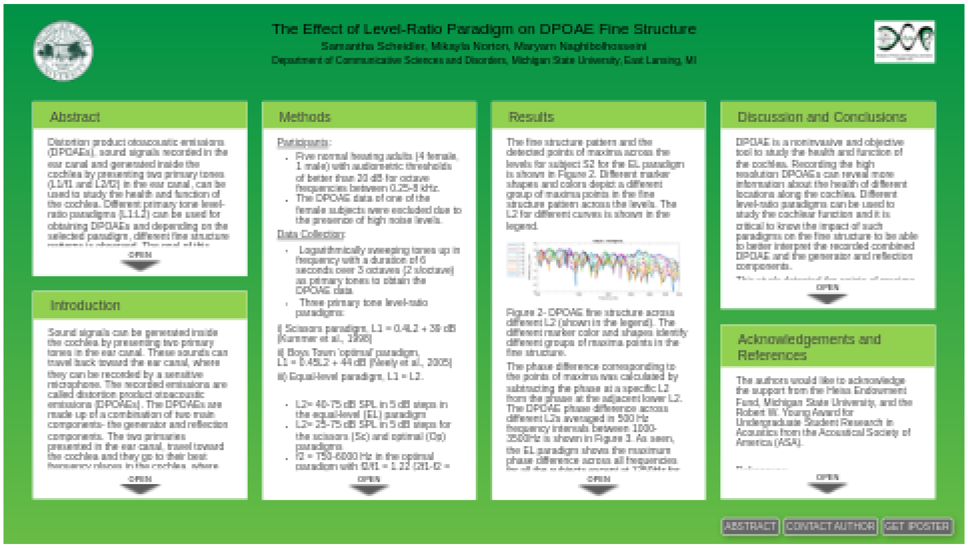
The Effect of Level-Ratio Paradigm on DPOAE Fine Structure



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ABSTRACT

Distortion product otoacoustic emissions (DPOAEs), sound signals recorded in the ear canal and generated inside the cochlea by presenting two primary tones (L1/f1 and L2/f2) in the ear canal, can be used to study the health and function of the cochlea. Different primary tone level-ratio paradigms (L1:L2) can be used for obtaining DPOAEs and depending on the selected paradigm, different fine structure patterns is observed. The goal of this study is to understand how three common level-ratio paradigms affect DPOAE fine structure, generated by sweeping primary tones in frequency. The paradigms used are scissors, L1=0.4L2+39 dB; Boys Town 'optimal', L1=0.45L2+44 dB; and the equal-level, L1=L2. The main components of the DPOAE signals, generator and reflection components, are extracted using a least squares fit algorithm. For each level paradigm, the frequency distance between adjacent fine structure maxima were determined. This analysis is carried out for different primary levels and all paradigms. The interaction of the primary tones inside the cochlea and their impact on the fine structure pattern for each paradigm is studied.

INTRODUCTION

Sound signals can be generated inside the cochlea by presenting two primary tones in the ear canal. These sounds can travel back toward the ear canal, where they can be recorded by a sensitive microphone. The recorded emissions are called distortion product otoacoustic emissions (DPOAEs). The DPOAEs are made up of a combination of two main components- the generator and reflection components. The two primaries presented in the ear canal, travel toward the cochlea and they go to their best frequency places in the cochlea, where they overlap and due to their nonlinear interaction, mechanical waves are generated at different frequencies such as 2f1-f2 (see the schematic in Figure 1). Each generated wave travels back to the ear canal and can be recorded as the generator component. A part of the wave travels to its own best place at 2f1-f2 in the cochlea while being amplified due to the cochlear gain and it gets reflected back, which is recorded as the reflection component in the ear canal.

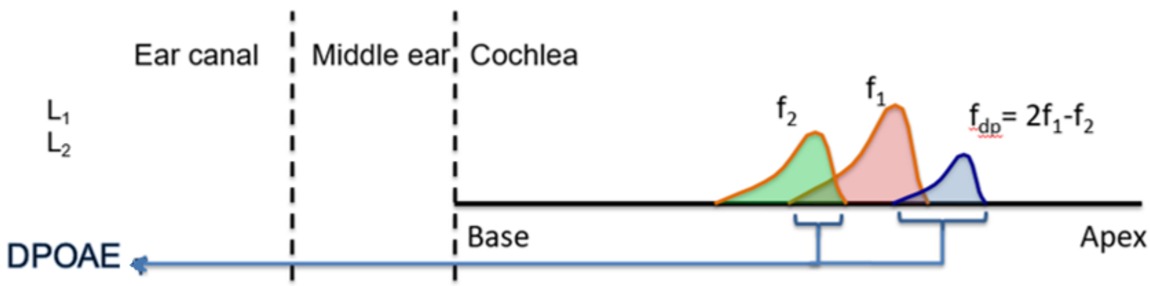

Figure 1- The schematic of the DPOAE production.

