Distortion Product Otoacoustic Emissions: Twelve Months Experience in a Diagnostic Clinic

CELENE McNEILL AND CHRISTOPHER WHITFELD
Hearing Research and Diagnostic Clinic , 350 Victoria St Darlinghurst NSW 2010

Over the past twelve months we have measured the distortion product otoacoustic emissions (DPOAE) of 626 patients with various aetiologies of sensori-neural hearing loss. The results were compared to the contour of the audiogram to assess the test's ability to predict configuration of hearing loss. The DPOAE amplitudes from 317 patients were compared to the behavioural hearing threshold at 500, 1000, 2000 and 4000 Hz. The data demonstrate a relationship between emission size and degree of cochlear hearing loss. The findings indicate that the test can be a useful tool to predict degree of cochlear hearing loss as well as the contour of the audiogram in up to 70% of cases. The test was not very effective to screen for retro-cochlear lesion as only 18% demonstrated DPOAE that differentiated them from cochlear lesions.

The clinical potential of otoacoustic emissions (OAE) have been discussed in extensive review articles such as Martin, Probst and Lonsbury-Martin (1990) and Probst , Antonelli and Pieren (1991). Our clinic was initially attracted to the objective nature of the test for the purpose of estimating hearing losses amongst clients seeking compensation for industrial deafness. Whilst we have access to electrophysiological testing to perform objective measurements, the ability to make a quick and objective assessment for every case within the routine appointment schedule was sought.

The possibility to use the procedure to predict retro-cochlear lesions as reported by Ohlms, Lonsbury-Martin and Martin (1990) was also of great interest for a diagnostic clinic. Patients with retro-cochlear lesions are expected to present emissions which are not compatible with their hearing levels.

There are two classes of OAE which are defined as spontaneous and evoked (Kemp, Ryan and Bray, 1990). DPOAE and transient evoked otoacoustic emissions (TEOAE) are the two main types of evoked OAE used for clinical purposes. DPOAE are elicited by a combination of two pure tones of different frequencies (F1 and F2) which are presented at the same time and a third frequency, generated by the outer hair cells, is measured in the ear canal during the stimulation. TEOAE are generated by repeated presentation of a stimulus of short duration, usually a click, and the emissions are measured after the stimulation (Martin et al, 1990).

The DPOAE technique was selected for our clinic because of its acclaimed frequency specificity, as we were looking for more than a screening procedure. Our choice was influenced by Probst's assertion that "it is not possible to obtain detailed information concerning the frequency configuration of the hearing loss from the TEOAE spectrum, because the absence of a certain frequency cannot be interpreted as an HL > 30 dB"

(Probst et al 1991). The frequency specificity of the TEOAE technique however is maintained in papers such as Kemp et al (1990).

This paper is a review of our experience after one year of clinical use of the DPOAE technique. Analysis of the DPOAE results compared to the behavioural pure tone audiogram of 626 patients with different hearing losses will be discussed in order to assess the clinical usefulness of this test as a routine procedure.

METHOD

The equipment used is a commercially available distortion product otoacoustic emission analyser (Virtual Model 330). The device incorporates an ear probe with a microphone housed in it for the recording of the emission from within the ear canal. Two separate earphones are connected into the probe via tubes for the generation of the eliciting stimulus. The probe is connected to a small preamplifier and then to a signal processing board within a Macintosh computer. The software to drive the probe and record the results is in the computer. Two pure tone signals F1 and F2 (one for each earphone) are generated and delivered to the ear canal via the probe simultaneously. The microphone records the sound pressure in the canal. It is delivered back to the computer where a fast Fourier transform is carried out to establish the frequency spectrum of sound in the ear canal during the stimulation. A typical measurement during one of these pairs of tones is shown in Figure 1. The figure shows various measurements which are made by the computer. They are, the frequency and sound pressure level of the eliciting tones F1 and F2, the frequency and sound pressure level of the distortion product emission (Fdp), the sound pressure level and measurement frequency of the noise floor (Fn) and the geometric mean of F1 and F2 (Fe). Fe is the frequency where the amplitude of Fdp is plotted and is the frequency to which the emission is generally ascribed when relating pure tone audiogram to distortion product emissions.

