MEASUREMENT OF HUMAN EXPOSURE TO VIBRATION TRANSMITTED TO HAND-ARM SYSTEM DURING LEISURE CYCLING ACTIVITY IN PORTO ALEGRE, BRAZIL

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Abstract. *This work presents a study of measurement and evaluation of human exposure to hand-arm vibration in cycling activity. Vibration measurements are performed for three pavement types, asphalt (AS), precast concrete slabs (PC), and interlocking concrete blocks (BI), using two bicycle models (time trial speed racing, S and mountain bike, MB), and cyclists with different physical features. Using an objective analysis for each configuration – pavement type vs bike model vs cyclist – is evaluated the daily vibration exposure A(8), as defined in ISO 5349-1 Standard, for 2h of daily exposure. It is also evaluated the maximum daily exposure in order to reach limit values, as defined in Directive 2002/44/EC. Using a subjective analysis, it is evaluated the degree in comfort on vibration exposure offered for each pavement type, according to the cyclist's opinion. Finally, the results are compared using both objective and subjective analysis. It has been noticed that the most appropriate pavement type is the asphalt pavement (AS), followed by the concrete pavement (PC) and by the interlocking concrete blocks pavement (BI).*

Keywords*: vibration measurement in bicycles, pavement to cycle paths, hand-arm vibration, human exposure to vibration.*

1. INTRODUCTION (Times New Roman, bold, size 10)

The exposure of the human body to vibration is present in everyday situations, can be a source of discomfort and in some cases may cause health problems. Particularly in the case of vibration transmitted to the hand-arm system, there may be disturbances in finger's blood circulation and hand's neurological and motor function injuries. Thus, the research related to this activity, where this exposure would exist, is very important. On the other hand, the cycling activity has been increasing in recent years, either as a means of leisure or physical activity or as means of transport. Some cities have already developed plans that include feasibility studies, design, construction and management of cycleways, setting up networks of cycling routes, which allow, for example, the displacement of the population from home to a public transport, or even from home to your workplace. Currently, the city of Porto Alegre, in Brazil, is one, which owns a Cycleway Path Integrated Plan (CPIP), institutionalized by a local Complementary Law (2009), which reports a network of 495 km length of cycling roads. More specifically, cycle paths that were built with concrete blocks suffered criticism from cyclists regarding this trepidation during the cycling activity which deserved more attention and quantitative evaluation by the government.

Considering the raised points and due to lack of specific studies on the topic, the present work justifies with the overall objective of assessing human exposure to vibration transmitted to the hand-arm during the cycling activity. This study was conducted through vibration measurements performed for three different types of paving: asphalt, concrete and interlocking concrete blocks, using two bike models and several cyclists with different physical characteristics.

Moreover, the work has the following objectives:

• Evaluate, by measuring tests (type of pavement x bike's model x Cyclist), if the daily exposure to vibration A(8) exceeds the limits set by the Directive 2002/44/EC (ELV-exposure action value and ELV-exposure limit value), for a given duration of daily exposure to the appropriate cycling activities;

• Evaluate the maximum daily exposure to vibration for each test, so that the limits specified by the Directive 2002/44/EC are met.

• Evaluate, between types of analyzed paving, which one is most suitable for cycling activity,

• Evaluate the influence of the bike and the cyclist's physical feature on the values of daily exposure to vibration.

2. BRIEF BIBLIOGRAPHICAL REVIEW

2.1 Vibration characterization

According to Fernandes (2000), a body is said to vibrate when he describes an oscillatory motion about a reference point. The number of times a complete cycle of movement occurs during the period of one second is called frequency, measured in cycles per second or Hertz (Hz). This movement of vibration can be regular, consisting of a single frequency or irregular, with multiple components of motion at different frequencies and different directions as in the cycling activity.

A vibration signal can be represented in a graph of vibration amplitude *vs.* time or amplitude of vibration *vs.* frequency (called the frequency spectrum). Like frequency and amplitude of vibration (m/s^2), there are other important parameters that can characterize a vibrating signal, for example, the *rms* (root mean square) value, peak value, peak-to-peak value, mean value, crest factor, etc. The *rms* value is the most important because it allows, according to Fernandes (2000), to assess the average energy in the vibration, showing the actual harmful potential of the vibration. For a continuous function *f(t)* defined over the time interval $T_1 \le t \le T_2$, its f_{rms} value may be evaluated by:

$$f_{rms} = \sqrt{\frac{1}{T_2 - T_1}\int_{T1}^{T2}[f(t)]^2\,dt} \tag{1}$$

2.2 Human exposure to vibration

According to Griffin (1990) and Balbinot (2001) the human body, despite its higher complexity, can be considered as a biomechanical system for analysis of vibration. It can be modeled as a multi-degree of freedom system in the frequency range of 1-80 Hz, in the case of whole body vibration. For vibrations of hand-arm system, these frequencies may be higher, reaching up to 1250 Hz.

