

Whole Body Vibration Exposure to Train Passenger

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Abstract: Problem statement: Train is one of the important and famous public transportations in the whole world. High magnitude of whole-body vibration formed by the train may cause diseases and health problems to the human especially a low back pain. This study will give an account of daily exposure to vibration A(8) and Vibration Dose Value (VDV) exposed to the passengers travelling in the train and the effects produced by the exposure towards human body. **Approach:** One national train travelled from East Coast to the South has been chosen to conduct the study. The whole-body vibration exposure was measured in 8 h, which is equal to the duration for normal occupation condition. All the data was computed by using IEPE (ICP™) accelerometer sensor connected to DT9837 device which is capable to measure and analyze vibration effectively. The vibration results attained were displayed in personal computer by using custom Graphical User Interface (GUI). MATLAB software was used to interpret the data obtained. From the results shown, the whole-body vibration exposure level can be determined. **Results:** The values of daily exposure to vibration A(8) and Vibration Dose Value (VDV) in Experiment 3 were $0.3749 \text{ m sec}^{-2}$ and $1.2513 \text{ m sec}^{-1.75}$ respectively. **Conclusion:** It can be concluded that the whole-body vibration absorbed by human body enhanced when the duration of vibration exposure and the total of the trips that has been passed by the passengers increased. This can be proved by the increasing of the value of daily exposure to vibration A(8) and Vibration Dose Value (VDV) calculated in the study.

Key words: Whole-body vibration, vibration dose value, low back pain

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 disciplines are psychology, cognitive sciences, physiology, biomechanics, applied physical anthropology and industrial systems engineering (Kroemer *et al.*, 2003). Matilla (1996) mentioned that the importance of safety and ergonomics had grown significantly. The latest technology had increased the option to broaden the ergonomics and safety features of products and equipment. However, it will also create new risks and the way to manage it would become more complicated. Therefore, it is important for the designer to use ergonomic knowledge in making decision during of machines, equipment, products and systems. There is substantial epidemiologic evidence of associations

between physical ergonomics exposures at the workplace, such as lifting, constrained postures, repetitive movements, fast work pace, heavy material handling, forceful exertions and vibration and the occurrence of upper extremity musculoskeletal disorders (Bernard, 1997; Grieco *et al.*, 1998; Hagberg *et al.*, 1995; National Research Council, 2001; Van Der Windt *et al.*, 2000). To be more specific, ergonomics (also called human factors or human engineering in the United States) 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, were suggested to tackle musculoskeletal

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problems in industries (Wang *et al.*, 2003; Weestgard and Winkel, 1997).

Various definitions have been given to Whole-Body Vibration (WBV) by dictionaries, companies and authors themselves. From the Directive 2002/44/EC of the European Parliament and of the Council, the term 'whole-body vibration' means the mechanical vibration 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 (EC, 2000). WBV is defined as vibration occurring when a greater part of the body weight is supported on a vibrating surface. WBV principally occurs in vehicles and wheeled working machines. In most cases exposure to WBV occurs in a sitting position and the vibration is then primarily transmitted through the seat pan, but also through the back rest. WBV may impair performance and comfort. It has also been claimed to contribute to the development of various injuries and disorders. In many work situations WBV is therefore an evident and annoying occupational health problem (Griffin, 1990).

Low Back Pain (LBP) is among the most common and costly health problems (Garg and Moore, 1992; 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 evidence on occupational risk factors for back disorders (Wilder and Pope, 1996; Burdorf and Sorock, 1997; Bovenzi and Hulshof, 1999; Lings and Leboeuf-Yde, 2000; Waddell and Burton, 2000). All these reviews conclude that there is strong epidemiological evidence for a relation between occupational exposure to WBV and LBP. In five European countries (Belgium, Germany, Netherlands, France, Denmark), LBP and spinal disorders due to WBV are currently recognized as an occupational disease (Hulshof *et al.*, 2002). However, high exposures and adverse effects still occur as WBV is a common occupational risk factor for LBP, affecting 4-8% of the workforce in industrialized countries (Palmer *et al.*, 2000). Important high risk groups are drivers of off-road vehicles (for example, earth moving, forestry and agricultural machines), drivers of forklift trucks, lorries, or buses, crane operators and helicopter pilots.

MATERIALS AND METHODS

Whole-body vibration measurement was done according to ISO 263-1:1997. The triaxial accelerometer sensor was located between the passenger contact points with the vibration source.

