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DETECTION OF LOW INTENSITY AUDITORY EVOKED RESPONSES

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A signal processing technique based on the use of crosscorrelation functions is proposed for the analysis of the auditory evoked brainstem response (*ABR*). Detection of a response as well as estimation of its position along the time axis (group latency) are shown to be significantly improved after correlation analysis. Results indicate that the method may be applied to systematical investigations of the responses measured – with surface electrodes on the scalp – at extremely low intensity levels.

1. Introduction

Analysis of short latency auditory evoked responses (whole-nerve Action Potential and auditory evoked brainstem response, or *ABR*) generated at medium to low intensity levels is of particular interest for several reasons. First, at the lowest intensities, the frequency specific mechanisms active at cochlear levels, as those observed in the frequency threshold curves [11, 8] are such that the short latency responses originate mainly from the cochlear regions tuned to the peak(s) of the stimulus spectrum [2, 3, 13, 14, 10, 1]. At medium to low intensities, the region excited by the stimulus widens and consequently the frequency – or "place" – specificity is progressively lost. The "place" specificity of low intensity responses has been proposed for use in extracting information on the peripheral hearing at specific frequencies [4, 17]. Secondly, despite the fact that the literature accumulated on the early evoked responses during the last decade is very rich, many aspects concerned with the analysis of responses evoked at very low intensity levels are still uncovered.

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Thirdly, at medium to high intensities, in a variety of hearing losses, the response waveshapes and latencies tend to approximate the normative standards [6]. On the other hand, interpretation of the recordings at medium to low intensities is difficult because the signal-to-noise ratio is poor; at intensities of 30-20 dB *SL* the detection of a response and the identification of its components may be impossible, in particular for the *ABR*.

The aim of the present paper is twofold: 1) we want to show how and to what extent the use of a signal processing technique (crosscorrelation analysis) may improve the response detection in a given set of recordings, and 2) we present evidence for the constant presence of an *ABR* at intensity levels as low as 0-10 dB re the subject's threshold sensation level for the same stimulus. We shall confine our study to the *ABR* measured with electrodes on the scalp, in humans.

Some preliminar results have been presented elsewhere [9]. The use of crosscorrelation techniques for the analysis of evoked potentials from the cortex was introduced by WOODY [16] and MCGILLEM and AUNON [12] and by ROSENHAMER [15] and ELBERLING [7] for the *ABR*.

2. Methods

The proposed procedure

The regular and monotonic changes of amplitudes and latencies of the *ABR*s over the intensity range suggest that the response evoked at a given stimulus intensity I_1, $s_1(t)$, may be used to predict the presence of a signal and its time location (group latency) in a recording obtained at an intensty I_2, $s_2(t)$. It can be assumed that $I_2 < I_1$. A first approximation model of the response $s_2(t)$ is therefore given by

$$s_2(t)\, a s_1(t-\tau). \tag{1}$$

This expression means that $s_2(t)$ may be considered as a shifted version of $s_1(t)$, the relative time delay being τ, apart from a scale factor. Expression (1) is a reasonable approximation of the real situation at least as far as I_1 and I_2 are close together.

Then, evaluation of the crosscorrelation function between $s_1(t)$ and $s_2(t)$ will provide information on the presence of a response at the lower intensity I_2 and on its relative time delay. As it will be shown in the next sections, the results of correlation analysis do confirm *a posteriori* the assumptions above.

Recording and processing procedures

The responses were recorded with Ag$-$AgCl disk electrodes pasted on the ipsilateral (+) and contralateral ($-$) mastoid, with the forehead as ground. Rarefaction rectangular pulses (100 µs duration) were delivered through TDH-49 earphones, with MX-41/AR cushions, at a rate of 11/s, at levels ranging from 120 to 20 dB (peak equivalent at 3kHz) *SPL*, in 5 or, more frequently, 10 dB steps. The subjects were lying comfortable on a bed in a quiet room. Responses were sampled over a time window of 10 ms (512 sampled data points); filters were set at 200-2000 Hz (24 dB/oct). Recordings were averaged over 2048 sweeps and stored on floppy disks for offline processing. Stimulus generation, data acquisition and processing were under the control of a (Fortran programmable) Amplaid MK 6 system. Before the beginning of the recording session, the subjects (all trained normal hearing listernes involved in the Biomedical Engineering Program at the Polytechnic of Milan) were asked to make by themselves the determination of the threshold sensation level, by entering the stimulus intensity from the computer keyboard. Typical values were in the range of 35-40 dB *p.e. SPL*.

Offline processing of the signals included:

I. demean of the record;

II. tapering with a cosine window over 75 points, at the beginning and at the end of each record;

III. zero-phase shift bandpass digital filtering; bandpass of 100-2000 Hz or 150-2000 Hz (24 dB/oct) has been most commonly used;

IV. normalization in amplitude according to the *rms* value.

Crosscorrelation functions are then computed for the entire sequence of responses, in 10 dB steps, from the highest to the lowest intensity levels, respectively.

