THE INFLUENCE OF WHOLE-BODY VIBRATION ON THE TEMPORARY THRESHOLD SHIFT OF HEALTHY VOLUNTEERS

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Abstract. *Several studies investigate the influence of whole-body vibration (WBV) on human beings. Depending on the objective of the study, a specific application or group is focused. For example, whole-body vibration health effects are mainly directed to drivers, although it may also exist some other groups submitted to dangerous vibration levels as well. So, in 2002, the European Parliament drew the Directive 2002/44/EC establishing two different parameters (the EAV: Exposure Action Value and the ELV: Exposure Limit Value) for an eight-hour journey vibration exposure, assessed in accordance with the ISO Standard 2631-1 (1997). However, maybe for simplicity, neither the Directive nor the Standard mentions the influence that WBV has on different parts of the human body. Moreover, very few studies are found in the literature investigating the influence of vibration on human hearing. Generally, they are associated with some investigation about noise levels as well, since they are usually performed in loco. However, in laboratory is much easier to isolate the effects of one stimulus or the other and not many references are found in that respect. In the present study, a laboratory investigation was devised to evaluate the influence of WBV on the Temporary Threshold Shift (TTS) of healthy subjects. For that, the Distortion Product Otoacoustic Emission (DPOAE) was used. The finds of the current investigation showed that for the direction, frequency, level and duration of the vibration used, there was no influence of the whole-body vibration on the hearing of the volunteers tested. The parameters used during the tests respected the levels set by the Directive and were used conservatively, although there are some studies showing that real levels may be higher than the ones used here.*

Keywords: *Whole-body Vibration (WBV), Temporary Threshold Shift (TTS), Distortion Product Otoacoustic Emission (DPOAE)*

1. INTRODUCTION

Whole-body vibration (WBV) is present in many human daily activities such as: transport, leisure or work. They may be caused by different factors including road excitation, machine or even building motion. There are a lot of studies investigating the influence of whole-body vibration (WBV) on human beings. The majority of those studies are related with either comfort, interference with activities or health effects. So, depending on the objective of the study, besides focusing these specific applications, they may be interested in a specific group also. For example, whole-body vibration health effects are mainly directed to drivers, although it may also exist some other groups submitted to dangerous vibration levels as well. Also, such studies normally tend to check the effects of WBV on the spine of the drivers.

What make WBV a health risk are the time of exposure and the amplitude of the vibration. In working environments, for example, workers may be exposed to high levels of vibration for even 8 hours a day (Silva, 2002). So, in 2002, the European Parliament drew some guidelines on the minimum health and safety requirements regarding the exposure of workers to the risks arising from vibration by means of the Directive 2002/44/EC (2002). It established two different parameters: the Exposure Action Value (EAV) and the Exposure Limit Value (ELV) for an eight-hour journey. The assessment of the levels of exposure is made in accordance with the ISO standard 2631-1 (1997). However, maybe for simplicity, neither the directive nor the standard investigates the influence that WBV has on different parts of the human body.

Until the publication of the Directive, there were few references about the security levels for human exposure to vibration (Diaz *et. al.* 2003). For that reason there were not many studies about the health effects of WBV. Even now, when studies are found covering this topic, they are normally investigating the effects of WBV on the drivers' spine. Very few studies are found in the literature investigating the influence of vibration on human hearing. Generally, the latter are associated with some investigation about noise levels as well, as the studies are usually performed in loco. However, it is possible to isolate the effects of one stimulus or the other in laboratory, although not many references are found in that respect.

This is a laboratory study that aims to check the influence of WBV on the Temporary Threshold Shift (TTS) of healthy subjects, respecting the limits set by the European Directive (2002). The volunteers do not have any hearing problem or occupational exposure to noise or vibration. The methodology used is to compare the results of the Distortion Product Otoacoustic Emissions (DPOAE) test made before and after the exposure to WBV. Once the effects of WBV on TTS are known, it is possible to work in prevention.

2. FUNDAMENTALS

As mentioned previously, according to the European Directive (2002), there are two distinct values in order to avoid health problems related to the exposure to vibration: the Exposure Action Value (EAV) and the Exposure Limit Value (ELV). The EAV is the value for a total daily exposure when employers should take preventive measures and improvement actions to reduce vibration levels. For WBV exposures, the EAV is 0.5 m/s^2 for an 8-hour journey (what corresponds to a Vibration Dose Value – VDV of 9.1 $m/s^{1.75}$ according to ISO 2631-1 (1997)). The ELV is the value that no exposure should exceed, also for a daily exposure period of 8 hours. Its value for WBV is 1.15 m/s^2 (or a VDV of 21 $m/s^{1.75}$).