When the frequency of an external excitation reaches the value of one of these natural frequencies, the resonance phenomenon can occur, increasing the effects of vibration on health. Human exposure to vibration is classified due to their peculiarities, in:

• Whole Body Vibrations (WBV): vibrations that, as the name suggests, affect the whole body, particularly in a frequency range 0.5 to 80 Hz. This type of vibration may be present in transport systems, for example, in a moving bus, cars, etc.

• Hand-Arm vibration (HAV): vibrations that affect and are transmitted specifically to the hand-arm system, in a frequency range from 6.3 to 1250 Hz. This type vibration may be present in oscillatory hand power-tools, for example, on pneumatic hammers and saws. It is also the type of vibration that may be present in cycling activity, whose evaluation is the focus of this work.

It should be noticed that this classification is formal, so you can experience a simultaneous exposure to both types of vibration. A bus driver, for example, may be exposed to whole body vibration on the global movement of the vehicle, and also exposed to vibration of the hand-arm system, from vibrations transmitted by the vehicle's steering system.

2.3 Effects on health caused by exposure to vibration

Many factors can influence the health effects caused by human exposure to vibration. As an example, one can mention the frequency spectrum and amplitude of vibration, the duration of daily exposure and previous accumulated exposures to vibration. Moreover, certain people may have greater susceptibility to developing other diseases caused by exposure to vibration. In the case of whole body vibration, the main health effects may present themselves in the form of dizziness, decreased vision acuity, nausea and disorders of the labyrinth, occasioned by vibrations in the frequency range of 0.1 to 0.7 Hz or effects like increased frequency heart due to vibrations of frequencies below 20 Hz. Also, many studies, such as those of Rehn *et al.* (2000), Hoy *et al.* (2000) and Tripepi *et al.* (2000), indicate that drivers of dump trucks, tractors, forklifts, and other type of off-road vehicles, have a high incidence of back pain, related to exposure to vibration transmitted to the whole body.

In the case of vibrations transmitted to the hand-arm system, disorders independent or simultaneously may occur in the vascular level and in the neurological and muscle-skeletal system. They are generally known as hand-arm syndrome. The main problem is Raynaud's phenomenon or "white fingers" disease, where a decrease of irrigation of the hand's peripheral vessels and arteries, with resultant bleaching of the ends of the fingers, caused by exposure to hand-arm vibration associated to a supportive factor as cold environments. The assessment of human exposure to vibration should be in accordance with International Standards ISO (International Organization for Standardization). Table 1 presents the main existing ISO Standards.

3. EVALUATION METHODOLOGY ACCORDING TO ISO 5349-1:2001

In the following, it is presented the methodology for assessing human exposure to vibrations transmitted to the hand-arm system in accordance with ISO 5349-1:2001. The primary variable used to characterize a vibration is its *rms* acceleration. This *rms* acceleration should be weighted in frequency domain (weight curve W_h) and passed by a narrow band filter, thereby producing a value defined as weighted frequency *rms* acceleration a_{wh} in m/s^2. This weighting indicates the importance that the vibration at different frequencies may affect human health.

Figure 1 shows the frequency-weighting curve (W_h) used in the assessment of exposure to vibration transmitted to the hand-arm system. As can be seen in Fig. 1, there is a higher weighting factor for a frequency range between 4 and 31.5 Hz, which corresponds precisely to the range where the health effects caused by vibration in hand-arm system may be harmful.

Table 1. Key ISO standards for assessment of human exposure to vibration.

Whole Body Vibration	ISO 2631-1:2009 Mechanical vibration and shock - Evaluation of human exposure to whole-body vibration - Part 1: General requirements
Hand-Arm Vibration	ISO 5349-2:2001-Mechanical vibration- Measurement and evaluation of human exposure to hand-transmitted vibration- Part 1: General requirements - Part 2: Practical guidance for measurement at the workplace

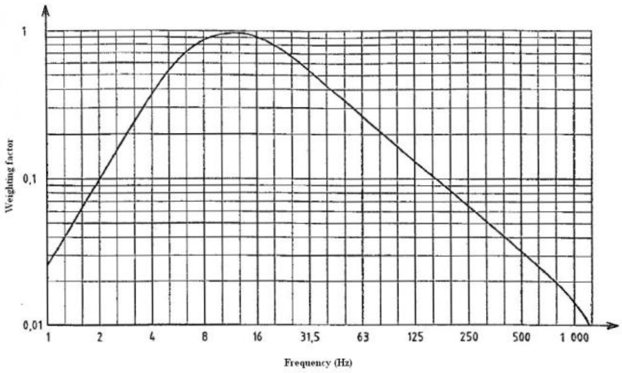


Figure 1. Curve of frequency weighting for W_h to hand-arm vibration, including narrow band (ISO 5349-1:2001).

Vibrations transmitted to the hand-arm should be measured in three directions, according to an orthogonal coordinate system as defined in Fig. 2. There are two kinds of systems: the biodynamic and basicentric. However, according to standard practices the basicentric coordinate system should be adopted.

