Otoacoustic emissions and recreational hearing loss

The risk of noise-induced hearing loss from amplified high-intensity music was predicted by Careau et al. in 1982, who noted that, in a study of 994 subjects aged 16 to 20 years, “...the accumulated exposure of some of them to noise is such that, if their reverberant patterns remain the same, they are at risk of some noise-induced hearing loss by their mid-20s. Further empirical studies are necessary to determine whether these hearing losses will eventuate.”

In this issue of the Journal (page 580), LePage and Murray use the relatively new technique of otoacoustic emission (OAE) analysis to investigate noise-induced hearing loss resulting from the use of personal stereo headsets. Their results suggest that personal stereo use results in a decline in cochlear function analogous to rapid ageing of the cochlea, and comparable to hearing loss from industrial noise trauma. They also emphasize that, as OAE analysis can detect decline in cochlear function long before there is any clinically detectable hearing loss, this technique can potentially provide early warning of noise-induced hearing loss.

Otoacoustic emissions were first described by Kemp in 1978. They are sounds thought to be generated by the cochlear outer hair cells in response to an external sound stimulus. Normal hearing threshold is achieved by a cochlear mechanism, thought to reside in the healthy outer hair cell, which magnifies the stimulus internally. When the mechanism loses the peak of its performance, OAEs diminish and hearing threshold is raised. As OAEs can be recorded in the outer ear, they may provide an objective, non-invasive and quantitative measure of hair-cell function. OAEs are relatively stable, with individuality demonstrated for individuals, although there is variability between subjects.

Four types of OAEs have been described.2,3 Spontaneous OAEs occur in 68% of infants younger than 18 months, but the incidence falls to 35% in adults under 50, and to 20% of adults over 50 years.4 Transient-evoked OAEs (TEOAs), a response to acoustic clicks delivered to the outer ear, are currently thought to be the most clinically useful OAEs, as they are detectable in 98% of people with normal hearing, regardless of age or sex, and the two ears of any individual produce similar TEOAs. Stimulus-frequency OAEs occur in 88%–100% of people with normal hearing, and recordable TEOAs in behaviour. They represent fixed-place emissions corresponding to specific frequency sites along the organ of Corti, but their usefulness as a clinical test is limited by technical factors. Distortion-product OAEs (DPOAEs) also occur in 100% of people with normal hearing, and, while small in amplitude, can be used to intentionally test a specific frequency region of the cochlea. DPOAEs are technically difficult to measure, but will become an essential tool in the investigation of tonotopic outer hair cell function.

Probst et al have provided an extensive review of the technical details, experimental and clinical findings of otoacoustic emission analysis.4,5 Measurement of OAEs has become a useful audiologic and otoneurologic diagnostic test for neonatal screening,4,6,7 otocleisis,8 otosclerotic hearing loss,8,9 Menière’s disease,10 acoustic neuromata,11 tinnitus,12 ototoxicity,13 and noise-induced hearing loss.14,15 A limiting factor in this kind of ear testing is the eustachian tube dysfunction will reduce otoacoustic emission energy. Therefore, tympanometry is essential if no otoacoustic emission can be measured. The reduction in outer hair cell activity in patients with noise-induced hearing loss, measured by DPOAEs, is directly related to frequencies of the audiometric loss. In one study, emissions were absent in 93.2% of ears with noise-induced hearing loss and in teenagers exposed to noise, and were found to be useful in the prediction of noise susceptibility.16 In another, ears with a noise-induced impairment showed a significant reduction in the incidence of both spontaneous emissions and spectral peaks in evoked emissions that was not evident in ears with similar patterns of hearing loss caused by other factors.4

Are the listening habits of the younger generation potentially dangerous to hearing? Being et al studied 681 students aged 10 to 19 years.17 Although 50% of students listened to music for less than one hour per day, 10% listened for four or more hours. Among those aged 12 to 16 years, 10%, chose to set the listening level at 110 dB (A). It was estimated that 7% were exposed to noise levels likely to damage the cochlea. They recommended that the sound levels for portable music players be limited to 90 dB (A). Hearing loss has been documented in people who attended rock music concerts,18 in employees of urban music clubs,19 and one report indicates that exercise combined with exposure to music presents a greater risk to hearing than the music alone.20 These authors conclude that “the results have implications related to contemporary lifestyle issues such as aerobics and the utilisation of personal music systems during physical exertion.”

