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A STUDY CONCERNING THE DRIVER COMFORT IMPROVEMENT AS REGARDS THE TRANSMITTED VIBRATIONS BY THE VEHICLE RUNNING ON ROADS IN ROMANIA

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Abstract: In this paper was studied the way in which the driver/passengers comfort can be improved during a ride in regard to the vibrations transmitted by the vehicles. For this were measured the vibrations accelerations transmitted by the vehicle when: the driver sits directly on the car seat and the driver sits on a gel-foam cushion or on ergonomic seat cushion, in different cases: driving on asphalt, on macadam and on ground. For this the accelerometers were fixed on the floor, on the seat, on the lumbar, on the cervical and on the forehead, at ten male subjects with different body weights, ages and work experience. Comparisons were made between the root mean square average vibration, the vibration dose value, the time period needed to reach the value of the exposure which triggers the action and the limit exposure value, TWA Peak, Raw (+/-) Peak and the seat effective amplitude transmissibility for A_w and VDV. It was discovered that all the values which are specific to the vibrations transmitted by the vehicle to the entire body of the driver/passengers are notable modified, scilicet the travelling conditions are improved, if gel-foam cushion or ergonomic seat cushion are used. Because of this we move that all the seats in transportation: car, public transportation and work equipment should be provided from start with vibrations dampers, preferable ergonomic seats with gel-foam cushion included.

Keywords: WBV, vibration comfort, seat cushion, seat effective amplitude transmissibility for A_w and VDV

1. INTRODUCTION

The drivers' body is exposed to vibrations during driving. It was proved that vibrations lead to disorders of the muscular and skeletal system, of the hand as well as of the arm, neck and back (Picu, 2011).

There are two types of occupational vibrations: of one segment and of the whole body. The vibrations from the steering wheel are transmitted through the hand and arm and lead to some specific disorders like Raynaud Syndrome. The whole-body vibration is transmitted through the support surfaces of the body: legs, for the vertical position case, or buttocks and back, for the seated position.

Besides the problems of the muscular and skeletal systems, the whole-body exposure to vibrations from the vehicles leads also to disorders of the psychomotor, physiological and psychological system (Mansfield et al., 2006).

If in contact to a vibrating vehicle the energy of the vibration is transferred to the human body. Depending on the type of exposure, the vibrations can affect an important part of the workers' body or only a certain body-part. The effects of exposure to vibrations are also influenced by their frequency. Each organ has its own resonance frequency. If the exposure happens at that resonance, or at a close frequency, the result is emphatic (Bovenzi, 2010).

The energy of the whole-body vibration is transmitted to the body through the floor or chair and affects the whole body or a lot of body-parts. The exposed groups include truck drivers, bus drivers, tractor drivers but also the ones who work on vibrating surfaces (Wijaya et al., 2003).

The effects of the vibrations on organism subjected to whole-body vibrations, in the case of the heavy vehicles drivers were put against the ones obtained on workers from a similar environment but who were not exposed to whole-body vibrations. The studies showed that back problems are appear more often and are more serious if there is a case of exposure to vibrations.

The human response to whole-body vibrations depends on the frequency of the vibration, on the acceleration and on the exposure time (M-Pranesh et al., 2010). Because of the difficult evaluation of the response to vibrations and of the inconsistency of the data obtained after research, ISO 2631-1:1997, ISO 2631-4:2001 established *The Evaluation of the Human Exposure to Whole- Body Vibrations*.

Some studies show that the standards are not low enough and that the problem of the muscular and skeletal systems also appear after exposure to vibrations under the standard (Lewis & Griffin, 1995). The standard is eligible only for healthy people with a normal life routine and who are subjected to a normal work-day. The standard puts forward the numerical limits for the exposure to vibrations transmitted from solid surfaces to the human body, for the frequency range of 1-80Hz.

The standard refers to 3 different concerning levels: comfort abatement, handiness abatement due to fatigue and the exposure limits. Many studies published the levels of vibrations for different vehicles used in civil engineering, agriculture and industry. The vibrations values were measured on different types of terrain with vehicles of different fabrication years, etc (Table 1).

