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Classification of the level and the type of hearing loss based on the analysis of audiograms of workers exposed to high level of occupational noise

S.M.N. Sethunga[1], J.A.P. Bodhika[1]*, U.I.P. Abeysuriya[2], W.G.D. Dharmaratna[1] and S.A. Wickramasinghe[2]

[1]*Department of Physics, University of Ruhuna, Matara, Sri Lanka*
[2]*ENT Unit, Teaching Hospital, Karapitiya, Galle, Sri Lanka*

*Correspondence: *jbodhika@phy.ruh.ac.lk*; ORCID: https://orcid.org/0000-0001-5703-1500

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Abstract This paper presents some health effects of workers exposed to high occupational noise for a long period. The main objective of this study was to classify the level and the type of hearing loss of such workers plus to study the effects on their health. Out of a sample of 99 workers exposed to 85 dB(A) or more occupational noise, 73 (74%) workers who were exposed over 40 hours per week for five years or more were selected for this study. Their hearing levels were tested audio-metrically and audiograms of Air Conduction (AC) and Bone Conduction (BC) measurements were taken. Depending on the degree of Hearing Loss (HL) of audiograms, the sample was classified into Normal hearing (0-25 dB(A)): 10.5%, Mild HL (26-40 dB(A)): 67.0%, Moderate HL (41-55 dB(A)): 21.75%, and Moderate-to-severe HL (56-70 dB(A)): 0.75%. None of these falls into Severe HL or Profound HL categories. Based on the HL and the configuration of audiograms of AC and BC measurements, 89.5% of the sample was classified as Conductive Hearing Loss (CHL 2.25%), Sensorineural Hearing Loss (SNHL 85.75%), and Mixed Hearing Loss (MHL 1.5%). Some SNHL samples were identified as Meniere's disease 19%, Acoustic Trauma 12%, and Noise-Induced Hearing Loss (NIHL) 6%. NIHL were recorded among highly exposed workers to noise in the frequency range 3000-6000 Hz. Percentage statistics of various levels of hearing levels along with associated symptoms based on the response to the questionnaire are also presented.

Keywords: Noise exposure, Health impacts, Audiometric hearing test, Hearing threshold shift.

1 Introduction

Exposure to intense noise, especially at the workplace causes adverse health effects and hearing loss (HL) (Onuu 2000, Ishiyama and Hashimoto 2000, Stansfeld and

Matheson 2003, Tak and Calvert 2008, Stucken and Hong 2014, Arenas and Suter 2014, Domingo *et al.* 2016). It has become a severe problem in many countries (Tak and Calvert 2008, Arenas and Suter 2014, Domingo *et al.* 2016). The impact of noise on human health has been previously reviewed (Banerjee 2012). HL problems at the workplace can be reduced by taking proper actions (Frederiksen *et al.* 2017).

The audiometric hearing tests are used to identify the auditory acuity of human ears. Hearing Threshold (HT) shifts due to prolonged exposure to intense noise (Carder and Miller 1971). Exposure to a noise level greater than 85 dB(A) over 8 hours, i.e. LAeq,8h > 85 dB(A), could cause a loss of hearing acuity temporarily (Arenas and Suter 2014), which could cause a permanent threshold shift if exposed to an extended period depending on the other health conditions (Turunen-Rise *et al.* 1991, Nordmann *et al.* 2000). Two types of hearing assessments, i.e., Air Conduction (AC) and Bone Conduction (BC) are typically performed (Vogel *et al.* 2007). Three types of hearing losses, namely, Conductive Hearing Loss (CHL), Sensorineural Hearing Loss (SNHL), and Mixed Hearing Loss (MHL) are identified by the degree of hearing thresholds and differences in configuration (shape) of audiograms (Norena and Eggermont 2003, NIDCD 2016). Furthermore, different types of SNHL such as Meniere's disease (NIDCD 2016, Bess and Humes 2008), Noise-Induced Hearing Loss (NIHL) (Arenas and Suter 2014, Domingo *et al.* 2016), Acoustic trauma (Norena and Eggermont 2003) can be recognized under the same classification.

