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Evaluation of whole body vibration levels in urban bus drivers of the Federal District

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Abstract. Bus drivers are exposed to whole body vibration (WBV) during their workday. Vibration is a physical agent capable of unleashing serious health risks, and when overexposed, is commonly associated with low back pain. The objectives of the present research were to obtain whole body acceleration in urban transport drivers that execute four different routes, based on ISO 2631-1 and Occupational Hygiene Standard (NHO 09) and to verify if there is a correlation between body mass index or percentage of body fat and acceleration. The elaboration and application of an anamnesis questionnaire was carried out aiming at the qualitative characterization of the co-partner's drivers regarding their health and their perceptions related to the vibratory stimuli present in their workplace. The results of the questionnaire showed that the vibration bothers a significant part of the drivers and that the complaint of pain is mainly concentrated in the region of the lumbar spine. The results of the experimental measurements of vibration pointed out that the vertical axis (Z) is the one with the highest values of weighted acceleration. The analysis of the correlation between the values of fat percentage or body mass index (BMI) with acceleration resulting from partial exposure suggests that there is interaction of two or more factors with BMI and percentage of fat, which generate the acceleration result. That is, the acceleration is not affected solely and individually by the BMI or fat percentage.

Keywords: Whole Body Vibration, Drivers, Urban buses.

1. INTRODUCTION

Whole-body vibration (WBV) is transmitted to the entire body of the subject by his contact with a vibrating source, usually when he is sitting or standing on a vibrating surface (Smith and Leggat, 2005). The WBV is present in numerous realities of work and in occupational populations can cause discomfort during the work day, damages in the performance and if at high levels can pose risks to the health of the workers.

The sensation of discomfort due to the WBV is frequently observed in professional drivers, being observed the increase of the discomfort with the elevation of the magnitude and time of exposure to vibration (Sekulić *et al.*, 2016). Furthermore, exposure to WBV is widely recognized as one of the causes associated with musculoskeletal disorders of the spinal system of drivers, and with early degeneration of the spine and the onset of back pain (Okunribido *et al.*, 2006; Yasobant *et al.*, 2015). About 81% of American bus drivers (for Health Statistics *et al.*, 2004), 49% of the Swedish bus drivers (Magnusson *et al.*, 1996) and 45% (Alperovitch-Najenson *et al.*, 2010) of the Israeli bus drivers reported the presence of back pain in their current job.

However, there is currently limited data available on the levels of full body vibration experienced by workers in traffic systems, but much of the studies that have been published suggest that workers' exposures exceed recommended standards (Lewis and Johnson, 2012). (Figueiredo *et al.*, 2016) carried out an observational study in a city in the state of Minas Gerais, whose values obtained with the application of the procedures described in the European directive 2002/44 / CE showed the overcoming of action level indexes for the public transport driver. And several of these research and epidemiological studies investigate the correlational causes and risk factors involved in their work assignments (Kumar *et al.*, 1999; Keyserling, 2000; Noorloos *et al.*, 2008).

The objectives of the present research were: to obtain whole body acceleration in urban transport drivers that execute four different routes and to verify if there is a correlation between body mass index or percentage of body fat and acceleration.

2. METHODOLOGY

The methodology used in this work can be illustrated by the flowchart of Fig. (1). The method involved initially submitting the project to the research ethics committee, as requested by Resolution No. 466/12 of the Brazilian National Health Council in case studies involving humans.
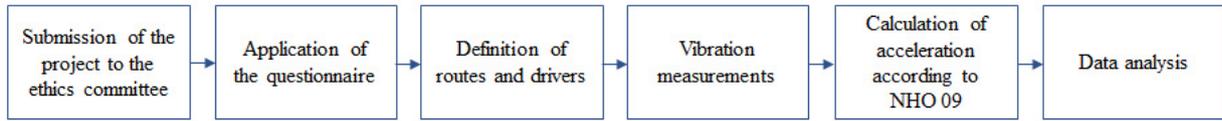

Figure 1. Methodology

With the approval of the ethical evaluation, the questionnaire for anamnesis was elaborated. This one was produced based on the bibliographical review carried out and with the assistance of the health and safety professionals of the co-participant bus company, being elaborated to meet the interests of this research. The informations included in the interview were as follows: Personal data (full name, age, sex, height and weight), personal habits and antecedents (smoker, alcoholic drink, physical activity, other paid activity and health leave) and low back and psychological aspects (feeling of pain in the body, pains in the spine, family history of illness in the spine, discomfort with WBV and feelings of stress on a typical work day). The questionnaire was applied in 5 public transport terminals serviced by the company contemplating a sample of 182 responses.