The Directive does not say much about the health effects caused by WBV, only provides guidelines for safety. So, many authors investigated these effects, since the human beings are frequently part of industrial processes involving some kind of vibration. However, since it is necessary to guarantee safety and due to the difficulty in finding volunteers, it is not easy to study and understand the health effects of vibration on humans. The use of guinea pigs is not very representative due to the differences in size and body dynamics, Harris (1998). The sensibility of the human body to vibration depends on several factors such as body posture, muscle tension and on an individual tendency for problems. The body has differences on its internal structures, tendons, connective tissues, etc. and it will respond to vibration stimuli in different ways. Each human body has its own biodynamic characteristic and its vibratory responses will be affected not only by its mechanical characteristics but also by its psychological or sensitive characteristics, Chaffin *et al.* (2001).

Griffin (1996) classifies the effects of the exposure to WBV in intense or chronical. Intense effects are those felt immediately after an exposure and chronical effects are due to more prolonged exposure situations, such as a cumulative effect of months or years. Both of them should be a matter of concern, mainly when the objective is health.

Low back pain is the most common symptom associated to the WBV exposure, Griffin (1996), Ling and Leboueuf-Yde (2000), Sorainen *et al.* (1998), Lenzuni and Pieroni (2003), Palmer *et al.* (2000), Goglia and Grbac (2005) and Mabbott *et al.* (2001), Bovenzi and Hulshof (1999). The last authors believe that long-term vibration exposure probably increases the muscle fatigue caused by the mechanical overload on the spine, causing the pain.

There are other physical problems related to occupational exposure. Mabbott *et al.* (2001) mentions that drivers suffer fatigue and make complains related to joint and muscle disorders. Some other occupational problems reported are related to blood flow, respiratory system, endocrinal and metabolic systems, digestive problems, reproductive damage on women, vision and balance disability. Santos Filho *et al.* (2003) described vision problems, irritability, lumbar disorders and digestive problems.

In order to occur changes in the worker's health, the exposure must be frequent for many years, and it is important to consider individual factors about the complains like discomfort, Fernandes and Morata (2002).

Very few studies were found about hearing effects caused by WBV in an isolated way. Most of the studies were combined situations with noise, since that is the most common occupational risks association. The combination of noise and WBV in laboratorial situations showed clearly that there is a synergic effect on hearing (Seidel *et al.* 1989, 1992, 1997; Manninen 1983 a, 1983 b, 1984 a, 1984 b, 1985, 1986). In loco, situations did not show the same results (Morata *at al.*, 1995; Silva, 2002).

In general, laboratory studies measure the hearing thresholds before and after the exposures, looking for changes between the tests. The shifts are known as the Temporary Threshold Shifts (TTS). The TTS allows verifying immediate damage on hearing. They are temporary because the hearing thresholds come back to normal after a resting period. Nudelmann *et al.* (1997) described the TTS as a hearing fatigue post-stimulus that produces a temporary hearing loss after exposure to noise. Katz (1999) says that the TTS information can be useful to foretell the damage effects of noise, since he understands that the cause of TTS are similar to the permanent hearing loss. So, the TTS measurement is used in laboratory researches as a way to detect hearing problems in an early stage, mainly related to noise, Santos *et al.* (2005), but also caused by other factors such as heat and vibration, Manninen (1983a, 1983b, 1984b, 1985), Katz (1999), Santos *et al.* (2005), Keeler (1968), Nordmann *et al.* (2000), Strasser *et al.* (2003), Quaranta *et al.* (2003), Nassar (2001). In loco researches generally use regression methods for comparison with actual situations, finding different results (Morata *et al.*, 1993; Bovenzi and Hulshof, 1999).

3. METHODOLOGY

3.1. General Information

The data collection was made at the Othorinolaringology Sector of the Felício Rocho's Hospital at the city of Belo Horizonte, Brazil. The ethics committee for human research of the Federal University of Minas Gerais (COEP/UFMG) approved the study previously, as recommended by Griffin (1996).