3. Results

A complete set of *ABR*s measured over a range of 100 dB is illustrated in Fig. 1a. It can be seen that the responses evoked at stimulus levels below approximately 70-60 dB *p.e. SPL* are hardly discernible. Fig. 1b and c illustrate the results obtained after application of the procedure above to the original recordings.

Interpretation of the crosscorrelation functions (*c.c.f.*) requires some comments. First of all it is noted that strong periodical components are present in the *c.c.f.*s over the whole intensity range – a reflection of the quasi-periodical time course of the *ABR*s as a result of our recording technique. It is noted also that the waveshapes of the *c.c.f.*s are remarkably constant, apart from a delay reflecting the response (group) latencies. Removal of the low frequency components ($< 150 : 200$ Hz, see *Methods*) from the original recordings emphasizes the periodicities in the *ABR*s and, consequently, in the *c.c.f.*s. We have deliberatedly chosen the mastoid-mastoid electrode derivation to the same purpose; in fact, with a vertex-mastoid or earlobe-vertex derivation, the *c.c.f.*s have a rather broad single-peaked waveshape, as a consequence of the relative

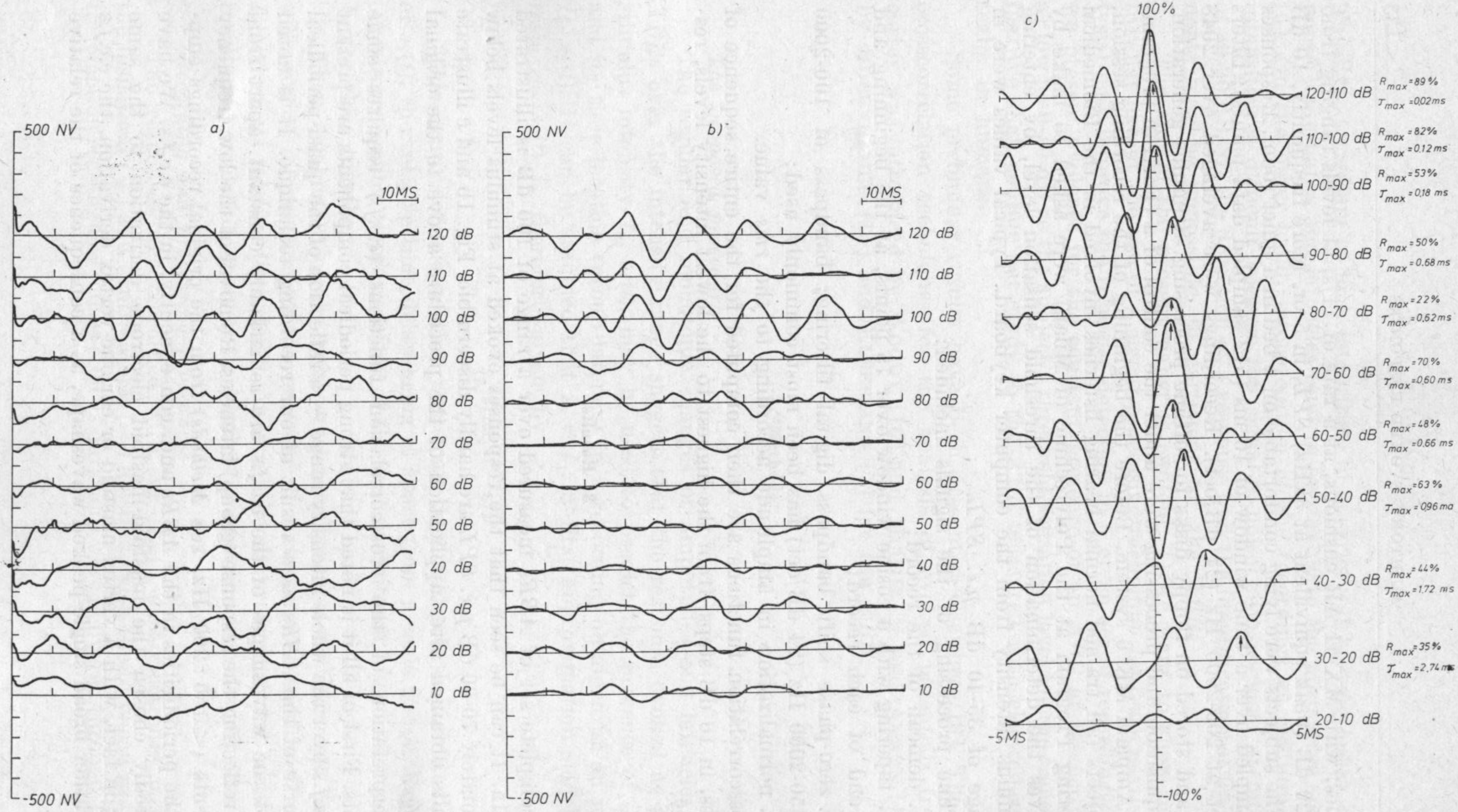

Fig. 1. a) *ABR*s from a normal hearing subject. Amplitudes are the same for all the recordings. b) Responses after bandpass filtering. c) Crosscorrelation functions computed from the responses of b), according to the present procedure. Arrows indicate the peak corresponding to the maximum correlation. For each function, the values of the maximum correlation ($R_{\max}$ %) and its abscissa ($\tau_{\max}$) are reported

