COMBINED EFFECTS OF NOISE AND WHOLE-BODY VIBRATION (WBV) ON HUMAN HEARING: BIBLIOGRAPHIC REVIEW AND PROPOSED STUDY METHODOLOGY

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Abstract: *Through a bibliographic review in libraries and databases such as Medline, Lilacs, Bireme and periodicals' Capes, several studies on the combined effects of whole body vibration (WBV) and noise on hearing were reviewed. They cover until 2009 without initial period limitation. The majority of the studies found a synergic effect of both agents, in other words, the noise when associated with WBV enhances the hearing damage. However, in a recent study by the Group of Acoustics and Vibration in Humans Beings ($GRAVI_{HB}$) of UFMG about this combined effect exposure on hearing, an antagonistic effect at the 4kHz frequency was found, that is, the combination of noise and WBV led to lower results than the exposure to noise alone. This paper aims at presenting a more updated review about the subject, in order to try to justify why such a difference was found. Thus, a new methodology of testing this combined effect is proposed here. Initially, an increase on the sample used is planned. Later on, the combined effects at other frequencies of excitation should be studied, which may represent more real world environments and it will allow a better comparison with the bibliography. An investigation about the cumulative influence of the combined exposure should also be considered, as that may be the explanation for the above discrepancy. The use of other objective methods for hearing assessment must also be researched and proposed. It is believed that with the improvement and greater control of such factors a better comparison between studies is possible and will lead to more reliable results.*

Keywords: *whole-body vibration (WBV), hearing, noise, and temporary threshold shifts (TTS2)*

LIST OF ABREVIATIONS

WBV = Whole-body vibration
SPL = Sound Pressure Level
VDV = Vibration Dose Value
HAV = Hand Arm Vibration
NIHL = Noise Induced Hearing Loss
TTS2 = Temporary Threshold Shift (after 2 min.)
DPOAE = Distortion Product Otoacoustic Emission

1. INTRODUCTION

It is known that whole-body vibration (WBV), as well as high sound pressure levels (SPL), are physical stimuli that, besides being frequently present in many workplaces, such as industries, transport, construction, railway, mining, agricultural machinery, are also found in the daily lives of people. It is known that such agents have an effect on hearing (VINET Report, 2001). However, such combination is not very much researched. It is possible to find studies where the combined effect of WBV and noise is associated with others impairments that not on hearing, like changes on cognitive performance (Ljungberg *et al.* 2004).

It is more common to find studies investigating the influence of one agent or the other separately. For instance, the majority of the studies investigation the influence of WBV in humans does so evaluating their effects on the human spine. It is possible to find a lot studies about the influence of WBV on that as presented in the reviews made by (Bovenzi and Hulshof, 1999) and (Lings and Lebouef-Yde, 2000). It is clear that an association exists between WBV and spinal system disorders (Wider, 2007). (Vinet Report, 2001) and (ISO2631-1, 1997) mentions that WBV may cause apart from spine problems, other associated disorders such as neck-shoulder problems, circulatory, reproductive, digestive, genital/urinary and auditory effects. However, such problems are less clear than the association between WBV and low back pain (LBP). Therefore, more studies on that are necessary, mainly their influence on the auditory system. It is important to mention that the health effects of WBV occur only after several years (ISO2631-1, 1997), (Griffin, 1996).

There are very few articles about the effects of noise and vibration isolated and/or combined on human hearing and these studies are normally quite old. It is possible to find studies investigating such influence, however, considering hand-arm vibration (HAV), instead of WBV (Zhu *et al.* 1997), as it is the objective of this work. There is a lot of studies performed long ago correlating hand-arm exposure to vibration with hearing impairment (Griffin, 1996). There are some other articles that only investigate the levels and the effects of noise alone (Araújo, 2002), (Zannin, 2006) and none was found about the levels of WBV alone on human hearing.

As mentioned by Griffin (1996), the increase of hearing loss among subjects exposed to vibration might be attributed to the transmission of the vibration to the inner ear. That might either directly affect hearing or increase the susceptibility of the subject to NIHL (Noise Induced Hearing Loss). There is a suggestion there as well that, due to the occupational exposure to combined noise and vibration, multiple correlation techniques should be used to determine how hearing loss relates to both parameters.

