One way ANOVA model to study whole-body vibration attributes among taxi drivers- An emphasis on the role of speed

Milad Derakhshanjazari¹, Mohammad Reza Monazzam²*, Seyed Mostafa Hosseini³, Mohammad Saeid Poursoleiman⁴

¹Department of Occupational Health Engineering, Tehran University of Medical Sciences, Tehran, Iran
²*Department of Occupational Health Engineering, Tehran University of Medical Sciences, Tehran, Iran
³Department of Epidemiology and Biostatistic, Institute of Public Health, Tehran University of Medical Sciences, Tehran, Iran
⁴Kermanshah Petrochemical Industrial Company HSE Manager, Kermanshah, Iran

*Corresponding author: Mohammad Reza Monazzam; Email: monazzammreza@gmail.com; Tel/Fax: +982166910454

Abstract

Introduction: Taxi drivers are daily exposed to whole body vibration (WBV) for a relatively long period of time. This can cause complications such as back pain, digestive disorders, and impaired concentration among them. Since the vibration level depends on many factors, the present study was performed to model the impact of vehicle speed on the attributes of WBV among the Peugeot 405 taxi drivers.

Methodology: in this experimental study, the WBV was measured while other variables including tire pressure, engine speed, road gradient, number of passengers, and type of tire, springs, and shock absorbers had been fixed. The measurements were done according to ISO2631-1 at different speeds of 20, 40, 60 and 80 km/h. Relationship between the measured variables was analyzed using one way ANOVA model and post Hoc test.

Results: increasing the vehicle speed caused an increase in the average value of vibration attributes including Z-axis (vertical) rms acceleration, 8-hour equivalent acceleration, vibration
dose value, and crest factor ($P < 0.05$). At the speed of 80 km/h, the average vibration dose value (17.6) exceeded the upper limit of the ISO 2631-1:1997 health caution zone (>17). Further, 8-hour equivalent acceleration, at the speeds of 60 and 80 km/h, was beyond the upper limit (>0.9 m/s$^2$). According to the crest factor, increasing speed would cause greater vibration peaks along the axis Z (worst-case axis).

**Conclusion:** The amount of vibration transmitted to the whole body is sensitive to speed changes so that urban taxi drivers who are usually driving at low speeds for inner-city transits will be exposed to a lower average value of WBV. Due to the evident effect of speed on WBV attributes, it is strongly recommended to be given full consideration to this factor in preparing vibration control plans for vehicles.

**Key words:** speed, whole body vibration, Taxi, Peugeot 405

1. **Introduction**

Taxi drivers are daily exposed to frequent and prolonged whole body vibration (WBV) [1]. This type of vibration falls within the frequency range of 1-80 Hz [2]. It is considered as one of the hazardous physical factors in workplace and leaves many harmful effects on the body. The harmful health effects will appear when a person is in contact with a vibrating surface. The most common side effects are back pain, digestive disorders, damage to auditory system, and impaired concentration. In a study by Mitsuhiko et al. (2004) on 248 taxi drivers, the prevalence of back pain was estimated at 45.8% [1]. Typically, people in everyday life are exposed to WBV in automobiles, buses, trains, bicycles, and motorcycles [2]. The roughness of road driving surface causes vertical vibration in vehicles, which is transmitted to the body of driver and passengers. This, in addition to the mentioned disorders, reduces the safety of people inside vehicles [3]. When a vehicle is moving on the road, it plays the role of a vibration system whose vibration frequency depends not only on road roughness but also on springiness and mass of the vehicle [4]. Springiness which is dependent on the springs and shock absorbers has a considerable impact on reducing vibrations imposed on driver and passengers’ whole body. In view of the foregoing, assessment and control of exposure to WBV among taxi drivers would be of utmost importance whereas they spend many more hours in their car. Mitsuhiko et al. (2004) reported that taxi drivers in Japan work 18 hours every other day. They assessed WBV among drivers of 12 types of taxi vehicles and concluded that the WBV level was within the range of health
caution determined by ISO2631-1 standard [1]. Various factors affect the levels of WBV among taxi drivers. Bouazara et al (2006) and Hansson et al (2002) reported that suspension system under the seat has led to considerable decrease in WBV; but this suspension is a lot of cost and complexity [5, 6]. Funakoshi et al (2004) and Chen et al (2003) found that decrease of speed is an important factor for low back pain caused by whole body vibration [7, 8]. Hostens and Ramon (2003) showed that vehicle speed associated significantly with vibration magnitude measured at the seat [9]. Besides, the same study has noted that increasing the speed of the vehicle resulted in increase in vibration [10-12]. Despite the importance of the issue, literature reviews revealed that so far there have not been any similar studies on WBV of taxi drivers in Iran. Accordingly, the present study was conducted to assess WBV attributes among the Peugeot 405 taxi drivers. Currently, around 150,000 Peugeot 405 vehicles offer transport services to the passengers in Iran. The large number of this type of vehicles and relatively long working hours (10 hours a day) of drivers apparently indicate the importance of addressing this issue in Iran. Drivers compete along the route to pick up passengers. This causes the more frequent the speed change of vehicles on the path. Given that speed can be one of the influential factors on the level of WBV, therefore, the present research measured the vibration at different speeds to investigate the effect of varying speed on WBV levels among drivers.

