

TEOAE FINDINGS IN ADOLESCENTS

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Abstract: Measurement of the transient evoked otoacoustic emissions (TEOAE) is widely used in research of hearing. In this paper we present a study on the time-frequency properties of TEOAE's. The group under study consists of 257 children of age 14. Time-frequency features of the TEOAE's are analysed. Examples of some typical results are presented. Relationship of the findings to earlier history of patients and benefits of TEOAE testing are discussed.

Keywords: TEOAE, filter bank, PCA

1 INTRODUCTION

In addition to the audiometric test, the measurement of the transient evoked otoacoustic emissions (TEOAE) can be used in examination of hearing. The results of the audiometric test depend completely on the patient's subjective observation. Measurement of the (TEOAE) is believed to provide objective information on the condition of the cochlea.

2 TRANSIENT EVOKED OTOACOUSTIC EMISSION

Otoacoustic emission is a result of active movements of the hair cells in the cochlea when sensing sound. TEOAE is a measurable sound emission after a transient stimulus. This phenomenon was first discovered by Kemp in 1978 [1] and a clinically acceptable measuring equipment was developed by Bray [2]. Now the TEOAE's are accepted as a part of audiological practise.

3 ANALYSIS METHODS

3.1 Time-Frequency Analysis

The time-frequency analysis is done using a filter bank [3]. Bandwidth of each filter is 1 Bark, according to the critical bandwidth of the human ear. Relationship of the frequencies f in Hz and x in Bark can be approximated up to 6 kHz by [4]

$$x[\text{Bark}] = 7 \operatorname{asinh}(f / 650) = 7 \ln \frac{f}{650 + \sqrt{1 + (f / 650)^2}} \quad (1)$$

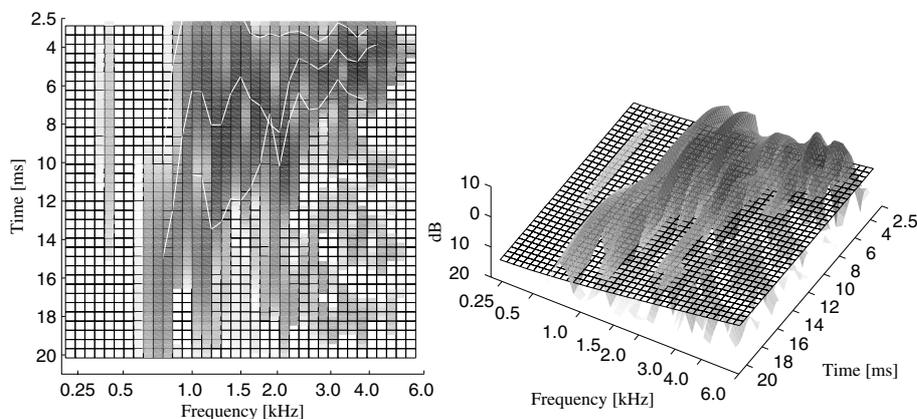


Figure 1. Time-frequency plane of a measurement from ear with normal hearing viewed from different angles.

The delays of the responses at different frequencies are one of the main interests. Because the TEOAE signals are stored on disk and we don't need a real time application we can use noncausal forward-backward filtering [6], which causes a zero group delay.

The measurement is quite sensitive to the position of the measurement plug in the ear channel [5]. The analysis program provides a user interface to view the stimulus and the fft-spectrum of the response and to cut out the inadequate measurements. The program produces a graphical presentation of the time-dependent spectrum (figure 1). Numerical values of the most important features are saved for further analysis.

3.2 Principal Component Analysis

Principal Component Analysis (PCA) [7] transforms a multivariate data matrix into a small set of orthogonal components. These Principal Components (PC) or factors are linear combinations of the original variables and describe the major variations in the data. They also form an orthogonal basis for the space spanned by the original data matrix.

