Effects of the Combined Whole-Body Vibration (WBV) and Noise Exposure on the Hearing Temporary Threshold Shift (TTS) of Seated Subjects


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Abstract: It is very common to have in the workplace, or even in leisure activities, the simultaneous exposure to noise and whole-body vibration (WBV). Such association may have significant effects on hearing, although that is very little studied. Therefore, the understanding of such phenomena may be very important as a public health measure. So, the present study aims to investigate the combined effects of noise and WBV on hearing. For that, two simultaneous exposures to noise and WBV during 18 minutes each, with a 10-12 minutes average interval between exposures, were used. The WBV exposure was applied in the vertical axis (z-axis) at 5Hz, 2.12 m/s² amplitude and it was combined with the high Sound Pressure Levels (SPL) white noise at 96 dB(A). These parameters were chosen to be within the health safety levels, although the latter was expected to cause TTS. The influence of the combined exposure on hearing was evaluated statistically by analyzing the results of the Distortion Product Otoacoustic Emission (DPOAE) exam using the parametric Student t test. The evaluation was performed after each individual exposure so to investigate the cumulative influence. A total of 19 volunteers took part in the study although due to the absence of response at some frequencies, fewer volunteers were used in the statistical test at some frequencies. The statistical analysis was performed considering the right ear, as there were no major differences between ears and that was the one with the greatest number of responses. Only for the 6000Hz the left ear was used for the same reasons. The results indicated that the combination (WBV+SPL) caused significant temporary hearing shift, particularly at high frequencies. However, although it will not be shown in this study, the combination was not significantly worse than the noise exposure alone, in other words, there was no synergic effect of the combination (WBV+SPL).

Keywords: Whole-Body Vibration (WBV), Sound Pressure Level (SPL), Temporary Threshold Shift (TTS), Distortion Product Otoacoustic Emission (DPOEA)

INTRODUCTION

Whole-body vibration (WBV) and noise are physical stimuli that, besides being frequently present in many workplaces, are also found in the daily lives of people. As mentioned by Griffin (1996), the increase of hearing loss among subjects exposed to vibration might be attributed to the transmission of vibration to the inner ear. That might either directly affect hearing or increase the susceptibility of the subject to NIHL (Noise Induced Hearing Loss).

Such combined exposure (WBV + Noise) is the most common real exposure. Therefore, that is the one considered in the present study. Some other authors have also investigated that combination, however, considering different exposure levels (Manninen 1986, 1985, 1984, 1983a e 1983b; Seidel et al. 1992; Izumi, 2006). Faced with this fact this study sought to investigate what are the effects of the combined WBV and noise exposure on human hearing. A higher level of WBV exposure than the one used at Izumi’s study (2006) was used, in order to understand if the negative effect at the latter was due to the level used, since some of the other mentioned studies found a positive correlation between this physical stimulus and the hearing loss.

None of the found studies have monitored the quantity of the whole-body vibration that really reaches the inner ear. Therefore, this was not the case in the present study either, since such monitoring is quite difficult in real time.
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**METHODS**

**Volunteers Selection**

The data collection was made at the Audiology Sector of the Clinics’ Hospital of the Universidade Federal de Minas Gerais at the city of Belo Horizonte, Brazil. The ethics committee for human research of such university (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. There were a total of 19 subjects (10 men and 9 women).

All the selected volunteers were submitted to a battery of hearing tests that aimed to check their good auditory condition. The hearing tests performed were: a) Otoscopy, for checking possible obstructions in the external ear and b) Distortion Product Otoacoustic Emission (DPOAE) test, to investigate answers of the cells of the inner ear in the frequency band from 750 Hz to 8 kHz. Volunteers with any alteration in the auditory tests should be excluded, as this could mask or even prevent the accomplishment of the DPOAE tests and the detection of a possible TTS. Nevertheless, for the present sample, that was not the case. The examinations were performed in a soundproof booth properly calibrated and a suitably calibrated equipment AUDX - Bio-logic® was used to measure and register the DPOAE of the inner ear. Before any exposure to either WBV alone, noise alone or combined WBV+noise two values were obtained for the DPOAE tests. So, the average value was used as reference for the comparison with the results obtained after each mentioned exposure, so to verify its influence.

