PERCEPTION THRESHOLDS OF PURE TONE IN NOTCHED NOISE CORRELATE WITH GENERATOR COMPONENT OF DISTORTION PRODUCT OTO-ACOUSTIC EMISSIONS

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Abstract:

According to our computational model of tinnitus, the strength of tinnitus is a function of the degree of compression of the cochlear amplifier. Thus, the specific aim of this study was to find a link between the strength of gain-adaptation and cochlear compression. We hypothesized that gain adaptation may be assessed psychophysically by the sensitization that a priming signal can induce on the detection of pure tones. We measured perception thresholds of pure tones in notched-noise following various priming signals (band and notched noise, with silence and white-noise as control conditions). Cochlear compression was assessed by extracting the generator component of DPOAE across frequency using primaries sweeping continuously from 1kHz to 4kHz . The psychophysical experiment revealed more sensitization than expected by conventional forward masking ($p<0.04$, N=6, not shown). This highlights the uniqueness of the observed sensitization effect, which is counter to the more common increase in perceptual thresholds. We did not, however, find a link between sensitization and compression. Instead, stronger sensitization correlated with stronger DPOAE for low primer levels ($c=0.27$, $p<0.01$, N=11). Together these data suggest that the short-term dynamic adaptation leading to sensitization is mediated by the amplification mechanism of outer hair cells. Interestingly, compression correlated with perception thresholds across frequencies for individual subjects ($c=0.67\pm0.13$, $p<0.05$, N=8 of 11 subjects). This reliable, within-subject correlation of a psychophysical perception threshold with the objective physiological measure of compression establishes our particular DPOAE paradigm as a strong candidate for the assessment of peripheral hearing. This is particularly relevant given the simplicity of the test, making it attractive for use in a clinical setting.

Subjects and Procedures:

- 11 normal hearing subjects were recruited and hearing was evaluated on the right ear.
- Masked perceptual thresholds were measured using a three-interval-forced-choice (3AFC) and a modified PEST procedure at 12 frequencies in the range of 1-4kHz.
- DPOAE were measured using continuous frequency sweeps for various input levels (25dB-75dB) over a range of two octaves (1-4 kHz) in approximately 1.5 hours.

Psychoacoustic Experiment:

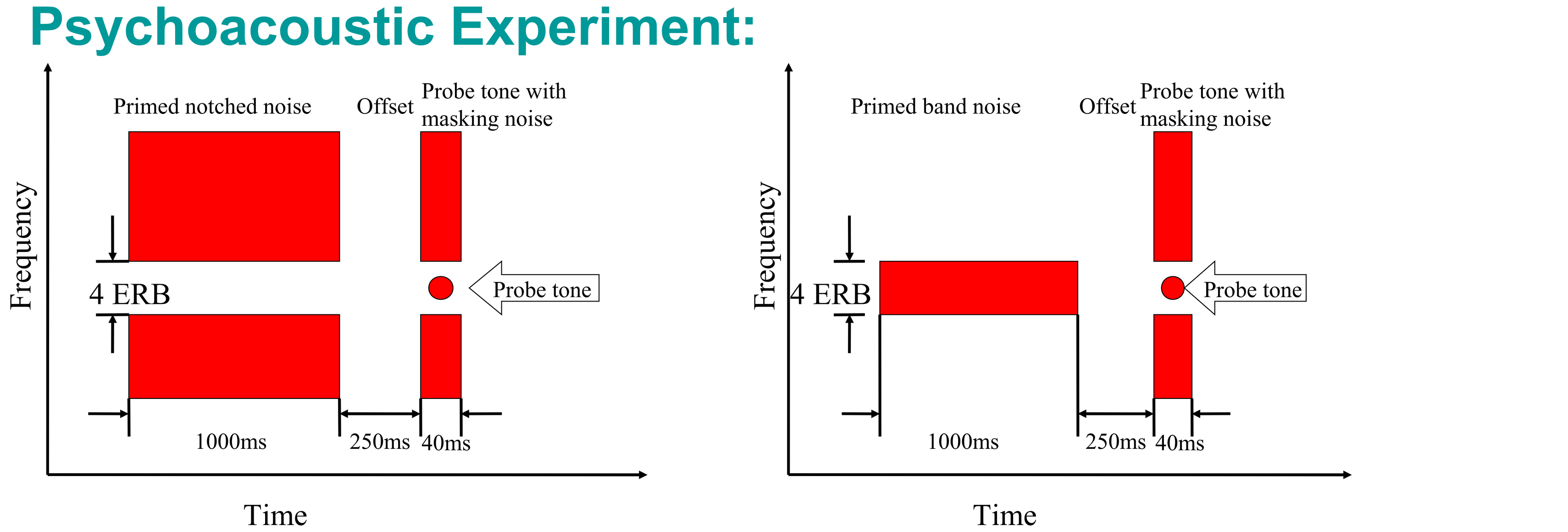

Fig.1 Schematic showing the spectral (y-axis) and temporal (x-axis) characteristics of signal and precursor (notched-noise and band-noise)

