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Distortion product otoacoustic emission fine structure as an early hearing loss predictor

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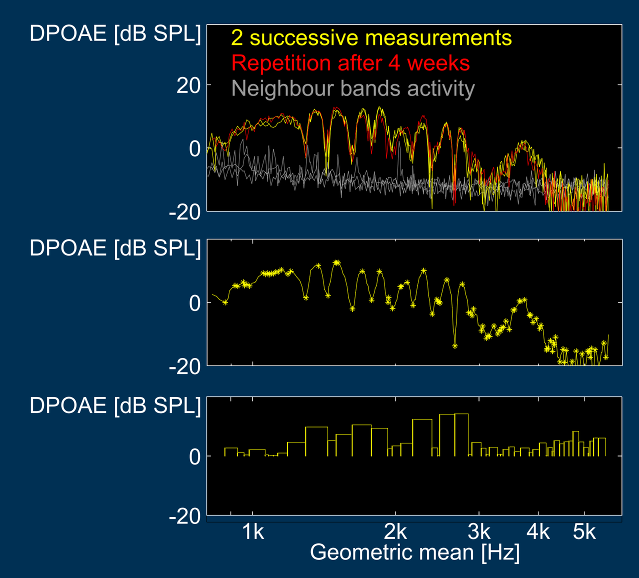
DPOAE (fine structure)

Otoacoustic Emissions (OAE) are sounds generated by the inner ear as part of the normal hearing process. They can occur spontaneously and can be evoked by stimulating the ear acoustically. OAEs are a by-product of the active mechanism of the outer hair cells and a sensitive measure of that cochlear function. Distortion product otoacoustic emission (DPOAE) is the response to two pure-tone stimuli (the primaries f_1 and f_2 with $f_1<f_2$). For the DPOAE measurement the primaries are varied while keeping their frequency ratio constant. Usually the cubic distortion product $2f_1$-f_2 is measured and plotted in dependence of the geometric mean of the primaries.

When DPOAEs are measured with a high frequency resolution, a DPOAE fine structure can be revealed [1-12]. The fine structure is characterized by consistent patterns of amplitude maxima and minima with level variations of up to 20 dB. In the literature [4,6] the disappearance of DPOAE fine structure is suggested to be a sensitive measure for the detection of hearing loss and might serve as a sensitive indicator of hearing impairment.

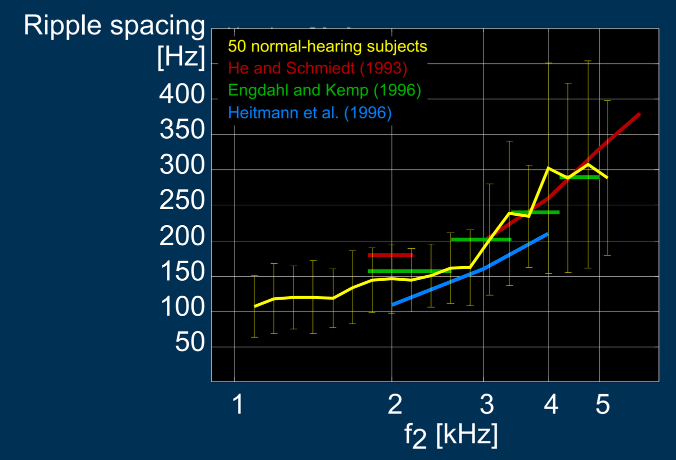
The purpose of this study [13] was to test for prevalence of fine structure in normal-hearing humans and to analyze the characteristics of the fine structure.



$2f_1$-f_2 DPOAEs were measured with a resolution of 50 to 180 primaries per octaves using primary levels of L_1/L_2 = 65/45 dB and a frequency ratio of f_2/f_1=1.22. A schematic fine structure is calculated in order to analyze spacing and prevalence of the fine structure.

