VIBRATION ANALYSIS BASED ON HEALTH AND COMFORT LEVEL ON RIDE VEHICLES

Francisco Kaderli, francisco.kaderli@ufrgs.br
Herbert Martins Gomes, herbert@mecanica.ufrgs.br
UFRGS, Federal University of Rio Grande do Sul, Porto Alegre, Rio Grande do Sul, Brazil. Tel.: (+55 51)3308-3681

Abstract. *This study aims at examining the degree of driver comfort in relation to vibration. Automotive vehicles of popular class (1000cc) are evaluated. Comparisons based on type of pavement and car´ speeds are used as basis for analysis in each case. The type of pavement, speed and location of measurement are elected as conditions for comparison. The vibration measurement is done by accelerometers placed in the contact parts of the driver with the vehicle. It is also used accelerometers installed on the steering wheel to measure the level of vibration transmitted to the arms and accelerometers coupled to the driver's seat through a "seat pad" to measure the vibration transmitted to the body. It is revised standards related to comfort in vehicles and possibly assess the degree of health risk in using these vehicles on working conditions (8 hours daily). The situations analyzed are compared separately considering the available car brands. It could be statistically observed trends related to vibration on the car brands based on the acquired data. It was also possible to infer about the potential harm to the health of professional drivers using these vehicles.*

Keywords*: mechanical instrumentation, vehicle comfort, daily exposure to vibration, whole body vibration, hand-arm vibration.*

1. INTRODUCTION

Nowadays, with the automotive market in expansion there is more interest in cars, being this mean of transportation more attractive to the man and of more usefulness on day-to-day life. The number of vehicles in circulation has been increased proportionally with the increase of the population. Due to this fact, it is logical that these vehicles provide well-being to the driver and their passengers.

Countless automotive magazines seek to inform the population which of the produced vehicles provides to the user the best usage conditions. Among the evaluated characteristics it can be evidenced the fuel consumption, acceleration from 0 to 100 km/h, power and comfort. This last one is the most important criteria to measure the quality of a vehicle exposed to different types of vibrations imposed by roads (Maia , 2002).

However, on the most of the comfort evaluations descendant of these publications, it is not established a criteria, or tangible data that prove which of the vehicles being evaluated provides a better level of comfort to the driver. It is important a study in the area of automotive comfort resulting from the vibration, once the vibrations are manifestations of regular dynamic behavior to all vehicles.

The present work is about a study of vibration measurements in different conditions, such as pavement (asphalt and cobbled pavements) and speed, in four vehicles of the same category from different manufacturers available on the Brazilian automotive market. The vibration measurements were performed on the steering wheel, seat and backseat of the respective vehicles. This study has a general purpose to obtain sufficient data to estimate which of the tested vehicles can be considered most comfortable in terms of vibration transmission to the driver. It is possible, this way, to estimate the human exposure to the vibration on the steering wheel transmitted to the hand-arm system and to the whole body, due to the vibration of the backseat and of the seat of the respective vehicles.

Furthermore, this study presents the following specific objectives: (a) to estimate among the measured sets, if daily exposure to the vibration exceeds the limits specified by standards, verifying if the vibration can be sources of possible harm to the driver's in case of intensive use in service, (b) to statistically estimate the influence/correlation of the vibration transmitted to the driver with vehicles speed and the pavement type.

2. DEVELOPMENT

2.1. Literature Review

The human exposure to the vibration is classified, according to its particularities, on (a) vibrations of the whole body: are the vibrations that reach all the body, but particularly on a frequency band from 1 to 80 Hz. (b) vibrations of the members: those vibrations transmitted to the hands and to the arms, on a frequency band from 6.3to 1250 Hz.

It is worth to remind that in the present work there is a simultaneous exposure to both types of vibration. To the whole body, referring to the global movement of the vehicle and to the hand-arm system transmitted by the steering wheel of the same. Whereby, the necessity of standardize and evaluate this vibrations originated many standards. The

most important international standards are the ISO standards (*International Organization for Standardization*) and the European standards.
For both comfort and health evaluation, it is necessary to follow a methodology based on standards. In this work, basically two different standards are used. The ISO 5349-1:2001 used to the evaluation of the human exposure to the vibration transmitted to the hand-arm system, in this case, considering the analysis of the steering wheel of the vehicles. And also, to the analysis of the vibration on the seat and backseat, it is used the ISO 2631-1:1997 standard which is characterized by the evaluation of the human exposure to the whole body vibration.

According to Griffin (1990), the most common way of quantifying the vibration is through the acceleration. Whereby, both of the adopted standards use the *rms* acceleration to characterize vibrations. However, Becker (2006) explained that the direct ways to quantify the oscillatory movement, based on the *rms* value, do not consider the possible effects of frequency. Measured signals of vibration with different spectral content may have identical values to different parameters (average, *rms*, etc.), but its effect on the human body can be completely different (Walber, 2009). To correct this problem, one idealized weighing curves to the measurements of the oscillatory movements of the body. These curves are frequency function and are used as a factor that attributes different weights to movements with different frequencies. Aiming to qualify the vibrations in the frequencies that the human body presents higher sensibility the result of this weighting is the obtainment of a defined value, denominated *rms* acceleration weighted by the frequency a_w, in m/s².The a_w, acceleration is given by the Eq. (2):

$$a_w = \left[\sum_i (W_i . a_i)^2 \right]^{\frac{1}{2}} \quad (2)$$

where W_i is the weighting factor and a_i is the *rms* acceleration to given frequencies.