Degree of Hearing Loss falls into different categories: normal HL (-10 to 15 dB(A)), slight HL (16 to 25 dB(A)), mild HL (26 to 40 dB(A)), moderate HL (41 to 55 dB(A)), moderately severe HL (56 to 70 dB(A)), severe HL 71 to 90 dB(A) and profound HL (>90 dB(A)) (Clark 1981). However, up to 25 dB(A) is accepted as no hearing impairment (WHO 1991). In this study, HL in the range of 0-25 dB(A) has been considered as normal hearing.

The main objective of this study was to identify workers who were exposed to a high level of occupational noise for an extended period, investigate their audiograms, categorize the level of HL, identify the types of HL and map them to corresponding health effects.

2 Materials and Methods

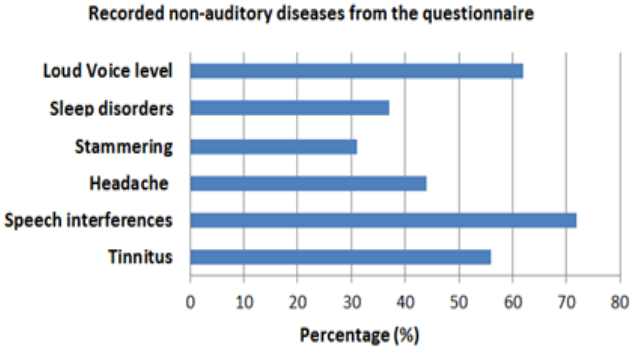
The study was based on volunteers who were exposed to occupational noise levels of 85 dB(A) or more. Every respondent was well informed of the study, and all have given written consent for their voluntary participation. The sample doesn't include the people who had HL in their childhood, genetically, or for other reasons. A questionnaire was used to gather necessary information directly interviewing the participants. The information collected included their age, nature of the occupation, period of employment at the same place exposing to noise, mental agitation, stammering effect, hearing levels, tinnitus, sleep disturbances, communication disturbances, annoyance,

disturbance to reading and writing in a noisy environment, social behaviour and impact of noise on performance. The research group, which was trained by an Ear-Nose and Throat (ENT) surgeon, interviewed each participant and recorded their response to gather this information. A member of the research team interviewed each participant for more than 30 minutes filling out the questionnaire. Out of an initial sample of 99 workers exposed to 85 dB(A), (LAeq,8h > 85 dB(A)) or more occupational noise, 73 workers who responded satisfactory to the questionnaire and were exposed over 40 hours per week for five years or more were selected for this study. The sample of 73 participants consists of long-distance bus drivers (16), point controllers and labourers of bus stations in Galle and Matara cities (41), and workers in a factory (16). The average noise level measured at their workplaces or buses was greater than 85 dB(A) based on the measurements taken during a minimum period of two years. An ENT surgeon has verified this sample.

BandK Type-2250 hand-held analyzer (IEC 61672-1; 2002 Class1) was used to measure the noise level. The analyzer was calibrated using BandK sound calibrator type 4231 before and after each measurement session. Amplaid A321 audiometer was used to measure both air conduction and bone conduction to obtain audiograms. The service of an experienced audiologist was taken to get audiograms. The test was conducted under a very low background noise level (<25 dB), which is less than the recommended highest value given by ANSI S3.1 (ANSI, 1999) for such measurements. Threshold of hearing for frequencies of 250 Hz, 500 Hz, 1000 Hz, 2000 Hz, 4000 Hz, and 8000 Hz were tested in pure tone audiometry. If noise notch (sudden drop of hearing threshold more than to 15 dB) was observed in 4000 Hz additionally 3000 Hz and 6000 Hz were tested to confirm NIHL. The information gathered in the questionnaire was compared with the results of the analysis of their audiograms.

3 Results and Discussion

The statistics of responses to the questionnaire survey among the selected 73 workers are shown in Figure 1. The outcome of the survey, as depicted in Figure 1, revealed that 56%, 72%, 44%, 31%, and 37% of individuals in the sample were suffering from tinnitus, speech interferences, headaches, stammering, and sleep disorders, respectively. 62% of the individuals in the sample said that they were speaking loudly at home due to HL. None of the respondents was found to have been recorded as suffering from high or low blood pressure. According to the survey, many of those speaking louder were suffering from speech interferences, and their audiograms indicated that they were suffering from SNHL. Therefore, the loudly speaking feature of a worker would be a pre-warning sign of SNHL after being exposed to a higher noise level.