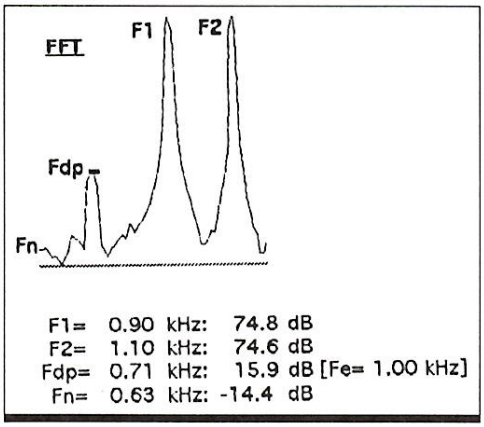

FIGURE 1

DPOAE measurement at 1 kHz where Fdp is the frequency and amplitude of the emission which is found at the frequency (2 x F1 – F2); Fn is the frequency and amplitude of the noise floor measurement and Fe is frequency of hearing to which the emission is ascribed.

The stimulus tones were set to 75 dB SPL each. Although studies such as Probst, Antonelli and Pieren (1990) have shown that the largest emissions are found with F1 approximately 10 dB louder than F2 others such as Hauer and Probst (1991) have demonstrated that this effect is reduced particularly in the high frequencies with a moderately high stimulus level. Thus we have chosen 75 dB SPL in order to get a robust emission from as many subjects as possible.

Louder stimuli were avoided as they can elicit the stapedial acoustic reflex and consequently reduce the amplitude of the recorded emissions (Whitehead, Martin, Lonsbury-Martin, 1991)

The results are displayed in a graph with emission size in SPL plotted as a function of the geometric mean of F1 and F2 together with the noise floor. This type of representation was chosen for its similarity to an audiogram. The displayed noise floor is a combination of patients biological and background noise.

The model 330 also enables selection of parameters to improve signal to noise ratio and demonstrate repeatability of measurements. To this end the device was set to

repeat each measurement in a stimulus where F1 and F2 were presented together in 8 bursts. The ear canal SPL recorded during these 8 bursts is then averaged to reduce the noise floor. The fast Fourier transformation is then carried out on the averaged ear canal SPL. This process was then repeated 4 times to demonstrate repeatability. If a signal to noise ratio of 10 dB was not obtained (Fdp > Fn + 10) the measurement was repeated up 4 times more and the best 4 measurements in terms of signal to noise ratio are shown. If there was any difference between the 4 measurements the machine displays the standard deviation on either side of the mean. DPOAE were also recorded across frequencies such that the geometric mean of F1 and F2 occurred six times per octave between 500 Hz and 8 kHz.

The test parameters were set such that it would provide a reliable measurement in a minimum amount of time. The evaluation procedure of the two ears takes approximately 5 minutes.

Pure tone audiometry and tympanometry were performed on all subjects prior to the DPOAE measurements. Any ears with conductive hearing loss or abnormal tympanometry were excluded from our sample. Tympanometry was considered abnormal if the middle ear pressure was less than -150 mmH_20 and/or if the compliance was smaller then 0.3 or greater than 2.5 cc.

The test was conducted in a quiet but not sound treated room. The patient was instruct-

