Assessment of workers' exposure to hand-arm and whole body vibration in one of the furniture industries in east of Tehran

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ABSTRACT

Workers in wood industry are exposed to vibration and its damages. The purpose of this study was to evaluate exposure to hand-arm and whole body vibration in the wood industry. In this study, the parameters of whole body and hand-arm vibrations such as effective acceleration, overall equivalent acceleration, Vibration Dose Value and crest factor were studied on two Thicknessing planes, two sliding panel saw machines, two orbital sander, and three operators of perforate procedure. Assessments were done by the use of an oscillator and an analyzer of Svantak Co. Evaluating Hand-arm and whole body vibrations were conducted based on ISO 5349-1, ISO 5349-2 and ISO 2631-1 standards, respectively, and the findings/ the evaluated data were analyzed.

The mean amount of daily exposure to hand-arm vibration (RMS) in Thicknessing plane, Orbital Sander and Sliding panel saw machine operators are respectively 5.56, 5.49 and 3.37 m/s2 . In addition, the average crest factor of the 3 jobs is higher than 6. Mean of daily Exposure to whole body vibration in 3 machine operators of Thicknessing plane, perforate procedure and Sliding panel saw is respectively, 0.28, 0.24 and 0.17 meters per square second. The crest factor for all the exposures was to be less than 6 and the mean of the calculated daily vibration dose equaled 5.83 with the standard deviation of 0.87(m)⁄s^1.75 .

In further measured situations, exposure to hand-arm vibration is more than the standard level, so engineering and management measures are required to reduce the amount of exposure and support the health of the operators and the equipment.

Key words: Wood Industry, Vibration, Hand-arm vibration, Whole body vibration

INTRODUCTION

It is currently estimated that, only in Europe one out of four workers is exposed to hand- arm and whole body vibrations [1]. Basically, hand-arm vibration occurs when a vibrating instrument is in hand, and whole body vibration happens when an individual's body (legs, hips or his/her whole body) is in contact with a vibrating surface. Prolonged and excessive exposure to hand-arm exposure associates with numerous health effects well-known as the syndrome of hand-arm vibration. This type of vibration influences on the circulatory, nervous and musculoskeletal systems [2, 3]. Frequency, magnitude, and duration of exposure influence on the sense of the worker and the type of subsequent side effects. [4, 5]

A Spanish portrait reveals that, 22.8% of the workers that use portable electric and pneumatic tools report being exposed to vibration. A number of studies have attempted to determine the real effects of these limits on the appearance of HAVS in specific sectors such as construction, forestry or a heavy engineering production workshop, with results that seem to suggest that, although the prevalence of HAVS is reduced, the action level, currently established in the EU, is not a safe one. [6-8]

In addition, in the study of Marie A, Coggins *et al.*, which was done in construction and property management company, the vibrations of Orbital sander, Saw machine, and Grinders were evaluated. Besides, in 2008, Margarita Vergara studied the exposure of the operators of Orbital sander/polisher/grinder and Grinder saw machine (grinder, circular saw cutter) in her research [9,10].

Whole body vibration associates with low back pain, nausea, dizziness, blurred vision, problematic circulatory system and weak nervous system. It should be noted that, the effects of exposure to whole body vibration are not as apparent as the effects of exposure to hand-arm vibration. [11-13]

Although the submitted data by equipment manufacturers should be the basics, the tendency of the manufacturers in giving insufficient information should be considered as well. Measuring and evaluating the equipment's vibrating surfaces is complex and expensive, but for evaluating the accepted risk the vibrating surfaces of the equipment need to be evaluated by experienced experts and their proper instruments [14-16]. These days, in developing low income countries less attention is paid to the occupational health and immunity of small industries such as wood industry. The workers of wood industry are exposed to numerous harmful physical and chemical external agents, especially hand-arm and whole body vibrations at occupational places; working with portable and fixed machinery of wood industry, changing and adjusting blades and servicing them expose these workers to hand-arm and whole body vibrations.