Using sweeping primary tones (in frequency) leads to a formation of patterns of minima and maxima in the combined DPOAE level as a function of frequency, called the fine structure. The appearance of the fine structure in the combined DPOAE is due to the in-phase and out-of-phase interactions of the generator and reflection components. Different level-ratio paradigms have been used to obtain the DPOAE data. Understanding how the selection of such paradigms affect the pattern of minima and maxima is important in deciding what paradigm to use to study the health and function of the cochlea. Long et al. (2009) compared the amount of frequency shift at the points of extrema across different primary levels in the fine structure for the equal-level, optimal, and scissors paradigms. In this study, we analyzed the phase of the generator and reflection components and how they change across levels and frequencies using the aforementioned level-ratio paradigms.

METHODS

Participants:

- Five normal hearing adults (4 female, 1 male) with audiometric thresholds of better than 20 dB for octave frequencies between 0.25-8 kHz.
- The DPOAE data of one of the female subjects were excluded due to the presence of high noise levels.

Data Collection:

- Logarithmically sweeping tones up in frequency with a duration of 6 seconds over 3 octaves (2 s/octave) as primary tones to obtain the DPOAE data
- Three primary tone level-ratio paradigms:

i) Scissors paradigm, L1 = 0.4L2 + 39 dB (Kummer et al., 1998)

ii) Boys Town ‘optimal’ paradigm, L1 = 0.45L2 + 44 dB (Neely et al., 2005)

iii) Equal-level paradigm, L1 = L2.

- L2= 40-75 dB SPL in 5 dB steps in the equal-level (EL) paradigm
- L2= 25-75 dB SPL in 5 dB steps for the scissors (Sc) and optimal (Op) paradigms
- f2 = 750-6000 Hz in the optimal paradigm with f2/f1 = 1.22 (2f1-f2 = 480-3836 Hz)
- f2 = 1000-8000 Hz for the scissors and equal-level paradigms with f2/f1 = 1.22 (2f1-f2 = 640-5120 Hz)

Data Analysis:

The generator and reflection components, and the combined 2f1-f2 DPOAE were extracted from the recordings using a Least Squares Fit (LSF) Analysis. A wide-band analysis window was used to extract the combined DPOAE. Then, a narrow-band analysis (with a group delay function) was performed to separate the generator and reflection components, which allowed us to estimate the phase and amplitude of each component.

The points of maxima in the DPOAE fine structure were extracted across the levels for all the subjects and paradigms automatically through identifying the local maxima points. These points were double checked visually to ensure that each group of the detected maxima points across the levels were aligned. The frequency shifts across the levels for the points of maxima were calculated next. The amount phase change between the points of maxima across levels were determined for the generator and reflection components, and the combined DPOAE. The mean of the phase change across the levels and frequencies were analyzed accordingly. The phase-based analysis of the frequency shifts is a robust method and less sensitive to the level of the noise.

RESULTS

The fine structure pattern and the detected points of maxima across the levels for subject S2 for the EL paradigm is shown in Figure 2. Different marker shapes and colors depict a different group of maxima points in the fine structure pattern across the levels. The L2 for different curves is shown in the legend.