Figure 1 presents the weighting curves by W_k and W_d frequencies used in different cases in the evaluation of the exposure to the vibration transmitted to the whole body. Table 1 shows which case these curves are exerted.

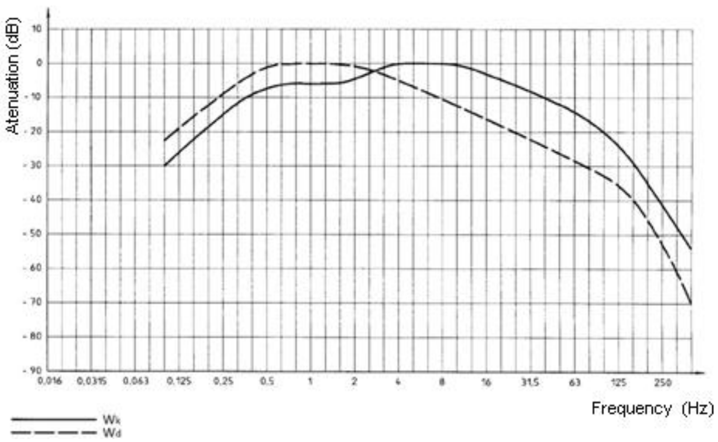

Figure 1. Wk and Wd weighting curves for whole-body vibration (ISO 2631-1:1997).

Other weighting curves applied in this study can be viewed on the referred ISO standards. Nevertheless, in all the curves used, it is observed that the frequency bands are more harmful to the human body are precisely those that have a higher weighting factor (in dB). Due to the fact of the vibration measurement be done following a system of tri-axial coordinate, it is obtained, for each of the x, y and z axis, an *rms* acceleration value weighed by the frequency, represented by a_{wx}, a_{wy} and a_{wz}, (m/s²). Besides, k_i multiplication factors are used, in which the objective is to attribute weights to the different coordinate axis according to the measurement done. Fact that is justified, because according Griffin (1990), the vibration on different frequencies or on different axis, can produce different sensations on different body parts. Also, it is worth to cite, that by the large quantity of experimental data on the z direction, it is used a weighting factor of 1.0 to health analysis cases. To other directions, due to lack of experimental data and information, it is used the factor of 1.4 for sake of safety.

With these values, through the sum of the acceleration squares of each component multiplied by the square of the specific multiplication factor, it is obtained the total vibration a_v, in m/s^2 as follows

$$a_v = \sqrt{k_x^2 a_{wx}^2 + k_y^2 a_{wy}^2 + k_z^2 a_{wz}^2} \quad (3)$$

where k_x, k_y and k_z are the multiplication factors applied to their respective axis.

For those cases where the exposure to the vibration consists in two or more periods of exposure to different duration and magnitudes of vibration, it is calculated the $a_{v,e}$ total vibration equivalent corresponding to the total exposure, according to the Eq. (4):

$$a_{v,e} = \left[\frac{\sum a_{vi}^2 . T_i}{\sum T_i} \right]^{\frac{1}{2}} \tag{4}$$

where a_{vi} is the total vibration to the exposure duration Ti.

Table 1 lists the different weighting curves and multiplication factors applied to the measurements using as reference ISO 2631-1:1997 and ISO 5349-1:2001 standards.

Table 1. Weighting curves and multiplication factors.

		hand-arm (steering)			**whole-body (seat)**			**whole-body (seatback)**		
		x	**y**	**z**	**x**	**y**	**z**	**x**	**y**	**z**
Weighting Curve	**health**	w_h	w_h	w_h	w_d	w_d	w_k	w_d	w_d	w_k
	comfort	w_h	w_h	w_h	w_d	w_d	w_k	w_c	w_d	w_d
Multiplication Factor	**health**	1.0	1.0	1.0	1.4	1.4	1.0	1.4	1.4	1.0
	comfort	1.0	1.0	1.0	1.0	1.0	1.0	0.8	0.5	0.4

It is also observed that the variables in question may be applied to different situations. Depending if the evaluation of the human exposure to vibration is regard to comfort or health, or even to different measurement sites, the appropriate multiplication factors should be observed.

As noticed in Eq. (3), the vibrations transmitted to the human body must be measured in three directions, so the vibration measurements are referred to an orthogonal coordinate system both for whole-body and hand-arm measurements. Figure 2 shows the adopted coordinate system. It is important to highlight that the coordinate system on both cases use the basicentric system. This system is originated on a point where the vibration is entering in the body.

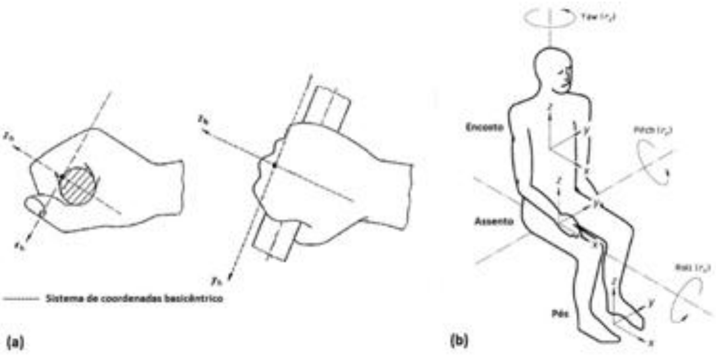

Figure 2. Basicentric coordinate system used for (a) hand-arm and (b) whole body measurements (ISO 5349-1:2001 and ISO 2631-1:1997).