Hand-arm vibrations cause musculoskeletal, nervous and circulatory disorders; two of the commonest disorders amongst them are Raynaud syndrome and white finger fibrosis. Also, neurological complications have attracted much attention; feeling pain, hand fingers tingling, reduced tactile sense and sleeping disorders are examples of neurological complications [17, 18].

While the body is exposed to vibration, a complicated distribution of motions and fluctuating forces are created in the body that might decrease the health, activity and the operator’s convenience and cause motion disorders. Realistically, one’s sensitivity to vibration depends on different stratifications of it; that is, range, acceleration speed or the rate of acceleration change. Mechanical damages to the body are due to the strain on its organs’ tissues caused by vibration and discompability of physiological effects with frequency and other aspects of vibration [5, 19-21]

The commonest standards for hand-arm vibration which has been submitted for evaluating hand-transmitted vibration are ISO 5349- 1, 2 whose second version replaced its previous version in 2001. ISO 5349-1 attempts to mention the correct form of measuring hand-arm vibration; this standard does not determine the immunity levels and allowed range/limits of hand-arm vibration, but ISO 5349-2 has been presented for vibration assessment and submitting allowed actions and limit levels. Moreover, BS6842 standard for presenting the guidelines of measuring hand-arm vibration – like the previous version of ISO 5349 — has already been designed in Britain; in 2001, the standard of International Standard Organization replaced BS6842 in Britain and was acknowledged as the national standard of Britain with the name of BS ISO 5349[19, 22-25]. For assessing the health effects caused by whole body vibration, the commonest standards are ISO 2631-1 and BS 6841. The relevance of studying hand–arm vibration in power tools is highlighted by a statistical portrait revealing that 17% of European workers report being exposed to vibration through handheld tools or machinery for at least half of their working time. Very little is known about the utilized equipment types and associated vibration emissions under real work conditions for many occupational sectors across the EU [1, 26].

Provide control measures to eliminate or reduce the risks of required studies to identify and evaluate the leading cause of injury in work. In order to submit the required control measures for decreasing and even omitting the dangers of whole-body and hand-arm vibrations in the workers of wood industry, the present study has been conducted in one of the furniture industries with the aim of evaluating the amount of the workers’ exposure to hand- arm and whole body vibrations.

MATERIALS AND METHODS

Exposure duration of workers (both of hand-arm and whole body vibrations) of a furniture industry in Khorramdasht Industrial Township was determined throughout this cross-sectional study while they were doing their daily normal work. Surfacing and Thicknessing plane with the width of 320 millimeters, Sliding table panel saw with the width of 3200 mm, Orbiting sander with the dimensions of 130 × 280 millimeters (Made in Germany) and perforate procedure were the target machinery that measurements were done on them; the electrical power for the first and second groups was provided through 3 phase electrical power and for the third and fourth operators through single phase electrical power.

This study was done on two Surfacing and Thicknessing planes, two sliding panel saw machines, two orbital sanders, and three operators of perforating procedure. The measurements were repeated three times, and their mean was calculated and finally recorded in separate tables for hand and body-transmitted vibrations.

Measuring whole body vibration and hand-arm vibration were respectively done based on the guidelines of ISO 2631-1: 1997 and ISO 5349-1:2001. The assessments were conducted with the use of an oscillator and SVAN 985 Analyzer (Svantek co.) and tri-axial accelerometer of each vibration. Machinery calibration with its related sensors was separately done by using the calibrators of the aforementioned company before and after the assessments. While assessing the two types of vibration, detection time of the oscillator was set on 100 milliseconds (10 samples per second), and the utilized weighing frequency band filter for measuring whole body vibration on X, Y, and Z axes was respectively adjusted on Wd, Wd and Wk; it was adjusted on Wh for measuring hand-arm vibration.