PCA decomposes the data matrix X of m measurements and n variables, as the sum of the outer product of vectors \mathbf{t}_i and \mathbf{p}_i and residual matrix E :

$$\mathbf{X} = \mathbf{t}_1\mathbf{p}_1^T + \mathbf{t}_2\mathbf{p}_2^T + \dots + \mathbf{t}_k\mathbf{p}_k^T + E \tag{2}$$

k is the number of PC's used. If all possible PC's are used the residual reduces to zero. Vectors \mathbf{t}_i are called scores. The \mathbf{p}_i are the eigenvectors of the covariance matrix and are called loadings. The PC's are ordered according to the corresponding eigenvalues.

4 TEOAE FINDINGS

The study was performed in Tampere University Hospital. This child group was randomly selected of the children born in Tampere City between December 1978 and March 1980. These children form a homogenous and representative part of their peers. The mean age is 13.8 years. TEOA was registered from most of the children. Total of 479 TEOAE measurements from 257 children have been under study.

4.1 Features from time spectrum

There were 3 features selected from the time-dependent spectrum, each of them at 4 different frequencies. The features are; maximum of the response in dB, delay of the maximum in ms and total energy of response. The frequency bands used are 1 bark wide with central frequencies 0.5, 1, 2, and 4 kHz.

4.2 Principal Component Analysis

First 2 principal components (PC's) of the 12 features capture 40.5% of the variance. Scores and loadings are shown in Figure 2. Scores plot shows the location of measurements projected onto the plane spanned by the first two PC's.

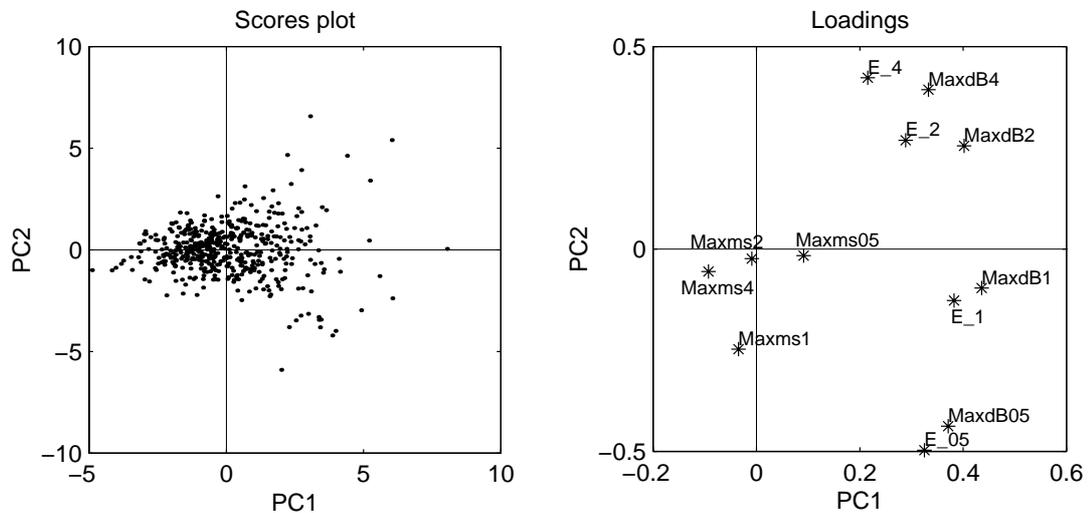


Figure 2. Scores and loadings projected on first two PC's.

Loadings show the direction of influence of each feature. The labels in the plot are MaxdB for maximum response in dB, E_ for total energy and Maxms for the delay of the maximum response. Each title has a suffix 05, 1, 2, and 4, which mean the frequency ranges 0.5, 1, 2 and 4 kHz.

4.3 TEOAE and otitis

Measurements were divided into 4 groups. Division was made by number of otitis had by the age of 15 years. The selected numbers of otitis are 0, 1 to 5, 6 to 15 and more than 15. Figure 3 shows the projections of these groups on the first PC's.

There seems to be no difference in between the groups. Thus the number of otitis has not affected the inner ear and TEOAE's.

