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Shlomo Silman*†‡
Michele B. Emmer*†
Carol A. Silverman*†§**

Abstract

**Purpose:** To present a case study in order to alert clinicians to the possibility of occurrence of intermodulation distortion during otoacoustic emissions testing that arises from the cavity formed by the external auditory meatus and tympanic membrane rather than from the inner ear, compromising the reliability and validity of otoacoustic emissions testing.

**Research Design:** Prospective case study.

**Study Sample:** A young (26-year-old) female adult with a longstanding, bilateral, essentially moderate to severe sensorineural hearing loss presented with robust distortion product otoacoustic emissions.

**Results:** Repeat otoacoustic emissions testing with another device of the same model revealed essentially absent distortion product otoacoustic emissions and transient otoacoustic emissions. Calibration of both otoacoustic emissions devices using a 1 cc membranous cavity indicated present intermodulation distortion for the device that yielded robust distortion product otoacoustic emissions for the patient but absent intermodulation distortion for the device that revealed absent distortion product otoacoustic emissions and absent transient evoked otoacoustic emissions for the patient. The calibration findings for the device yielding intermodulation distortion in the cavity were confirmed by an engineer of a technical instrumentation company. The device was shipped back to the manufacturer of the device for repair. The manufacturer’s engineers diagnosed the problem as an interruption in the relay system. Following repair, calibration revealed the absence of intermodulation distortion in the 1 cc membranous cavity.

**Conclusions:** The findings have implications for the reliability and validity of otoacoustic emissions. Clinicians should routinely calibrate otoacoustic emissions devices using 1.0 and 0.5 cc membranous cavities to rule out intermodulation distortion that could produce artifactual otoacoustic emissions in patients.

**Key Words:** Artifact, auditory neuropathy, calibration, distortion product otoacoustic emissions, intermodulation distortion, transient evoked otoacoustic emissions

**Abbreviations:** DPOAEs = distortion product otoacoustic emissions; TEOAEs = transient evoked otoacoustic emissions

Intermodulation distortion occurs when two or more signals of differing frequency (e.g., \( f_1 \) and \( f_2 \)) are used as inputs into a nonlinear system. These signals interact and generate sounds in addition to the input signals. The new signal is comprised of nonharmonically spaced, yet mathematically predictable, components that can reflect the sums and differences of the input signals, such as \( 3f_1 - 2f_2 \), \( 2f_1 - f_2 \), and \( 2f_2 - f_1 \). The power of the input signals becomes attenuated with the production of the newly derived components. The inner ear and membranous cavity formed by the external auditory meatus and the tympanic membrane represent nonlinear systems in the ear. The nonlinearity of the inner ear is related to the characteristics of the outer hair cells.

*Department of Speech Communication Arts and Sciences, Brooklyn College, City University of New York; †Au.D. Program of the Health Sciences Doctoral Programs, Graduate Center, City University of New York; ‡Ph.D. Program in Speech and Hearing Sciences, Graduate Center, City University of New York; §Communication Sciences Program, Hunter College, City University of New York; **Department of Otolaryngology—Head and Neck Surgery and Hearing and Balance Center, Ear Institute, New York Eye and Ear Infirmary

Shlomo Silman, Ph.D., Department of Speech Communication Arts and Sciences, Brooklyn College, City University of New York, 2900 Bedford Avenue, Brooklyn, NY 11230; Phone: 718-951-4869; Fax: 718-951-4363; E-mail: shlomosilman@yahoo.com
Intermodulation distortion of the cavity formed by the outer ear and tympanic membrane can occur during clinical measurement of the ipsilateral acoustic reflex. The ipsilateral acoustic-reflex measurement system of many commercial acoustic-immittance devices incorporates a multiplexing circuit involving alternating presentations of the activating and probe tones to prevent intermodulation distortion artifacts. Whereas intermodulation distortion during measurement of the ipsilateral acoustic reflex is undesirable, intermodulation distortion produced by the inner ear is desirable as it signals functional integrity of the inner ear during distortion product otoacoustic emissions testing.