Whole-body vibration evaluations are generally performed using either the weighted RMS acceleration (m/s^2) or the Vibration Dose Value (VDV) ($m/s^{1.75}$) (Griffin, 1996), (ISO2631-1, 1997). The accelerometer has to be placed as close as possible to the first contact point between the vibration source and the subject. The energy transmitted to the subject is linked to both the exposure time and amplitude (ISO2631-1, 1997), (Duarte, et al., 2008). All vibration measurements should be made in reference to a daily exposure of 8h a day, as that is the normal working hours, and the values set by the European Parliament (Directive 2002/44/EC, 2002) should be used for that. On the Internet is possible to find calculators (HSE, 2006) to perform such calculation according to the (ISO2631-1, 1997) standard, following the values set by the (Directive 2002/44/EC, 2002). When considering laboratory studies, the recommendations of the (ISO13090-1, 1998) should also be observed in order to guarantee the safety of the volunteers during the tests performed. The ISPESL (Istituto Superiore per la Prevenzione e la Sicurezza del Lavoro) in Italy has on the internet a database containing a list of different types of vehicles where it is possible to find the levels of WBV of each vehicle. There, it is possible to see that the maximum amplitude values vary a lot, depending on the type of vehicle, manufacturer, etc. Some values range from below the EAV (Exposure Action Value) of 0.5 m/s^2, others to above the ELV (Exposure Limit Value) of 1.15 m/s^2 set by the European Directive (Directive 2002/44/EC, 2002). As the drivers of most of the vehicles listed there are exposed to the combined effect of noise and WBV, such database has its importance on laboratory studies to set more realistic amplitudes values for the experiments. There is no clear limit established on the literature correlating WBV levels with hearing problems.

The influence of noise on hearing is very well established, being included in many standards around the world (Fundacentro, 1999; NIOSH, 1998; NR-15 Brasil,1978). One the other hand, the influence of WBV on hearing is not. Moreover, the combined effects on hearing are even less clear. In order to isolate the influence of WBV from other physical agents on hearing, it is generally necessary to have laboratory studies. There, it is possible to have a better control of the parameters under study. Most researches investigating the effects of WBV and noise on hearing, alone and combined, found that such combination causes a synergic effect, in other words, together, they potentiates the hearing damage. However, in a study by the $GRAVI_{HB}$ (Group of Acoustics and Vibration on Human Beings) researchers of UFMG (Izumi, 2006), it was found that the combination of these agents in a particular frequency had antagonistic effect.

Due to this fact, this paper aims to present an updated review about the subject, in order to try to justify why such difference was found, and propose a new methodology of testing for verification of the combined effects.

2. WBV AND NOISE EFFECTS ON HEARING: A BIBLIOGRAPHIC REVIEW

In order to understand if the combined effects of WBV and noise on hearing are synergic or not, it is necessary to understand the isolated effect of each agent in separate. For that, it is necessary laboratory studies to isolate only one effect or the other. Two major researchers investigated the combined and/or isolated effects of noise and vibration on hearing: Manninen and Seidel. Some other studies were performed investigating such influence *in-loco*, however, there it is possible to understand only the combined exposure effects.

In this section, articles, dissertations and theses, about the effects of sound pressure levels (SPL) and whole-body vibration (WBV) on hearing are presented without limitation of initial period until 2009. The search was conducted in libraries and databases such as Medline, Lilacs, Bireme and periodicals' Capes. The studies are presented in chronological order and on a table to easy the comparison between them. Table 1 presents the references mentioned with information about the sample used, the WBV and SPL test conditions as well as the hearing assessment method, the conclusions drawn and information about some other parameters evaluated during the study that not hearing.

Apart from the studies presented in Table 1, Griffin (1996) showed in Section 5.2.5, other very old studies investigating the influence of WBV on hearing. They are not going to be included in the table, since some of the features of the tests or conclusions are not clear. For instance, Griffin (1996) mentions that after exposing the subjects to 30 min WBV at 17 Hz and white noise (no level mentioned), Morita (1958) found that while WBV appeared to have improved hearing, the combined exposure was synergic, that is, the TTS (Temporary Threshold Shift) was greater than produced by noise alone. Griffin also presents the work by Coles *et al.* (1965) where it was found a small hearing shift due to a high magnitude of whole-body vibration at 15 Hz and some evidence that vibration may lessen the temporary threshold shift produced by noise. Coles *et al.* explain that as a possibility of an acoustic reflex facilitation. Their finds could be considered close to the results obtained by $GRAVI_{HB}$ researchers (Izumi, 2006) in a sense that the combined exposure was suggested to be benefic; however, they have used a different frequency, as it will be presented in section 3. There are some others studies mentioned in Griffin (1996) where it was reported an effect of 5 Hz whole-body vibration on hearing (Yamamura *et al.*, 1970; Okada et *al.*, 1972; Yokoyama *et al.*, 1974; Manninen, 1981), however, with no details about which effect was found or the characteristics of the experiments. The same happened for the work of Teare (1963) which reported variable effects of vibration in the range of 1-27 Hz on hearing threshold.

