WHOLE-BODY-VIBRATION MEASUREMENT AND ASSESSMENT FOR CAIRO SUBWAY (METRO), CAR AND BUS PASSENGERS

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ABSTRACT

This study quantifies whole-body vibration on a range of the transportations used in Cairo, Egypt. Subway (Metro), car and bus are the important transportations in Cairo. They are well-known public transportations and play an important role for the human to travel from one place to another. High magnitude of whole-body vibration formed by these transportations may cause diseases and health problems to the human especially a low back pain. It may lead to a muscular and bone system disorder of the neck and back. After daily exposure over a number of years, these same whole-body vibrations can result in a number of health disorders affecting your entire body including permanent harm to internal organs, muscles, joints and bone structure. The measured data were analyzed according to ISO 2631-1 and ISO 2631-5 standards. The ISO 2631-1 (1997) standard utilizes the daily exposure $A(8)$ and VDV, whereas the new ISO 2631-5 (2004) standard methodology uses the parameters $S_{ed}$ and R factor. During the analysis it was found that the whole-body vibration absorbed by human body increased when the magnitude and duration of vibration exposure experienced by the passengers increased. The shock parameters (VDV and $S_{ed}$) were computed from data and compared to see if the same trend obtained. The results show high levels of vibration and adverse health effects on the lumbar spine are expected. It was found that subway (Metro) passengers were identified to have a high risk of exposure little more than bus and car passengers respectively in accordance with health guidance caution zone boundaries with $A(8)$ as a measure. Similar results were achieved from the $S_{ed}$ and R factor values which were the measure of ISO 2631-5. The main conclusion from this study is that musculoskeletal symptoms and disorders of low back and in the neck and upper extremities, among passengers of the selected transport may be a result of long-term exposure to shock-type, vertical and horizontally oriented seated WBV.

KEYWORDS: Whole-Body Vibration (WBV), Vibration Dose Value (VDV), Daily Exposure to Vibration $A(8)$, Low Back Pain (LBP)

INTRODUCTION

Industrialization leads to movement of people from one place to another. Several modes of travel such as road, rail, air and sea are available. Human vibration is defined as the effect of mechanical vibration on the human body. During our normal daily lives we are exposed to vibrations of one or other sort e.g. in buses, trains and cars. Many people are also exposed to other vibrations during their working day, for example vibrations produced by hand-tools, machinery, or heavy vehicles. The effect of vibration and jerks on human is usually evaluated by means of frequency weighted accelerations. Many international and national standards for example ISO 2631-1, ISO 2631-4 and BS 6841 are available to evaluate and assess the effect of vibration on the human. These standards differ in evaluation and assessment. Whole-body vibration is transmitted to the body as a whole, generally through the supporting surface (that is, feet, buttocks, back, etc.). A person driving a vehicle, for example, is subjected to whole-body vibration through the buttocks, and if there is back support, through the back as well. Exposure to whole-body vibration can either cause permanent physical damage, or disturb the nervous system. Daily exposure to whole-body vibration over a number of years can result in serious physical damage, for
example, ischemic lumbago. This is a condition affecting the lower spinal region. Exposure can also affect the exposed person's circulatory and/or urological systems. People suffering from the effect of long-term exposure to whole-body vibration have usually been exposed to this damaging vibration in association with some particular task at work. Exposure to whole-body vibration can disturb the central nervous system. Symptoms of this disturbance usually appear during, or shortly after, exposure in the form of fatigue, insomnia, headache and "shakiness". Many people have experienced these nervous symptoms after they have completed a long car trip or boat trip. However, the symptoms usually disappear after a period of rest. Long-term exposure can cause serious health problems, particularly with the spine like, disc displacement, degenerative spinal changes, lumbar scoliosis, intervertebral disc disease, degenerative disorders of the spine, herniated discs, disorders of the gastrointestinal system, and uro-genital systems ("Whole Body Vibration", 2005; ISO 2631-1, 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 (Griffin, 1990). Low Back Pain, LBP, is among the most common and costly health problems. Several critical reviews have discussed the evidence on occupational risk factors for back disorders. 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 (Griffin, 1990; Garg, and Moore, 1992; Tulder et al., 1995; Wilder and Pope, 1996; Burdorf and Sorock, 1997; Bovenzi and Hulshof, 1999; Lings and Leboeuf-Yde, 2000; Waddell and Burton, 2000). The health risks associated with regular and continuous exposure to mechanical vibration has been assessed based on published standards. The most widely accepted standard for measurement and evaluation of human exposure to WBV and subsequent prediction of health risks is the International Organization of Standards (1997) report entitled ISO 2631-1: Mechanical vibration and shock—Evaluation of human exposure to whole-body vibration, Part 1—General requirements.

This standard provides guidance on the quantification of WBV in relation to human health and comfort, the probability of vibration perception, and incidence of motion sickness. In 2004 the International Organization for Standardization introduced a new standard for the evaluation of human exposure to WBV that contains multiple shocks, called ISO 2631-5: Mechanical vibration and shock—Evaluation of human exposure to whole-body vibration, Part 5—Method for evaluation of vibration containing multiple shocks. The foundation for the new standard was laid by a series of research reports commissioned by the United States Army Aero medical Research Laboratory between 1991 and 1997. The new ISO standard was established to quantify health risks specifically to the lumbar spine and the vertebral endplates as a result of WBV exposures containing multiple shocks (Eger and Stevenson et al., 2008).