The population chosen as volunteers was composed by young adults, with normal hearing and with no history of occupational exposure to noise or vibration. Although the population used is not representative of the whole Brazilian population, the intention of the study was to use subjects with no prior hearing problem or hearing exposure, so to get a better influence of the effects. There were a total of 13 subjects (10 men and 3 women), with an average age of 23.9 years (standard deviation of 5.6), average weight 70.2 kg (standard deviation of 10.8) and average height of 1.75 m (standard deviation 0.07).

The volunteers were selected after answering questions about their hearing and health, habits, occupational risks and other factors that could interfere with their participation on the tests. They were then informed about how the tests would be performed and signed a term of consent after that.

A resting time of 14h was observed between general exposure to noise or vibration, since this is necessary in order to allow the hearing to recover. Another important observation to be made is about the correct moment to measure the TTS. The ideal time is 2 min. after the exposure in order to detect the TTS at the higher amplitude, Kinsler (1982). For the research carried out, several exams were used in order to evaluate the hearing loss (see the following item). As the Tonal Audiometry was performed immediately after the exposure, the DPOAE tests were measured approximately 2 min. after the exposure to WBV, as recommended.

3.2. Hearing Tests

All the selected volunteers were submitted to a battery of hearing tests that aimed to check their good auditory condition. The results were used as references for the comparison after the exposure. The hearing tests performed were: a) Othoscopy, for checking possible obstructions in the external ear; b) Timpanometry, in order to measure the function and the integrity of the internal bone system; c) Tonal Audiometry, in the frequencies band from 0.25 kHz to 8 kHz, to test the good hearing condition and d) DPOAE test, to investigate answers of the internal cells of the inner ear in the frequencies band from 0.5 to 8 kHz. Volunteers with any alteration in the auditory tests were excluded, as these could mask or even prevent the accomplishment of the DPOAE tests and the detection of a possible TTS.

The hearing test used to detect the influence of WBV on hearing and presented in this study was the DPOAE. The criterion used to consider the occurrence of the OAEs was the presence of emission intensity by distortion products 6 dBNPS above the background noise, Musiek (2001). It is important to point out that the DPOAE test can show positive answers in cases of light to moderate levels of hearing losses up to 50 dBNA. Also, the answers at low frequencies generally suffer interference from external noise, so the best performance of the test is for frequencies above 2 kHz, Figueiredo (2003). Besides the interference from that, the test can also suffer variations coming from the subject or the equipment position. So, considering these facts, two tests were performed for each volunteer at each tested situation in order to avoid systematic errors.

The equipment AUDX - Bio-logic® was used to measure and register the DPOAE. The average result of the two tests performed before any exposure to WBV, were used as reference for the comparison with the results obtained after the exposure, when the same procedure was adopted.

3.3. Vibration Tests

3.3.1. Fundamentals

The vibration tests performed tried to simulate real working conditions. Most of the studies found only measured the vibration levels according to the European Directive (2002), without any mentioning about frequencies and/or amplitudes associated. Rehn *et al.* (2005), Scarlett and Stayner (2005) and Diaz *et al.* (2003) reported that off-road vehicles and vehicles used in construction produced WBV levels above the EAV, being the levels for the great majority between the EAV and the ELV. The main direction of vibration varied according to the machine considered.

On the Internet, it is possible to find the associated Daily Exposure Levels that may end up on EAV or ELV levels, however, it is necessary to know the exposure time and amplitudes involved (Health and Safety Executive, 2006).

Balbinot (2001) reproduced a table from Wilder *et al.* (1982), showing that the maximum frequency and amplitude at that frequency for a series of different types of vehicles in different activities ranged from 3.5 to 7.5 Hz, with maximum amplitude from 0.71 to 6.64 m/s^2, but with no mentioning about the exposure times. There, he also reproduced, from the same authors, a table of resonance frequencies for a transmissibility study from bottom to head, where they shown that the first human resonance frequency is around 5 Hz (4.9 ± 0.24 Hz for men and 4.75 ± 0.24 Hz for women). Such parameters served as basis for the methodology adopted in this work.

Generally, the studies focusing the effects of vibration on hearing are performed in loco and are performed together with some noise effect studies as well, Silva (2002), Fernandes and Morata (2002). In laboratory, Seidel (1989, 1992 and 1997) and Manninen (1983a, 1985) headed the research about the subject. Manninen results arrived to similar conclusions to Seidel, that is, there is a synergic effect between noise and WBV.

