DPOAE I/O Functions in Normal and Impaired Human Ears

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Background

- Compressive nonlinearity is a hallmark of normal cochlear function.
- This compressive nonlinearity affects threshold sensitivity, which can be estimated using a variety of behavioral and electrophysiological techniques.
- It also affects response growth, and, therefore, the dynamic range of hearing.
- Outer hair cells (OHCs) are responsible for this compressive nonlinearity.
- OHCs are physiologically vulnerable, meaning damage to them affects compressive nonlinearity.

Clinical Issues

- OHC damage is involved in the majority of hearing losses we encounter clinically.
- One focus of clinical work is to estimate degree and configuration of hearing loss, i.e., threshold.
- If OHC damage only caused threshold elevation, then providing hearing-aid gain equivalent to the hearing loss would completely overcome any hearing problems.
- However, patients with hearing loss also experience other auditory problems related to how loudness grows, which is a behavioral manifestation of auditory response growth.

Clinical Questions Associated with Our Research Program

- Can objective measurement techniques be used to describe auditory function in humans?
- Can information gained from the use of these techniques lead to better diagnostic and rehabilitative decisions for patients with hearing loss?
- Can all of this be done on infants, young children and other patients with developmental disabilities?

Questions Being Posed by the Current Research Program

- Can we develop objective estimates that relate to response growth in normal ears?
- Can we gain insights into the range and magnitude of compression in normal and impaired ears?
- Can we develop paradigms that can be used in the clinic?
- Do our measures correlate with perceptual phenomena, such as loudness? This is the really hard question to answer, and we haven't answered it yet.

DPOAE I/O Functions as Measures of Response Growth

- I/O functions are measured by holding primary frequencies constant and varying primary levels.
- In many ways, they resemble other more direct measures of response growth.
- They are linear at low levels, compressive at moderate levels, and perhaps linear at high levels.

Stimulus Conditions for Measuring DPOAE I/O

- Pair of primaries (f_1, f_2; $f_2/f_1 \approx 1.22$) are presented
- L_2 varied from 10 to 95 dB SPL, depending on f_2
- L_1 adjusted to maximize response level in normal ears ($L_1 = 0.4L_2 + 39$ dB) for $L_2 <$ 75 dB SPL. $L_1 = L_2$ for $L_2 \geq 75$ dB SPL
- These measurements were made both in normal and in impaired human ears

