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THE INSTRUMENTATION FOR MEASUREMENTS OF EVOKED OTOACOUSTIC EMISSIONS

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Evoked Otoacoustic Emissions (EOAEs) are studied by the use of the recently built EOAEs processor. For this purpose 101 dentist students underwent screening earphone audiometry and electrostimulation high-frequency tests and were tested with use of the EOAEs processor. Three different parameters were evaluated from the recorded waveforms. Great inter- and intraindividual differences within the recordings were observed. The problems concerning the probe fitting are also discussed.

1. Introduction

The first description of the measurement of EOAEs was reported by D.T. Kemp in 1979 [1] and, since then, it has been studied by many investigators. Otoacoustic emissions are a release of audiofrequency energy into the ear canal from the cochlea, transmitted throught the ossicular chain and tympanum are considered as an energy leakage from the cochlear travelling wave. The physical source of the audiofrequencies metioned above are the outer hair cells, situated in the cochlea. The observations of cochlear mechanics show that the healthy cochlea vibrates far more at the specific frequencies, in response to stimulation, than a disordered cochlea. The full understanding of cochlear functions in the hearing process still has not been achieved. However, the outer hair cells are supposed to be a part of active biomechanical feedback intended to sharpen up the tuning and enhance the sensitivity of the cochlea to the sound excitations [2].

Otoacoustic emissions would seem therefore to be a tool for examining certain functional aspects of the cochlea, as for example:

- a screening hearing test in neonates [3],
- confirmation of peripheral auditory impairment in children [4],
- differential diagnosis of endocochlear and retrocochlear types of hearing loss [5].

Spontaneous or unstimulated otoacoustic emissions (SOAEs) are pure tones of about 20 dB SPL found in the quiet ear canal in 25 to 60% of healthy ears [6]. They can be modulated by pressure on the tympanum. However, the particular internal cochlear feedback conditions needed to sustain spontaneous emissions are not always present. Therefore, SOAEs have found till now limited clinical application.

EOAEs recordings are usually obtained by averaging the acoustical signal measured by a miniature microphone. The avergaing process is synchronised to the presentation of a repeated transient stimulus, usually a click or a tone burst. The stimulus is generated by a miniature earphone. Both the microphone and the earphone are placed in a small probe sealed in the auditory meatus. The probe is equipped with tabular waveguides to obtain the optimal matching to the acoustic impedance of the meatus. An additional pipe is placed between the waveguides to appease the pressure increase during the probe fitting procedure. The construction details for the otoacoustic probe and the block diagram of the EOAEs recording system are shown in Fig. 1.

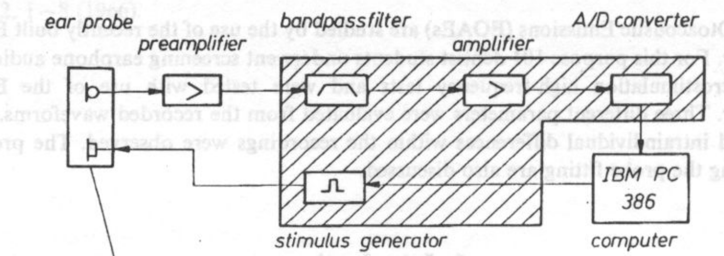

Fig. 1. Block diagram of the EOAEs Analyser and the construction details of the EOAEs probe.

The intensity of EOAEs is generally less than 20 db SPL [7]. This is smaller than the level of electrical noise generated within the microphone and, as well as physiological and ambient noise, picked up by the microphone. The total noise level usually exceeds the level of a few microvolts when the signal level is about one microvolt RMS. The use of a low noise preamplifier and an audio-bandpass filter is necessary but insufficient. To improve the poor signal to the noise ratio (ca. — 20 dB) the averaging process is used. Every response to the stimulus of about 20 ms duration is transformed into a digital form by means of fast A/D converter, and stored in the computer memory as a single „time window". The „time window" starts a few ms after the stimulus because the intial period is contaminated by the acoustic oscillations which invitably foloow the stimulus emitted in the limited cavity. For the consisted EOAE waveform and Gaussian noise averaging process of consequent sweeps improves the signal to noise ratio (SNR) factor equal to the square root of the sweep number. In practice the number of about 1000 sweeps yielding 29 dB SNR improvement is used.

