

AN INVESTIGATION OF THE CORRELATION BETWEEN DISTORTION PRODUCT AND TRANSIENT EVOKED OTOACOUSTIC EMISSIONS IN THE HUMAN AND THE CHINCHILLA

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ABSTRACT

Otoacoustic emission recordings are being used as a clinical tool in detecting cochlear hearing loss. Whilst transient evoked otoacoustic emissions (TEOAEs) possess high sensitivity, their frequency specificity has been questioned. For more reliable information about threshold changes at specific frequencies, distortion product otoacoustic emissions (DPOAEs) are being used. It is the aim of this study to investigate the correlation between these two types of evoked OAEs. The study is comprised of two parts. The first part involves measurements of DPOAE and TEOAE amplitudes in eighteen ears of nine normally-hearing humans, in the 1 to 5 kHz range. The second part of the study employs a similar protocol with recordings made from 18 normally-hearing *chinchilla* ears. In the first investigation, human DPOAE responses are plotted against the corresponding TEOAE responses across a whole frequency range (1 - 5 kHz). The *chinchilla* data are similarly analyzed and the results from both investigations suggest some correlation between DPOAE and TEOAE amplitudes in the 1-5 kHz frequency region.

SOMMAIRE

On se sert des émissions 'otoacoustic' comme résultats des 2 investigations suggère une corrélation entre les amplitudes DPOAE et TEOAE outils pour détecter la perte d'ouïe 'coehlear'. Même si les émissions 'otoacoustic' (TEOAEs) possèdent une grande sensibilité, les caractéristiques de leurs fréquences ont été questionnés. Pour de l'information plus assujetti a une fiabilité plus grande a propos des points de changement de tolérance a des points de fréquences spécifique, les distorsions produit 'otoacoustic' émissions (DPOAEs) sont utilisé. Le but de cette étude est d'étudié la corrélation entre ces deux types d'OAE non-spontane. Cette étude comprend 2 parties. La première partie comprend la prise de mesure des amplitudes DPOAE et TEOAE dans dix- huit oreilles de neuf humains d'ouïe normal, d'un écart de 1 à 5 Khz. La deuxième part de cette étude emploie une procédure similaire de prise de mesure de 18 oreilles de *chinchilla* d'ouïe normale. Dans la première investigation les donner des résultats DPOAE sur les humains sont placer sur un graphe contre les donner correspondante TEOAE a travers des fréquences de 1-5 Khz. Les donnés des chinchillas sont analysés de façon similaire et les résultats des 2 investigations suggère une corrélation entre les amplitudes DPOAE et TEOAE dans la zone de fréquence de 1-5 Khz.

1. INTRODUCTION

Since the early 1980's, advances in auditory science have provided clinicians with new methods to test and screen against cochlear hearing loss, especially in high risk

neonates. These advances, are the result of David Kemp's discovery in 1978 that low stimulus levels elicit a delayed response in the form of an acoustic emission which can be recorded in the external ear canal.

Approximately, 35% to 55% of normal human ears exhibit spontaneous otoacoustic emission (Probst, 1990). These spontaneous otoacoustic emissions are thought to be caused by the activity of outer hair cells within the cochlea and perhaps with energy which is of metabolic origin. The exact mechanism of production of these emissions has not yet been definitively determined. However, a number of experiments have shown that the hair cell can expand and contract during activation and perhaps feed back mechanical energy to the basilar membrane. This movement can subsequently be recorded as sound waves in the external meatus (Brownell, 1984).

Almost all normal ears produce *evoked* otoacoustic emissions, of which, there are two types: distortion product OAEs (DPOAEs) and transient evoked OAEs (TEOAEs). Both types of emission can conveniently be detected by fitting a miniature microphone with a built-in sound source, in the external ear. When low level, click-stimuli are presented, the high frequency components of the TEOAE are detected with the least delay, and the lower frequency ones, with longer delays (Kemp et al., 1990). Only individuals with a normally functioning cochlea are capable of producing TEOAEs, and this makes TEOAE measurements a useful clinical tool.

In cochlear hearing loss, or as the cochlea ages, a significant decrease in the TEOAE amplitudes is observed until the frequency components are at or below the noise floor (Norton et al., 1990).