Frequency range of whole body vibration in the present study was from 0.5 to 80 Hz, and frequency range of hand-arm vibration, using Wh filter for its measurement, was from 8 to 1000 Hz. [19, 27, 28]

Measurement duration of each sample is indicated in table 1. The standards suggest that when it is possible, the measuring period should be 20 min and when it is not possible, the measuring period should be 3 min for whole body vibration and 1 min for hand-arm vibration on each axis. However, prolonged measurements are possible in the half of the exposure time [11, 19, 29]. The least measuring period in this study took 5 min. The mean, minimum, maximum acceleration values and the standard deviation for that hand tool or machine were calculated and then illustrated in tables and results section.

Related tri-axial thimble sensors were utilized for measuring hand-arm vibration. These sensors are designed as thimbles were put on the middle finger of their dominant hand (right hand) while measuring, and measurement process started after the operator's activation.

In this way, the effects of the initial activities and severe shakes at the start of the job are omitted. On the basis of the guidelines of ISO 5349-1 and ISO 5349-2, the most important quantity for describing hand-transmitted energy is r.m.s (the square root of the mean squared acceleration) by m/s2. Comprehensible exposure assessment needs measuring acceleration on the three axes, frequencies and exposure duration. Based on ISO's tips, three orthogonal axes of coordinate system are: Z axis along with the metacarpal bones of the hand, X axis perpendicular to Z and Y axes parallel to the instrument's longitude axis. Based on the devise's assessment capability, vibration assessment was simultaneously done on the three axes. Using thimble oscillator measures the real amount of transferred acceleration to the individual's hand [10, 24, 25].

Based on ISO 5349, final vibration assessment should be shown from 3 directions, which are the total ahy vibration or the weighed frequency acceleration, expressed as the mean square root of the three evaluated amounts/values or effective acceleration.

$$a_{\mathrm{hw}} = \sqrt{a_{\mathrm{hwx}}^2 + a_{\mathrm{hwy}}^2 + a_{\mathrm{hwz}}^2}$$

This index is indeed the only submitted value for assessing hand-transmitted vibration, in which ahwx, ahwy, ahwz are the values of effective acceleration on the three axes.

SV 39A/L, a tri-axial hips oscillator (in the frequency range of 0.5 to 3 KHz), which is designed based on ISO 2631 and SAE j1013 and installed in a plastic pad with the thickness/ width of 12 mm, was used in order to measure whole body vibration. This device is capable of measuring acceleration in 3 different directions, separately and simultaneously. Accelerations of the three axes were measured on the floor in the closest proximity to the operator's feet next to the device on the basis of ISO 2631-1.Two methods have already been presented in 1997 version of the standard of the International Standard Organization for assessing whole body acceleration known as Basic method and Vibration Dose Value. For the latter one the standard suggests that, when the amount of crest factor exceeded 9, VDV method is the one that should be utilized for assessing individuals' exposure to whole body vibration; because vibratory signal might consist of numerous shocks faking the real effective acceleration of the person [16, 20, 29].

For predicting the health risk of whole body vibration in humans, r.m.s. weighed frequency accelerations, with the symbol of az ،ay و ax on x, y, and z axes, mixed to one another, and overall equivalent acceleration was calculated with the following formula.

$$A_{eq(T)} = \sqrt{(1.4a_x)^2 + (1.4a_y)^2 + (1a_z)^2}$$

After weighing up test data, the square root of the mean squared acceleration, (RMS), and its VDV were calculated based on the submitted equations of ISO 2631-1. In this study, crest factor was calculated with the use of the following equation [16]:

$$\mathrm{CF} = \frac{(aw(t))max}{(aw)r.m.s}$$

For combining the coordinate axes of VDVs, the following formula is used:

$$VDV_{xyz} = \sqrt[4]{VDV_x^4 + VDV_y^4 + VDV_z^4}$$

VDV_{xyz} is the combined/ composed vibration dose, and VDVx, VDVy and VDVz are vibratory doses on X, Y and Z axes, respectively.

