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Automatic removal of sonomotor waves from auditory brainstem responses

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ABSTRACT

We have developed a computerized technique for automatic detection and removal of sonomotor waves (SMWs) from auditory brainstem responses (ABRs). Our approach is based on adaptive decomposition using a redundant set of Gaussian and 1-cycle-limited Gabor functions. In order to find optimal parameters and evaluate the efficiency of the methods, simulated data were first used before applying it to clinical data. Results were good and confirmed by an expert with years of clinical experience in ABR evaluation.

1. Introduction

Auditory brainstem responses (ABR, [1,2]) belong to the class of auditory evoked potentials (AEPs). ABRs are changes in electric potential recorded on the scalp due to auditory stimuli. They reflect synchronous activity of groups of neurons in the VIIIth nerve and subsequent segments of the auditory pathway. The ABR waveform is made up of five major component waves with characteristic amplitudes and latencies. The exact values of these parameters depend on stimulus characteristics and on a number of physiological processes along the auditory pathway. The wave with the most clinical significance is wave V, which reflects synchronous activity of groups of neurons in the lateral lemniscus and inferior colliculus.

ABRs are commonly used as a standard objective threshold estimation method [3]. Although ABR tests are based on objective measures, they still suffer from a subjective element in their interpretation since the operator has to decide whether a response is present through visual examination of recorded waveforms. As the accuracy of this decision relies on skill, this subjective factor can cause inconsistency in interpretation [4]. The probability of error increases as disturbing factors increase [5]; possible contributory factors here are the brain's spontaneous electrical activity (electroencephalogram—EEG) or artifacts related to muscle electrical activity (electromyogram—EMG). Amplitudes of ABRs are measured in tenths of a microvolt and are small compared to the background from ongoing EEG and EMG. Because ABRs are tightly associated with the auditory stimulus, unwanted EEG and EMG activities can be decreased by averaging multiple responses and rejecting any high amplitude responses that contain artifacts [6].

Another important class of unwanted signals that contaminate AEP recordings are sonomotor responses. These include the jaw reflex [7], the inion potential [8], and vestibular evoked myogenic potentials. Another serious contaminant, especially when using high-intensity stimuli, is the postauricular muscle response [9]. It takes the form of a sonomotor wave (SMW) occurring at a latency near 12 ms, and often has a higher amplitude than the ABR. The possible occurrence of a high-amplitude SMW with a latency near that of wave V increases the risk, especially among inexperienced clinical operators, of misidentifying wave V. Our research was aimed at developing a system capable of automatically removing SMWs from ABR recordings, thereby reducing such a risk. Extraction of the SMW component from ABR traces is also relevant in situations, increasingly common, where automatic response detection systems are used [10–14].

As the SMW is a stimulus-related response, its contribution to the ABR cannot be decreased by means of artifact rejection or averaging of multiple records. Our research sought a way of extracting the sonomotor component without distorting the ABR response. We have found an automatic SMW detection and removal technique based on novel signal processing methods.

2. Materials and methods

2.1. Simulated data

To evaluate system performance and optimize parameters, we first worked on simulated data. The advantage of this approach is

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that large numbers of simulated data, with precisely defined characteristics, can easily be generated. Simulated data were obtained by adding models of SMWs and spontaneous electrical activity of the brain to ABR response templates. Fig. 1 shows the process of generating simulated data and an example of a simulated ABR waveform.

Response templates were obtained by averaging a range of selected ABR traces that had typical morphology and wave latencies. All the data were collected in a group of patients with normal hearing who had pure tone audiometry thresholds below 20 dB HL. Each trace was already the average of a number of single sweeps. The number of waveforms used for template averaging are given in Table 1. Fig. 2 presents response templates obtained for stimulus intensities of 10–80 dB nHL, used in this research.

SMWs from the postauricular muscle reflex were described by Picton et al. [15] as highly variable from subject to subject and even within subjects. Patuzzi and O'Beirne [16] showed high variability in postauricular muscle responses caused by uncontrolled eye movements. In the present research, SMWs were simulated by means of a Gabor function (Eq. (1)) with its sinusoidal component limited to one cycle. The SMW model was characterized in terms of: amplitude (A), latency (u), frequency (f), time span (s), and phase (ϕ). Amplitude was a random variable with values taken from a uniform distribution with boundaries at [0 $A_{\max}$]; latency and time span were taken from a normal distribution centered at u_0 and s_0. Value ranges and central values for these parameters were taken from clinical ABR data. The Gabor function is then:

$$g(t) = A \times e^{-\pi((t-u)/s)^2} \sin(2\pi f(t-u)+\phi). \quad (1)$$

In order to evaluate the contribution of SMW to the simulated ABR waveform, a decibel signal-to-wave ratio (SWR) was defined as in Eq. (2).