In general, the comfort limits (or discomfort) on a vehicle's passenger or driver are difficult to determine due to the variation in individual sensibility to vibration (Wong, 2001). However, ISO 2631:1978 standard, establishes some criteria to evaluate the comfort due to vibration.

However, it is chosen to use the *rms* acceleration weighed values by the frequency on the three coordinate axis obtained by Eq.(2) and Eq.(3) with different weighting curves and multiplication factors.ISO 2631-1:1997 standard provides the *rms* acceleration weighed values an indication to the comfort's limits as indicated in Tab.2.

Table 2. Comfort reactions to vibration environments (ISO-2631-1:1997).

Comfort Level	**Likely Reaction**
Less than 0.315 m/s^2	Not comfortable
0.315 m/s^2 to 0.63 m/s^2	A little uncomfortable
0.5 m/s^2 to 1 m/s^2	Fairly uncomfortable
0.8 m/s^2 to 1.6 m/s^2	Uncomfortable
1.25 m/s^2 to 2.5 m/s^2	Very uncomfortable

Greater than 2 m/s²	Extremely uncomfortable

It is worth mention that the referred standard to the hand-arm system does not quantify at any moment limit values to the comfort analysis. Furthermore, the present study uses the same methodology that are present on the whole body vibration standard to verify the comfort of the vehicles only as a criteria of comparison among samples and not to evaluate the comfort level on the hand-arm system.

The only actual standard in Brazil for health evaluation purposes is the Norma Regulamentadora Nº 15 (NR 15). There, it is indicated that health vibration limits should be defined by the standards ISO 2631 and ISO 5349. According to Palmer et al. (2000) the vibration is pointed as one of the occupational risks in the industry, and is also directly linked to the incidence of backache on professional drivers. Beyond the analysis and evaluation of the comfort level, the present study has as objective to evaluate the vibration health levels verifying if these can be a harmful source. So, it must be taken in consideration the daily exposure *T*, in hours, where T accounts all the times where people stays exposed to determined vibration during a day.

The daily exposure to vibration A(8), in m/s^2, is defined as:

$$A(8) = a_{v,e}\sqrt{\frac{T}{T_o}} \qquad (5)$$

where $a_{v,e}$ is the equivalent total vibration in m/s² given by the Eq. (4). In cases where there is only one period of exposure, $a_{v,e}$ can be substituted by a_v, defined as the combined weighed acceleration on the three axis given by the Eq. (3), and T_0 is a fixed reference duration of 8 hours. In order to decide if the vibration level will not be harmful to the health, there are prescribed standard limit values to the daily exposure to vibration (A(8)). One of these limits is called ELV (exposure limit value) which means that for values above this limit there is the necessity of immediate cease or remove of exposure, since there is a potential risk to health. The other limit is called EAV (exposure action value) which means that for values above this value but below the ELV, there is the necessity of actions that mitigate or eliminate this exposure. Values below the EAV do not represent a health hazard. In Fig. 3 the weighed acceleration limits in function of the time exposure adopted by the standard ISO 2631-1:197 are verified.

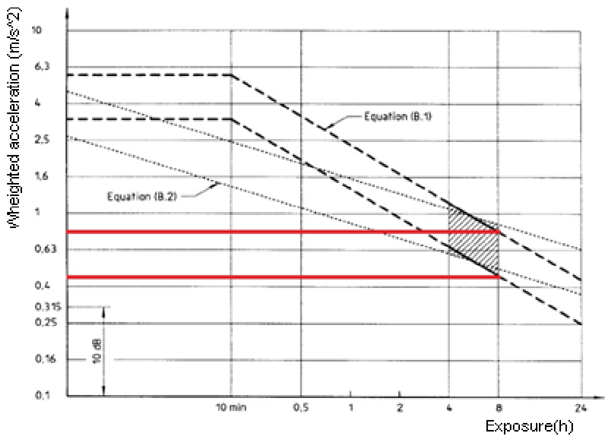

Figure 3. Daily exposure limits as function of the weighted acceleration to the whole body (ISO 2631-1:1997).

The standard has the option to choose between two equations (B1 and B2) to obtain these values. However, in this paper it is used just Eq.B1 since the exposure limits result on lower values. To obtain these values of EAV and ELV, it is enough to visualize on abscissa axis the exposure duration of 8 hours, and project them on the vertical axis. They can be visualized by the red lines in Fig. 3. With the projection of these lines, the used values are obtained.

ISO 5341-1:2001 does not establish exposure limit values. So, in order to obtain comparative values, the values present on the Journal of the European Communities (Directive 2002/44/EC) are used as reference to limit values.

So, the values of daily exposure action value (EAV) and daily exposure limit value (ELV) used can be visualized on the Tab.3. The values showed at the Tab.3 represent the limits of the daily exposure to the vibration A(8), defined according to the methodology of evaluation.