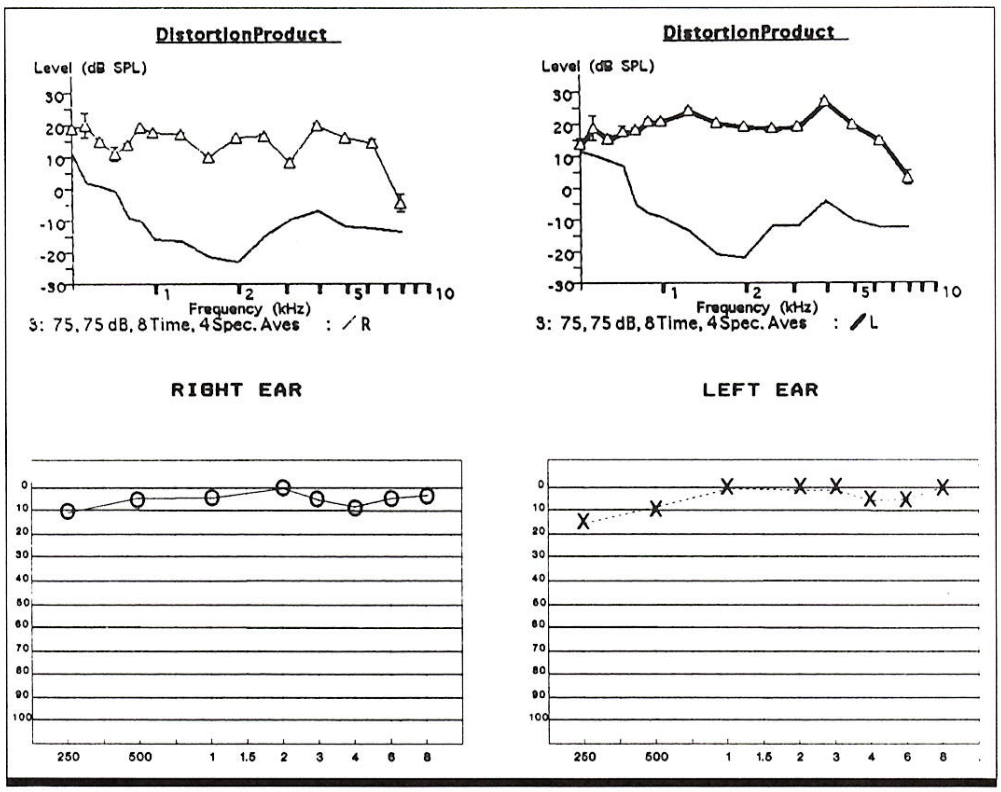

FIGURE 2

DPOAE results for right and left ears of an adult with normal hearing. The triangles represent the emissions and the lower line shows the noise floor levels.

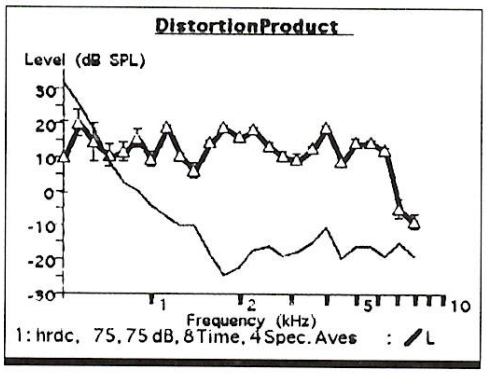

FIGURE 3

DPOAE results for the left ear of an adult with normal hearing. The emissions cannot be measured at 500 Hz due to the high levels of the noise floor.

ed to sit as still as possible for the duration of the test and the probe tip was inserted in the ear canal so as to obtain a firm seal. When the noise floor was too high (above 15 dBSPL at 500 Hz) the probe tip was re-inserted in an attempt to reduce the noise levels. The emissions were considered present when they appeared above the noise floor.

The DPOAE results of the 626 patients were compared to the contour of their respective audiogram to assess the frequency specificity of the test. Each DPOAE result was visually compared to its respective audiogram by two audiologists (authors). If they both considered that the contour of the DPOAE results followed the slope of the audiogram a correspondence was considered present. The emissions were required to be present at frequencies where the hearing was normal in the audiogram and reduced or absent at frequencies where there was a hearing loss. The absolute amplitude of the emis-

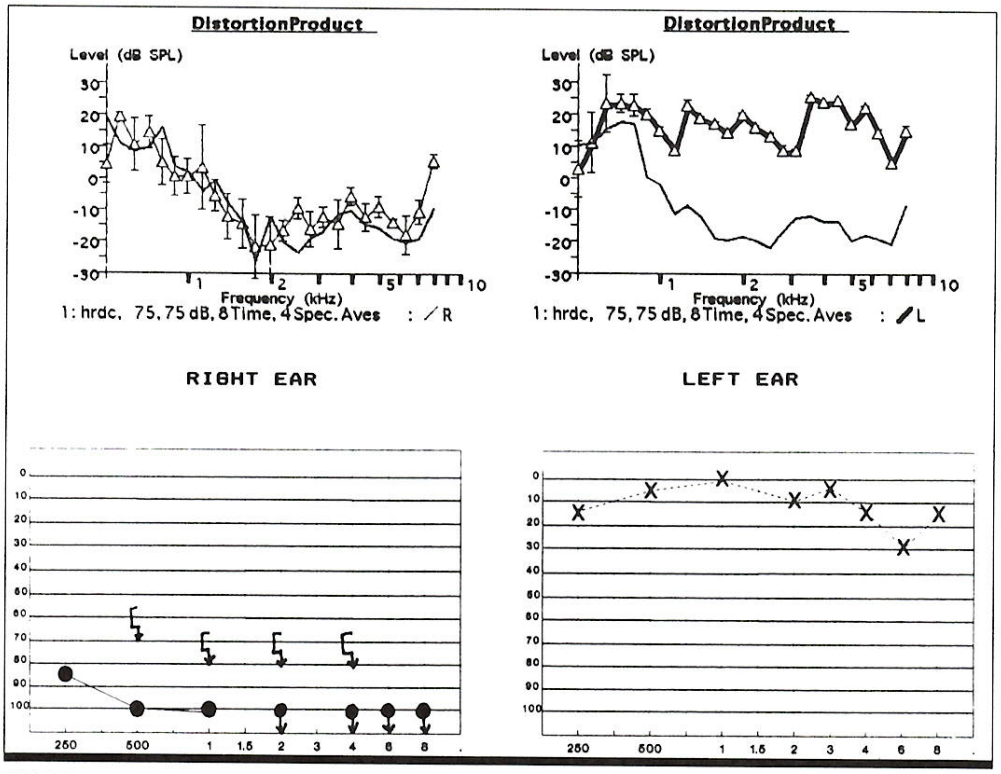

FIGURE 4

DPOAE results and audiogram of an adult with a profound hearing loss in the right ear due to cochlear viral infection and normal hearing in the left ear.