The stimulus paradigm contains the following three components: (1) a fixed-level (50dB) notched-noise or band noise precursor with 4ERBs, (2) a variable-level probe tone (initial volume is 50 dB), (3) a fixed-level (50dB simultaneous notched-noise masker (4ERBs bandwidth).

Distortion Product Oto-acoustic Emission (DPOAE):

Stimuli

- DPOAE recording were made using a continuous sweeping primaries procedure with a fixed primary ratio (f2/f1) of 1.22 (Long et al., 2008).
- Primary frequencies, f1 and f2 (f1<f2), were logarithmically swept from an f2 frequency of 1000 Hz to 4000 Hz at a rate of 2s/octave.
- Primary tone presentation levels were set based on the scissors level paradigm according to the equation $L1=0.4L2+39$ dB (Kummer at al., 1998), for L2=25-75 dB in 5 dB steps.

Data Analysis

- Spectrograms of the individual sweeps were visually inspected, and noisy sweeps are eliminated, ensuring an even number of sound files, before averaging at each level.
- A least squares fit (LSF) procedure using a narrowband analysis window with fixed latency was used to extract the level of the **generator component** of DPOAE.

Results and Discussion:

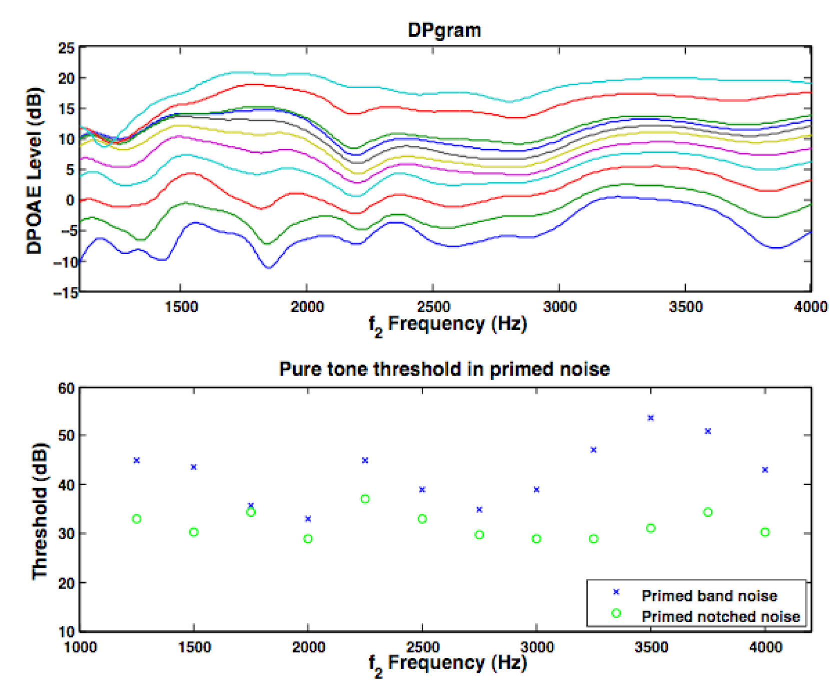

Fig.2 High resolution DPOAE, and pure tone threshold with different precursors.

The top panel shows DP level (dB) for 11 primary input levels (25dBSPL-75dBSPL in steps of 5dB). Spread indicates input/output function, which corresponds to compression factor (wider spread indicates less cochlear compression).

Bottom panel shows perceptual thresholds for pure tunes primed by different precursor: band noise (blue) and notched noise (green). The difference indicates perceptual sensitization following the notch-noise precursor.