Table 1. Vibration values for different vehicles (Hulshof & van Zanten, 1997)

Vehicle	$a_{x, y, z}$ (m/s^2)
Elevator	0.8
Bulldozer with standard seat	0.52 – 0.64
Tractor on pavement	1.76 – 2.03
Bulldozer with vibrations absorbing seat	0.43 – 0.80
Crane	0.4 – 2.3
Tractor on soil ground	0.6
Wagon	1.0
Excavating machine	0.5 – 2.3

Between 1997-2010, in Romania, the occupational diseases due to osteomuscular overstraining are on the top positions, followed by occupational diseases due to noise, cutaneous diseases, Raynaud syndrome, etc, (Fig. 1, Table 2) (http://www. protectiamuncii.ro).

Table 2. Total occupational diseases due to physical agents (noise and vibrations) 1997 – 2010

Occupational diseases due to vibrations overstraining	23313
Hypoacusis and deafness	8615
Raynaud syndrome	2515
Osteoarticular occupational diseases due to vibrations	317

There are many standard methods of measurement and evaluation of the vibrations transmitted to the whole body in the case of moving vehicles (Miyashita, et al, 1992).

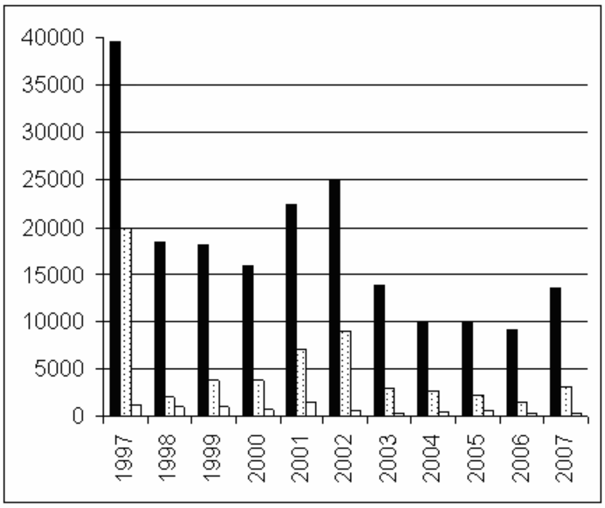

Figure 1. Occupational diseases due to vibrations between 1997 and 2007 in Romania
(■) – All occupational diseases, (░) - occupational diseases due to noise, (□) - occupational diseases due to vibrations

The fundamental principles of these methods are known as well as the way in which the accelerations must be measured near the seat and/or near the floor of the car or of the equipment, where the workers are. Some of these techniques also include methods to determine the comfort of the passengers who are in a vibrations transmitting vehicle (Nawayseh & Griffin, 2005).

2. WORK METHODS

The objective of this paper is to study the way in which seating on vehicle seats during long car rides can be improved. But these results can be also applied on long train rides or plane trips.

To determine the way in which the vibrations transmitted by the vehicle influence the passengers or the drivers' bodies, the following measurements will be made:

A) The vibrations accelerations transmitted by the vehicle to the driver will be measured in 3 cases:
a) the driver sits directly on the car seat (Fig. 2a);
b) the driver sits on a gel-foam cushion (Fig. 2b);
c) the driver sits on ergonomic seat cushion (Fig. 2c);

B) The vibrations accelerations transmitted by the vehicle to the driver will be measured in 3 cases:
a) driving on asphalt (Fig. 3a);
b) driving on macadam (Fig. 3b);
c) driving on ground (Fig. 3c);

C) The vibrations accelerations transmitted by the vehicle to the driver will be measured in 5 cases:
a) the accelerometer is fixed on the floor (Fig. 5a);
b) the accelerometer is fixed on the seat (Fig. 2a);
c) the accelerometer is fixed on the lumbar (Fig. 5b);

d) the accelerometer is fixed on the cervical (Fig. 5c);
e) the accelerometer is fixed on the forehead (Fig. 5d);

D) The vibrations accelerations transmitted by the vehicle to the driver will be measured in 10 cases: (Table 3).