Table 1 - Bibliographic review on the effects of noise and vibration on Human Hearing

Study Number	Reference	Sample	WBV and SPL Test Conditions; Hearing Assessment Test	Conclusions	Other parameters evaluated and comments
1	Manninen (1983a)	• 370 male volunteers (divided in three independent groups);	• 5 Hz WBV at 2.12 m/s^2 ; • 10 Hz WBV at 2.65 m/s^2 ; • 85 dB(A) ; • 90 dB(A) ; • 98 dB(A) ; • three 16 min exposure period (noise and/or WBV with the above characteristics); • TTS2 was evaluated using audiometry.	• TTS2 induced by noise was increased by vibration; • Vibration at 5 Hz and noise with bandwidth of 1-4 kHz, 1-8 kHz and 0.2-16 kHz: most significant combination; • Vibration and noise increased the TTS2 more than noise alone; • WBV alone did not induce the same amount of TTS2.	
2	Manninen (1983b)	• 11 male volunteers	• 5 Hz WBV at 2.12 m/s^2 ; • 75 dB(A) ; • 85 dB(A) ; • 95 dB(A) ; • TTS2 was evaluated using audiometry.	• TTS2 greatest at 4 and 6 kHz and smallest at 8 kHz.	• R Wave: Dry bulb temperatures of 20^0C and 30^0C.
3	Manninen and Ekblom (1984)	• 10 male volunteers • mean age: 22.7 years; • mean weight: 73.2 kg ; • average height: 179 cm;	• 5 Hz WBV at 2.12 m/s^2; • 5 Hz WBV at 2.44 m/s^2; • 90 dB(A) White Noise; • Control period of 30 minutes; • 3 consecutive exposure of 16 min. (noise and/or WBV with the above characteristics); • TTS2 was evaluated using audiometry.	• Higher TTS2 changes for the combined exposure at 2.44 m/s^2 and lower TTS2 changes for the 2.12 m/s^2 WBV exposure; • Major changes due to the combined exposure at 4 and 6 kHz when compared to noise or WBV alone; • Increase in the TTS2 values at 2.44 m/s^2 WBV alone, and decrease at 2.12 m/s^2 .	• Body upright posture.
4	Manninen (1984)	• 90 male volunteers • mean age: 22.5 years; • mean weight: 73.6 kg; • average height: 180.0 cm.	• 90 dB(A) white noise; • 5 Hz sinusoidal WBV at 2.12 m/s^2; • 2.8-11.2 Hz stochastic WBV at 2.12 m/s^2 ; • 3 consecutive exposure of 16 min. (noise and/or WBV with the above characteristics); • TTS2 was evaluated using audiometry.	• Noise alone or the combined noise and WBV exposure caused major changes in TTS2 values at 4 and 6 Hz.	• Heart rate.
5	Manninen (1985)	• 108 male volunteers • mean age: 22.5 years; • mean weight: 73.5 kg; • average height: 180.1 cm.	• 5 Hz sinusoidal WBV at 2.12 m/s^2; • 2.8-11.2 Hz stochastic WBV at 2.12 m/s^2 ; • 90 dB(A) white noise; • 3 consecutive exposure of 16 min. (noise and/or WBV with the above characteristics); • Temperature of 20^0C and 30^0C; • TTS2 was evaluated using audiometry.	• Higher values of TTS2 at 4 and 6 kHz for the combined exposure at 30^0C; • At 4 kHz the stochastic vibration caused higher TTS2 when combined with noise and temperature of 20^0C, while the sinusoidal vibration caused higher TTS 2 at the temperature of 30^0C.	• Heart rate and blood pressure.