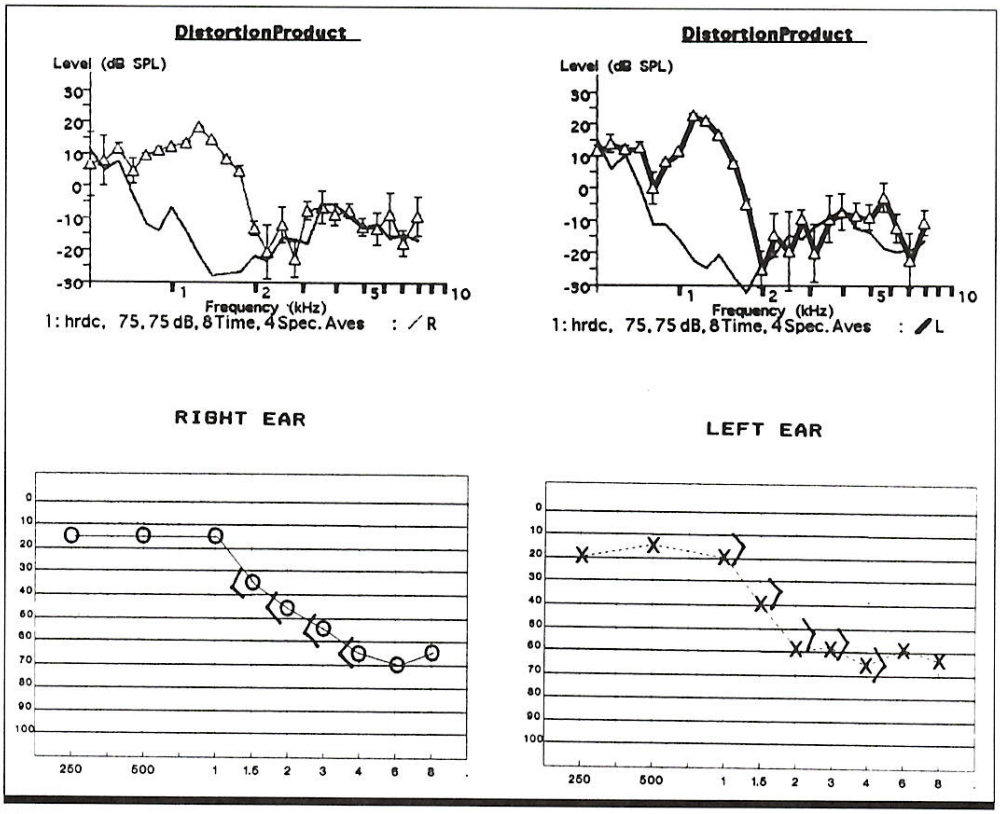

FIGURE 5
DPOAE results and audiogram of an adult with noise induced hearing loss.

sion was not taken into account for this comparison but rather if there was a reduction in emission's size and/or absence of emission around the frequencies where a hearing loss was seen in the audiogram.

Threshold measurements for 500 Hz, 1 kHz, 2 kHz and 4 kHz for each ear of 317 patients were matched with their respective DPOAE measurements in order to establish the relationship between behavioural hearing levels and size of emission.

RESULTS

Figure 2 displays a typical DPOAE result of a patient with normal hearing (thresholds better than 20 dBHL at 250, 500, 1000, 2000, 3000, 4000, 6000 and 8000 Hz). The emissions are present well above the noise floor across all frequencies. The results are easily identified as belonging to normal ears by the large gap between the emissions and the noise floor across the frequencies.

Figure 3 also displays the results of a normal hearing adult. It should be noted that the emissions at 500Hz do not appear above the noise floor. We found that 82% of the patients with normal hearing at 500Hz did not present an emission at that frequency.

