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Comparative Assessment of the Whole-Body Vibration Exposure Under Different Car Speed Based on Malaysian Road Profile

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Abstract: The purpose of this study was to evaluate and validate the Daily Exposure to Vibration A(8) and Vibration Dose Value (VDV) experienced by the car driver, with care taken to elucidate the effects of WBV on the human body and all at once to introduce a newly developed real-time WBV measurement instrumentation. Cars are one of the most important transportation worldwide. It plays a significant role for the human to travel from one place to the other places promptly. However, high magnitude Whole-Body Vibration (WBV) that can be associated with car may lead to various diseases and health problems, such as lower back pain, in humans. This study was conducted on a national car. The WBV exposure was measured for 10 min. Data was collected using an IEPE (ICP^{TM}) accelerometer sensor connected to a DT9837 device, capable of effectively measuring and analyzing the vibrations. The vibration results were displayed on a personal computer using a custom Graphical User Interface (GUI). MATLAB software was used to interpret the results and determine the WBV exposure level. The values of Daily Exposure to Vibration A(8) and the Vibration Dose Value (VDV) during one stretch of car travel were measured as 0.8778 and 3.8862 m sec$^{-1.75}$, respectively. The results here confirm that WBV absorbed by the human body increases with an increase in the duration and magnitude of vibration exposure by the driver, illustrated by the increase in the value of Daily Exposure to Vibration A(8) and the calculated Vibration Dose Value (VDV).

Key words: Vibration, dose, exposure, human, road profile, safety

INTRODUCTION

Ergonomics is the application of scientific principles, methods and data drawn from a variety of disciplines to the development of engineering systems in which people play a significant role. Among the basic contributing disciplines are psychology, cognitive sciences, physiology, biomechanics, applied physical anthropometry and industrial systems engineering (Kroemer *et al*., 2003). The importance of safety and ergonomics has grown significantly over the past years (Matilla, 1996). The latest technology has allowed for the expanded used of ergonomics and additional safety features in products and equipment. At the same time, new technology has created new risks and the management of these risks is more complicated. For this reason, it is important for a designer to use his knowledge of ergonomics during the design process of machines, equipment, products and systems. There is substantial epidemiologic evidence that links physical ergonomics exposures at the workplace, such as lifting, constrained postures, repetitive movements, fast work pace, handling of heavy material, forceful exertions and vibration, to the occurrence of upper extremity musculoskeletal disorders (Bernard, 1997; Grieco *et al*., 1998; Hagberg *et al*., 1995; National Research Council and Institute of Medicine, 2001; Van Der Windt *et al*., 2000). Ergonomics (also called human factors or human engineering in the United States) can be defined as the study of human characteristics for the appropriate design of the living and work environment. Its fundamental aim is that all human-made tools, devices, equipment, machines and environments should advance, directly or indirectly, the safety, well-being and performance of human beings (Kroemer *et al*., 2003). Several ergonomic interventions, such as employee training, redesign of process tools or workstations and improvement of work conditions, have been suggested and implemented to tackle musculoskeletal problems related to industrial work (Wang *et al*., 2003; Weestgard and Winkel, 1997).

Depending on the source, WBV has been given a variety of definitions. From the Directive 2002/44/EC of the European Parliament and of the Council, the term whole-body vibration refers to the mechanical vibration

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that, when transmitted to the whole body, entails risks to the health and safety of workers, in particular lower-back morbidity and trauma of the spine (Directive 2002/44/EC). WBV is defined as the vibration that occurs when the greater part of a person's weight is supported on a vibrating surface. WBV principally occurs in vehicles and wheeled working machines. In most cases exposure to WBV occurs when the person is in a sitting position and the vibration is thus primarily transmitted through the seat pan, with additional transmittance through the backrest. WBV may impair performance and comfort. It may also contribute to the development of various injuries and disorders. In many work situations, WBV is a prominent and troublesome occupational health problem (Griffin, 1990).