RESULTS

The participating workers in this study were simultaneously exposed to both types of vibrations while doing their daily work, so the evaluations were as regard to both types of vibrations with their related indicators. In the case of hand-arm vibration, the results of effective acceleration in three vibratory directions, acceleration's resultant on the three axes, and daily 8-hour total acceleration which was conducted based on the guidelines of ISO 5349-1and mentioned equations of the examined jobs, could be observed in table1. As it is explicitly shown in table 1, the range of the effective acceleration, which is less than 2 m/s2 in the direction of Y axis, is for the orbital sander; and the one which is more than 9 m/s2 in the direction of the Z axis is for the Thicknessing plane. Crest factor values, a parameter without dimension, varied from 8 to 23 for hand-arm vibration in this study.

Table 1: Measured amounts of hand-arm vibration, features and measuring times and daily exposure

Job	Measurement duration (sec)	Average daily exposure (sec)	Weighed frequency acceleration (m/s^2)				Daily total acceleration A(8)
			X	Y	Z	XYZ	
Thicknessing plane	445	5400	8.19	3.5	9.26	12.84	5.56
Orbital sander	362	7200	7.36	1.95	7.92	11	5.49
Sliding panel saw machine	312	7200	3.03	2.6	5.44	6.75	3.37
Mean	373	6600	6.19	2.68	7.54	10.19	4.18
Standard deviation	67.2	1039	2.77	0.78	1.93	3.12	1.24

The Shown data in table 1 demonstrate that, the mean amount of daily exposure to hand-arm vibration (effective acceleration) in the operators of Thicknessing plane equals 5.56 m/s2, and in the operators of orbital sander/ shaking device and sliding panel saw machine is 5.49 and 3.37 m/s2, respectively. The operators of Thicknessing plane devices expose the longest to vibration in comparison to the operators of other machinery. In fact, the mean amount of effective acceleration to which the operators of thicknesses plane in different directions of x, y, and z are exposed is 8.19, 3.5 and 9.26 m/s2.

The mean amount of effective acceleration for the operators of the orbital sanders in the above-mentioned directions is 7.36, 1.95, and 7.92. This amount for the operators of the sliding panel saw machine varies from 2.6 m/s2 on Y axis to 5.44 m/s2on Z axis. Reviewing vibratory signal shows that, sliding panel saw machine has the highest crest factor amongst other devices. Indeed, the average crest factor of hand-arm vibration for the operators of sliding panel saw, Thicknessing plane and orbital sander is 22.94, 20.10, and 13.76, respectively; the highest amount of crest factor belongs to the Z axis of the sander, while the lowest amount of it (6.7) goes to the Y axis of the Thicknessing plane. Based on the instructions of ISO 2631-1, Weighed frequency vibratory acceleration, the resultant of the three axes, 8-hour-long total acceleration of a day, and crest factor was measured for assessing exposure to whole body vibration, and the output was recorded in table 2.

Table 2: the results of assessing whole body vibration, measurement features, crest factor, evaluated acceleration values of different axes, and the overall daily equivalent acceleration

Job	Measurement duration (sec)	Average daily exposure (sec)	Crest factor			Weighed frequency acceleration (m/s^2)				Daily equivalent acceleration A(8)
			X	**Y**	**Z**	**X**	**Y**	**Z**	**XYZ**	
Perforate procedure	505	21600	3.66	3.7	2.8	0.26	0.24	0.17	0.39	0.17
Sliding panel saw	428	7200	3.52	3.5	3.3	0.33	0.33	0.14	0.49	0.24
Thicknessing plane	389	5400	5.24	5.2	4.9	0.37	0.37	0.19	0.56	0.28
Mean	440.7	11400	4.14	4.1	3.6	0.32	0.31	0.16	0.48	0.23
Standard deviation	59.03	8879	0.96	0.9	1.1	0.06	0.07	0.02	0.09	0.06

According to table 2, the operators of the Thicknessing device are the most exposed ones to whole body vibration in comparison to the operators of surfacing devices and sliding panels with the width of 3200 mm.

