Evaluation of Noise-Induced Hearing Loss with Audiometer and Distortion Product Otoacoustic Emissions

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Objective: *To compare the results of audiogram and distortion product otoacoustic emissions (DPOAEs) parameters between staffs working in a noisy environment and normal subjects.*
Material and Method: *Hearing function of 32 noise-exposed workers and 18 reference subjects were assessed with DPOAEs and pure-tone audiometry. Results were compared among three groups: 1) ears of reference subjects, 2) audiometrically normal ears of noise-exposed subjects, and 3) audiometrically abnormal ears of noise-exposed subjects.*
Results: *DPOAEs parameters, statistically significant difference were found between group 1 and 2 and group 1 and 3 at all frequencies. Statistically significant differences in pass rate for DPOAEs at 4-6 kilohertz (kHz) were also found between group 1 and 2.*
Conclusion: *DPOAEs are more sensitive than audiometry to detect pre-symptomatic inner ear damage. It may play a role as screening and monitoring test for noise-exposed workers.*

Keywords: *Otoacoustic emissions, Occupational health*

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People who work in potentially hazardous noisy places or have excessive exposure to environmental and leisure activities, the hearing loss may develop slowly over 15- to 20- year period. These are the results of regular and repeated noise, which has damaged the outer hair cells of the inner ear that interpret sound vibrations as words, music or other sounds[1,2]. Typically, the first to be affected are high tones.

Noise-induced hearing loss is permanent and not correctable by medical or surgical treatment, but is the most preventable type of hearing impairment. Severe hearing impairment caused by noise is best avoided by early detection and prevention. Noise-induced hearing loss is currently detected and monitored with pure- tone audiometry. This method is subjective, time-consuming, and not quite sensitive to small changes in pure tone thresholds. Since recently, a modern diagnostic method - otoacoustic emissions, may be used as an accurate, objective, fast, and non-invasive tool for assessing the function of outer hair cells in clinical practice.

Otoacoustic emissions (OAEs) are low-level sounds originating within the cochlea. Through reverse propagation, some of this acoustic energy leaks from the cochlea and travels through the middle ear to the external auditory meatus, where it can be recorded using a sensitive microphone. First described by Kemp[3], OAEs are believed to be the acoustic by products of outer hair cell motility.

Two clinically popular OAEs are transient evoked otoacoustic emissions (TEOAEs) and distortion product otoacoustic emissions (DPOAEs), which are evoked by different stimuli and provide different cochlear information[3-5]. TEOAEs are evoked by a click stimulus and represent the activation of broad regions of hair cells; whereas DPOAEs are evoked by two primary functions (f1/f2) simultaneously presented tones of slightly different frequencies and represent

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the stimulation of more focused, restricted regions of hair cells.

Many experiments in animals have shown that exposure to loud noise causes morphological change of outer hair cells and reduces TEOAEs and DPOAEs levels[6,7]. In studies on a population of workers exposed to high levels of noise, Lucertini et al[8] found a statistically significant difference of TEOAEs parameters (signal to noise ratio, response level, reproducibility and latency) of the following two groups: 1) between normal and impaired ears, and 2) between ears either exposed or unexposed to noise that were audiometrically normal. Vinck et al[9] also found that the DPOAEs response and some TEOAEs parameters (band reproducibility and signal to noise ratio - SNR) were significantly reduced and had not fully recovered after the postexposure interval in the 4-kilohertz (kHz) frequency region, although the pure tone audiogram showed no evidence of hearing loss at that time. It has been proposed that otoacoustic emissions (OAEs) may be a more sensitive test of cochlear function than pure-tone audiometry in early detection of subclinical cochlear damage[10-13]. Although both OAEs tests have been used in studying the effect of noise on the cochlea[14-18], DPOAEs are probably most useful because of their better performance at 4 kHz, which is the most affected frequency in noise-induced hearing loss[19].

In Songklanagarind Hospital Thailand, the prevalence of noise-induced hearing loss diagnosed with pure-tone audiometry in people who work in hazardous noisy places increased from 28.1% in 1988 to 35.2% in 2001[20,21]. The objective of the present study was to evaluate noise-induced hearing loss in a group of people who worked in potentially hazardous noisy places in Songklanagarind Hospital with pure-tone audiometry and DPOAEs. DPOAEs may be an alternative to pure-tone audiometry in monitoring cochlear changes in subjects exposed to occupational noise.

Material and Method

Subjects

In this cross-sectional study the hearing of 32 workers with an average noise exposure period of 15.2 years, aged between 24 to 45 years and 18 subjects with no history of noise exposure were examined. They were classified according to a pure tone audiometric test and the history of noise exposure into three groups:

1) a reference group or audiometrically normal ears of subjects non-exposed to noise

2) audiometrically normal ears of subjects exposed to noise

3) audiometrically abnormal ears of subjects exposed to noise.