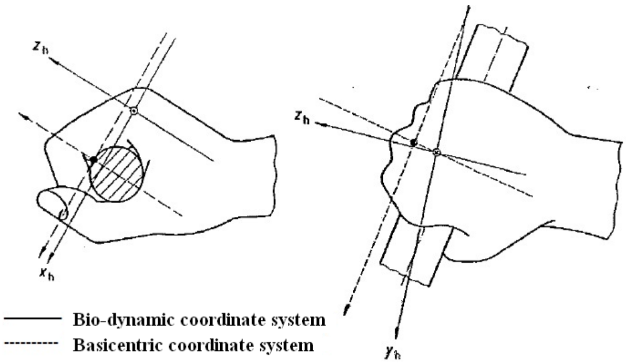


Figure 2. Hand-arm vibration coordinate system (-) biodynamic and (--) basicentric (ISO 5349-1:2001).

As the measurement of vibration should be performed following a system of tri-axial coordinates, we obtain a value of frequency weighted *rms* acceleration for each axis, *x*, *y* and *z*, represented by a_{hwx}, a_{hwy} e a_{hwz} in m/s^2. Combining these three values, through the root of the sum of the squares of each component, we obtain the total weighted vibration a_{hv} in m/s^2:

$$a_{hv} = \sqrt{a_{hwx}^2 + a_{hwy}^2 + a_{hwz}^2} \quad (2)$$

Besides the magnitude of vibration, represented by the total weighted vibration a_{hv}, the assessment of vibration exposure takes into account the daily duration of exposure T, in hours, defined as the amount of time that the hands are exposed to vibration in one day. Thus, it is defined the daily exposure to vibration $A(8)$ in m/s^2, as:

$$A(8) = a_{hv}\sqrt{T/T_0} \quad (3)$$

where T_0 is a reference duration of eight hours. This reference time T_0 is adopted to ease comparisons between daily exposures to vibration of different durations. Daily exposure to vibration $A(8)$ is interpreted as a vibration total value weighted by the frequency, expressed as an equivalent of eight hours of daily exposure.

3.1 Human limits to vibration exposure

Due to various effects caused by the human body and the degree of severity that they can reach, exposure to vibration is the subject of legislation on health and safety at work. The Brazilian Standard Regulatory No. 15 (NR 15) defines that activities and operations, which expose workers without adequate protection to localized or whole body vibration, will be characterized as unhealthy, through expertise performed in the workplace. According to NR 15, the expertise should base this judgment on the exposure limits set by ISO 2631 and ISO 5349, or their substitutes.

However, in case of exposure to vibration transmitted to the hand-arm system, the ISO 5349-1:2001 establishes itself in its scope that it does not define safe limits for exposure to vibration, but rather provides a guide for assessment of exposure. Moreover, the European Union established a directive 2002/44/EC, requiring its member countries to implement in their legislation the minimum health and safety requirements, on exposure of workers to risks arising from physical agents (vibration). In the case of vibration transmitted to the hand-arm system, these requirements are established by two reference values:

- Exposure Action Value (EAV) of 2.5 m/s^2
- Exposure Limit Value (ELV) of 5.0 m/s^2

These benchmarks correspond to the daily vibration exposures $A(8)$, established in accordance with the methodology of assessment of exposure to vibration in ISO 5349-1:2001 and calculated according to Equation 3. So these values limits will be used instead of those indicated by the ISO 5249-1:2001. Figure 3 shows a plot for a_{hv} *vs* recommended total daily exposure time T, with curves representing the daily exposure to vibration $A(8)$.

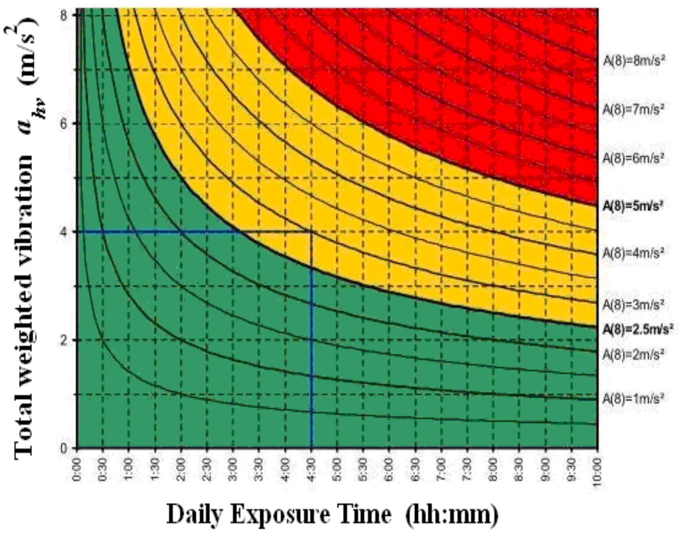


Figure 3. Graph vibration a_{hv} *vs* total daily exposure time T, with curves representing the daily exposure to vibration $A(8)$ (Griffin *et al.*, 2006).