3. OBJECTIVE EVALUATION OF THE VIBRATION

3.1. Measurement Equipments

The vibration measurements on vehicles were performed using VI-400Pro, S/N 12430, which consists on a portable analyzer of vibration. In addition to measuring the vibration, the equipment is capable of storing the data in an internal memory with capacity of 32 Mb. The device is also capable of measuring four input channels simultaneously, three of them, used to measure the vibration on the three coordinate axis.

Table 3. Exposure action valures (EAV) and Exposure Limit Values (ELV).

Reference Values (m/s^2)	EAV	ELV
Hand-arm system (Directive 2002/44/EC)	2,50	5,00
Whole-body (ISO 2631-1:1997)	0,43	0,88

In order to measure vibrations on the backseat and seat, it was used a device called seat pad, a flexible disc-shaped of standard semi-rigid rubber, which has the role of measure the vibrations on three directions not changing the dynamic properties of the interface of the body and seat. A type 070-030 seat-pad, S/N 646, with a tri-axial accelerometer of nominal sensitivity of 100.3 mV/g into each of its axes was used.

Steering wheel vibration measurements are performed using a tri-axial piezoelectric accelerometer Dytran, Model 3023A2, S/N 4147 with a nominal sensitivity of 10mV/g for each axis. Both devices have valid calibration certificates.

The device also has the help of processing software, *QuestSuite Professional II*, which enables to set the instrument with weighting curves, ordering the coordinate axis. In addition, the software has a feature of post-processing data, where the stored data by the equipment are transferred to a microcomputer, allowing further analysis of the obtained results.

3.2 Vehicles models

Measurements were carried out on four vehicles with same weight and power class. All of the measured vehicles have power steering, with engines of 1.0 liters. They are: Volkswagen Gol, Renault Sandero, Ford Fiesta and Fiat Palio. Table 4 shows the main features of each vehicle.

It is important to highlight that all the tested vehicles were in full service conditions and with all original features like wheels, tires, etc. The tires of each model were calibrated by the same device, and according to the recommendations of pressure from each manufacturer. It is also worth to mention that during the measurements, all the cars had the same driver with a mass equal to 77 kg, accompanied by a passenger, in order to maintain the standardization of the tests. It is possible to notice, according to the features listed on Tab.4 that although the vehicles fit the same category, they have some slightly differences, such as the total mass, tire specifications and engine power. Figure 4 shows the four vehicle models used in the measurements.

Table 4. Characteristics of the measured vehicles.

Features	Volkswagen Gol	Renault Sandero	Ford Fiesta	Fiat Palio
Front tires pressure	30 psi	29 psi	30 psi	27 psi
Rear tires	30 psi	29 psi	30 psi	27 psi
Wheel diameter	14"	14"	14"	14"
Tire code	175/70	185/70	185/70	185/65
Total weight	934 kg	1025 kg	1076 kg	940 kg
Engine power (G/A-flex)	72/76 cv	76/77 cv	71/73 cv	65/66 cv
Manufacturing year	2009	2009	2008	2007
Model year	2010	2009	2008	2008

Figure 4. Tested vehicles.

3.3 Vehicle Instrumentation

The instrumentation was performed using two types of accelerometers. An accelerometer attached to the steering wheel, near the hilt of the hand as recommended by ISO 5349. The measurements on the seat and backseat were made using a seat pad, positioned on the driver's interface with the vibrating surface. Each measurement was performed separately for 60 seconds in each condition and location.

It is also emphasized the importance of the correct placement location of the transducers, in agreement with the standard. It is necessary that both transducers are in alignment with respect to standard axis, being acceptable misalignments of 15º. Figure 5 shows the coordinate system for seat pad and accelerometer for hand-arm measurements.

Figure 5. Coordinate system for seat pad and accelerometer measurements.

3.4 Type of pavement

Two types of pavement were chosen to perform the tests: asphalt pavement and cobbled paving. The asphalt pavement where the tests were conducted is located at AJ Renner Avenue in Porto Alegre, having as characteristic being a surface of smooth bearing, but, with some irregularities elapsing from the excessive abrasion and lack of maintenance, very common scenario in roads of this country. The pavement of cobbled pavements, located on José Pedro Boéssio Street, at the same city, presents a surface with constant interruptions, due to the fact that the small size of each cobbled pavement, having a high number of joints along the road, making the surface rich on irregularities. Figure 6 shows the two types of pavements.

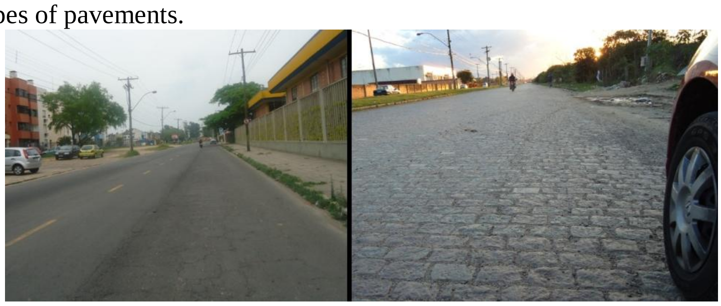

Figure 6. Asphalt pavement and cobbled pavement.