Lower Back Pain (LBP) is among the most common and costly health problems (Garg and Moore, 1992; Van Tulder *et al*., 1995). Occupational, non-occupational and individual risk factors play a role in the development, the duration and the recurrence of LBP. Several critical reviews have discussed the occupational risk factors that result in back disorders (Wilder and Pope, 1996; Burdorf and Sorock, 1997; Bovenzi and Hulshof, 1999; Lings and Leboeuf-Yde, 2000; Waddell and Burton, 2001). All of these reviews conclude that there is strong epidemiological evidence relating occupational WBV exposure to LBP. In five European countries (Belgium, Germany, Netherlands, France, Denmark), LBP and spinal disorders due to WBV are currently recognized as occupational diseases (Hulshof *et al*., 2002). However, WBV remains a common occupational risk factor for LBP, with high exposures and the resulting injuries affecting 4 to 8% of the workforce in industrialized countries (Palmer *et al*., 2000). Important high risk groups include drivers of off-road vehicles (such as those used for earth moving, forestry and agriculture), drivers of forklift trucks, lorries and buses, crane operators and helicopter pilots.

A serious weakness with the existing data employed today is that it is not the latest data and cannot comprise of all types of occupational vibration. Most of the instruments available in the market today are in the form of data logger and not real-time data. For this reason, this study seeks to assign an alternative way for the present data logger accessible in the market nowadays.

MATERIALS AND METHODS

WBV measurements were conducted according to ISO 2631-1:1997. The triaxial accelerometer sensor was located between the car's driver contact points and the vibration source. The accelerometer was placed on the seat of the driver (Fig. 1). During the test, the driver sat on the accelerometer.

Fig. 1: Triaxial accelerometer sensor used for WBV measurement

Table 1: Speed of the car

Experiment	Measurement time (min)	Car speed (km h^{-1})
1	10	30
2	10	60

Excessive exposure of WBV typically occurs when the exposure duration is long and accompanied with a large vibration magnitude. Of the various modes of transportation, the car most often produces high magnitude of vibration. The car speed is a big dominant parameter towards WBV especially at low frequency. The Malaysian national car was chosen for this study. WBV measurements using a randomly chosen driver was performed two times at two different speeds. In this study, WBV measurement was conducted by changing the speed of the car. The WBV was sampled 1000 times sec^{-1}. For each experiment, the exposure time was set to 10 min. The total WBV exposure time was set to 8 h, which is equivalent to the duration of a typical occupational exposure time. The study has been conducted at the Faculty of Law, University kebangsaan Malaysia. The measurement of the car speed for each experiments is listed in Table 1. WBV measurement explored by the car driver was accomplished two times at two different car speeds which were at 30 and 60 km h^{-1}. After the accelerometer and DT9837 were connected, the data collection began. The total vibration along each axis (x, y and z) felt by the passenger was displayed in a graph using MATLAB.

The two measurement devices used in the study were the IEPE (ICP™) accelerometer sensor and a DT9837 instrument. The IEPE (ICP™) accelerometer sensor (also known as triaxial seat accelerometer) was a DYTRAN Model 5313A. The sensor was used to assess the vibration level. The accelerometer consists of a piezoelectric element connected to a known mass. When the accelerometer is vibrated, the mass applies force to the piezoelectric element, generating an electrical charge that is proportional to the applied force. Then this charge was deliberated to determine the vibration characteristics. Most accelerometers require a current source of 4 mA and a compliance voltage of at least 18V to drive their internal circuitry. Other accelerometers require a 2 mA current source, but have limitations in cable length and bandwidth.

The DT9837 instrument was a highly accurate five channel data acquisition module that is ideal for portable noise and vibration measurements. It has 4 simultaneous, 24-bit A/D channels for high resolution measurements. This instrument supports for four IEPE inputs, including 4 mA current source. Portable operation can be done by the DT9837 because no external power supply needed and runs on USB power. The DT9837 has tachometer input support in the A/D data stream for synchronizing measurements. Sampling rate of over 52 kHz was produced by this instrument. It has low frequency measurements supported with a wide pass band of 0.5 Hz to 25.8 kHz (0.49 x sampling frequency). The DT9837 was a programmable trigger for analog input operations for maximum flexibility.