6	Manninen (1986)	• 7 male volunteers	• 90 dB(A) white noise; • 1.4–11.2 Hz stochastic WBV at 2.12 m/s^2; • 5 Hz sinusoidal WBV at 2.12 m/s^2. • 5 consecutive exposure of 16 minutes (noise and/or WBV with the above characteristics); • TTS2 was evaluated using audiometry.	• TTS2 values at 4 and 6 kHz increased in the simultaneous exposure significantly more than due to the exposure to noise alone.	• Body posture sway amplitudes in the X and Y direction, • heart rate, • R wave amplitude, • systolic and diastolic blood pressure, • pulse pressure and • the index characterizing haemodynamic activity (HDI)
7	Hamernik et al. (1989)	• 82 chinchilas;	• All animals were exposed for 5 day; • 30 Hz WBV at 3 g RMS; • 20 Hz WBV at 1.3 g RMS; • 95 dB SPL; • 113dB SPL at a rate of one impact every second; • 119 dB SPL impact once every 4 s; • 125 dB SPL impact once ever 16s. • Hearing was evaluated using Auditory Evoked Potential.	• The addition of vibration to either the continuous noise or the three different impact noises did alter some of the dependent measures of hearing; • The two vibration alone exposures resulted in no significant audiometric changes.	
8	Seidel et al. (1992)	• 12 male volunteers • mean age:23.8 years; • mean height: 180.7 cm; • average weight:73.8 kg.	• 60 dB(A) white noise; • 80 dB(A) white noise; • 2.01 Hz sinusoidal WBV at 2 m/s^2 ; • 2 exposures of 11 minutes (noise and/or WBV with the above characteristics) interrupted by a 4 minutes break; • TTS2 was evaluated using Auditory Event Related Brain Potentials.	• Noise has a strong effect on the auditory responses that can be exacerbated when combined with WBV; • Difficulty of discrimination of the acoustic signal due to the combined effects • There is a synergic effect of the combination of noise and WBV.	
9	Fernandes and Morata (2002)	• 73 workers of a storage and cleaning of public roads company • Group I (N = 38): operators of power brush cutter/string trimmers; • Group II (N = 35): operators of grader, shovel loader, roller and backhoe; • similar mean age; • similar occupational exposure;	• Group I :exposed to HAV and SPL (6 hours/day); • Group II: exposed at WBV and SPL (7 hours/day); • SPL: 92 dB(A). • Levels of WBV and HAV: not measured. • Homogeneous time of previous, current and total exposure.	• group II: largest number of workers with complain of tinnitus, twice higher than in group I; • number of changed audiograms greater in group I; • Suggestion for other studies to assess the adequacy of the current limits of exposure when there is continuous exposure to noise and vibration.	• Health complaints.

10	Soliman et al. (2003)	• 40 healthy guinea pig • same age; • same sex; • same average weight.	• 100dB SPL white noise; • 6-8Hz WBV; • 6 hours/day for 4 consecutive weeks; • TTS2 was evaluated using DPOAE.	• The sample exposed only to noise: - DPOAE amplitude reduced in almost all frequencies, except at 1.006 Hz - In the electron microscopy: the outer hair cells were swollen; • The sample exposed only to WBV: - low DPOAE amplitude only at the 4036 and 6060 Hz frequencies - microscopy showed normal outer hair cells and inner hair cells with dark mitochondria, appearance of necrosis; • The group submitted to the combination exposure: - reduced amplitudes in all frequencies in the otoacoustic emissions - In the microscope: outer hair cells wrecked and darkened inner hair cells with appearance of necrosis; • The combined exposure caused synergic effect, led to destruction of the stria vascularis, metabolic exhaustion and ionic circulatory changes between perilymph and endolymph in the cochlea.	
11	Bochnia et al. (2005)	• 40 guinea pigs; • male and female • Average weight: 270g.	• 10 Hz sinusoidal WBV at 1.4 g RMS; • 30 days: 3 hours/day; • 90 days: 3 hours/day; • 180 days: 3 hours/day; • TTS2 was evaluated using Cochlear Microphone.	• reduction of threshold hearing at 4 kHz in all groups exposed; • the microscopy indicate damage in the upper portion of the cochlea (inner hair cells and external), spreading gradually to base, affecting mainly the hearing in low and average frequencies; • It was also observed damage to the auditory nerve fibers in accordance with increasing exposure to WBV.	
12	Silva and Mendes (2005)	• 190 bus drivers in São Paulo; • Group I: 105 drivers with 3 years or less of cumulative exposure time within the company; • Group II: 85 drivers with cumulative exposure time over 5 years;	• Study performed *in-loco* where the levels of noise and WBV where measured.	• Weekly exposure of 83.6 dB (A) for bus drivers with front engine and 77 dB (A) for drivers operating vehicles with rear engine; • Average vibration acceleration of 0.85 m/s^2: well above the 0.63 m/s^2 tolerance limit for eight hours exposure established by the ISO 2631 (1985), indicating a significant risk situation; • Model of logistic regression, multivariable analysis: no association was found between WBV and noise exposure; • In another model, single variable analysis: it was suggested that the association between WBV and noise induced hearing loss NIHL.	