Distortion product otoacoustic emissions (DPOAEs), a type of evoked otoacoustic emissions, are low-level sounds generated by the outer hair cells of the cochlea. The two input signals (primaries) in DPOAE testing ($f_1$ and $f_2$ with $f_2 > f_1$) are introduced into the external auditory meatus at a specific ratio ($f_2/f_1$) such as 1.2, and they travel through the outer ear, middle ear, and cochlea. While passing through the outer ear, the signals form intermodulation distortion in the membranous cavity formed by the external auditory meatus and tympanic membrane. When the signals reach the inner ear, they form another intermodulation distortion because of nonlinearity of the outer hair cells of the cochlea. The DPOAE measurement system differentiates between the two distortion products primarily based on their latencies. The system is designed to reject the intermodulation distortion of the cavity formed by the external auditory meatus and tympanic membrane while retaining the intermodulation distortion of the inner ear.

Although the technique for calibration of intensity of the input signals from the probe has been well described and measurement parameters of the DPOAEs such as frequencies, intensities, and ratios of the primary tones have been widely investigated, literature is lacking on DPOAE artifacts from intermodulation distortion in the membranous cavity formed by the tympanic membrane and external auditory meatus rather than from intermodulation distortion in the inner ear.

The purpose of this case study was to alert clinicians to artifactual DPOAEs resulting from intermodulation distortion in the membranous cavity formed by the tympanic membrane and external auditory meatus rather than from intermodulation distortion in the inner ear.

**CASE**

A 26-year-old adult female with moderate to profound sensorineural hearing loss was seen for an audiologic evaluation. The otoacoustic emissions results are presented for one ear (right ear) only as the follow-up otoacoustic emissions testing at the end of the evaluation led to patient fatigue.

The DPOAEs were recorded using the ILO 88 (devices A and B). The intensity of the primaries was 70 dB SPL, and the ratio of the primary frequencies was $f_2/f_1 = 1.2$. The transient evoked otoacoustic emissions (TEOAEs) were recorded using the ILO 88 (device B) with click stimuli presented at 80 dB peak equivalent SPL.

Figure 1 shows the pure-tone audiogram. Tables 1–4 show the speech audiometry and acoustic-immittance findings. The pure-tone findings are consistent with a bilateral, essentially moderate to severe, sloping sensorineural hearing impairment. The speech and acoustic-immittance findings were consistent with the pure-tone results.

Figure 2 shows DPOAEs elicited with device A. The robust DPOAEs well above the noise floor were surprising in light of the degree of the sensorineural hearing impairment. The results of studies suggest a low probability of occurrence of DPOAEs when the magnitude of sensorineural hearing loss of cochlear etiology exceeds 50–55 dB HL (Harris, 1990; Probst...
and Hauser, 1990; Bonfils and Avan, 1992; Harris and Probst, 1997).

The DPOAE test was repeated on device B. Figure 3 shows that the amplitude of the DPOAEs exceeds the noise floor by at least 6 dB at only 1 frequency, consistent with the patient’s audiologic findings. TEOAE testing in the same ear also was done using device B; the absent TEOAEs (see Fig. 4) were consistent with the DPOAE test results and the patient’s audiologic findings.

Calibration of device A was accomplished by performing DPOAE testing in a 1 cc membranous cavity to determine if the device produced artifactual intermodulation distortion, which the relay system of the device should cancel. Figure 5 shows robust, intermodulation distortion present at all frequencies well above the noise floor. This calibration was repeated with device B. Figure 6 shows the absence of any intermodulation distortion at all frequencies in device B.

An engineer from a technical instrumentation company came to our laboratory to repeat the calibration of device A. The engineer confirmed our findings of intermodulation distortion in device A, and shipped the device to Otodynamics, Ltd. in the United Kingdom for repair. The manufacturer’s engineers diagnosed the problem as an interruption in the relay system. After the company repaired the device and shipped it back to us, we repeated the calibration in the 1 cc membranous cavity, and no intermodulation distortion was present.

**DISCUSSION**

Intermodulation distortion was present in the 1 cc membranous cavity during calibration of device A but not device B. Thus, the DPOAEs recorded in our patient in device A reflected intermodulation distortion of the cavity formed by the external auditory meatus and tympanic membrane rather than the inner ear. The intermodulation distortion that yielded artifactual DPOAEs occurred only in ILO 88 device A and did not occur in ILO 88 device B. To ensure that the artifactual DPOAE was unrelated to a problem in the probe assembly, the same probe assembly was used for both devices when doing all DPOAE and TEOAE testing, and the probe was checked for any obstruction (no obstruction was present). The phenomenon of artifactual DPOAEs from intermodulation distortion in the cavity formed

| Right | 55 | 88 @35 dB SL | 50 | Recorded |
| Left | None | 70 | |
| Masking level in right ear | None | 60 | |