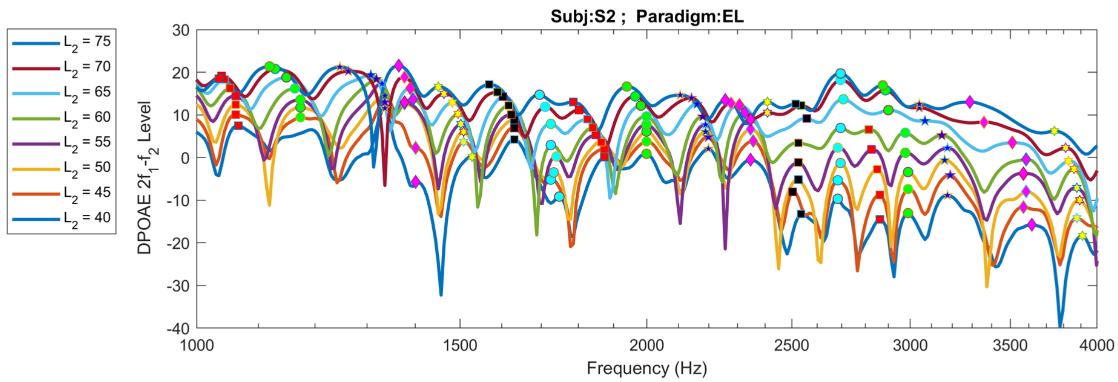

Figure 2- DPOAE fine structure across different L2 (shown in the legend). The different marker color and shapes identify different groups of maxima points in the fine structure.

The phase difference corresponding to the points of maxima was calculated by subtracting the phase at a specific L2 from the phase at the adjacent lower L2. The DPOAE phase difference across different L2s averaged in 500 Hz frequency intervals between 1000-3500Hz is shown in Figure 3. As seen, the EL paradigm shows the maximum phase difference across all frequencies for all the subjects except at 1250Hz for S3. The minimum phase difference is observed for the Op paradigm across all frequencies and subjects. The phase differences for the EL and Sc paradigms are negative in most frequencies. However, the phase difference for the Op paradigm is negative mainly for S2 and at several frequencies for S1 and S3.

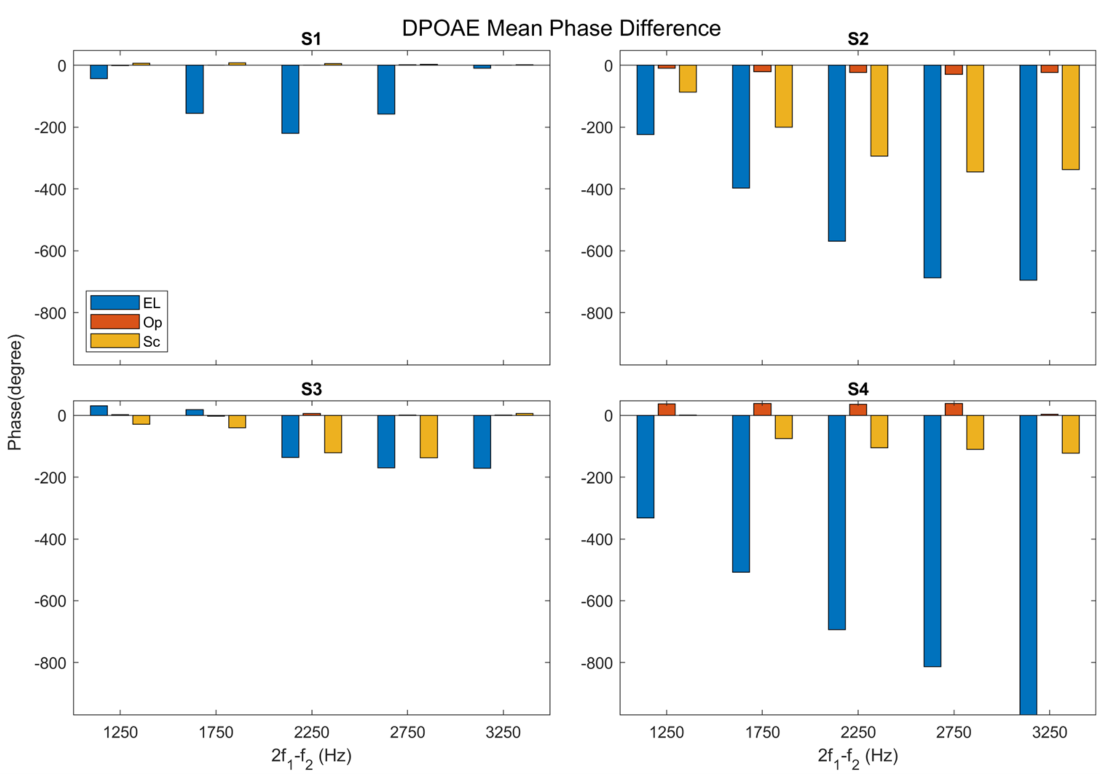

Figure 3- Mean DPOAE phase difference at the points of maxima in the fine structure between different levels. The mean phase difference was calculated in 500 Hz frequency intervals between 1000-3500Hz.