Subsequently, according to the logistics used by the company were defined the drivers and routes to be studied. The analysis for the selection of the routes under study was made in a qualitative and subjective way with the help of the company's operation supervisors, being selected routes considered more softer and more critical regarding the road conditions for the strengthening of the subsequent discussions. Four routes were chosen that although they have as their point of origin the same terminal, has as destination different satellite cities, also possessing different mileage and time spent to carry out the route.

The investigation for the selection of the drivers was based on the answers obtained in the anamnesis questionnaires in order to approach drivers with different BMI values and feelings of pain and discomfort during the working day. Experimental planning culminated in the selection of 25 drivers and 29 experiments and tab. (1) presents the routes to be studied, having its mileage, the time spent for a trip of the route, besides the number of drivers involved and the quantity of realized experiments. It is important to note that certain conductors were evaluated on different routes and for route C three experiments were carried out on the same conductor.

Table 1. Description of experimental planning.

Route	Mileage [km]	Duration [min]	Number of drivers	Number of experiments
A	52,02	90	8	8
B	17,95	40	8	8
C	33,83	80	5	7
D	36,97	90	6	6

The experimental measurements were then carried out. In order to measure the fat percentage of the drivers involved, a body fat monitor from AVANUTRI was used, and the height and mass values of the drivers were previously measured. Regarding WBV measurements, these were performed using the method defined in the occupational hygiene standard 09 (NHO 09). For this purpose, the portable vibration analyzer, Human Mensurement 100 (HVM) and the triaxial seat accelerometer, Seat Pad model Sen07, both manufactured by Larson Davis, were used. Being the Seat Pad positioned at the interface formed by the driver and the vehicle seat.

The equipment calculates the average acceleration per axis (am_j) that corresponds to a quadratic average of the instantaneous acceleration values in a measurement period, according to Eq. (1).

$$am_j = \left[\tfrac{1}{t_2-t_1} \int_{t_1}^{t_2} a_j^2(t)dt \right]^{\frac{1}{2}} \tag{1}$$

Being that $a_j(t)$ corresponds to the values $a_x(t)$, $a_y(t)$ or $a_x(t)$, which are the frequency-weighted instantaneous acceleration values per axis, and $t_2 - t_1$ corresponds to the interval time of measuring. It is important to report that the equipment was properly configured before each measurement with the weighting curves for each axis indicated by the NHO 09.

The equipment also gives the resulting mean acceleration (amr) values corresponding to the square root of the sum of the squares of the mean accelerations per axis, defined by Eq. (2):

$$amr = \sqrt{[(1.4 \cdot am_x)^2 + (1.4 \cdot am_y)^2 + (am_z)]} \qquad (2)$$

From amr values it is possible to calculate acceleration resulting from partial exposure (arep) which corresponds to the average acceleration resulting from occupational exposure over a portion of the daily work time. This parameter is the result of Eq. (3).

$$arep = \frac{1}{s} \sum_{k=1}^{s} amr_k \qquad (3)$$

Each of the routes was measured during the entire time needed to complete the entire route and all measurements were taken on a basic type vehicle with chassis OF 1721 from Mercedes Benz and Caroceria CAIO model APACHE VIP.

3. RESULTS

3.1 Anamnesis questionnaire

The answers obtained by completing the anamnesis questionnaire by the drivers allowed a qualitative analysis of the driver population of the company. The questions were answered by 182 drivers of the cadre around 900 hired drivers. The vast majority of workers are males, making up 99% of the total. Being only 1% the female representativeness.