Figures 4 to 7 are examples of DPOAE results and the respective audiogram of patients with cochlear hearing losses of different configurations showing the test to be frequency specific. Out of a total of 626 cases 428 DPOAE results were considered to

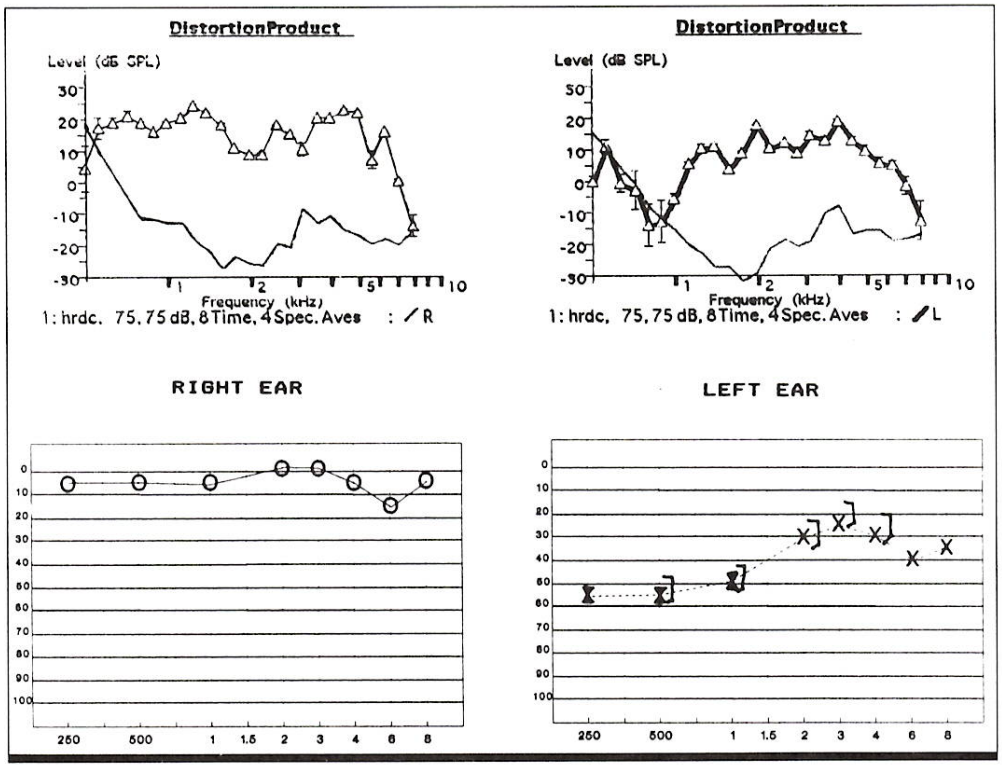

FIGURE 6

DPOAE results and audiogram of an adult with normal hearing in the right ear and a moderate hearing loss predominantly at the low frequencies due to Meniere's disease.

follow the slope of the audiogram by both audiologists. There was therefore a correspondence between DPOAE results and contour of audiogram in 70% of the cases.

Sixteen of our patients had confirmed unilateral retro-cochlear lesions, but only three of them presented better emissions than expected for their degree of hearing loss. Figure 8 shows an example of a patient with acoustic neuroma in the left ear and whose DPOAE results were not compatible with the audiogram.

After comparing size of emission with hearing threshold at four frequencies the patients were grouped according to their hearing thresholds into either "normal" (0 to 20 dBHL), "mild loss" (25 to 45 dBHL) or "moderate and over" (50 dBHL and over). For the purposes of this analysis the different ear pathologies, age and gender were not taken into account.

Figures 9, 10, and 11 show the relationship between behavioural hearing threshold and amplitude of DPOAE for 270 patients (523 ears) for the frequencies 1kHz, 2kHz and 4kHz respectively. The mean emission size for the different frequencies are shown. It should be noted that the figures only represent those ears with significant emissions as no attempt has been made to analyse data for any ears without significant emissions. The bars on either side of the means represent one standard deviation. No graph is shown for 500Hz as only 62 ears had significant emissions and they all had normal hearing at that frequency.