One current use for these emissions is to screen for cochlear hearing loss in high risk neonates, as well as to monitor objectively, other types of cochlear hearing loss in children and adults. The use of TEOAEs in neonatal cochlear hearing loss, has received much attention for a number of reasons. They provide a method by which a newborn's hearing can be examined non-invasively. Moreover, the method is less time consuming than auditory brain stem evoked potential recording, and does not require any behavioral response.

However, TEOAEs exhibit a number of limitations when used in a clinical setting. For example, with a hearing loss of more than 25 dB, TEOAEs disappear and as a result hearing thresholds cannot be determined. Moreover, the frequency specificity of screening methods involving TEOAEs has been questioned (Probst and Harris, 1993). Hence, methods involving TEOAEs are limited only to label a cochlea as "normal" or "abnormal."

Distortion product OAEs are evoked emissions that are produced at non-stimulus frequencies, when the cochlea

is subjected to two continuous pure tone frequencies. They are predictable phenomena with respect to the frequency at which they occur. For example, in response to a two-frequency stimulus f_1 and f_2 , one of the largest DPOAE amplitudes always appears at $2f_1-f_2$ (Kim, 1980). DPOAE measurements have recently become more used in auditory studies, partly because they are potentially more frequency specific than TEOAEs (Probst and Harris, 1993), and partly because there are more devices available on the market to measure DPOAEs than TEOAEs.

Many experiments have supported the theory that DPOAEs are an electromechanical manifestation of the non-linear processes involving the cochlear outer hair cells. However, it is not clear whether the mechanism by which DPOAEs are produced is the same as that involving the production of transient evoked OAEs. A study by Wier et al. (1988) for example, has demonstrated significantly different effects of salicylates on the two types of evoked OAEs in the same ear. Consequently, the question arises as to which OAE measurement is most appropriate for clinical purposes. It has been argued that the amplitude of discrete DPOAEs do not closely correlate with corresponding TEOAE frequency components. It is therefore crucial, to examine the relationships, if any, between the TEOAE response amplitudes and those of the distortion product responses. Such comparisons between DPOAE and TEOAE response amplitudes have not yet been undertaken in animal models. For this purpose we have used the chinchilla. In this study, we examine the correlation between the two types of OAEs in this species, as well as in the human, so as to provide a better understanding of the nature of, and the correlation between DPOAEs and TEOAEs. Our experimental hypothesis is that the distortion product otoacoustic emission amplitudes *are* correlated with the transient evoked otoacoustic emission amplitudes at corresponding frequencies, in the 1 kHz to 5 kHz frequency range.

2. MATERIALS AND METHODS

2.1 Subject

Two species were used in this experiment; humans and chinchillas.

Humans

Nine adult humans who ranged in age from 21 to 42 years old, and had normal hearing thresholds within 20

dB of audiometric norms (0.5 - 8 kHz). These subjects were screened against having upper respiratory inflammatory diseases, or prior history of conductive hearing loss. Human subjects were tested in the awake state, in a seated position.

Chinchillas

Nine adult chinchillas with normal audiometric thresholds were used, ranging in weight from 445 grams to 690 grams. Animal studies were carried out in the anaesthetized animal using the following regime. Loading dose: atropine sulfate - 0.04 mg/kg; xylazine - 2.5 mg/kg; and ketamine hydrochloride - 15 mg/kg, with supplementary doses of ketamine hydrochloride.

The chinchilla data were all collected in a sound attenuation booth which provided more than 30 dB of isolation across all audiometric frequencies.

All animal experiments, were carried out in accordance to strict guidelines of the Canadian Council on Animal Care and the Local Animal Care Committee.

2.2 Recording Systems

Two recording systems were used; one for recording distortion product OAEs and one for transient evoked OAEs. Each system was comprised of: a host 386 computer, running on MS DOS; an ILO computer interface card; an ILO dual channel analogue signal conditioning unit; and ILO92 or ILO88 software. The recording systems were standard and commercially