With regard to age, one can notice a great variability among drivers. Drivers aged between 25 and 67 answered the questionnaire. In addition, 43% of the employees are aged 36 and 45. In the age group of 46 to 55 years, are found 24% of the drivers. The youngest drivers, aged between 25 and 35, account for 15% and the oldest drivers (between 56 and 67 years) represent 7% of the category in the company. The remaining percentage did not answer this question.

From the values of height and mass it was possible to calculate the values of body mass index (BMI) of the employees and classify them according to the World Health Organization (WHO). The data obtained were alarming, as shown in Fig. (2 a). Professionals who are overweight have the highest percentage, according to the WHO classification, covering 40% of the total. Those with a normal BMI accumulated 31% of the responses and no underweight driver was recorded. Percentages were still recorded in all classes of obesity.

The questioning about the perception of stress in a typical work day was still made (Fig. 2b). More than half of the responses obtained considered the perception of stress in a normal working day in the occasional light stress rating. With 25% of drivers considering that they do not suffer from stress in their daily journey followed by 12% who consider themselves suffering from frequent moderate stress. Another 5 % of drivers state that they perceive frequent high stress and 2 % of constant high stress. And 5% of drivers chose not to answer that question.
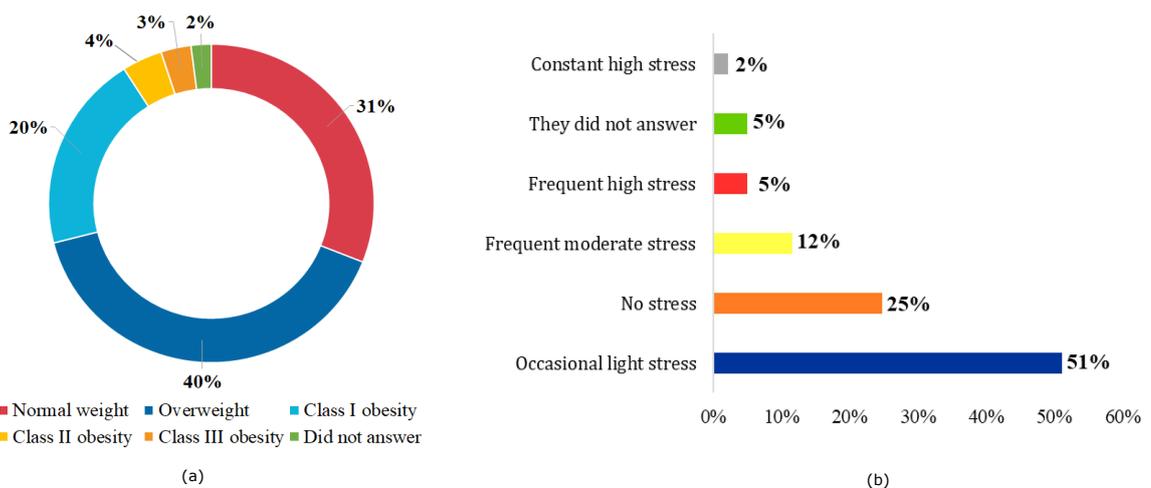

Figure 2. Body Mass Index of drivers (a) and Perception of stress during the work day (b).

Another question raised was related to possible other jobs that drivers could have. The majority of drivers said they did not perform other duties (98%) and only 2% of employees confirmed that they had another job. When it comes to moving away from work, 73% of drivers did not get away from their work for health reasons. While the remaining 27% have already been absent from work for medical reasons.

About the habits and antecedents individuals, he vast majority declared themselves as non-smokers, accumulating 90 % of responses. Being 10% of the remaining drivers are smokers. In terms of alcohol consumption, responses were

more equated, with 53% of professionals responding who did not consume and 46% declaring consumption at different frequencies. The remaining 1% did not respond to this questioning.

The practice of physical activity is frequent among the drivers of the co-participant company, since that most of the answers (58%) indicated the accomplishment of some physical activity in their daily life. Of those surveyed, 41% were sedentary and 1% chose not to answer this question.

