Distortion Product Oto-Acoustic Emission: A Superior Tool for Hearing Assessment Than Pure Tone Audiometry

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Abstract

Objective: Hearing plays a crucial role in the performance of a soldier and is important for communication and speech processing. Service personnel are constantly exposed to high levels of noise and hence predisposed to occupational health disabilities, principally noise-induced hearing loss (NIHL) and tinnitus. NIHL is a significantly common impairment in the military and can affect the warfare performances. Parochial awareness about the effects of uproarious noise which exacerbates their hearing, acceptance rate of use of hearing protection devices and follow-up audiological tests have become the major drawback for prevention of NIHL and are less pondered upon. Method: The present study focuses on the effects of noise on the hearing of service crew operating and maintaining military equipment and explores the efficacy of DPOAE’s to substitute pure tone audiometry as a quick, easy to operate and implementable test technique for monitoring of hearing status. Results: The results suggest that DPOAE test is important and more coherent than audiometry alone for the early detection of cochlear injury due to noise from military operations and efficacious for detecting NIHL.

Keywords: Audiometry, noise, OAE

INTRODUCTION

Noise is unwanted sound judged to be unpleasant, loud or disruptive to the hearing of a person when continuously exposed to more than 85dBA.[1] Exposures beyond 85 dBA for 8 hours duration may lead to noise-induced hearing loss (NIHL).[1] Twenty-two million workers are exposed to potentially damaging noise at work each year.[2] Worldwide, an estimated 16% hearing disability is caused by occupational noise exposure.[3] NIHL is a public health problem that can limit usual daily activities. Hearing loss can reduce physical and social execution behavior status and may induce psychological symptoms of anxiety and depression.[4] Hearing problems can be a notable reason for personnel to lag behind in their trainings and disruption of their armed forces services.

The prevalence of hearing loss and tinnitus in armed population are greater than in the general public. Almost every soldier, sailor, airman or mariner will be exposed to hazardous noise levels at some point in their career.[5-7] The source of noise in the military are as varied as the activities.
carried out by the personnel of the army, navy, air force, marine corps, and coast guard. Obvious sources of potentially hazardous noise are weapon systems and jet engines. However, ground vehicles, other air-craft, watercraft, communication systems, and industry-type activities also serve as sources of potentially damaging noise.[8] According to Annual Benefits Report 2013, the two most prevalent service connected disabilities for veterans in the United States at the end of fiscal year 2012 remain tinnitus and hearing loss, with tinnitus affecting 115,638 veterans (9.7%) and hearing loss affecting 69,326 veterans (5.8%). In Finland, despite the increasing use of hearing protection devices, a large proportion of professional soldiers experience disabling tinnitus and hearing loss.[5] The presence of tinnitus and hearing loss can significantly impair a personnel’s ability to hear important acoustic cues or communication signals from the unit or the enemy. Despite evidence of hazardous noise exposure among service men and trainees, no safety standards or guidelines are mandated for the prevention from occupational noise exposure. Even though short periods of exposure to amplified sound may not cause permanent hearing loss, the damage from persistent exposure to these sound levels is cumulative so that a slight hearing loss in early exposures can eventually become a substantial one with extended duration of exposures. The prevention of such hearing loss begins with education with hearing conservation programs ideally targeting the service men having exposed ears or ripe ears and young trainees having green ears without exposure.

**OBJECTIVE/NEED FOR THE STUDY**

NIHL is the most commonly seen ominous problem among personnel due to increased exposure to high levels of continuous and impulse noise during daily operations of machines and/or during training with weapons and weapon systems. Occupational Safety and Health Association (OSHA, USA)[9] defines standard threshold shift (STS) as a change for the worse in either ear of 10 dB or more in the average of thresholds at 2, 3, and 4 kHz relative to the baseline. In the Indian military services, a large number of fresh recruits who have never been exposed to firearms are exposed to firing trainings for the first time. The incidence of hearing impairment amongst green ears of recruits in the Indian scenario is not given due consideration, with the new inductees undergoing hearing tests not aimed at critical evaluation and record of their hearing status. This study is aimed to evaluate the hearing status of armed personnel having green ears without any prior exposure to high intensity continuous/impact noise and air crew with 6 years of exposure to the operations of high performance aircraft noise coupled with annual monthly exposures whilst undergoing shooting trainings, towards assigning the ‘right man to the right job’ to optimize performance, assess the impact of exposures with duration/years of service, explore the patho-physiology of effects and strategies of prevention.