3.5 Evaluated vehicle's speeds

During the measurements, it was set up speeds ranges for all vehicles. It were developed constant speeds of 30 km/h and 60 km/h verified by each vehicle's speedometer. These values were chosen due to the fact that they are usually developed speeds in urban areas. It was also stipulated the speed of 0 km/h with the stopped vehicle, only picking up vibrations resulting from the operation of the engine on idling speed and from the other automobile components. This condition, that has the purpose to simulate the frequent traffic jams and stops at traffic signals characteristic of cities with high population density and high number of vehicles.

4. RESULTS AND ANALYSIS

4.1 Comfort evaluation

In the following Figures, the results for comfort evaluation can be visualized. Using Eq.(3) and the correct weighting curves and multiplication factors presented in the Tab.1, it is calculated the *rms* weighed acceleration by the frequency on the three axis a_v, given in m/s². According to the graphs, it is possible to visualize the magnitude of acceleration as function of two speed ranges (30 and 60 Km/h). The graphs presented on Fig. 7 and 8 represent the analysis of comfort on the asphalt pavement and on the cobbled pavements, respectively.

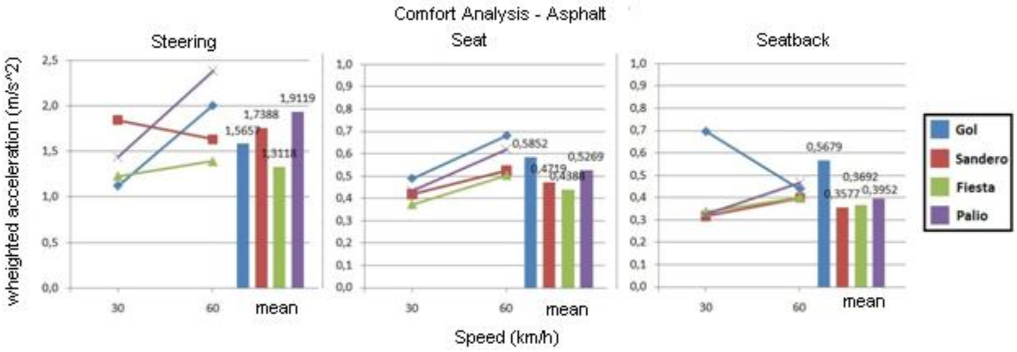

Figure 7. Comfort analysis on asphalt in different sites of measurement/speed.

Each graph is separated by the measurement site, having in the x-axis the speed developed by the vehicles and on the vertical y-axis the total vibration, given in m/s ². It is worth to observe that, on the graph of measurements on the steering wheel, on both pavements, it is verified a larger scale on the vertical axis, indicating previously higher magnitude of vibration in this location. Verifying that the present components on the vehicles seat such as springs and foam are very important, they have great influence in reducing the vibration transmitted to the driver. It is also evident that regardless of the measurement site, the vibration caused on the pavement of the cobbled pavements is higher in comparison to the asphalt one.

It was attributed a color to each vehicle that can be visualized in Fig. 7 and 8. On the lines that link the dots, it can be visualized that as expected, *rms* acceleration increases with the increase of speed, independent of the pavement or the measurement site. The bars on the right of each graph represent the average values of the measurement sites to each vehicle referred to both speeds analyzed.

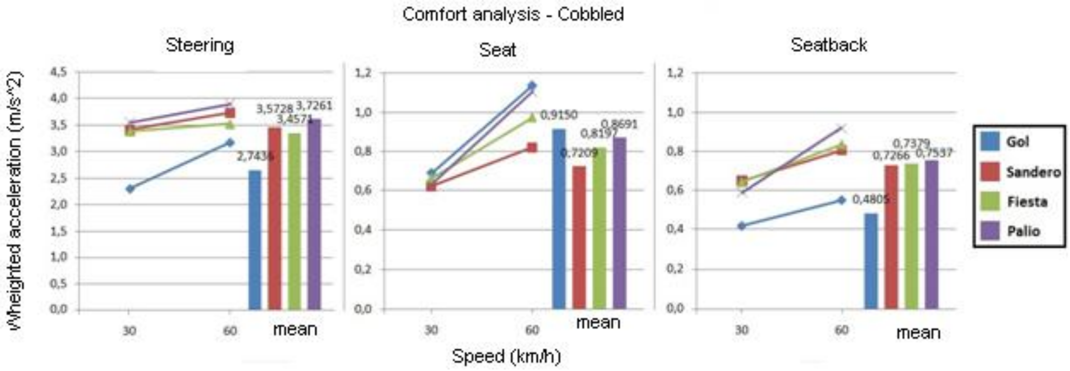

Figure 8. Comfort analysis on cobbled pavements in different sites of measurement/speed.

Evaluating each case individually, it is verified from the graphs the difference in behavior of each vehicle regarding the pavement changes and the measurement site. As an example, the Ford Fiesta, which in some cases presented superior levels of comfort compared to other vehicles (steering wheel and seat on asphalt), but in other measurement sites and pavements it did not keep the same behavior.