And concerning spinal pain, a significant percentage of 44% of drivers felt pain in this region of the body. Of the drivers who reported feeling pain, 58% reported that these pains are recurrent in their routine.

The questioning regarding the feeling of discomfort from the vibration showed that 49% of the drivers feel uncomfortable with the vibration experienced in the development of their work activities (Fig.3a). When questioned about what causes the most discomfort: the vibration in the seat due to the engine or the vibration in the hands and arms, 59% of the drivers stated that they feel more uncomfortable with the whole body vibration. While 28% reported that the cause of the most discomfort is hand-arm vibration (HAV), as shown in Fig. (3b).
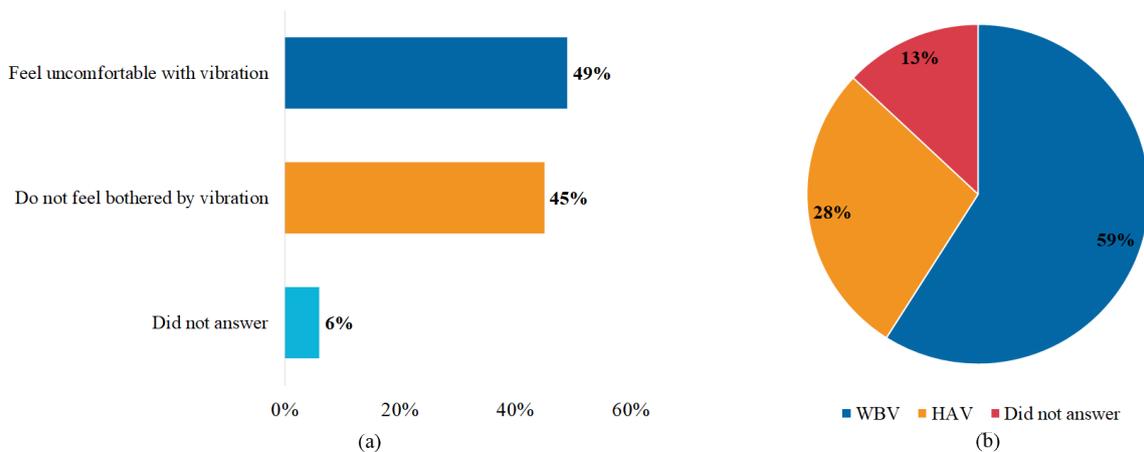

Figure 3. Sensation of discomfort due to vibration (a) and discomfort due to WBV and HAV (b).

3.2 Vibration measurements

The results of exposure to whole body vibration are shown in terms of the mean axle-weighted acceleration values for each of the routes (am_x, am_y, am_z) and of the acceleration value resulting from partial exposure ($arep$). The identification of the driver, the classification of BMI and the percentage of body fat are also tabulated.

3.3 Route A

Route A was driven by eight different drivers, with fat percentages of 14.50% to 27.10% and the results found are shown in Tab. (2). It is possible to note that half of the drivers involved in this case study are considered in the range corresponding to healthy weight, while other drivers are overweight or have some degree of obesity.

The largest values of axle-weighted acceleration are those relative to the z-axis, which is associated with the greater tendency of the movement occur vertically (Seidel, 2005).

Table 2. Exposure to whole-body vibration (route A)

Driver	BMI classification	% FAT	am_x [$\frac{m}{s^2}$]	am_y [$\frac{m}{s^2}$]	am_z [$\frac{m}{s^2}$]	$arep$ [$\frac{m}{s^2}$]
1	Healthy weight	15.60	0.32	0.32	1.04	1.22
2	Overweight	20.20	0.31	0.34	0.80	1.03
3	Healthy weight	14.80	0.29	0.34	0.93	1.12
4	Healthy weight	14.50	0.34	0.34	0.91	1.14
5	Obesity II	27.10	0.24	0.29	0.77	0.93
6	Obesity I	23.20	0.30	0.32	0.72	0.95
7	Obesity I	23.10	0.29	0.31	0.90	1.09
8	Healthy weight	18.40	0.28	0.29	0.88	1.04

Figure (4) show respectively the $arep$ graphs as a function of fat percentage (a) and BMI (b). The fat percentage graph shows that the three drivers with the lowest fat are associated with the highest values of the acceleration value resulting

from partial exposure measured. And yet the driver where the lowest value of exposure was measured is the one with the highest percentage of body fat.