13	Izumi et al. (2006)		• Bibliographic search about the effects of WBV on hearing • Search covering from December 2004 to December 2005; • Studies published could be older;	• WBV affect hearing and the combination of noise with WBV produces a synergic effect increasing the hearing damage; • The association between these physical factors is potential sources of problems on hearing of exposed workers.	
14	Izumi (2006)	• 10 males and 3 females volunteers; • average age :23.9 years; • mean weight: 70.2 kg; • average height: 175 cm.	• 100 dB (A) white noise for 15 minutes; • 6 Hz WBV at 2.45 m/s^2 for 18 minutes; • Combined exposure to noise and WBV with the above characteristics, with noise starting 3 minutes after the WBV exposure. • TTS was evaluated using audiometry and DPOAE.	• WBV alone did not cause significant temporary hearing threshold shift; • Noise alone affected the threshold hearing at the frequencies from 0.5 to 8 kHz; • For the combined exposure: - There was a change on the hearing thresholds, but these changes were not greater than due to the exposure to noise alone; - At 4 kHz, it was observed a smaller hearing threshold when compared to exposure to noise alone; - For the levels used, the combination of noise and WBV had no synergic effect in the TTS2, but antagonistic at the above frequency.	
15	Sorainen et al. (2007)	• 16 timber trucks and timber cranes of different ages and manufactures.	• Vibration recorded in the 3 axis (x, y and z); • Noise recorded inside the cabin.	• The RMS vibration acceleration measured at the driver's seat exceeded the Exposure Action Value (EAV) of 0.5 m/s^2 set by the European Directive (2002) in 63% of the cases; • In the vertical direction, the highest seat vibration amplitudes occurred at frequencies between 1 and 12.5 Hz; • In the longitudinal and transverse directions the highest seat vibration occurred at frequencies below 5 Hz; • The drivers´ noise exposure during the working days was below 80 dB(A); • Inside the cabin of the truck, noise was most significant at frequencies between 63 and 2000 Hz.	• Although there were measurements of noise and WBV exposures, there was no association to hearing loss or any other health effects.

3. DISCUSSION

Table 2 shows a summary of the studies presented in Tab. 1. The number below each situation presented here is the study number shown in Tab. 1. As it can be seem, the great majority of the studies were performed in humans, although some animal studies could also be found. The main importance of the latter studies is that the levels used could be higher than in humans, as shown in the test conditions presented in Tab. 1.

Table 2 – Summary of the studies presented in Tab. 1

Type of Study	Humans	Animals	Bibliography	Measurement
Study number	1, 2, 3, 4, 5, 6, 8, 9, 12 and 14	7, 10 and 11	13	15

Type of Hearing Assessment	Cochlear Microphonic	Audiometry Only	DPOAE Only	Evoked Potential	Audiometry + DPOAE
Study number	11	1, 2, 3, 4, 5, 6, 9 and 12	10	7 and 8	14

Type of Exposure	WBV and/or SPL	WBV only	WBV and SPL	
Study number	1, 2, 3, 4, 5, 6, 7, 8, 10 and 14	11	9, 12 and 15	

Type of Effect (WBV + SPL)	Synergic	Antagonistic or no influence	
Study number	1, 2, 3, 4, 5, 6, 7, 8, 9, 10 and 12	12 and 14	

From the conclusions obtained (as shown in Tab. 1 and 2), do not taking into account the bibliographic study (number 13) and the measurement one (number 15), it was observed that 10 studies found synergic effects for the combination of whole body vibration and noise and only 2 studies did not found that. However, one of them, (Silva and Mendes, 2005) was conducted *in loco* and reported that in the multivariable analysis no synergic effect was observed, but in the single variable analysis the results suggested synergic effect caused by this combination. The other study (Izumi, 2006) was conducted in laboratory and found that, for the levels of noise and vibration used, no synergic effect occurred, as the hearing thresholds after the combined exposure were not greater than after the exposure to noise alone. Besides, at the 4kHz frequency, the effect was antagonistic, that is, a better hearing can be expected due to this combined exposure.