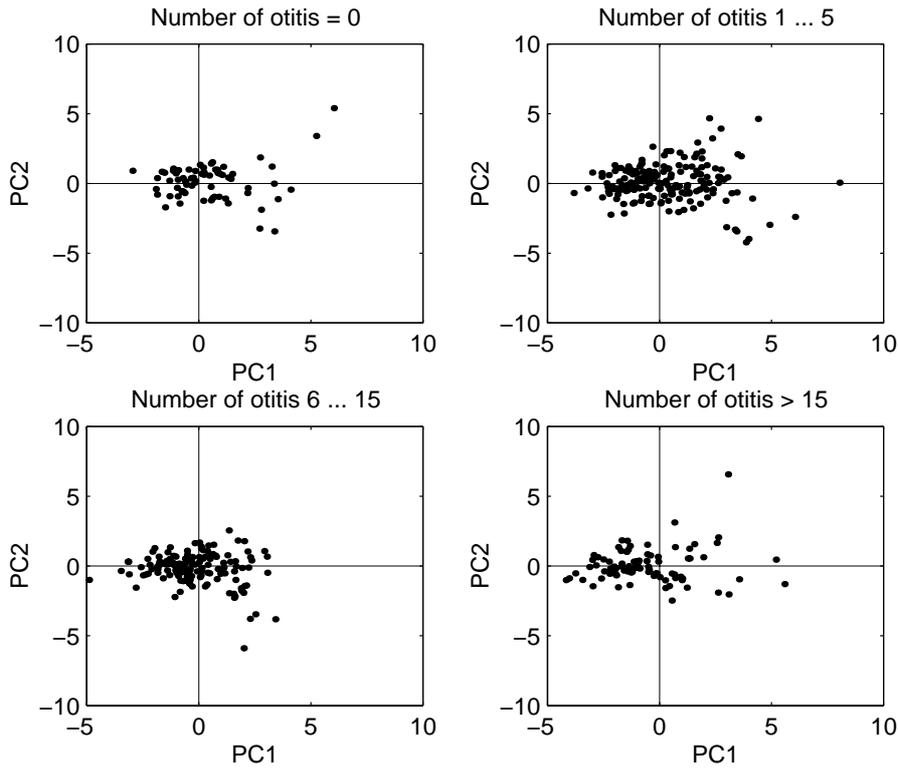


Figure 3. Different otitis groups projected on first two PC's.

4.3 Middle ear pathology

There is a group of 14 measurements (11 patients) with otomicroscopically stated middle ear pathology. PC scores of the TEOAE measurements of this group is presented in figure 4.

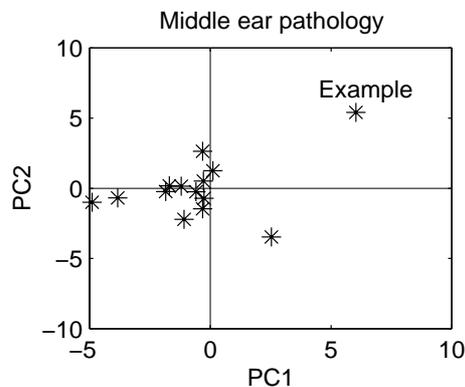


Figure 4. Group of patients with middle ear pathology projected on first two PC's.

Most of the cases are concentrated in the left-hand side. This suggests that the TEOAE responses are lower than the average. There is one exception in the upper right corner of the plane (noted as Example in Figure 4). From loadings plot in Figure 2 we can see that the effecting variables in this part of the plane are energy and maximum of the response in frequency bands 2 and 4 kHz.

The time-frequency spectrum in Figure 5 shows the reason for these unusually high responses. There is a so-called ringing phenomenon in these frequencies. The response does not attenuate normally, but instead stays ringing, which causes very large total energy in these bands.