Regarding the BMI chart, three of the four drivers who are in the healthy weight classification range have the highest values of acceleration resulting. While the driver who presents degree of obesity II is associated with the lowest exposure value to VCI.

It is noticeable that the graphs follow an analogous trend, with the higher acceleration values corresponding to drivers with the lowest fat percentage and consequently lower BMI values. The experimental data were adjusted using the least squares method and since both follow a similar trend, they culminated in first degree polynomials,, with R^2 values equal to 0.68 and 0.66, respectively. The equations that describe the straight are shown above the graphs.
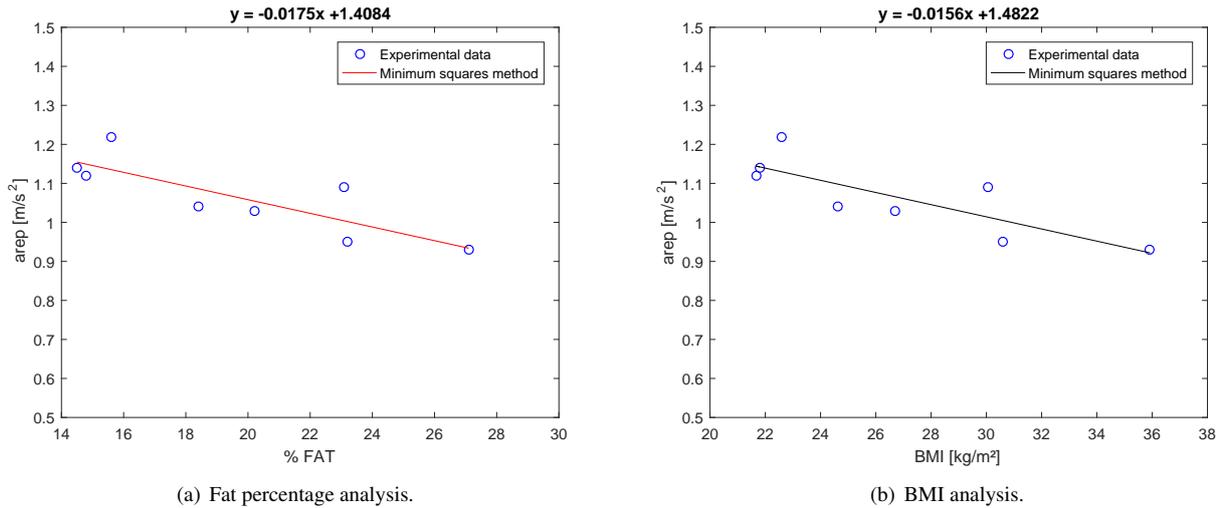

(a) Fat percentage analysis.

(b) BMI analysis.

Figure 4. Route A.

3.4 Route B

Route B was driven by eight different drivers too, with fat percentages of 11.50% to 25.00% and the results found are shown in Tab. (2). The BMI classification was very alarming. With seven of the drivers showing overweight or obesity grade 1, which may be a risk factor for the increase of occupational diseases.

Similar to the one obtained for the previous route, the highest values of acceleration per axis are those referring to the vertical axis (z).

Table 3. Exposure to whole-body vibration (route B)

Driver	BMI classification	% FAT	$am_x \left[\frac{m}{s^2}\right]$	$am_y \left[\frac{m}{s^2}\right]$	$am_z \left[\frac{m}{s^2}\right]$	$arep \left[\frac{m}{s^2}\right]$
6	Obesity I	23.20	0.25	0.27	0.55	0.75
9	Healthy weight	11.50	0.34	0.32	0,72	0,97
10	Overweight	19.50	0.24	0.28	0.67	0.85
11	Overweight	21.30	0.25	0.26	0.59	0.73
12	Obesity I	25.00	0.32	0.29	0.64	0.84
13	Obesity I	24.40	0.28	0.32	0.67	0.90
14	Overweight	18.90	0.27	0.27	0.75	0.93
15	Overweight	19.50	0.23	0.26	0.76	0.91

Figure (5) show respectively the $arep$ graphs as a function of fat percentage (a) and BMI (b) for route B. It is possible to note that the largest acceleration value resulting from partial exposure for the graph of Fig. (5 a) is corresponding to the driver with the lowest percentage of fat. The BMI chart follows the trend verified for the percentage of fat with the only driver considered in healthy weight presenting the highest exposure to WBV.