The graph in Fig. 3 represents an alternative way to calculate the daily exposure to vibration $A(8)$, for data values of a_{hv} and total vibration exposure time T. For example, at the point indicated by the blue lines, for a time of daily exposure of T= 4h30min and a total vibration a_{hv} of 4 m/s^2 has a daily exposure to vibration $A(8)$ of 3 m/s^2, this value above the action limit of 2.5 m/s^2. According to the Directive 2002/44/EC, a vibration exposure above the "action limit" requires the employer to implement a program of measures aimed at reduction or elimination of exposure. Besides, a vibration exposure above the "limit" requires the immediate action for vibration reduction and the employee is not allowed to continue working until the exposure limit value is respected.

4. VIBRATION IN CYCLING ACTIVITY

The objective assessment of human exposure to vibration transmitted to the hand-arm during the cycling activity consisted of a technical survey, following the methodology described by ISO 5349-1:2001. So, there were vibration measurements for three different types of paving: asphalt (AS), precast concrete slab (PC) and interlocking concrete blocks (BI), using two models of bicycle, time trial speed racing (S) and mountain bike (MB), and seven cyclists with different physical characteristics. It is accomplished a measurement for each of the combinations - type of pavement *vs.* bike model *vs.* cyclist - on a linear path of 500 meters at an average speed standard of 15 km/h. The speed was controlled by the cyclist with the aid of a simple digital speedometer.

4.1 Measuring equipment

For the vibration measurement, it is necessary to use a transducer that converts mechanical energy from acceleration into a proportional electrical signal. In the performed measurements, the transducer used is a calibrated tri-axial piezoelectric accelerometer Dytran, Model 3023A2, S/N4147, with nominal sensitivity of 10 mV/g for each of its axes x, y and z. Besides the transducer, it is necessary to use an apparatus for analyzing and storing the acceleration measurement. In this case, it is used the Quest VI-400Pro, S/N12430, a portable vibration analyzer that simultaneously measures tri-axial vibrations from the accelerometer (Fig. 4).

Figure 4. VI400-Pro equipment and accelerometer used in measurements.

Among the parameters of the vibration signal measured, analyzed and stored by the VI-400Pro, there is the value of frequency weighted *rms* acceleration for each axis (a_{hwx}, a_{hwy}, a_{hwz}) and a_{hv} the total exposure to vibration and extrapolated daily exposure to vibration $A(8)$, as defined by ISO 5349-1:2001 and as explained in previous section.

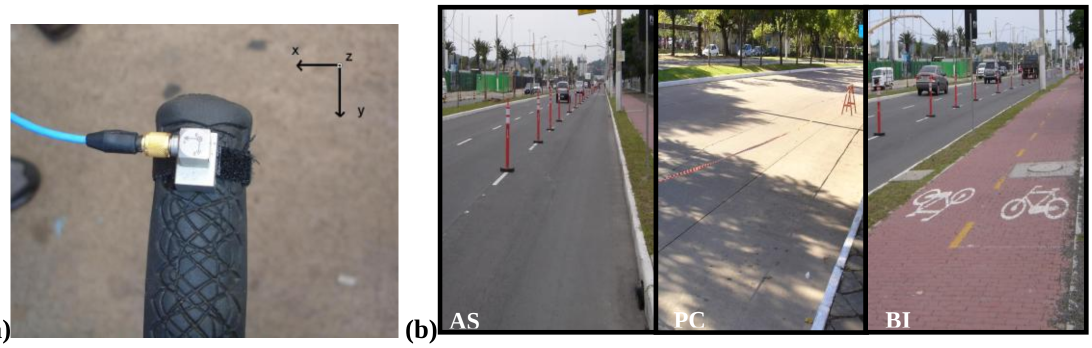
To setup the parameters of the VI-400Pro it is used the Quest Suite Professional II software. It defines what weighting curves should be used for weighting acceleration measurements. In this case, it is adopted the frequency weighting curve W_h, (see Figure 3) recommended by ISO 2631 standard. Moreover, using the software one can perform the post-processing of measured data. Using the exposure calculator tool, for each measurement, the maximum daily exposure to vibration in order to reach the exposure action value (EAV), T_{max}, and the maximum daily exposure to vibration in order to reach the exposure limit value (ELV), T_{max}.

4.2 Bike instrumentation and set up

The instrumentation of the bike is performed fixing the accelerometer on your handlebars, with the aid of a proper band, so that it is rigidly attached to the structure. The positioning of the accelerometer was carefully checked to assure consistent measurements. The accelerometer is attached to the handlebars following the basicentric coordinate system, as presented in Figure 4. Besides the correct alignment of the axes of the accelerometer, it needs to be positioned at the point close to the hand grip on the handlebars, but without interfering in the normal cycling activity. Figure 5(a) shows a picture of the coupling of the accelerometer on the handlebars of the bicycle, along with the adopted coordinate system.