DISCUSSION

Analysis of Figures 9, 10 and 11 indicate a loose relationship between threshold and size

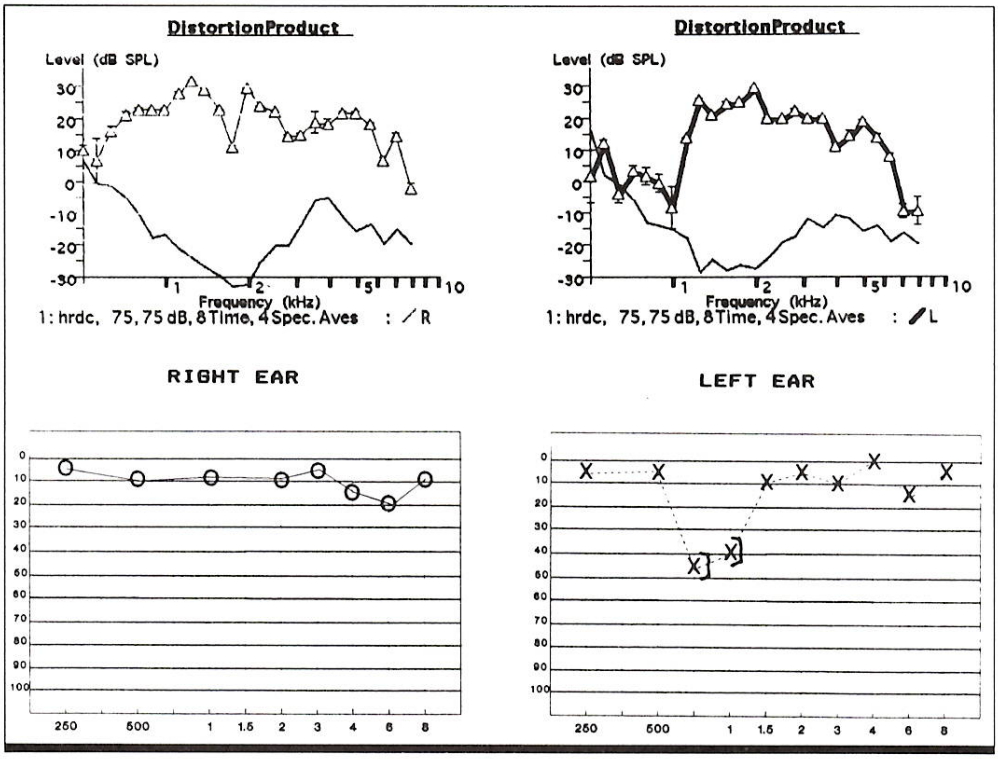

FIGURE 7

DPOAE results and audiogram of an adult with normal hearing in the right ear and a hearing loss at the mid frequencies. The unusual hearing loss was noticed after a screech through a cordless telephone.

of emission. There is considerable overlap in DPOAE amplitude in the different groups. It is, therefore, not possible to use amplitude of DPOAE alone as an accurate predictor of hearing threshold. Other factors such as age may influence this relationship. Although this factor has not been considered in this study, our impression is that younger ears produce stronger emissions than older ears with the same behavioural thresholds. Further investigation is needed on this aspect.

It is possible however to establish criteria from the data which enables us to assert the approximate hearing levels at 1000, 2000 and 4000 Hz based on the amplitude of the emissions at those frequencies. At 1 kHz for instance the overlap between normal and mild and over groups would require that a criterion level of at least 5 dBSPL be used to predict normal hearing. At 2 kHz a criterion of 0 dBSPL could be used to predict at worst a mild loss. At 4 kHz a dual criterion could be used with 10 dBSPL being required to establish normal hearing and a 5 dBSPL to establish at worst a mild hearing loss.

Comparing the contour of DPOAE results to their respective audiogram contours, out of 626 patients tested 428 showed a good correspondence. In other words, the DPOAE results in 70% of the cases were a good predictor of the configuration of their audiogram. Whenever there was a loss of hearing at a particular frequency in the audiogram the DPOAE was reduced and/or absent around that same frequency, as illustrated by Figures 4 to 7.