Otoacoustic emissions exhibit nonlinearity both in the time and frequency domain. This means that output level is not proportional to the input, and that the components of a complex input interact with each other. The results of clinical EOAE test are often contaminated by the oscillations caused by the echooes of the stimulus in the meatus. The intensity of the echos depends of the fitting of the probe. The effect of EOAE nonlinearity in the time domain allows to reduce the influence of the oscillations. According to the procedure proposed by Bray and Kemp [7], the EOAE waveforms are averaged when stimulated with a nonlinear differential block, shown in Fig. 2. Every

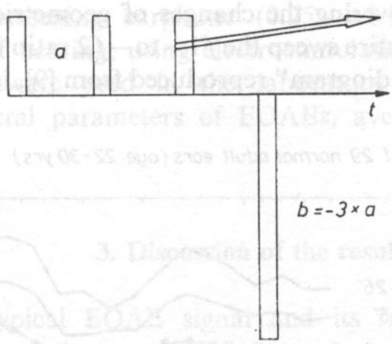

Fig. 2. The signal block used in differential nonlinear stimulation technique.

fourth component of the nonlienear stimulus is invered and three times greater amplitude than three other components of the stimulus. The acoustic responses to all linearly behaving systems i.e. nonphysiological responses are cancelled by the summation of all the stimulus components. Only the saturated part of the physiological emission signal is passed to the further processing units. In practice, only half of the saturated EOAE remains due to its partial cancellation. Signal-to-noise ratio is therefore worse when compared to the Basic EOAEs Echo Technique. In clinical conditions the small loss of the SNR is rarely significant, and the advantages of the method overcome its drawbacks.

Distortion-product otoacoustic emissions are continuous signals that appear at some combination of harmonic tone stimulation, considering the nonlinearity in the frequency domain of the cochlea mentioned above. The first DPOEs measurements were reported by D.T. KEMP in 1979. In practical applications [9] the two-tone stimulation method is used. That kind of stimulation leads to interaction between the two travelling waves in the cochlea, creating several distortion products (DP). For the tones labelled $f1$ and $f2$, the $2 \times f1 - f2$ DP is belived to be generated at the place being the point of maximal interactions between the two travelling waves. The instrumentation for recording the DPOEs is more complicated than that used for echo techniques. The ear probe equipped with two earphones is fed by two generators transmitting $f1$ and $f2$.

The pure tone waveforms are synthesited by the computer. The duration of the emission of the chosen tone combination is about 4 seconds. The microphone placed in the ear probe detects the DPOE signal. The processing procedure of this signal consists of:

• high- and lowpass filtering 100–8000 Hz,

• averaging in the time domain,

• evaluating the $2 \times f1 - f2$ component by means of Fast Fourier Transform (FFT),

• evaluating the level of the background noise as the average of the magnitudes of four FFT components adjacent to the $2 \times f1 - f2$ frequency two above and two below the main frequency. To obtain the „DPOE audiogram" the procedure described above is repeated covering the changes of geometric mean is realised in a 1/4 octave step, and for the entire sweep the $f1$ – to – $f2$ ratio is held at the value of 1.2. The example of „DPOE audiogram" reproduced from [9], is presented in Fig. 3.

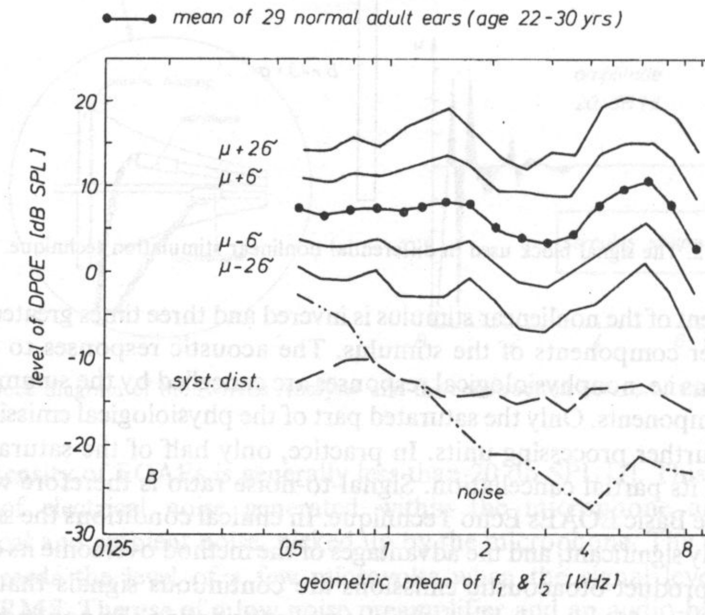

Fig. 3. An example of distortion-product otoacoustic emission audiogram (μ and δ — mean and standard deviation from all the ears examined) [9].

