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 whose 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

PHYHOSIS

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

DPOAE unmixing using a time windowing technique (Long et al., 2008).

CONCLUSIONS

- ASSR compression estimates for levels above 30 dB HL are consistent with psychoacoustical data.
- ASSR IO functions recorded in HI subjects reflect the loss of sensitivity at lower input levels.
- Significant correlation 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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REFERENCES


Slopes of growth IO functions for ASSR vs DPOAE.

Fig. 5: Comparison between slopes from best fitted curve in ASSR versus DPOAE IO functions of 12 NH subject. Different symbols represent the four center frequencies: 500 Hz, 1 kHz, 2 kHz and 4 kHz.

Assuming DPOAE to reflect basilar membrane motion and ASSR IO functions brainstem coding, the difference in compression estimates could lead to an additional compression mechanism in the peripheral auditory system.

ASSR I/O functions in HI subjects reflect the loss of sensitivity at lower stimulus levels.

DPOAE in NH:

- 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.

HI subjects show higher variability in the results.

Significant response 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.

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

- Multiple and single frequency stimulation elicit similar responses.
- No interaction among 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.

Fig. 4: The panels show magnitude of the DPOAE generator component IO functions recorded in a HI subject (left axis). Right axis show compression estimated as the slope of the fitted line (Neely et al., 2003). Panel A: f2 = 0.5 kHz, Panel B: f2 = 1 kHz, Panel C1, f2 = 2 kHz, Panel D, f2 = 4 kHz. On each panel, the left unfilled rectangle shows the slope of the linear fit (NH). The subject had a mild hearing impairment at 4 kHz only (35 dB HL), as shown in the inset audiogram (panel A).

Fig. 6: Averaged parameters obtained from the best fitted curve to ASSR IO functions from individuals. Panel A: f2 = 0.5 kHz, Panel B: f2 = 1 kHz, Panel C1, f2 = 2 kHz, and Panel D, f2 = 4 kHz. On each panel, the left unfilled rectangle shows the slope of the linear fit (NH). Higher slopes are shown in NH (non-impaired frequencies, and HI in the impaired frequency), and indicate a greater deviation from the linear fit. Inset graph of each parameter shows the two-slope fitting model. The number of subjects (N) is shown on top of each rectangle.

Fig. 1: The panels show ASSR IO functions for four different carrier frequencies recorded in a NH subject. Panel A: f2 = 0.5 kHz, Panel B: f2 = 1 kHz, Panel C1, f2 = 2 kHz, and Panel D, f2 = 4 kHz. 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: f2 = 0.5 kHz, Panel B: f2 = 1 kHz, Panel B: f2 = 2 kHz, Panel C1, f2 = 2 kHz, and Panel D, f2 = 4 kHz. On each panel, the left unfilled rectangle shows the slope of the linear fit (NH). The subject had a mild hearing impairment at 4 kHz only (35 dB HL), as shown in the inset audiogram (panel A).

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