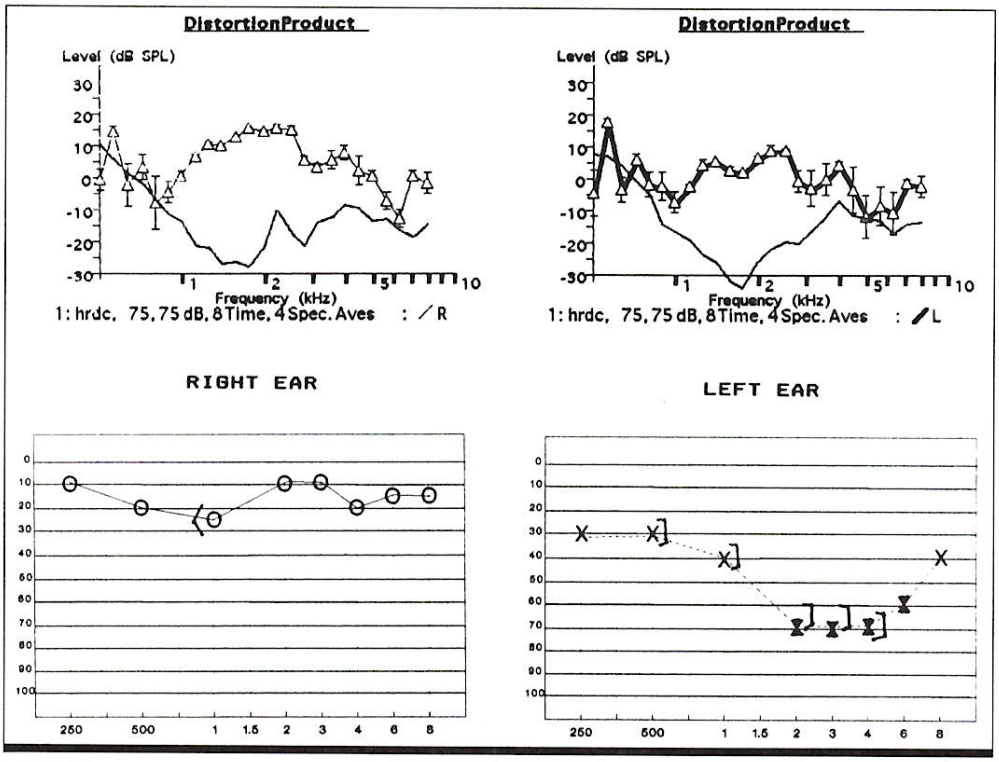

FIGURE 8

DPOAE results and the audiogram of an adult with an acoustic neuroma in the left ear. There is little difference between the DPOAE results of each ear despite the significant difference shown in the audiogram.

For 30% of our patients, however, no relationship was found between the DPOAE results and the audiogram configuration. Figure 12 is an example of poor correspondence between the two results. One reason hypothesised for this poor correspondence was the possibility of middle ear dysfunction which prevented the emission from being measured. Although all our patients had type A tympanograms and no conductive hearing loss showing in the audiogram, it may be that they have some undetected middle ear dysfunction, such as tympanosclerosis, which prevents the emission from being transmitted into the ear canal.

Another possible explanation for the poor correspondence between DPOAE and audiogram is confusion between emission and noise floor. Figure 13 is an example of an adult with normal hearing whose emissions could not be measured as it was not possible to reduce the noise floor. A further examination of the data will be carried out which takes into account the signal to noise ratio for every measurement.

For many patients the noise floor is high at the low frequencies and decreases at the higher frequencies. Many investigators such as Ohlms et al. (1990) and Harris & Probst (1991) do not measure DPOAE at 500 Hz owing to the high noise floor level at this frequency. We found however, that this frequency provides useful information. The absence of emissions at 500Hz does not mean absence of hearing, but on the other hand, its presence is a strong indicator of normal hearing at that frequency. The amount of time saved by excluding 500 Hz

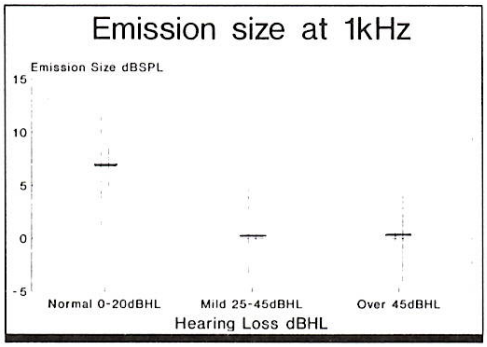

FIGURE 9
DPOAE amplitudes for each group of behavioural hearing thresholds at 1 kHz. The horizontal mark is the mean emission amplitude for each group and the vertical bars show one standard deviation on each side of the mean.

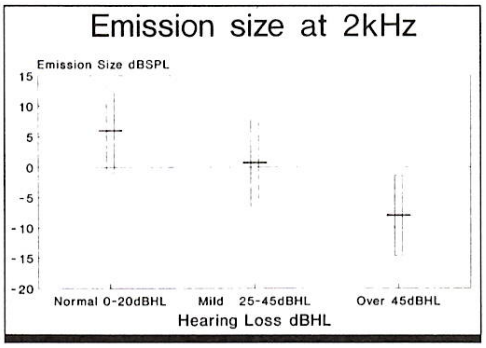

FIGURE 10
DPOAE mean amplitudes and standard deviation for each group of behavioural hearing thresholds at 2 kHz.

from the measurement is not sufficient to justify its exclusion.