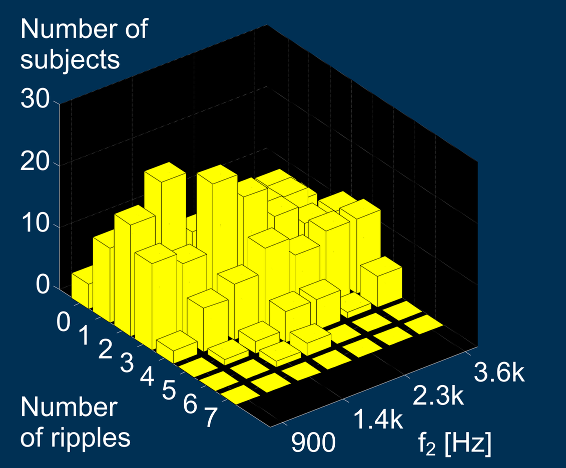
The DPOAE fine structure is smoothed by averaging three successive measurement points. Maxima and minima of the smoothed DPOAE are calculated.

The schematic fine structure is derived by calculating spacing (distance between two minima) and the ripple height (distance from maximum to mean of neighboring minima) of the smoothed fine structure.



For each test subject, ripples spacing for ripples with height > 3 dB are determined and plotted as individual data. The ripple spacing is averaged in 1/8 octave bands and the mean over 41 test subjects calculated. The results show that with increasing geometric mean the average bandwidth increases from 50 Hz at low frequencies to 200 Hz at high frequencies, corresponding to a decrease from 1/8 to 1/16 octaves.

The number of DPOAE fine structure ripples with height > 3 dB is counted for each test subject in 1/3 octave bands and the results presented as bars. The height of the bars represent the number of test subjects that have the same number of ripples in a frequency band. All test subjects show the presence of fine structure in at least one 1/3 octave band. The prevalence is high in the mid frequency range and rather low at high and low frequencies.



The measurement of DPOAE fine structure in 50 young, normal-hearing subjects has shown that all test subjects show the characteristic patterns of amplitude maxima and minima with level variations of up to 20 dB. The fine structure is not prevalent over the entire measured frequency range in all subjects.

When divided into groups of best-hearing students, and students with slightly elevated thresholds, there was a difference in the nature of the fine structure ripples. These were generally more narrow and had lower height for the students with sligthly elevated thresholds. These results are presented in [13,14].

Broad band effects

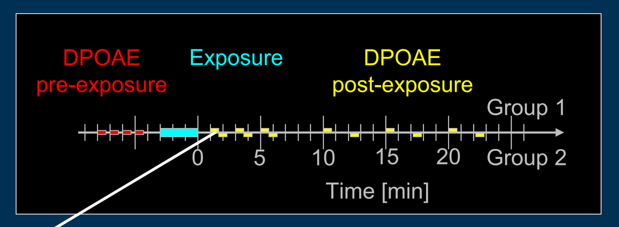
Acoustical over-exposure is considered to be one of the main causes of hair cell damage and can result in temporary threshold shifts (TTS). OAE measured before and after acoustical exposure suggest that OAE is a sensitive measure for hearing loss.

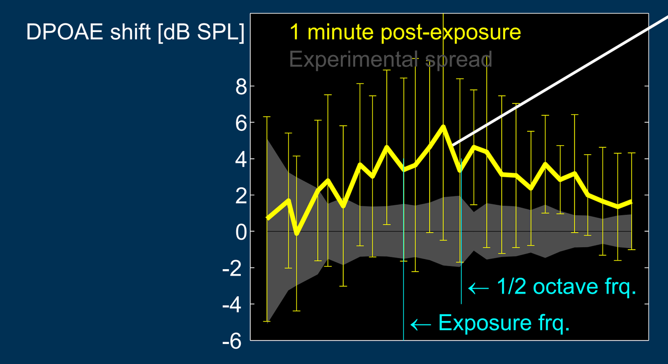
The purpose of this study [4] was to investigate the effects of a tonal over-exposure on the broad-band DPOAE to find out whether DPOAEs are effected by the exposure and which frequency range is effected. DPOAEs were measured before and after a tonal over-exposure.

The exposure tone was a 1 kHz tone, presented via headphones and lasting for 3 minutes at an equivalent threshold SPL of 105.5 dB. This corresponds to 80 dB normalized to an 8 hour working day (ISO 1999:1990).