**PATHOPHYSIOLOGY**

Injury from noise can occur by high level, short duration continuous/impulse exposure exceeding more than 85dBA or 140 dB peak respectively, causing the delicate inner ear tissues to stretch beyond their elastic limits leading to mechanical disruption of the stereocilia and direct damage to supporting and sensory cells.[10] This type of acoustic trauma can result in immediate and permanent hearing loss. Moreover, long term exposure to low level noise damages the cochlea metabolically rather than mechanically. It involves biochemical pathways leading to cell death through apoptosis or necrosis.[11] Exposure to intense sound can cause auditory thresholds to become elevated permanently or temporarily. Reversible hearing loss is referred to as temporary threshold shift (TTS). Depending on duration of exposure, recovery from TTS can occur over a period of minutes to hours or days. If TTS does not recover, permanent hearing loss results and this is referred to permanent threshold shift (PTS).[12] Noise not only increases hearing threshold, but it can also cause tinnitus, recruitment, distortion or abnormal pitch perception and hyperacusis.

**CLINICAL RELEVANCE**

Personnel may exhibit difficulty in listening to high-frequency noise such as alarms, whistles, buzzers or warning signals. If they are in areas where there is significant background noise, they may also have difficulty perceiving and differentiating some speech consonants. However these symptoms are typically subtle and most patients with NIHL may not notice their deficiency until it starts affecting the communication. These effects of NIHL can make the personnel lag behind in his trainings.

**MATERIAL AND METHODS**

106 male Service personnel (mean age 21.2 years) were recruited for the study. 53 Service personnel recruits with green ears and 53 with exposed ears were selected from the regional training centre. They were asked to answer a questionnaire about symptoms and maintenance of aural hygiene. Subjects were acoustically at rest for auditory examination and testing.

**Physical examination**

The subjects underwent a thorough physical examination and testing—Otoscopy for the inspection of the outer ear canal and the Tympanic membrane status by the ENT. Recruits with Green Ears having any history of current or past history of hearing problems, history of systemic diseases, history of using ototoxic drugs, previous excessive exposure to noise, ototoxic chemicals, abnormal tympanic membrane, ear surgery, and mixed or conductive pathologies were excluded and recruits with exposed ears having abnormal tympanic membrane, ear surgery, and mixed or conductive pathologies were excluded.
**Audiometric and physiological assessment**

Recruits underwent Pure Tone Audiometry (PTA) by modified Hughson-Westlake method in an appropriately sound treated audiometric chamber with ambient noise levels within permissible limits according to ANSI standards (ANSI S3.6-ISO389). Using a MAICO MA53 audiometer Air conduction thresholds were determined at octave and mid-octave frequencies from 250Hz to 8 KHz bilaterally and DPOAE (Distortion Product Oto-Acoustic Emissions) for both the ears were recorded using GSI AUDIOscreener+ (Grason-Stadler) and both PTA and DPOAE values were compared.

**Pure tone audiometry**

Auditory thresholds up to 25 dBHL[12] were considered normal. Changes in the ear following firing training were recorded in the form of complaints such as tinnitus, hyperacusis, hypertension and hearing loss. All the data were recorded and compiled. Baseline audiograms of subjects with TTS were studied to look for possible indicators of susceptibility to TTS which indicated significant chances of susceptibility to NIHL. The dip or notch at 4 KHz or 6 KHz is a symptom of NIHL.

**Distortion product-oto-acoustic emissions (DP-OAE)**

The DP gram method, \( L_{1}-L_{2} \) intensity of 10 dB with \( L_{1}=65 \text{dB} \) and \( L_{2}=55 \text{dB} \), was applied in DPOAE testing (an \( f_{1}/f_{2}=1.22 \) ratio was used; the maximum test duration was 90 seconds). Testing comprised 2,000 to 6,000 Hz frequencies and their distortion products, which were considered present if the amplitude was above \(-10 \text{dB} \) and the signal-to-noise difference was greater or equal to 6 dB. The pass/fail criterion was used in DPOAE testing; The 3 dB algorithm method was applied as a criterion for presence.