Seven of the experimental studies with humans that found synergic effect cited in the review have adopted in the methodology the following features: sinusoidal WBV in the Z axis with frequencies of 2.01 to 10 Hz and amplitudes ranging from 2 to 2.65 m/s^2 or stochastic WBV within the frequency range of 1.4-11.2 Hz together or not with white noise ranging from 60-98 dB (A). The time of exposure to each stimulus ranged from 11-16 minutes with consecutive exposure between 2–5 times. The number of individuals that participated in the studies ranged from 10 to 370 (this last one, divided in 3 independent groups), the average age ranged from 22.5-23.8 years, average weight 73.2-73.8 kg and mean height from 179.7-180.7 cm.

The experimental study with humans that did not find synergic effect for the combined exposure to noise and WBV (Izumi, 2006) adopted in the methodology: sinusoidal WBV in Z axis at 6 Hz with 2.45 m/s^2 amplitude during 18 minutes and a 100 dB (A) white noise during 15 minutes, with the combined exposure assuming the highest duration. The weighted acceleration level equivalent to an 8h exposure in such case was 0.47 m/s^2, below the EAV limit of 0.5 m/s^2 set by the European Parliament (Directive 2002/44/EC, 2002). There was only one series of exposure to each stimuli alone or combined. The sample consisted of 13 subjects with a mean age of 23.9 years, mean weight 70.2 kg and average height of 175 cm.

4. NEW METHODOLOGY PROPOSED

After comparing the mentioned studies (with x without synergic effect), it was found that the levels of WBV and noise and the number of exposures used by (Izumi, 2006), although within the range of the other studies presented, differed from them especially on the latter. It is believed that such difference may have influenced the disagreement of the results with the other studies. The main difference may be attributed not to the small differences in levels but to the number of exposures each individual was submitted. When analyzing either the total VDV (Vibration Dose Value) or the total acceleration exposure equivalent to an 8h journey the individuals were exposed in each situation, it can be concluded that the total level at Izumi (2006) study was smaller than the others. Therefore, their influence was different than at the other studies, although the frequencies and levels used considering only one exposure were not.

Faced with such disagreements and due to the importance to establish the influence of whole body vibration and noise on hearing, it is necessary to carry out a new experimental research about the combined and isolated effects of these physical factors, but using a more precise methodology. The combination of such physical risks is generally the most common in work environments (Seidel, 1989, 1992, 1997).

Therefore, initially, an increase of the sample is planned in other to make the analysis more representative. It will be possible to verify if the sample size is important in such case, since the sample size varies greatly from study to study presented. For that, the same methodology used by Izumi (1996) should be used at the beginning. Then, the frequency of excitation needs to be changed to be similar to the studies that found synergic effect. By doing that, it will be possible to study the frequency influence on the hearing shift and to compare alike situations. The addition of another objective auditory test (transient otoacoustic emissions), for confirmation and greater confidence of results about hearing should also be used.

5. CONCLUSION

There is a scarcity of studies reporting on the combined effects of WBV and noise on human hearing and there is a predominance of old researches. In order to understand if the combination is synergic or not, laboratory studies should be undertaken in order to isolate the effect of one agent or the other. The great majority of the studies found converged to the same result, that is, there is a synergic effect associated with such combination, in other words, the combined exposure worsen the hearing damage.

Due to a disagreement between this influence on hearing found at 4 kHz on a recently study, this paper proposed a new methodology of tests to try to study such influence in more detail. It is believed that the development of such research in laboratory conditions, enabling the realization of tests in fixed and well defined conditions and with the improvement and more control of the methodology adopted, may lead to more precise results and consequently a work able to show with reliability the real effects of noise and WBV combination on human hearing.

6. REFERENCES

Araújo, SA., 2002, "Noise induced hearing loss in metallurgical workers" Rev. Bras. Otorrinolaringologia,vol.68, pp.47-52.

Bochnia, M., Morgenroth, K., Dziewiszek, W., Kassner, J., 2005, "Experimental vibratory damage of the inner ear", Eur Arch Otorhinolaryngol, vol. 262, pp.307-313.

Bovenzi, M., Hulshof, CTJ., 1999, "An update review of epidemiologic studies on the relationship between exposure to whole body vibration and low back pain", Int. Arch. Enviroment Health, vol.72, pp. 351-365.

Coles, R.R.A., Guignard, J.C., Knight, J.J.,1965, "Observations on the background–noise effect: a study of the effects of vibration and noise of hearing", Report He.S.89. Medical Research Council, Royal Naval Personnel research Committee, Hearing sub-committee, London. Apud Griffin (1996).