2. Material and methods
2.1. Study environment
In this experimental study, experiments were conducted on a Peugeot 405 taxis car produced in 2014 in Iran. The driver of the taxi works 10 hours a day continuously. The mileage of the taxi at the start of testing was about 30000 km. In order to increase precision and eliminate confounding factors, before the start of testing, the vehicle underwent technical examinations at the Light Vehicle Mechanized Technical Inspection Center. The examinations included testing the springs and shock absorbers by SAXON Vehicle brake tester (Figure 1) and tire balance by Tire Balance Tester. In order to test the springs and shock absorbers based on Figure 1, a vibration at a fixed frequency (typically 16 Hz) and amplitude of about 1 cm is applied to the tires on the front and rear axles. Then, the tester specifies the isolation percentage of the applied vibration. The springs and shock absorbers will be applicable if the percentage is greater than 50%. According to the steering wheel deviation test, in cases of tire imbalance or vibration while on the move, a lead
piece is connected to the uncoordinated part of the tire to re-balance it. Confirmation of the examination results by the centre (OK) indicates that the vehicle is safe technically and no additional vibration is transmitted to the cabin. When the results are not accepted by the technical inspection centre (Not Ok), the defective parts should be replaced or repaired.

![Shock Absorber Tester](image)

**Figure 1.** Test conditions of springs and shock absorbers

After the technical safety of the taxi, The WBV attributes were measured in a real environment on the Highway Karaj-Qazvin in the Alborz Province. The asphalt-paved highway is almost straight and has a length of approximately 95 km. It should be noted that during testing, tire pressure (30 PSI (pounds per square inc) ), engine speed (3000 rpm (rotations per minute)), the type of driver's seat, type and size of tires, tire rims, springs, shock absorbers, and type of tire tube were constant.