The experimental data from both graphs were adjusted according to the minimum squares method, generating second-degree polynomials whose equations are shown in Fig. (5). The values of R^2 are respectively 0.39 and 0.46 for percentage of fat and BMI.
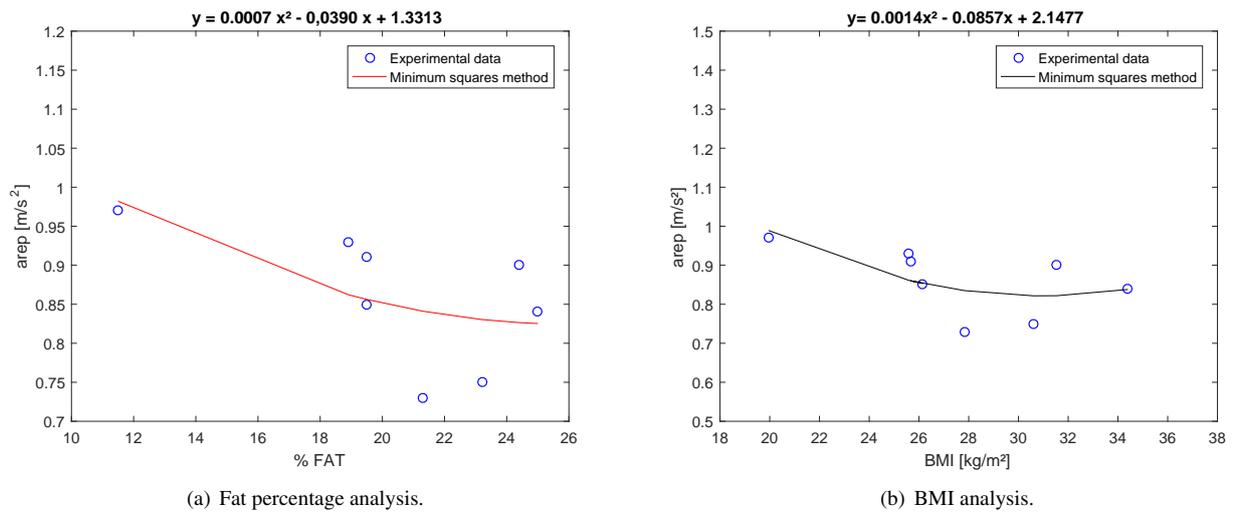
(a) Fat percentage analysis.

(b) BMI analysis.

Figure 5. Route B.

3.5 Route C

The measurements for route C covered seven experiments, with five different conductors (Tab. 4). With three measurements taken for the same driver. It is possible to notice that the workers present alarming BMI classifications, only one of these in healthy weight. The tendency for greater accelerations per axis to occur in that vertical was also observed in route C. The analysis for the fat percentage and the acceleration values for this route were shown in Fig. (6a).

Table 4. Exposure to whole-body vibration (route C)

Driver	BMI classification	% FAT	$am_x \left[\frac{m}{s^2}\right]$	$am_y \left[\frac{m}{s^2}\right]$	$am_z \left[\frac{m}{s^2}\right]$	$arep \left[\frac{m}{s^2}\right]$
15	Overweight	19.50	0.24	0.27	0.74	0.90
16	Overweight	22.10	0.23	0.25	0.54	0.74
17	Healthy weight	17.70	0.28	0.32	0.70	0.92
18	Overweight	18.60	0.24	0.26	0.70	0.86
19	Overweight	19.40	0.22	0.23	0.66	0.80
19	Overweight	19.40	0.21	0.22	0.63	0.76
19	Overweight	19.40	0.22	0.22	0.65	0.79