Directive 2002/44/EC of the European Parliament and of the Council, 2002. On the Minimun Health and Safety Requirements Regarding the Exposure of Workers to the Risks Arising from Physical Agents (vibration), 2002.

Duarte M.L.M., Horta F.C. and Arenales G.G.R., de Carvalho, L.A.P. Exposure Time Influence in Whole Body Vibration Tests: Same Vibration Dose Value Investigation [Journal]. - [s.l.] : Society of Automotive Engineers, Inc., 2008. - 0534 : Vol. 36. - ISSN 0148-7191.

Fernandes, M., Morata, TC., 2005, "Auditory and extra auditory effects of occupational exposure to noise and vibration" ("Estudo dos efeitos auditivos e extra auditivos da exposição ocupacional a ruído e vibração"), Rev Brasileira de Otorrinolaringologia, vol. 68, pp. 705-713.

Fundacentro, 1999, "Ocupational Exposure to Noise Evaluation" (In Portuguese: Avaliação da Exposição ocupacional ao Ruído), NHO-01, São Paulo.

Griffin, M.J., 1996, Handbook of Human Vibration, Academic Press, London , edition 1996.

Hamernik, RP., Ahroon, WA., Davis, RI., 1989, "Noise and vibration interaction: effects on hearing", J. Acoust. Soc. Am., vol.86 (6), pp. 2129-2137.

HSE - Health and Safety Executive Whole-body Vibration calculator, version may 2006,< http://www.hse.gov.uk/vibration/wbv/wholebodycalc.htm> .

ISO 2631/1, 1997, International Organization for Standardization – " Mechanical Vibration and Shock – Evaluation of Human Exposure to Whole-Body Vibration – Part1:General Requirements", Second Edition.

ISO 13090/1, 1998, International Organization for Standardization – "Mechanical Vibration and Shock – Guidance on safety aspects of tests and experiments with people – Part 1: Exposure to whole-body mechanical vibration and repeated shock", first edition.

ISPESL (Istittuto Superiore per la Prevenzione e la Sicurezza del Lavoro), 12 may 2009 < http://www.ispesl.it/.>

Izumi, R., Mitre, EI., Duarte, MLM., 2006, " Effect of whole body vibrations on hearing" ("Efeito das vibrações de corpo inteiro na audição"), Rev. Cefac, vol. 8, pp. 386-392.

Izumi,R., 2006, "Effects of whole body vibration and high sound pressure levels in the hearing temporary threshold shift" ("Efeitos da vibração de corpo inteiro e dos níveis de pressão sonora elevados na mudança temporária de limiar auditivo"), M.Sc. Dissertation, Mechanical Engineering Department, UFMG, pp.1-94.

Lings, S., Lebouef Yde, C., 2000, "Whole body vibration and low back pain: a systematic, critical review of the epidemiological literature 1992-1999" Int Arch Occup Enviroment Health, vol. 73, pp. 290-297.

Ljungberg, J., Neely, G., Lundstrom, R., 2004, "Cognitive performance and subjective experience during combined exposures to whole body vibration and noise", Int Arch Occup Environ Health, vol. 77, pp. 217-221.

Manninen, O., 1981, "Combination of noise, vibration, temperature and physical work and temporary threshold shift of hearing", 5Th International Symposium on Circumpolar Health, pp. 9-13. Apud Griffin (1996).

Manninen, O., 1983a, "Studies of combined effects of sinusoidal whole body vibrations and noise of varying bandwidths and intensities on TTS2 in men", Int Arch Occup Environ Health, vol. 51, pp.273-288.

Manninen, O., 1983b, "Simultaneous effects of sinusoidal whole body vibration and broadband noise on TTS2's and R wave amplitudes in men at two different dry bulb temperatures", Int Arch Occup Environ Health, vol. 51, pp. 289-297.

Manninen, O., Ekblom, A.,1984a, "Single and joint actions of noise and sinusoidal whole body vibration on TTS2 values and low frequency upright posture sway in men", Int Arch Occup Environ Health, vol. 54, pp. 1-17.

Manninen, O., 1984b, "Hearing threshold and heart in men after repeated exposure to dynamic muscle work, sinusoidalvs stochastic whole body vibration and stable broadband noise", Int Arch Occup Environ Health, vol. 54, pp.19-32.

Manninen, O., 1985, "Cardiovascular changes and hearing threshold shifts in men under complex exposures to noise, whole body vibratios, temoeratures and competition type psychic load", Int Arch Occup Environ Health, vol. 56, pp. 251-274.