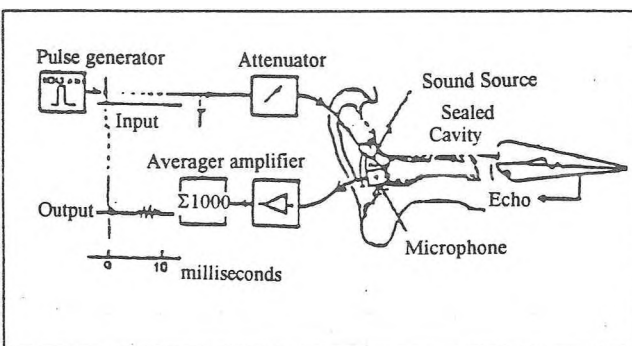


Fig. 1 Setup of the TEOAE recording system. (Adapted from Kemp et al. 1990). Pulses produced by the pulse generator are attenuated and introduced to the external meatus. The otoacoustic emission (labelled "echo") which is generated is detected by the microphone, amplified, and averaged to improve signal to noise ratio.

available from Otodynamics Limited, with no significant modifications. The setups for these recording systems are shown in figures 1 and 2.

2.3 Recording Protocol

Human Ear

1. The conscious human subject was seated in an upright position, while keeping swallowing and other movements to a minimum.
2. The microphone/sound source(s) assembly (i.e. the probe) was then fitted snugly in the external ear canal with the aid of a soft disposable probe tip.
3. One DPOAE and one TEOAE recording were measured in each of the subject's two ears. The probe assembly was not moved within each recording session. A sample of the raw data is illustrated in Figure 3. The upper panel shows TEOAE recordings. The lower section shows the "DPOAE audiogram."
4. The DPOAE recording was done under default setting (stimulus level = 70 dB SPL, rejection threshold = 8 mPa) and was terminated after 2 sweeps. The TEOAE recording was also done under default setting (stimulus level = 75 dB pk, rejection threshold = 47.3 dB) and was terminated after 260 averages were performed.

Chinchilla Ear

1. The anesthetized chinchilla was placed with its head

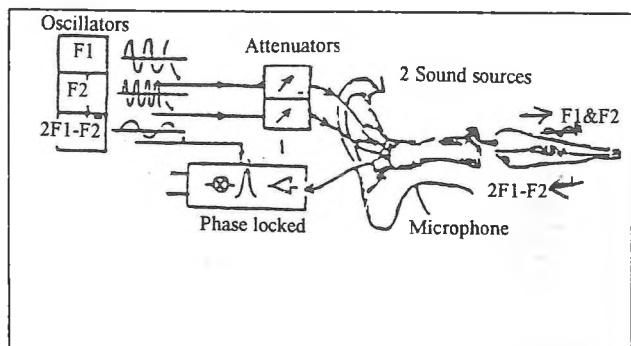


Fig. 2 Setup of the DPOAE recording system. (Adapted from Kemp et al. 1990). In this setup, two sound sources produce f_1 and f_2 signals. Within the cochlea, these signals generate the distortion product $2f_1-f_2$ which is detected in the external canal by the microphone. The $2f_1-f_2$ distortion product is separated out with a phase-locked amplifier.

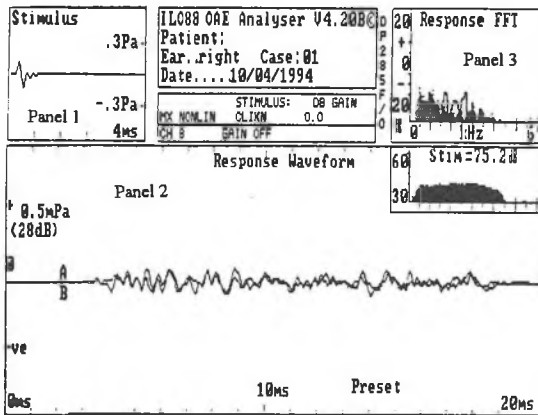
in a normal position.

2. Same as Step 2 above for the human ear.

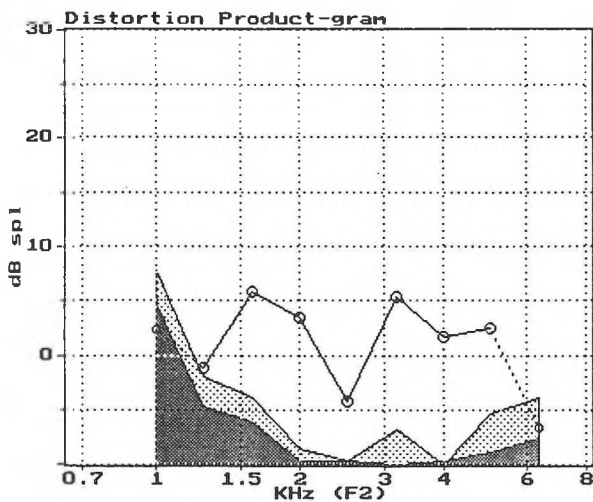
3. Three consecutive records of each type of evoked OAEs were collected from each ear. This procedure made it possible to detect, by comparing the 3 recordings, any instances where ambient noise or other artifact caused an evoked OAE to be erroneously recorded. Sample outputs for the raw data are shown in Figure 4: TEOAE in the upper panel; distortion product - gram

in the lower panel.