The rest of the paper is organized as follows Section 2 outlines the general architecture and design of the system prototype and defines the role of each component. Section 3 presents the methodology. Section 4 presents the measurement tests of WBV. Section 5 presents results and mathematical definition of evaluation methods and discussion of the results and compares it with the threshold limit values defined in the standards. Section 6 summarizes and concludes the paper.
MATERIALS AND METHODS

Experimental System

This section explains the details of our design, including the selection of devices and a sample measurement data. The wireless body sensor system consists of a wearable sensor unit and a data logger unit, as shown in figure 1. The wearable Micromachined Accelerometer (MMA7361L) sensor unit is carried by a person at the contact points.

It acquires the vibration signals. The measured data are fed into a microcontroller and sampled via an analog-to-digital converter (ADC). The sampled data are then transmitted wirelessly to the data logger unit, which is connected to a computer through a USB connection. The measured data is analyzed using software programs.

In this study, the assessment of whole-body vibration is completed by deciding a sampling rate of 200 samples/sec. This would be enough since it has been found that the frequency range considered for whole body vibration is (ISO 2631-1, 1997)

- 0.5 Hz to 80 Hz for health, comfort and perception.
- 0.1 Hz to 0.5 Hz for motion sickness.

Computation of the exposure time was set to 8 h for each trip, which equal to the duration for normal occupation stipulation. The study has been conducted at different locations. The total vibration of each axes x, y and z felt by the passenger is displayed in plotted graphs. Whole-body vibration measurement explored by the passenger was done three times at different metro trip areas and two times at different car and bus trip areas.

Wearable Sensor Unit

The Freescale tri-axial analog Micromachined Accelerometer (MMA7361L) is selected as the measurement device on the wearable sensor unit mainly because of its low price, small size, capability of continuous measurement, and ease of integration. This accelerometer has two different measurement ranges (±1.5g and ±6.0g) that can be dynamically set by one input pin. Each range provides different measurement sensitivity levels.

The accelerometer continuously records accelerations in all three axes. The measured data are read by MICROCHIP PIC18F4520 Enhanced Flash microcontroller with 10-Bit A/D and nano Watt Technology. The microcontroller does simple processing on the data.

The processed data are fed to a wireless transceiver and sent wirelessly to the data logger unit, which is connected to PC. The measured data will be downloaded to a PC through a USB connection and analyzed using software programs.

Selection of Wireless Standard

The ZigBee transceiver is a wireless device that works on the IEEE 801.15.4 protocol (IEEE Standard 802.15.4, 2003), allowing the creation of a WPAN network (Wireless Personal Area Network). The main features of this device include low power consumption, support for various network settings, serial communication using UART (Universal Asynchronous Receiver), power management settings, eight digital inputs/outputs, four 10-bits Analog-to-Digital Converter, and two PWM (Pulse-Width Modulation) outputs, easy implementation, low-cost interface, easy configuration, redundancy of devices, high node density per physical layer (PHY) and medium access control layer (MAC), and they allow the network to work with a great number of active devices—a critical and interesting attribute for applications with sensors.
Data Logger Unit

With the XBee Explorer dongle you can now plug the unit directly into your USB port. No cables needed! This unit works with all XBee modules. Upon receiving the measurement data from the wireless interface, the processed data will be downloaded to a PC and then serve as the basis for the required calculations and analysis by the developed software.

Figure 1: A Wireless Body Sensor System for Acceleration Measurement

METHODOLOGY

In order to characterize the vibrations produced by different types of transportation means measurements were made on the first line metro, 2 types of private cars and 2 common types for public buses. Vibration measurements were done in normal working conditions, according to the measuring procedure outlined in ISO 2631-1 (1997), which is also applicable to ISO 2631-5 (2004). The velocity during the trips was normal for a working day. At this study, the participant had a mean age of 29 (yrs), mean body mass of 75 (kgs) and mean body height of 1.67 (m). Acceleration levels were measured in three perpendicular directions (seat x– longitudinal, seat y–transverse, seat z–vertical, as shown in fig.2) and on the floor beneath the seat.

The tri-axial accelerometer sensor was located between the passenger contact points with the vibration source in the direction of translational vibration, the feet of standing person, the buttocks, back and feet of a seated person or the supporting area of recumbent person. Signals from the tri-axial accelerometer were passed to 3-channel of PIC 18f4520 microcontroller ADC which did the digital data recording then pass these data to the wireless transmitter Zigbee module which send these data wirelessly to the other receiver Zigbee module which is directly connected to the computer and start to download the acceleration data for post processing and further analysis.

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 Matlab software, as shown in fig.3, fig.4 and fig.5 (for the first trip of metro, car and bus respectively). Besides, the data and vibration signal can be saved in the personal computer for next analysis. The same data set was used for the analysis using the two standards ISO 2631-1 (1997) and ISO 2631-5 (2004). Standards for WBV exposure specify daily vibration exposure levels (exposure action value, EAV and exposure limit value, ELV), as shown in table 1. Where a passenger is likely to be exposed to vibration, an assessment of the likely daily vibration exposure is to be made. If the exposure level is above the EAV, a range of actions must be taken to reduce exposure and decrease risks. If ELV is exceeded, immediate action must be taken to reduce vibration exposure below the ELV and procedures be implemented to prevent it being exceeded again. Prediction WBV health risks is based on ISO 2631-1 (1997), health guidance caution zone, HGCZ limits, and 2631-5 (2004) are shown in table 1.
Two assessment methods are set out in the standard 2631-1 (1997). The Basic Evaluation method uses weighted root-mean-square (WRMS) acceleration value. For shock type vibration (jolts and jars) the fourth power vibration dose value (VDV) method is more sensitive to peaks than the basic evaluation method. The standard provides guidelines for exposure durations. The guidance criteria for WRMS and VDV are shown in Table 1. For exposure below the zone, health effects have not been clearly documented and/or objectively observed; in the zone, caution with respect to health risks is indicated and above the zone health risks are likely. ISO 2631-5 (2004) gives guidelines for the evaluation of vibration containing multiple shocks based on an equivalent Static Compressive Stress ($S_{ed}$) and Risk Factor (R) values.