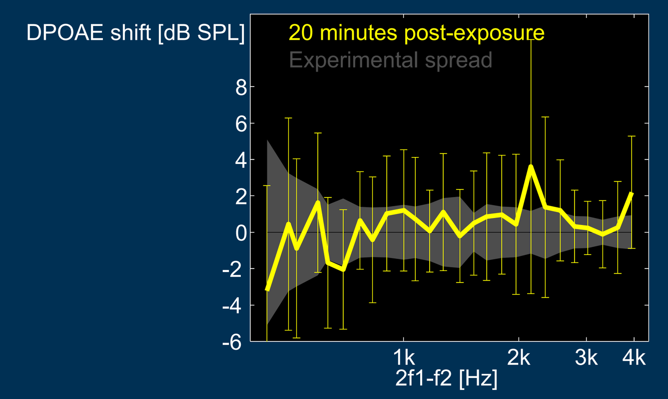
DPOAEs at $2f_1$-f_2 were measured with primary levels of L_1/L_2 = 65/45 dB, a primary ratio of 1.22 and with a resolution of 1/8 octaves in a frequency range of f_2=708-6165 Hz. The DPOAE shift is calculated by subtracting the post-exposure measurements from an averaged pre-exposure value.

Time schedule for the DPOAE measurements before and after the exposure. The 32 test subjects are divided into 2 groups of 16 test subjects each. The two groups differ in their post-exposure DPOAE measurement times. Each sweep covers the measured frequency range.





DPOAE shift of the measurement starting 1 minute after the exposure for the 16 test subjects of group 1. The DPOAE is shifted in a relatively broad frequency range. The region of highest shift is around ½ octave above the exposure frequency when the DPOAE is plotted in dependence of $2f_1$-f_2. There is a large intersubject variation in DPOAE shift.

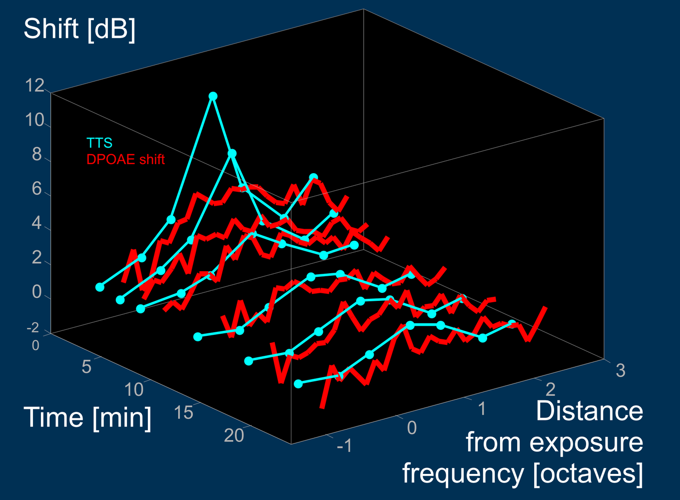


For the same group of test subjects the mean DPOAE shift at 20 minutes after the exposure is plotted. The mean DPOAE has recovered to its pre-exposure value within the observed time interval.

The effects of a tonal over-exposure on the broad-band DPOAE were investigated in 32 test subjects. Overall, the DPOAE level is decreased after the exposure and increases to its pre-exposure values within 20 minutes of recovery. A relatively broad frequency range is affected. The individual DPOAE shifts vary considerably between subjects.

DPOAE shift vs TTS

DPOAE shift compared to Temporary Threshold Shift (from [15]). The data compare quite well in the recovery period, even in absolute terms (dB difference in hearing threshold, and dB difference in DPOAE sound pressure level).



Fine structure effects

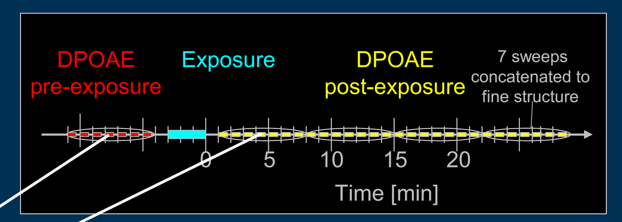
In the literature [4,6] the disappearance of DPOAE fine structure is suggested to be an indicator of early hearing loss. This indicates that in TTS experiments the DPOAE fine structure would be expected to be modified rather than a shift in the overall DPOAE level.