Similar phase difference plots were created for the generator and reflection components, as can be seen in Figure 4 and 5, respectively. The maximum phase difference for the generator component can be observed in the EL paradigm for all participants and all frequencies. The minimum phase difference for the generator component is observed for the Op paradigm across all frequencies and subjects except at 3250Hz for S1. The phase differences are positive for the generator components in all three paradigms at almost all frequencies for S2, S3, and S4. Negative values of phase difference can be observed in the Sc and Op paradigms for S1.

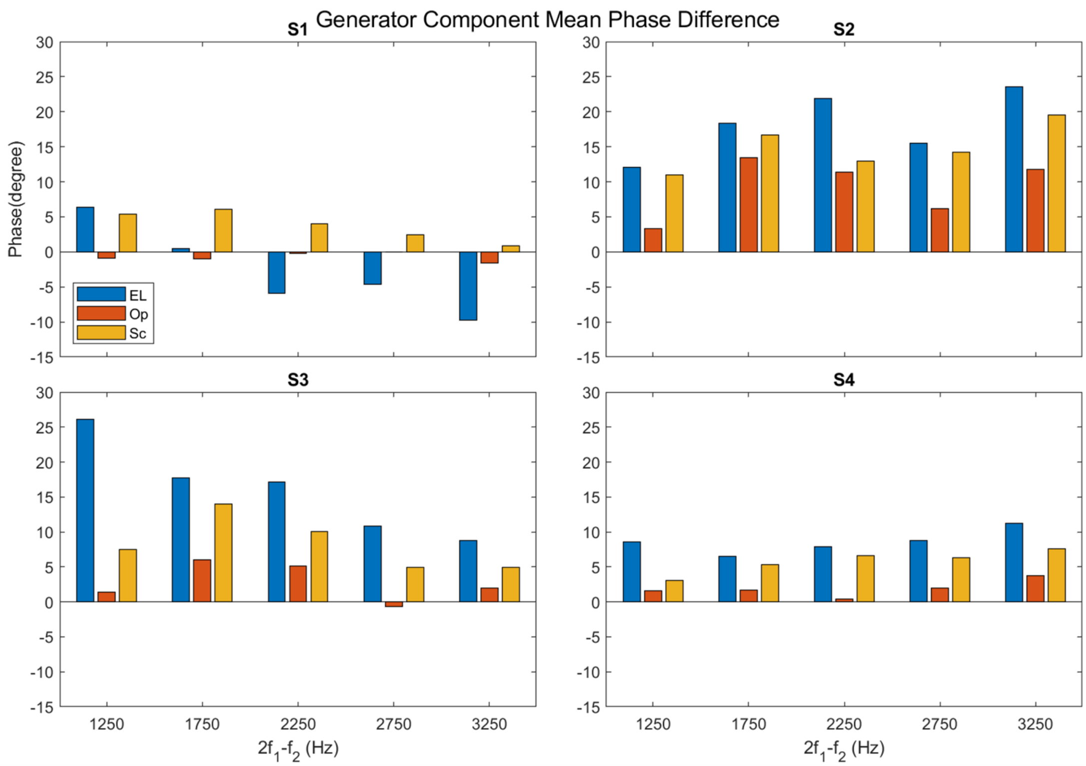

Figure 4- Mean generator component phase difference at the points of maxima in the fine structure between different levels. The mean phase difference was calculated in 500 Hz frequency intervals between 1000-3500Hz.

As seen in Figure 5 , the phase difference for the reflection component in the EL paradigm is larger than the other paradigms at most frequencies for S1 and S4 but is maximum in the Op paradigm for S2 and S3. The minimum phase difference occurs in the Sc paradigm for all subjects. The phase differences are mostly negative but positive phase differences are observed in the EL paradigm for S3 and the Sc paradigm for S2.