**Computation of ISO 2631-1 (1997) Parameters**

In accordance with the requirements of ISO 2631-1 (1997) and European Directive 2002, the acceleration time histories recorded to compute the following:

- Measurement of axis-weighted acceleration RMS time histories $a_w$ (m/s$^2$);
- Estimated passenger daily vibration exposure $A(8)$ (m/s$^2$) and Vibration Dose Value (VDV) (m/s$^{1.75}$) forms;
- Crest factor CF;
- Time to reach the EAV and ELV, when specified both in daily exposure to vibration $A(8)$ form;
- Exposure points system.

The data acquired was measured for 20 minutes to 30 minutes. However, this was measured in such a way as to represent the vibration levels experienced by the passenger related to the normal 8-hour work period. The required parameters were then computed and extrapolated to cover the entire duration of exposure. The time domain data was read and then converted to m/s$^2$. The data was then weighted according to ISO 2631-1 (1997) whole-body vibration weighting filter. Subsequent to the weighting, the WRMS and VDV parameters were then computed.


The new multiple shocks standard relies on biodynamic models described to calculate acceleration response at the lumbar spine. Dedicated software was also used to compute an equivalent Static Compressive Stress ($S_{ed}$) and Risk Factor (R) parameters based on ISO 2631-5 (2004). These parameters were then used in predicting risk to health. The calculation of the risk factor, R, takes into account the number of years and days per year of exposure and factors in the vertebral bone ultimate strength which depends on the age of the operator at the time of exposure.

**Vibration Measurements**

The vibrations were measured according to ISO 2631-1 which required to measure vibrations in all the three directions (X, Y and Z). For each trip done, the evaluation methods were computed. The mathematical definition of the
Weighted Root Mean Square (WRMS), the Crest Factor, daily exposure to vibration A(8) value, VDV, and exposure points value are calculated using equation (1) to equation (5) based on ISO 2631-1 (1997) and European Directive 2002 (ISO 2631-1, 1997; Directive 2002/44/EC, 2002). Once the spinal accelerations have been generated, an acceleration dose (D_x, D_y, and D_z) is calculated. The dose then is normalized to an average workday based on duration of the available record and the expected length of the workday, to obtain Dxad, Dyad, Dzad and calculate the total daily exposure. The ISO 2631-5 (2004) provides guidance for assessment of health effects of multiple shocks. Given the calculated total daily acceleration dose in each of the basicentric axes, they are combined to obtain an equivalent static compressive stress (Sed) which is used to compute risk factor, R, for use in the assessment of the adverse health effects. These parameters are calculated using equation (6) to equation (10) based on ISO 2631-5 (2004), (ISO 2631-5, 2004; Nabih ALEM, 2005).

The Weighted r.m.s Acceleration (WRMS)

It is expressed in m/s^2 for translational vibration and calculated as follows:

\[ a_w = \left[ \frac{1}{T} \int_0^T a_w^2(t) dt \right]^{\frac{1}{2}} \]  
(1)

Where \( a_w(t) \) is the weighted (see ISO 2631-1 (1997) weighting curve) acceleration time history and \( T \) is the duration of the measurement. (ISO 2631-1, 1997).

The Crest Factor (CF)

\[ CF = \frac{\text{max}(a_w)}{a_{w.r.m.s}} \]  
(2)

The Crest Factor is the modulus of the ratio of the maximum instantaneous peak value of the frequency weighted acceleration signal to its r.m.s. value. (ISO 2631-1, 1997).

Daily Exposure to Vibration A(8)

The 8-hour energy equivalent vibration total value for a worker in meters per second squared (m/s^2), including all whole-body vibration exposures during the day.

\[ A(8) = k a_{wi} \sqrt{\frac{\text{exposure time}(\text{min})}{480(\text{min})}} \]  
(3)

Where \( a_{wi} = \) Frequency-weighted acceleration (m/s^2) in the i direction (i = x, y, z). (Directive 2002/44/EC, 2002).

k = multiplying factor (for x-axis: k=1.4, y-axis: k=1.4 and z-axis: k=1). The 1.4 factor is the ratio of the longitudinal and traversal curves values, of equal answer in human answers, the most sensible.

Vibration Dose Value (VDV)

A cumulative dose is based on the fourth root of the fourth power of the acceleration signal. VDV has units of \( m/s^{1.75} \).

\[ VDV = \left\{ \int_0^T \left[ a_{wi}(t) \right]^4 dt \right\}^{\frac{1}{4}} \]  
(4)

\( T = \) the total period of the day during which vibration may occur(s). (ISO 2631-1, 1997).
Exposure Points Value

For any vehicle or machine operated, the number of exposure points accumulated in an hour \(P_{E,1h}\) in points per hour) can be obtained from the vibration magnitude \(a_w\) in m/s² and the factor \(k\) (either 1.4 for x- and y-axes or 1.0 for the z-axis) using: (Directive 2002/44/EC, 2002).

\[
P_{E,1h} = 50 \left( ka_w^2 \right)
\]  

(5)

The Acceleration Dose (\(D_k\))

\[
D_k = \left[ \sum_{i=1}^{m} A_k^6 \right]^{1/6}
\]  

(6)

Where \(A_k\) is the \(i^{th}\) peak of the acceleration in the k-direction (k = x, y or z), and m is the number of peaks in the measured signal. (ISO 2631-5, 2004; Nabih ALEM, 2005).