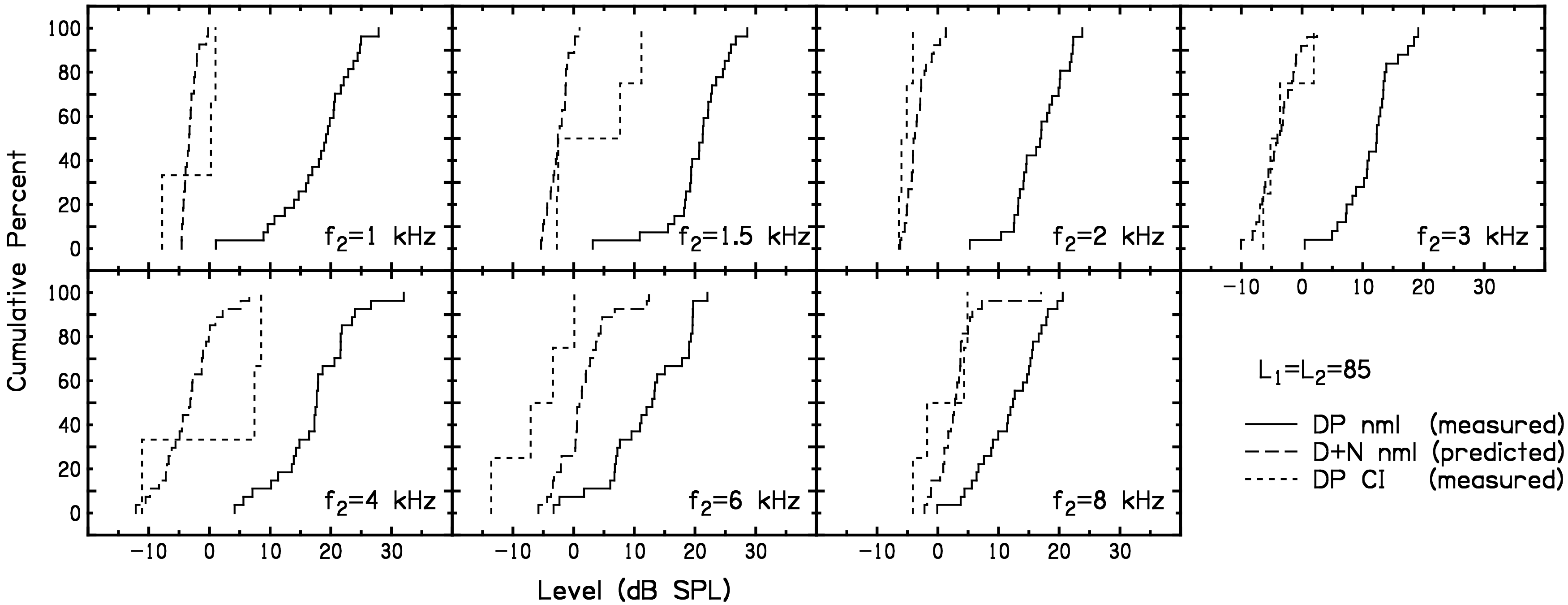
Estimates of System Distortion

- All systems eventually will produce distortion, especially at high level
- System distortion must be distinguished from biological distortion, especially in ears with hearing loss
- Our approach was to estimate system distortion in six different cavities, from which an algorithm was developed to predict system distortion
- This algorithm was then tested on ears with cochlear implants (implants turned off).

Data from Normal-Hearing and Cochlear-Implant Subjects

- In the next slide, $L_1 = L_2 = 85$ dB SPL
- Solid line shows cumulative distributions of DPOAE level from 27 normal-hearing subjects (DP nml (measured)).
- Long dashed line shows estimated system distortion, based on cavity measurements (D+N nml (predicted)).
- Short dashed line shows measurements in patients with cochlear implants DP CI (measured)).