In this study, MATLAB software was used to analyze the vibration signal gathered by the DT9837 instrument via a USB port. The MATLAB Graphical User Interface (GUI) scripts were examined using the GUIDE function for ease of measurement and assessment of WBV exposure. Using this MATLAB script, three graphs, displaying the three different axes of vibration, were displayed for real time observation. The collected data were also saved in the computer for subsequent analysis. Thus, in this study, the total daily exposure to vibration towards humans was evaluated using an accelerometer sensor, a DT9837 instrument and MATLAB software. MATLAB was a well known interactive software environment for data acquisition and analysis, report generation and test system development. It provides a complete set of tools for acquiring and analyzing analog and digital input output signals from a variety of PC-compatible data acquisition hardware. The MATLAB Data Acquisition Toolbox configured the external hardware devices, read data into MATLAB and Simulink for immediate analysis and send out data for controlling the system. The diagram shown in Fig. 2 depicts an example using MATLAB and the MATLAB Data Acquisition Toolbox with Data Translation's DT9837 to acquire vibration data from USB modules. Notice that the Data Translation provides an interface layer, called the DAQ adaptor for MATLAB, which allows the MATLAB Data Acquisition Toolbox to communicate with Data Translation's hardware, while the Data Acquisition Toolbox is collecting data, MATLAB can analyse and visualise the data.

RESULTS AND DISCUSSION

From the two experiments conducted, the Daily Exposure to Vibration A(8) value, Vibration Dose Value (VDV) and Exposure Points value were evaluated using MATLAB features, according to formulas 1-3 listed below. The results were displayed in the custom made graphical user interface (GUI).

The Daily Exposure to Vibration A(8) was calculated as follows:

$$A(8) = \text{Vibration value}\left(\frac{m}{s^2}\right) \times \sqrt{\frac{\text{Exposure time (min)}}{480\ (\text{min})}} \tag{1}$$

The Vibration Dose Value (VDV) was calculated as follows:

$$VDV = \left(\int_0^T a^4\ (t)dt\right)^{0.25} \tag{2}$$

Where:

a(t) = Frequency-weighted acceleration (m sec^{-2})

T = The total period of the day during which vibration may occur (sec)

The exposure point was calculated as follows:

$$\text{Exposure points} = 2 \times (\text{vibration value})^2 \tag{3}$$

In this study, two different car speeds were completed for WBV assessment occurred in the car. The speeds were set to 30 and 60 km h^{-1}. All the data obtained in the experiments are shown in Table 2. During the experiments, data for all the parameters shown in Table 2 such as daily to vibration A(8), exposure points system,

Table 2: Whole-body vibration measurement data collected in car

Analysis method parameter	Experiment 1 (10 min) 30 km h^{-1}	Experiment 2 (10 min) 60 km h^{-1}
Daily exposure to vibration A(8)	0.8778 m sec^{-2}	0.9671 m sec^{-2}
Exposure points system	308.206 point	374.094 point
Vibration dose value (VDV)	3.8862 m $sec^{-1.75}$	4.1834 m $sec^{-1.75}$
Daily exposure action value time (0.5 m sec^{-2})	1 h 19 min	1 h 5 min
Daily exposure limit value time (1.15 m sec^{-2})	7 h 0 min	5 h 46 min
Points h^{-1}	38.5257	46.7618
Time achieving 1.7 m $sec^{-1.75}$	95 h 19 min	70 h 59 min