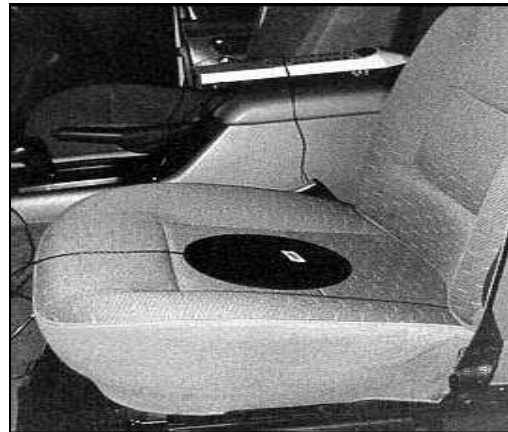


Fig. 1: Triaxial accelerometer sensor used for WBV measurement

Table 1: Location measurement

| Experiment | Location |
|------------|-------------------------|
| 1 | From kajang to seremban |
| 2 | From seremban to gemas |
| 3 | From segamat to tampin |

One passenger was picked randomly in the train. Then the passenger sat on the accelerometer, for example as in Fig. 1.

In this study, the assessment of whole-body vibration was completed by deciding number of sampling rate to 1000 samples sec^{-1} . Computation of the exposure time was set to 8 h for each experiment, which equal to the duration for normal occupation stipulation. The study has been conducted at different locations. The location measurement for each experiment was explained in Table 1. After the accelerometer and DT9837 instrument were connected, the process of collecting the data acquisition of the train vibration was started. The total vibration of each axes which were x, y and z-axis felt by the passenger was displayed in a plotted graph by using Mat lab software.

Whole-body vibration measurement explored by the passenger was done three times at different train trip areas. Among the areas passing by the train were namely from Kajang to Seremban, from Seremban to Gemas and from Segamat to Tampin.

Description of subject: Excessive exposure of whole-body vibration usually occurred at working area which involved long duration of exposure and high-level of vibration magnitude. Train is one of the most public transportations that produced high magnitude of vibration. The one national train travelled from East Coast to the South has been chosen to conduct the study.

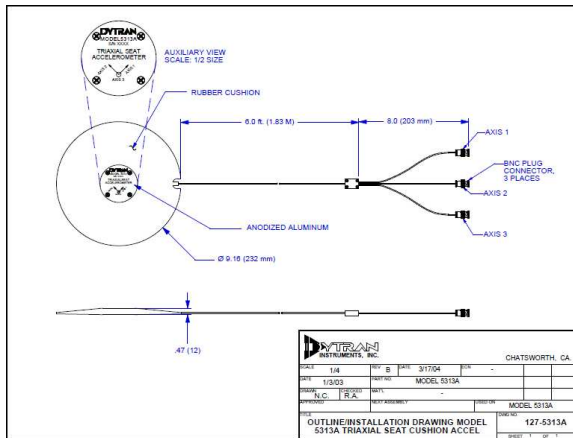


Fig. 2: Triaxial seat accelerometer (DYTRAN model 5313A)

Equipments: There were two devices used in the study which were IEPE (ICP™) accelerometer sensor and DT9837 instrument.

Based on Fig. 2, the IEPE (ICP™) accelerometer sensor (also known as triaxial seat accelerometer) been used in this study was DYTRAN Model 5313A. The sensor was utilized 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. Figure 3 showed how the accelerometer works. Most accelerometers require a current source of 4 mA and a compliance voltage of at least 18 V 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 sources. 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 0.5-25.8 kHz (0.49 × sampling frequency). The DT9837 was a programmable trigger for analog input operations for maximum flexibility. Figure 4 and Table 2 showed the DT9837 model and the summary features of the instrument.

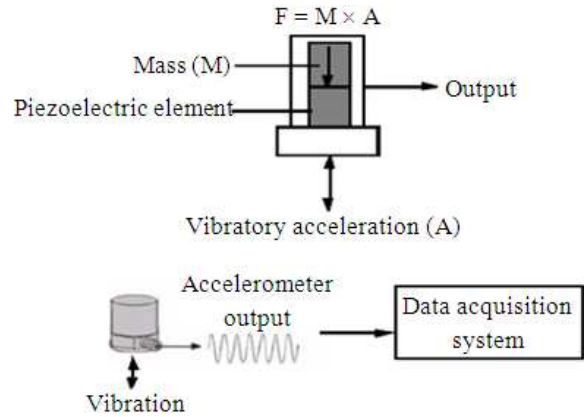


Fig. 3: How accelerometers work



Fig. 4: DT9837 model

Table 2: Summary features of DT9837

| Summary of features | | | | | |
|----------------------------|----------------------------|-------------------------------------|----------------------------------|-----------------------------|--|
| A/D throughput per channel | D/A channels | Tachometer input | Simultaneous subsystem operation | Application | |
| 52.734 kHz | 4 channels or single value | 1 synchronous to analog data stream | Yes | Vibration, acoustics, sonar | |

Description of software and custom Graphical User Interface (GUI): In this study, MATLAB software was applied to analyze the vibration signal gathered by DT9837 instrument from USB port. The MATLAB Graphical User Interface (GUI) scripts have been examined by using GUIDE function for ease measurement and assessment of WBV exposure.

