Combining Levels and Phases for DPOAE analysis

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INTRODUCTION

NONINVASIVE MONITORING OF INTRACRANIAL PRESSURE CHANGES: Detection of increases in intracranial pressure (ICP) is essential in the treatment of several brain damaging conditions which can lead to severe brain injury or death. Intracranial pressure (ICP) monitoring is currently an invasive procedure which requires entry in the intracranial space through the skull (Fig. 1). Previous and current work relating ICP variations to changes in distortion-product otoacoustic emissions (DPOAEs) (Buki et al. 1996, Buki et al., 2000, Frank et al. 2000, de Kleine et al. 2000, 20001, Voss et al. 2006) indicates that increases in ICP are likely to be detectable through changes in DPOAEs. **Development of a systematic analysis for changes in DPOAEs is therefore an essential tool in the implementation of a noninvasive ICP monitoring system based on DPOAE measurements.**

Figure 1: Surgical placement of an ICP monitoring device. Picture from: http://www.djo.harvard.edu/files/2791_333.jpg

GOAL OF THIS WORK: The goal of this work is to include both the level and phase components of the DPOAEs in an analysis to detect changes in DPOAEs. Although DPOAE correlation with ICP has been analyzed in terms of changes in DPOAE levels, there has been no attempt to describe the effects of ICP changes on DPOAEs by incorporating both level and phase in one representation. Here, we compare the individual level and phase representations with a representation that combines the DPOAE level and phase, with each DPOAE measurement a point whose distance from the origin is related to DPOAE level and whose angle is related to the DPOAE phase. Ultimately, the goal is to identify a representation that will provide information regarding changes in DPOAEs.

EXPERIMENTAL METHODS

OVERVIEW: DPOAEs were measured on five normal-hearing, healthy subjects at two postural positions (upright at 90° and -45 degrees) on a tilting table (Figure 2) to characterize how posture, and presumably intracranial pressure (ICP), affects DPOAEs. At these positions, it is expected that ICP varies from about 0 (90°) to 22 mm Hg (-45°) (Chapman et al., 1990; de Kleine et al, 2000). Changes in DPOAEs taken at the two positions are examined in terms of both levels and phases and also as a combination of level and phase through a scatter plot.

SUBJECTS: Data were collected from five healthy, normal-hearing female subjects (ages 19 to 39) following an otoscopic screening to ensure the lack of excessive wax in the ear canal. All subjects gave their informed consent to participate in the experiments approved by the Smith College Science Center Institutional Review Board. Audiometric testing indicated normal thresholds (<20 dB) at all test frequencies (500, 1000, 2000 and 4000 Hz).

Figure 2: Measurements were made with subjects on a tilting table at two positions (angles 90° and -45° to the horizontal). Since de Kleine et al. (2000) demonstrated that stability in emission measurements is typically reached within 30 seconds after a postural change, DPOAE measurements were made after a subject was in position for at least one minute.

TYMPANOMETRY: Tympanometry was performed at the beginning of each measurement to monitor middle-ear conditions. Subjects were asked to swallow at each postural position to maintain middle-ear pressure as close to 0 as possible; four subjects had variations in middle-ear pressure no greater than 24 dPa and one subject (Subject 1) had a maximum variation of 36 dPa.

DPOAE MEASUREMENT: DPOAEs were measured with an Etymotic ER-10c probe using HearID v4.0 (Mimosa Acoustics). To maximize the low-frequency responses, measurements were at frequencies $f_{dp}=2f_1-f_2$ with $f_2 / f_1=1.25$ and $L_1=L_2=75$ dB SPL. Four measurements were performed during each session, one for each ear at the two chosen postural positions, adjusted using a tilting table - supine and tilted minus 45 degrees to the horizontal. All measurements were repeated five times per subject on different days. Results from the right ear of each subject are reported here.