The methodology used by Manninen (1983a, 1985) was similar to the one proposed in this work, since they also used the TTS to investigate the hearing loss caused by WBV and noise. These works used a Z direction excitation at 5 Hz with amplitude of 2.12 m/s^2 during 3 distinct periods of 16 min. each. They served as basis to the methodology adopted for the tests here and presented initially by Duarte *et al.* (2006). There, it was proposed the use of a 5 Hz sinusoidal excitation at the Z direction, with average amplitude of 2.45 m/s^2 rms, during 20 minutes. However, due to stabilization problems, the average amplitude used at that time was around 2.518 m/s^2. So, both methodologies, that is, Manninen and Duarte et al., resulted in a total EAV level higher than the value set by the European Directive (2002).

The EAV and ELV values are defined for a daily period of 8 hours. However, it is possible to find the WBV correspondent amplitude for a smaller period, considering that the exposure is equal through the whole period, as shown in Eq. 1. There, T_1 is the sought estimated time for a smaller journey, T_2 is the standard value of 8 hours, a_{w2} represents the EAV value of the Directive (that is, 0.5 m/s^2 for the EAV), a_{w1} is the measured value and e = 2 when using maximum amplitude r.m.s. or e = 4 when using VDV (Rehn *et al.*, 2005):

$$T_1 = \left(\frac{a_{w2}}{a_{w1}} \right)^e T_2(8\text{h}) \qquad (1)$$

So, after some problems with the shaker when using the excitation at 5 Hz for the proposed period of time of 20 minutes, the frequency used was changed to 6 Hz. Also, it was decided to use a smaller amplitude level of a_{w1} = 2.45 m/s^2 during 18 minutes which resulted in an a_{w2} = 0.47 m/s^2, therefore, smaller than the value used to reach the EAV. The results presented in this work were obtained using these parameters.

3.3.2. Experimental Setup

Siqueira (2006) proposed the experimental setup and Izumi (2006), or Izumi *et al.* (2006), the methodology used to provide the desired vibration levels presented in this work. The subjects sat in a wooden chain having metallic feet, with backrest but no cushion. It was positioned over a metallic plate (750 x 1000 x 3 mm) with reinforced edges. The position of the chair was such that the center of gravity of the setup (chair + subject) was coincident with the geometry center of the plate, in order to avoid undesirable rotational movements that could damage the shaker (see Fig 1). The plate was supported by four compression steel springs with 76 mm external diameter, 350 mm height, wire diameter of 6 mm and 9 spirals.

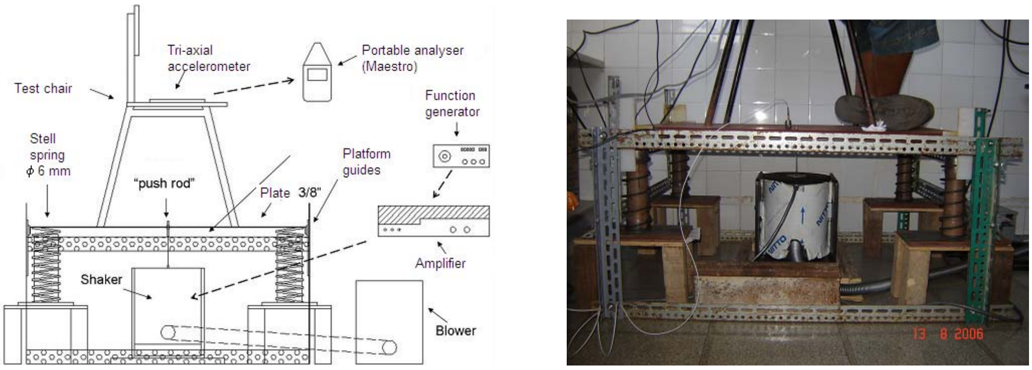

Figure 1. Test setup: schematic drawing and photo

The springs were guided by PVC tubes positioned outside a steel tube welded to a straight steel base, which guaranteed the vertical movement of the springs, therefore, of the platform (see details in Fig. 2).