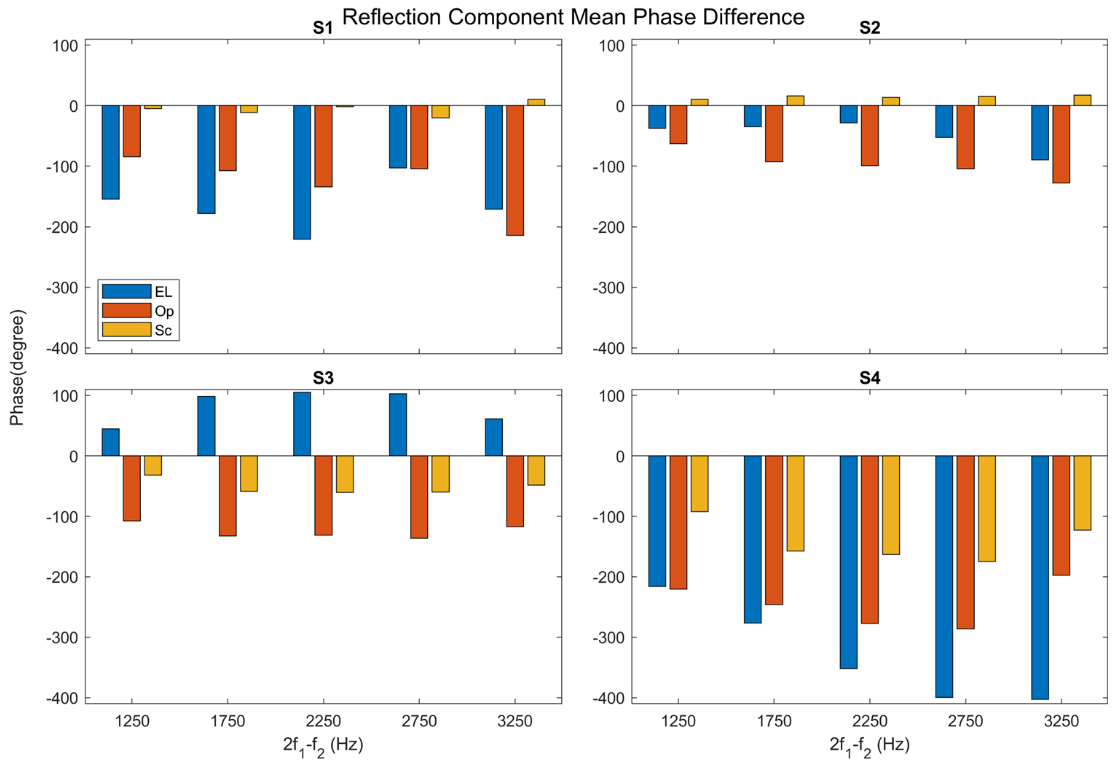

Figure 5- Mean reflection component phase difference at the points of maxima in the fine structure between different levels. The mean phase difference was calculated in 500 Hz frequency intervals between 1000-3500Hz.

The mean value of the phase differences across all the frequencies and levels for the DPOAE, and generator and reflection components are shown for different subjects in Figure 6. As can be seen, minimum mean phase difference in DPOAE is observed for the Op paradigm for all subjects and maximum phase difference is observed in the EL paradigm for 3 of the subjects. The same observation can be made for the generator components. The mean phase difference of the reflection component for the Sc paradigm shows minimum values in all subjects, and the Op paradigm shows the largest values.

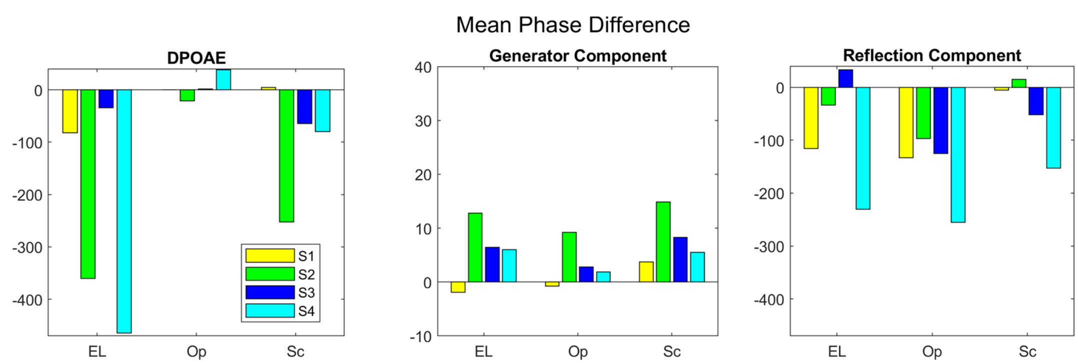

Figure 6- Mean phase difference across levels and frequencies for the DPOAE, and generator and reflection components.

In addition to the mean phase difference, the mean of the negative phase gradient is also showed for the combined DPOAE, and the generator and reflection components in Figure 7. As can be seen, the lowest DPOAE phase gradient is observed for the Op paradigm and the highest phase gradient is observed for the EL paradigm in 2 subjects and for the Sc paradigm in 2 other subjects. The highest values of the phase gradient difference for the generator and reflection components were observed in different subjects and paradigms. However, the maximum and minimum values of the gradient difference were more similar for the participants when comparing their values for the DPOAE and the generator components.