4.3 Rated pavements

Measurements were performed for three different types of paving asphalt (AS), precast concrete (PC) and interlocking concrete blocks (BI). The AS is considered a flexible type and characterized by a relatively smooth and uninterrupted rolling surface. The measurements in this type of pavement were performed on the right side of the Daily News Avenue, in Porto Alegre, Brazil. The PC paving is considered a rigid type and characterized by a rolling surface with some interruptions due to the joints between the slabs. In the case evaluated, the slabs have dimensions of 2 m wide by 6 m long, with joints every 6 m in length of the track. Measurements on this type of pavement were held at Érico Verissimo Avenue in Porto Alegre, Brazil. The BI pavement is also considered a rigid type, but characterized by a rolling surface with periodic interruptions, due to the joints between the blocks. In the case evaluated, the blocks have dimensions of 10 cm wide by 20 cm long and were paved transversely to the direction of the bike path, with joints at every 10 cm of its wide. Measurements on this pavement were held in the cycle way beside the Eduardo Schann Avenue, in Porto Alegre, Brazil. Fig. 5(b) shows images for the three evaluated types of pavements.



(a) (b)

Figure 5. (a)Attachment of accelerometer on the bike's handlebar and the coordinate system adopted in the measurements. (b) Types of pavements used in measurements: Asphalt (AS), precast concrete slabs (PC) and interlocking concrete blocks (BI).

4.4 Bicycle models

Measurements were performed using two models of bicycles, speed (S) and mountain bike(MB). The main features of each model are shown in the Tab. 2.

Table 2. Bicycle models characteristics: speed (S) and mountain bike(MB).

Feature / Model	Speed (S)	Mountain Bike (MB)
Frame	carbon fiber and aluminum	aluminum
Mass	8,7 kg	12 kg
frame heigh	53 cm	45,7 cm
wheelbase	98 cm	108 cm
Tire (Diameter x width)	700 mm x 23 mm *slick*	660,4mmx49,5mm knobby
Tire balancing	110 psi	45 psi
Handlebars type	*dropped* – 44 cm	straight 58 cm

As can be seen in Tab. 2, the main differences between each bike model relate to their shape, calibration and tire width. The MB model is 3.3 kg heavier than the S model and has a tire width more than twice the S model and a tire pressure considerably lower. None of the bikes has absorbers, since this type of bike is not so common on weekend bikers. Figure 6 presents the two models of bikes used in the measurements.

4.5 Bikes and ride characterization

Measurements in the three types of pavements and with the two bike models were conducted with seven riders. However, two of the bikers were not involved in the measurements of PC pavement. This totals 38 measurements. Table 3 presents the main characteristics of each rider. They were mass ordered from largest to smallest.

The subjective evaluation of human exposure to vibration transmitted to the hand-arm during the cycling activity consists of a survey that captures the perception of cycling in the conditions of comfort offered by each type of pavement. At the end of each measurement, it is applied an interview to the rider, where he/she is asked to give a grade on a 0-5 scale, according to the degree of perceived comfort. The grades levels correspond to concepts, ranging from Very bad (0-1), bad (from 1.1 to 2), regular (from 2.1 to 3), good (from 3.1 to 4) to very good (from 4,1 to 5). Moreover, the rider is asked to give their opinion about the quality of the ride, with the following alternative answer: "acceptable," "unacceptable" and "undecided."

Figure 6. Bicycle models used in measurements: speed (S) and mountain bike (MB).

Table 3. Characteristics of cyclists (* cyclist did not participate in the measurement of PC pavement).

Id	gender	age (years)	mass (kg)	height (m)	body mass index
A	M	28	89	1,86	25,73
B	M	36	81	1,74	26,75
C*	M	31	80	1,82	24,15
D	M	50	73	1,63	27,48
E*	F	29	68	1,64	25,28
F	F	28	61	1,75	19,92
G	M	36	59	1,72	19,94

* *riders that were not involved in the PC pavement measurements*

5. OBJECTIVE ASSESSMENT OF VIBRATION IN CYCLIST ACTIVITY

In the following, some graphs are plotted and the main results comparing the measures are discussed. For each of the measurements settings - type of pavement *x* bike model *x* biker we obtain a value of frequency weighted *rms* acceleration for each axis, *x*, *y* and *z*, represented by a_{hwx}, a_{hwy} a_{hwz}. From these accelerations and according to Eq. (2), it is obtained the total weighted vibration a_{hv}.

Using the total weighted vibration a_{hv}, the daily exposure to vibration *A*(8) is estimated, according to Eq.(3). However, this calculation requires the assumption of the exposure time *T*.

This is a difficult parameter to be estimated for the cycling activity, since the days one can practice this activity can vary greatly from rider to rider. We chose to examine the daily exposure to vibration *A*(8) for a daily duration of exposure *T*=2h, representing an average exposure time for leisure purposes. Figure 7 shows a graph for the daily exposure to vibration *A*(8) for *T*=2h, for the three evaluated pavements.