2. Experimental

The investigation of EOAEs in Laboratory of Audiology, ENT Clinic.Dentist Dep. in Warsaw Medical Academy started in 1990 (9, 10, 11, 12] under direction of Prof. W. Bochenek. Basic click-evoked echo technique using the instrumentation shown in Fig. 1 is applied. The EOAEs processor is equipped with three probes of different sizes of our design, and one original probe offered by D.T. Kemp [13]. Three stimulus, types may be generated under control of the computer: positive click, negative click and modulated sine burst.

The recorded signal is amplified in the separate low-noise. Fet-driven preamplifier and in the main filter and amplifier section. The total gain is adjustable in the range of 60 – 100 dB. The lower frequency limit is set to 5000 Hz and the upper to 12 kHz. To record the signal in the computer memory, a fast 8-bit, 40 kHz analog to digital converter is used. This allows to represent a EOAEs signal of 18 ms duration as 720 bytes long waveform and enables us to obtain a 100 Hz resolution for Fast Fourier Transformation.

Recordings were collected in a group of young, normal hearing persons. The group consisted of 101 dentist students of mean age 23.1. They underwent routine otoscopy, screening earphone (0.25 – 8.0 kHz) audiometry and check *of the upper limit of hearing, using electrostimulation high-frequency audiometry* (SEHFA). The software used in the laboratory enabled the comparison of amplitude and spectral parameters of EOAEs, averaged within a certain group of subjects.

3. Discussion of the results

In Fig. 4 the typical EOAE signal and its frequency spectrum is shown. The upper curves are the results of two consequent series of 1024 sweeps. Below the crosspower spectrum of two sweep series (the dashed bars) and the power of the noise, obtained by substracting the two sweep series (the black bars) is presented. The spectral line representing the maximal power component was in the investigated group a subject of significant variation within the range of 0.9 to 2.8 kHz. The correlation between the upper limit of hearing and the spectral maximum power component has not been defined because of the variations mentioned above. After collecting more data will be possible to verify the theory that there is a correlation between the spectral maximum power component of EOAE and the patient's age, described in [14].

The average delay between the oneset of the click and the maximal amplitude of the EOAE was about 7 miliseconds. There were some cases of registration of longer delays (ca 10% increase), accompanying the presence of slight ear impairements.

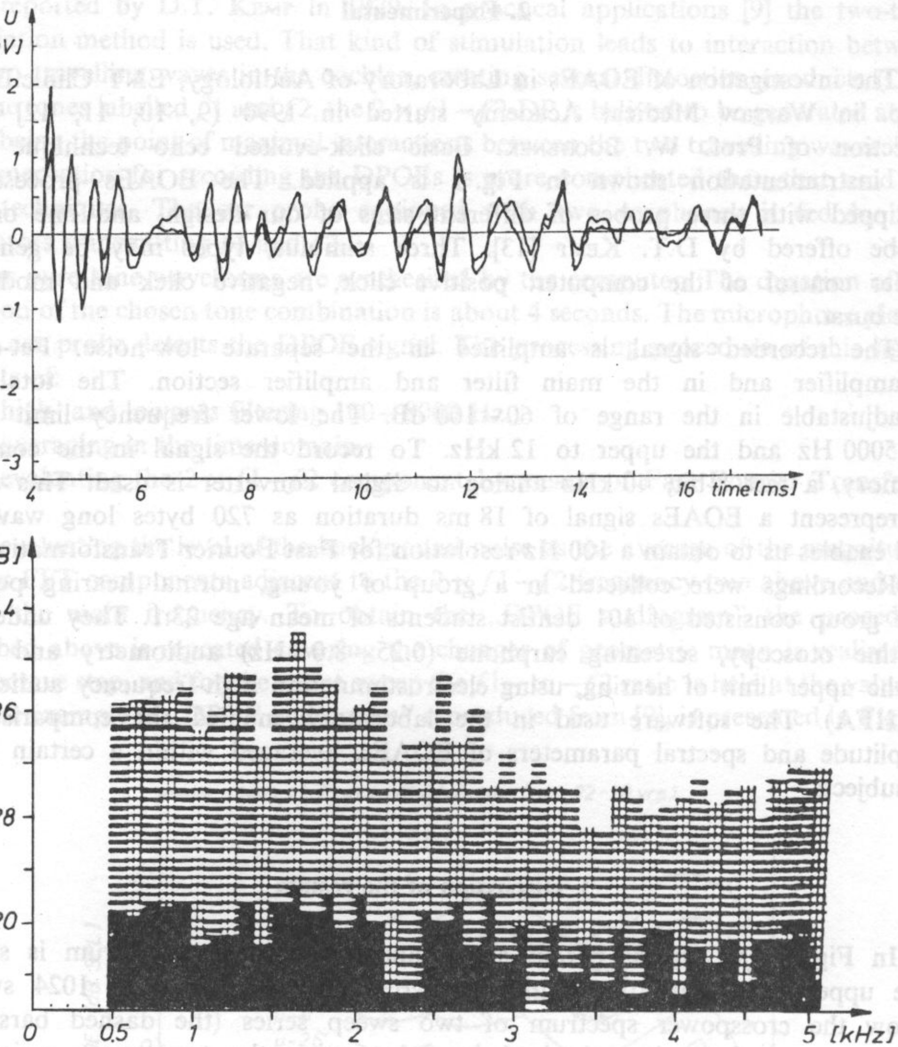

Fig. 4. The typical EOAE signal and its frquency spectrum (below).