The Average Daily Dose (\(D_{kd}\))

\[
D_{kd} = D_k \left[ \sum_{i} \frac{t_d}{t_m} \right]^{1/6}
\]  

(7)

For assessment of health effects the average daily dose, \(D_{kd}\), for each direction k is obtained by normalizing the dose measured over a period \(t_m\) to the duration of an average workday \(t_d\). (ISO 2631-5, 2004; Nabih ALEM, 2005).

The Daily Equivalent Static Compressive Stress (\(S_{ed}\))

\[
S_{ed} = \left[ \sum_{k=x,y,z} m_k D_{kd} \right]^{1/6}
\]  

(8)

Where \(m_k\) is empirical constant for x, y, and z directions. Recommended values for these constants are: \(m_x = 0.015\), \(m_y = 0.035\) and \(m_z = 0.032\) MPa/(m/s²). Finally, the health risk for healthy seated males may be projected to a lifetime, using a risk factor R. (ISO 2631-5, 2004; Nabih ALEM, 2005).

The R Factor

The R factor is defined for use in adverse health effects related to the human response acceleration dose. (ISO 2631-5, 2004; Nabih ALEM, 2005).

\[
R = \left[ \sum_{i=1}^{N} \left( \frac{S_{ed} \cdot N \cdot c}{S_{ui} - c} \right) \right]^{1/6}
\]  

(9)

Where \(N\) is the number of exposure days per year; \(i\) is the year counter; \(n\) is the number of years of exposure; \(c\) is a constant representing the static stress due to gravitational force (a value of \(c = 0.25\) MPa can be normally used for driving posture); \(S_{ui}\) is the ultimate strength of the lumbar spine for a person of age \((b+i)\) years; \(b\) is the age at which exposure starts (assumed to be 20 years in this study). From in-vitro studies (ISO 2631-5, 2004), the following relationship between \(S_{ui}\) (in MPa) and \(b + i\) (in years) had been derived:

\[
S_{ui} = 6.75 - 0.066 \times (b+i)
\]  

(10)
One first line metro travelled from Helwan to El Marg has been chosen to conduct the study. The study has been conducted at different locations. Three different trips were done by metro. Among the areas passing by the metro were namely from El Marg to Ghamra, from Helwan to Mar-gergis, and from Ahmed Orabi to Hadayk Helwan. Road surface circumstance is a brig dominant parameter towards whole-body vibration. Two different cars, for two different trips, have been chosen to conduct the study. Whole-body vibration measurement was done by changing the road condition passed by the car. Also, one national bus has been chosen to conduct the study. Two different trips have been done with bus and measure the whole-body vibration. For a brief description about the selected transportation means in this study and road conditions for each trip see table 2.

**Table 1: Exposure Action and Limit Values and Health Guidance Caution Zone Values for Whole-Body Vibration**

<table>
<thead>
<tr>
<th>Standard</th>
<th>HGCZ Lower Limit</th>
<th>HGCZ Upper Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>ISO 2631-1 (1997)</td>
<td>0.43 m/s² (WRMS)</td>
<td>0.86 m/s² (WRMS)</td>
</tr>
<tr>
<td></td>
<td>8.5 m/s¹.75 (VDV)</td>
<td>17 m/s¹.75 (VDV)</td>
</tr>
<tr>
<td>European Directive 2002</td>
<td>0.50 m/s² (WRMS)</td>
<td>1.15 m/s² (WRMS)</td>
</tr>
<tr>
<td></td>
<td>9.1 m/s¹.75 (VDV)</td>
<td>21 m/s¹.75 (VDV)</td>
</tr>
<tr>
<td>ISO 2631-5 (2004)</td>
<td>0.50 MPa (S&lt;sub&gt;ed&lt;/sub&gt;)</td>
<td>0.80 MPa (S&lt;sub&gt;ed&lt;/sub&gt;)</td>
</tr>
<tr>
<td></td>
<td>0.80 ®</td>
<td>1.20 ®</td>
</tr>
</tbody>
</table>

**DISCUSSIONS AND RESULTS**

For figure 3, figure 4, and figure 5 the graph of whole-body vibration (Time domain acceleration) was collected for the first trip of metro, car, and bus, in x, y, and z axis. It can be seen that shocks are present in these time acceleration histories. These time histories were used in the computation of the WRMS and VDV based on ISO 2631-1 (1997). Sensitivity of the human body to mechanical vibration is known to be dependent on both the frequency and the direction of excitation. These factors need to be taken into account if the harmful effects of a vibration are to be assessed. The ISO (International Standards Organization) has devised the three weighting curves, which can be used to take the aforementioned factors into account when assessing the harmfulness of a vibration. For integration of the frequency-weighted acceleration time history, the frequency weighting shall be determined as appropriate. The frequency range of measured signal was obtained by conducting an FFT analysis on that signal; figure 6 shows the power of the DFT of z-axis (the dominant axis- the highest value of WBV) of the first car trip.