On the graph presented on Fig. 9, it is visualized the acceleration measured at each measurement site and vehicle, considering that it is stopped, with no displacement, only with the operation of its engine in idling speed and other components. The main purpose was to evaluate the comfort of vehicles simulating the frequent stops in traffic jams common in urban areas. Figure 9 is divided by red lines which separate the measurement site, each bar color representing a specific vehicle. Besides, the right bars give the average acceleration of each vehicle regarding to the three measurement sites. Visualizing the values presented in Fig. 9, and comparing them with the discomfort scale of the Tab. 2, all the vehicles can be considered comfortable in this situation, according to the ISO 2631-1:1997 standard.

It is noticed that in vibrations on the steering wheel and on the seat, the Volkswagen Gol presents lower acceleration values, it can be attributed a higher level of comfort to the given situation. Also, in a general way the Volkswagen Gol presented less vibration levels in relation to the other vehicles, with an average acceleration resulting from the three measurement sites with value 0.0667 m/s^2, which represents a difference of 92.6% in comparison to the Fiat Palio, the worst positioned.

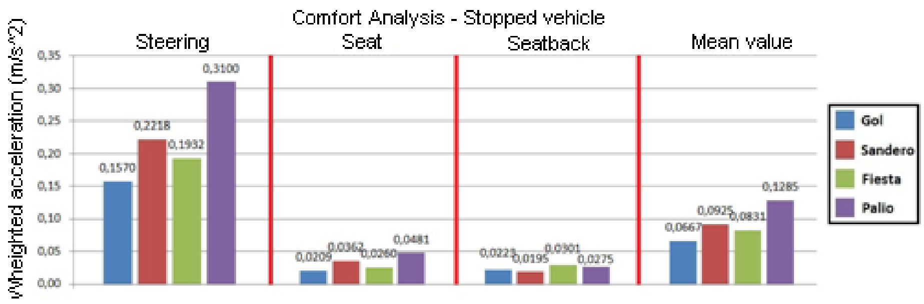

Figure 9. Comfort analysis at 0 km/h.

Figure 10 shows the average acceleration of all measurement sites and speed regarding the pavements, depending on each vehicle, on an attempt to compare in a global way the performance of each of them. Vehicles are represented by a color legend like the previous presented Figures. Bars located on the left of the Figure 10 represent the mean value of all measurements performed on the asphalt pavement, and each bar represents the average of each vehicle. On the central region there is the average value performed on the cobbled pavements, and on the right, the averaged total acceleration, including all measurements performed on each vehicle.

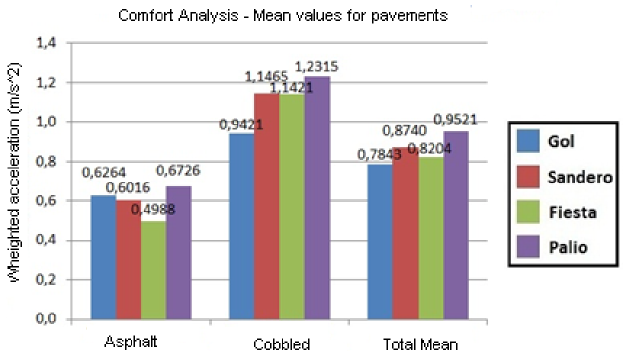

Figure 10. Comfort analysis mean values for different pavements.

Visualizing the total acceleration average, it is noticed that although the Ford Fiesta presents favorable results on the asphalt, the Volkswagen Gol presents a better comfort level when referred to all the measurements. It is notice also that the Fiat Palio, which obtained the highest acceleration values on both pavements, has similar behavior to the previous analysis. The common sense indicates that the vibration level on the cobbled pavements pavement should be higher than on asphalt. This fact is proved observing Fig. 10. It is noticed that the total average for all measurement sites and for all the vehicles were higher for the cobbled pavement. The average difference on the type of pavement was around 85.9% considering the measurements performed on all vehicles.

4.2 Health evaluation

Analyzing the data for comfort and comparing them to the acceleration values of the discomfort scale from the ISO-2631-1: 1997 standard at Tab.2, several situations can be classified as extremely uncomfortable. Thus, it is verified the necessity of an analysis of human exposure to vibration with focus on the health, especially of professional drivers, in order to estimate if the present acceleration values can be harmful to the health of those with the referred use of these vehicles. Now it is used weighting curves and multiplying factors related to health, according to the ISO standard. Using Eq. (3) it is calculated the *rms* weighed acceleration, and next, it is calculated the total equivalent vibration, given by the Eq. (4). Considering that a professional driver is exposed to different vibration magnitudes and time exposure during his daily work journey, it was simulated a workday of eight hours, through different routines, including the various combinations of speed and pavements measured in this work. Table 5 shows three work routines assumed to a professional driver. It is noticed in the Tab.5 that each routine has a different feature. The routine A has a higher usage of the vehicles on asphalt pavement, remaining one hour with the vehicle off for a large period. The routine B has similar characteristics to the routine A, but without any breaks during the workday, in order to be able to compare the influence of a rest in relation to the daily exposure to the vibration. In the routine C, it is presented a much higher use on the cobbled pavement, which has the objective to verify if the results obtained in this condition have higher values compared to the asphalt pavement. In all the routines, it was set out an hour a day, with the car to 0 km/h, representing the engine running at idling speed, simulating possible traffic jams and stops at traffic signals.