COMBINING LEVEL AND PHASE DATA: Figure 3 illustrates how each DPOAE measurement is represented by a point whose distance from the origin is L_{dp}+20 (we add 20 so that the distance is always positive) and whose angle is 2p times the DPOAE phase (in cycles). An equivalent view of this representation describes the DPOAE in terms of the two components X_{dP} and Y_{dP}.

$$X_{dP} = (L_{dP}+20) \cos(2pf_{dP})$$

$$Y_{dP} = (L_{dP}+20) \sin(2pf_{dP})$$

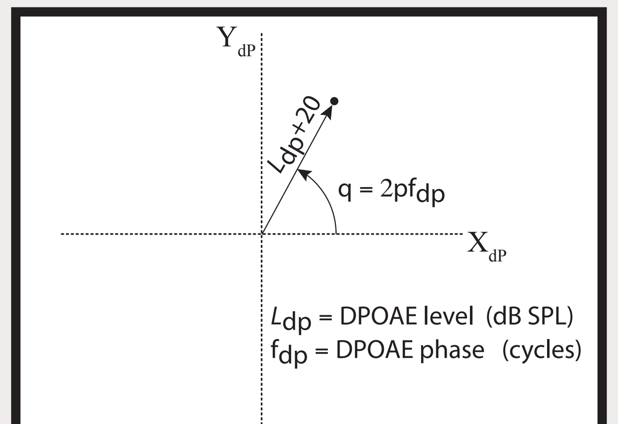

Figure 3: Representation of DPOAE level and phase.

RESULTS

1 **Figure 4** compares DPOAE levels and phases for the two positions, upright and -45 degrees. Five measurements were made on different days on each of five subjects. Presumably, the -45 degree position increases the subject's intracranial pressure (ICP).

2 **Figure 5** combines the DPOAEs levels and phases for the two positions, upright and -45 degrees.

3 **Figure 6** tests the significance for which the data in Figures 4 and 5 differ based on postural position.

