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

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ABSTRACT

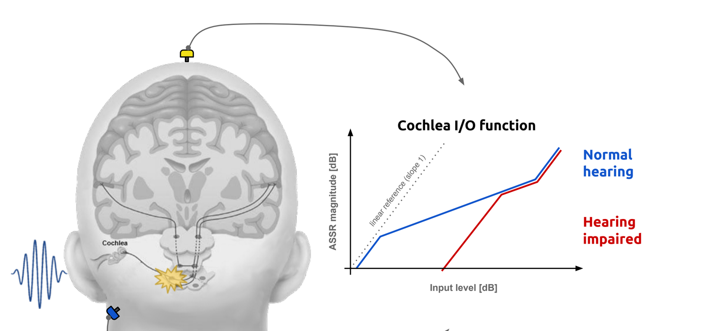
The healthy auditory system shows a compressive input/output (I/O) function as a result of healthy outer-hair cell function. Hearing impairment often leads to a decrease in sensitivity and a reduction of compression, mainly caused by loss of inner and/or outer hair cells. Compression is commonly estimated 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 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 investigated here whether ASSR can be used to estimate compression along the peripheral auditory pathway. 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 (DPOAEs) recordings.

Results show compressive ASSR I/O functions for NH subjects. For HI subjects, ASSR reveal the loss of sensitivity at low stimulus levels. Growth slopes are smaller (more compressive) in ASSR than in DPOAE I/O functions.

HYPOTHESIS

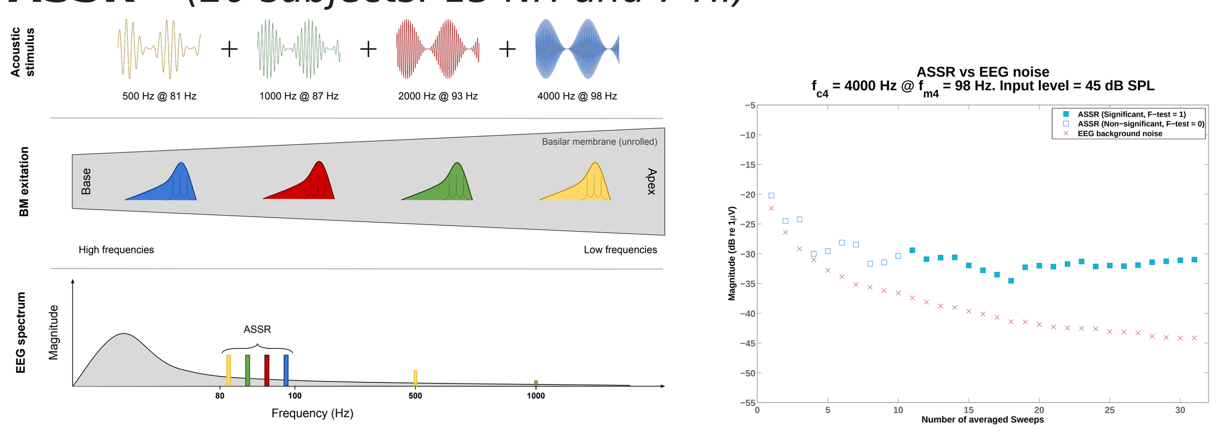
Peripheral compression can be estimated through ASSR I/O functions in NH subjects. HI subjects show a change in sensitivity and compression estimate.



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

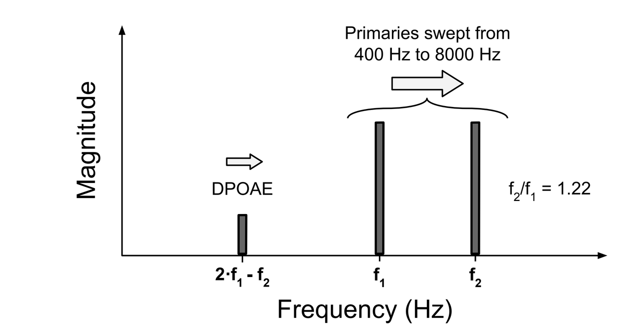
METHODS

ASSR *(20 subjects. 13 NH and 7 HI)*

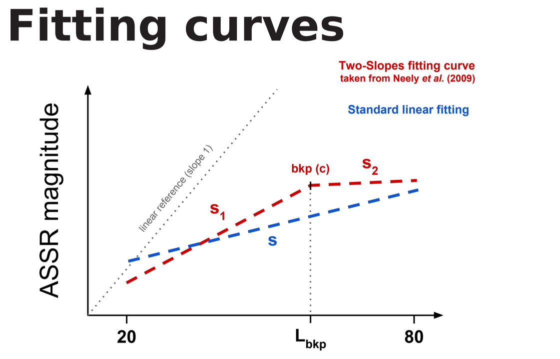


- 64-channel EEG system with active electrodes (Biosemi).
- ASSR magnitude obtained from the recorded ASSR spectrum, computed from the weighted averaged waveform.
- Detection of significant results using F-test (p-value ≤ 1%)

