the other hand, they cause positive effects in terms of improving muscle performances circulation and increasing bone density (Avelar et al. 2013; Frost et al. 2007; Martinez-Pardo et al. 2014; Pel et al. 2009; Yu et al. 2014; Yu et al. 2015). However, a conclusion was reached that improving performances (using a vibration platform) occurs with certain frequencies (0-50 Hz) and oscillation amplitudes (0-9 mm), length of exposure (about four months), and where r.m.s. results show the value of 0.904 ± 0.454 m.s^{-2}. Avelar et al. (2013) and Yu et al. (2015) emphasize also that there is a pain in the muscles during a long-term exposure to vibration of 50 Hz. The knee angle of 90° is presented as the one with the most favourable results.

While steering a vehicle an angle bigger than above-mentioned is expected. Furthermore, considering the lower limbs pressure on the surface on the vehicle floor, it might be expected that vibration can be more distinctive on the feet's than on the rest of the lower limbs (knees and hips). From the enclosed results on the presented tables can be realized that the daily vibration exposure A (8), is mostly within the normal range. These results depend on the road type, moving speed, buses characteristics between other parameters.

Supplementary, the vibration exceeding occurs when the speeds are increased (83.4 (± 7.4) km/h) on the old freeway where on the tri-axial axis z increases averaging 0.51 m.s^{-2}, while x is in the range of 0.13 to 0.20 m.s^{-2}, and y is from 0.14 to 0.21 m.s^{-2}(Lewis et al. 2012). However, as the final assumption, it should be noted that the floor r.m.s. is (in the range from 0.545 to 0.723 m.s^{-2}) considerably higher than the seats r.m.s. (an average from 0.281 to 0.369 m.s^{-2}) and consequently future researches should be dedicated to the effect of the whole-body vibrations on the drivers' lower limbs.

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