(a) Fat percentage analysis.
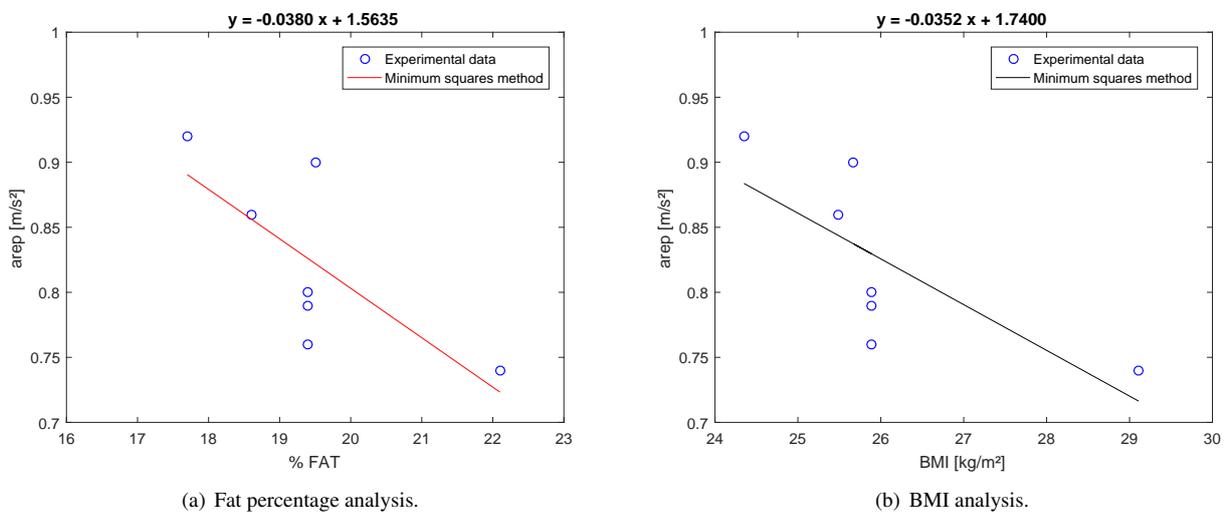

(b) BMI analysis.

Figure 6. Route C.

The highest acceleration value resulting from partial exposure is the one corresponding to the driver with the lowest percentage of fat. And the lowest measured acceleration value is associated with the driver with the highest percentage

of fat. The data in question were adjusted according to a first order polynomial whose equation is shown in Fig. (6a) resulting in a value of R^2 of 0.59.

The results obtained for BMI were similar to those obtained for fat percentage, since the only driver in the healthy weight range was the one in which the highest level of acceleration was measured (Fig. 6b). The data for BMI were adjusted according to a first order polynomial too whose equation is shown in Fig. (6b) resulting in a value of R^2 of 0.64.

3.6 Route D

The measurement set for route D approached 6 different drivers, as shown in Tab. (5). It is noticeable that half of the drivers are considered healthy, while the other half is either overweight or in degree I of obesity.

It is still possible to note that, regardless of the route, the greatest acceleration per axis is in the vertical direction, with the result for route D being similar to that obtained for the other routes.

Table 5. Exposure to whole-body vibration (route D)

Driver	BMI classification	% FAT	$am_x \left[\frac{m}{s^2}\right]$	$am_y \left[\frac{m}{s^2}\right]$	$am_z \left[\frac{m}{s^2}\right]$	$arep \left[\frac{m}{s^2}\right]$
20	Healthy weight	14.50	0.33	0.37	0.80	1.06
21	Obesity I	24.60	0.25	0.26	0.72	0.89
22	Obesity I	24.40	0.26	0.25	0.59	0.79
23	Healthy weight	16.60	0.28	0.28	0.82	0.99
24	Healthy weight	16.30	0.29	0.32	0.69	0.91
25	Overweight	20.60	0.27	0.26	0.60	0.80