Manninen, O., 1986, "Bioresponses in men after repeated exposures to single and simultaneous sinusoidal or stochastic whole body vibrations of varying bandwidths and noise", Int Arch Occup Environ Health, vol. 57, pp.267-295.

Morita, M., 1958, "Experimental studies on the acoustic influence of vibration and noise" Otolaryngology Fukuaka, vol. 4, pp. 327-341. Apud Griffin (1996).

NIOSH, 1998, National Institute for Occupational Safety and Health –NIOSH, Criteria for a Recommended Standard: occupational noise exposure-revised criteria 1998, Cincinnati OH United States , publication n^{o} 98-126.

NR-15, Brasil, 1978, Norma Regulamentadora n^{o} 15- NR 15, "Tolerance Limits for Continuous and Intermitent Noise" (In Portuguese: Limites de tolerância para ruído contínuo ou intermitente), <http://www.mte.gov.br/legislacao/normas_regulamentadoras/nr_15.pdf>.

Okada,A., Miyake, H., Yamamura, K., Minami, M., 1972a, "Temporary hearing loss induced by noise and vibration" The Journal of the Acoustical Sociey of America, vol. 51, pp. 1240-1248. Apud Griffin (1996).

Seidel, H., Richter, J., Kurerov, NN., Schajpak, EJ., Bluthner, R., Erdmann, U., Hinz, B., 1989, "Psychophysical assesment of sinusoidal whole body vibration in Z axis between 0,6 and 5 Hz combined with different noise levels", Int Arch Occup Environ Health, vol. 61, pp. 413-422.

Seidel, H., Bluthner, R., Martin, J., Menzel, G., Panuska, R., Ullsperger, P., 1992, "Effects of isolated and combined exposures to whole body vibration and noise on auditory event related brain potentials and psychophysical assessment", Eur J Applied Physiology and Occupational Physiology, vol. 65, pp. 376-382.

Seidel, H., Schust, M., Seidel, H., Bluthner, R., Rothe, H.J., 1997, "Subjective evaluation of the effects of noise with a different tonality combined with random low frequency whole body vibration", United Kingdom Group Meeting on human response to vibration held at the ISVR, University of Sothampton, England.

Silva, LF., Mendes, R., 2005, "Combined exposure to noise and vibration and its effects on worker's hearing"("Exposição combinada entre ruído e vibração e seus efeitos sobre a audição de trabalhadores"), Ver. Saúde Publica, vol. 39, pp. 9-17.

Soliman, S., El Atreby, M., Tawfik, S., Holail, E., Iskandar, N., Abou Setta, A., 2003, "The interaction of wholebdy vibration and noise on the cochlea", International Congress Series Oto Rhino Laryngology, vol. 1240, pp. 209-216.

Sorainen, E., Oksanen, M., Vähänikkilä, A., Rytkönen, E., 2007, "Exposure of timber truck drivers to whole body vibration and noise", 14th International Congress on Sound and Vibration.

Teare, R.J.,1963, "Human hearing and speech during whole-body vibrations", Technical Report D3-3512-3. The Boeing company, Wichita, Kansas. Apud Griffin (1996).

VINET Report, 2001, "Research Network on detection and prevention of Injuries due to Occupational Vibration Exposures (Vibration Injury network - VINET), Final report Appendix W1A, Guidelines and questionnaires for whole body vibration health surveillance", may 2001.

Wilder, DG., 2007, "The biomechanics of vibration and low bach pain", American Journal of Industrial Medicine, vol. 23, pp. 577-588.

Yamamura,K., Okada,A., Miyake, H., 1970, "Temporary hearing loss due to vibration and noise", Japanese Journal of Hygiene,vol.25,pp. 472-478. Apud Griffin (1996).

Yokoyama, T., Osako, S., Yamamoto K., 1974, "Temporary threshold shifts produced by exposure to vibration, noise and vibration-plus-noise" Acta otolaryngolica, vol.68, pp. 207-212. Apud Griffin (1996).

Zannin, PHT., 2006, "Occupational noise in hurban buses" Int Journal of industrial ergonomics, vol. 36, pp. 901-905.

Zhu, S.K., Sakakibara, H., Yamada, S., 1997, "Combined effects of hand-arm vibration and noise on temporary threshold shifts of hearing in healthy subjects", Int Arch Occup Enviroment Health, vol.69, pp. 433-436.