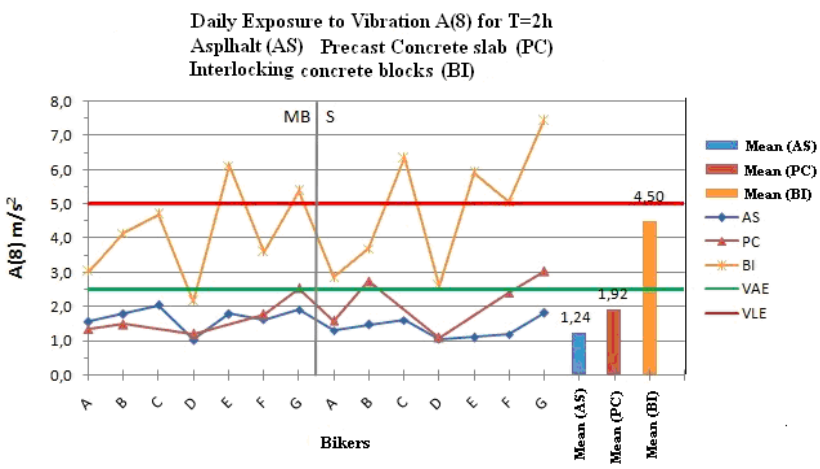


Figure 7. Daily exposure to vibration *A*(8) with a daily duration of exposure of *T*=2h, for the three types of pavements evaluated.

Each point on the graph represents one measurement. In the x-axis are the bikers and at the y-axis, their daily vibration exposure *A*(8). The vertical line in the middle of the graph indicates the division between measurements made with the bicycle mountain bike (MB) and the speed bicycle (S). Bars on the right indicate the arithmetic mean of daily exposure to vibration *A*(8) for AS, PC, and BI pavements. The horizontal lines represent the exposure action value(EAV) and exposure limit value (ELV) according to Directive 2002/44/EC.

From the bar chart above, you can get a general idea of exposure to vibration in each type of pavement. AS have the lowest exposures, with all ratings below the exposure action value (EAV) and with an average daily exposure to vibration *A*(8) of 1.24 m/s^2. PC has a relatively higher values of vibration, including some ratings above the exposure action value (EAV) and with an average daily exposure to vibration *A*(8) of 1.92 m/s^2. BI presents exposures that reach values considerably larger, on all measurements, except one, above the exposure action value (EAV) and some exposures above the exposure limit value (ELV). The average daily exposure to vibration *A*(8) for this pavement is 4.5 m/s^2.

Thus, one can sort the types of pavements, as to daily exposure to vibration *A*(8), so that AS is the most suitable surface for cycling activity, followed by PC and BI.

To evaluate a possible influence of the bike on these values, it was generated independent graphs, showing *A*(8), for each type of pavement, as can be seen in Fig. 8, 9 and 10.

For AS pavement, as indicated by the graph in Fig. 8, the ratings with the bicycle speed (S) gave values of *A*(8) slightly smaller, with an average exposure 1.12 m/s^2 to 1.37 m/s^2 against the bicycle mountain bike (MB). The average daily exposure to vibration *A*(8) for AS pavement, considering the ratings for the two models of bike is 1.24 m/s^2, as the third bar graph indicates.

As for the PC pavement, as indicated by the graph in Fig. 9, the situation is reversed, i.e., the measurements with the bicycle speed (S) showed *A*(8) values slightly larger. Finally, for the BI pavement the ratings had a third behavior, with some lower values of *A*(8) to for bike speed (S) and smaller ones for the mountain bike (MB), as shown in the graph in Fig. 10.

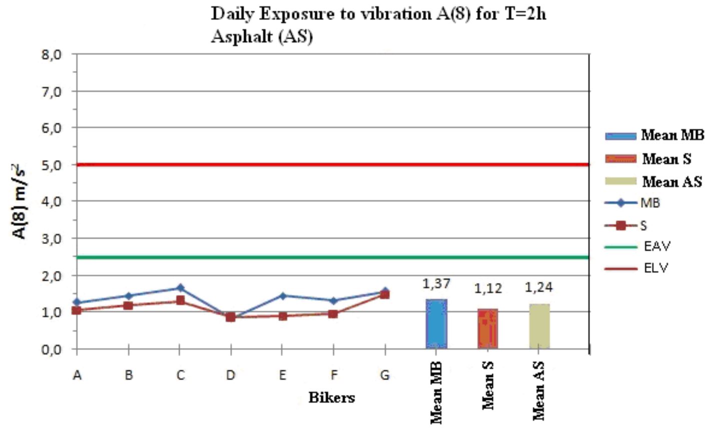


Figure 8. Daily exposure to vibration *A*(8) with a daily duration of exposure of T=2h, for the asphalt pavement (AS).