Three recordings of one type of evoked OAE (e.g. DPOAE) were made from one ear, then the other type of evoked OAEs was recorded without readjusting probe fit in the ear. This ensured that the DPOAEs and the TEOAEs were recorded under identical conditions, at least with respect to the fitting of the probe. This procedure was carried out in both ears and collectively, six recordings were gathered from each ear of the chinchilla.

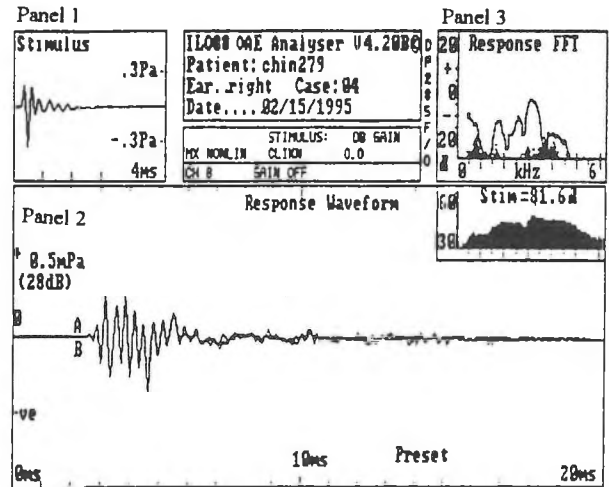


(a)

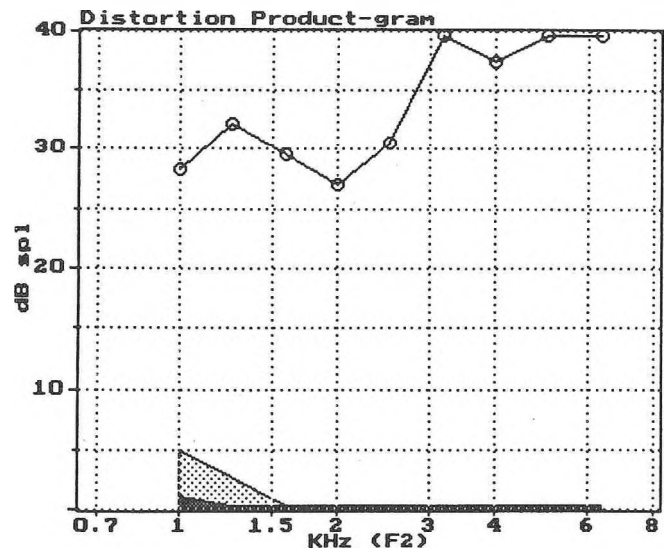


(b)

Fig. 3(a) The standard ILO 88 output generated in the recording of human TEOAE amplitudes. Refer to the text for a description of panels. (b) The standard output of the ILO 92 software used to record human DPOAEs in the study.



(a)



(b)

Fig. 4(a) The standard ILO 88 output generated in the recording of chinchilla TEOAE amplitudes. Refer to the text for a description of panels. (b) The standard output of the ILO 92 software used to record chinchilla DPOAEs in the study.

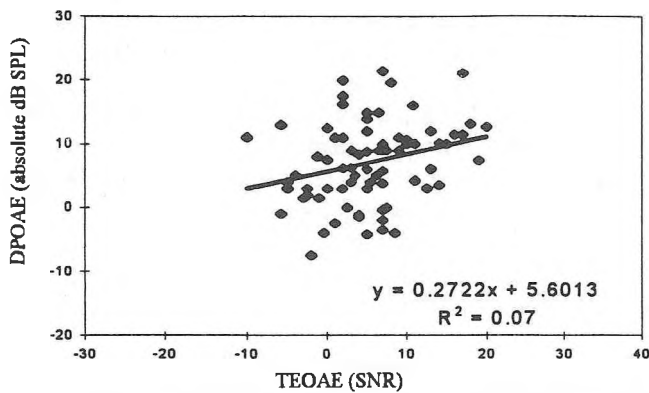


Fig. 5 The plot of the human DPOAE amplitudes (absolute dB SPL) against those of TEOAE (dB signal above noise) in the entire 1 to 5 kHz frequency range. The correlation between the DPOAEs and the TEOAEs is characterized by a positive-slope linear regression with a correlation coefficient value of $R^2=0.07$.