The risk of recreational noise-induced hearing loss is real, and our patients must be advised of this risk. LePage and Murray have demonstrated that early warning is now available in the form of the transient-evoked otoacoustic emission test.

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Latent cochlear damage in personal stereo users: a study based on click-evoked otoacoustic emissions

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Abstract

Objective: To assess the effects of use of personal stereo systems (PS) on hearing by means of the objective measures of transient-evoked otoacoustic emissions. Participants and setting: People aged between 10 and 59 years who had transient otoacoustic emissions recorded by the National Acoustic Laboratories: between 1989 and 1997 were eligible for inclusion. Recordings from participants with hereditary disorders or any form of aural disease (eg, otitis media, tinnitus, fluctuant hearing loss, Meniere’s syndrome, or exposure to ototoxic substances) were excluded. Methods: Transient-evoked otoacoustic emission (TEOAE) records were obtained with a standard 250 repetitions of an 80 dBn train of clicks used for recording outer hair cell activity. The measure of otoacoustic emission strength was the DPOAEs at 25 dBn difference. For each participant, all the test factors relating to their hearing history were assessed from patient referral information or from demographic information obtained in writing at the time of recording either in the form of a detailed questionnaire or verbal assessment. Otoacoustic emission data were analysed according to age, industrial noise exposure and personal stereo use. Results: Usable otoacoustic emission records were obtained from 1724 people (1366 males and 568 females). Otoacoustic emission strength declined with age, and was significantly lower in males than females, lower in people exposed to industrial noise than those not exposed, and significantly lower in users of personal stereo systems than non-users. People with both kinds of noise exposure had values which were significantly lower again, indicating an additive effect. Conclusions: As only 39 people with PS exposure addicited any hearing impairment in otoacoustic emission strength foregrounds premature hearing loss in personal stereo users.

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1: Otoacoustic emissions

The cochleas of mammals contain two sets of hair cells — the inner hair cells (IHC) and the outer hair cells (OHC). The IHC are passive, sensory cells which directly stimulate the auditory nerve, while the OHC are active, muscle-like cells which act as a "cochlear amplifier". The primary reason people suffer a permanent hearing loss is a significant decline in the numbers or functionality of OHC's, leading to loss of internal amplification.

Otoacoustic emissions (OAEs) are the sounds that the activity of the OHCs generate in the ear canal, which can be measured with a microphone and, with modern technology, separated from sounds entering the ear canal. OAEs are usually too weak to be heard audibly, but they are easily distinguishable from sensorineural hearing loss.

We used the OtoDynamics ILO88 analyser (OtoDynamics Ltd, Herfordshire, England) in this study. A probe containing both a speaker (which delivers the stimulus) and a microphone (for recording the response) is sealed in the ear canal. We used the transient-evoked (or click-evoked) otoacoustic emission (TEOAE) technique, which specifically targets the active OHC response and ignores the acoustic response of the external and middle ear. A standard 2460 repetitions of an 80 dB click train of clicks lasting 1 ms are delivered to the ear, and the otoacoustic emission response from the outer hair cells is detected by the microphone. The first 20 ms of the response following the click is averaged to improve the quality of the signal. Stability of probe placement is routinely monitored and displayed as a percentage with the record. Data collection for approximately one minute gives a clinically useful waveform. Alternate responses are summed into two arrays and at the end of recording the correlation coefficient between the arrays is calculated. This coefficient (range, -1.0 to 1.0) is normally expressed by OtoDynamics as a percentage, denoted by the term Wavepromax (designated by some authors as Wholerpromax%), which is a measure of strength of the emission.

Complete sets of OHCs (such as in neonates) produce emissions near 100%. As the ear ages or is progressively damaged, the Wavepromax decrease. Wavepromax may be compared across the population provided a standard 80 dB peak stimulus is used.

The ability of TEOAE to measure net activity of any ear is of particular relevance to this report, which relates otoacoustic emissions to age and two specific risk factors. The relationship between Wavepromax and pure tone threshold hearing levels is illustrated, showing that the Wavepromax needs to decline to below about 35% before hearing loss is detectable by audiometry. Hence, TEOAE may be able to detect accumulated ear damage in the preclinical range. If so, the technique may prove useful in detecting latent damage caused by noise and other factors.