System Distortion

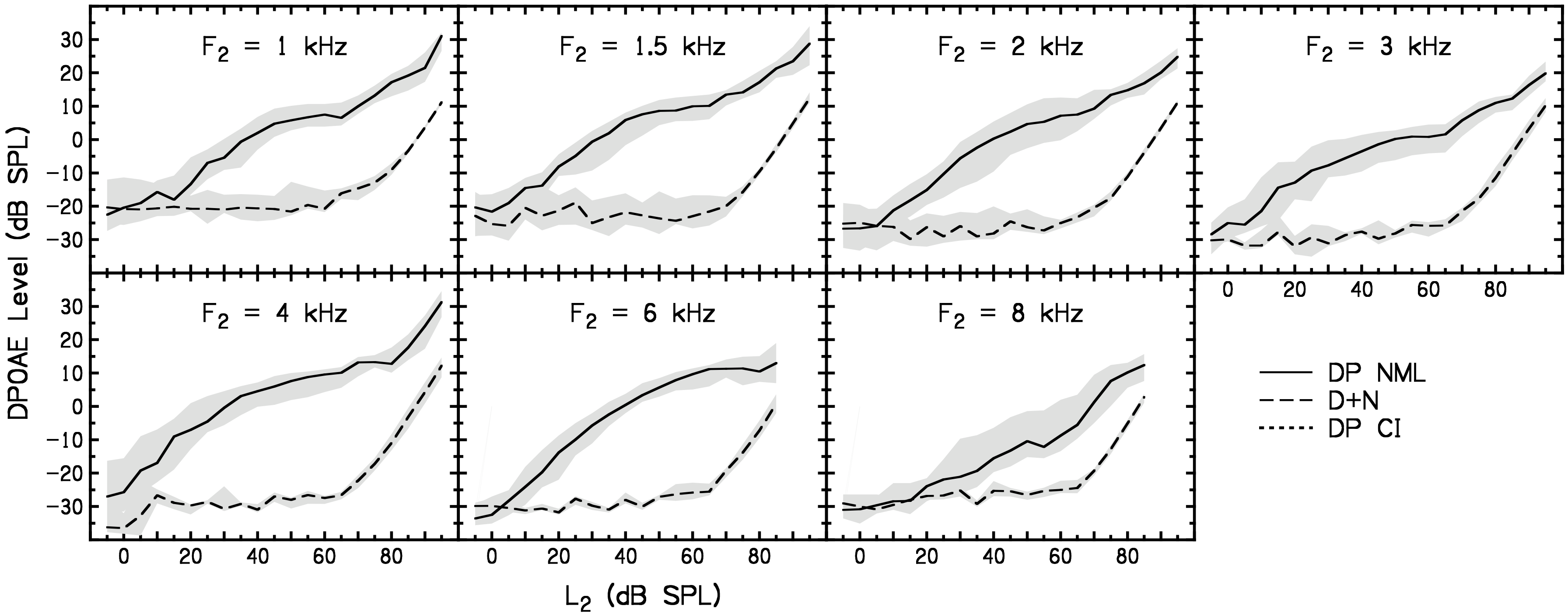


System Distortion

- Normal DPOAEs above system distortion at all f_2 frequencies
- Levels in CI ears $\leq$ predicted system distortion at 5 f_2's, validating approach at these frequencies
- Levels in CI ears exceed system distortion when f_2 = 1.5 or 4 kHz, questioning the approach at these two frequency.

