

Influence of multiple TEOAE components on measurement of growth and delay

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INTRODUCTION

Previous work suggests that transient-evoked otoacoustic emissions (TEOAEs) elicited at low levels are generated primarily by linear coherent reflection¹. Recent work has suggested TEOAEs contain multiple components with different delays and amplitude growths². Presence of multiple emission components may affect group delay measurement when using frequency domain analysis. This study examined time- and frequency-domain analysis of multiple TEOAE components.

METHODS

Fig 1. Spectrum and waveform of transient stimuli (1-4 kHz bandwidth, 2 ms duration). Stimuli were presented to 18 normal-hearing ears and 2 ears with severe sensorineural hearing loss. Stimuli were presented at 33.3 clicks/sec using an ER-10C probe assembly. Eight stimulus levels were used (45 – 85 dB peSPL). TEOAEs were extracted using a nonlinear double-evoked paradigm³. Synchronous spontaneous OAEs (SSOAEs) were present in 5 ears, which were excluded from subsequent analysis.

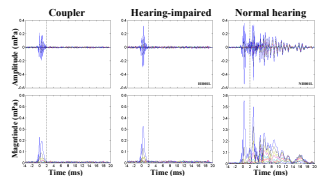
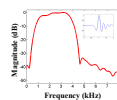
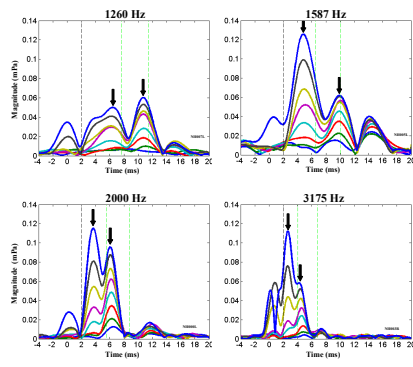


Fig 2. TEOAE waveforms (top row) and envelopes (bottom row). Stimulus levels are represented by different colors. Time zero is relative to the stimulus peak. The horizontal dashed line at 2 ms denotes the time where the stimulus stopped ringing in a IEC711 artificial ear and in the subject with sensorineural hearing loss.

Fig 3. Time domain analysis. Waveforms were filtered with 1/3-octave wide FIR filters centered at frequencies between 1000 and 4000 Hz in 1/3-octave steps. Hilbert transforms were calculated, and envelopes were obtained from the magnitude of the analytic signal. Subjects typically had two envelope peaks for each filter center frequency. **Fig. 3** shows envelopes at four center frequencies from four subjects. Stimulus levels are represented by different colors. The green dashed lines indicate 95% confidence intervals for expected SFOAE latencies⁴. Responses occurring earlier than 2 ms (black dashed line) may contain artifact and were excluded from analysis. Black arrows show location of peaks. The amplitude and time of the peaks were obtained and used to characterize change in amplitude and delay with stimulus level.



RESULTS

Fig 4. Effect of stimulus level on magnitude and delay. Results shown for three center frequencies from a representative subject. Early peak values are shown in red, late peak values are shown in blue. **Top row** shows magnitude as a function of stimulus level. Data were fit with a power function (dashed lines). **Middle row** shows rate of magnitude change (dB/dB). For this subject, both components grow compressively, with the early component growing less compressively than the late component. **Bottom row** shows peak delay as function of stimulus level. Data were fit with a quadratic polynomial (dashed red and blue lines). Dotted green lines show 95% confidence intervals for expected SFOAE delays⁴. For this subject, late peaks fell within expected latencies, while early peaks occurred earlier than expected at 1260 and 3175 Hz.

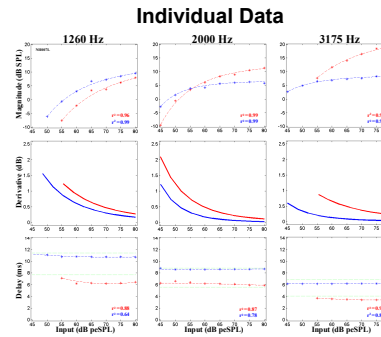


Fig 5. Group data showing effect of stimulus level on magnitude and delay. Data relating to early and late components are shown in red and blue, respectively. **Top row** shows magnitude as function of level. Robust fits (ax^b+c) are shown as thick red and blue lines. Individual data points shown as asterisks. Grey triangles represent data from ears with SSOAEs (excluded from fits). **Middle row** shows derivatives of fitted lines in top row. Early components grow less compressively than late components. **Bottom row** shows peak delay as function of level. Linear polynomial fit shown as thick red and blue lines. At all center frequencies, late components fell within expected delays while early components occur before expected delays. Slopes of fits were non-significant.