Table 3: Whole-body vibration measurement data collected in train

| Analysis method | Experiment 1 | | Experiment 2 | | Experiment 3 | |
|---|-------------------------------|----------------|-------------------------------|-------------|-------------------------------|--------------|
| | From Kajang | To Seremban | from Seremban | To Gemas | From Seremban | To Tampin |
| Daily exposure to vibration A(8) | 0.3221 m sec ⁻² | | 0.2884 m sec ⁻² | | 0.3749 msec ⁻² | |
| Exposure points system | 41.4867 point | | 33.2716 point | | 56.206 point | |
| Vibration Dose Value (VDV) | 1.1014 m sec ^{-1.75} | | 1.0973 m sec ^{-1.75} | | 1.2513 m sec ^{-1.75} | |
| Daily exposure action value time (0.5 m sec ⁻²) | 9 h 50 min | | 12 h 16 min | | 7 h 16 min | |
| Daily exposure limit value time (1.15 m sec ⁻²) | 52 h 3 min | | 64 h 54 min | | 38 h 25 min | |
| Points per h | 5.1858 point | | 4.159 point | | 7.0258 point | |
| Time achieving 1.75 m sec ^{-1.75} | 1 h 29 min | | 1 h 30 min | | 53 min | |

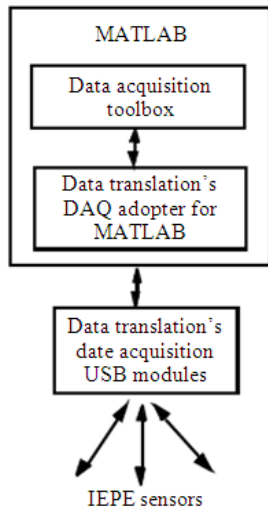


Fig. 5: Flow chart of data acquisition process

From this MATLAB script, three graphs of each axes been meditated for current analysis. Besides, the data and vibration signal can be saved in the personal computer for next analysis. Thus, the total of daily exposure to vibration towards human can be evaluated through the accelerometer sensor, DT9837 instrument and this 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. 5 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 analyze and visualize the data.

RESULTS

From the three experiments done, daily exposure to vibration A (8) value and Vibration Dose Value (VDV) and exposure points value were evaluated by using formula (1), (2) and (3). But, by employed the MATLAB Graphical User Interface (GUI), the calculation of those values was done by choosing the analysis method from the organize MATLAB menu. When the option was made followed the passenger's need, the calculated values completed by connect the update button. Hence, the results were displayed in the custom made Graphical User Interface (GUI).

Daily exposure to vibration A(8):

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

Vibration Dose Value (VDV):

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

Where:

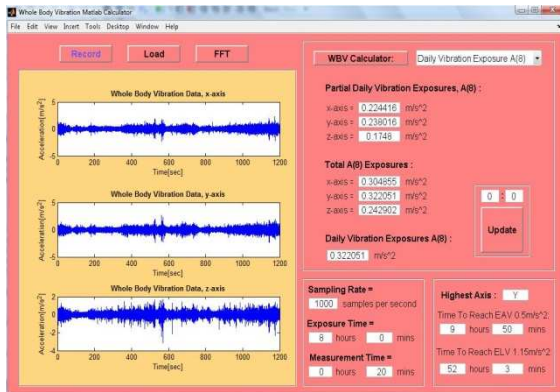
a (t) = Frequency-weighted acceleration (m sec⁻²)

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

Exposure points value:

$$\text{exposure points} = 2 \times (\text{vibration value})^2 \quad (3)$$

All the data obtained in the experiment were organized in Table 3. Whole-body vibration graphs were demonstrated in Fig. 6. For Fig. 6a, the graph of whole-body vibration was collected namely from Kajang to Seremban, while Fig. 6b was from Seremban to Gemas and Fig. 6c from Segamat to Tampin.