sickness	# of people	Percentage (%)
Loud Voice Level	45	62
sleep disorders	27	37
stammering	23	31
headaches	32	44
speech interferences	53	72
tinnitus	41	56

Fig 1: Statistics of response to the questionnaire survey by a sample

In the study of audiograms, 146 ears were analyzed individually. However, person-wise analysis was done wherever needed. The audiograms were classified into three main classes, namely CHL, SNHL, and MHL. The classification was performed following the guidelines of the references given in Section 1, based on the configuration of audiograms and the level of the hearing threshold. Selected audiograms, typical for each class, Case 1: Conductive HL (larger AC HL), Case 2: Sensorineural HL (same order AC and BC HL), and Case 3: Mixed HL (large AC and BC HL, with higher AC HL), are shown in Figure 2. Analyses of audiograms were compared with the information given in the questionnaire.

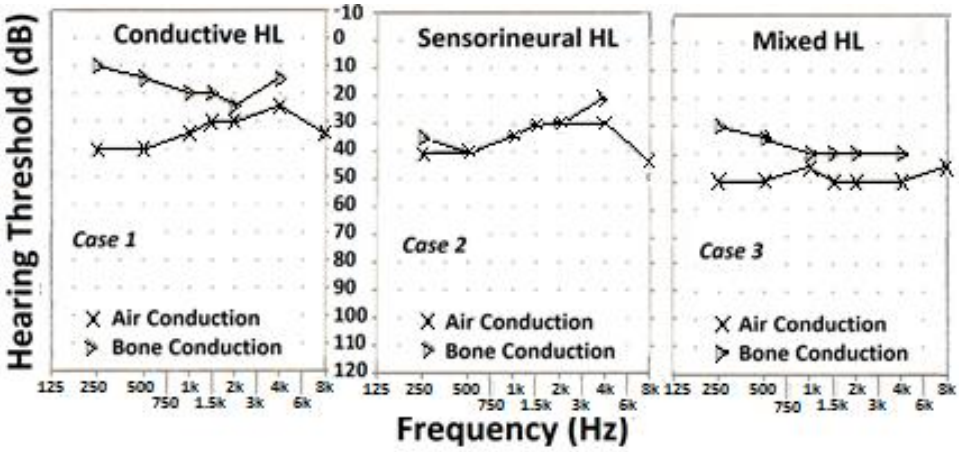
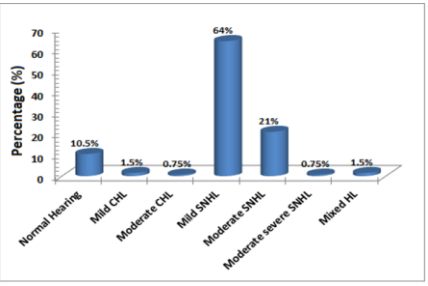


Fig 2: Variation of Hearing Threshold with the frequency for three main classes of hearing losses identified in the Audiometric Hearing Test. (Case 1: CHL, Case 2: SNHL, and Case 3: MHL)

The audiometric test revealed that a significant fraction (89.5%) of the sample studied suffered from mild, moderate, or moderate-severe HL. Normal hearing (<25 dBA) was

recorded for 10.5% of the sample. The 89.5% of the sample distributes as CHL (2.25%), SNHL (85.75%) and MHL (1.5%). All 89.5% of the sample, who were exposed to LAeq,8h of 85 dB(A) or more for more than five years were suffering from mild (26-40 dB(A)), moderate (41-55 dB(A)) or moderate-severe (56-70 dB(A)) HL.



Disease	No. of Ears	Percentage (%)	
Normal	15	10. 5	10.5
Mild Conductive HL	2	1.5	2.25
Moderate Conductive HL	1	0.75	
Mild SNHL	93	64.0	85.75
Moderate SNHL	32	21.0	
Moderate Severe SNHL	1	0.75	
Mixed HL	2	1.5	1.5

Fig 3: Classification of the sample (146 ears) based on the analysis of audiograms of workers exposed to intense noise (>85 dB(A)).