Methods

The protocol we used for obtaining transient-evoked otoacoustic emission records is described in Box 1.

The data for this study were obtained from 2500 people tested as part of the National Acoustic Laboratories research program between 1989 and 1997. Information about participants' hearing histories was obtained from data supplied by referring clinics or otologists (12%), standardised questionnaires filled out (60%) or verbal evaluation (18%) at the time of recording, or from Australian Hearing's NALCOMM (National Acoustic Laboratories Computer Aided Management) database (10%). Subjects were asked about a history of occupational hearing loss, exposure to loud noise, music exposure, long hours in noise, hearing protection use, and recent noise exposure.

Acceptable exposure histories were obtained by asking subjects to estimate their average number of hours per week and their years of exposure with any adverse activity, such as musical exposure, playing an instrument, noise exposure, and personal stereo. Participants' data were included in the analysis only if an acceptable pair of recordings were obtained for both left and right ears in the same recording session. Participants' records were excluded if the recording stability value was less than 80%, if participants failed otoscopic inspection, or if they had a conductive or sensorineural hearing loss, aural debris, middle-ear disorders, otosclerosis, or fluctuant hearing loss (Meniere's syndrome, or exposure to ototoxic substances).

For the 4.3% of participants who provided repeat records over the nine years of recording, we included only the pair of records with the highest emission strength. Participants were aged 10 years to less than 60 years on the day of recording.

On the basis of the sound exposure histories recorded in the database, participants who reported personal stereo (PS) use were divided into three categories: PS = 0 (no exposure), PS = 1 (moderate, 1 hour or less exposure per week), and PS = 2 (heavy, > 6 hours per week). Similarly, subjects were classified into two industrial noise (IND) categories according to whether they ever worked in a noisy industry: IND = 0 ("no"), and IND = 1 ("yes"). These classifications did not exclude other noise exposure factors.
Statistical analysis
We applied analysis of variance with multiple linear regression in which the independent variables were sex, age (grouped by decade: 10-19, 20-29, 30-39, 40-49 and 50-59 years), PS use category, and industrial noise category. The dependent variable was the mean of values for both ears of otosomatic emission strength (TEOAEs, Waverrops%); see Box 1). The multiple linear regression was performed using Stata software."
4: Multiple linear regression model showing additive effects relative to the reference conditions for each of the risk categories

<table>
<thead>
<tr>
<th>Variable</th>
<th>Reference condition</th>
<th>Added risk</th>
<th>Effect</th>
<th>Standard error</th>
<th>Confidence interval</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.001</td>
</tr>
<tr>
<td>Sex Female</td>
<td>Male</td>
<td>-5.4</td>
<td>1.3</td>
<td>-7.9 to -2.9</td>
<td>&lt;0.001</td>
<td></td>
</tr>
<tr>
<td>Age (years)</td>
<td>10-19</td>
<td>-3.5</td>
<td>2.0</td>
<td>-7.4 to 0.4</td>
<td>0.083</td>
<td></td>
</tr>
<tr>
<td></td>
<td>20-29</td>
<td>-8.4</td>
<td>2.1</td>
<td>-12.5 to -4.3</td>
<td>&lt;0.001</td>
<td></td>
</tr>
<tr>
<td></td>
<td>40-49</td>
<td>-12.9</td>
<td>2.2</td>
<td>-17.2 to -8.6</td>
<td>&lt;0.001</td>
<td></td>
</tr>
<tr>
<td></td>
<td>50-59</td>
<td>-24.1</td>
<td>2.5</td>
<td>-29.0 to -19.2</td>
<td>&lt;0.001</td>
<td></td>
</tr>
<tr>
<td>Objective stereo use</td>
<td>Negligible Moderate</td>
<td>-10.7</td>
<td>1.6</td>
<td>-13.7 to -7.6</td>
<td>&lt;0.001</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Severe Moderate</td>
<td>-12.3</td>
<td>2.0</td>
<td>-16.2 to -8.4</td>
<td>&lt;0.001</td>
<td></td>
</tr>
<tr>
<td>Industrial noise exposure</td>
<td>None</td>
<td>-7.6</td>
<td>1.7</td>
<td>-10.8 to -4.3</td>
<td>&lt;0.001</td>
<td></td>
</tr>
</tbody>
</table>