### 2.2. Measurement of WBV attributes

In this study, WBV attributes were measured in accordance with ISO 2631-1 while the vehicle was in motion [2]. As mentioned earlier, the frequency of WBV varies in the range 1 to 80 Hz. Since the risk of damage is not the same at all frequencies of the vibration, so ISO 2631-1
suggests using weighing frequency band. According to which, frequency weighting filters of \(W_c\) for vibration in the X-axis, \(W_d\) for vibration in the Y-axis, and \(W_k\) for vibration in the Z-axis (seated position) were used in this research. However, to assess the magnitude of the vibration, this standard proposes to select the axis that has the highest intensity (as worst-case axis) \([2]\). If the crest factor (CF) is more or less than 9, there should be measured the effective vibration acceleration (Arms) in each of the three axes, resultant effective vibration acceleration in the three axes, and 8-hour equivalent frequency-weighted r.m.s. acceleration. The ISO2631-1 standard has defined a health caution zone for exposure to the 8-hour equivalent frequency-weighted r.m.s. acceleration. The upper and lower limits of the health caution zone are 0.9 m/s\(^2\) and 0.45 m/s\(^2\), respectively. The standard also recommends calculating the CF. If the CF value is greater than 9, and then calculation of vibration dose value (VDV) is also proposed. Similar to \(A(8)\), the VDV has also a health caution zone for vibration exposure. The upper and lower limits of the zone are 17 m/s\(^{1.75}\) and 8.5 m/s\(^{1.75}\), respectively. It is worth mentioning that measurement of vibration attributes was carried out by calibrated SVAN 958A Vibration Level Meter and Analyser, a product of America and Poland. The device is equipped with a whole body vibration sensor to a thickness of 12 mm. According to the standard, this sensor was placed on the driver's seat. This study was done on an urban taxi. Because of the high traffic of cars in the city, the maximum speed limit for the taxis in Tehran is 80 Km/h. For this reason, in this study the vibration attributes were measured at speeds below 80 Km/h. The measurements were done for 30 minutes.

Since the measurements were carried out in a real environment with many possible confounding factors, in order to increase precision and accuracy, the measurements were done at each speed with 18 replications and the mean value was recorded for each attribute. Vibration meter was set in accordance to the ISO 2631-1 standard for the measurement of WBV. Subsequently, frequency-weighted r.m.s. acceleration was measured 18 times in three axes of X, Y, and Z and at each of the considered speed levels (Equation 1).

\[
a_{\text{w.r.m.s.}} = \sqrt[\frac{1}{T} \int_0^T a_{\text{w}}^2(t) \, dt}
\]

(1)

Where;
a_{w r.m.s} = frequency-weighted r.m.s. acceleration (m/s²), T = measurement duration (it was 30 minutes in this research), and a_{w (t)} = frequency-weighted r.m.s. acceleration (m/s²) at the time of t.

According to the ISO2631-1 standard, the resultant average frequency-weighted r.m.s. acceleration in the axes of X, Y, and Z at each of the speed levels was calculated by Equation (2). In this equation, the frequency-weighted r.m.s. acceleration values in horizontal axes (X, Y) are multiplied by a factor of 1.4.

\[ A_{\text{XYZ}} = \sqrt{1.4a_x^2 + 1.4a_y^2 + a_z^2} \]  

(2)

In which:
\[ A_{\text{XYZ}} = \text{resultant vibration acceleration (m/s}^2\text{) in three axes of X, Y, and Z.} \]
\[ a_x, a_y, \text{ and } a_z = \text{magnitude of vibration acceleration (m/s}^2\text{) in the axes of X, Y, and Z, respectively.} \]

This study examined the exposure of drivers to 8-hour equivalent frequency-weighted r.m.s. acceleration (A(8)) at different speed levels. Considering that the driver drives in the entire 10-hour work shift, then the A(8) at each of the speed levels of 20, 40, 60, and 80 km/h was calculated using the Equation 3.

\[ A(8) = \sqrt{\frac{1}{8} \sum_{n=1}^{N} a_{wn}^2 t_n} \]  

(3)

Where;
\[ A(8): \text{8-hour equivalent frequency-weighted r.m.s. acceleration (A(8)), n = sub-task (driving at each of the studied speed levels), N = main task (driving), A_{wn} = frequency-weighted r.m.s. acceleration for the sub-task of n (m/s}^2\text{), t_n = exposure time for the sub-task of n (it was considered 10 hours for the sub-task in this study).} \]

Peak vibration acceleration (A_{peak}) in worst-case axis was measured during 30 minutes at each of the speed levels. According to the ISO263-1, frequency-weighted r.m.s. acceleration (A_{r.m.s}) was measured in the axis with the highest vibration acceleration level (worst-case axis). Further, CF was calculated using these two attributes (A_{peak} and A_{r.m.s}) based on the Equation 4.

\[ CF = \frac{a_{\text{peak}}}{a_{r.m.s}} \]  

(4)