Exposure action and limit values and health guidance caution zone values for whole-body vibration that was suggested by the ISO 2631-1 (1997) standard, ISO 2631-5 (2004) standard and European Directive 2002 as guidelines are indicated by table 1. ISO 2631-1 (1997) standard suggested that if the WRMS value is less than 0.43 m/sec² (EAV) then this shows that there is no negative health effects expected. Whilst the frequency weighted value is in between 0.43 and 0.86 m/sec² then the negative health effects still can be accepted. If the frequency weighted acceleration value is greater than 0.86 m/sec² (ELV) then this indicates high risks of bad health problems were anticipated. The European Directive 2002 suggests the Daily vibration exposure A(8) value which equal 0.5 m/sec² (EAV) showed that there was negative health effect expected and a range of actions must be taken to reduce exposure and decrease risks. Daily vibration exposure A(8) value which is equal or greater than 1.15 m/sec² indicates that the negative health effects are exceeded, so immediate action must be taken to reduce vibration exposure below the ELV. The ISO 2631-5 (2004) suggests that R < 0.8 indicates a low probability of an adverse health effect and R > 1.2 indicates a high probability on an adverse health effect. This is equivalent to stating that S<sub>ed</sub> = 0.5 MPa and S<sub>ed</sub> = 0.8 MPa are the lower and upper boundary of a caution zone for a normal person during a typical working day.
All the data obtained in the metro was organized in table 3. Results indicate that the frequency weighted acceleration WRMS value along three trips exceeded the ISO 2631 (1997) guidelines. It can be seen that the r.m.s acceleration values are align between 0.4209m/s$^2$ to 0.5631m/s$^2$ for x-axis, 0.56m/s$^2$ to 1.3052m/s$^2$ for y-Axis and 1.2825m/s$^2$ to 1.7862m/s$^2$ for the z-Axis). Besides that Partial Daily vibration exposure A(8) value of each trip (Highest axis) was closely to the permissible value of exposure action value, EAV, stated according to European Directive 2002. In addition, the daily exposure action value time only required approximately 35 min to meet the standardized value of 0.5 m/s$^2$ in the third trip. It seems possible that these results were due to indelicate track passed by the metro, the metro operation style

![Figure 3: Unweighted Acceleration during First Trip of Metro in x, y, z Directions](image1)

![Figure 4: Unweighted Acceleration during First Trip of Car in x, y, z Directions](image2)

![Figure 5: Unweighted Acceleration during First Trip of Bus in x, y, z Directions](image3)
Table 2: The Selected Transportation Means

<table>
<thead>
<tr>
<th>Transportation Means</th>
<th>A Brief Description</th>
<th>Road Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>The Metro</td>
<td>One of first line metros was used during three different trips.</td>
<td>Part of Indelicate track passed by the metro during the second and third trips.</td>
</tr>
<tr>
<td>The car</td>
<td>The first trip in Helwan streets - hyundai accent 1300cc model 99 – the speed in the range of 40-60 km/h.</td>
<td>Uneven and zigzag road</td>
</tr>
<tr>
<td></td>
<td>The second trip in Sheraton districts streets - pointer volkswagen 1000cc – the speed in the range of 60-65 km/h.</td>
<td>even and straight road</td>
</tr>
<tr>
<td>The bus</td>
<td>Two different types of buses were used during two different trips.</td>
<td>Uneven mixed with straight and zigzag parts of the road</td>
</tr>
</tbody>
</table>

Table 3: Calculations of Whole-Body Vibration Levels Based on ISO 2631-1 (1997) and European Directive 2002 Using WRMS Parameter of Data Collected in the Metro

<table>
<thead>
<tr>
<th>Analysis method</th>
<th>Trip 1 (Sitting-20 Min)</th>
<th>Trip 2 (Standing-20 Min)</th>
<th>Trip 3 (Sitting-30 Min)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>from El-Marg to Ghamra</td>
<td>from Helwan to Mar-gergis</td>
<td>from Ahmed Orabi to Hada’k Helwan</td>
</tr>
<tr>
<td>WRMS a_w (m/s²)</td>
<td>0.5631</td>
<td>0.6014</td>
<td>1.7862</td>
</tr>
<tr>
<td>Crest Factor (CF)</td>
<td>17.88</td>
<td>8.78</td>
<td>3.21</td>
</tr>
<tr>
<td>Partial Daily vibration Exposures A(8) (m/s²)</td>
<td>0.16</td>
<td>0.17</td>
<td>0.36</td>
</tr>
<tr>
<td>Time (min) to reach Daily exposure action value (0.5 m/sec²) (for highest axis)</td>
<td>37.61</td>
<td>72.96</td>
<td>35.94</td>
</tr>
<tr>
<td>Time (min) to reach Daily exposure limit value (1.15 m/sec²) (for highest axis)</td>
<td>198.97</td>
<td>385.94</td>
<td>190.12</td>
</tr>
<tr>
<td>Daily vibration Exposure points system</td>
<td>10</td>
<td>12</td>
<td>53</td>
</tr>
<tr>
<td>Points per hour</td>
<td>160</td>
<td>82</td>
<td>167</td>
</tr>
<tr>
<td>Fourth Power vibration dose value VDV (m/s²)</td>
<td>12.835</td>
<td>6.7912</td>
<td>16.2768</td>
</tr>
</tbody>
</table>


<table>
<thead>
<tr>
<th>Analysis Method</th>
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<tr>
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<td>from Ahmed Orabi to Hada’k Helwan</td>
</tr>
<tr>
<td>Acceleration Dose (D_a)</td>
<td>20.35</td>
<td>42.44</td>
<td>22.49</td>
</tr>
<tr>
<td>Equivalent daily static compressive stress (S_ea)</td>
<td>2.53</td>
<td>3.10</td>
<td>2.48</td>
</tr>
<tr>
<td>Risk factor (R)</td>
<td>3.63</td>
<td>4.46</td>
<td>3.56</td>
</tr>
</tbody>
</table>
and speed differences compared to trip 1 and 2. High Crest Factor values means the vibration signal contain occasional shocks. The whole-body vibration exposure is highest axis VDV for each trip.

The first and second trip VDV values were $16.2768 \text{ m/s}^1.75$ and $16.2141 \text{ m/s}^1.75$ respectively, which are greater than EAV that suggested by European Directive 2002 and they are more close to the ELV that suggested by ISO 2631-1 (1997) as a guidelines. In the third trip VDV was $19.9342 \text{ m/s}^1.75$, i.e. close to the exposure limit value that suggested by European Directive 2002 as a guidelines but it is greater than the ISO 2631-1 (1997) ELV guidelines.