Further, for males exposed to both PS use and industrial noise, the ototoxic emission strength was significantly lower (P<0.001) in all age ranges other than the 10-19 years and 40-49 years range. Remarkably, for the 30-39 years range there was no significant difference between the group exposed to industrial noise and the PS use group, both of which were significantly different from the non-exposed groups (P<0.001). Yet the young adult PS users (20-29 years) had ototoxic emission strengths significantly lower than non-users (P<0.001), suggesting that the decline occurs in the late-teenage and early-adult period—a decade earlier than the expected industrial effect.

The multiple regression analysis showed that, in our sample, the apparent rate of decline in ototoxic emission strength among young adults was greater for PS users who were also exposed to industrial noise. However, it is worth noting that this group included a subgroup of 26 deep coal miners whose mean values were a whole standard deviation lower than males with no industrial noise exposure.

Based on existing guidelines for occupational noise level limits in all Australian States and Territories of an eight-hour equivalent continuous A-weighted sound pressure level of 85 dB, it is surprising that PS use for less than six hours weekly at typical sound levels of 95 dB results in such a high level of damage accumulation. This leads to speculation that there may be other factors involved with sound delivered through earphones compared with free-field sound, such as more efficient delivery of high-frequency sound coupled with the high dynamic range of modern PS units. The popular- ity in recent years of units offering "additional bass boost" is consistent with the notion that users may be endeavouring to enhance the sense of sound envelopment which occurs at higher levels. Our findings strongly support the previous assertions by Waugh and Murray of increased risk of ear damage from PS use, particularly if personal stereo are used in other environments in which users tend to raise the listening level to mask our background noise (such as on public transport or while engaging in aerobic exercise), which may lead to generalised inner-ear problems.

A 1996 study by Meyer-Bisch appears to be the only one to have succeeded in showing a significant difference between actual hearing levels of PS users and those of a con-

Discussion

Our findings suggest that there is a strong trend for the strength of ototoxic emissions to decline with protracted use of PS headers, and that the site of this decline is propor- tional to the amount of exposure. Although the separa-
tion of PS users into moderate and heavy categories was based on self-report, the multiple regression showed an effect between the moderate and heavy users. However, the design of our study did not exclude the effects of other forms of noise to which people who tend to use PS systems may also be exposed. If PS exposure is associated with other lifestyle factors, our analysis would not have differentiated them between them. Other factors, such as leisure and other non-occupational noise exposure (eg, power tools, car racing, concerts) and forms of injury to which males are more exposed (eg, head injury, baro-

parison as very few women [33] had had industrial noise exposure compared with men [286]). Thus, the four lowest curves in Box 3 compare four mutually exclusive noise expo-
sure groups for males only. The corresponding sample sizes for males in these exposure categories are also shown in Box 3. Considering each age range in turn, there was no significant

 difference between four noise exposure groups at 10-19 years of age. However, for participants aged 20-29 years, all noise exposure groups were significantly different from each other (P<0.01), with the exception of groups IND=1 (industrial noise exposure only) and PS=0, IND = 0 (neg-

ligible PS use and no industrial noise exposure). In the 30-39-years group there was no significant difference between the PS=0, IND=0 group and the group with both PS and industrial noise exposure (P<0.01). For both the 40-49-years and the 50-59-years groups, the PS=0, IND=0 group was significantly different from the group with PS use only, and also the group with both PS and industrial noise exposure (P<0.01). The mean values for the industrial noise exposure only group were the same as for the PS exposure group but the sample size was small.

Box 4 shows the results of the multiple linear regression. For each of the sections conditions tested, the slopes (the "Effect" column) representing the rates of decline of Wavepre-

% are highly significant. This Table indicates that Wavepre% for males was about 5% lower than for females. Wavepre% for moderate PS users was about 11% lower than for non-users, while for heavy PS users this value was 1.6% lower still; Wavepre% for respondents indicating industrial noise exposure was also 8% lower than for non-

exposed people. The age dependence was a decline in Wavepre% of 0.49% per year, or 4.9% per decade.

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References


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