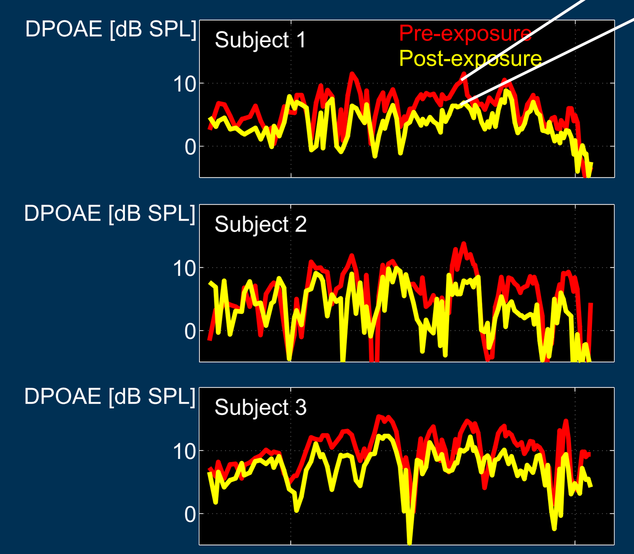
The DPOAE fine structure was measured in 16 young normal-hearing test subjects before and after a tonal over-exposure.

The exposure tone was the same as in the "Broad band effects" experiment.

DPOAE were measured in a frequency range of f_2=903-2295 Hz with a frequency resolution of 1/50 to 1/130 octaves. The DPOAE fine structure frequency range is chosen to cover both the exposure frequency, ½ octave frequency above the exposure frequency and a frequency range, in which the prevalence of fine structure is relatively high [13].

Time schedule for the DPOAE measurements before and after the exposure. The first sweep starts one minute after the exposure. The measurement for the full frequency range lasts 7 minutes. Four DPOAEs covering the measured frequency range were recorded within 29 minutes.





The pre-exposure measurement and the post-exposure measurement starting at 1 minute after the exposure are shown for 4 test subjects.

In all test subjects the post-exposure DPOAE is decreased in level. From the examples shown a clear disappearance of DPOAE fine structure can not be seen. The DPOAE rather seems to be shifted in level.

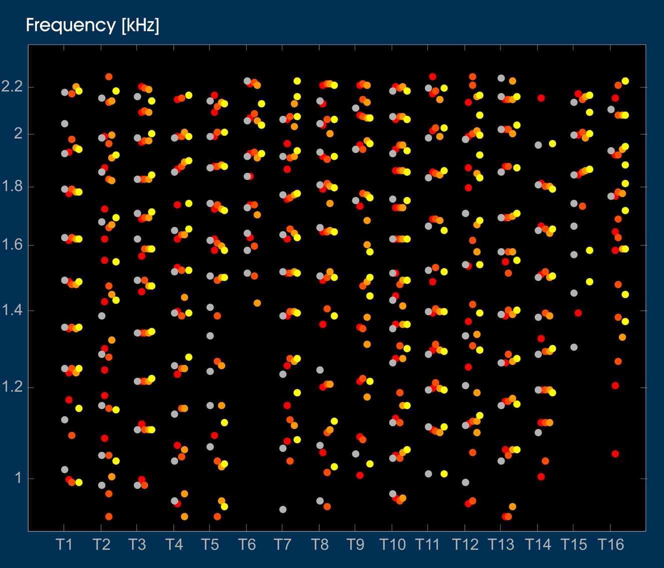
The measurement starting at 22 minutes after the exposure (not shown in the figure) shows that the DPOAE level and structure has recovered to its pre-exposure value.

The fine structure is the result of two or more distortion product sources on the basilar membrane. The primary component comes from a place close to f_2, and the secondary (reflection component) from the $2f_1$-f_2 site.

The fine structure will be more or less pronounced, depending on the strength relations between the two components, which again depends on the state of hearing (e. g. OHC damage).

Frequency shift of ripple minima

The placement of ripple minima is shown for each individual subject (Tx). The grey spots are pre-exposure data, whereas the red, orange and yellow spots are post-exposure values with approximately 7 minutes in between. It can be seen that frequency placement of ripple minima are rather unaffected by the exposure for some subjects (e.g. T1 andT3) The frequencies of the minima are in other cases increased or decreased after exposure.