(a)

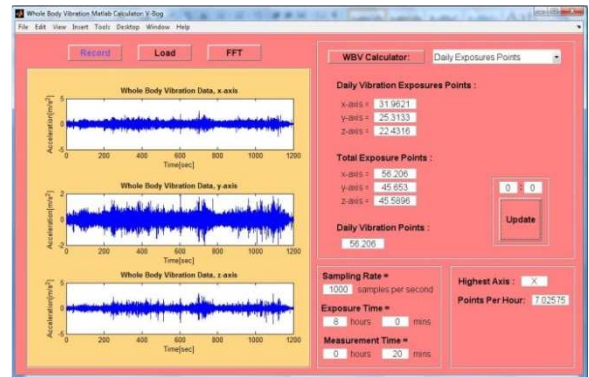
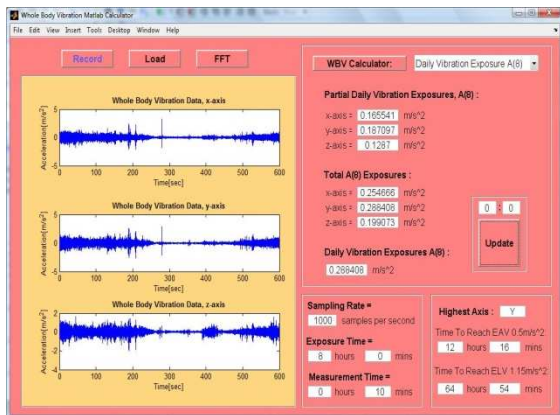


Fig. 7: Exposure points system calculation



(b)

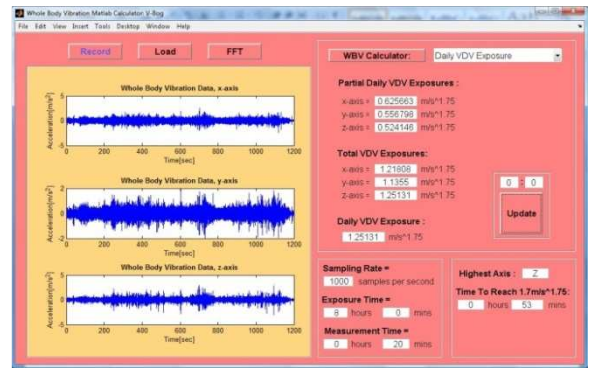
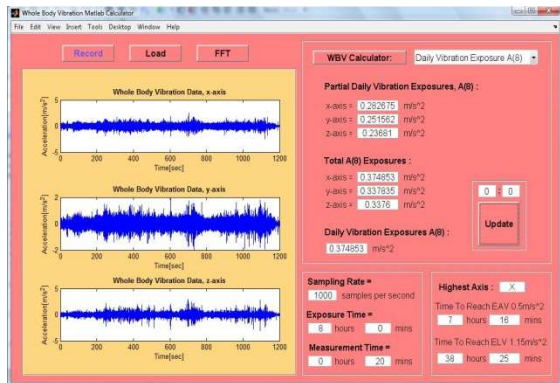


Fig. 8: Vibration dose value (VDV) computation



(c)

Fig. 6: Whole-body vibration custom data acquisition system (a) from Kajang to Seremban, (b) from Seremban to Gemas and (c) from Segamat to Tampin

Figure 7 showed the calculation of exposure points system. The Vibration Dose Value (VDV) measurement was illustrated in Fig. 8.

DISCUSSION

From the results attained, the frequency weighted acceleration value indicated in the study was closely to the permissible value of exposure limit stated according to ISO 2631-1:1997. Therefore, the high magnitude of WBV may cause musculoskeletal disorders to the train passengers.

The basic method (frequency weighted r.m.s. method) in ISO 2631-1 is primarily applicable to assessment of health risks from stationary vibrations not containing severe multiple or single event shocks. Single event shocks can be analyzed with the additional method running r.m.s. in 2631-1, although there is no information on health risk levels. The additional method VDV (frequency weighted fourth power vibration dose value) is more sensitive to shocks than the basic method, but it will still underestimate the health risk of vibration containing severe shocks in comparison to the health risk of vibration not containing severe shocks. The EU Physical Agents Directive uses the basic method for assessment of health risk with VDV as an alternative. The two methods give different assessment results.

