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# Evaluation of Pure-Tone Thresholds and Distortion Product Otoacoustic Emissions Measured in the Extended High Frequency Region

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# Pure-tone thresholds and distortion product otoacoustic emissions measured in the extended high frequency region

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## Introduction

When the cochlea is stimulated with two primary tones ($f_1$ and $f_2$) some of the energy is reflected back and propagates via middle ear into the outer ear. Due to cochlear nonlinearities, distortion product otoacoustic emissions (DPOAEs), may be detected by a probe microphone sealed in the ear canal. Reduced DPOAEs may indicate subclinical cochlear lesions. The relationship between hearing sensitivity and the strength of DPOAEs is debatable, especially in the extended high frequency (EHF) region (≥8 kHz). Monitoring cochlear function corresponding to the EHF range is important for detecting early stages of hearing loss, which typically begins above 8 kHz. Complex interactions of high-frequency pure-tones in the ear canal result in standing waves that increase test-retest variability of DPOAEs measured for $f_2$≥6 kHz.

The aim of the project was to evaluate reliability of DPOAEs measured up to 12 kHz with a system used routinely in audiology clinics.

## Methods

DPOAEs were measured with a GSI Corti system applying a standard protocol, a DP-gram, used routinely in the clinics.

Frequency $f_2$ was varied from 1.5 to 12 kHz with $f_2/f_1$=1.22.

Data were collected for $L_1/L_2$=65/55 dB SPL.

Pass criterion for each pair of the primaries required a signal-to-noise ratio (SNR) of at least 6 dB.

For each ear, DP-grams were collected twice with the probe removed and repositioned after the first test.

**Participants**:
31 young adults; age: 18-30 years;

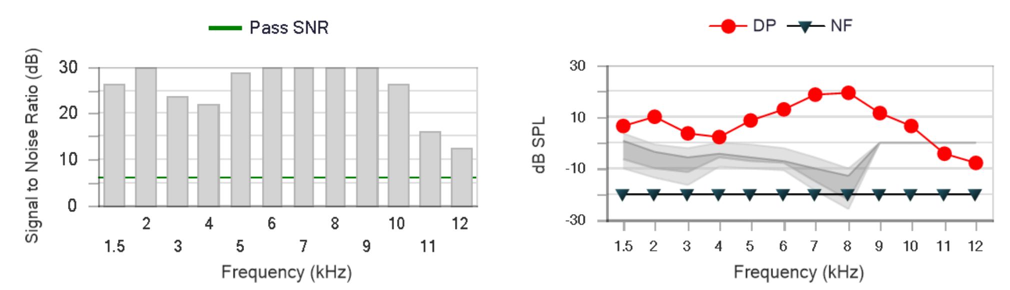
male:7; female: 24;

normal middle ear function based on otoscopy and tympanometry;

normal behavioral thresholds in conventional frequency region, from 250 Hz to 6000 Hz;

no prior otologic history.

## An example of a DP-gram




| F2 | L1 | L2 | DP | NF | SNR |
|---|---|---|---|---|---|
| 1.5 | 64 | 57 | 6.6 | -20.0 | 26.6 |
| 2.0 | 67 | 55 | 10.0 | -20.0 | 30.0 |
| 3.0 | 65 | 55 | 3.5 | -20.0 | 23.5 |
| 4.0 | 66 | 55 | 1.9 | -20.0 | 21.9 |
| 5.0 | 65 | 55 | 8.6 | -20.0 | 28.6 |
| 6.0 | 75 | 61 | 13.0 | -20.0 | 33.0 |

| F2 | L1 | L2 | DP | NF | SNR |
|---|---|---|---|---|---|
| 7.0 | 71 | 54 | 18.5 | -20.0 | 38.5 |
| 8.0 | 68 | 54 | 19.3 | -20.0 | 39.3 |
| 9.0 | 57 | 65 | 11.4 | -20.0 | 31.4 |
| 10.0 | 69 | 55 | 6.2 | -20.0 | 26.2 |
| 11.0 | 77 | 56 | -4.0 | -20.0 | 16.0 |
| 12.0 | 70 | 59 | -7.7 | -20.0 | 12.3 |

Fig. 1. DP-gram data recorded in the right ear of participant P1. The bar graph on the left depicts SNR values for each $f_2$ frequency. The graph on the right represents DPOAE and noise levels, red circles and black triangles, respectively.