In general, exposure amount to whole-body vibration in the operators of Thicknessing devices, perforate machinery and sliding panels was 0.28, 0.24, and 0.17 m/s2. Contrary results were drawn from vibration assessment in different directions, in all three machinery groups; that is, the perforation device had the highest amount of exposure in the direction of X axis, while sliding panel saw machines had the highest amount of vibration in the direction of Y axis; and exposure amount in the direction of X and Y axes were alike for Thicknessing planes, more than the exposure amount in the direction of its Z axis. Besides, the highest amount of crest factor relates to the thicknessing device that was 5.24, 5.2, and 4.9 in X, Y, and Z directions showing that all the crest factor values are less than number 9, the number/ value submitted by the standard. The highest amounts of crest factor, 3.66 and 3.52, belong respectively to perforation and sliding devices in the direction of their X axes.

Table 3: Results of assessing whole body vibration, vibration dose on different axes, axes' resultant, and total vibratory dose

Job	Measurement duration (sec)	Average daily exposure (sec)	Vibration dose value (m/s ^ 1.75)				VDV (m/s^1.75)	
			X	Y	Z	XYZ	VDVn*	VDV total**
Perforation operator	505	21600	1.67	1.58	1.16	1.99	5.1	5.1
Sliding panel's operator	428	7200	2.33	2.33	0.13	2.77	5.6	5.6
Thicknessing operator	389	5400	2.7	2.71	1.59	3.26	6.8	6.8
Mean	440.7	11400	2.23	2.21	0.96	2.67	5.83	5.83
Standard deviation	59.03	8879	0.52	0.57	0.75	0.64	0.87	0.87

*: vibration dose related to the job

**: total vibration dose for working shift assuming that at other times of the daily working shift , there is no exposure to vibration.

The highest amount of average vibration dose value on Y axis of the sliding panel saw machines equals 2.71, and the lowest amount, which is 1.16 m/s1.75, goes to Z axis of the perforation device.

Average daily vibration dose for the operators of Thicknessing, sliding, and perforation devices had been reduced and was 6.8, 5.6, and 5.1 m/s1.75, respectively; the related mean equaled 5.83 m/s1.75. Vibration dose of other axes in all the exposures is shown in table 3.

The average amount of effective acceleration accompanied by upper and lower levels of HGCZ range, related to r.m.s acceleration, is demonstrated in Fig. 1.

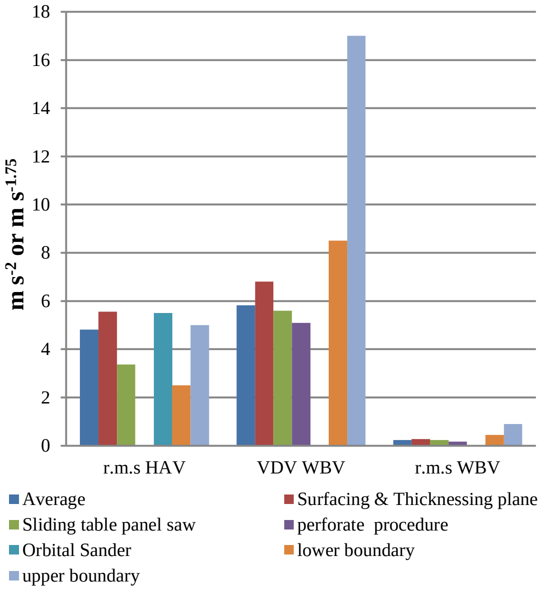

Fig.1: comparing the results of average exposure of different jobs and the operators of different devices to the ISO's submitted allowed range

DISCUSSION

As the findings show, the average value of daily total acceleration, A (8), of exposure to Thicknessing and sander operators is more than the allowed amount of 5 m/s2 suggested by ISO and BS. Although, this amount has been considered as the highest allowed level of exposure acceleration by Physical Agents Committee of EU, the daily exposure of the operators of sliding panel saws, 3.37 m/s2, is less than that of the other operators. Hence, in the initial evaluations the vibration exposure amount of sliding panels' operators – if exposure duration is in the range of 3 hours – is secure and lower than the allowed Limit level of International Standard Organization for 8 hours of daily work and 40 hours of weekly work. The average amount of perceived vibration on Z axis and also the resultant vibration amount of the operators of this device is more than 5 m/s2, but as it is obvious in table1, the daily 8-hour-long exposure to the Action Level is 2.5 and 5 m/s2.