At the same time, exposure whole-body vibration points system value in first and third trips was higher than Exposure action value ($0.5 \text{ m/s}^2 = 100 \text{ points}$). ISO 2631-5 (2004) analysis based on data organized in table 4. The calculated values of R and $S_{ed}$ factors during three trips (table 4) were more than the permissible value of the ELV (above the HGCZ upper limit value). Therefore, long term exposure to these types of vibration accelerates onset of lumbar spine disorders and possibly adversely affects the gastro-intestinal and cardiovascular systems and gives an indication of high probability of an adverse health effect.

In the car study, there are two different trips with two different road surface conditions have been passed through. All the whole-body vibration measurement data collected in car were organized in table 5. Results indicate that the frequency weighted acceleration WRMS value along two trips exceeded the ISO 2631 (1997) guidelines.

It can be seen that the r.m.s acceleration values are align between $0.5432 \text{m/s}^2$ to $0.8034 \text{m/s}^2$ for x-axis, $0.7642 \text{m/s}^2$ to $0.2306 \text{m/s}^2$ for y-Axis and $1.5964 \text{m/s}^2$ to $1.1815 \text{m/s}^2$ for the z-Axis). But the Partial Daily vibration exposure A(8) value of each trip (Highest axis) was less than the exposure action value, EAV, stated according to European Directive 2002. It was $0.40 \text{ m/s}^2$ and $0.30 \text{ m/s}^2$ respectively.

In addition, the daily exposure action value time only required approximately 47 min to meet the standardized value of 0.5 m/s$^2$ in the first trip, which is less than the time needed during the second trip to reach EAV. It seems that these high results of the first trip were due to the uneven and zigzag road condition of the car first trip.

The whole-body vibration exposure is highest axis VDV for each trip. VDV values were $16.04 \text{ m/s}^1.75$ and $15.00 \text{ m/s}^1.75$ for the first and second trip respectively which are greater than EAV that suggested by European Directive 2002 and they are more
Table 5: Calculations of Whole-Body Vibration Levels Based on ISO 2631-1 (1997) and European Directive 2002 Using WRMS Parameter of Data Collected in the Car

<table>
<thead>
<tr>
<th>Analysis Method</th>
<th>Trip1 (Sitting - 30 Min)</th>
<th>Trip2 (Sitting - 30 Min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>WRMS $a_w$ (m/s²)</td>
<td>x 0.5432</td>
<td>y 0.7642</td>
</tr>
<tr>
<td>Crest Factor (CF)</td>
<td>x 18.48</td>
<td>y 13.18</td>
</tr>
<tr>
<td>Partial Daily vibration Exposures $A(8)$ (m/s²)</td>
<td>x 0.19</td>
<td>y 0.27</td>
</tr>
<tr>
<td>Time (min) to reach Daily exposure action value (0.5 m/sec²) (for highest axis)</td>
<td>x 47.09</td>
<td></td>
</tr>
<tr>
<td>Time (min) to reach Daily exposure limit value (1.15 m/sec²) (for highest axis)</td>
<td>x 249.09</td>
<td></td>
</tr>
<tr>
<td>Daily vibration Exposure points system</td>
<td>x 14</td>
<td>y 29</td>
</tr>
<tr>
<td>Points per hour</td>
<td>x 127</td>
<td></td>
</tr>
<tr>
<td>Fourth Power vibration dose value VDV (m/sⁱ.⁷⁵)</td>
<td>x 13.80</td>
<td>y 15.73</td>
</tr>
</tbody>
</table>


<table>
<thead>
<tr>
<th>Analysis Method</th>
<th>Trip1 (Sitting - 30 Min)</th>
<th>Trip2 (Sitting - 30 Min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acceleration Dose ($D_k$)</td>
<td>x 24.22</td>
<td>y 36.95</td>
</tr>
<tr>
<td>Equivalent daily static compressive stress ($S_{ed}$)</td>
<td>x 2.06</td>
<td></td>
</tr>
<tr>
<td>Risk factor (R)</td>
<td>x 2.96</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 7: Calculations of Whole-Body Vibration Levels Based on ISO 2631-1 (1997) and European Directive 2002 Using WRMS Parameter of Data Collected in the Bus

<table>
<thead>
<tr>
<th>Analysis Method</th>
<th>Trip1 (sitting - 30 Min)</th>
<th>Trip2 (Sitting - 30 Min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>WRMS $a_w$ (m/s²)</td>
<td>x 0.8382</td>
<td>y 1.1472</td>
</tr>
<tr>
<td>Crest Factor (CF)</td>
<td>x 12.01</td>
<td>y 8.61</td>
</tr>
<tr>
<td>Partial Daily vibration Exposures $A(8)$ (m/s²)</td>
<td>x 0.29</td>
<td>y 0.40</td>
</tr>
<tr>
<td>Time (min) to reach Daily exposure action value (0.5 m/sec²) (for highest axis)</td>
<td>x 43.62</td>
<td></td>
</tr>
<tr>
<td>Time (min) to reach Daily exposure limit value (1.15 m/sec²) (for highest axis)</td>
<td>x 230.76</td>
<td></td>
</tr>
<tr>
<td>Daily vibration Exposure points system</td>
<td>x 34</td>
<td>y 64</td>
</tr>
<tr>
<td>Points per hour</td>
<td>x 138</td>
<td></td>
</tr>
<tr>
<td>Fourth Power vibration dose value VDV (m/s¹.⁷⁵)</td>
<td>x 15.49</td>
<td>y <strong>18.00</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Analysis Method</th>
<th>Trip1 (sitting - 30 min)</th>
<th>Trip2 (sitting - 30 min)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>from Sheraton to Roxy</td>
<td>from Sheraton to Roxy</td>
</tr>
<tr>
<td></td>
<td>X</td>
<td>Y</td>
</tr>
<tr>
<td>Acceleration Dose ($D_k$)</td>
<td>35.51</td>
<td>39.23</td>
</tr>
<tr>
<td>Equivalent daily static compressive stress ($S_{ed}$)</td>
<td>2.19</td>
<td>2.46</td>
</tr>
<tr>
<td>Risk factor (R)</td>
<td>3.14</td>
<td>3.54</td>
</tr>
</tbody>
</table>