The use of DPOAE to predict retro-cochlear lesions has not been encouraged by our sample of patients. We have tested 16 ears with known retro-cochlear pathology but in only 18% of these cases was the DPOAE markedly greater than would be expected for our sensori-neural population. The majority of our retro-cochlear hearing losses were due to acoustic neuroma. The cochlear involvement in this pathology is well known. As the OAE reveals the function of the outer hair cells in the cochlea, whenever there is a cochlear loss the presence of the emissions will be affected. The test therefore will be a good predictor of retro-cochlear lesion only when the hearing loss is purely neural or central with no cochlear involvement.

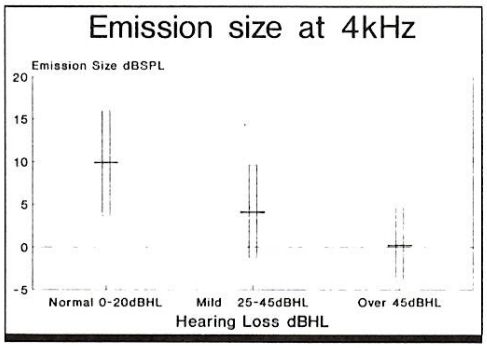

FIGURE 11
DPOAE mean amplitudes and standard deviation for each group of behavioural hearing thresholds at 4 kHz.

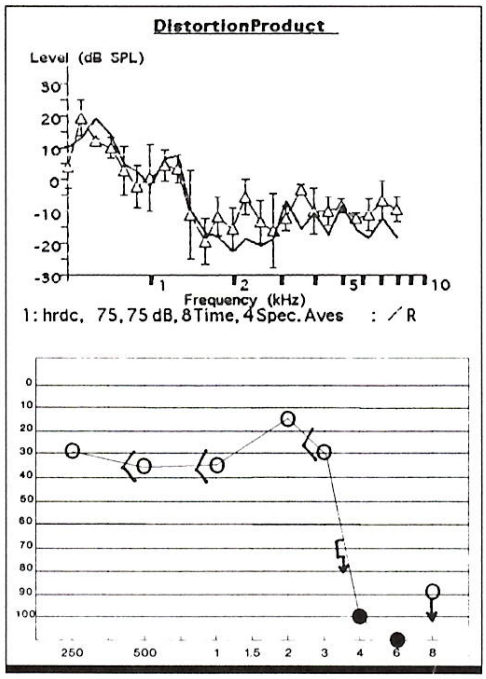

FIGURE 12
DPOAE results which are incompatible with the behavioural audiogram of an adult with a cochlear hearing loss.

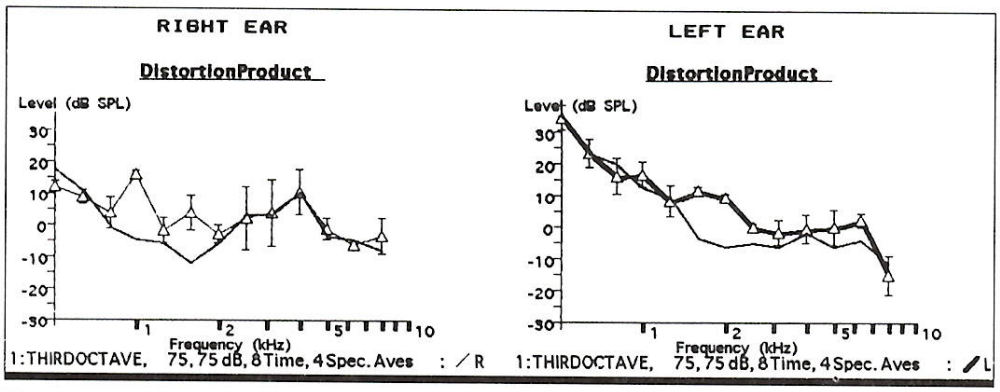

FIGURE 13
DPOAE results of an adult with normal hearing where the noise floor could not be reduced.

Our twelve months experience with DPOAE testing indicate the procedure to be a useful tool in routine audiological assessment. It cannot be considered a conclusive test by itself and does not allow accurate measurement of hearing thresholds. Whenever an objective assessment to establish percentage loss of hearing is required, cortical evoked response audiometry with all its pitfalls, is still our choice of test. DPOAE, in our clinic, has not replaced any existing audiological test but is an important contribution to the battery of tests used in the clinical routine.

It may be that by taking age into account and by using other testing parameters such as different F1 and F2 ratios or input/output measurements we could obtain a more precise correlation between DPOAE and behavioural threshold. We intend to look at this possibility. At this stage, the test is useful to give a prediction of degree of hearing loss and expected contour of audiogram for those patients who cannot or deliberately will not co-operate with the pure tone audiometry.

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