Where;
A_{peak} = \text{peak vibration acceleration and } A_{rms} = \text{effective acceleration}

If the CF is greater than 9, it is recommended to calculate Vibration Dose Value in addition to the WBV attributes. In this study, the VDV at the time of 30 minutes was measured using the resultant frequency-weighted r.m.s. acceleration at each of the speed level (Equation 5).

\[
VDV_{part}=\sqrt{\int_{0}^{T} a^2_w(t)dt} \tag{5}
\]

Where;

\(VDV_{part}= \text{Vibration Dose Value at the time of measurement (m/s}^{1.75}), t=\text{measurement duration (it was 30 minutes in this study), and } a_w(t) \text{ frequency-weighted r.m.s. acceleration (m/s}^2) \text{ at the time of } t.\)

Considering that the driver spends 10 hours driving per day on average, therefore, Vibration Dose Value (VDV) of each speed level was expanded to the 10- hour work shift using the Equation 6.

\[
VDV=VDV_{part}*\sqrt{\frac{T}{t}} \tag{6}
\]

Where;

\(VDV= \text{Vibration Dose Value during the entire work shift of 10 hours (m/s}^{1.75}), T=\text{length of work shift (it was equal to 10 hours in this study), and } t \text{ measurement duration (it was 30 minutes in this study).}\)

Given that this research is an experimental study, it requires statistical analysis to confirm the obtained results. To determine the proper statistical test for the analysis, the normality of each of the variables was initially tested using the Kolmogorov-Smirnov test (KS-test) with a margin of error greater than 0.05. After ensuring normal distribution of data, one way ANOVA and post Hoc test (Bonferroni) were used to compare the average values of WBV attributes including frequency-weighted r.m.s. acceleration (Arms) in each of the axes X, Y, and Z, and resultant value of the three axes (A_{XYZ}), as well as 8-hour equivalent frequency-weighted r.m.s. acceleration (A(8)) and Vibration Dose Value (VDV) at different speed levels of 20, 40, 60, and 80 Km/h.
3. Results
In this study, technical safety of the Peugeot 405 taxi was approved by the Light Vehicle Mechanized Inspection Centre. The technical inspection examination results are presented in Table 1.

Table 1. Test results of Light Vehicle Mechanized Inspection Centre

<table>
<thead>
<tr>
<th>Technical examination tests</th>
<th>Technical status</th>
<th>Test result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shock Absorber Tester</td>
<td>90%</td>
<td>Ok</td>
</tr>
<tr>
<td>Tire Balance Tester</td>
<td>balanced</td>
<td>Ok</td>
</tr>
</tbody>
</table>

The results showed flawless functionality of the springs and shock absorbers. This means that there was no need to replace or repair these parts, and they could well-reduce sudden vibrations. The results also indicated that the car tires were in perfect balance. In other words, the tires of each axle were quite parallel, without any deviation relative to each other. As a result, they could not cause any interference while measuring the WBV attributes. Based on the foregoing, the vibration attributes are mainly due to the roughness of the road surface. The measured values of the XBV attribute at different speed levels are presented in the Table 2.

Table 2. Average value of WBV attributes at different speeds

<table>
<thead>
<tr>
<th>Speed [km/h]</th>
<th>Weighted rms acceleration [m/s²]</th>
<th>8-hour equivalent acceleration A(8) [m/s²]</th>
<th>Average seat Crest factor (worst axis)</th>
<th>Vibration dose values (VDV) [m/s¹.⁷⁵]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>X</td>
<td>Y</td>
<td>Z</td>
<td>Axyz</td>
</tr>
<tr>
<td></td>
<td>mean</td>
<td>SD</td>
<td>mean</td>
<td>SD</td>
</tr>
<tr>
<td>20</td>
<td>0.32</td>
<td>0.08</td>
<td>0.32</td>
<td>0.08</td>
</tr>
<tr>
<td>40</td>
<td>0.31</td>
<td>0.07</td>
<td>0.30</td>
<td>0.07</td>
</tr>
<tr>
<td>60</td>
<td>0.33</td>
<td>0.08</td>
<td>0.42</td>
<td>0.04</td>
</tr>
<tr>
<td>80</td>
<td>0.32</td>
<td>0.07</td>
<td>0.5</td>
<td>0.11</td>
</tr>
</tbody>
</table>