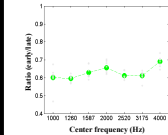
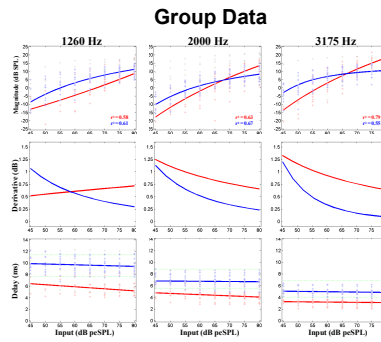


Fig 6. Ratio of early component delays to late component delays as a function of filter center frequency. Grey asterisks show group mean delays at each stimulus level. Green dots show mean delay across stimulus levels. Mean ratios were approximately 0.6-0.7 for all conditions tested.

Relationships Between Early and Late Components

Fig 7. Early (red) and late (blue) components as a function of time across different levels for subject NH007L. Responses were filtered with a center frequency of 2520 Hz and the envelope was obtained from the analytic signal. The response to a stimulus of 65 dB peSPL (thick lines) was specifically examined because the two components were approximately equal in magnitude at this input level.

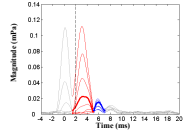


Fig 8. Instantaneous frequency of early (red) and late (blue) components corresponding to thick lines in Fig. 7. Grey lines show instantaneous frequency for responses at other stimulus levels. Instantaneous frequency was calculated as the derivative of the analytic signal phase. Both components appear to have the same frequency content. Black arrows correspond to the peaks of the envelopes in time.

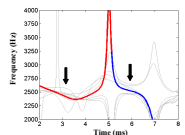


Fig 9. Relative magnitudes of early (red) and late (blue) components as a function of frequency, calculated as the DFTs of each component separately. The grey line shows magnitude of the DFT of both components together. Note the notch in the combined magnitude (grey) near 2500 Hz, which suggests a phase interaction between components at this frequency.

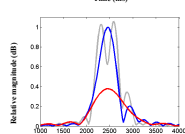


Fig 10. Model of component interaction. The phases at 2500 Hz were obtained at the peak of each component using a least-squares fitting procedure. Model envelopes were chosen to be consistent with those shown by the thick lines in Fig. 7. The two components were found to be out of phase at 2500 Hz, resulting in partial cancellation where the waveform envelopes overlapped. Further analysis of the model yielded results similar to those in Figs. 8 and 9 (not shown).

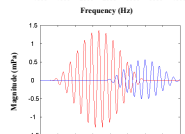
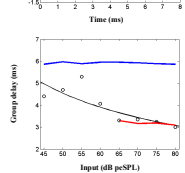


Fig 11. Delay as a function of input level. The peaks of early (red) and late components (blue) are approximately constant. Black circles show group delay calculated from the phase gradient (including both components). The black line shows a fit using a power function. Peak values suggest no change in the delay of the early or late components. The change in phase gradient does not appear to represent actual changes in delay. Rather, it is consistent with growth rates of early and late components.



CONCLUSIONS

- TEOAEs have early and late envelope peaks with different amplitude growth rates but constant delays, as a function of stimulus level.
- Late components grow more compressively than early components, and therefore tend to dominate the emission at lower stimulus levels.
- Early and late components can be out of phase with each other, resulting in partial cancellations and potentially misleading group delay values when analyzed together, e.g. via DFT.

ABSTRACT

In time-domain analyses, transient-evoked otoacoustic emissions (TEOAEs) appear to contain multiple components. Components appearing earlier in time grow less compressively with increasing stimulus level compared to later components, but the delays of individual components appear to be invariant with level. In frequency-domain analyses, delays calculated using time windows that include multiple components may be influenced by differential growth of the components, yielding misleading results. The current study compared delays obtained using time domain and frequency domain calculations. Transient stimuli were presented at eight levels to subjects. Recordings were bandpass filtered, time windowed, and transformed via FFT. Amplitude growth and delay was obtained from analysis of time domain envelopes. Multiple peaks with different growth patterns but invariant delays were found. Group delay analysis revealed decreasing delay with increasing level. However, the change in phase gradient appears to represent the differential growth rates of early and late components rather than actual changes in delay of individual components.

REFERENCES

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