The shaded areas correspond to normative data. The top light-gray line corresponds to the 95th percentile of DPOAE levels recorded in impaired ears. Thus, DPOAEs above that line are interpreted as certainly normal levels, i.e., a strong indication of normal cochlear function. Note: there are no norms for $f_2$>8 kHz.

## Participant P3: EHF hearing loss

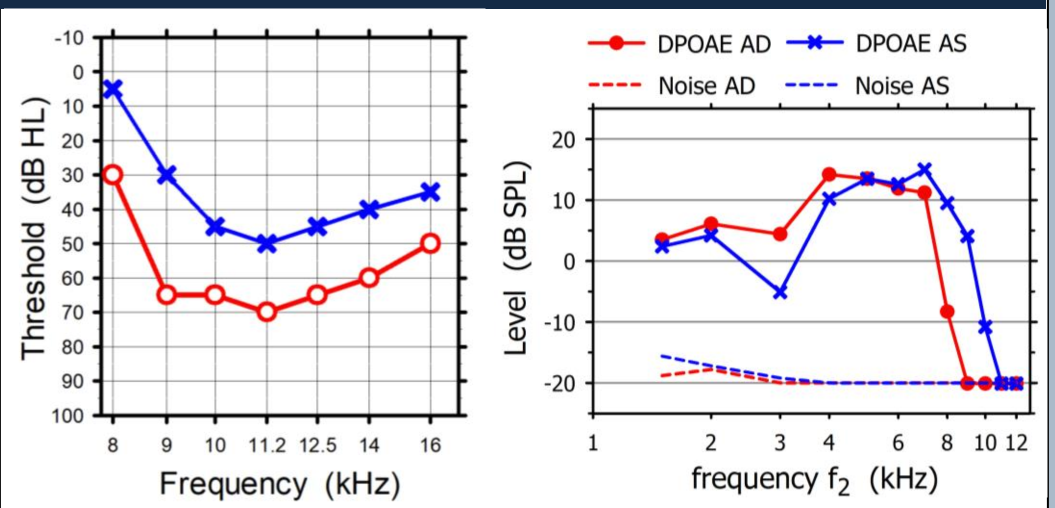



Fig. 2. Results for participant P3 who reported listening to loud music through headphones for extended periods of time. The EHF audiogram (left panel) indicated elevated thresholds, especially in the right ear.

For both ears, the DP-gram (right panel) showed DPOAEs within the normal range up to 6 kHz, as expected based on the normal audiogram in that frequency range. For the right ear, the DPOAE level decreased at $f_2$ = 8 kHz in agreement with the threshold of 30 dB HL. The DPOAEs were not detectable above the noise for $f_2$ ≥9 kHz confirming behavioral thresholds between 50 and 70 dB HL in the EHF range. The EHF thresholds in the left ear were elevated less significantly, resulting in high DPOAE levels up to 10 kHz but not detectable above the noise floor for $f_2$ ≥11 kHz.