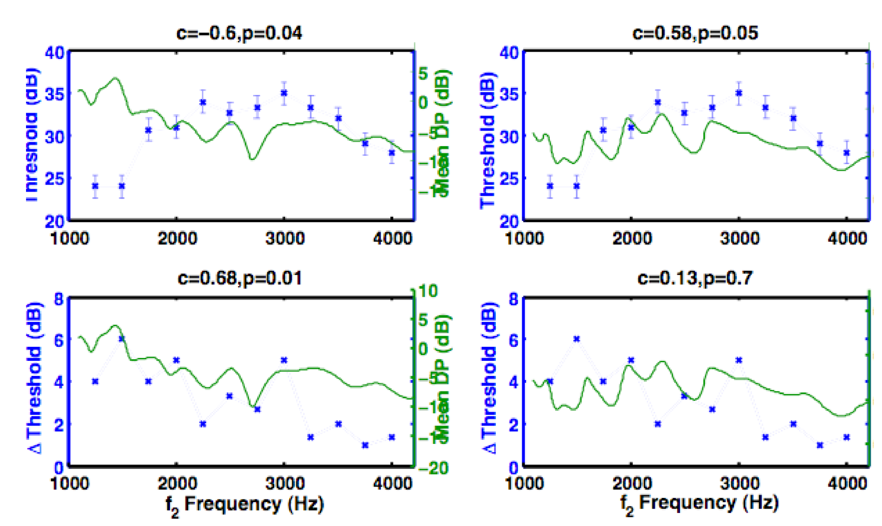

Fig.3 Correlation between the DPOAE and perception thresholds.

Correlations between masked perceptual thresholds (top panels), mean DP (left panels), threshold improvement (bottom panels) and DP slope (right panels). Mean DP is the average DP measured for all primary input levels. DP slope is a measure of compression and is computed here as the difference in DP for maximum and minimum primary input levels. Error bars in thresholds (blue) indicate range of values in two repeated measures, where available.

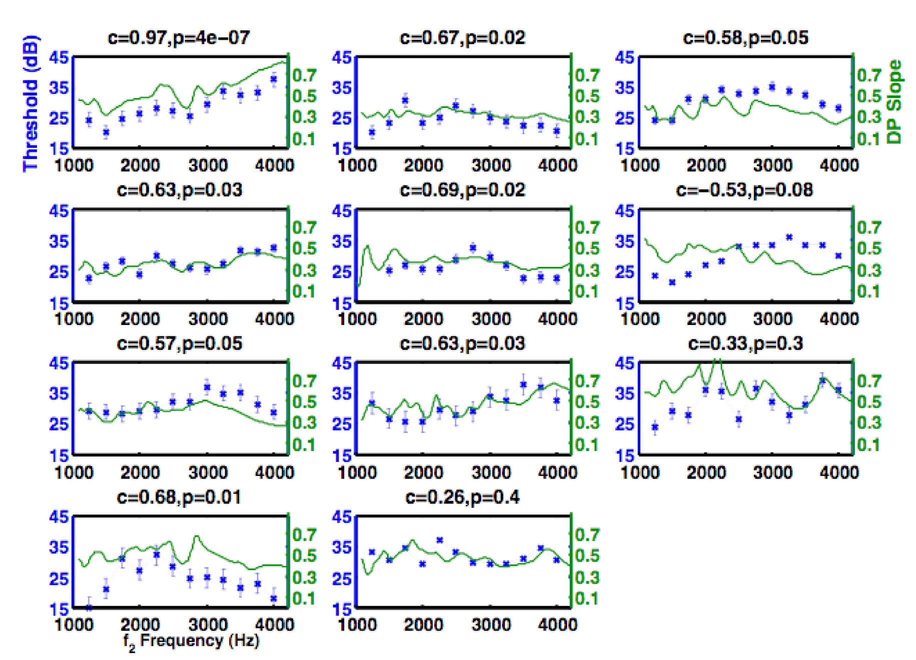

Fig.4 Correlation between the I/O slope and perception threshold with notched-noise precursor for each subject.

Each panel shows perceptual thresholds primed by notched-noise (blue points) and DP compression (green curve). Significant correlation across frequency ($p<0.05$) is observed for 8 of 11 subjects with ($c=0.67\pm0.13$).