At the time of Questionnaire analysis all participants were included to check the general opinion and knowledge about the use of Hearing Protection Devices (HPDs)/Ear Protection Devices (EPDs) during the Noise exposure period.

**STATISTICAL ANALYSIS**

For statistical analysis, unpaired t-test was applied using GraphPad 5Software, California, USA. Mean±SEM was calculated for the measurements for PTA, DPOAE, and SNR of Green Ears (GE) with 4 months of noise exposure and Exposed ears (EE) with 3 years of noise exposure. Unpaired t-test was used to assess level of significance \( P < 0.05 \) was considered significant in this study.

**RESULTS**

**Pure tone thresholds**

Pure tone average of thresholds at 2000, 3000, 4000, 6000 Hz was calculated for both ears separately, GE (Green Ears), and EE (Exposed ears). Pure tone average in the right ear was 16.1 dB for Green ears and 23.8 dB for Exposed ears. In the left ear, the pure tone average changed from 13.9 dB to 21.9 dB following three years of exposure to noise from operations of high-performance aircrafts and helicopters. In the distinct analysis of frequencies, after noise exposure significant differences in PTA at 2000, 3000, 4000 and the most significantly difference at 6000Hz were observed for the right ear and no significant difference at 2000 Hz for the left ear was observed. Pre-exposure assessment records showed that all participants had normal PTA as well as DPOAE. Comparison between PTA results in different frequencies of GE and EE after exposure showed that there was a significant difference at 2000 Hz (\( P < 0.0001 \)), 3000 Hz (\( P < 0.0001 \)), 4000 Hz (\( P < 0.0001 \)) and 6000Hz (\( P = 0.0001 \)) in the right ear and a significant difference at 3000 Hz (\( P = 0.0072 \)), 4000 Hz (\( P < 0.0001 \)) and 6000 Hz (\( P = 0.0001 \)) in the left ear, however significant difference at 2000 Hz (\( P = 0.3107 \)) frequency was not observed in the left ear. There were significant differences between the two groups in relation to threshold changes suggesting NIHL with Right ear more affected than the left ear [Table 1].

The results were categorized into normal auditory thresholds (up to 25 dB) and abnormal auditory threshold suggesting impact-induced NIHL—a threshold with an acoustic notch at 4000 and/or 6000 Hz were taken into account. The differences in hearing profiles were statistically significant. As per OSHA guidelines 76 subjects were found to have significant threshold shift. Mean age of these subjects were 22.43 years. Audiogram of 39 subjects showed an audiometric notch at 4 kHz in right ear and 33 subjects in left ear whereas 46 subjects in right ear and 38 subjects in left ear at 6 kHz. Double notch was observed in the audiograms of personnel having exposed ears i.e., 31 subjects in right ear and

**Table 1: Frequency-specific air conduction thresholds with standard mean error audiometric results in the group of personnel having green ears and the exposed ears**

| Fq  | Green ears (rt) | Exposed ears (rt) | Green ears (lt) | Exposed ears (lt) |
|-----|-----------------|------------------|-----------------|------------------|
| 2 KHz | 11.50943±0.5051424 | 18.22642±0.5214148* | 9.358491±0.4812103 | 16.26415±0.7348622* |
| 3 KHz | 13.77359±0.8075485 | 20.54717±0.8208884* | 11.39623±0.5767254 | 18.67924±1.242619* |
| 4 KHz | 15.45283±0.7631603 | 24.6415±1.200839* | 13.73585±1.066564 | 22.4159±1.284448* |
| 6 KHz | 19.207±1.313478 | 26.33962±1.176371* | 16.26415±1.379970 | 24.84906±1.269663* |