Therefore, if evaluation criterion was one axis with the highest amount of effective acceleration, the time to reach to Action and Limit Levels would be longer, and the workers would be able to work more in the exposure of the mentioned vibrations. In fact, average allowed amount of exposure duration for Thicknessing operator's increases from 1hour and 13 min to 2 hours and 20 min, for Orbital Sander's operator from 1 hour and 39 min to 3 hours and 11 min, and for sliding panel's operator from 4 hours and 23 min to 6 hours and 14 min.

Furthermore, the results Show that, the highest amounts of vibration for the operators of the Thicknessing plane, Orbital Sander, and Sliding panel saw machine on Z axis is 9.89, 8.03, and 5.69 m/s2, respectively. Thus, in this case the priority of corrective measures for the wood industry and even

for other similar industries goes to Thicknessing planes and orbital sanders and then to the sliding panel, saw machines.
In the study by Marie A. Coggins *et al.*, the evaluated r.m.s acceleration of hand-arm (vibration) for Orbital sander and saw machine are in the range of 1.3-10.9 and 0.28-12.25 m/s2, to which the shown data of table 1 of this paper are similar. Moreover, in the study by Margarita vergara *et al.*, the evaluated range for orbital sander is from 0.9 to 7.4, which is in contrast with the results of the present study; in fact, the findings of this research are higher in value. The evaluated range for the Grinder saw Machine in her study was from 1.7 to 5.1, lower than the evaluated range of this paper; such contrast might depend upon the statifications of the utilized machinery, their lifelong, and their consuming power [9,10].
It has been shown that use time in some types of devices (Sliding panel saw, or sander/polisher) is long. Although these devices present low vibration levels, one should be careful when it comes to selecting them. It has also been shown that workers are not really aware that the levels of vibration transmitted to their hands exceed certain limits, which represent an additional risk. They should at least be informed about the effects of these vibrations can have.
Another index, something like whole body vibration dose, seems to be necessary for evaluating the vibratory poly-shock signals. It is suggested to conduct a group of future researches related to hand-transmitted vibration, concerning such an index.
For assessing the health effects caused by whole body vibration, the commonest standards are ISO 2631-1 and BS 6841; for sure, there are other standards that have been presented by some organizations such as HSE, ACGIH, and Physical Agent Committee of EU.
In ISO 2631-1: 1997 there is a Health Guidance Caution Zone (HGCZ) for interpreting the results of an axis with the highest frequency weighed acceleration. This graph gives a guideline in the form of a caution zone whose upper part is the "probable risk and health effect zone" while on the lower part of that the health effects have not been plainly recorded. In Caution zone, potential health risks have been illustrated. The lower boundary of HGCZ shows the allowed 8-hour long exposure, almost 0.45 m/s2, and the Upper boundary of HGCZ in the 8-hour exposure, about 0.9 m/s2. In the assessments dealing with VDV method, the upper and lower boundary of HGCZ is 8.5 m/s2 and 17 m/s2, respectively.[12, 14, 16]
EU in its physical agent's instructions (vibration) has submitted two criteria of Action Level and Limit Level for rms and VDV methods to evaluate whole body vibration, which are very close to the highest and lowest limits of HGCZ. The amounts for the action level and limit level of daily 8-hour-long exposure of r.m.s are 0.5 and 1.15 m/s2, and for daily 8-hour-long exposure of VDV are 9.1 and 21 m/s2[14].
The guidance of ACGIH (American Conference Governmental of Industrial Hygiene) for controlling the exposure to whole body vibration in occupational environments is compatible with the guidelines of ISO 2631-1 and ANSI. According to this guidance, the allowed exposure range/limit in 8 hours is 0.315 m/s2 in the frequency range of 4 to 8 Hz, and in 4 hours is 0.53 m/s2. Limits provided by this organization for different time periods with increasing frequency decline until 4 Hz, and increase to more than 8 Hz[30].
I n the year 2005, Alem suggested some changes for HGCZ limits which related to VDV in order to predict risks and questioned the limits of ISO 2631-1. He suggested that the lower boundary of HGCZ (presented in Annex B, ISO 2631-1) should be 3.5 m/s2 and the higher boundary of it should be 4.8 m/s2 [31]. If the recent levels were used in this study, the calculated daily exposure in all the three cases would be higher than the mentioned level, so it would be categorized in a group with a high probability of risk and health effects. Currently, major vibration risk in these jobs is hand-arm vibration, and whole body vibrations do not cause severe health damages for the workers in these kinds of jobs. However, control measures for whole body vibrations are suggested, as well. Easy control measures such as installing oscillators and elastic floor pads to work environments would be helpful and constructive. The values that were measured in this study show that there can be important differences in the levels of vibration generated by the same kind of tools, which suggest that vibration can be reduced by studying the way they are designed. Furthermore, applying ergonomic design in the studied working locations in order to improve the working conditions can eliminate vibration exposure amount and eventually reduce the health and immunity risks.