The results of the analysis of Audiogram information of 146 ears are shown in Figure 3. As seen from Figure 3, only 10.5% of the sample shows normal hearing, while others were classified as 1.5% with Mild CHL, 0.75% with Moderate CHL, 64% with Mild SNHL, 21% with Moderate SNHL, 0.75% with severe SNHL and 1.5% with Mixed HL. All 89.5% of the sample were able to classify as one of the three types, CHL, SNHL, or MHL, based on the level of HL and the shape of the audiograms. The most common hearing loss identified in this study was SNHL, and 85.75% of the sample recorded different levels of HL (mild, moderate, and severe). Furthermore, mild and moderate level HL cases of CHL were recorded.

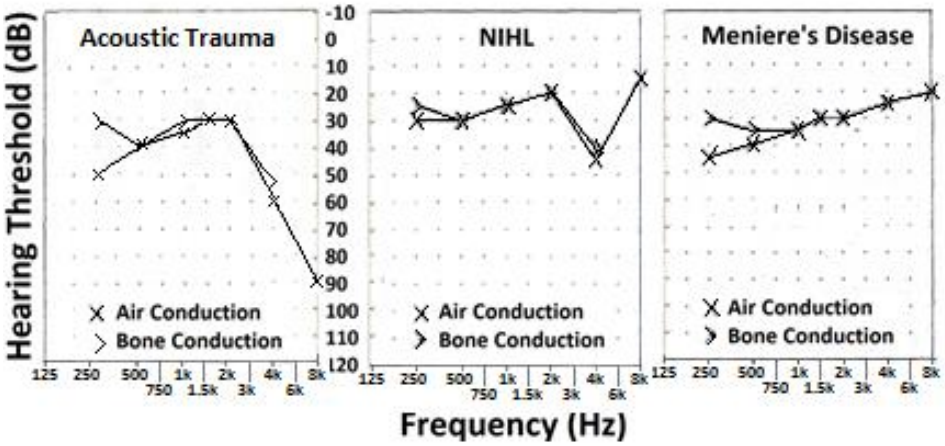
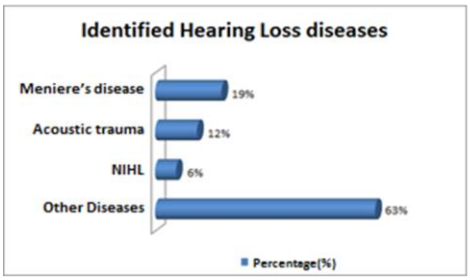


Fig 4: Typical audiograms identifying Acoustic Trauma, NIHL, and Meniere's Dieses, depending on the features of the audiogram.

Within the dominant group of SNHL (85.75% of the sample), three sub-categories, namely, Acoustic Trauma, NIHL (Noise-Induced Hearing Loss), and Meniere's disease could be identified following the references given in Section 1. The configuration of audiograms can recognize these three categories, response to the questionnaire and patients' medical history. The typical audiograms of patients having Acoustic trauma (Higher HL at high frequencies), NIHL (Higher HL at frequencies around 4000 Hz or 6000Hz), and Meniere's disease (Higher HL at low frequencies) obtained from the sample are shown in Figure 4.

The sample size of audiograms classified as Meniere's disease, Acoustic Trauma, and NIHL were 19%, 12%, and 6%, respectively, as shown in Figure 5. The remaining 63% of the SNHL sample, marked as other diseases, could not be classified further from these audiograms.



Disease	# of ears	Percentage (%)
Meniere's disease	28	19
Acoustic trauma	18	12
NIHL	9	6
Others	91`	63

Fig 5: Identified diseases according to audiometric test, out of the sample identified with SNHL

According to the information collected through the survey, all the workers identified with Meniere's disease were suffering from tinnitus, vertigo/dizziness, temporary HL, and a feeling of fullness (congestion in the ear). In most Meniere's disease cases, the HL was noticed only in one ear but it is spread over both ears with noise exposure (Beasley and Jones, 1996). In this study, 15% were unilateral and, 4% were bilateral out of 19% of Meniere's disease cases. It is in complete agreement with the evidence given by the National Institute of Deafness and other Communicative Disorders (NIDCD) fact sheet. Especially, operators of heavy machines or driving vehicles with vertigo/dizziness will be at high risk to their own life and a third party.