Using Eq.(4) and Eq. (5) it is obtained the total equivalent vibration value A(8). Figure 11 presents three graphs, one for each measurement site (steering wheel, seat and backseat), comparing the daily exposure to vibration A(8), referring to each vehicle and to each routine proposed. The horizontal lines represent the exposure action value (EAV) and exposure limit value (ELV) according to the values presented in Tab.3. On the horizontal axis of the graphs are included all vehicles, and each bar represents a routine, and on the vertical axis, the corresponding values of daily exposure to vibration A(8).

Table 5. Assumed routines for professional drivers.

	Stand still (no vibration)	Engine running 0km/h	30 km/h Cobbled pavement	60 km/h Cobbled pavement	30 km/h Asphalt	60 km/h Asphalt	Exposure Time (h)	Daily work time (h)
Routine A	1h	1h	0.25h	0.25h	2h	3.5h	7h	8h
Routine B	0h	1h	0.5h	0.5h	2.5h	3.5h	8h	8h
Routine C	1h	1h	2h	3.5h	0.25h	0.25h	7h	8h

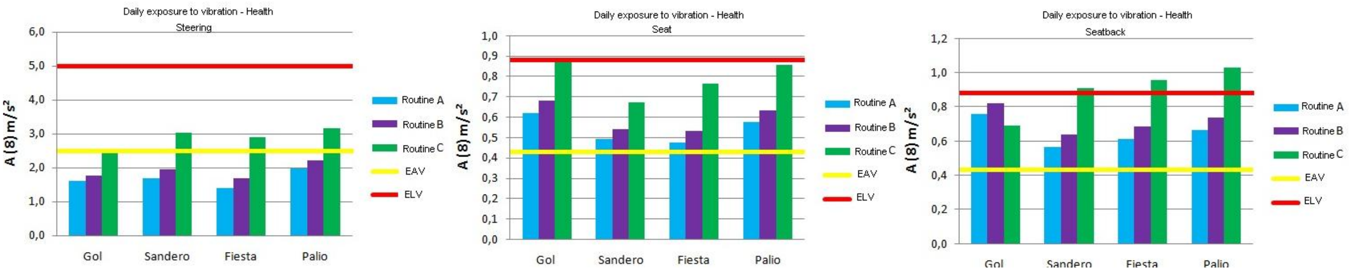

Figure 11. Health analysis for different daily work journeys.

From the graphs, it is possible to visualize that all the measurements performed on the steering wheel, for the routines A and B, the evaluations were found below of the action values. For the routine C, three vehicles presented values above the action value, and for this situation there is the necessity of measures that aim the decreasing or elimination of this exposure. For the measurements of vibration on the seat, all the proposed routines presented values above the action value (EAV) in all vehicles. A similar situation occurred for the measurements on the backseat, but in three vehicles were measured values above the daily exposure limit (ELV) for the routine C, and, with these values it is necessary an immediate measure for its reduction, because certainly, it will cause a problem to the driver to the given condition in a few years, such as lumbar pain or spinal problems. It is worth remembering that each measurement site was analyzed separately, one at a time, due to the instrument limitations. It should be noticed the superiority of the value of A(8) in all vehicles in the routine C, a fact already proven before, and this routine has the biggest tendencies to traffic through the cobbled pavements pavement. Another important factor that can be observed on the graphs is the importance of a break during the workday, and can be visualized by the difference of the daily exposure values A(8), between the routines A and B at all of the measurement sites and all the vehicles analyzed.

4.4 Analysis of Variance (ANOVA)

Aiming to verify whether there is any significant difference in the vibration levels measured inside of the vehicles regarding the variation of speed, it is performed an analysis of variance (ANOVA) on the data collected. Related to the first verification, an analysis of the vibration level in the pavement type is performed. The main idea is to verify what the common sense says and the graphs indicate, i.e., the significant difference of the vibration level in relation to the speed variation and the pavement type. According to Callegari-Jacques (2003), one of the easiest models of variance analysis is the one that analyze the data to a classification criterion. Thus, for the verification in the present work, it is used the analysis of variance of a single factor. For the analysis of variance, two hypotheses are assumed: (a)H0, the treatments do not affect the variable of interest, (b). H1, the treatments in some way affect the variable of interest being possible to investigate how this relationship happens. If the analysis parameter F is greater than critical F the hypothesis H1 is accepted indicating a correlation between the treatments and the variable. Otherwise the hypothesis H1 is rejected and it is adopted H0. These analyses, in a standard form, are performed to a significance level of 0.05, meaning, a 95% of confidence. To the verification of differences in the vibration level regarding to the speed, the speed was separated into 3 groups (0, 30 and 60 km/h), with each group comprising the acceleration values measured on all vehicles and at all the measurement sites. To the analysis of the influence of the pavement, it was preceded in a similar way, but dividing the analysis into only two groups: asphalt and cobbled pavements. It is noteworthy that in both analyses the factor to be verified is the *rms* weighed acceleration by the frequency.

To both analysis (type of pavement and speed), the Value F (variance among the groups), were superior to the critical value F ($F=6,92 > F_{crit}=4.05$ for type of pavement and $F=13.93 > F_{crit}=3.12$ for speed). Based on these data, it is possible to ensure that the results of both analyses are significant, meaning, there are significant differences and relationships of the vibration inside the vehicle regarding the speed ranges. And, there are also statistically significant differences on the internal vibration of the car as function of the bearing surface, a little bit intuitive fact, however, statistically proven.