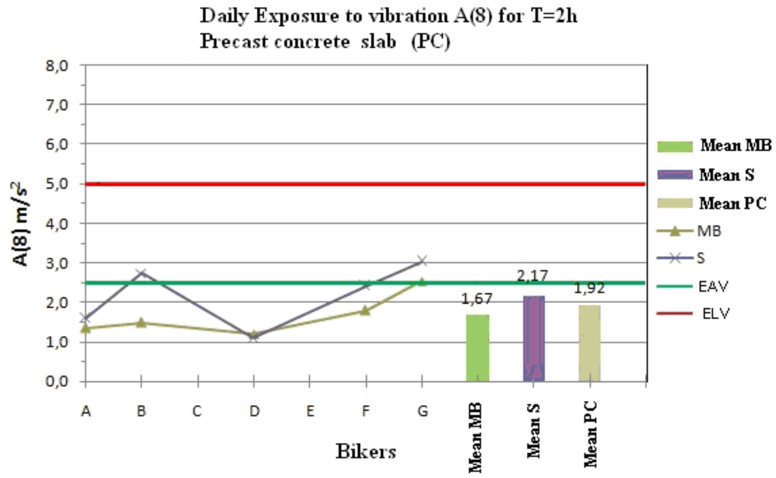


Figure 9. Daily exposure to vibration *A*(8) with a daily duration of exposure T=2h, for precast concrete slabs cast on site concrete (PC).

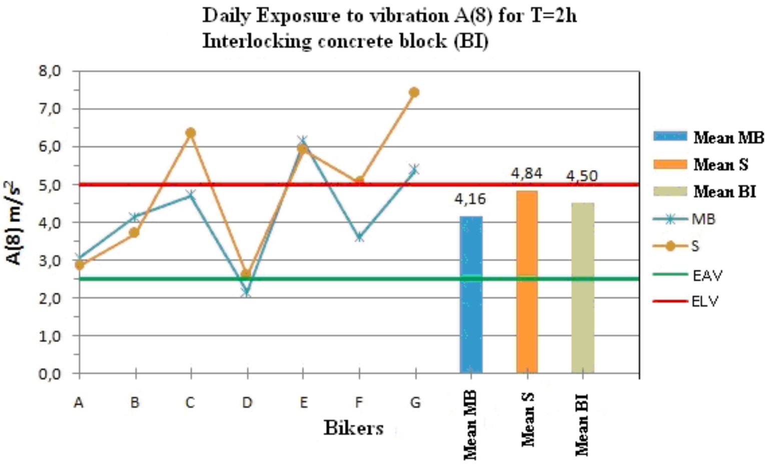


Figure 10. Daily exposure to vibration *A*(8) with a daily duration of exposure of *T*=2h, fo interlocking concrete block(BI).

It was expected, mainly due to differences in width and tire pressure, that the mountain bike model (MB) had a greater capacity for vibration damping, resulting in lower *A*(8). However, this is not confirmed by the results. Moreover, one can say that for most measurements (comparing the two bike models), even for the same cyclist and same pavement, there was a significant difference between the values of *A*(8). From the graphs presented in Fig. 8, 9 and 10 one can also analyze a possible influence of the physical characteristics of cyclists on the values of *A*(8). Remembering that cyclists are sorted from largest to smallest mass, the graphs of Fig. 8, 9, 10 do not present any pattern of behavior in the values of *A*(8). For instance, although the D cyclist has a value of intermediate mass in relation to other cyclists, in all tests he presented the lowest daily exposure to vibration *A*(8). So, it is not possible to say that the mass of the cyclist significantly influence *A*(8) values. Another measured parameter is the time for each measurement in seconds. By using this value and the distance traveled in each measurement (500m), one can estimate the average speed V_{med} in km/h. The average speeds V_{med} developed in all measurements was 14.1 km/h.

When analyzing the average speeds developed by cyclist D, one can identify that in all measurements, except for PC pavement with the mountain bike (MB), its values were below the overall average speed of 14.1 km/h. This fact may explain their low values of daily vibration exposure *A*(8), compared to the values of other cyclists. From another point of view, one can set in equation (3) the amount of daily exposure to vibration *A*(8) as the exposure action value (EAV) or the exposure limit value (ELV) and calculate to each measurement the maximum daily exposure to vibration in order to achieve the those values, T_{maxEAV} and T_{maxELV}, respectively. Figure 11 shows T_{maxEAV} for the pavements evaluated. Exposure times greater than 8h are shown for convenience as 8h. As can be seen in the Fig. 11, the highest maximum exposures times to vibration in order to achieve EAV, T_{maxEAV}, are found in AS pavement, followed by PC pavement and by BI pavement. In the latter, the average value T_{maxEAV} =0.91 h or 55 min, which represents the allowable time to relatively low cycling activity practice. Some measurements, T_{maxEAV} are close to or less than 30 min.