$$SWR = 10 \times \log_{10}\left(\frac{E_{sig}}{E_{smw}}\right), \quad (2)$$

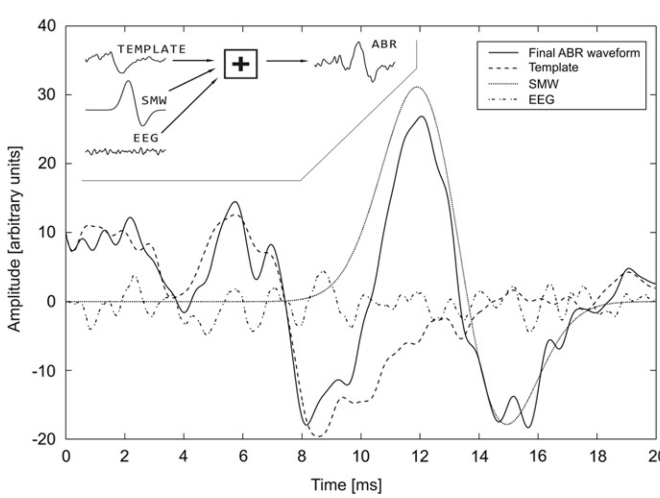

Fig. 1. Inset: Generation of simulated ABR data by adding waveforms from EEG and SMW models to a response template. Main figure: example of a simulated ABR waveform (solid line), built up from the components marked.

Table 1
Number of averaged ABR traces used to obtain response templates.

Stimulus intensity [dB nHL]	80	70	60	50	40	30	20	10
Number of averaged ABR traces	6	9	19	73	104	132	144	148

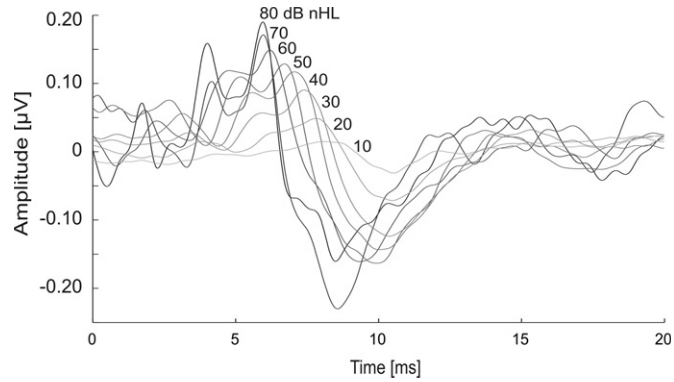

Fig. 2. ABR response templates obtained by averaging a range of ABR traces.

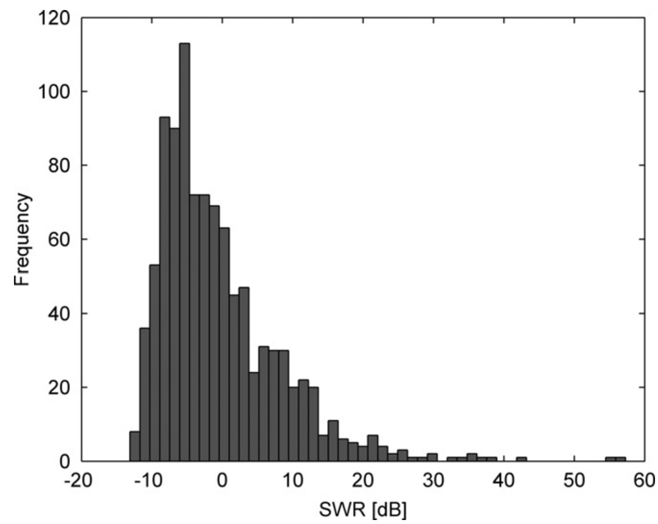

Fig. 3. Histogram of signal-to-wave ratio for 1000 simulated traces.

where: E_{sig} is the ABR response template energy, E_{smw} is the SMW model energy.

The distribution of SWRs in 1000 simulated traces used for parameter optimization and evaluation of system performance is presented in Fig. 3.

Spontaneous electrical activity of the brain (EEG) was simulated by means of the autoregressive model of Yu et al. [17,18] and is specified in Eq. (3). Over the time-scale of an ABR ($\sim$10 ms), the EEG can be considered to be noise. Its contribution to ABR recordings depends on many factors like averaging rate or degree of patient relaxation and has a large variability. The ratio of EEG signal power to response template power was a random variable which formed a uniform distribution with boundaries found from clinical data. The EEG signal is then:

$$EEG[t] = 1.508 \times EEG[t-1] - 0.1587 \times EEG[t-2] - 0.3109 \times EEG[t-3] - 0.051 \times EEG[t-4] + W[t] \quad (3)$$

where: W—white noise satisfying a Gaussian distribution.

2.2. Clinical data

The ABRs were measured using the EPTEST system version 1.5 (software ver. 2.1), manufactured by the PEM company (Warsaw, Poland) in a group of patients with normal hearing. The EPTEST system consisted of the external stimulus generation and response recording unit controlled by the PC computer. As stimulus, a