close to the ELV that suggested by ISO 2631-1 (1997) as a guidelines. At the same time, exposure whole-body vibration points system value in first trip was higher than Exposure action value ($0.5 \text{ m/s}^2 = 100 \text{ points}$). ISO 2631-5 (2004) analysis based on data organized in table 6. The calculated values of $R$ and $S_{ed}$ factors during three trips (table 6) were more than the permissible value of the ELV (above the HGCZ upper limit value).

The reasons for this high magnitude of vibration value may be due to the road conditions e, the age, and the needed maintenance for it. That high magnitude of whole-body vibration exposure produced by the car will contribute to musculoskeletal disorders to the passengers. The second trip measurements values are below those obtained for the first trip. This may be due to the second trip road surface conditions.

In the bus study, there are two different trips with two different types of buses for the same road. All the whole-body vibration measurement data collected in car were organized in table 7. Results indicate that the frequency weighted acceleration WRMS value along two trips exceeded the ISO 2631 (1997) guidelines. It can be seen that the r.m.s acceleration values are align between $0.8382\text{m/s}^2$ to $0.2817\text{m/s}^2$ for x-axis, $1.1472\text{m/s}^2$ to $0.1823\text{m/s}^2$ for y-Axis and $1.6586\text{m/s}^2$ to $1.713\text{m/s}^2$ for the z-Axis). But the Partial Daily vibration exposure $A(8)$ value of each trip (Highest axis) was less than the exposure action value, EAV, stated according to European Directive 2002. It was $0.41\text{m/s}^2$ and $0.43\text{m/s}^2$ respectively.

For the second trip, the daily exposure action value time only required approximately 41 min to meet the standardized value of $0.5 \text{ m/s}^2$, which is less than the time needed during the first trip to reach EAV. VDV values were $18.00 \text{m/s}^{1.75}$ and $17.22 \text{m/s}^{1.75}$ for the first and second trip respectively which are greater than ELV that suggested by and ISO 2631-1 (1997) and more closely to the ELV suggested by European Directive 2002 as a guidelines. High Crest Factor values means the vibration signal contain occasional shocks.

ISO 2631-5 (2004) analysis based on data organized in table 8. The calculated values of $R$ and $S_{ed}$ factors during three trips (table 8) were more than the permissible value of the ELV (above the HGCZ upper limit value). At the same time, exposure whole-body vibration points system value in the two trips was higher than Exposure action value ($0.5 \text{ m/s}^2 = 100 \text{ points}$). Therefore, the harmful and higher values of WBV lead to increase of health problems risk and may cause musculoskeletal to the bus passengers.

These results shown here indicate that all selected transport had their highest vibration r.m.s.-magnitude in the z-direction (the dominant direction) compared to other directions (x- and y-axes). In general, subway (metro) had the highest VDV in the z-direction, which was significantly higher compared to the other directions (for first and second trips), but VDV was the highest in the y-direction (for the third trip).

The dominant magnitudes for subway (metro), VDV were found in the z- and y- axes. Car had its highest VDV in the z-direction (for first trip), but x-direction (for second trip). Bus had its highest VDV in the y-direction (for the first
trip), but z-direction (for second trip). When evaluating the most dominant direction, by use of r.m.s.-magnitude (according to ISO 2631-1 (1997)), all these transport in this study held vibration magnitudes exceeding the limit value. But with European Directive 2002 guidelines, all partial daily vibration exposure A(8) are below the action value.

When analyzing VDV (VDV is more sensitive to shocks compared to the r.m.s.-value), subway (metro) third trip and both bus trips had VDV exceeding the limit value (suggested by ISO 2631-1 (1997)). All other trips in this study showed magnitudes exceeding the action value.

The shock parameters (VDV and $S_{ed}$) corresponding to ISO 2631-1 (1997) and ISO 2631-5 (2004) standard methodologies were computed from data and compared to see if the same trend obtained. The VDV and $S_{ed}$ parameters of interest are plotted against WRMS (for metro, car and bus) in figure 7 and figure 8.

The use of WRMS as the abscissa was simply to scatter the two other variables and allow a better visual inspection of their values. Interestingly, the VDV exhibited some correlation with WRMS. The ISO 2631-1 allows the use of an estimated vibration dose value and gives the values corresponding to the lower and upper boundaries of the caution zone as $8.5 \, m/s^{1.75}$ (action level) and $17 \, m/s^{1.75}$ (limit value) respectively (ISO 1997, clause B.3.1).

According to ISO 2631-1 (1997) based on the WRMS and VDV values (both parameters are from ISO 2631-1), the selected data set shows (fig.7) that the VDV of two trips of metro and all car trips exceeded the action level of $8.5 \, m/s^{1.75}$, but only one metro trip and all bus trips exceeded the limit value of $17 \, m/s^{1.75}$. The plot of VDV against WRMS shows some correlation between the two parameters.