## Participant P25: EHF hearing loss

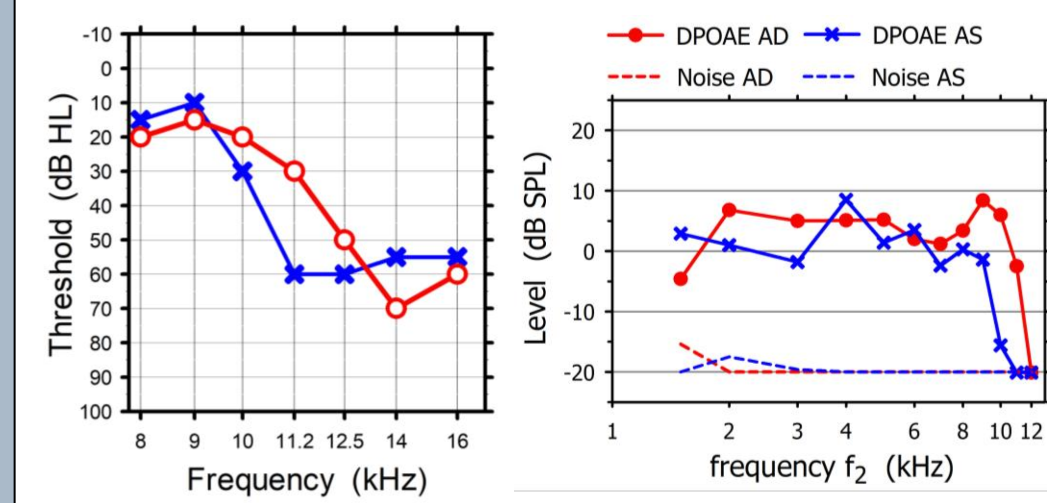



Fig. 3. Results for participant P25 who did not report any noise exposure or extended period of listening to music at high levels. The EHF audiogram (left panel) indicated elevated thresholds above 10 kHz.

For both ears, the DP-gram (right panel) showed high-level DPOAEs up to 9 kHz, as expected based on normal audiogram in that frequency range. For the left ear, the DPOAE decreased at $f_2$ = 10 kHz in agreement with the threshold of 30 dB HL. The DPOAEs were not detectable above the noise floor for $f_2$ = 11 and 12 kHz confirming behavioral thresholds of 60 dB HL. The EHF thresholds in the right ear were elevated less significantly, resulting in high DPOAE levels up to 11 kHz but not detectable above the noise floor for $f_2$ = 12 kHz.

## Participant P5: a dip in the DP-gram

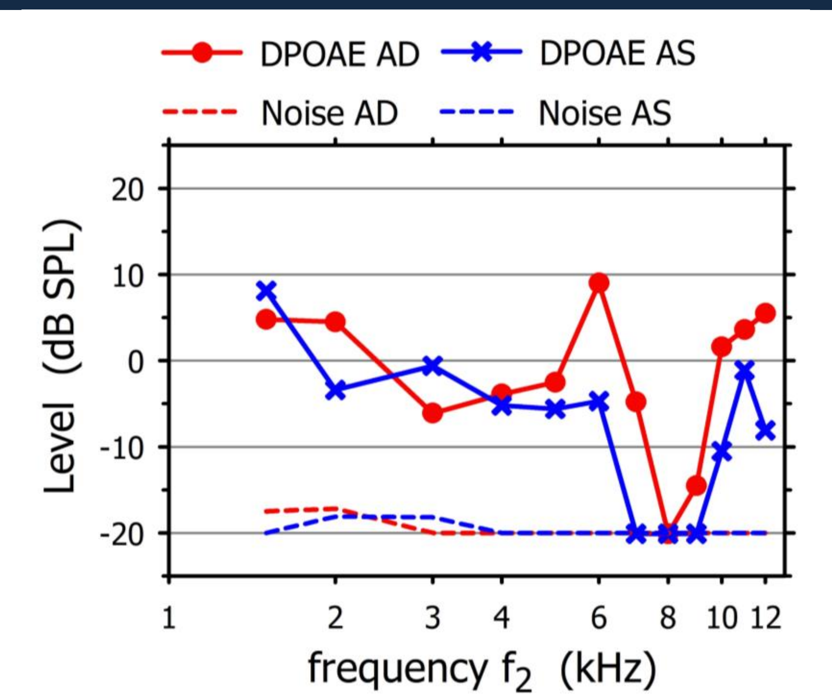



Fig. 4. Results for participant P5 who had normal EHF thresholds.

A lack of detectable DPOAEs in the 8-kHz region was not expected based on normal pure-tone thresholds. Complex physical interactions of high-frequency primary tones in the ear canal can result in standing waves impacting the probe calibration and DPOAEs measured by the probe microphone at a particular location.