5. CONCLUSIONS

According to the comfort evaluation concerning the vibration, analyzing each vehicle depending on each speed range and pavement separately, there was not a predominance of the vibration values assigned to a specific vehicle brand, in relation to the change of pavement type and speed. In other words, to given conditions, vehicles in certain situations, showed different behaviors, and for some cases, presented superior values of acceleration, but in other situations the same behavior was not followed. However, it is verified that the difference among the total *rms* acceleration averages of each vehicle, presented very similar values. It was observed different behaviors to each measured vehicle according to the speed and pavement type. However, in general, the Volkswagen Gol presented a lower average vibration value to the other vehicles, followed by the Ford Fiesta, Renault Sandero and Fiat Palio. It can be assigned a superior level of comfort to the Volkswagen Gol, in relation to the others.

Also, according to the discomfort scale from the ISO-2631-1: 1997 standard, several situations in certain vehicles presented vibration levels that can be considered uncomfortable. It also concluded that, the vibrations resulting from the moving vehicle are significantly greater than those originated from a rest situation.

Related to the health evaluation, it is noticed that for a professional driver work routine predominant on irregular surfaces, the daily exposures to vibration A(8) reach values considerably higher, being able to exceed the exposure limit value (ELV). However, it is seen that hardly a professional driver in an urban area will spend a long period on a surface of irregular bearing. It is noticed that the vibrations resulting from the backseat and seat are of more concerning, at all vehicles tested, these exceeded the value of exposure action value (EAV) requiring measures that aim at reducing or mitigating this vibration. It was also concluded that short breaks on work daily journey may reflect in a significant reduction on the value of daily exposure to vibration, a factor that can be compensated in cases of exceeding the values stipulated by the standard.

Regarding the variation of vibration inside the vehicle due to speed and type of pavement, it was possible to statistically prove that there is a significant difference in the *rms* acceleration as function to the different road conditions and speeds. Observing Figure 8, it is verified that the higher is the speed of the vehicle in question, the higher the level of internal vibration will be, so to a smooth surface, as to asphalt and to an irregular surface such as cobbled pavements. And, in general, more irregular pavements induce more vibration regardless the speed value.

6. REFERENCES

Balbinot, A. Caracterização dos níveis de vibração em motoristas de ônibus: um enfoque no conforto e na saúde. Tese para obtenção de título de doutor em engenharia.(*in portuguese*), Porto Alegre: UFRGS, 2001.

Becker, T. Desenvolvimento de uma mesa vibratória para estudos sobre vibração no corpo humano, medições em um grupo de motoristas e ajuste de um modelo biodinâmico. Tese para obtenção de título de doutor em engenharia. (*in portuguese*)Porto Alegre: UFRGS, 2006.

Callegari-jacques, S.M. Bioestatística: Princípios e Aplicações. (*in portuguese*) Porto Alegre: Ed. Artmed, 2003.

Directive 2002/44/EC. On the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (vibration). The European Parliament and the Council of the European Union. Official Journal of the European Communities, L177/13-19, 2002.

Griffin, M. J. Handbook of human vibration. U.S.A: Academic Press, 1990.

ISO 2631-1:2009. Mechanical vibration and shock – Evaluation of human exposure to whole body vibration – Part 1: General requirements. International Organization for Standardization, 2009.

ISO 5349-1:2001. Mechanical vibration – Measurement and evaluation of human exposure to hand-transmitted vibration – Part 1: General requirements. International Organization for Standardization, 2001.

ISO 5349-2:2001. Mechanical vibration – Measurement and evaluation of human exposure to hand-transmitted vibration – Part 2: Practical guidance for measurement at the workplace. International Organization for Standardization, 2001.

Maia, R. H. Análise de sensibilidade aplicada a estudos de conforto vibracional em automóveis. Tese para obtenção de título de mestre em engenharia (*in portuguese*). Belo Horizonte: PUC Minas, 2002.

NR15. Norma Regulamentadora No.15. Atividades e operações insalubres - Anexo Nº8 Vibrações(*in portuguese*). http://www.mte.gov.br/legislacao/normas_regulamentadoras/nr_15.pdf acessado em 08/10/2010.

Palmer, K. T., Griffin, M. J., Bendall, H., Pannett, B. Prevalence and pattern of occupational exposure to whole body vibration in Great Britain: findings from a national survey. Occupational Environmental Medicine, 2000.

Quest-technology. Real-time vibration Analyzers, VI-400PRO, Preliminary owner's manual. 2005.

Savionek, D. Medição e Avaliação da Exposição Humana à Vibração Transmitida ao sistema mão-braço durante a atividade ciclística. Monografia para obtenção to título de engenheiro mecânico(*in portuguese*). Porto Alegre: UFRGS, 2010.

Walber, M. Avaliação dos Níveis de Vibração Existentes em Passageiros de Ônibus Rodoviários Intermunicipais, Análise e Modificação Projetual. Tese para obtenção do título em Doutor em Engenharia(*in portuguese*). Porto Alegre: UFRGS, 2009.

Wong, J. Y. Theory of Ground Vehicles. 3rd ed. USA: John Wiley and Sons, 2001.

7. RESPONSIBILITY NOTICE

The author(s) is (are) the only responsible for the printed material included in this paper.