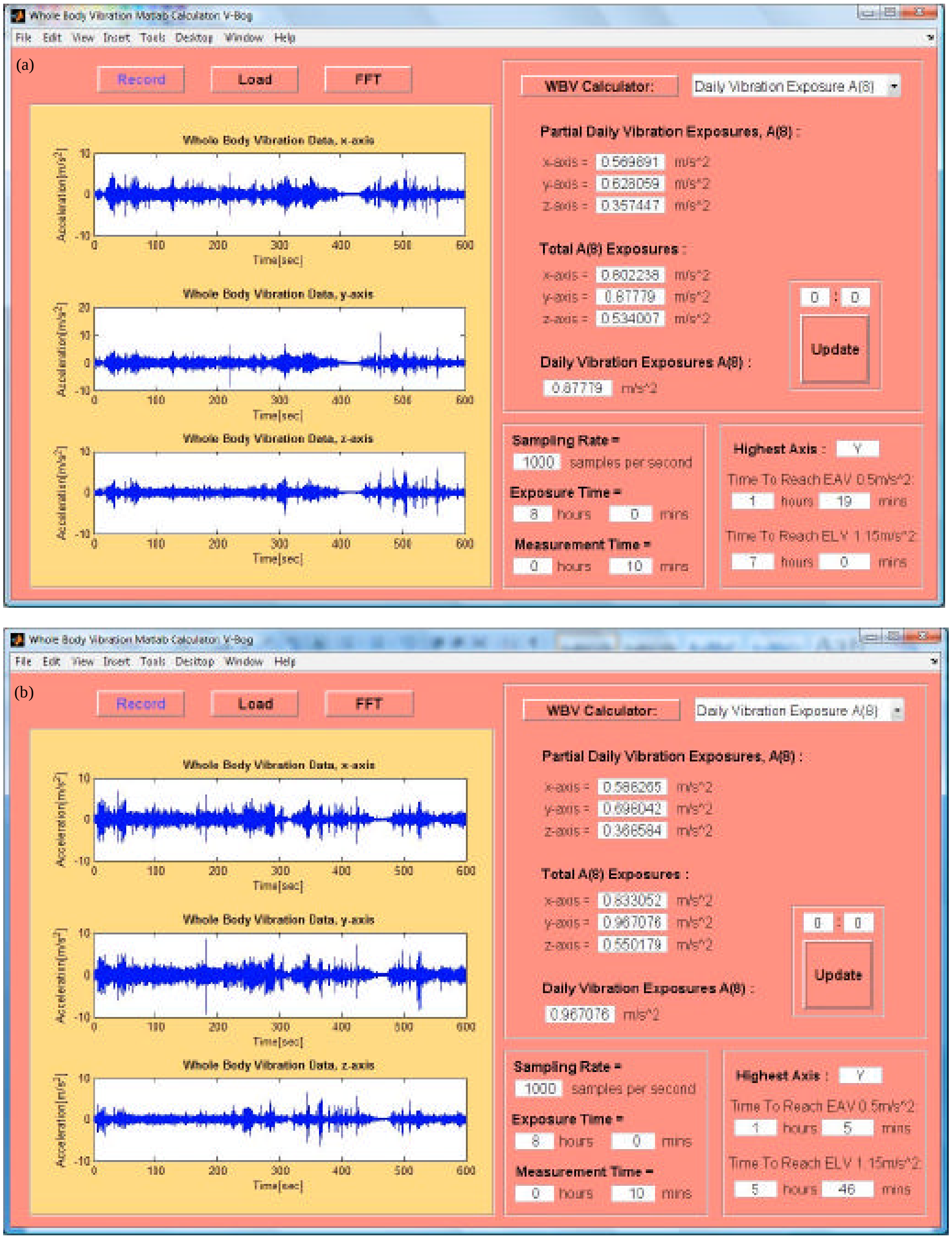

Fig. 2: Whole-body vibration custom data acquisition system (a) at 30 km h^{-1} speed, (b) at 60 km h^{-1} car speed

vibration dose value (VDV), daily exposure action value (EAV) time, daily exposure limit value (ELV) time and points h^{-1} were collected. WBV custom data acquisition system graphs were demonstrated in Fig. 2. The WBV data shown in Fig. 2a, were collected at 30 km h^{-1}, while the data in Fig. 2b were collected at 60 km h^{-1} speed.