DPOAE *(12 NH subjects)*



Fitting curves



- Least-squares-fit (LSF) method used to obtain the magnitude and phase of the $2f_1 - f_2$ DPOAE component.
- DPOAE generator unmixed using a time windowing technique *(Long et al., 2008)*.

RESULTS

NORMAL-HEARING:

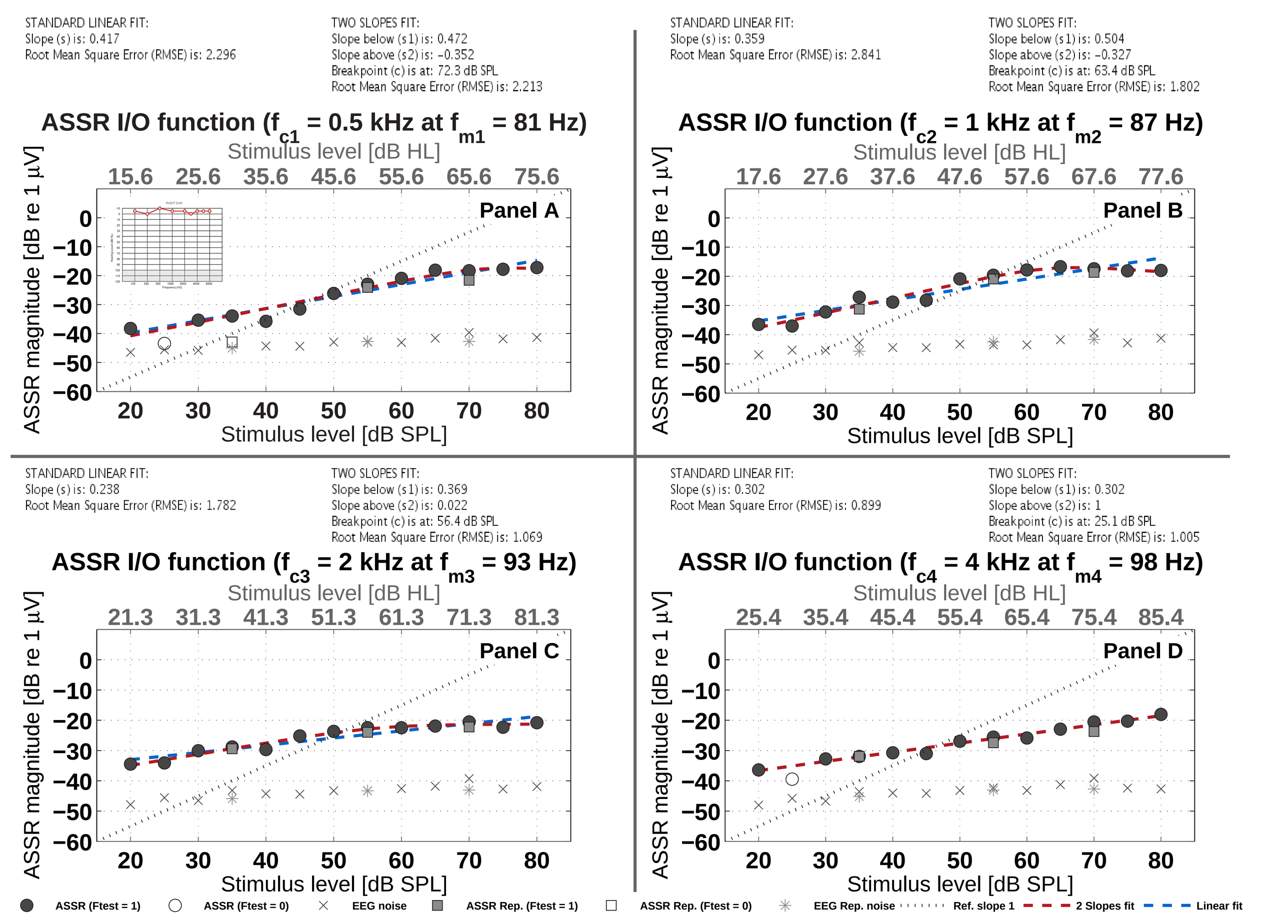


Fig.1 The panels show ASSR I/O functions for four different carrier frequencies recorded in a NH subject. *Panel A*: f_{c1} = 0.5 kHz @ f_{m1} = 81 Hz, *Panel B*: f_{c2} = 1 kHz @ f_{m2} = 87 Hz, *Panel C*: f_{c3} = 2 kHz @ f_{m3} = 93 Hz, and *Panel D*: f_{c4} = 4 kHz @ f_{m4} = 98 Hz. The subject has normal-hearing (pure tone audiogram ≤ 20 dB HL), as shown in the inset audiogram (*panel A*).

- 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.

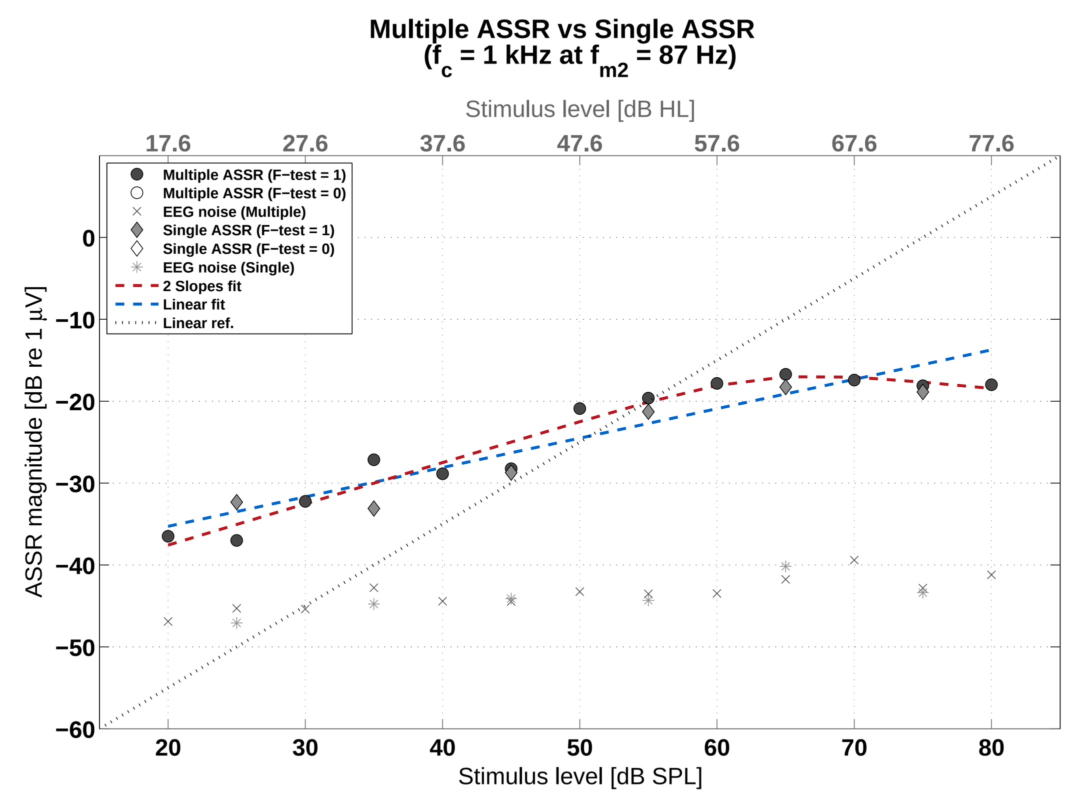


Fig.3 Comparison of ASSR I/O function with multi-frequency (●) and single frequency (♦) stimulation at a center frequency of 1 kHz.

- Multiple and single frequency stimulation elicit similar responses.
- No interaction among the different SAM tones seems to be shown 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.