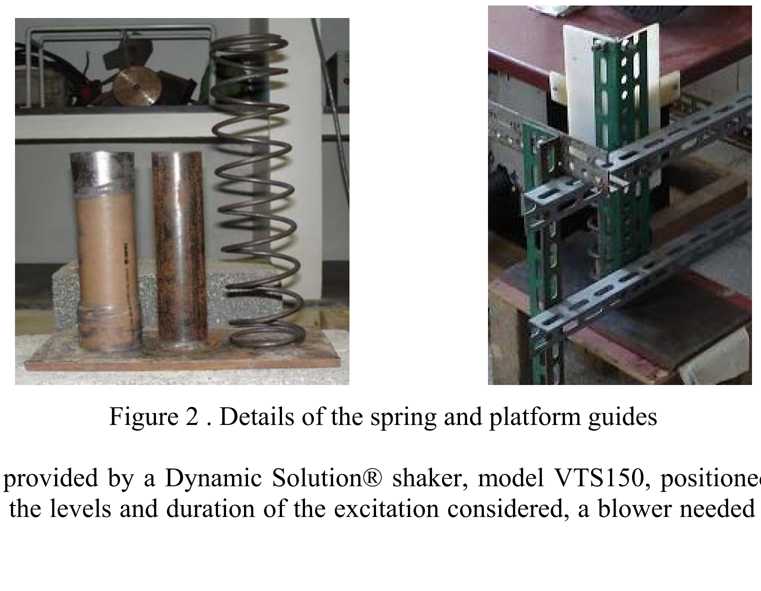

Figure 2 . Details of the spring and platform guides

The excitation was provided by a Dynamic Solution® shaker, model VTS150, positioned under the platform (as shown in Fig 1). Due to the levels and duration of the excitation considered, a blower needed to be used on the shaker for the entire length of the test. The noise produced by the blower was around 70 dBA NPS, so, for the WBV tests alone, an auricular protector model 1435 (CA7442) from 3M was used. A steel pushrod with 3.0 mm diameter and 107 mm of length with screws of 5 mm welded in each end was used to transmit the excitation to the platform. As the pushrod was screwed at both the shaker and the platform (see Fig. 3), it guaranteed a continuous path of excitation transmission to the platform.

Figure 3. Details of the pushrod used to provide the vibration levels

The 6 Hz sinusoidal frequency used was generated by a Topward Function Generator® 8102 and amplified by a Crown Amplifier® CE2000. An APTechnologies® AP5213 tri-axial accelerometer was positioned on the chair seat, using a standard seat pad, Griffin (1996). It was connected to a 4 channel portable analyzer, model Maestro from 01 dB®, which processed the responses according to the ISO 2631-1 (1997) for WBV measurements. The weighted acceleration collected by the analyzer was then used to adjust the acceleration amplitude sent by the function generator to the shaker, in order to keep the signal into the desired level of 2.45 m/s^2. After stabilizing in that level (that is, $2.45 \pm 0{,}05 m/s^2$), the excitation was maintained for 18 min, being the whole process made in a manual way by the researchers.

4. RESULTS

In order to compare the influence of the WBV on the hearing of the volunteers, a comparison of the results obtained before and after the exposure to WBV was performed. Such comparison was performed statistically using the non-parametric test of Wilcoxon (Siegel, 1975). Such test is very useful to analyze related and small samples. The null hypothesis (H_0) was considered as the absence of differences between the tests before and after the exposure to WBV, and the alternative hypothesis (H_1) as being when this difference is present and statistically significant. The confidence level (α) used was set as 5%. For the OEA exams, H_1 checked if the results after the WBV exposure presented smaller results than the reference results (obtained before the WBV exposure), since it is aimed a decrease on the response amplitude after exposure (that is, post-WBV < reference).

As the hearing results obtained are of interest for medical doctors and audiologists, a question was posed. They normally analyze such results without considering that they are measured in decibel scale, which is logarithmic, and needs to be converted to linear scale prior to any operation. So, in order to compare that influence also, both analyses were performed, that is, for the results in decibel and linear scales.

Table 1 presents the OEA analysis for the dB results. For the confidence level used, it is possible to see that for the WBV exposure alone, there was no significant difference between the results obtained before and after the exposure. As for the OEA tests, two measurements were performed and the average results used, using that in dB or linear scale should cause some differences. However, for the WBV exposure alone, the differences were not sufficient to cause statistically any change in results. That is the reason why they are not presented here. Only for the situation where the volunteers were exposed to high SPL (Sound Pressure Levels), the Wilcoxon results showed differences when considering the values in dB or linear (Izumi, 2006).