1 Individual Levels and Phases

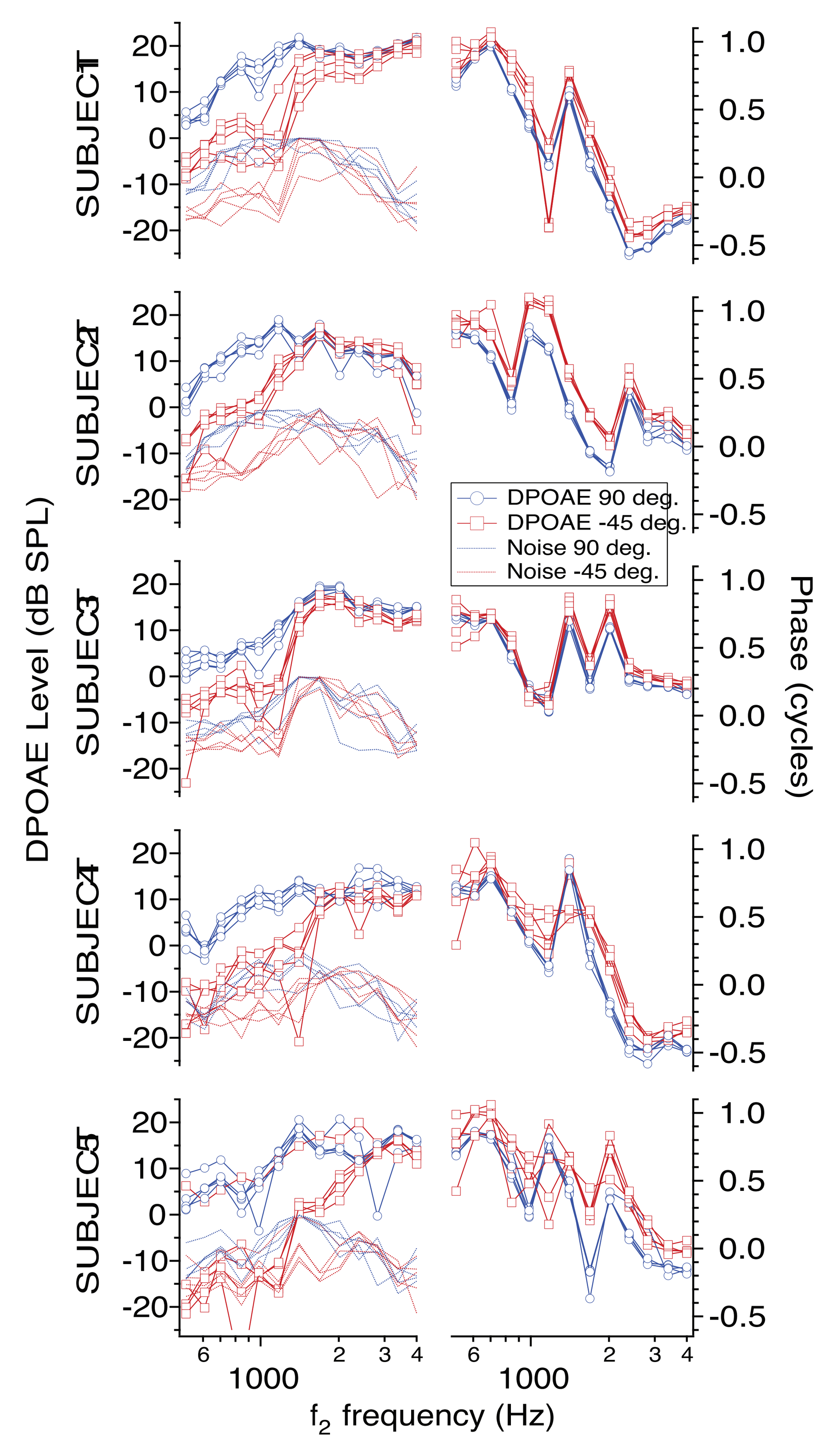

Figure 4. DPOAE levels (left column) and phases (right column) from the right ear of five subjects, with five measurement sessions per ear. Measurements were made for two postural positions: upright (blue circles) and with the subjected tilted at -45 degrees relative to the horizontal (red squares). Noise floors associated with each measurement are shown in dashed lines. Noise levels are generally higher for upright postures because the measurements were stopped once the signal to noise level reached 15 dB.