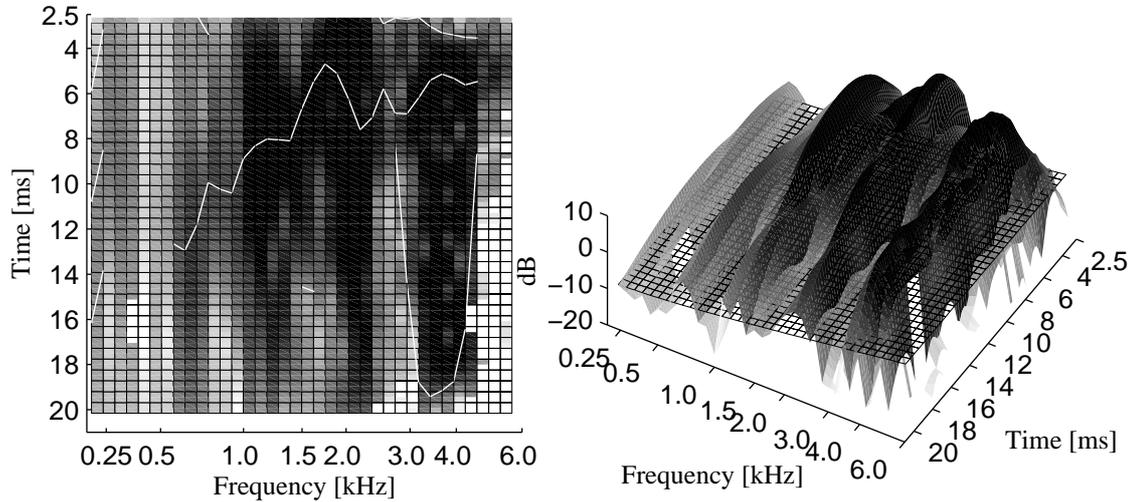


Figure 5. Time-frequency planes of the example case.

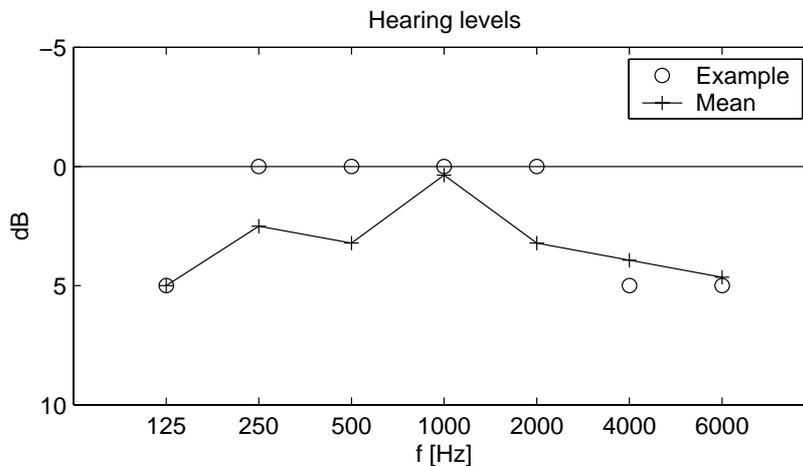


Figure 6. Hearing levels of the example case and the average of group with middle ear pathology.

Hearing levels of the example case are not significantly different from the mean of the average of the group. In 4 kHz the example is slightly below the average despite of the very strong responses.

5 DISCUSSION

TEOAE's are objective measurements based on the most important part of the cochlea analysis. The results are consistent if the measurements are made properly with care. It may be applied on a very large scale of patients of different ages. It is like a window to look at the hair cells of inner ear. TEOAE is nonlinear and saturates and therefore direct correlation to hearing level has not been found. It is very useful in detecting normal hearing in screening tests and objective verification of noise trauma. It is also very useful in basic research of peripheral hearing.

The number of otitis does not seem to have any effect on the TEOAE measurements. Middle ear pathology, however does affect the TEOAE's. This can be seen in the behaviour of the features of time-dependent spectrum. The ringing phenomenon causes bias to TEOAS responses and makes use

of TEOAE's more difficult. From time-dependent spectra this can be found and thus can be taken into account in further analysis.

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