WBV risks towards human's health enhanced when the magnitude of the vibration signal absorbed by the human body increased. This situation has been proved by the comparison of the two experiments conducted in the study. From the findings obtained, it can be concluded that when the speed of the car raised, the exposure of WBV towards the driver amplified because of the magnitude of the vibration generated by the car increased. This condition can be proved by comparing the results obtained in the experiment 1 and 2. For experiment 1, the car speed used was 30 km h^{-1}. Therefore, the value of daily exposure to vibration A(8) and vibration dose value (VDV) gained in the experiment 1 was not as much of in the experiment 2 which were 0.8778 m sec^{-2} and 3.8862 m $sec^{-1.75}$. As a result, time achieving daily exposure action value (0.5 m sec^{-2}) in the experiment 1 took longer time which was 1 h 19 min and for daily exposure limit value (1.15 m sec^{-2}) only took 7 h to achieve compared to experiment 2.

This study finds that, the frequency-weighted acceleration value associated with car travel in Malaysia is close to the permissible exposure limit stated in ISO 2631-1:1997. Hence, the high magnitude of WBV experienced by a driver of a moving car may cause musculoskeletal disorders.

The basic method discussed in ISO 2631-1 involves a frequency-weighted root-mean-square (rms) calculation that is primarily applicable to the assessment of health risks from stationary vibrations and does not account for severe single or multiply occurring shock events. Single shocks events can be analyzed with additional methodology that involves a running rms calculation as described in 2631-1, although no information on the health risk levels of single event shocks is provided in the literature. This additional method involves a (frequency-weighted fourth power Vibration Dose Value (VDV)) and is more sensitive to shocks than the basic method. However, the VDV method will underestimate the health risks of vibration that contains severe shocks in comparison to the health risks of vibration that does not containing severe shocks. The EU Physical Agents Directive uses the basic method for the assessment of health risks, with VDV as an alternative. The two methods give different assessment results (Spang and Miltek, 1999).

The (rms) vibration magnitude is expressed in terms of the frequency-weighted acceleration at the seat of a seated person or the feet of a standing person, in units of meters per second squared (m sec^{-2}). The r.m.s vibration magnitude represents the average acceleration over a measurement period. The vibration exposure is assessed using the highest of the three orthogonal axes values ($1.4a_{wx}$, $1.4a_{wy}$ or a_{wz}). A frequency-weighted acceleration value less than 0.45 m sec^{-2} mean that no negative health effect should be expected. A frequency-weighted value between 0.45 and 0.90 m sec^{-2} implies the possibility of negative health effects. A frequency-weighted acceleration value greater than 0.90 m sec^{-2} suggests high risks of negative health problems.

Table 3: Standard value of RMS acceleration

Exposure limit	8	4	2.5	1	30	5	1
	(h)				(min)		
RMS acceleration (m sec^{-2})	2.8	4.0	5.6	11.2	16.8	27.4	61.3

Table 3 shows the r.m.s acceleration value limits for exposures up to 8 h. Vibrations experienced by the train passengers must not exceed the given limits, or they risk the development of vibration-related health problems.

A study in 1983 looked at exposure to accident risk, including characteristics of the amount of travel, conditions of travel and characteristics of the driver and vehicle undertaking the travel (Ziari and Khabiri, 2006). The high WBV exposure may result in musculoskeletal disorders to the drivers. Musculoskeletal disorders continue to be a major source of disability and lost work time (Ghasemkhani *et al*., 2006). There are several examples in the literature that relate WBV exposure from occupational vehicles to musculoskeletal disorders. The term musculoskeletal disorder refers to conditions that involve the nerves, tendons, muscles and supporting structures of the body (Bernard, 1998).

