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 diseases, including trauma and certain types of tumors. Intracranial pressure (ICP) monitoring is currently an invasive procedure which requires entry into the intracranial space through the skull (Fig. 1). Previous and current work relating ICP variations to changes in dissociated product mean-ear pressure emissions (DPOAEs) (Bakke et al., 1996; Baki et al., 2006; Frank et al., 2006; de Kleine et al., 2001; 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 step in the implementation of a noninvasive ICP monitoring system based on DPOAE measurements.

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. 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 within 30 seconds after a postural change, presumably increasing ICP. Tympanometry was performed at the beginning of each measurement to ensure no greater than 24 dPa and one subject (Subject 1) had a maximum variation of 36 dPa. 

The results of the tympanometry and the measurement setup are shown in Figure 3. The position of the microphone relative to the subject’s intracranial pressure (ICP).

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. 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 within 30 seconds after a postural change, presumably increasing ICP. Tympanometry was performed at the beginning of each measurement to ensure no greater than 24 dPa and one subject (Subject 1) had a maximum variation of 36 dPa.

DPOAE MEASUREMENT: DPOAEs were measured using the equipment from Dynamic EEC-3000 series. At the beginning of each measurement, the subject was asked to swallow. The equipment from Dynamic EEC-3000 series was used to measure DPOAEs. DPOAE measurements were performed during each measurement, one for each ear at the two chosen postural positions, all at the same tilted angle 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 a DPOAE measurement is categorized by a point whose distance from the origin X0 ≤ 20 (or add 20 to obtain the distance in decibels) and whose angle is ≤ 50° the DPOAE phase (in cycles). 

An appropriate size of the representation can be obtained by stretching the DPOAE in the terms of the two parameters, X0 and X1:

\[ X_0 = (L_{10} + 20) \cos(2 \pi dPf_1) \]

\[ X_1 = (L_{10} + 20) \sin(2 \pi dPf_1) \]

EXPERIMENTAL RESULTS

The data from Figure 2 are shown in Figure 4. Figure 5 shows the DPOAE levels and phases for the two postural positions, upright and -45 degrees. Five measurements were made on different days for each subject. Presumably, the -45 degree position increases the subject’s intracranial pressure (ICP).

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REFERENCES

Bakke et al. (1996) demonstrated that stability of DPOAEs is therefore an essential tool in the implementation of a noninvasive ICP monitoring device. Picture from: "Combining Levels and Phases for DPOAE analysis" by Modupe F. Adegoke, Susan E. Voss, Nicholas J. Horton, Yamama Raza, Christopher A. Shera.

Figure 6: DPOAEs captured at the two postures (upright) (90°) 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 (1500-1900 Hz) (Fig. 6).

Combining level and phase is a consistent measure for DPOAE changes at all frequencies. This approach uses all the 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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