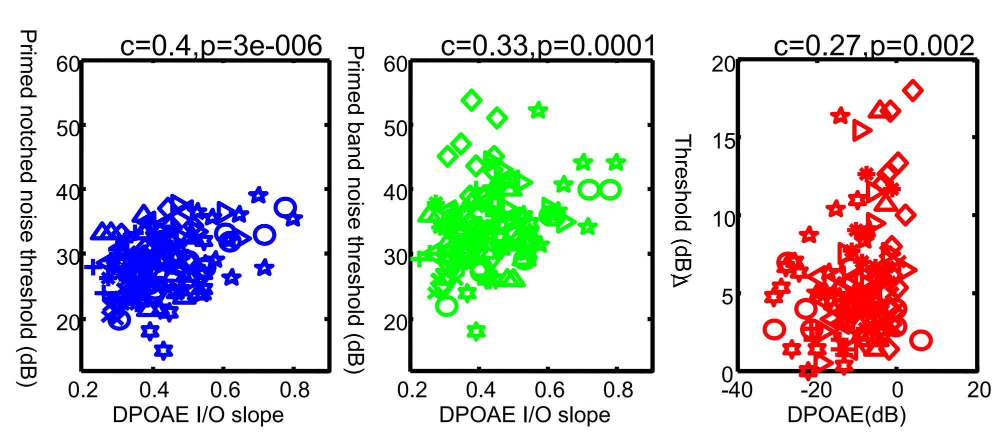

Fig.5 Comparison of DPOAE and perception thresholds:

Each panel shows the correlation between perceptual thresholds and compression (left and center) or with the DPOAE measured using the lowest primary level and change in threshold (right). Each symbol represents an individual subject at several measured frequency points.

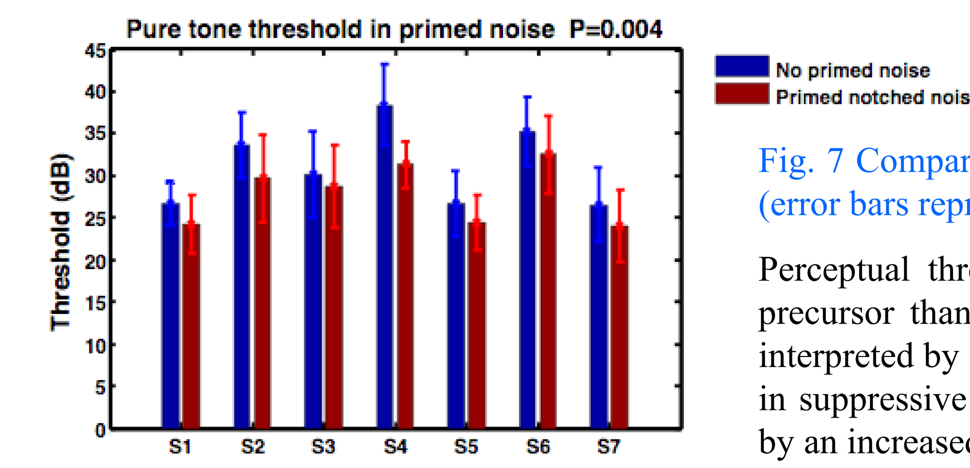

Fig. 7 Comparison of perception thresholds with and without precursor. (error bars represent standard deviation across frequency)

Perceptual thresholds are significantly different with a notched-noise precursor than without. This decrease in perceptual threshold may be interpreted by a decrease in masking provided by the precursor (decrease in suppressive masking) at the masker frequency (Strickland, 2004), or by an increased sensitization at the signal frequency.

Two control conditions:

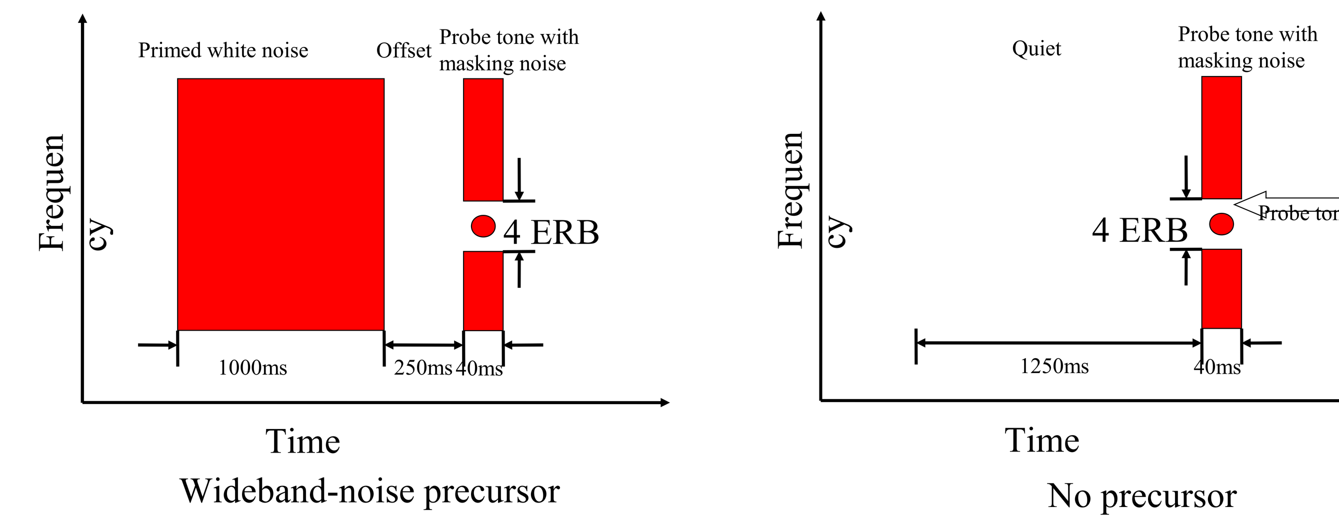

Fig. 8 Schematic showing two additional control conditions.

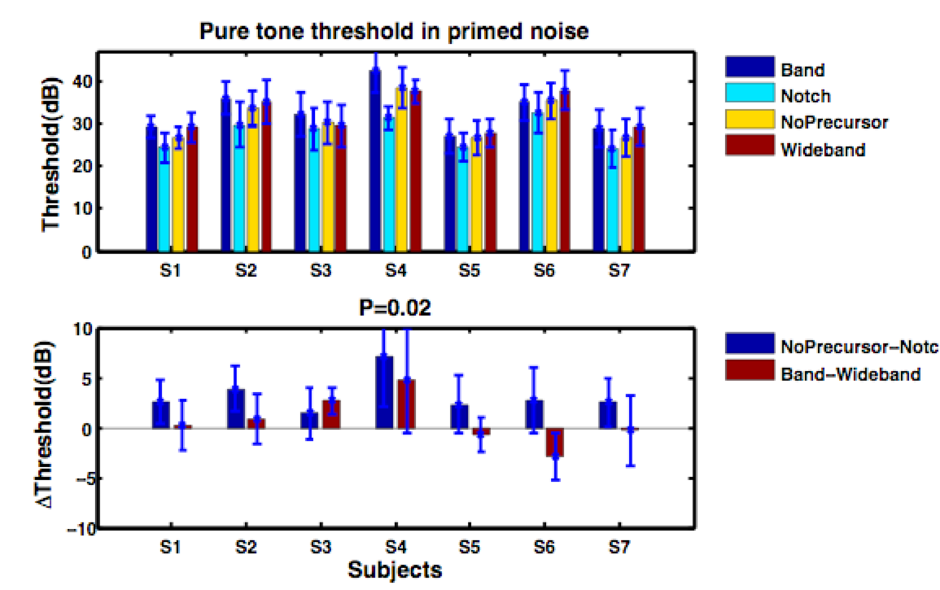

Fig. 9 Results with two additional control conditions. (error bars represent standard deviation across frequency)

The effect of forward masking on thresholds with various noise precursors is: band $\Delta I_B = I_B - I_Q$, notched $\Delta I_N = I_N - I_Q$, wideband $\Delta I_W = I_W - I_Q$. Under the null hypothesis (H_0) of an additive masking effect one expects for the wideband-noise precursor a threshold shift of: $\Delta I_W = \Delta I_B + \Delta I_N$ or equivalently $I_B - I_W = I_Q - I_N$. Second panel shows the likelihood for H_0 is $p<0.02$, N=7, indicating that masking is not sufficient to explain the strength of sensitization.

Conclusions:

We find reliable sensitization of perceptual thresholds ($= I_B - I_N$) following notched noise. Conventional forward masking can be ruled out as an explanation. The data remains in agreement with our existing hypothesis of neuronal gain-adaptation.

No significant correlation between this sensitization and DPOAE compression was found indicating that sensitization can not compensate for loss of compression as we had expected. Instead, both mechanisms may act independently.

However, sensitization correlated with DPOAE level measured with the lowest primary level. Since DPOAE at the lowest level are strongly affected by the health of outer hair-cells this indicates that the observed sensitization is mediated by outer hair-cell function.

Additionally, significant correlation between perceptual thresholds and compression was found for 8 of the 11 subjects. This establishes our particular DPOAE paradigm as a strong candidate for the assessment of peripheral hearing in a clinical setting.

References:

- Kummer, P., Janssen, T., and Arnold, W. (1998). The level and growth behavior of the $2f_1$-$2f_2$ distortion product otoa-coustic emission and its relationship to auditory sensitivity in normal hearing and cochlear hearing loss, The Journal of the Acoustical Society of America 103, 3431‐3444.
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