HEARING-IMPAIRED:

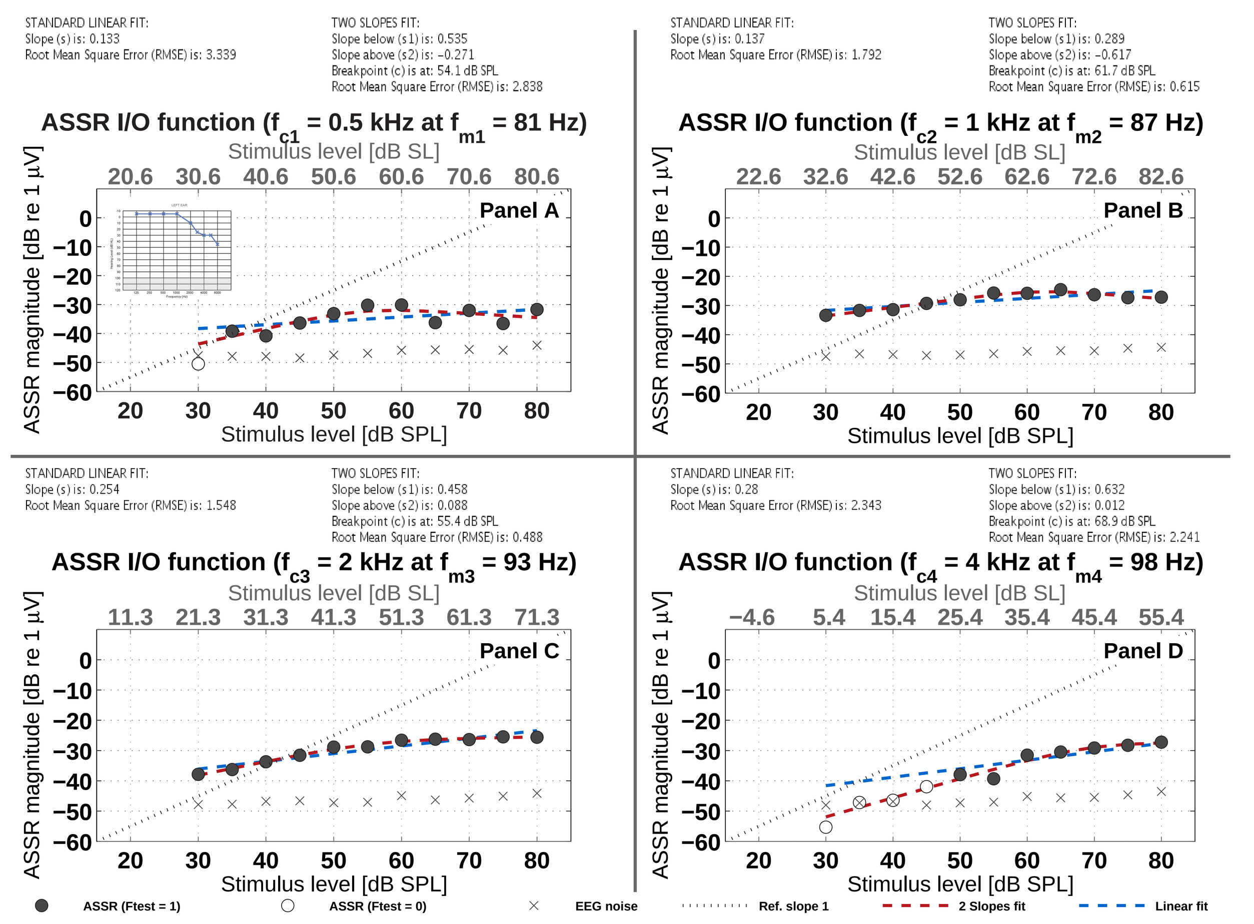


Fig.2 The panels show ASSR I/O functions recorded in a HI subject using 4 simultaneous SAM tones. *Panel A*: f_{c1} = 0.5 kHz @ f_{m1} = 81 Hz, *Panel B*: f_{c2} = 1 kHz @ f_{m2} = 87 Hz, *Panel C*: f_{c3} = 2 kHz @ f_{m3} = 93 Hz, and *Panel D*: f_{c4} = 4 kHz @ f_{m4} = 98 Hz. The subject had a mild hearing impairment at 4 kHz only (35 dB HL), as shown in the inset audiogram (*panel A*).