*\( P < 0.001; \) **\( P < 0.01 \) compared with green ear versus exposed ear in both right and left. Data present in Mean±SEM.
The age of the subjects was in the range of 18–22 years. In present study for the distinct analysis of frequencies, following 3 years of noise exposures significant differences in PTA at 2000, 3000, 4000 and 6000 Hz were observed for the right ear and no significant difference at 2000 Hz for the left ear was observed. Comparison of audiometric results in different frequencies of GE and RE after exposure and showed that there was a significant difference at 4000 Hz ($P < 0.001$), 1000 Hz and 6000 Hz($P < 0.001$) Hz in the right ear. However, in the left ear, there was no significant difference at 2000 Hz frequency. In a study by Ghasemi et al. the most significant shift in hearing thresholds was seen at 4 kHz. In this study, STS was observed in 12 subjects. Mean age of these subjects was 19.33 years. Of the 12 subjects four had STS in bilateral ears, four in the right side and rest four in the left side. The range of STS (as compared to baseline) varied from 18 to 43 dB (air conduction thresholds). A total of four subjects had audiometric notch, two at 2 kHz, one each at 4 kHz and 6 kHz. Nair and Kashyap studied the classical audiometric notch at 4 kHz (Aviators notch) as mentioned in the literature as pathognomy of NIHL was seen replaced by 6 kHz notch in a significantly large number of Indian Air Force personnel. This study emphasizes the significance of early involvement of 6 kHz in the present noise environment in detecting NIHL. Chung describes 27 cases of NIHL from 1000 Hz and 6000 Hz ($P < 0.001$), and 6 kHz ($P < 0.001$) in the right ear [Table 2] and at 4 kHz ($P < 0.001$) and 6 kHz ($P = 0.0284$) in the left ear [Table 3].

**Oto-acoustic emissions**

The functional status of cochlear Outer hair Cells was checked by the recording of Distortion Product-OAEs. The DPOAE amplitudes of the personnel having green ears are maximal and for the personnel with exposed ears the DPOAE amplitudes decreased. The DPOAE amplitudes in Exposed ears were significantly smaller than those in Green ears ($P < 0.0001$, one-way ANOVA). DPOAE testing revealed a significant difference at 3 kHz ($P = 0.0072$), 4 kHz ($P < 0.0001$), and 6 kHz ($P = 0.0001$) in the right ear [Table 2] and at 4 kHz ($P < 0.0001$) and 6 kHz ($P = 0.0284$) in the left ear [Table 3].

**DISCUSSION**

The present study is conducted on new inductees who have never been exposed to noise from military operations earlier (green ears) and the armed personnel who have been exposed to noise for over three years. In the distinct analysis of frequencies, following exposures significant differences in PTA at 2000, 3000, 4000 and 6000 Hz were observed for the right ear and no significant difference at 2000 Hz for the left ear was observed. There were significant differences between the two groups in relation to threshold changes suggesting NIHL and right ear to be more affected than the left ear.

Similar differences were observed in DPOAEs. The decrease of DPOAE amplitudes in exposed ears was more in exposed ears than in green ears. At 4 kHz and 6 kHz, most of the DPOAEs were practically absent whereas at 2 kHz, 3 kHz, 4 kHz and 6 kHz some of the DPOAEs were measurable. In this study cross-sectional sampling is used, hearing evaluation was done for GE and Right Ear after exposure to noise from military operations. The GE hearing thresholds were used as controls. No separate control group was included in the study.

Glorig published that green ears had greater TTS than those whose ears have already been exposed for a long period (ripe ears). The mean age of subjects in the present study was 21.26 years and being all male. The age of the subjects was in the range of 18–22 years. In present study for the distinct analysis of frequencies, following 3 years of noise exposures significant differences in PTA at 2000, 3000, 4000 and 6000 Hz were observed for the right ear and no significant difference at 2000 Hz for the left ear was observed. Comparison of audiometric results in different frequencies of GE and RE after exposure and showed that there was a significant difference at 4000 Hz ($P < 0.001$), 1000 Hz and 6000 Hz($P < 0.001$) Hz in the right ear. However, in the left ear, there was no significant difference at 2000 Hz frequency. In a study by Ghasemi et al. most significant shift in hearing thresholds was seen at 4 kHz. In this study, STS was observed in 12 subjects. Mean age of these subjects was 19.33 years. Of the 12 subjects four had STS in bilateral ears, four in the right side and rest four in the left side. The range of STS (as compared to baseline) varied from 18 to 43 dB (air conduction thresholds). A total of four subjects had audiometric notch, two at 2 kHz, one each at 4 kHz and 6 kHz. Nair and Kashyap studied the classical audiometric notch at 4 kHz (Aviators notch) as mentioned in the literature as pathognomy of NIHL was seen replaced by 6 kHz notch in a significantly large number of Indian Air Force personnel. This study emphasizes the significance of early involvement of 6 kHz in the present noise environment in detecting NIHL. Chung describes 27 cases of NIHL from 1000 Hz and 6000 Hz ($P < 0.001$), and 6 kHz ($P < 0.001$) in the right ear [Table 2] and at 4 kHz ($P < 0.0001$) and 6 kHz ($P = 0.0284$) in the left ear [Table 3].