Table 1 – Wilcoxon Test results for the OEA exam (WBV alone) – dB scale

α =0,05	**676 Hz**	**932 Hz**	**1283 Hz**	**1797 Hz**	**2566 Hz**	**3640 Hz**	**5133 Hz**	**7288 Hz**
Reject H_0? H_1: WBV < reference	No	No	No	No	No	No	No	No

Figure 4 shows the boxplot representation of the results obtained for the OEA tests considering the dB scale. There, the top vertical line represents the maximum value; the top box, the 75% quartile; the thick horizontal line, the mean value (or 50% quartile); the bottom box, the 25% quartile and the bottom vertical line, the minimum value. It can be seen that the mean values oscillate around the 0 dB difference, confirming therefore, no significant differences also.

Figure 5 shows the boxplot considering linear scale. The boxplot uses the same scale from the previous figure in order to easy the comparison of results. Some differences are found when comparing both figures, being more significant at 676 and 1797 Hz. However, even there, statistically speaking, no influence was found.

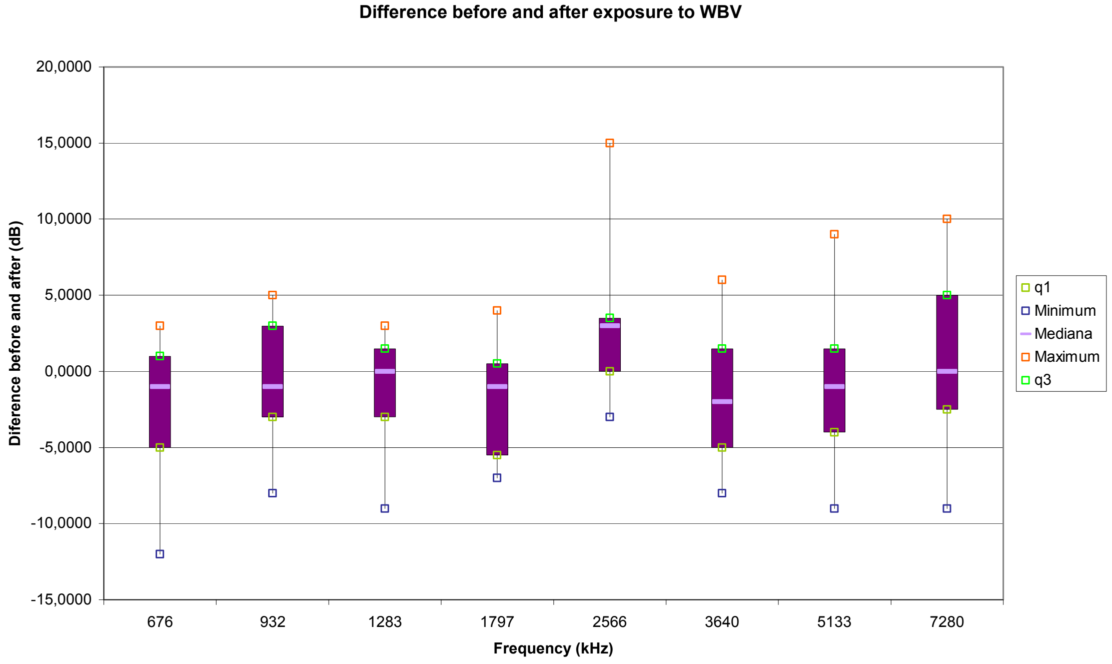

Figure 4. Boxplots for the OEA results considering only WBV exposure – dB scale

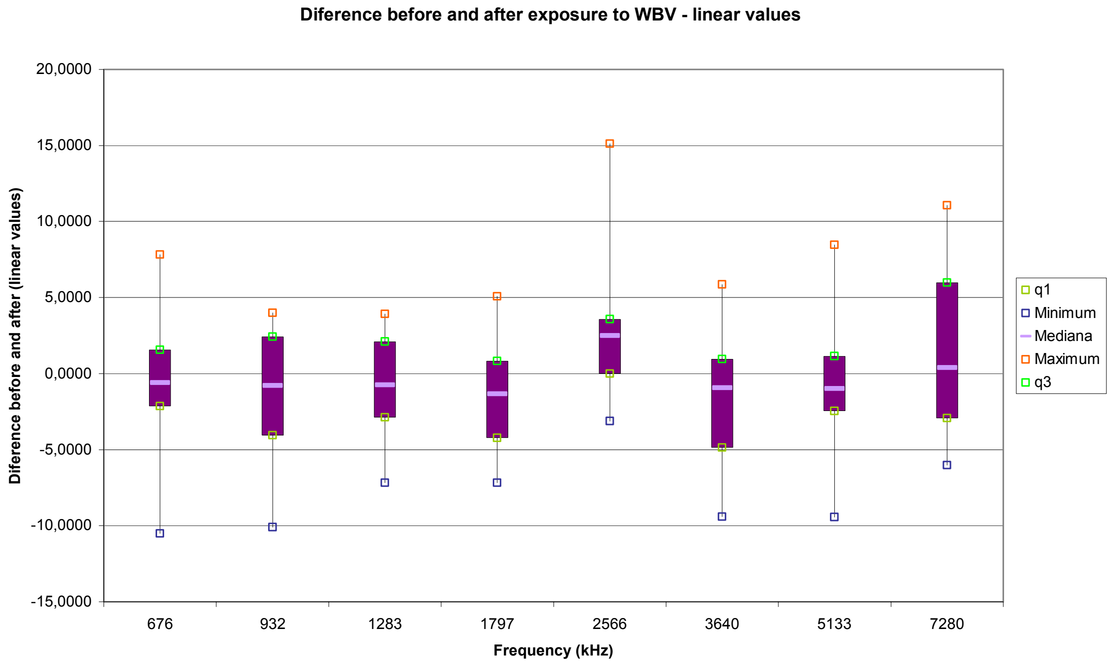

Figure 5. Boxplots for the OEA results considering only WBV exposure – linear scale

When comparing the results obtained in this work with the ones found in the literature, a completely different conclusion was obtained. Seidel *et al.* (1989, 1997) and Manninen (1983a, 1983b, 1984a, 1984b) found significant effects of WBV exposure alone on the TTS of healthy humans. This divergence may be explained by the levels used in this work, which were different from the ones used in the mentioned references. Also, some of the these studies have used different hearing tests to detect the influence of the WBV on hearing. Only the study presented by Silva (2002) arrived to similar results than the one found here. He investigated the effects of WBV and noise on bus drivers of different models and found no interaction between the exposure to WBV and occupational hearing loss, even when analysing the combined associaiton with noise. However, he also points out that his results were different from the literature and recomends further work. Although his methodology was different from the one used in this work, his conclusions are similar to the ones found here.

5. CONCLUSIONS

