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# Effects of Noise on the Intensity of Distortion Product Otoacoustic Emissions

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***Abstract:*** Distortion product otoacoustic emission (DPOAE) is a widely used differential diagnostic method for diagnosing inner ear disorders. It provides us information on the condition of the outer hearing cells (OHCs). Otoacoustic emission occurs only when the OHCs are functioning normally. Changes in thresholds of DPOAE curves can provide us important information on the activity of the OHCs. The inner ear shows nonlinear properties if the OHCs are functioning normally. If OHCs are injured and thus function improperly, the system stops showing nonlinear properties. If we have a system with periodic excitation and, with the addition of white noise, the signal-to-noise ratio on the output increases (at least for small noise intensities), we have witnessed what is called *phenomenon stochastic resonance*. Our goal was to elucidate how white noise influences the intensity of DPOAE. If there is emission, that specific ear surely exhibits nonlinear behavior, which in turn is the basic property needed for stochastic resonance.

***Key Words:*** distortion product otoacoustic emission; nonlinear systems; otoacoustic emission; stochastic resonance

If we view a system with two inputs—one coherent signal and one source of white noise—and with one output that is some function of the inputs and the internal dynamics of the system, two possibilities ensue. First, if we increase the intensity of white noise on one of the inputs, the signal-to-noise ratio (SNR) on the output will decrease. This is the system with linear characteristics, which has linear or mildly nonlinear internal dynamics.

Second, if we increase the intensity of white noise on one of the inputs, the SNR on the output will increase. This is true of a system with nonlinear internal dynamics with stochastic resonance [1]. Thus, the studied system must usually be bistable and must have at least two inputs—coherent periodic signal and white noise. Figure 1A shows the characteristic properties of a system with stochastic resonance.

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The SNR has been plotted against the intensity of the added white noise. The SNR increases as we begin to increase the intensity of the white noise. After a peak value, the SNR begins to decrease as the intensity of the white noise becomes significantly greater than that of the signal's (i.e., as long as the noise does not dominate the combined signal). Figure 1B shows the behavior of a system with linear (or mildly nonlinear) properties (the "classic" case). We see that if we increase the intensity of noise on one of the inputs, the SNR decreases.

## MATERIALS AND METHODS

We carried out our experiments in 10 healthy, normally hearing persons between the ages of 23 and 26 years; 20 ears were evaluated, and 240 measurements were taken. All persons had a pure-tone threshold in every frequency between 0 and 10 dB and have had normal distortion product otoacoustic emission intensity plots (known *as DP-grams*). The input noise was applied with contralateral stimulation via earphone. The DP-grams were taken at measure-tone intensities of sound pressure levels 60 and 70 dB, respectively. The ratio of

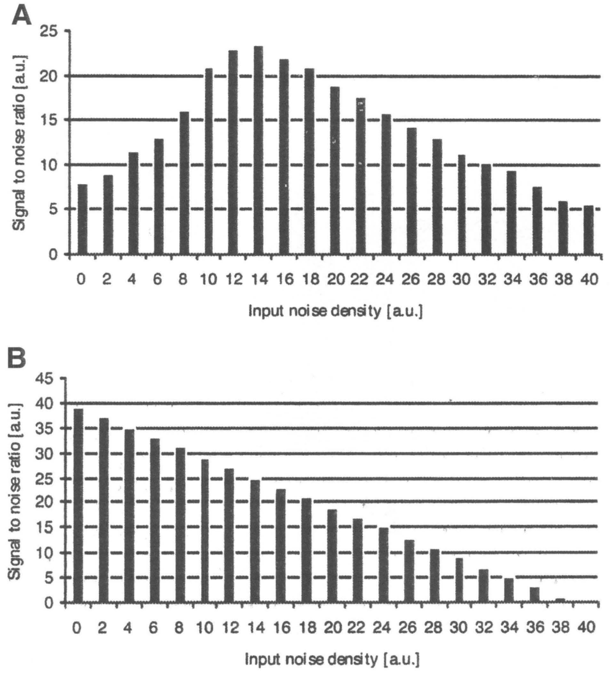


**Figure 1.** (A) System showing the characteristic properties of stochastic resonance. (B) Linear system's response against the addition of white noise.

the two stimulus frequencies, $F_1$ and $F_2$, was $F_2/F_1 = 1.2$. The recordings were taken with the resolution of three points per octave. The intensity of the contralateral white noise was changed in 10-dB increments from 0 to 80 dB SPL. Between the successive measurements, approximately a 1-minute pause was taken to avoid the effect of short-term high-intensity white-noise exposure, which probably would have given false results [2]; otherwise the effect of short-time high-intensity white noise exposure would have given false results.

The experimental setup for contralateral white-noise stimulation and measurements can be seen in Figure 2.