The driving was carried out on 10 km inside the city. The streets are pretty humpy here and there. The measurements taken on those humps were ruled out. The speed of the vehicle did not exceed 50 km/h, and the average speed was 32 km/h.

At the beginning of every test the driver was asked to set the seat in the desired position and to sit comfortable, to drive as usually and the measurement system was calibrated. The measurement time for every test set was 15 minutes.

The vibrations were measured in normal working conditions, according to International Standard ISO 2631-1. The whole body vibration, in different conditions, was measured on the 3 axes x, y and z from the centre of the human body. The whole body vibrations were measured using:

- 01dB NetdB Multichannel digital recorders and real-time analysers with 12 activated channels acquisition (Fig. 4);
- triaxial whole-body accelerometer SEAT-pad (Seat Effective Acceleration Transmissibility) mounted on the driver's floor, seat and lumbar (Fig. 5a, 3a, 5b);
- triaxial whole-body accelerometer PCB Piezotronics 356A16 mounted on the driver's cervical and forehead (Fig. 5c, 5d).

The accelerometer was fixed with clips on the steering wheel, according to ISO 5349-2:2001. The axes were oriented in the directions specified in EN 1032:2003. The accelerations generated by vibrations were calculated using the weight factors set by ISO 2631. The calibration of the accelerometers was made with VE-10 Rion.

Whole-body vibrations values were calculated over the whole route (all road segments), as well as by individual road segment.

A GPS was also used to collect and integrate the data and to identify the location, velocity, and the type of road associated with the WBV exposures.

Each experiment was repeated 10 times in order to obtain a accurate averaging of the experimental data.

Ten male subjects were chosen for this experiment with different body weights, ages and work experience (Table 3). From these subjects half are amateurs and half are pros who drive more than 3h/day consecutively. Another selection criterion was the driving experience: 2 drivers have a 10–19 driving experience and 7 drivers have more than 20 years of driving experience.

Table 3 Subjects information (a)- amateur; (p)- professional

Subject	Weight (kg)	Age	Driving (h/day)	Number of years	Driver type
1	≤70	≤30	0–1	0–9	a
2	≤70	≥50	≥3	≥20	p
3	71–93	≥50	2–3	≥20	a
4	71–93	30-50	≥3	≥20	p
5	71–93	30-50	2–3	≥20	a
6	71–93	30-50	≥3	≥20	p
7	≥94	≥50	≥3	10–19	p
8	≥94	≥50	≥3	≥20	p
9	≥94	30-50	2–3	10–19	a
10	≥94	30-50	2–3	≥20	a

3. DATA PROCESSING

The data processing was made with dBFA Suite-Control Software for data acquisition and post-processing. The data acquired during the experiments were processed using the calculation given by ISO 2631-1:1997.

Comparisons were made between seats, road types, accelerometer positions and driver weights. The ISO 2631-1 parameters evaluated included:

a) Root mean square average vibration (A_w) calculated at the floor, seat, lumbar, cervical and forehead:

$$A_w=\left[\frac{1}{T}\int_0^T a_w^2(t)dt\right]^{1/2} \quad (m/s^2) \qquad (1)$$

b) Vibration dose value (VDV). This value is more sensitive to impulsive vibration and reflects the total, as opposed to average vibration:

$$VDV=\left[\frac{1}{T}\int_0^T [a_w(t)]^4 dt\right]^{1/4} \quad (m/s^{1.75}) \qquad (2)$$

c) The time period needed to reach the value of the exposure which triggers the action (EAV) and the limit exposure value (ELV):

$$T_{EAV_{A(8)}}=8\left(\frac{0,5}{A_w}\right)^2 \quad (h) \qquad (3)$$

$$T_{ELV_{A(8)}}=8\left(\frac{1,15}{A_w}\right)^2 \quad (h) \qquad (4)$$

d) TWA Peak: the highest magnitude of A_w measured during the measurement period.

e) Raw (+) Peak and Raw (−) Peak: the highest vibration measured in the positive/negative direction (Z-axis topping/bottoming out).