4. The same default recording conditions were used as in Step 4 of the human recording protocol.

3. RESULTS

Figures 3 and 4 show examples of the raw data collected from individual human and chinchilla subjects, using ILO92 and ILO88 devices. The ILO88 output (figures 3a and 4a) gives the waveform of the stimulus presented at the external ear (Panel 1). Panel 2 displays the response waveforms in time domain. The cross-power spectrum for the response waveform, is shown in Panel 3. The ILO 92 output is shown in figures 3b and 4b and displays graphically, the $(2f_1 - f_2)$ response amplitudes above the

noise floor, as a function of frequency.

3.1 Human Data

Figure 5 shows DPOAE amplitudes (absolute dB SPL) from the 18 ears plotted against their corresponding TEOAE amplitudes (dB signal above noise) for all frequencies from 1 kHz to 5 kHz. The correlation is represented by an R^2 -value of 0.07. Furthermore, a linear regression through the data points has a positive slope.

In further analysis, the DPOAE and TEOAE responses are divided into 2 categories: (1) High Frequency Responses: OAE responses generated in the 3 to 5 kHz frequency range, and (2) Low Frequency Responses: OAE responses in the 1 to 2 kHz frequency range. The data are shown in the plots of figures 6 and 7, respectively.

In the high frequency data, shown in Figure 6, the linear regression again has a positive slope, and the correlation coefficient (R^2) is 0.10. Similarly, the plot of DPOAE against TEOAE responses, for the low frequency category (Fig. 7), has a positive-slope regression and the correlation coefficient is 0.11.

3.2 Chinchilla Data

Figure 4 displays records obtained from one of the chinchillas in the study.

The data collection protocol for the chinchilla was different than for human subjects, in that three recordings of each type of OAE were performed on each ear. The resulting

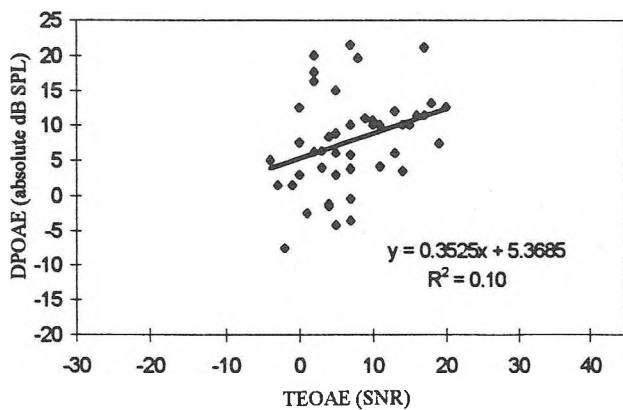


Fig. 6 The plot of human DPOAE responses versus the TEOAE responses, in the High Frequency Response Range (3-5 kHz).

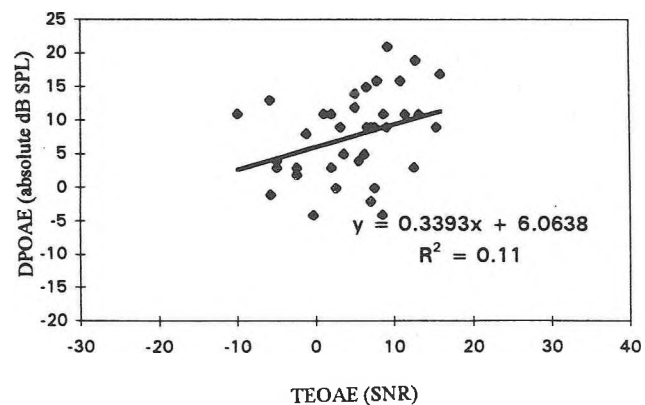


Fig. 7 The plot of the human DPOAE against TEOAE amplitudes, in the Low Frequency Range (1-2 kHz).