**Experimental Setup**

Figure 1 shows the vibratory system used during the tests. A detail of the vibration platform can be seen in the photograph presented at Figure 2.

![Figure 1 – Schematic view of the vibrating system used in tests](image1)

![Figure 2 - Photo of the vibrating platform](image2)

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. 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. The excitation was provided by a Dynamic Solution® shaker model VTS150, positioned under the platform. A steel pushrod with 3.0 mm diameter and approximately 107 mm variable length with screws of 5 mm welded in each end was used to transmit the excitation to the platform. The 5 Hz sinusoidal frequency used was generated by a Photon II acquisition board from LDS and amplified by two amplifiers (a Crown Amplifier® CE2000 and a B&K 4810 amplifier). An AP Technologies® AP5213 tri-axial accelerometer was positioned on the chair seat, using a standard seat pad, Griffin (1996). That signal was sent to a portable analyzer model Maestro from 01dB. A control system was developed using a National Instrument acquisition board model NI Speed 33 to maintain the excitation at the desirable level (Batista Filho et al, 2010). For that, a standard ICP control accelerometer model 352A from PCB Piezotronics was used.
Testing Parameters

The vibration tests performed tried to simulate real working conditions, although respecting the safety levels set by the European Directive (Directive 2002/44/EC, 2002). It was proposed two z-direction (ISO2631-1, 1997) sinusoidal excitation exposures at 5 Hz, with average amplitude of 2.12 m/s\(^2\) rms during 18 minutes each exposure. Between the first and second exposure there was an interval of 10-12 minutes, which was the necessary time to perform all the necessary hearing evaluations. The WBV was applied simultaneously with a 96 dB(A) white noise.

The noise level used in the present study was based on the Fundacento (2001) occupational standard that set the limit values as a function of the exposure time so to preserve the hearing health. Moreover, it was similar to the level used on similar studies so to allow a comparison between the findings (Manninen 1986, 1985, 1984, 1983a e 1983b; Seidel et al. 1992; Izumi, 2006). However, as the objective of the study was to verify the occurrence of TTS due to the noise exposure, the level used was chosen so that the phenomena would be present. The white noise applied was recorded through a computer to a MP3 player and transmitted to the same audiometer used on the tonal audimetric exams (AC33 – Interacoustics). The audiometer received the noise, adjusted its intensity and transmitted such signal to the TDH-39 phones, properly calibrated and adjusted.

RESULTS

Only the tests using WBV+noise exposure are going to be analyzed in the present work. In order to compare the influence of such combined exposure on the hearing of the volunteers, a comparison of the OEA results obtained before and after the exposures was performed. Such comparison was performed statistically using the parametric Student t-test. The null hypothesis \((H_0)\) was considered as the absence of differences between the tests before and after the combined exposure, and the alternative hypothesis \((H_1)\) as being when this difference is present and statistically significant. The confidence level \((\alpha)\) used was set as 5%. For the OEA exams, \(H_1\) checked if the results after the combined exposure presented smaller results than the reference results (obtained before any exposure), since it is aimed a decrease on the response amplitude after exposure (that is, post-exposure < reference).

In the case of DPOAE exam, the goal is to check whether there was significant decrease of OEA amplitudes, specifically at the outer hair cells (OHC’s), found in the inner ear and responsible for the otoacoustic emission.

Table 1 presents the OEA analysis results on dB scale for the right ear (except for the 6000 Hz, where the left ear was used) for the first and the second combined exposure in that order. For the confidence level used, and the OEA exam, after the 1\(^{st}\) exposure hearing shift was verified at 2016Hz and 3984Hz and after the 2\(^{nd}\) exposure only at 3984Hz. The greatest shift was observed at 3984Hz.