DPOAE I/O Functions From Ears With Normal Hearing

Normal DPOAE I/O Functions

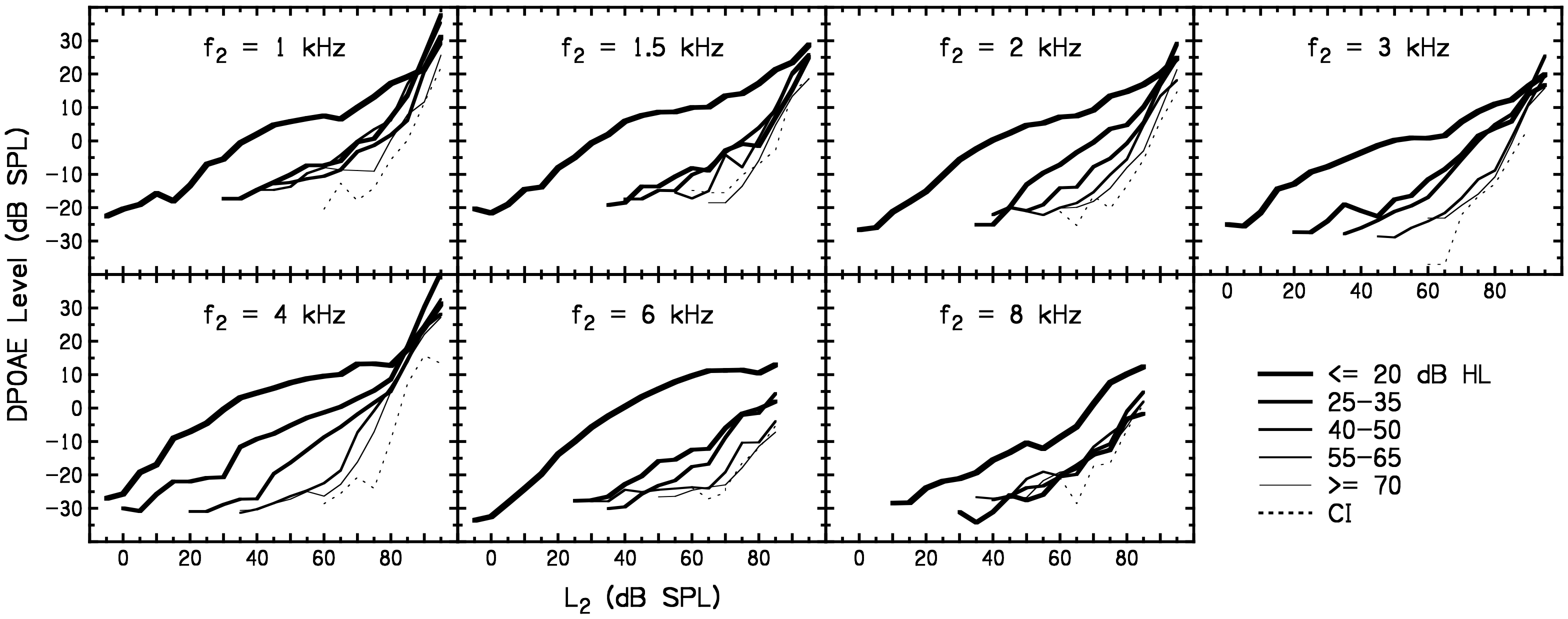


Normal DPOAE I/O Functions

- Rapid growth at low stimulus levels
- Slower “compressive” growth at intermediate stimulus levels
- Rapid growth at high levels
- All responses above levels of system distortion plus noise; thus, they are probably biologic in origin, although exact source of high-level section remains unknown
- Pattern reminiscent of direct measures of basilar membrane response growth in lower animals (i.e., Ruggero and colleagues).