Subjects in all these groups had no underlying disease (diabetes mellitus, hypertension, dyslipidemia) and were selected on the basis of the lack of exposure to ototoxic agents, ear trauma or surgery, chronic ear diseases, and a family history of hearing loss. These groups were only different in relation to the history of noise exposure. Individuals in the noise-exposure group underwent experimental testing at least 14 hours after they stopped working. They had no history of upper respiratory tract infection or ear problems and were not under the influence of alcohol, so any confounding effects were avoided**.**

The research proposal was approved by the ethical committee, Faculty of Medicine, Prince of Songkla University, and informed consents were obtained in all subjects.

Procedures

The subjects completed a questionnaire regarding the history of noise exposure, ear diseases, and underlying diseases. Conventional pure-tone audiometry and DPOAEs were conducted after otoscopic examination, which included the removal of wax from the ear canal.

Conventional pure-tone audiometry

The conventional pure-tone audiometry was conducted in a sound-treated room. The hearing thresholds of each ear at frequencies of 0.25, 0.5, 1, 1.5, 2, 3, 4, 6, and 8 kHz were measured. Standard audiometric procedures were applied during audiometric investigation.

The examined ear was defined as “normal” if a threshold shift larger than 25 decibels (dB) was not found over the whole frequency range. For abnormal audiogram, threshold shifts larger than 25 dB in any audiometric range (frequency $\geq$ 3 kHz) of the ear were defined as “high frequency impairment”. For noise-induced hearing loss, the audiogram showed a notch pattern in the 3,000 to 6,000 Hz region and normal thresholds in the 8-kHz frequency.

Otoacoustic emissions

DPOAEs were recorded on both ears in a soundproof room by an audiologist. The ILO292 Otodynamic analyzer was used. The DPOAEs test consisted of presenting two primary tones at frequencies f1 and f2 and levels L1 and L2. The frequency ratio f2/f1 was fixed at 1.22. The stimuli levels were held constant at L1= 65dB sound pressure level (SPL) and L2 = 55 dB SPL. The level amplitude and SNR of the DPOAEs occurring at the 2f1-f2 frequency were measured with f2 frequency in Half-octave-band frequencies of 1, 1.4, 2, 2.8, 4, and 6 kHz.

DPOAEs test results

Amplitude of ≥ 6 dB above the level of noise floor was regarded as an indication of a distortion product (DP) being present, and the subjects are assigned as a pass case.

Statistical analysis

For the three groups of ears, median and range were used to describe continuous data (non normal distribution). The statistical differences among the groups have been evaluated according to Kruskal Wallis test and Mann-Whitney U test. Results of pass rate for DPOAEs were compared by Chi-square test or Fisher's exact test. All analyses were performed using SPSS version 13, p-value less than 0.05 was statistical considered significant.

Results

Audiometric testing

Thirteen out of 32 subjects with noise exposure had a hearing loss (40.6%). Seven subjects had unilateral hearing loss. However, high frequency hearing loss was most common (13 out of 19 ears). Only six ears presented with a typical noise-induced hearing loss.

Audiometric testing showed that all subjects with noise exposure had normal hearing levels (25 decibels hearing level or better) at lower and middle frequencies (0.25-2 kHz). The pure-tone thresholds obtained from the subjects with noise exposure and those from the reference group showed a statistically significant difference at 2- to 8-kHz frequencies (Table 1).

DPOAEs testing

As shown in Fig. 1 and 2, statistically significant differences between the reference group and noise exposure subjects could be shown by comparing the two with DPOAEs parameters (response amplitude and SNR). Noise-exposed with abnormal audiogram subjects (Group 3) showed the lowest mean response amplitude and SNR with statistically significant difference from the reference group at all frequencies. In noise-exposed with normal audiogram (Group 2) also showed lower mean response amplitude and SNR than the reference group and significantly differed at all frequencies.

Fig. 3 demonstrates the percentages of ears that passed DPAOEs test. SNR ≥ 6 dB was regarded as an indication of a DP being present, and the subjects were assigned as a pass case. Pass rate differed significantly between the noise exposure with abnormal audiogram subjects (Group 3) and the reference group. Lower pass rate for the noise exposure with normal audiogram subjects (Group 2) than reference groups were recorded and were statistically significantly different at 4- and 6-kHz frequencies.