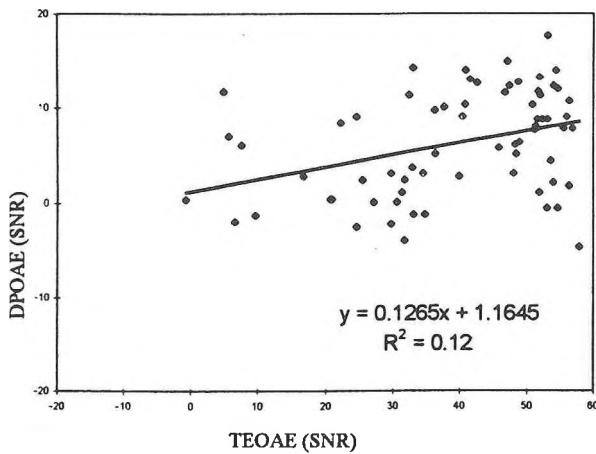


Fig. 8 The plot of the averaged, chinchilla DPOAE amplitudes (dB signal above noise level) against those of averaged TEOAEs (absolute dB SPL) in the entire 1 kHz to 5 kHz frequency range. The linear regression has a positive slope with a correlation coefficient of $R^2 = 0.12$.

three DPOAE amplitudes were averaged and plotted against the average of the three TEOAE amplitudes, at 1 kHz intervals, from 1 to 5 kHz. In all cases we use dB signal above noise level. The resulting plot is shown in Fig. 8. A linear regression exhibits a positive slope, as in the plots for human responses. The correlation coefficient (R^2) is 0.12.

4. DISCUSSION

The plots of DPOAE versus TEOAE amplitudes, for both humans and chinchillas, have positive slopes which indicate that as TEOAE responses increase, so do the DPOAE responses. However, the correlation (R^2) values associated with these linear regressions are low: 0.07 - 0.11 for the human data; 0.12 for the chinchilla data. Nevertheless, a statistical analysis of the data (Spearman rank order correlation) does indicate a significant relationship between DPOAE and TEOAE amplitudes in all cases (see Table).

Similar comparisons between DPOAE and TEOAE amplitudes have been carried out in human subjects by Probst and Harris (1993), as well as Smurzynski and Kim (1992). In both of these studies, higher R^2 values were reported.

Probst and Harris (1993), reported R^2 values from 0.4 to 0.6. These values are considerably higher than the ones reported in the present study. The reason for this

discrepancy is unclear. However, Probst and Harris chose subjects with a wide range of hearing thresholds. In fact, over 75% of the data were collected from ears of subjects with sensorineural hearing loss. This high percentage of pathologic data, resulted in many points in the lower left hand corner of the DPOAE versus TEOAE plot, since pathologic ears generally give rise to low-amplitude DPOAE and TEOAE responses. These low amplitude data pairs may have increased the correlation coefficient of the linear regression analyses.

The study by Smurzynski and Kim (1992), also reported higher correlation coefficients ($R^2 = 0.16$ to 0.22) than observed in this paper. This discrepancy is not due to inclusion of pathologic data, since their subjects are reported not to have suffered from any type of hearing loss.

Although some correlation has been established between distortion product and transient evoked otoacoustic emissions in this study, as well as in the studies of Probst and Harris, and Smurzynski and Kim, findings have been reported in the literature that indicate otherwise. One such experiment was conducted by Martin et al. (1988), which showed that small laboratory animals have DPOAE amplitudes that are much larger than those of primates. However, they also observed that these small animals possess smaller TEOAE amplitudes than primates, leading them to conclude that perhaps DPOAEs and TEOAEs are produced by separate mechanisms. Furthermore, Wier et al. (1988) have showed that salicylates affect the 2 types of evoked OAEs differently in humans, indicating DPOAEs and TEOAEs to be only indirectly related.

The present study supports the notion that DPOAEs and TEOAEs are correlated, at least to a limited extent, and this fits with the generally accepted notion that they are generated by the same non-linear, biomechanical processes of the cochlea. As such, clinical measurements

Table: Statistical analysis of the correlation coefficients for the human and chinchilla data.