CONCLUSION

In vibration evaluation, using the standards and advices of different organizations ensures the experts to present preventive measures; therefore, the results of this study, which were derived from two kinds of evaluation methods, confirmed the safety of the workers' exposure to whole body vibration. (However, environmental control measures are suggested for providing the workers' health.). But the amount of exposure to hand-arm vibration in two different ways (while using the dominant axis and while using to combines all three axes) was mainly over the limit levels submitted by different standards. Hence, engineering and management control measures are necessary for operators.

REFRENCES

[1] Donati P. Workplace exposure to vibration in Europe: an expert review. Vol. 7 , office for official publications of, 2008.
[2] Griffin MJ. Minimum health and safety requirements for workers exposed to hand-transmitted vibration and whole-body vibration in the European Union: a review. Occupational and Environmental Medicine. 2004; 61(5):387-397.
[3] Dias B, Sampson E. Hand arm vibration syndrome: health effects and mitigation. IOHA: Pilanesberg, South Africa. 2005; B1-4.
[4] McDowell TW, Dong RG, Xu X, Welcome DE,Warren C. An evaluation of impact wrench vibration emissions and test methods. Annals of occupational hygiene. 2008; 52(2): 125-138.
[5] Holmberg S, Thelin A, Stiernstrom E, Svardsudd K. Low back pain comorbidity among male farmers and rural referents: a population-based study. Annals of Agricultural and Environmental Medicine. 2005; 12(2):261-268.
[6] Edwards DJ, Holt GD. Hand-arm vibration exposure from construction tools: results of a field study. Construction Management and Economics. 2006; 24(2):209-217.
[7] Sutinen P, Toppila E, Starck J, Brammer A, Zou J, Pyykkö I. Hand-arm vibration syndrome with use of anti-vibration chain saws: 19-year follow-up study of forestry workers. International archives of occupational and environmental health. 2006; 79(8):665-671.
[8] Burström L, Hagberg M, Lundstrom R, Nilsson T. Relationship between hand-arm vibration exposure and onset time for symptoms in a heavy engineering production workshop. Scandinavian journal of work, environment & health. 2006; 198-203.
[9] Coggins MA, Mccallig M, Paddan G, Moore K. Evaluation of hand-arm and whole-body vibrations in construction and property management. Annals of occupational hygiene. 2010; 54:904-914.
[10] Vergara M, Sancho JL, Rudriguez P, Perez Gonzalez A. Hand-transmitted vibration in power tools: Accomplishment of standards and users' perception. International Journal of Industrial Ergonomics. 2008; 38(9):652-660.
[11] CEN. Mechanical Vibration - Testing of Mobile Machinery in Order to Determine the Vibration Emission Value. EN 1032, Brussels, Belgium, 2003.
[12] Cooperrider N, Gordon J. Shock and impact on north American locomotives. Journal of Sound and Vibration. 2008; 318:809–819.
[13] Eger T, Stevenson J, Boileau P, Salmoni A. Predictions of health risks associated with the operation of load-haul-dump mining vehicles: Part 1-Analysis of whole-body vibration exposure using ISO 2631-1 and ISO-2631-5 standards. International Journal of Industrial Ergonomics. 2008; 38:726–738.