**Table 2. Acoustic Admittance Results**

<table>
<thead>
<tr>
<th>Right ear</th>
<th>Left ear</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tympanometric peak pressure (daPa)</td>
<td>–30</td>
</tr>
<tr>
<td>Equivalent ear-canal volume (cm³)</td>
<td>1.2</td>
</tr>
<tr>
<td>Peak-compensated static-acoustic admittance (mmho)</td>
<td>1.1</td>
</tr>
</tbody>
</table>

**Table 3. Acoustic-Reflex Thresholds**

<table>
<thead>
<tr>
<th>Stimulus ear</th>
<th>Mode</th>
<th>500 Hz</th>
<th>1000 Hz</th>
<th>2000 Hz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Right</td>
<td>Contralateral</td>
<td>90</td>
<td>90</td>
<td>105</td>
</tr>
<tr>
<td>Left</td>
<td>Contralateral</td>
<td>90</td>
<td>85</td>
<td>110</td>
</tr>
<tr>
<td>Right</td>
<td>Ipsilateral</td>
<td>90</td>
<td>85</td>
<td>100</td>
</tr>
<tr>
<td>Left</td>
<td>Ipsilateral</td>
<td>85</td>
<td>90</td>
<td>105</td>
</tr>
</tbody>
</table>

**Table 4. Acoustic-Reflex Adaptation (≥50% adaptation within 10 sec)**

<table>
<thead>
<tr>
<th>Stimulus ear</th>
<th>Mode</th>
<th>500 Hz</th>
<th>1000 Hz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Right</td>
<td>Contralateral</td>
<td>Negative</td>
<td>Negative</td>
</tr>
<tr>
<td>Left</td>
<td>Contralateral</td>
<td>Negative</td>
<td>Negative</td>
</tr>
</tbody>
</table>

**Figure 2.** DPOAE test results from the right ear of the patient, obtained with device A (device with artifact).
by the external auditory meatus and tympanic membrane canal could occur in otoacoustic devices from any manufacturer. Therefore, the clinician should regularly calibrate their otoacoustic emissions device in 1 cc and 0.5 cc membranous cavities to rule out artifactual DPOAEs during DPOAE testing that occurs from intermodulation distortion in the cavity formed by the external auditory meatus and tympanic membrane rather than the inner ear. Calibration to rule out such artifactual DPOAEs can be performed by using a plastic medical syringe (used for injections), cutting both ends of the syringe down to the appropriate volume using the measurement markers on the syringe, and then sealing one end with the fingertip of a latex glove. The otoacoustic emissions probe then can be inserted into the syringe for calibration.

Perhaps intermodulation distortion from the cavity formed by the external auditory meatus and tympanic membrane also can occur in some TEOAE devices as the click stimuli comprise energy across a wide frequency range. Therefore, it would be prudent for audiologists to calibrate their TEOAE device, as well as their DPOAE device, using the aforementioned calibration procedure.

In the case presented herein, the presence of a substantial hearing loss alerted us to the possibility that the apparent DPOAEs were artifactual DPOAEs resulting from intermodulation distortion of the cavity formed by the external auditory meatus and tympanic membrane.
the tympanic membrane rather than the inner ear. Functional hearing loss was unlikely given the correlations among speech audiometry, acoustic immittance findings, and the audiometric findings; the congenital nature of the hearing loss; and the observed impact of the long-standing sensorineural hearing loss on the patient’s articulation and voice. Generally, the clinician would have little basis to doubt the validity of the occurrence of otoacoustic emissions when performing DPOAE or TEOAE testing. This makes it imperative to perform routine calibration of otoacoustic emissions devices to rule out such artifactual intermodulation distortion that compromises the reliability and validity of otoacoustic emissions testing.

Many infant screening programs identify auditory neuropathy on the basis of the presence of otoacoustic emissions with abnormal auditory brainstem response findings. Berlin et al (2005) include abnormal middle-ear muscle reflexes as a criterion for auditory neuropathy. If the findings of our patient had occurred in an infant, the auditory brainstem response probably would have been abnormal (due to the magnitude of the hearing impairment), so auditory neuropathy would most likely have been the (mis)diagnosis. The ipsilateral and contralateral acoustic reflexes most likely would have been absent for a low-frequency probe tone (Bennett, 1984; Sprague et al, 1985), furthering the (mis)diagnosis of auditory neuropathy.

Research is needed to determine how widespread the problem of intermodulation distortion is among various otoacoustic emissions devices (models and manufacturers).

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REFERENCES