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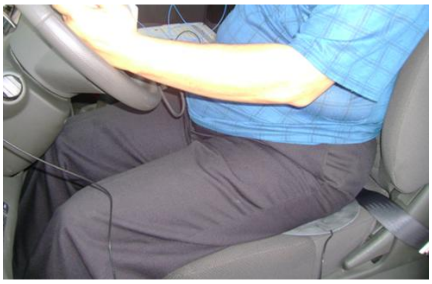
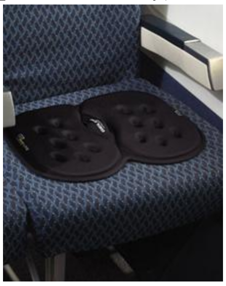


a) Without cushion (with seat pad under body)

b) Gel-foam cushion



c) Ergonomic seat cushion

Figure 2. Cushions used in this study

a) asphalt

b) macadam

c) ground

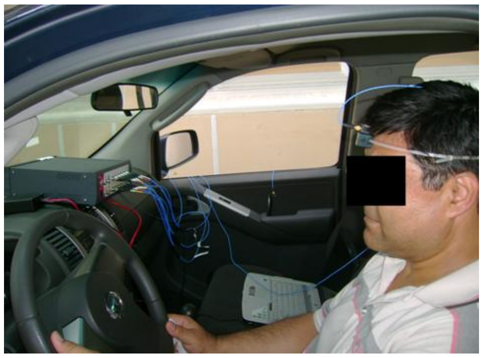
Figure 3. Types of roads

Figure 4. Data Acquisition Systems

a) Triaxial accelerometer (SEAT) under the foot

b) Triaxial accelerometer (SEAT) on the lumbar

c) Triaxial accelerometer on the cervical



d) Triaxial accelerometer on the forehead

Figure 5. Positions were the accelerometers were fixed

f) Seat effective amplitude transmissibility (SEAT) (for A_w and VDV) provides a measure of how well a seat is suited to the spectrum of vibration entering the seat:

$$\text{SEAT } A_w = \frac{A_{w\,seat}}{A_{w\,floor}} \text{ x } 100 \quad (\%) \qquad (5)$$

$$\text{SEAT VDV} = \frac{VDV_{seat}}{VDV_{floor}} \text{ x } 100 \quad (\%) \qquad (6)$$

4. DISCUSSIONS AND CONCLUSIONS

a) Parallel between the root mean square average vibration, calculated at the floor, seat, lumbar, cervical and forehead, when running on asphalt, macadam and ground, in the 3 cases: without cushion and with gel-foam and ergonomic seat cushion.

Figure 6 shows that at the floor level, $A_{w\ ground}$ (A_{wG}) is 1.53 times higher than $A_{w\ asphalt}$ (A_{wA}). It is clear the influence of the road type on which the car is rolling.

- If the driver does not use the seat cushion, A_{wG} is 1.14 (lumbar)÷1.46 (cervical) times higher than A_{wA} in the same conditions,
- If the driver does use the seat cushion: A_{wG} is 1.12 (gel-foam)/1.03 (ergonomic) times higher than A_{wA} (lumbar), respectively A_{wG} is 1.45 (gel-foam)/1.44 (ergonomic) times higher than A_{wA} in the same conditions.

It can be seen that in all cases, with or without cushion, the root mean square average vibration in the case of running on ground is higher than the root mean square average vibration in the case of running on asphalt.

b) Parallel between vibration dose value, calculated at the floor, seat, lumbar, cervical and forehead, when running on asphalt, macadam and ground, in the 3 cases: without cushion and with gel-foam and ergonomic seat cushion.

Figure 7 shows that at the floor level, vibration dose value in the case of running on ground (VDV_G) is 1.42 times higher than vibration dose value in the case of running on asphalt (VDV_A). It is clear the influence of the road type on which the car is rolling.