Table 1 –Student T-Test results for the OEA exams – dB scale

<table>
<thead>
<tr>
<th>Exposure</th>
<th>750 Hz</th>
<th>984 Hz</th>
<th>1500 Hz</th>
<th>2016 Hz</th>
<th>3000 Hz</th>
<th>3984 Hz</th>
<th>6000 Hz</th>
<th>7969 Hz</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st (WBV + Noise)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(right ear)</td>
<td>H_1: (WBV + Noise) &lt; Ref.</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>2nd (WBV+ Noise)</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>(right ear)</td>
<td>H_1: (WBV + Noise) &lt; Ref.</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
</tbody>
</table>

For this frequency, the results of the left ear were considered.

Figure 3 shows a boxplot representation of the obtained results at some of the DPOEA exam. Emphasis has to be given for the results at 2016 Hz and 3984 Hz, where, at Table 1 was show the influence of the combined exposure on the results.

Figure 3 – BoxPlot of OEA exams compared with the reference values at some frequencies
The greatest change of hearing amplitude, that is, decrease of amplitude, was observed at 3984 Hz. At that frequency, the average registered amplitude after the 1st exposure was 7.33 dB(NPS) and after the 2nd exposure was 6.21 dB(NPS). The greatest difference between the values pre-exposure and the reference one occurred at this frequency of 3984 Hz, between -1.5 dB(NPS) after the 1st exposure and -2.62 dB(NPS) after the 2nd exposure to the combination of WBV + Noise. Since the WBV isolated did not cause hearing shift (Dornella et al, 2011), it was concluded that the hearing shifts detected after the combined exposure were caused by the noise occupational agent.

Such findings are in accordance with the studies of Yokoyama, Osako e Yamamoto (1974); Manninen (1983a); Manninen (1983b); Manninen e Ekblom (1984); Manninen (1984); Manninen (1985); Manninen (1986); Hamernik et al. (1989); Scidel et al. (1992); Pekkarinen (1995); Fernandes e Morata (2002); Soliman et al. (2003); Freitas e Nakamura (2003); Silva e Mendes (2005); Izumi, Mitre e Duarte (2006) e Izumi (2006). Such studies also verified hearing shifts in humans and animals exposed to the combined noise and WBV levels. Therefore, it is possible to see that the combined effect is much worse than the WBV exposure alone (Dornellas et al, 2011), where no influence on hearing was detected.

Although it is not shown here, the audiometric results showed much more influence (at all frequencies). It is supposed that the difference in results is due to the fact that the EAO results were obtained after the audiometric exams, what was collected approximately 4 minutes after each exposure. So, it is believed that the TTS was not registered at the highest peak amplitude that the literature (Kinsler, 1982) considers to be 2 minutes after the exposure (TTS$_2$).

**CONCLUSION**

The objective of this study was to check the combined influence of WBV+noise on the hearing of healthy subjects, aiming to understand this very common occupational risk problem in the health of workers.

It is possible to see that the combined exposure does have an influence on hearing, result that deserves careful examination. The fact that at some frequencies the effect was not present after the cumulative exposure may be attributed to the moment the EOA results were collected. It should have been measured 2 minutes after the exposure; however, as the audiometric results were collected first, that time was increased to 4 minutes. Nevertheless, the influence of the combined exposure on hearing is in accordance with the literature.

Further studies are necessary in order to verify if the sample size used was enough, although to get more volunteers is always a very difficult task. Also, it is important to check if for other levels of WBV the same results are obtained. Moreover, 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 of WBV used here, that is, 2.12 m/s$^2$ at 5 Hz + noise levels of 96dB(A), even for two simultaneous exposures, it was concluded that there was interaction between the combined exposure and hearing, evaluated using the TTS (Temporary Threshold Shift). However, the fact that the cumulative effect was better at some frequencies have to be investigated further.

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