## Data analyses

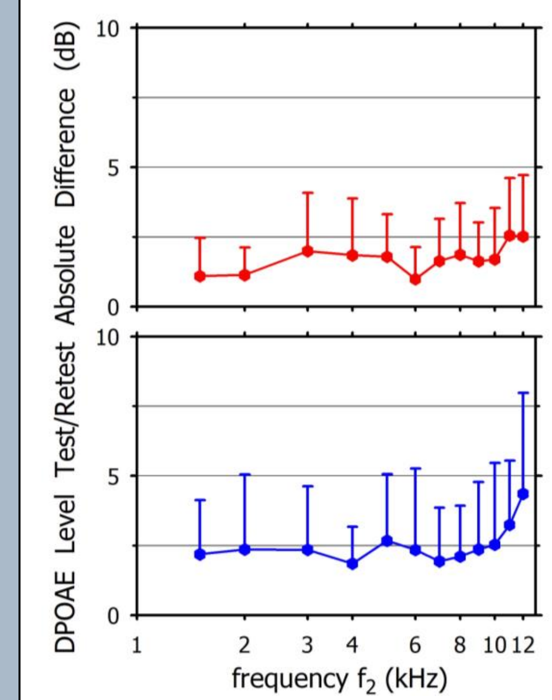



Fig.5. Means and SDs of test/retest DPOAE level differences calculated for the right and the left ears.

ANOVA showed the main effect of frequency both for the data in left and the right ears.

Post-hoc analyses showed significant differences for $f_2$ of 11 kHz (AD) and $f_2$ of 12 kHz (AS).

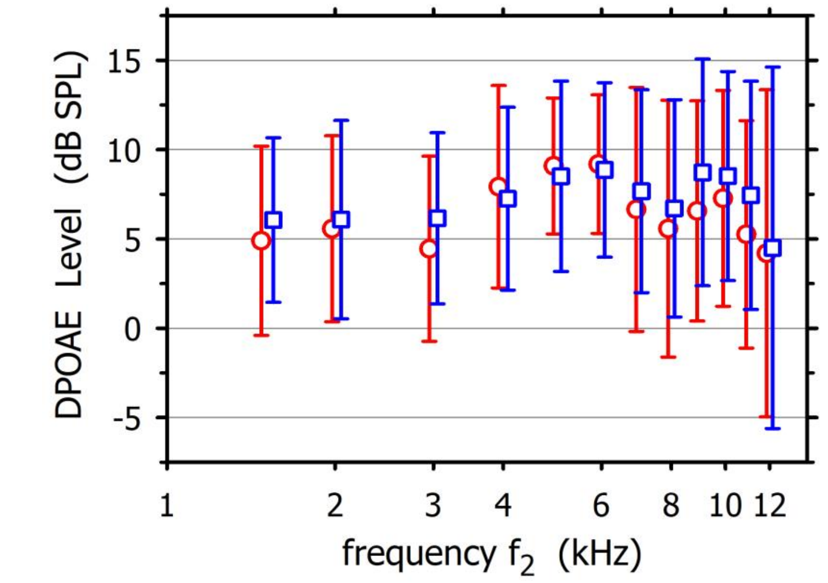



Fig.6. Mean and SDs of DPOAE levels calculated separately for the left and the right ears of subjects with normal thresholds in the EHF region.

There were no differences between mean DPOAE values in the left and the right ears. Yet, the SDs at 12 kHz were statistically significantly greater than those at any other frequency, both for the left and the right ears, per the F-test for variances.

## Conclusions

The intersubject variability of the DPOAE levels was moderate (SD≈6 dB or lower) but it increased in the 12-kHz region, possibly due to 1. the effects of standing waves on the high-frequency DPOAE reliability and/or 2. subclinical OHC pathology in the most basal portion of the cochlea.

Test/retest variability of DPOAEs was rather constant for $f_2$ frequencies up to 10 kHz but increased at 11 and 12 kHz. This finding may be a limiting factor when using DPOAE testing for longitudinal monitoring of cochlear function in the basal part, for example, due to administering ototoxic agents.

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