The variations in the average EOAE amplitude level achievd 15%. The factor of a great influence the quality of the EOAEs recording was the probe fitting and the patient noise. Figure 5 is an example of the recording with the poor fitting and the noises caused by loud breathing. The initial part of the sweep (5 – 8 ms) is highly contaminated by the oscillations of the click in the ear canal. The latter part of the signal (9 – 17 ms) exhibits considerable differences between the signal level during the first and the second averaging process. The presence of EOAEs is therefore impossible to detect here.

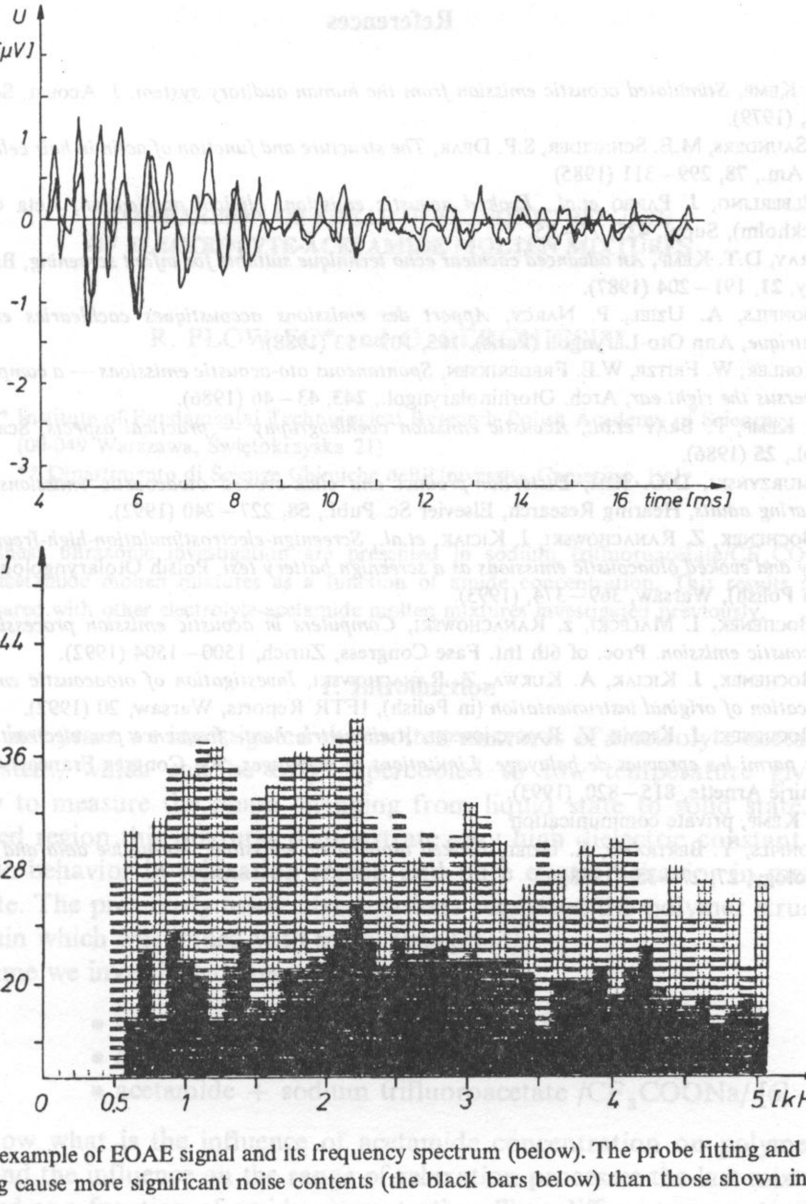

Fig. 5. An example of EOAE signal and its frequency spectrum (below). The probe fitting and the loudly breathing cause more significant noise contents (the black bars below) than those shown in Fig. 4.

Further modifications of the instrumentation should improve the procedure of recording the EOAEs signals. The aim is to optimize the rejection of artefacts caused by the click reflections in the meatus, using the Differential Nonlinear Stimulation Technique.

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