According to Table 2, the average value of the frequency-weighted rms acceleration varies in each axis. Its peak value was measured in the Z axis. Thus, the intensity of vibration acceleration
in this axis is dominant compared to that of the other axes. The highest average weighted rms acceleration values in the X and Y axes were measured at the speed of 80 km/h. The average value was 0.5 m/s² in the Y axis and 0.67 m/s² in the Z axis. The average frequency-weighted r.m.s. acceleration in the X-axis showed no significant difference in different speed levels studied. The highest 8-hour frequency-weighted r.m.s. acceleration values were 0.92 m/s² and 0.98 m/s² respectively measured at the speeds of 60 and 80 km/h. According to the standard ISO 2631-1, it can be noted that the driver of the Peugeot 405 at these speeds is exposed to the excessive WBV acceleration. Further, the 8-hour equivalent frequency-weighted r.m.s. acceleration were within the health caution zone at speeds of 20 and 40 km/h. The CF was measured using peak acceleration and effective frequency-weighted acceleration (\(A_{\text{r.m.s.}}\)) in the Z axis, which had the highest intensity of vibration acceleration. The highest CF was 42.3 measured at the speed of 80 km/h. As the table suggests, the highest VDV was 17.6 m/s\(^{1.75}\) recorded at the speed of 80 km/h. This value is beyond the upper health caution limit (17 m/s\(^{1.75}\)) recommended by ISO2631-1 standard. It should be mentioned that the DVD values at all speed levels were within the health caution zone. The lowest VDV recorded at the speed of 40 km/h was close to the lower limit of health caution zone (8.5 m/s\(^{1.75}\)) while the peak value measured at the speed of 80 km/h was near the upper limit (17 m/s\(^{1.75}\)). All quantitative variables, including frequency-weighted r.m.s. acceleration (\(A_{\text{rms}}\)) in each of the axes X, Y, and Z, and resultant value of the three axes (\(A_{\text{XYZ}}\)), as well as 8-hour equivalent frequency-weighted r.m.s. acceleration (\(A(8)\)) and Vibration Dose Value (VDV) at different speed levels of 20, 40, 60, and 80 Km/h had a normal distribution. Accordingly, one way ANOVA and Post Hoc test were used to analyze the measured variables at a confidence level of 0.95. Table 3 gives the results of statistical tests.
Table 3. one way ANOVA model to compare the average values of the quantitatively variables at different speed levels

<table>
<thead>
<tr>
<th>Dependent Variable (Between Group)</th>
<th>Independent Variable</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weighted rms acceleration [m/s²]</td>
<td>X</td>
<td>0.97</td>
</tr>
<tr>
<td></td>
<td>Y</td>
<td>0.07</td>
</tr>
<tr>
<td></td>
<td>Z</td>
<td>0.001</td>
</tr>
<tr>
<td>A_{XYZ}</td>
<td></td>
<td>0.02</td>
</tr>
<tr>
<td>daily vibration exposure A(8)</td>
<td></td>
<td>0.001</td>
</tr>
<tr>
<td>Average seat Crest factor (worst axis) [m/s²]</td>
<td>0.005</td>
<td></td>
</tr>
<tr>
<td>vibration dose values (VDV) [m/s^{1.75}]</td>
<td>0.001</td>
<td></td>
</tr>
</tbody>
</table>