Exposure to WBV is another occupational risk factor that may cause LBP in participants of occupational vehicles (Bovenzi and Hulshof, 1999). In western countries, an estimated 4-7% of all employees are exposed to potentially harmful doses of WBV. Experimental studies have found that resonance frequencies of most of the organs or other parts of the body lie between 1 and 10 Hz, which are in the range of frequencies found in occupational machines and vehicles. Six million workers are exposed to WBV, typically while in a seated position. Workers at risk include delivery vehicles drivers, forklift operators, helicopters pilots and construction equipment operators (Griffin, 2006). Tractor drivers have reported a 61-94% prevalence of LBP and pathological changes in the spine and heavy-equipment drivers report a 70% prevalence of LBP. WBV is recognized as an important risk factor for occupational LBP in a variety of occupational groups (Joubert and London, 2007). At least four European countries have placed WBV injury on their official lists of occupational diseases (Hulshof *et al*., 2002). Among such physical exposures encountered in working conditions, WBV has repeatedly been identified as a risk factor for LBP (Santos *et al*., 2008). Several epidemiologic studies conducted in the past several years have found strong evidence of a correlation between WBV exposure and the onset of LBP (Noorloos *et al*., 2008). The National Research Council (2001) reported that there is evidence of a clear relationship between back disorders and whole-body vibration. Joubert and London (2007) studied the association between back belt usage and back pain among forklift drivers that were frequently exposed to WBV. LBP has been identified as one of the most costly disorders among the working population worldwide and sitting has been associated with the risk of developing LBP (Lis *et al.*, 2007). It was shown that sustained truck sitting postures maintained by mining vehicle operators generates back muscle fatigue and postural balance issues (Santos *et al.*, 2008).

CONCLUSIONS

In this study, it was found that the exposure of the human body to WBV increased with an increase in the vibration exposure magnitude and duration, as illustrated. The increase in the Daily value of Exposure to Vibration A(8) values and Vibration Dose Values (VDV) with increasing travel time and trip quantity. In this study, the frequency-weighted acceleration value recorded on the Malaysian national car was found to be close to the accepted exposure limit set in ISO 2631-1:1997. Hence, most of the drivers on these cars are being subjected to potentially dangerous levels of WBV during their travel. WBV exposure is known to cause health problems in humans. Empirical studies have shown that drivers that are exposed to WBV while in occupational vehicles often have musculoskeletal disorders. However, in Malaysia there is currently insufficient research dedicated to the problem. Because the general public is unaware of the seriousness of WBV, car drivers are often not given information concerning WBV exposure and the related health risks. In conclusion, more studies are needed to provide clear evidence of the association between WBV and musculoskeletal disorders, especially involving to Malaysian occupational vehicles. A future study should focus on an occupational vehicles driver's exposure to WBV and the consequent health problems.

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REFERENCES

Bernard, B.P., 1997. Musculoskeletal Disorders and Workplace Factors: A Critical Review of Epidemiologic Evidence for Work-Related Musculoskeletal Disorders of the Neck. Upper Extremity and Low Back. US Government Printing Office, Washington, DC.

Bernard, B.P., 1998. Musculoskeletal disorders and workplace factors: A critical review of epidemiologic evidence for work-related disorders of the neck, upper extremities and low back. NASA No. 19980001289. http://www.cdc.gov/niosh/docs/97-141/.

Bovenzi, M. and C.T.J. Hulshof, 1999. An updated review of epidemiologic studies on the relationship between exposure to whole-body vibration and low back pain. Int. Arch. Occup. Environ. Health, 72: 351-365.

Burdorf, A. and G.S. Sorock, 1997. Positive and negative evidence of risk factors for back disorders. Scand. J. Work Environ. Health, 23: 243-256.

Garg, A. and J.S. Moore, 1992. Epidemiology of low-back pain in industry. Occup. Med., 7: 593-608.

Ghasemkhani, M., S. Aten and K. Azam, 2006. Musculoskeletal symptoms among automobile assembly line workers. J. Applied Sci., 6: 35-39.

Grieco, A., G. Molteni, G. de Vito and N. Sias, 1998. Epidemiology of musculoskeletal disorders due to biomechanical overload. Ergonomics, 41: 1253-1260.

Griffin, M.J., 1990. Handbook of Human Vibration. Academic Press, London, pp: 171-220.

Griffin, M.J., 2006. Health effects of vibration-the known and unknown. Proceedings of the 1st American Conference on Human Vibration, June 5-7, Morgantown, West Virginia, USA., pp: 3-4.