Discussion

Noise-induced hearing loss is usually diagnosed by pure-tone audiometry. This method is subjective, time consuming, and not quite sensitive to small changes in pure tone thresholds. OAEs are a diagnostic method that is used as an accurate, objective,

Table 1. Pure tone threshold at 0.25-8 kHz for the three groups of ears

Group	Median pure tone threshold (range), (dB HL)						
	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz	6 kHz	8 kHz
1. reference ears (n = 36 ears)	15 (15,15)	15 (15,15)	15 (15,15)	10 (10,15)	10 (10,15)	10 (10,15)	10 (5,15)
2. audiometrically normal ears of subjects exposed to noise (n = 45 ears)	15 (15,20)	15 (15,15)	15 (15,20)	15 (10,15)	15 (10,20)	15 (15,20)	15 (15,20)
3. audiometrically abnormal ears of subjects exposed to noise (n = 19 ears)	20 (15,20)	15 (15,20)	15 (15,20)	20 (20,25)	30 (25,45)	35 (30,45)	30 (25,45)
p-value (1 vs. 2)	<0.0001	0.725	0.202	0.006	<0.0001	<0.0001	<0.0001
p-value (1 vs. 3)	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

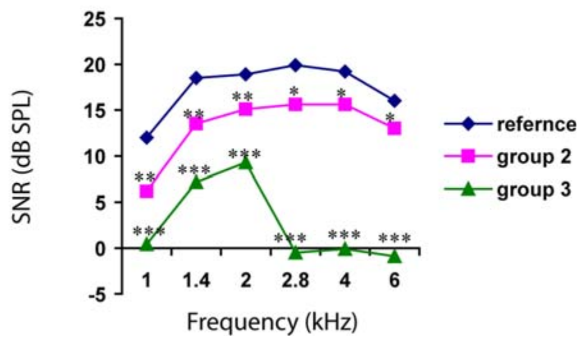

Fig. 1 SNR of DPOAEs of the three groups of ears
* p < 0.05, ** p < 0.01, *** p < 0.001, compared with reference group

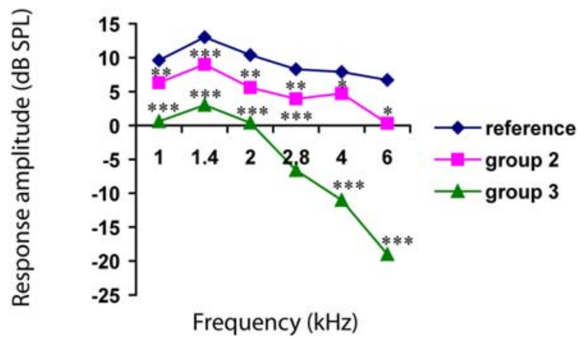

Fig. 2 Response amplitude of DPOAEs of the three groups of ears
* p < 0.05, ** p < 0.01, *** p < 0.001, compared with reference group

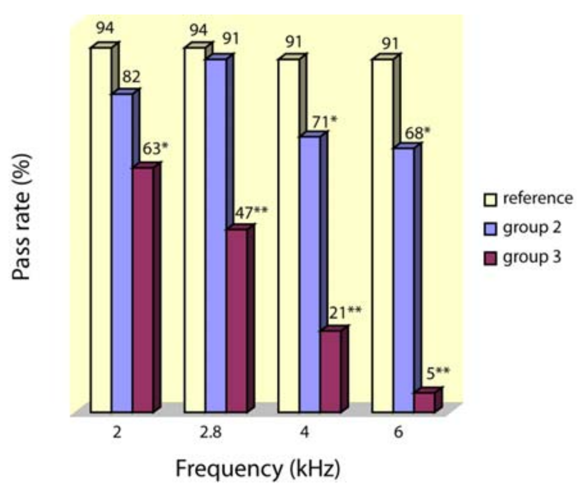

Fig. 3 Pass rate for DPOAE test at 2-6 kHz (Pass if SNR $\geq$ 6 dB)
Fisher's exact test, * p < 0.05, ** p < 0.01, compared with reference group

fast, and non-invasive tool for assessing the function of outer hair cells. For these reasons, OAEs have been proposed as an alternative method for monitoring cochlear function in cases with noise exposure(15-19).

DPOAEs are better for high than for low frequencies due to the higher contamination of noise at low frequencies(22), and have been used in a study of noise affected hearing at high frequencies (3-6 kHz). Results from several studies have demonstrated that OAEs parameters (response level, reproducibility, and SNR) are depressed following noise exposure(6-9). Sliwinska et al(22) found that DPOAEs demonstrated a very typical shape of Distortion Product gram (DP-gram) with the decrease in otoacoustic emissions primarily at the frequencies of 3-4 kHz in the case of industrial noise-induced hearing loss.

In the present study, the difference in DPOAEs parameters (amplitude level, SNR) between reference group and noise-exposed subjects with abnormal audiogram was expected, because DPOAEs are elicited in ears with normal hearing of up to 40 to 55 dBHL(19) and these parameters had already proven to be significantly correlated to the audiometric hearing loss.