2 Combined Levels and Phases

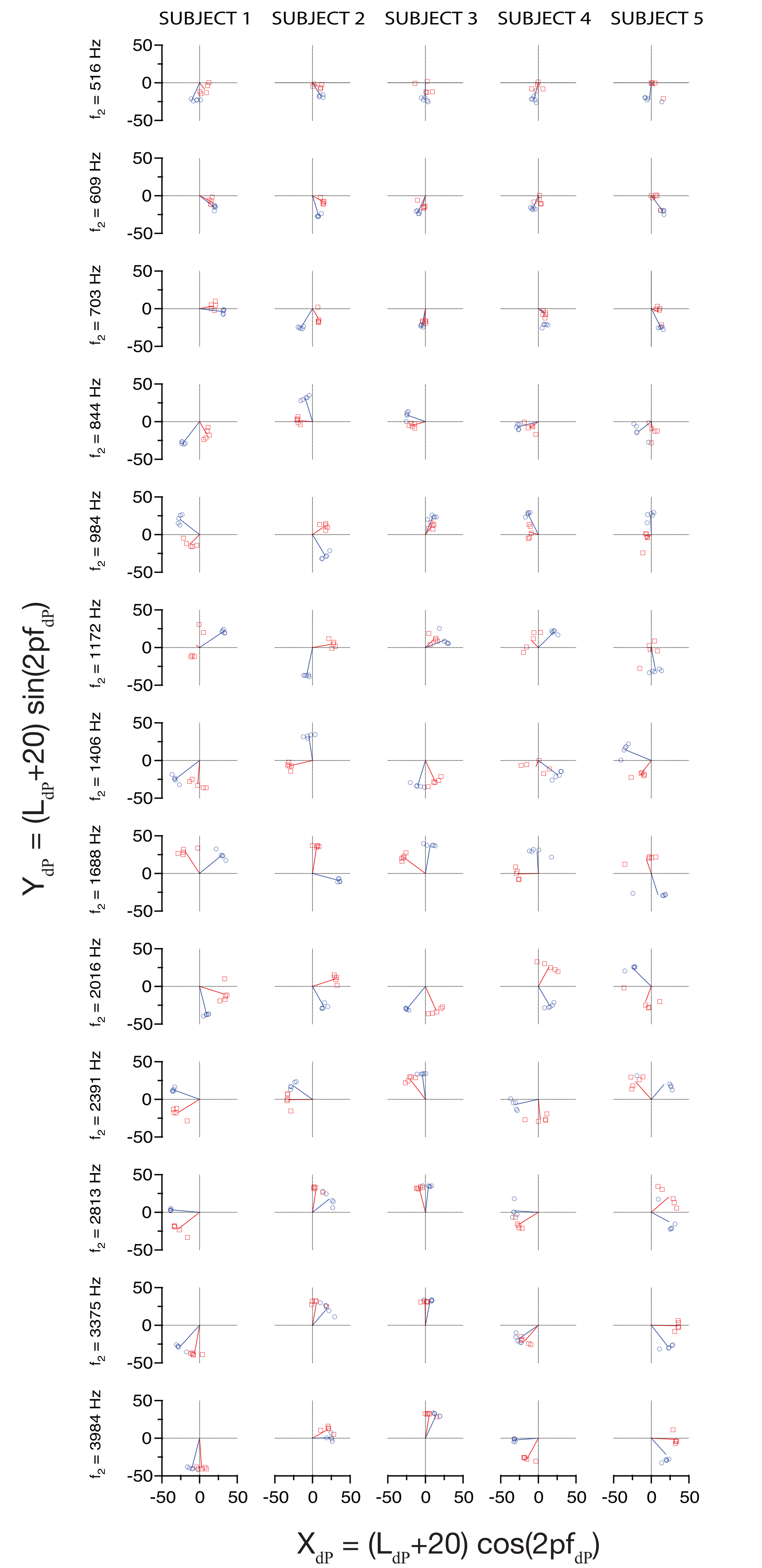

Figure 5. DPOAE measurements represented by a point whose distance from the origin is L_{dp}+20 (we add 20 so that the distance is always positive) and whose angle is 2p times the DPOAE phase (in cycles). Measurements are from the right ear of five subjects, with five measurement sessions per ear. Each column of plots is from one subject and each row is the data from one frequency. Measurements were made for two postural positions: upright (blue circles) and with the subjected tilted at -45 degrees relative to the horizontal (red squares). The colored line connects the origin to the centroid associated with the five data points from each postural position.