- If the driver does not use the seat cushion, VDV_G is 1.41 (seat)÷2.08 (forehead) times higher than VDV_A in the same conditions,
- If the driver does use the seat cushion: VDV_G is 1.47 (gel-foam)/1.42 (ergonomic) times higher than VDV_A (seat), respectively VDV_G is 2.04 (gel-foam)/2.1 (ergonomic) times higher than VDV_A in the same conditions.

It can be seen that in all cases, with or without cushion the vibration dose value in the case of running on ground is higher than the vibration dose value in the case of running on asphalt.

c) Parallel between time periods to reach the exposure value which triggers the action

Another value interesting value for studying vibrations which are transmitted to the divers as well as to the passengers during travelling and which depends on the road type and on the presence of the cushion under the driver is the time period necessarily to reach the exposure value which triggers the action.

Figure 8 shows that at the floor level, T_{EAV} in the case running on asphalt (T_{EAV-A}) is 2,35 times higher than T_{EAV} in the case of running on ground (T_{EAV-G}). It is clear the influence of the road type on which the car is rolling.

- If the driver does not use the seat cushion, T_{EAV-A} is 1.86 (seat)÷2.13 (cervical) times higher than T_{EAV-G} in the same conditions,
- If the driver does use the seat cushion, T_{EAV-A} is 1.25 (gel-foam)/1.06 (ergonomic) times higher than T_{EAV-G} (lumbar), respectively T_{EAV-A} is 2.12 (gel-foam)/2.07 (ergonomic) times higher than T_{EAV-G} (cervical), in the same conditions.

It can be seen that in all cases, with or without cushion T_{EAV} in the case of running on asphalt is higher than the T_{EAV} in the case of running on ground.

d) Parallel between time periods to reach the limit exposure value

This value is also very influenced by the accelerometers position, by the road type and by the presence of the cushion under the driver.

Figure 9 shows that at the floor level, T_{ELV} in the case of running on asphalt (T_{ELV-A}) is 2.34 times higher than T_{EAV} in the case of running on ground (T_{ELV-G}). It is clear the influence of the road type on which the car is rolling.

- If the driver does not use the seat cushion, T_{ELV-A} is 1.3 (lumbar)÷ 2.13(cervical) times higher than T_{ELV-G}, in the same conditions,
- If the driver does use the seat cushion, T_{ELV-A} is 1.25 (gel-foam)/1.06 (ergonomic), times higher than T_{ELV-G} (lumbar), respectively T_{ELV-A} is 2.12 (gel-foam)/2.07 (ergonomic) times higher than T_{ELV-G} (cervical), in the same conditions.

It can be seen that in all cases, with or without cushion T_{ELV} in the case of running on asphalt is higher than the T_{ELV} in the case of running on ground.

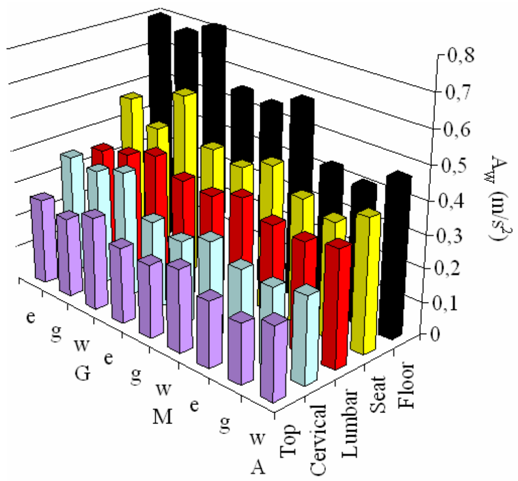


Figure 6. Aw average WBV measurements as a function of road type for different cases: without and with cushions (n=10)

