Comparison of peripheral compression estimates using auditory steady-state responses (ASSR) and distortion product otoacoustic emissions (DPOAE)

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ABSTRACT
The healthy auditory system shows a compressive input/output (IO) function as a result of healthy outer hair cell function. Hearing impairment often leads to a decrease in sensitivity and a reduction of compression, mainly caused by loss of inner and/or outer hair cells. Compression is commonly estimated based on behavioral procedures (Plack et al., 2004), which are time consuming and rely on assumptions regarding the ability to selectively investigate cochlear processing, or on objective recordings such as otoacoustic emissions (OAEs) (Neely et al., 2003), which allow to selectively study cochlear processing but where the interpretation of results for individual data is challenging. Auditory steady-state responses (ASSR) are another objective method which allows fast, reliable and frequency-specific measurements of hearing function. It is hypothesized that compressive behavior is observed in normal-hearing (NH) listeners while in hearing-impaired (HI) listeners, sensitivity and compression are reduced. ASSR data are later compared to data from distortion-product otoacoustic emissions (DPOAE) recordings.

RESULTS

NORMAL-HEARING:

- NH subjects consistently show compressive functions with slopes between 0.1 and 0.5 dB/dB.
- ASSR saturates or even decreases at higher stimulus levels.
- Repeated points (●) recorded in different sessions show small variability in the response.

HEARING-IMPAIRED:

- HI subjects show higher variability in the results.
- Significant responses at input levels of 30 dB SL and above have been obtained for HI subjects.
- ASSR IO functions in HI subjects reflect the loss of sensitivity at lower stimulus levels.

DPDQE in NH:

- Multiple and single frequency stimulation elicit similar responses.
- No interaction among the different SAM tones seems to be present in the ASSR recordings from the used multi-frequency stimulus.
- Results from single frequency stimulation recordings show slightly higher variability than results from multi-frequency stimulation.

DPDQE in HI:

- DPOAE recordings show growing IO function with constant slopes using mid-range stimulus levels.
- Compression estimate from DPOAE IO functions was obtained using the method proposed by Neely (2003).

HYPOTHESIS
Peripheral compression can be estimated through ASSR IO functions in NH subjects. HI subjects show a change in sensitivity and compression estimate.

How do compression estimate correlate when measured using ASSRs versus DPOAEs?

METHODS

ASSR
(20 subjects, 13 NH and 7 HI)

- 64-channel EEG system with active electrodes ( Biosens).
- ASSR magnitude obtained from the recorded ASSR spectrum, computed from the weighted averaged waveform.
- Detection of significant results using F-test (p-value ≤ 1%).

DPOAE
(12 NH subjects)

- Fitting curves

64-channel EEG spectrum

DPDQE

- Least-squares-fit (LSF) method used to obtain the magnitude and phase of the 2f2 − f1 DPOAE component.

REFERENCES


RESUL TS

Fig. 1. The panels show ASSR IO functions for four different carrier frequencies recorded in a NH subject. Panel A: f1 = 0.5 kHz @ f2 = 83 Hz, Panel B: f1 = 1 kHz @ f2 = 87 Hz, Panel C: f1 = 1.5 kHz @ f2 = 93 Hz, and Panel D: f1 = 2 kHz @ f2 = 100 Hz. The subject has normal-hearing (pure tone audiogram ≤ 20 dB HL), as shown in the inset audiogram (panel A).

Fig. 2. The panels show ASSR IO functions recorded in a HI subject using 4 simultaneous SAM tones. Panel A: f1 = 0.5 kHz @ f2 = 83 Hz, Panel B: f1 = 1 kHz @ f2 = 87 Hz, Panel C: f1 = 1.5 kHz @ f2 = 93 Hz, and Panel D: f1 = 2 kHz @ f2 = 100 Hz. The subject has a mild hearing impairment at 4 kHz only (15 dB HL), as shown in the inset audiogram (panel A).

Fig. 3. Comparison of ASSR IO function with multi-frequency (●) and single frequency (○) stimulation at a center frequency of 1 kHz.

Fig. 4. The panels show magnitude of the DPOAE generator component IO functions recorded in a NH subject (left axis). Right axis show compression estimated as the slope of the fitted line function (Neely et al., 2000). Panel A: f1 = 0.5 kHz, Panel B: f2 = 1 kHz, Panel C: f1 = 1 kHz, and Panel D: f2 = 2 kHz.

Fig. 5. Comparison between slopes from best fitted line curve in ASSR versus DPOAE IO functions of 12 NH subjects. Different symbols represent the four center frequencies. (●) 500 Hz, (▲) 1 kHz, (▼) 2 kHz and (▲) 4 kHz.

Fig. 6. Average parameters obtained from the best fitted line curve to ASSR IO functions from individuals. Panel A: f1 = 0.5 kHz, Panel B: f1 = 1 kHz, Panel C: f1 = 2 kHz, and Panel D: f1 = 4 kHz. On each panel, the left shaded rectangle shows the slope of the linear fit in NH. HI in non-impaired frequencies, and NH in the impaired frequencies, and the right shaded rectangle includes the three parameters for the two-slope fitting model. The number of subjects (N) is shown on top of each rectangle.

CONCLUSIONS

- ASSR compression estimates for levels above 30 dB HL are consistent with psychoacoustic data.
- ASSR IO functions recorded in HI subjects reflect the loss of sensitivity at lower input levels.
- Correlation analysis between ASSR and DPOAE recordings showed more compressive functions in ASSR than in DPOAE.
- Reduced compression at levels close to threshold (≤ 20 dB HL) could not be estimated using ASSR. Longer recording times are required to estimate compression with ASSR near threshold.

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