3 Quantitative comparison

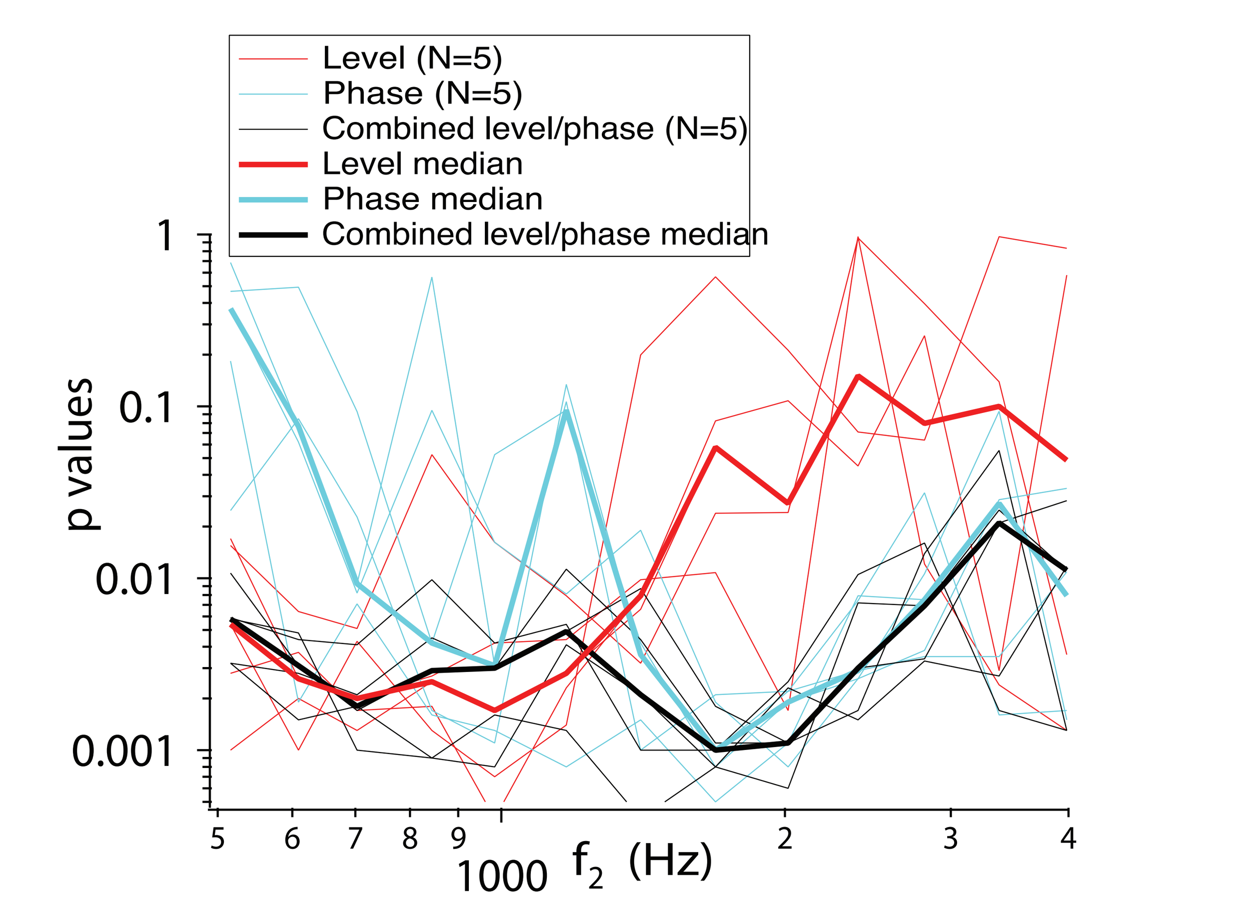

Figure 6. Computed p values to test the hypothesis that data collected at the two postural positions are different. Individual p values were calculated for each subject at each frequency for the three DPOAE representations: level (red), phase (blue), and combined level and phase (black). Values were computed with a numerical, bootstrap test (resampling) with 10,000 iterations and replacement, as described by Efron and Tibshirani; the test used distances calculated between centroids (combined level and phase) and mean values (levels and phases) for data collected at each posture. Thick lines represent the median p values for level (red), phase (blue) and combined level and phase data (black) for the five subjects.

SUMMARY

- ☞ DPOAEs measured at the two postures upright (90 degrees) and tilted (-45 degrees) show clear separation in level only, phase only, and combined level and phase (Figures 4 and 5).
- ☞ DPOAE levels are more sensitive to changes for lower frequencies (<1500 Hz), and phases are more sensitive at higher frequencies (f>1500 Hz) (Fig. 6).
- ☞ Combining level and phase is a consistent measure for DPOAE changes at all frequencies. This approach uses all information in the DPOAE signal. Future work will explore the sensitivity of the combined level and phase analysis to determine how points affected by noise might be identified.

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