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

DPOAE in NH:

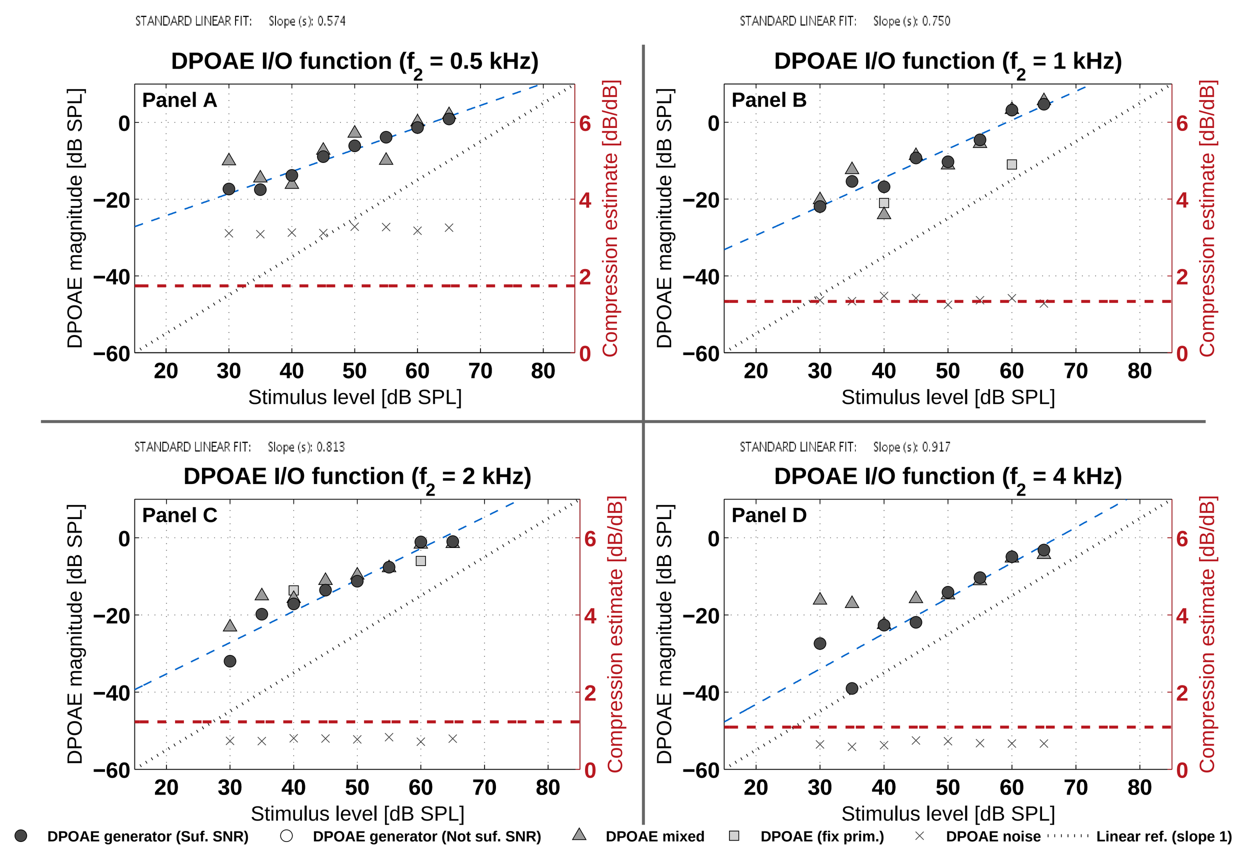


Fig.4 The panels show magnitude of the DPOAE generator component I/O functions recorded in a NH subject (left axis). Right axis show compression estimated as the slope of the fitted function (*Neely et al. (2009)*). *Panel A*: f_2 = 0.5 kHz, *Panel B*: f_2 = 1 kHz, *Panel C*: f_2 = 2 kHz, and *Panel D*: f_2 = 4 kHz.

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

DISCUSSION

Slopes of growth I/O functions for ASSR vs DPOAE.