The objective of this study was to check the influence of WBV (Whole Body Vibration) on the hearing of healthy subjects, aiming to understand this very common occupational risk problem in the health of workers. Not many references are found in that respect and, generally, the studies are performed in loco, including both WBV and noise effects on hearing. Even laboratory studies normally include both risks. Although the reference studies differ a lot in methodology and the way hearing loss is evaluated from the study presented here (what makes the comparison of results a bit difficult), their results generally arrived to a consensus that WBV has an effect on hearing. That was not the conclusion found in the present study.

The study reported here used the DPOEA (Distortion Product Otoacoustic Emission) test for the evaluation of hearing loss of healthy volunteers. They were submitted to a sinusoidal WBV exposure at 6 Hz, 2.45 m/s^2 average rms amplitude, at the Z direction, during 18 minutes. Such parameters provided a vibration level slightly below the EAV (Exposure Action Value) set by the European Directive (2002) as being the level above which the employers should take preventive measures. So, the tests reported here were conservative. The sample size used was small, composed by 13 subjects (10 males and 3 females, although gender showed having no influence). Further studies are necessary in order to verify if this sample size was enough and to check if for other levels of WBV the same results are obtained. The sample used was not representative of the Brazilian population but the intention was to use volunteers with no prior hearing problem or hearing exposure, so to get a better influence of the effects.

Also, it may be better to use random excitation, instead of sinusoidal one, as they are more representative of real situations. However, for the level and frequency used here, it was concluded that there was no significant interaction between the WBV exposure and hearing, evaluated using the TTS (Temporary Threshold Shift). Although it is presumed that in a noise environment the WBV could provoke increased hearing loss, from the tests performed here, nothing can be said in that respect.

6. ACKNOWLEDGMENTS

This work was supported by FAPEMIG under grant TEC932_05.

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