The correlation between the values of the acceleration resulting from partial exposure for route D and percentage of fat or BMI were analyzed according to the graphs of Fig. (7).
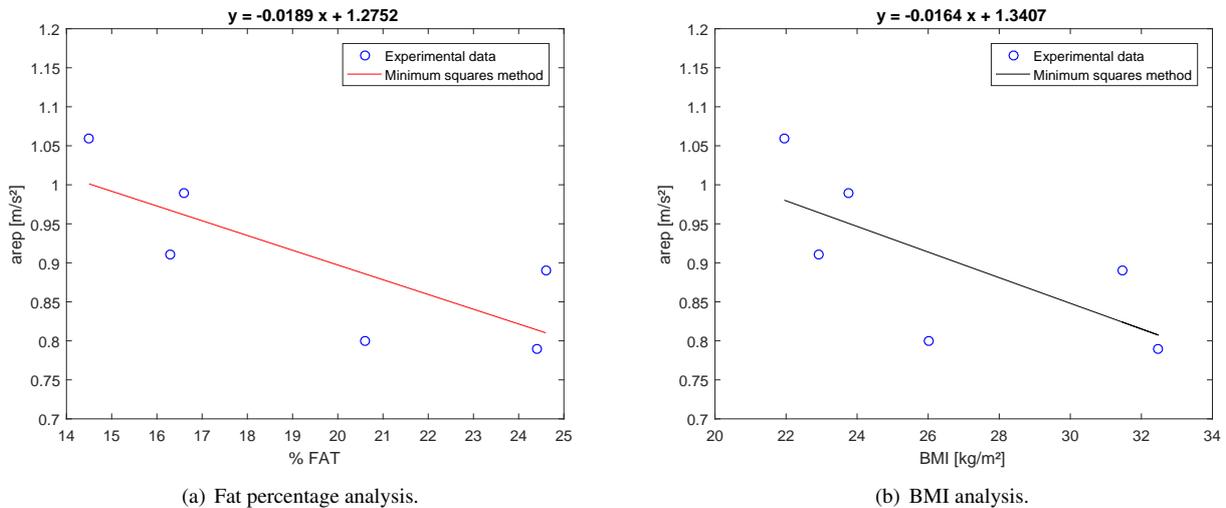

(a) Fat percentage analysis.

(b) BMI analysis.

Figure 7. Route D.

The two graphs show very similar behavior, since the driver of lower fat percentage and consequent lower BMI value was responsible for the higher acceleration resulting from partial exposure, in line with that shown for the previous routes. Both were fitted, from the minimum squares method, best to a first-degree polynomial whose equations are shown in Fig. (7a) and Fig. (7b), respectively for percentage of fat and BMI.

4. CONCLUSIONS

Considering the aspects analyzed, it is well known that Whole Body Vibration is an occupational agent that exposes bus drivers to risks related to their health.

It is possible to conclude from the answers presented by drivers who answered the anamnesis questionnaire that the pain of the lumbar region dating from the literature studied is commonly reported by this working class.

In general, most of the workers to be analyzed have no other job. Thus, the occupational pain and discomfort felt during his day are related to the development of his activities as urban bus drivers.

The vibration coming from his work environment is significantly determinant in the accomplishment of his work activities because a significant portion of the drivers mentioned that feels annoyed with the vibratory stimuli.

With regard to hand-arm vibration, whole body vibration is pointed out as the cause of the biggest discomfort. And the feeling of pain in the spine was pointed out by a considerable portion of the drivers.

The getting of higher weighted values of acceleration of its entire body to the z axis dated in the literature was proven in the present study. The analysis of the influence of fat percentage and BMI showed that the rcceleration resulting from partial exposure are not influenced solely and exclusively by these factors, indicating the interaction two or more parameters to obtain the acceleration values.

Thus, the investigation of the relationships that the WBV can have with different fat percentages is of extreme importance for the characterization of aspects related to the health and comfort of urban bus drivers. Analytical studies such as these may lead to the development of new technologies aimed at reducing the levels of vibration which are subject to the adoption of corrective and / or preventive measures that favor this workers.

5. ACKNOWLEDGEMENTS

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7. RESPONSIBILITY NOTICE

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