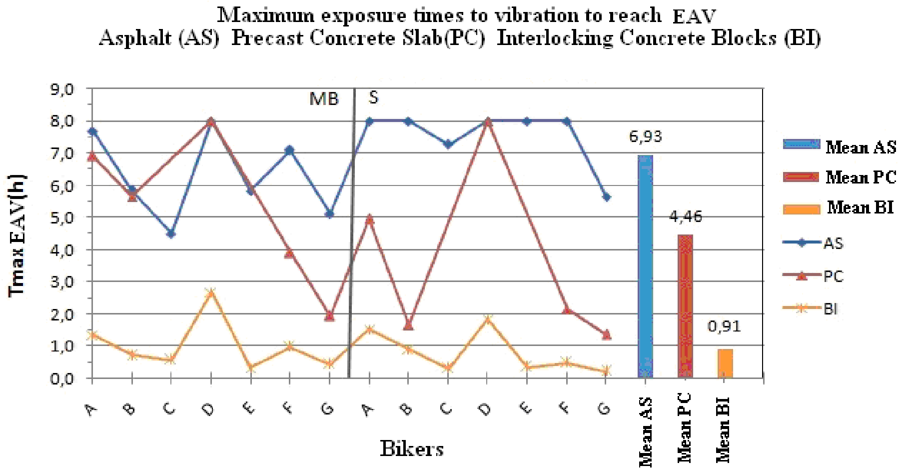


Figure 11. Maximum exposure times to vibration to reach EAV.

6. SUBJECTIVE EVALUATION OF VIBRATION IN CYCLING ACTIVITY

In the following, the main results are compared, by means of graphs, for the evaluated configurations. Figure 12 shows the concepts assigned by cyclists for each type of pavements evaluated.

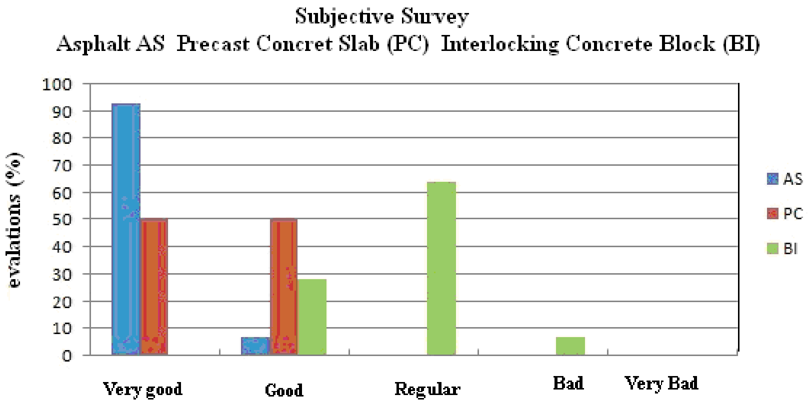


Figure 12. Concepts assigned by cyclists for each of the pavements evaluated.

As indicated in Fig. 12 the AS pavement more than 90% of the attributed concepts were “Very good”, with the remainder as “good”. For PC pavement, the attributed concepts were equally divided between “Very good” and “good”. Finally, for BI pavement, the attributed concepts were divided between “good”, with 29%, “regular”, with 64% of ratings, and “bad”, with 7% of cases. Furthermore, the cyclist was asked to deliver its opinion on the quality of the ride with the alternative answer: "acceptable," "unacceptable" and "undecided." For this variable, all the opinions were for the option "acceptable," except for an opinion of "undecided" and an opinion for "unacceptable” for BI pavements. Thus, in cyclist’s subjective evaluation, one can sort the types of pavements by degree of offered comfort, being AS the pavement most suitable for cycling activity, followed by PC and BI. This classification was the same obtained by the objective evaluation of vibration in cycling activity.

7. CONCLUSIONS

According to the objective assessment of human exposure to vibration transmitted to the hand-arm system, depending on exposure conditions, this phenomenon may be important in this cycling activity, so the maintenance of daily exposure to vibration *A*(8) within the limits established by 2002/44/EC Directive is crucial to ensuring the preservation of health of cyclists. For a daily exposure duration of T=2h, the evaluations for AS pavement had the lowest *A*(8) values, all values below the exposure action value (EAV). PC pavements have relatively higher *A*(8) values, including some ratings above the exposure action value (EAV). BI pavements presented higher values, with all measurements, except one, above the exposure action value (EAV) and some exposures above the exposure limit value (ELV). With respect to the analysis of the maximum daily exposure to vibration in order to achieve the exposure action value T_{maxEAV}, the largest allowable time are found in AS pavement, followed by PC and BI pavements. This last pavement type presented an average T_{maxEAV} less than 1 h, with some evaluations with values close to 30 min.

Thus, the AS pavement is the most suitable for the cycling activity followed PC and BI activity. This classification was also confirmed by the subjective survey. When one analyzes the influence of the bike in *A*(8) values, sometimes the bike speed (S) showed better performance and sometimes mountain bike (MB) presented better results. But in general, there is a significant variation in *A*(8) between the two models. Analyzing the influence of the physical characteristics of cyclists on *A*(8), particularly in relation to their masses, one can say that it is not possible to identify a behavior pattern in the values of A(8) due to the large standard variation on the results.

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