On the other hand, a plot of the $S_{ed}$ against the WRMS (figure 8) placed all cases above the caution zone (exceeded the limit value) defined in ISO 2631-5, indicating that they present a health risk. According to ISO 2631-1(1997), for events with CF greater than 9 which indicate the presence of shocks, the VDV parameter should be used whereas $S_{ed}$ is the daily parameter for assessing shock based on ISO 2631-5 (2004).

Hence, VDV parameter will ultimately be compared to $S_{ed}$ for transient shock events. The VDV is plotted against the $S_{ed}$, as shown in fig. 9. It is clearly seen that the predicted health risk

![Figure 7: Plots of Daily VDV vs. WRMS, Along with the Corresponding Caution Zones](image-url)
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Figure 8: Plots of $S_{ed}$ vs. WRMS, along with the Corresponding Caution Zones

Figure 9: Plots of VDV vs. $S_{ed}$, along with the Corresponding Caution Zones

Based on VDV are less conservative than the predicted risk based on $S_{ed}$ values as shown in figure 9 in the presence of shocks. One explanation for the failure of the VDV to detect signatures with high shock contents is that the threshold currently recommended in the ISO 2631-1 may be too high. In order for the VDV to be used for detecting high shock content in a vibration signature, the threshold should be lowered.

In reviewing the literature, Biodynamic research as well as epidemiological studies has given evidence for an elevated risk of health impairment due to long-term exposure with high-intensity whole-body vibration. Mainly the lumbar spine and the connected nervous system may be affected (ISO 2631-1, 1997). The most pronounced and common effect is lower back pain. This can be linked to the vibration acting on the musculoskeletal system of the body, causing the degeneration of the small cartilage (intervertebral) discs, allowing tissues and nerves to be strained and pinched leading to various back and neck problems. Long periods of sitting while the spinal column is being aggravated by vibration exposure
cause the nutrients needed for growth and repair to diffuse outwards. This causes irreparable damage at a cellular level and wears and reduced healing of discs and vertebra within the spinal column. Magnetic Resonance Imaging (MRI) is a more sensitive imaging study for the evaluation of degenerative disc disease.

Muscle fatigue also occurs as the muscles try to react to the vibrational energy to maintain balance and protect and support the spinal column. But these are often too slow as the muscular and nervous system cannot react fast enough to the shocks and loads being applied to the body. Other health effects that have been associated with whole-body vibration and especially the driving environment are haemorrhoids, high blood pressure, kidney disorders and even impotence – and other adverse reproductive effects in men and women. 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; Bernard, 1998). Exposure to WBV is another occupational risk factor that may cause LBP in participants of occupational vehicles (Bovenzi and Hulshof, 1999). Several epidemiologic studies conducted in the past several years found strong evidence for a correlation between exposure to WBV and the occurrence of LBP (Noorloos et al, 2008). There is evidence of a “clear relationship between back disorders and whole-body vibration” (National Research Council, Institute of Medicine, Musculoskeletal disorders and the workplace, 2001).

CONCLUSIONS

Researchers generally agree that exposure to shock increases the risk of spinal injury and lower back pain for occupational drivers. Extremely high shock levels, such as those encountered in a trucking accident, can cause compressive fracture of the spine (acute risk), while chronic exposure to lower levels can lead to disc degeneration and lower back pain. This study was made to evaluate the risks from using the most famous transportation means in Cairo, Egypt. The study was guided by the ISO 2631-1 (1997) and ISO 2631-5 (2004) safety criteria. It was found that WBV gained by human body increased when the magnitude of the vibration experienced by the passengers increased. This is clear by the increasing of daily exposure to vibration A(8) value and vibration dose value (VDV). Hence, It was clearly explained that most of the metro, bus and car passengers were exposed to worse WBV during their travelling time because the frequency-weighted acceleration value indicated in the study was higher than the value of exposure limit value according to ISO 2631-1 (1997). According to European Directive 2002 analysis methodology, it was found that the daily exposure to vibration A(8) value was closely to the value of exposure action value. It was found that all ISO 2631-5 (2004) parameters (Sed and R) values were exceeded the ISO 2631-5 (2004) threshold. Consequently, it is evident that the passengers of the selected public transport are exposed to higher and harmful values of vibrations and shocks in several directions so this conditions cause health problems to the passengers. It was found that subway (metro) passengers were identified to have a high risk of exposure little more than bus and car passengers respectively in accordance with health guidance caution zone boundaries with A(8) as a measure.

This may be due to the subway (metro) passenger’s seat material type and its design way. Also the high speed of subway (metro) is one of the main reasons that cause these high vibration values. It seems that passenger, of all these selected transport, should reported a high prevalence of symptoms from the low back disorders/problems (most vibration occurs in the vertical plane, the z-direction) and from the neck/shoulder musculoskeletal disorder. The purchase of newer and modern transportations means should be taken into account and allows increasing resting time during the day activities. The health and safety management should be carried out to prevent adverse health effects in metro passengers. Seats with arm rests, lumbar support, an adjustable seat back and an adjustable seat pan are also useful for correcting passenger surfaces to reduce vibration at the source. Seats with an air-ride suspension and a passive damper are used to
isolate the passenger from vibration. New seat design that supported with featuring viscoelastic foam padding and lower-back support may help reduce health risks to passengers. A further study with more focus on the drivers of different transportations means and heavy vehicle are therefore suggested.

REFERENCES


U.S. Army Vehicles", Industrial Health, 43, 403–412. U.S. Army Aeromedical Research Laboratory, Fort Rucker,
Alabama 36362–0577, USA.

evidence for work-related musculoskeletal disorders of the neck, upper extremity and low back", National
Institute for Occupational Safety and Health, Cincinnati, OH. visited on http://www.cdc.gov/niosh/docs/97-141/


index increase the risk of low back pain in a population exposed to whole body vibration? Applied Ergonomics,