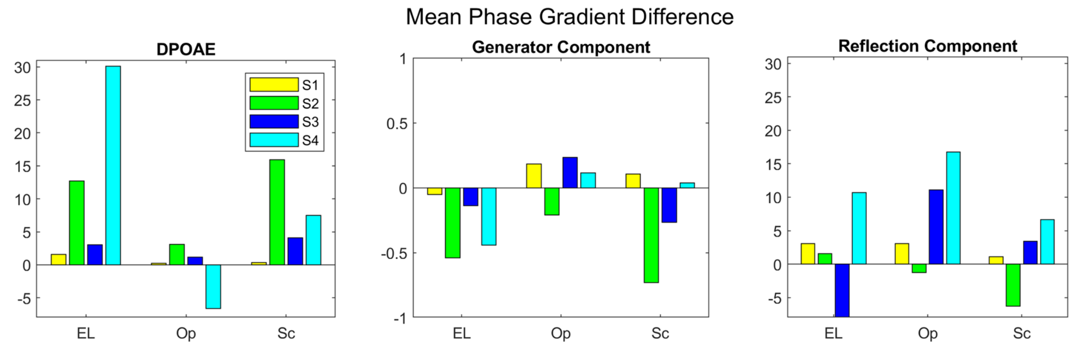

Figure 7- Mean negative phase gradient across levels and frequencies for the DPOAE, and generator and reflection components.

DISCUSSION AND CONCLUSIONS

DPOAE is a noninvasive and objective tool to study the health and function of the cochlea. Recording the high resolution DPOAEs can reveal more information about the health of different locations along the cochlea. Different level-ratio paradigms can be used to study the cochlear function and it is critical to know the impact of such paradigms on the fine structure to be able to better interpret the recorded combined DPOAE and the generator and reflection components.

This study detected the points of maxima in the DPOAE fine structure pattern across different levels, where the generator and reflection components have a constructive interaction for three level-ratio paradigms. The amount of phase change and phase gradient change across levels at the points of maxima were calculated and averaged across frequencies and then levels. The amount of phase change and phase gradient change were compared between the different paradigms and for the combined DPOAE, and the generator and reflection components.

The comparison of the mean phase change across levels (averaged in 500Hz frequency intervals) revealed more similar behavior between the combined DPOAE and generator component. They both showed maximum phase change in the EL paradigm and minimum phase change for the Op paradigm. Similar observations were not made in the amount of phase change for the reflection component. Similar observations were made for the mean phase difference across frequencies and levels for the three paradigms. The mean DPOAE gradient phase showed maximum values for the EL paradigm and minimum values for the Op paradigm, which were similar to our observation for the mean phase differences. However, the behavior of the reflection component was different from that of the DPOAE and generator component. Since the phase of the generator component remains almost unchanged across frequencies due to the cochlea scaling symmetry, it is believed that the phase of the reflection component plays a more critical role in the in-phase or out-of-phase interactions of the two components and therefore, in creation of the fine structure pattern, due to its steep slope. This study showed more similar behaviors in the amount of phase changes between the DPOAE and generator components showing the importance of the generator component phase in the fine structure pattern. In addition, the amplitude of the generator component plays an important role since the phase of the DPOAE depends on both the phase and amplitudes of the two components.

The points of minima were not included in this study due to their lower signal to noise ratio. We are planning to include the minima points in future in order to have a more complete picture about the impact of different paradigms on the DPOAE fine structure. Moreover, the amount of change in the levels of the generator and reflection components at the points of extrema needs to be included to investigate the impact of the two components levels along with their phases on the pattern of fine structure.

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References:

Kummer, P., Janssen, T., and Arnold, W. (1998). “The level and growth behavior of the 2f1- f2 distortion product otoacoustic emission and its relationship to auditory sensitivity in normal hearing and cochlear hearing loss," The Journal of the Acoustical Society of America 103(6), 3431-3444.

Neely, S.T., Johnson T.A., and Gorga, M.P. (2005). “Distortion-product otoacoustic emission measured with continuously varying stimulus level,” The Journal of the Acoustical Society of America 117, 1248-1259.

Long, G. R., Jeung, C., and Talmadge, C. L. (2009). “Dependence of distortion-product otoacoustic emission components on primary-level ratio," in Concepts And Challenges In The Biophysics Of Hearing: (World Scientific), 203-208.

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