Normal & Impaired DPOAE I/O Functions

Normal & Impaired I/O Functions



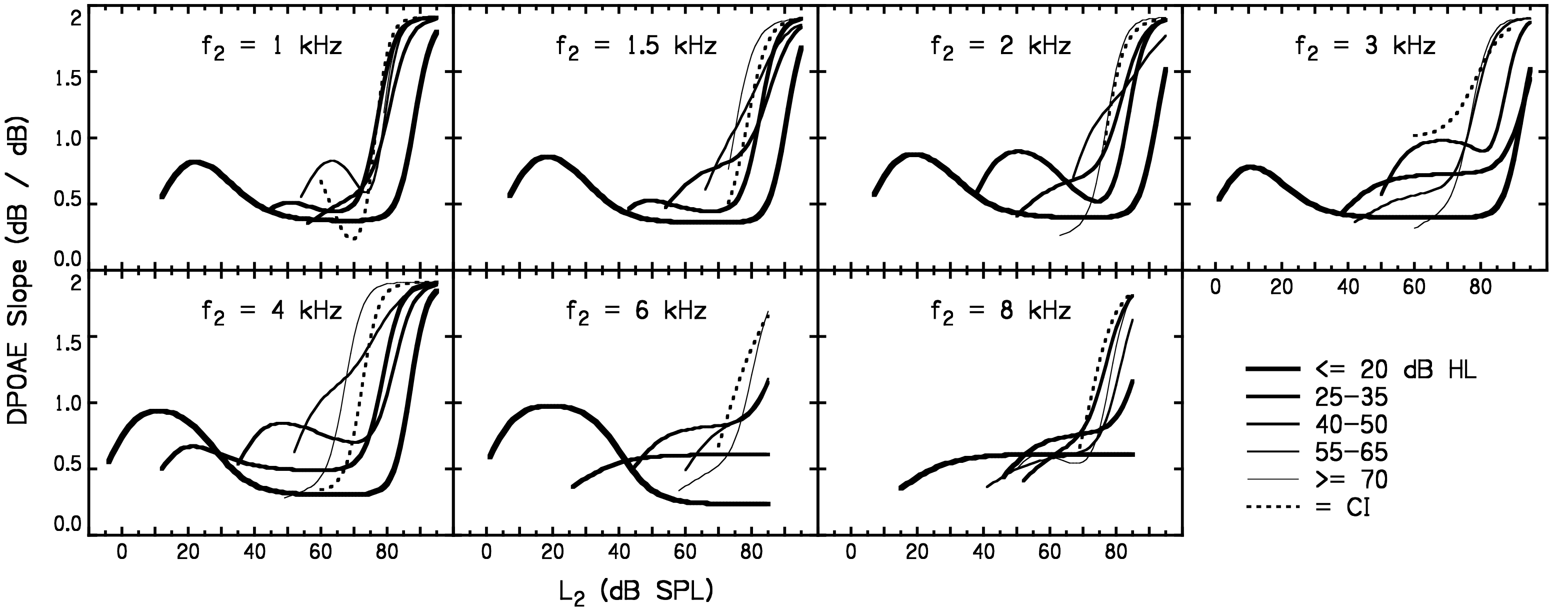
I/O Functions in Impaired Ears

- Thresholds are elevated
- Compressive pattern at moderate levels is reduced or absent
- DPOAE level increases rapidly at high stimulus levels, similar to normal ears
- Responses in some hearing loss groups exceed responses in CI ears
- In other HL categories, responses indistinguishable from results in CI ears, meaning that they may reflect system distortion

Estimating Amount of Compression and the Range of Levels Over which Compression Takes Place

Slope of the DPOAE I/O function as a function of Level (L_2)

Slopes of I/O Functions



Summary of Slopes of I/O Functions

- In normal ears, slope increases at low levels, achieves a local maximum, decreases as level increases, then grows rapidly at high levels.
- In some impaired ears, slope increases, reaches a local maximum at a higher level than normal ears, decreases, but not as much as in normal ears, and then increases rapidly at high levels.

Range of Levels Over which Compression Takes Place

- Defined as the difference in level (L_2) from the low-level local peak (with a maximum slope of about 1 in normal ears, about 20 dB SPL) to the high-level at which the same slope is achieved.

Table 1. Range of Compression in dB

	f_2 frequency (kHz)					
Audiometric Threshold	1.0	1.5	2.0	3.0	4.0	6.0
≤ 20 dB HL	65	71	72	79	75	76
25 to 35 dB HL	21	27	32		53	
40 to 50 dB HL					30	

Range of Input Levels over which Compression Takes Place

- In normal ears, the range of levels over which compression occurs ranges from 65 to 79 dB
- When it is possible to estimate it, the range of input levels for which compression takes place is reduced to 21 to 53 dB.
- For ears with slightly greater losses, this range could only be estimated at 4 kHz, and was reduced further.

Amount of Compression

- Defined as the minimum slope of the DPOAE I/O function.

Table 2. Maximum amount of compression (minimum slope of I/O Function)

	f_2 frequency (kHz)					
Audiometric Threshold	1.0	1.5	2.0	3.0	4.0	6.0
≤20 dB HL	0.31	0.29	0.34	0.34	0.24	0.16
25 to 35 dB HL	0.39	0.39	0.47		0.44	
40 to 50 dB HL					0.67	

Amount of Compression

- In normal-hearing ears, the amount of compression ranges from 3:1(minimum slope of 0.34) to 6:1 (minimum slope of 0.16).
- In mild hearing loss, the amount of compression ranges from 2.1:1 (minimum slope of 0.47) to 2.6:1 (minimum slope of 0.47).
- In the one case for which it could be estimated (4 kHz), the compression ratio was 1.5:1 for hearing losses of 40-50 dB.

Compression Summary

- Normal ears compress over a 60 to 80 dB range of input levels
- Range of levels over which compression occurs is reduced in ears with hearing loss
- Normal ears compress by a factor of 3 or 4 to 1
- When measurable, the amount of compression was reduced in ears with hearing loss

So, what do we know so far?

- I/O functions resemble more direct measures, suggesting we have an objective measure of response growth in humans.
- We have estimates of compression that are consistent with physiological data from lower animals.
- We have data in impaired ears, showing a reduction in both the range of levels over which compression occurs and in the amount of compression. This pattern would be consistent with a more rapid response growth in impaired ears.

What Do We Need To Know?

- Can we develop paradigms that can be used in the clinic? We think the answer to this question is yes.
- Do our measures correlate with perceptual phenomena like loudness recruitment? Our first foray into these measurements was unsuccessful, perhaps because we chose the wrong paradigm. We haven't given up yet. Future work hopes to address this question.