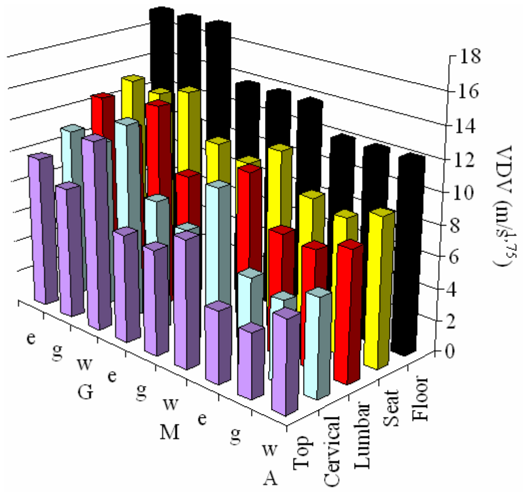


Figure 7. VDV average WBV measurements as a function of road type for different cases: without and with cushions (n=10) (w) Without cushion, (g) Gel-foam cushion, (e) Ergonomic seat cushion; (A) asphalt, (M) macadam, (G) ground
Floor, Seat, Lumbar, Cervical, Top

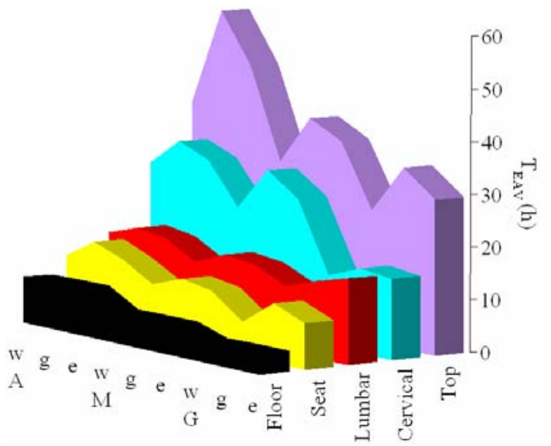


Figure 8. T_{EAV} average WBV measurements as a function of road type for different cases: without and with cushions

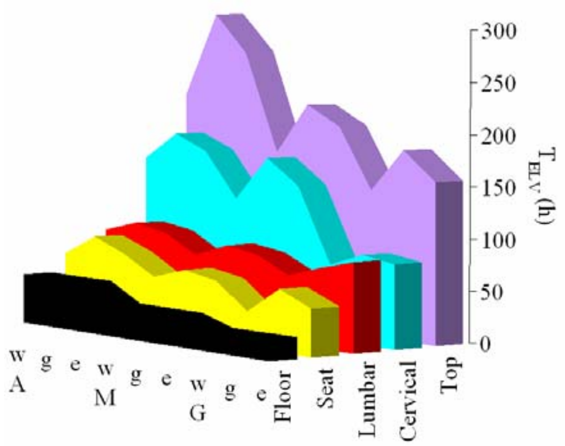


Figure 9. T_{ELV} average WBV measurements as a function of road type for different cases: without and with cushions
Floor, Seat, Lumbar, Cervical, Top

e) Parallel between TWA Peak calculate la floor level and seat

If we consider the highest magnitude of A_w measured during the measurement period obtained in the 3 situations (without cushion, gel-foam cushion and ergonomic seat cushion) on the 3 types of roads, only at the floor level, we get:

Figure 10 shows that at the floor level, TWA Peak in the case of running on asphalt (TWA_A) is 1.15 times higher than TWA Peak in the case of running on ground (TWA_G). It is clear the influence of the road type on which the car is rolling.

➢ If the driver does not use the seat cushion, TWA_G is 1.80 times higher than TWA_A (seat),

➢ If the driver does use the seat cushion, TWA_G is 1.19 (gel-foam)/1.7 (ergonomic) higher than TWA_A (seat).

It can be seen that in all cases, with or without cushion TWA Peak in the case of running on ground is higher than the TWA Peak in the case of running on asphalt.

f) Parallel between Raw (+) Peak calculated at floor and seat level

If we consider Raw (+) Peak obtained in the 3 conditions (without cushion, gel-foam cushion and ergonomic seat cushion) on 3 road types, only at floor and seat level, we get figure 11.

Figure 11 shows that, at floor level, Raw (+) Peak, in the case of rolling on asphalt ($Raw+_A$) is 1.61 times lower than Raw (+) Peak in the case of rolling on ground ($Raw+_G$). It is clear the influence of the road type on which the car is rolling.