**Table 2: Decrease in DPOAE amplitudes in right ear among the groups, that is, green ears (GE) and exposed ears (EE)**

| Fq (kHz) | SNR-green Ears (rt) | SNR-exposed ears (rt) |
|---------|---------------------|----------------------|
| 2       | 15.0042±1.15688     | 13.2553±1.26842      |
| 3       | 17.5349±1.48163     | 11.6608±1.54899*     |
| 4       | 17.7977±1.3755      | 5.5096±1.37902**     |
| 6       | 7.5526±1.24118      | 1.67755±0.78582**    |

* $P < 0.01$; ** $P < 0.001$ compared with green ear versus exposed ear. Data present in Mean±SEM.

23 subjects in Left ear and in personnel having Green ears i.e., 11 subjects in right ear and 6 subjects in Left ear.

**Table 3: Decrease in DPOAE amplitudes in left ear among the groups, that is, green ears (GE) and exposed ears (EE)**

| Fq (kHz) | SNR-green Ears (lt) | SNR-exposed ears (lt) |
|---------|---------------------|----------------------|
| 2       | 16.5194±1.33179     | 13.093±1.33456       |
| 3       | 18.9972±1.24966     | 12.3045±1.54119      |
| 4       | 19.4493±1.20736     | 7.55811±1.47983*     |
| 6       | 6.9243±1.35366      | 4.14868±0.95586**    |

* $P < 0.001$; ** $P < 0.05$ compared with green ear versus exposed ear. Data present in Mean±SEM.
SUMMARY AND CONCLUSION

In the military profession, hearing is a vital strength during maintenance and operations of different military equipment. Exposure to loud noises is inevitable indicating NIHL as a serious problem. The threshold differences between unexposed and exposed groups show that noise-exposed personnel are more likely to develop hearing loss. The results of DPOAE suggest that this test is important and more coherent than audiometry alone for the early detection of cochlear injury due to noise from military operations. Because these tests are quick, objective, and efficacious for detecting NIHL, it can be a standalone or supplementary test in occupational diagnostic audiology for assessing and monitoring hearing in workers exposed to noise. Our results have demonstrated that exposure to noise can disturb cochlear function in which DPOAE is more sensitive than PTA.

Prevention is still the cornerstone of treatment and the armed personnel need to be educated with regards to the use of Hearing Protection Devices (HPDs). Baseline-monitoring and assessment of hearing should be performed at the end of the training course for better evaluation of permanent changes. We also recommend that hearing assessment be performed for the frequencies that we did not assess in this study as reduced DPOAE levels in these frequencies may be the earliest sign of hearing loss. These findings can guide us in developing better hearing protection guidelines and aids. The goal of a hearing conservation program for this population should be to preserve hearing and educate these individuals about the importance of using hearing protection correctly.

The significance of audiological assessment at the beginning of military carrier for assigning the appropriate job to the new recruits following their completion of course work cannot be underestimated and needs to be implemented across the Defence Services/Paramilitary. The inability to clearly differentiate auditory cues generated due to improper functioning/malfunctioning of equipments may lead to error in judgment and mission failure, costing the armed forces huge sums of money in terms of loss of life and equipment. Further, an already impacted hearing will deteriorate in the severity of hearing impairment within a short span of service in the noisy military environs, rendering waste the money spent/shelled out on their training. Hence to optimize and enhance the performance of the troops, placing the right man with sound/intact hearing for those fine tasks coupled with use of appropriate hearing protective devices will go a long way not only in maintaining/sustaining the efficiency and combat preparedness of the troops but will minimize/prevent human errors. The results obtained for both pure tone audiometry and OAE’s are comparable and hence the latter may be used as an alternate means of assessment of hearing impairment due to simplicity in its implementation.

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Conflicts of interest

There are no conflicts of interest.

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