	Human (all freq)	Human (high freq)	Human (low freq)	Chinchilla Data
Spearman Correlation Coefficient	0.26	0.33	0.35	0.35
P value*	0.02	0.02	0.03	0.003
N	76	46	30	70

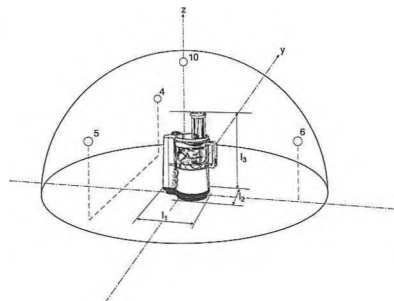
* For P values below 0.05, there is a significant relationship between the two variables.

of the two types of evoked OAEs may be used interchangeably. Moreover, since both types of evoked OAEs have shortcomings, for example in terms of frequency specificity and sensitivity (Probst and Harris, 1993), they may be used *jointly* to provide a more powerful diagnostic tool in assessing the functional integrity of the cochlea.

REFERENCES

- Allum, J.H.J., Allum-Mecklenburg, D.J., Harris, F.P., Probst, R. (1993) A comparison of transiently-evoked and distortion product otoacoustic emissions in humans. *Progress in Brain Research*. 97, 91-99.
- Brownell, W.E. (1984) Microscopic observation of cochlear hair cell motility. *Scanning Electron Microscopy*. (Pt. 3): 1401-1406.
- Harrison, R.V. (1986) Cochlear echoes, spontaneous emissions, and some other recent advances in auditory science. *J. Otolaryngol.* 15:1.
- Kemp, D.T. (1978) Stimulated acoustic emissions from within the human auditory system. *Journal of the Acoustical Society of America*. 64 (5), 1386-1391.
- Kemp, D.T., Ryan, S. and Bray, P. (1990) A guide to the effective use of otoacoustic emissions. *Ear Hear.* 11, 93-105.
- Kim, D.O. (1980) Cochlear mechanisms: Implications of electrophysiological and acoustical observations. *Hear. Res.* 2, 297-317.
- Lind, O. and Randa, J.S. (1990) Spontaneous otoacoustic emissions: Incidence and short-time variability in normal ears. *J. Otolaryngol.* 19, 252-259.
- Martin, G.K., Lonsbury-Martin, B.L., Probst, R., Coats, A.C. (1988) Spontaneous otoacoustic emissions in a non-human primate. *Hear. Res.* 33, 49-68.
- Norton, S.J., Widen, J.E. (1990) Evoked otoacoustic emissions in normal hearing infants and children: Emerging data and issues. *Ear Hear.* 11, 121-127.
- Otdynamics Limited. (1994) "The Otdynamics ILO 92 DP Research Software Manual". Second Edition.
- Probst, R. (1990) Otoacoustic emissions: An overview. *New Aspects of Cochlear Mechanics and Inner Ear Pathology*, Karger, Basel, 1-91.
- Probst, R., Lonsbury-Martin, B.L. and Martin, G.K. (1991) A review of otoacoustic emissions. *J. Acoust. Soc. Am.* 89, 2027-2067.
- Probst, R. And Harris, F.P. (1993) A comparison of transiently-evoked and distortion-product otoacoustic emissions in humans. *Progress in Brain Research*. 97, 91-99.
- Probst, F.P., Harris, P. (1993) Transiently-evoked and distortion-product otoacoustic emissions: Comparison of results from normally-hearing and hearing-impaired human ears. *Arch. Otolaryngol.-Head Neck Surg.* 119, 858-860.
- Smurzynski, J. and Kim, D.O. (1992) Distortion-product and click-evoked otoacoustic emissions of normally-hearing adults. *Hear. Res.* 58, 227-240.
- Wier, C.C., Pasanen, E.G. and McFadden, D. (1988) Partial dissociation of spontaneous otoacoustic emissions and distortion products during aspirin in

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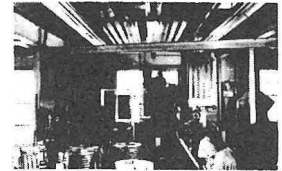


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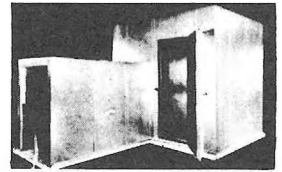
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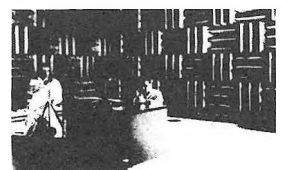
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