dominance of wave *V*. By use of the present recording and processing procedures the similarities observed in the *c.c.f.*s are more easily observed over the whole intensity range.

It is seen from Fig. 1c that the values of the maximum correlation ($R_{\max}$) are approximately a slowly decreasing function of the intensity level (see also Fig. 2 to be discussed later). This is due to the decrease of the signal-to-noise ratio with the decrease of the intensity as well as to some subtle changes of the *ABR* waveforms. However, the maximum correlation is still as high as 63 and 44% at 50-40 and 40-30 dB *p.e. SPL*, whereas the threshold sensation level of the subject was 37 dB *p.e. SPL*.

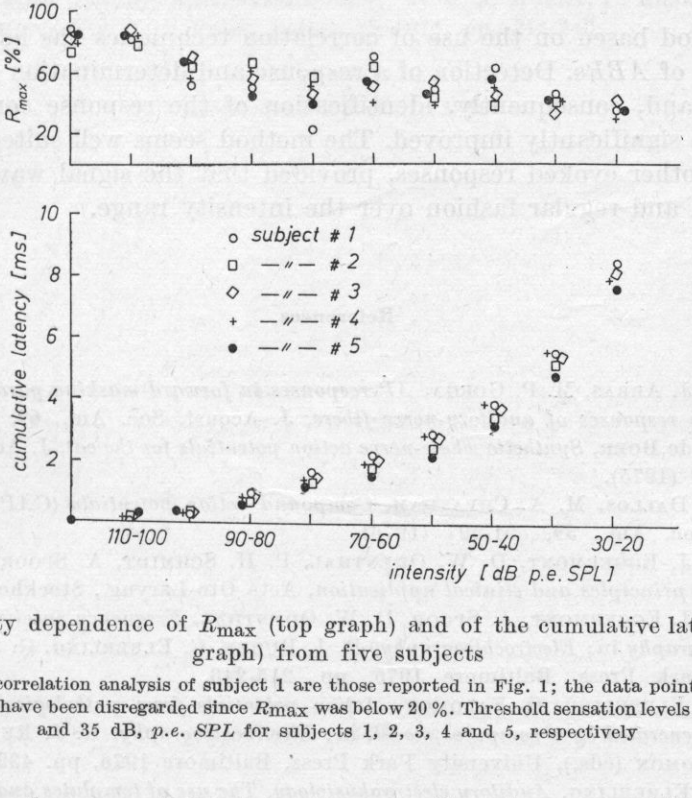

Fig. 2. Intensity dependence of $R_{\max}$ (top graph) and of the cumulative latency (bottom graph) from five subjects

the results of the correlation analysis of subject 1 are those reported in Fig. 1; the data points of subject 2 at 30-20 dB *p.e. SPL* have been disregarded since $R_{\max}$ was below 20%. Threshold sensation levels were 37,35, 40,37 and 35 dB, *p.e. SPL* for subjects 1, 2, 3, 4 and 5, respectively

Results as those illustrated in Figure 1 are typical for all the recordings analysed with the present procedure. Fig. 2 resumes the results of the correlation analysis for five subjects, in the form of $R_{\max}$ and of time delays. The top graph of Fig. 2 shows that, for intensity levels of 40-30 and 30-20 dB *p.e. SPL*, $R_{\max}$ is still high. With 10 dB steps between the input levels and with a time window of 10 ms, $R_{\max}$ falls abruptly at the lowest intensities. Data concerning the relative time delays have been processed as follows: a "cumulative latency" has been calculated, for each subject, by summing the values of $\tau_{\max}$ from the *c.c.f.*s, step by step, orderly from the higest to the lowest intensities.

The results, from the same five subjects are shown in the bottom graph of Fig. 2; as expected, the cumulative latency increases regularly and monotonically as the intensity is decreased.

4. Conclusions

A method based on the use of correlation techniques has been applied to the analysis of *ABR*s. Detection of a response and determination of its relative time delay and, consequently, identification of the response components are shown to be significantly improved. The method seems well suited also for the analysis of other evoked responses, provided that the signal waveshapes vary in a smooth and regular fashion over the intensity range.

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