Hofstetter et al(23) found that DP amplitude decreased at a rate of 4.1 dB for every 10% increased outer hair cell loss in chinchillas with outer hair cell destroyed by carboplatin. The finding of the present study of diminished DPOAEs amplitude at 1-6 kHz among noise-exposed subjects with normal audiogram confirmed that the damage of outer hair cells from noise can develop before it shows up on the audiogram. Additionally, abnormal findings for DPOAEs at all test frequencies in all noise-exposed subjects were found in the present study, whereas audiometric testing showed that all of them had normal hearing levels at lower and middle frequencies (0.25-2 kHz). Cochlear dysfunction in noise-induced hearing loss may extend beyond the frequency region suggested by the audiogram(15).

Results of pass rate for DPOAEs test at 2-6 kHz revealed that more than 90% of reference group passed DPOAEs at all frequencies, while the lowest pass rate was found in noise-exposed subjects with abnormal audiogram across all tested frequencies. Statistically significant differences in pass rate for DPOAEs at only 4-6 kHz were also found between noise-exposed subjects with normal audiogram and reference group.

DPOAEs provided functional information about well-defined frequency-specific regions of the cochlea. It has been shown that there is little intra-subject variability in OAEs measurements[24]. Therefore, DPOAEs may play a role as a screening tool for subjects exposed to occupational noise at the time of periodic screening audiometry. Workers with abnormal DP screening results, even if audiometric results are normal, should have follow-up counseling and evaluation of hearing-protective-device effectiveness to prevent irreversible noise-induced hearing loss.

However, there are no guidelines for the use of OAEs to detect and monitor noise-induced hearing loss now. Clarifying advantages of DPOAEs in terms of sensitivity to early manifestations of noise insults, or their utility in predicting future loss in hearing will require longitudinal follow up in which the same people are watched over time to see how their hearing changed with their otoacoustic emissions.

In conclusion, the presenting results are in agreement with the findings of previous studies, in that DPOAE testing was shown to be more sensitive to pre-symptomatic inner ear damage than conventional audiometry but cannot estimate hearing thresholds. DPOAE testing should be implemented as a screening and monitoring test for noise-exposed workers rather than as a replacement of audiometry.

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การประเมินภาวะประสาทหูเสื่อมจากเสียงด้วยเครื่องตรวจการได้ยินและเครื่องตรวจวัดเสียงสะท้อนจากหูชั้นใน

วิราภรณ์ อัจฉริยะเสถียร, สาธิต ชยาภัม, สุชาดา แซ่โค้ว

***วัตถุประสงค์**: เพื่อเปรียบเทียบผลการตรวจการได้ยินและการตรวจวัดเสียงสะท้อนจากหูชั้นใน ระหว่างกลุ่มคนงานที่มีประวัติสัมผัสเสียงดังกับคนปกติที่ไม่มีประวัติสัมผัสเสียงดัง*

***วัสดุและวิธีการ**: ตรวจการได้ยินในคนงานที่สัมผัสเสียงดัง 32 คน และคนปกติ 18 คน ด้วยเครื่องตรวจการได้ยินและเครื่องตรวจวัดเสียงสะท้อนจากหูชั้นใน (distortion product otoacoustic emissions, DPOAEs) ทำการเปรียบเทียบค่าที่ได้จากการตรวจระหว่าง 3 กลุ่มคือ 1. หูของคนปกติ 2. หูของคนงานที่สัมผัสเสียงดังและผลการตรวจด้วยเครื่องตรวจการได้ยินปกติ 3. หูของคนงานที่สัมผัสเสียงดังและผลการตรวจด้วยเครื่องตรวจการได้ยิน พบประสาทหูเสื่อม*

***ผลการศึกษา**: ค่าที่ได้จากการตรวจด้วยเครื่องตรวจวัดเสียงสะท้อนจากหูชั้นใน (DPOAEs) ทั้งในกลุ่มที่ 2 และ 3 (มีประวัติสัมผัสเสียงดัง) แตกต่างจากกลุ่มที่ 1 อย่างมีนัยสำคัญที่ทุกความถี่ของการตรวจ และอัตราการผ่านการตรวจด้วยเครื่องตรวจวัดเสียงสะท้อนจากหูชั้นใน (DPOAEs) ที่ความถี่ 4-6 กิโลเฮิรตซ์ ในกลุ่มที่2 ต่ำกว่ากลุ่มที่ 1 อย่างมีนัยสำคัญเช่นกัน*

***สรุป**: เครื่องตรวจวัดเสียงสะท้อนจากหูชั้นใน (DPOAEs) มีความไวในการตรวจพบความผิดปกติของหูชั้นในดีกว่าการตรวจด้วยเครื่องตรวจการได้ยิน ดังนั้นน่าจะมีบทบาทในการใช้เป็นเครื่องตรวจคัดกรองและเฝ้าระวังในคนงานที่สัมผัสเสียงดัง*