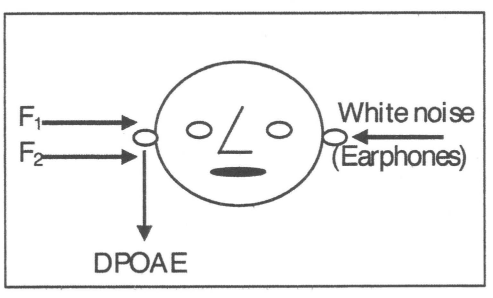


**Figure 2.** Experimental setup for contralateral white-noise stimulation.

We used the Student's $t$-test to measure the significance of our results. Only values of $p < .05$ were considered significant.

## RESULTS

Increasing the external noise, the output SNR of DPOAE initially increases. After reaching approximately a 40- to 50-dB SPL noise intensity, the DPOAE amplitude begins to decrease. The effects are frequency-specific: Significant changes could be found only at three frequencies: 2,531 Hz, 3,187 Hz, and 4,000 Hz ($F_1$ values). Figure 3 illustrates an example of our results showing the DPOAE intensity plotted against the measured frequencies. The changes can be seen clearly.

## DISCUSSION

Former examinations at our institution showed that after exposure to high-intensity white noise, the DPOAE signals increase in a fashion similar to that of the phenomenon of stochastic resonance [2]. The measurements were taken only after the noise exposure, however. These results were important during our tests.

Our results show that there is a connection between external noise and the DPOAE signals. Ehrenberger et al. [3], in contrast, elicited the role of white noise in cochlear signal transduction at the one-cell level. The noise of the hair cells themselves does not influence the results shown in Figure 3, because the applied noise intensity was much greater than the noise at the cellular level [3]. Nieschalk et al. [4] showed that even a contralateral exposure to pure tone could increase the threshold of DPOAE. Those authors used only pure sine tone with an intensity of a 30-dB hearing level. They found frequency-dependent significant changes if the contralateral sine tone's frequency was varied from 500 Hz to 4 kHz. The values—wherein the DPOAE's intensity was significantly greater than without contralateral stimulation—match with ours and with those of Santaolalla et al. [5]. Interesting but difficult to explain are the favored frequencies, especially in the case of contralaterally or ipsilaterally applied white noise.

Santaolalla et al. [5] carried out experiments with contralateral white-noise exposure. This group's results were similar to ours, but they found significant differences only at approximately 1.5, 2.0, and 3.0 kHz. Their and our results do not match, yet the issues clearly show that there is an increase in some of the DPOAE amplitudes. More measurements must be carried out to investigate this phenomenon and to account

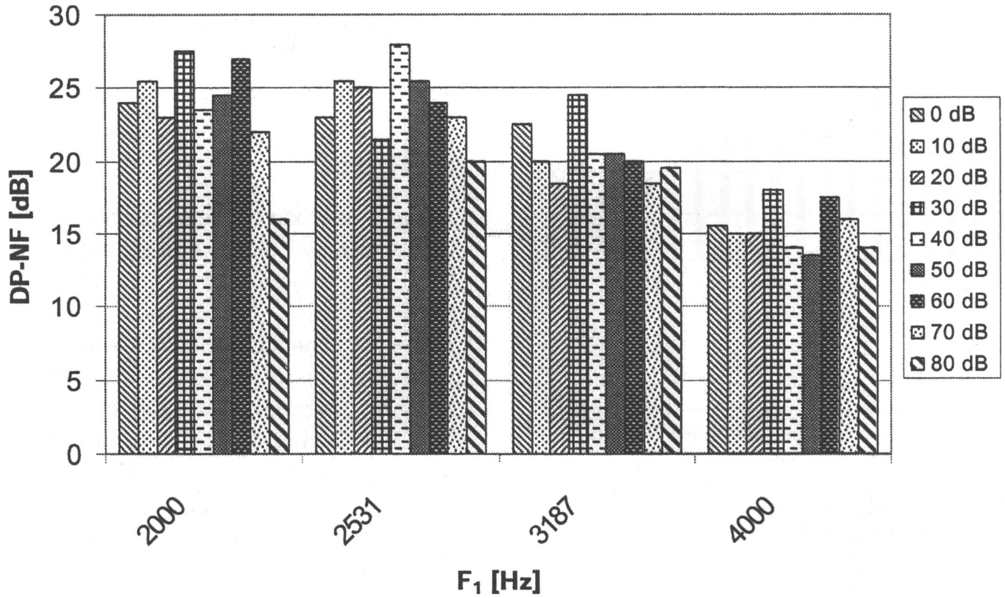


**Figure 3.** Results showing the amplitude increase of the distortion product otoacoustic emission with 0- to 80-dB white-noise stimulation (white noise intensities on the inset to the right). For clarity reasons, amplitudes of distortion product otoacoustic emissions only between 2,000 and 4,000 Hz are plotted.

for the specific frequencies involved in the amplitude changes.

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