According to the results of one way ANOVA and Post Hoc, no significant difference was observed in the rms acceleration of X and Y axes at each of the speed levels. According to which, it was concluded that speed has no effects on the frequency-weighted r.m.s. acceleration in these axes. However, the rms acceleration of Z axis was significantly different at all speed levels, except for 60 km/h and 80 km/h. With increasing speed, the average frequency-weighted r.m.s. acceleration increased dramatically in this axis. Furthermore, based on the results of Post Hoc test, the average resultant value of the three axes (A_{XYZ}) at the speed levels of 20 and 40 km/h were significantly lower than that of at speed 80 km/h. The average values of other variables (A(8), VDV, and CF) were significantly different at various speed levels of 20, 40, 60, and 80 km/h (P-value < 0.05). Increasing the speed of the vehicle resulted in a significant increase in A(8) (P-value < 0.05) so that for every 20 km/h increase in speed, A(8) increased approximately 0.1 m/s² on average. Besides, the speed level significantly associated with VDV (P-value < 0.05) so that the VDV was higher at high speeds. For every 20 km/h increase in speed, VDV increased about 0.5 m/s^{1.75} on average.

4. Discussion
Taxi drivers are subjected to prolonged exposure to WBV. A variety of factors affect the value of this type of vibration [1 and 2]. This study outlined the effect of vehicle speed on different WBV attributes including A_{rms}, A_{XYZ}, A(8), and VDV. The results of this study showed that increase in the vehicle speed causes an increase in the value of most of the XBV attributes. So, it can be concluded that taxi driver is exposed to higher levels of WBV at high speeds. This is in
line with the findings of Uys et al. (2007) on suspension settings for optimal ride comfort of off-road vehicles at different speeds. According to their reports, increasing speed causes further transfer of frequency-weighted rms acceleration by the vehicle suspension system [13]. They just outlined the impressibility of frequency-weighted rms acceleration and neglected other WBV attributes. This could be because their calculations were based on the simulated environment and there is the possibility that their simulations were not exactly close to reality. However, in this study, which was conducted in a real environment, the role of vehicle speed was evaluated effective on all of the vibration attributes including $A_{\text{rms}}$, $A_{\text{XYZ}}$, $A(8)$, and VDV. The reason is that, at high speeds, feedbacks from the road surface exert greater force on the vehicle and this will cause increased vibration attributes. As mentioned earlier, several factors affect the value of WBV among drivers. Sherwin et al. (2004) emphasized on the role of tire inflation pressure on the WBV transmitted to an operator in a cut-to-length timber harvester. They measured the vibration at three tire pressure settings of 138, 345 and 414 kPa and concluded that the WBV values were significantly reduced by a reduction in tire inflation pressure [14]. However, the present study examined the effect of speed on transfer of WBV to a taxi driver. Consequently, the deceleration was introduced as an effective factor in reducing the vibration applied on the driver’s whole body. In a study by Nguyen et al. (2011) on vibration of rear axle of tractor, the same results were reported [15]. Their findings revealed that tire inflation pressure and tractor velocity could significantly control vehicle vibration and springiness (an important factor in reducing the transmission of vibration) [15]. In a study by Paddin and Griffin on WBV in vehicles, it was revealed that frequency-weighted rms acceleration in Z axis is dominant over the other axes [16]. The same results were reported by Khavanin et al. (2014) on subway drivers’ exposure to WBV [17]. The present study also confirmed the higher frequency-weighted rms acceleration value in the Z axis compared to the other axes. The amount of which is related to the vehicle speed so that at high speeds, acceleration value in Z axis rises, more than other axes of X and Y. Similar results indicate the greater the amount of vertical vibrations in vehicles. This may probably due to the similarities of degrees of freedom in shock absorbers and other connections of tires to the vehicle body, which limit the movement of the vehicle against vibrations. According to the results of the present study, vehicle speed is an important parameter in transmit of WBV to drivers and can leave harmful effects on human health.
5. Conclusion
Measurement results of the WBV at different speeds revealed that the amount of vibration transmitted to the whole body of the Peugeot 405 taxi driver is significantly sensitive to speed changes. With increasing speed, the amount of WBV attributes will also increase. In other words, a driver who is driving in a city at a slow speed will be exposed to lower amounts of WBV upper health caution limit. Given these results, it is suggested to be given full consideration to the role of speed factor while preparing vibration control schemes for passenger cars (such as Peugeot 405).

References