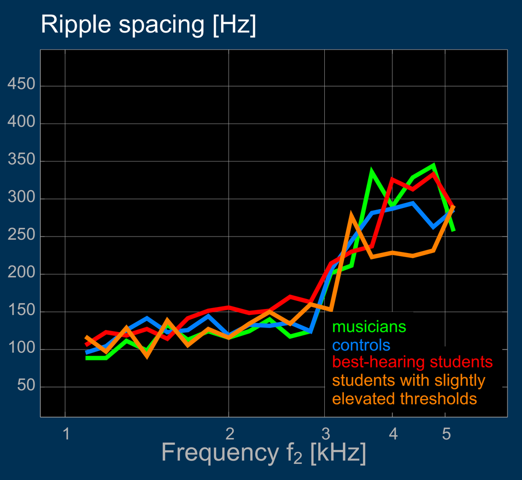
From the results shown above, it is not possible to find at general pattern for the effect of the exposure on the fine structure characteristics. This is a little surprising, since the exposure is well defined and the same for all subjects.

This suggests that there is a high degree of individual variance in either the resulting excitation of the basilar membrane for a given ear canal stimulus level, or sensitivity to be affected by over-exposure, or both.

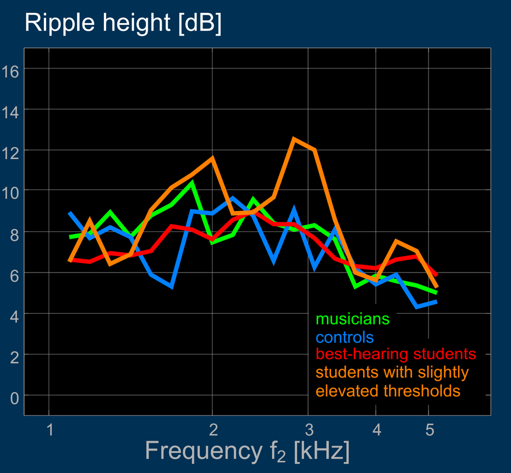
Group comparison

Another way to see if the fine structure characteristics are systematically influenced by the state of hearing is to compare fine structure statistics across groups of subjects, which have different exposure histories. In the present example, four different groups are included: Best-hearing students [13], students with slightly elevated thresholds [13], 12 symphony orchestra musicians [14], and a sex- and age-matched control group to musicians [14].

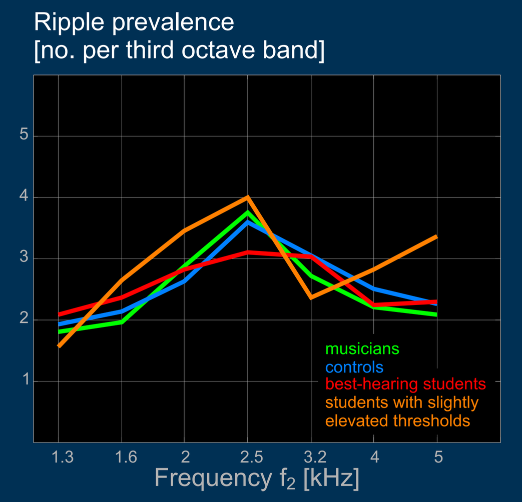
Fine structure characteristics were determined using the algorithm presented in [13], which determines:
- maxima and minima of fine structure ripples,
- ripple spacing (frequency difference between two minima),
- ripple height (level difference of maxima and mean of the two minima),
- number of ripples (ripples > 3 dB) per 1/3 octave.



The ripple spacing is quite similar for the four groups, although on average sligthly more narrow for the group of students with slightly elevated thresholds.



The ripple height is also quite similar for the four groups, although on average sligthly higher for the group of students with sligthly elevated thresholds.



The ripple prevalence is also quite similar for the four groups, although with a distinct bend around 3 kHz for the group of students with sligthly elevated thresholds.

The comparison between musicians and the control group, which were sex- and age-balanced to the musicians, revealed no significant difference in any measure. Both groups had generally good hearing for their age. Both the musicians and the control group differed from the younger group of best-hearing students by some of the fine structure characteristics (spacing and height) and - most convincingly - in overall DPOAE level. A such difference was also observed in the comparison of the two younger group of individuals, where the group of best-hearing individuals on average had wider and lower ripples in their fine structure.

The difference in fine structure characteristics has no simple explanation. It may be that the early age-related deterioration of the hearing leads to more irregularities on the basilar membrane. These may generally affect the secondary (reflection) component for more frequencies than the place-specific component, thus the higher number of dips is related to higher order reflections.

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