[14] Griffin MJ, Howarth HV, Pitts PM, *et al.* Guide to good practice on whole-body vibration. European Commission Directorate General Employment, Social Affairs and Equal Opportunities, contract VC/2004/0341, 2006.
[15] CEN. Mechanical vibration - measurement and calculation of occupational exposure to whole-body vibration with reference to health - practical guide 2003; EU14253.
[16] ISO. Mechanical vibration and shock - evaluation of human exposure to whole-body vibration—part 1: general requirements. ISO 2631-1; 1997.
[17] ISO. Mechanical Vibration and Shock – Evaluation of Human Exposure to Whole Body Vibration–Part 5: Method for Evaluation of Vibration Containing Multiple Shocks. ISO 2631-5; 2004.
[18] Johanning E. Vibration and shock exposure of maintenance-of-way vehicles in the railroad industry . Applied Ergonomics. 2010; 42(4): 555-562.
[19] Johanning E, Landsbergis P, Fischer S, Christ E, Gores B, Luhrman R. Whole-body vibration and ergonomic study of US railroad locomotives. Journal of Sound and Vibration. 2006; 298(3): 594–600.
[20] Mansfield N. Human response to vibration. 1st ed, CRC PRESS, London, 2005.
[21] Chaffin DB, Andersson G. Occupational biomechanics. Wiley interscience, New York, 1991.
[22] Tiemessen IJ, Hulshof CT, Frings-Dresen MH, Two way assessment of other physical work demands while measuring the whole body vibration magnitude. Journal of Sound and Vibration. 2008; 310(4): 1080-1092.
[23] South T. Managing Noise and Vibration at Work. 1st ed, Elsevier Butterworth-Heinemann, 2004.
[24] ISO. Mechanical vibration - Measurement and evaluation of human exposure to hand-transmitted vibration - Part 1: General requirements. ISO 5349-1, 2001.
[25] ISO. Mechanical Vibration- Measurement and Evaluation of Human Exposure to Hand-Transmitted Vibration- Part 2: Practical Guidance for Measurement at theWorkplace. ISO5349-2, 2001.
[26] European Commission. Work and health in the Europe (1997 – 2007), A statistical portrait. 2010 ed, publication Office of the European Union, Luxamborg, 2010.
[27] Griffin M J. Handbook of Human Vibration. 1st ed, Academic Press, London, 1990.
[28] Rehn B, Lundstrom R, Nilsson L, Liljelind I, Jarvholm B.Variation in exposure to whole-body vibration for operators of forwarder vehicles - aspects on measurement strategies and prevention.

International Journal of Industrial Ergonomics. 2005; 35(9):831–842.
[29] Prisby RD, Lafage-Proust M, Malaval L, Belli A, Vico L. Effects of whole body vibration on the skeleton and other organ systems in man and animal models: What we know and what we need to know. Ageing Research Reviews. 2008; 7(4):319–329.
[30] ACGIH. Threshold Limit Values (TLVs) and Biological Exposure Indices (BEIs) Resources. 1330 Kemper Meadow Drive. American Conference of Governmental Industrial Hygienists; Cincinnati, Ohio: 45240, 2009.
[31] Alem N. Application of the new ISO 2631-5 to health hazard assessment of repeated shocks in US army vehicles. Industrial Health. 2005. 43(3): 403-412.