A notch of about 15 dB in depth at 4000 or 6000 Hz pure tone measurements have been reported in audiograms of NIHL patients (Susan *et al.* 2010). Therefore, a sudden drop (notch) of the hearing threshold at these frequencies is typical in their audiograms. Here, the noise notch was recorded at 4000 Hz. One of the most exciting observations revealed from the survey result and noise level measurements done at their workplaces where all NIHL patients reported in this study had been exposed to the noise of frequencies in the range 1500-6000 Hz. The prominent noise was in the range 3150-4000 Hz for an extended period, which is a very good agreement with above results.

Some percentage statistics of various level of hearing levels along-with associated symptoms based on the responses to the questionnaire are shown in Table 1.

Table 1: Percentage of various hearing levels of the sample and their symptoms.

dB range	Hearing Level	Sample %	Symptoms
0 – 25	Normal hearing	10.5	No difficulties to hear both low and high pitched sound
26 - 40	Mild HL	67.0	Inattention. Difficult to suppress background noise in normal conversation. Increased listening efforts. Can't hear low pitched (soft) sound. Fatigued after listening for a long time.
41 - 55	Moderate HL	21.75	Conflict with peers in communication. Loud voice level at everyday speech. Hearing trouble in conversational- speech if it is low level (loudness).
56 - 70	Moderate-severe HL	0.75	Difficulties arise with speech. Decreased speech intelligibility. Do not hear most conversational-level speech (can hear shouted voice). Start bad voice quality.
71 - 90	Severe HL	0	No records available.
90 <	Profound HL	0	

The noise level at all locations studied exceeded the value prescribed by the National environment Act No. 47 in 1980, Amended act no 924/12 in 1996, which indicated the unhealthy level of noise pollution. The exposure period was also more than the recommended value (NIOSH 1998). The threshold hearing level shift at 4000 Hz of workers exposed to noise at the same frequency range of around 4000 Hz for an extended period was significant. 'Loud voice level' behaviour of workers, after being exposed to intense noise levels for some time, might be a pre-warning of SNHL.

4 Conclusions and Recommendations

The study showed that the workplaces of all employees in the sample, long-distance bus drivers, point controllers and labourers of bus stations of Galle and Matara cities and the workers in the selected factory were exposed to higher occupational noise levels (> 85 dB(A)), which is greater than the maximum allowed noise level 70 dBA by the Sri Lankan government act (National environment Act No. 47 in 1980,

Amended act no 924/12 in 1996). Furthermore, the exposure period was also more than the recommended value by National Institutes for Occupational Safety and Health in 1998. Out of the selected sample of 73, 89.5% suffered from mild (26-40 dB(A), 67%), moderate (41-55 dB(A), 21.75%) or moderate-severe (56-70 dB(A), 0.75%) hearing loss. Based on the level of hearing loss and the configuration of the 146 audiograms, one for each ear, all HL samples could be classified as CHL (2.25%), SNHL (85.75%) and MHL (1.5%), comparing the features of AC and BC measurements. Sensorineural HL is the most common type in this sample. This classification helps to locate the problem in the ear, whether it is the outer or middle ear (CHL) or the inner ear or nerve pathway to the brain (SNHL) (Clark, 1981). MHL indicates problems could be in both the outer or middle ear and inner ear. Out of the 126 samples of ears in the SNHL category, 19%, 12% and 6% could be classified as Meniere's, Acoustic Trauma and NIHL, respectively. Symptoms reported by the participant in the questionnaire have been mapped with the level of hearing loss. As expected, by studying the audiograms (AC and BC), the level and the type of hearing loss were classified successfully.

Following recommendations, based on this study, are given to reduce occupational noise and minimize the health effects on workers.

1. Actions must be taken to maintain the noise level at the workplace below the recommended level (i.e. 85dB(A)) by the Sri Lankan government act (National environment Act No. 47 in 1980, Amended act no 924/12 in 1996).
2. The audiometric test must be a rooting medical test of workers who work under high occupational noise.
3. Launch awareness programs among workers, employers, civilians and relevant authorities.
4. Wear proper ear guards or earmuffs during their work in high noise areas.
5. Reliable noise reduction techniques have to be implemented to minimize noise levels at the workplace.
6. The noise level of buses and their horns shall be annually checked when issuing revenue permits.

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