Investigation into the uniqueness of neonate transient otoacoustic emissions

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Abstract: This work presents initial findings from an investigation into the use of otoacoustic emissions (OAEs) for identifying individuals. A data set of 2009 neonate transient otoacoustic emissions was quantified for uniqueness using the Euclidean distance separation of the power spectra. Each sample was compared to all the others and the minimum separation recorded. The percentage separation for 50%, 95%, and 99% of the sample set was calculated and the distribution of the minimum separation plotted. The minimum separation between samples was 1.84% while 99% of the samples had a separation of 3.68%. A simple technique was able to achieve a separation of 3.68% for 99% of the data set, indicating it is highly likely that otoacoustic emissions are unique to an individual and of potential use as a biometric variable in an identification system.

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1. Introduction

Differences in the frequency and number of spontaneous otoacoustic emissions (OAEs) have been discovered between the genders[1] and people of different ethnic backgrounds.[2] Ongoing investigations into using otoacoustic emissions as a biometric included a study into the uniqueness of transient otoacoustic emissions (TEOAEs) as they offer other desirable qualities for a biometric.

In order for a physical characteristic to be used as a biometric it should ideally demonstrate the following features: universality (i.e., everyone must have it), uniqueness (no two people should be the same), permanence (invariance relative to time), and collectability (it must in some way be quantifiable).

Of the various OAEs, TEOAEs were studied for use as a biometric as work by Dr. S. Kapadia and Dr. M. Lutman substantially proved them to be a function of normal hearing[3] (universality) and TEOAEs demonstrate one of the largest responses from the cochlea, approximately 20 dB SPL in adults (collectability).

A database of neonate TEOAE recordings was studied in order to determine the biometric separation between individuals. Biometric separation is defined in terms of one or more values extracted by an algorithm. In this case the algorithm is to take the power spectra in the frequency domain and compute its Euclidean separation to its nearest neighbor. As the actual value has no meaning outside its context, it is expressed as a percentage of the maximum Euclidean distance recorded.

2. The data set

The data set is described fully by Lutman *et al.*[4] The data was collected from the following UK hospitals: Cardiff, two in Leicester, Manchester, two in Nottingham, Reading, and St. Georges Hospital in London.

Table. 1. The minimum separation, expressed as a percentage of the maximum separation, of statistically significant proportions of the data set.

Percentage of the data set	No. of samples	Minimum separation (%)
50	1005	12.57
95	1909	5.52
99	1989	3.68

The equipment used was the programmable otoacoustic emissions measurement system (POEMS)[5] which consisted of a controlling PC, a purpose built probe, click-generator, signal-conditioning, A/D converter, and software which implements the stimulus, sampling, averaging, and data storage.

Each sample was acquired as follows: a sweep consisted of a 100 ms square click stimulus and the response recorded across the epoch 3–23 ms at a sampling frequency of 12.8 kHz. The sweeps were performed 33 times a second. The system was tuned to the ambient environment by adjusting the gain of the preamplifier so 5% of the sweeps were rejected. Six sets of 500 sweeps were collected for each subject, two each at stimulus intensities of 70, 60, and 50 dB SPL. The sets were calculated by averaging the 500 sweeps.

Also available was a computed nonlinear component which was constructed by reducing the response to the 70 dB click by 10 dB and subtracting it from the response at 60 dB. This exploits the nonlinear growth of TEOAEs and their saturation at high levels of stimuli. This behavior is more fully exploited by the more complex technique used to compute the derived nonlinear response[6] which is unfortunately not available.

3. Analysis

The separation was performed on one of the two nonlinear responses of the subjects right ear. The nonlinear response contains the most information from the TEOAEs as it attenuates the linear characteristics of the ear canal and recording process.

The power spectra of the nonlinear component is extracted by performing a discrete Fourier transform and calculating the absolute value of every component. The nonlinear responses are 256 samples long so after the Fourier transform there are 128 components (Nyquists theorem). The first component, representing the constant component, is set to 0. Treating every sample as a 128-dimensional vector in Euclidean space we can simply compute the separation between them using Eq. (1) which gives the Euclidean separation D between the two power spectra, $\vec{x}$ and $\vec{y}$:

$$D=\sqrt{((x_1-y_1)^2+(x_2-y_2)^2+\cdots+(x_n-y_n)^2)}. \tag{1}$$

Analysis using Eq. (1) is not suitable for analyzing time domain TEOAE data as it would produce results that would be very sensitive to phase differences and any variation between the stimulus and the recorded data. When used to examine power spectra in the frequency domain the system is desensitized to those characteristics.

The minimum separation was found by subtracting the separation of the current spectra to the separation of every other spectra in the database and recording the smallest value.

The data was held in a MySQL database and the mathematical analysis was performed using a custom C++ program implemented with the Fastest Fourier Transform in the West (FFTW) discrete Fourier transform library.[7]

4. Results

The results are broken down into statistically significant sections shown in Table 1. The separation is expressed as a percentage of the largest separation calculated for this dataset. From

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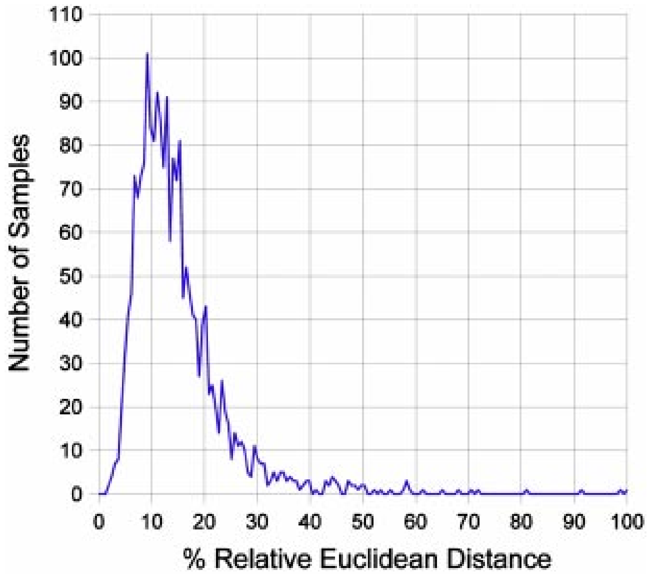

Fig. 1. Distribution of minimum separation expressed as a percentage obtained by Euclidean separation of the power spectra.

the table you can see 99% of the dataset lies at least 3.68% distant, while 95% of the data is 5.52% distant. The minimum separation was 1.84%. The shape of the distribution is shown in Fig. 1. The majority of the samples lie in the region below 20%.

The reproducibility was tested by using the above analysis on two identical recordings made on ten randomly selected individuals. The maximum difference was 2.94% which is below the 99% separability threshold, with a mean difference of 2.52%.

5. Discussion

The aim of this investigation was to determine from the data available an estimate of the uniqueness of TEOAEs. Using a simple analysis technique applied to a large data set (2009 samples) the results have proved TEOAEs to be significantly different from each other. From this information we are capable of distinguishing 99% of the population if there is <3.68% noise in the sampling system using the method discussed above. The reproducibility result suggests the noise is below the 3.68% threshold listed above, supporting this conclusion.

In conclusion we are able to distinguish between the 2009 individuals in this sample to a high degree, making it a reasonable assumption that transient otoacoustic emissions are highly individualistic and worthy of further investigation using more sophisticated analyses such as *k*-means[8] and the Gaussian mixture approach.[9]

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