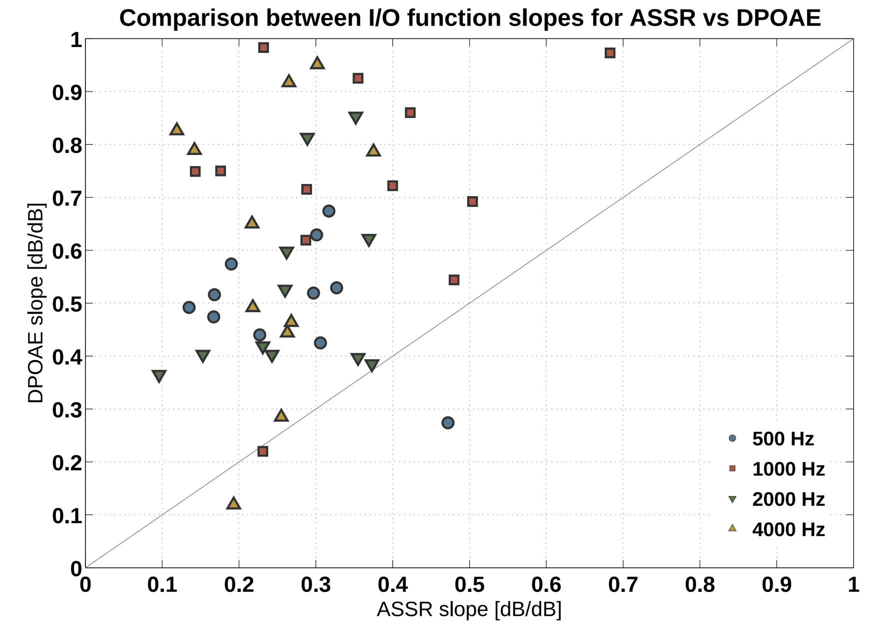


Fig.5 Comparison between slopes from best fitted curve in ASSR versus DPOAE I/O functions of 12 NH subjects. Different symbols represent the four center frequencies. (●: 500 Hz, ■: 1 kHz, ▼: 2 kHz and ▲: 4 kHz.

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

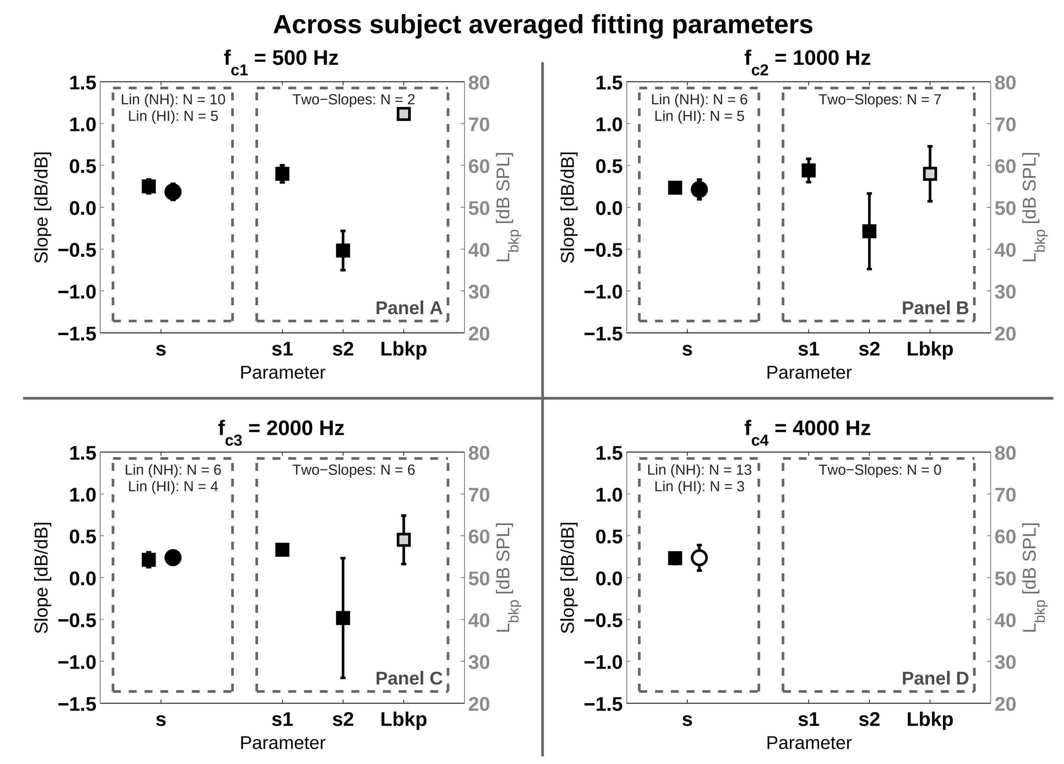


Fig.6 Averaged parameters obtained from the best fitted curve in ASSR I/O functions from individuals. *Panel A*: f_{c1} = 0.5 kHz, *Panel B*: f_{c2} = 1 kHz, *Panel C*: f_{c3} = 2 kHz, and *Panel D*: f_{c4} = 4 kHz. On each panel, the left dashed rectangle shows the slope of the linear fit(■: NH, ●: NH in non-impaired frequencies, and ❍: HI in the impaired frequency), and the right dashed rectangle include 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 psychoacoustical data.
- ASSR I/O 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.

ACKNOWLEDGMENT

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