➢ If the driver does not use the seat cushion, $Raw+_G$ is 2.37 times higher than $Raw+_A$ (seat),

➢ If the driver does use the seat cushion, $Raw+_G$ is 1.26 (gel-foam)/1.28 (ergonomic) times higher than $Raw+_A$ (seat).

It can be seen that in all cases, with or without cushion, Raw (+) Peak in the case of rolling on ground is higher than Raw (+) Peak in the case of rolling on asphalt.

g) Parallel between Raw (-) Peak calculated at floor and seat level

If we consider Raw (-) Peak obtained in the 3 conditions (without cushion, gel-foam cushion and ergonomic seat cushion) on 3 road types, only at floor and seat level, we get Figure 12.

Figure 12 shows that, at floor level, Raw (-) Peak, in the case of rolling on asphalt ($Raw-_A$) is 1.17 times lower than Raw (-) Peak in the case of rolling on ground ($Raw-_G$). It is clear the influence of the road type on which the car is rolling.

➢ If the driver does not use the seat cushion, $Raw-_G$ is 1.64 times higher than $Raw-_A$ (seat),

➢ If the driver does use the seat cushion, Raw-$_G$ is 1.27 (gel-foam)/1.58 (ergonomic) times higher than Raw-$_A$ (seat).

It can be seen that in all cases, with or without cushion, Raw (-) Peak in the case of rolling on ground is higher than Raw (-) Peak in the case of rolling on asphalt.

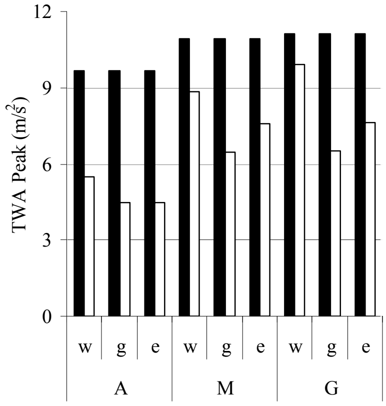


Figure 10. TWA Peak average WBV measurements as a function of road type for different cases: without and with cushions: (■) Floor, (□) Seat

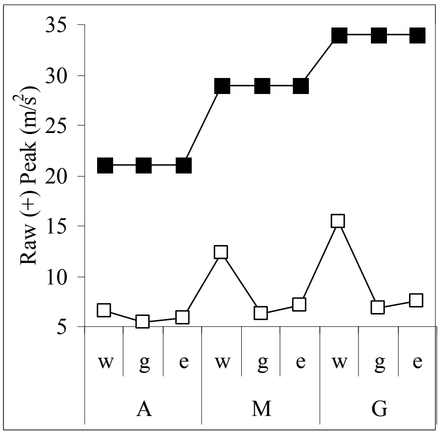


Figure 11. Raw (+) Peak average WBV measurements as a function of road type for different cases: without and with cushions: (■) Raw (+) Peak Floor, (□) Raw (+) Peak Seat

h) Parallel between seat effective amplitude transmissibility for A_w, calculated for rolling on asphalt, macadam and ground, in the 3 cases: without cushion and with gel-foam and ergonomic seat cushion

Figure 13 shows that:

➢ If the driver does not use the seat cushion, SEAT A_{wG} is 1.11 times lower than SEAT A_{wA},

➢ If the driver does use the seat cushion, SEAT A_{wG} is 1.27 (gel-foam)/1.21 (ergonomic) times lower SEAT A_{wA}.

It can be seen that in all cases, with or without cushion, SEAT A_w in the case of rolling on ground is lower than SEAT A_w in the case of rolling on asphalt.