Table 4: Standard value of RMS acceleration

| Exposure limit | RMS acceleration |
|----------------|--------------------------|
| 8 h | 2.8 m sec ⁻² |
| 4 h | 4.0 m sec ⁻² |
| 2.5 h | 5.6 m sec ⁻² |
| 1 h | 11.2 m sec ⁻² |
| 30 min | 16.8 m sec ⁻² |
| 5 min | 27.4 m sec ⁻² |
| 1 min | 61.3 m sec ⁻² |

The root-mean-square (r.m.s) 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, it is expressed in units of meters per second squared (m sec⁻²). The r.m.s vibration magnitude represents the average acceleration over a measurement period. It is the highest of three orthogonal axes values (1.4a_{wxx}, 1.4a_{wyy} or a_{wzz}) that are used for the exposure assessment.

For knowledge, the frequency weighted acceleration value which less than 0.45 m sec⁻² showed that there was no negative health effect expected. Whilst the frequency weighted value in between 0.45 and 0.90 m sec⁻² explained that the negative health effects still can be accepted. But, the frequency weighted acceleration value greater than 0.90 m sec⁻², high risks of bad health problems were anticipated.

The data from Table 4 indicated the r.m.s acceleration value for exposure limit in 8 h. The passengers exposed to the whole-body vibration exposure must not exceed this standard value. Otherwise, the passengers may have an experience of bad health problems.

The results of this study indicated that in Experiment 3, the values of daily exposure to vibration A (8) and Vibration Dose Value (VDV) were much higher than the other two experiments. The values of daily exposure to vibration A (8) and Vibration Dose Value (VDV) were 0.3749 m sec⁻² and 1.2513 m sec^{-1.75} respectively. It seems possible that these results were due to indelicate track passed by the train, the train operation style and speed differences compared to Experiment 1 and 2. In addition, the daily exposure action value time only required 7 h 16 min to meet the standardized value of 0.5 m sec⁻² to an 8 h reference period. Surprisingly, this result was found to exceed the standard time of whole-body vibration assessment which was 8 h stated in ISO 2631-1:1997. The reason for this is not clear but it may have something to do with the speed of the train that generated high magnitude of vibration value to the train. The high magnitude of whole-body vibration exposure produced by the train may contribute to musculoskeletal disorders to the passengers. In reviewing the literature, there was found the relation between occupational vehicles and

whole-body vibration exposure that lead to musculoskeletal disorders.

The term musculoskeletal disorder refers to conditions that involve the nerves, tendons, muscles and supporting structures of the body (Bernard, 1997). 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 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. 6 million workers are exposed to WBV typically while in a seated position including delivery vehicles drivers, forklift operators, helicopters pilots and construction equipment operators (Griffin, 2006). Tractor drivers have reported 61-94% prevalence of LBP and pathological changes in the spine and heavy-equipment drivers report 70% prevalence of LBP. WBV is recognized as an important risk factor for occupational LBP in a variety of occupational groups (Darren and Leslie, 2007). At least four European countries have placed WBV injury on their scheduled 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 found strong evidence for a correlation between exposure to WBV and the occurrence of LBP (Danielle *et al.*, 2008). The National Research Council (2001) reported that there is evidence of a “clear relationship between back disorders and whole-body vibration”. Darren and Leslie (2007) had determined the association between back belt usage and back pain amongst forklift drivers exposed to WBV. LBP has been identified as one of the most costly disorders among the worldwide working population and sitting has been associated with risk of developing LBP (Angela *et al.*, 2007). It was showed that sustaining trunk sitting postures corresponding to mining vehicle operators generates back muscle fatigue and postural balance (Santos *et al.*, 2008). On the other hand, Danielle *et al.* (2008) had been concluded that occupational participants exposed to WBV, with a high BMI do not have an increased risk for the development of LBP, so the focus should be on other factors.

CONCLUSION

WBV gained by human body increased when the duration of vibration exposure and the total train trips experienced by the subject enlarged. This phenomena

can be proved by the increasing of daily of exposure to vibration A(8) value and Vibration Dose Value (VDV). Hence, it was clearly explained that most of the train passengers especially at the national train located at Malaysia were exposed to worse WBV during their travelling time because the frequency-weighted acceleration value indicated in the study was closely to the value of exposure limit value according to ISO 2631-1:1997. Consequently, this condition may cause health problems to the passengers. Empirical studies showed that there was a relation between an occupational vehicles and whole-body vibration that lead to musculoskeletal disorders. But, from the scenario of Malaysian population, there is a deficient research on this problem. Because of insufficient knowledge of diseases affected by WBV, the passengers find difficulty to know exactly the exposure of WBV to them and how much they have been exposed. As a conclusion, more studies are needed to provide clear evidence of the association between WBV and musculoskeletal disorders especially on Malaysian occupational vehicles. A further study with more focus on the train drivers is therefore suggested.

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