Hagberg, M., B. Silverstein, R. Wells, M.J. Smith, H.W. Hendrick, P. Carayon and M. Perusse, 1995. Work related musculoskeletal disorder (WMSDs): A reference book for prevention: M. Hagberg *et al.*, Taylor and Francis Inc., 1900 Frost Road, Suite 101, Bristol, PA 19007, pp: 421. J. Biomech., 29: 837-838.

Hulshof, C., G. van der Laan, I. Braam and J. Verbeek, 2002. The fate of Mrs. Robinson: Criteria for recognition of whole-body vibration injury as an occupational disease. J. Sound Vibration, 253: 185-194.

Joubert, D.M. and L. London, 2007. A cross-sectional study of back belt use and low back pain amongst forklift drivers. Int. J. Ind. Ergon., 37: 505-513.

Kroemer, K., H.K. Kroemer and K.K. Elbert, 2003. Ergonomics: How to Design for Ease and Efficiency? 2nd Edn., Prentice Hall, USA., pp: 695.

Lings, S. and C. Leboeuf-Yde, 2000. Whole-body vibration and low back pain: A systematic, critical review of the epidemiological literature 1992-1999. Int. Arch. Occup. Environ. Health, 73: 290-297.

Lis, A.M., K.M. Black, H. Korn and M. Nordin, 2007. Association between sitting and occupational LBP. Eur. Spine J., 16: 283-298.

Matilla, M., 1996. Computer-aided ergonomics and safety-A challenge for integrated ergonomics. Int. J. Ind. Ergon., 17: 309-314.

National Research Council, Institute of Medicine, 2001. Musculoskeletal Disorders and the Workplace: Low Back and Upper Extremities. National Academy Press, Washington DC, ISBN: 0-309-07284-0.

Noorloos, D., L. Tersteeg, I.J.H. Tiemessen, C.T.J. Hulshof and M.H.W. Frings-Dresen, 2008. Does body mass index increase the risk of low back pain in a population exposed to whole body vibration?. Applied Ergonomics, 39: 779-785.

Palmer, K.T., M.J. Griffin and H. Bendall, 2000. Prevalence and pattern of occupational exposure to whole body vibration in Great Britain: Findings from a national survey. Occup. Environ. Med., 57: 229-236.

Santos, B.R., C. Lariviere, A. Delisle, A. Plamondon, P.E. Boileau, D. Imbeau and Vibration Research Group, 2008. A laboratory study to quantify the biomechanical responses to whole-body vibration: The influence on balance, reflex response, muscular activity and fatigue. Int. J. Ind. Ergonomics, 38: 626-639.

Spang, K. and K.S. Miltek, 1999. Project OSHA SME/2002/4668/DK. Ongoing standardization work of interest to the project. http://www.agrivib.com/pdf/RelevantStandards.pdf.

Van Der Windt, D.A., E. Thomas, D.P. Pope, A.F. de Winter, G.J. Macfarlane, L.M. Bouter and A.J. Silman, 2000. Occupational risk factors for shoulder pain: A systematic review. Occup. Environ. Med., 57: 433-442.

Van Tulder, M.W., B.W. Koes and L.M. Bouter, 1995. A cost-of-illness study of back pain in The Netherlands. Pain, 62: 233-240.

Waddell, G. and A.K. Burton, 2001. Occupational health guidelines for the management of low back pain at work: Evidence review. Occup. Med., 51: 124-135.

Wang, M.J.J., H.C. Chung and H.C. Wu, 2003. The evaluation of manual FOUP handling in 300 mm wafer fab. IEEE Trans. Semiconductor Manuf., 16: 551-554.

Weestgard, R.H. and J. Winkel, 1997. Ergonomic intervention research for improve musculoskeletal health: A critical review. Int. J. Ind. Ergonomics, 20: 463-500.

Wilder, D.G. and M.H. Pope, 1996. Epidemiological and aetiological aspects of low back pain in vibration environments-an update. Clin. Biomech., 11: 61-73.

Ziari, H. and M.M. Khabiri, 2006. Analysis characteristics and provide a prediction model of public bus accident in Tehran. J. Applied Sci., 6: 247-250.