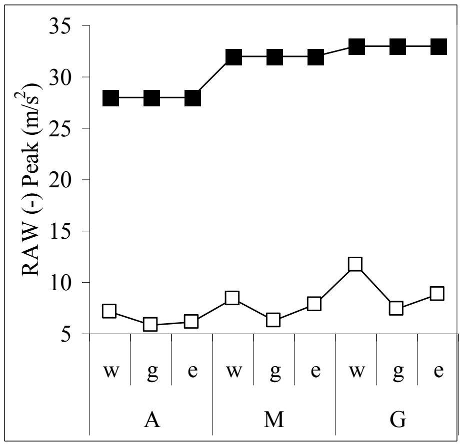


Figure 12. Raw (-) Peak average WBV measurements as a function of road type for different cases: without and with cushions: (■) Raw (-) Peak Floor, (□) Raw (-) Peak Seat

i) Parallel between seat effective amplitude transmissibility for VDV, calculated for rolling on asphalt, macadam and ground, in the 3 cases: without cushion and with gel-foam and ergonomic seat cushion

Figure 13 shows that:

➢ If the driver does not use the seat cushion, SEAT VDV_G şi SEAT VDV_A are aproximately equal,

➢ If the driver does use the seat cushion, SEAT VDV_G si SEAT VDV_A are aproximately equal.

j) Parallel between root mean square average vibration, calculated at the floor and seat, for rolling on asphalt, in the 3 cases: without cushion and with gel-foam and ergonomic seat cushion, depending on subject's weight

Figures 14 shows that, regardless of the accelerometer's position (on the floor or on the seat) and whether the driver uses or not the cushion, Aw is lower, for higher weights of the drivers. For example:

➢ without cushion, for drivers with $m \geq 94$kg, A_w is 15.5% lower than for drivers with $m \leq 70$kg,

➢ for gel-foam cushion, for drivers with $m \geq 94$kg, A_w is 31.7% lower than for drivers with $m \leq 70$kg,

➢ for ergonomic seat cushion, for drivers with $m \geq 94$kg, A_w is 26.2% lower than for drivers with $m \leq 70$kg.

It can be seen that in all cases, with or without cushion, A_w is significantly lower for drivers with higher weights.

In conclusion, for this paper we studied the way the existence on the car's seat of a certain kind of cushion favourably influences driver's/passenger's comfort. It can be seen that all values characterizing vibrations transmitted by the car to the whole body (A_w, VDV, T_{EAV}, T_{ELV}, TWA Peak, Raw (+/-) Peak and SEAT for A_w/VDV) of the driver/passenger undergo remarkable changes, improving travel conditions.

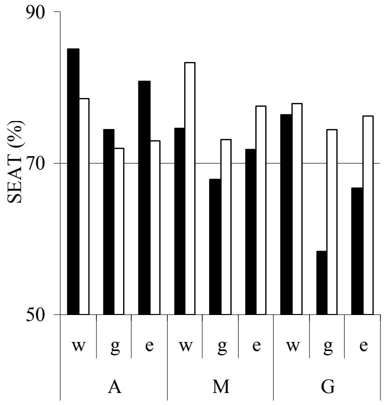


Figure 13. A_w average WBV measurements as a function of road type for different cases: without and with cushions (█) SEAT A_w, (□) SEAT VDV

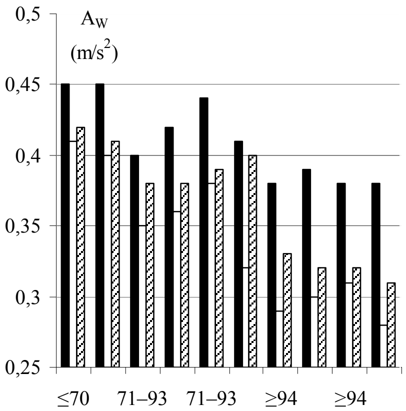


Figure 14. A_w average WBV measurements as a function of subject mass (≤70 kg, 71-93kg and ≥94kg) for different cases: without cushion (█), with gel-foam cushion (□) and ergonomic seat cushion (///)

It is therefore imperative that all seats of a means of transport: cars, public transportation (buses, trains, airplanes), as well as working machines (tractors, trucks, excavators, etc.) to be provided since the construction with vibration attenuators and it is proposed that they are ergonomic chairs, with gel-foam cushions.

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