Auditory Brainstem Response,
IPAN99 algorithm

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DETECTION OF WAVES OF AUDITORY BRAINSTEM RESPONSES USING IPAN99 ALGORITHM

The new method of automatic determination the I, III and V waves of Auditory Brainstem Responses is presented in the paper. The brainstem response arises as a result of acoustic stimulation of auditory system. The main aim of the presented study is to analyse an effectiveness of using IPAN99 algorithm for automatic wave I, III and V determination. The presented results of research show that the IPAN99 algorithm combined with time domain constraints can be useful for this application.

1. INTRODUCTION

The Evoked Auditory Brainstem Response (ABR) is an objective method for assessment of auditory functions from peripheral auditory system to the lower brainstem. The method of ABR analysis involves registration of electrical brainstem activity evoked with the acoustic stimulus. The brainstem response reflects stages of an auditory system [8],[11],[10].

The ABR registration is carried out using surface electrodes placed on patient's head. Positions of electrodes are showed in the Fig. 1.

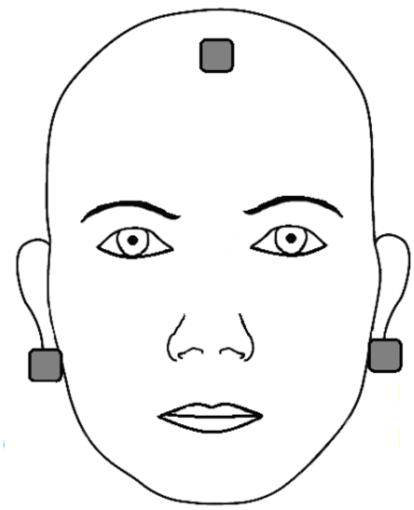

Fig. 1. Location of electrodes.

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Electrodes are placed as following: an active electrode is put on the top of the a patient's head, a reference electrode - on a mastoid bone or ear lobe and finally a ground electrode - on a mastoid bone or ear lobe of the opposite ear.

Registered ABR signals are averaged in order to distinguish stimulated brainstem responses from adventitious ones. The auditory brain stem response is formed in 10 ms from the stimulus. According to Burkard et al. [3] the averaged ABR signal consists of seven recognizable waveforms (also known as waveform peaks, wave, wave peaks) usually marked with Roman numerals I-VII (or with P1, P2,...,P7).

Waveform peaks I to V are identified as analysed clinically. The auditory system structures generating the auditory brainstem response are as follows: a wave I is generated by the peripheral portion of cranial nerve VIII, a wave II - by the central portion of cranial nerve VIII, a wave III - by the cochlear nucleus, a wave IV - by the superior olivary complex/lateral lemniscus, a wave V - by the lateral lemniscus/inferior colliculus [8].

Each wave appears after a specified time (latency) from the stimulus of auditory system. The assessment of a response is based on two criteria. The first one is the presence of each wave in the brainstem response signal. The second one is the latency of wave I, III and V, the time interval between peaks (interwave latencies) of waves I and III, III and V, I and V as shown in the Fig. 2.

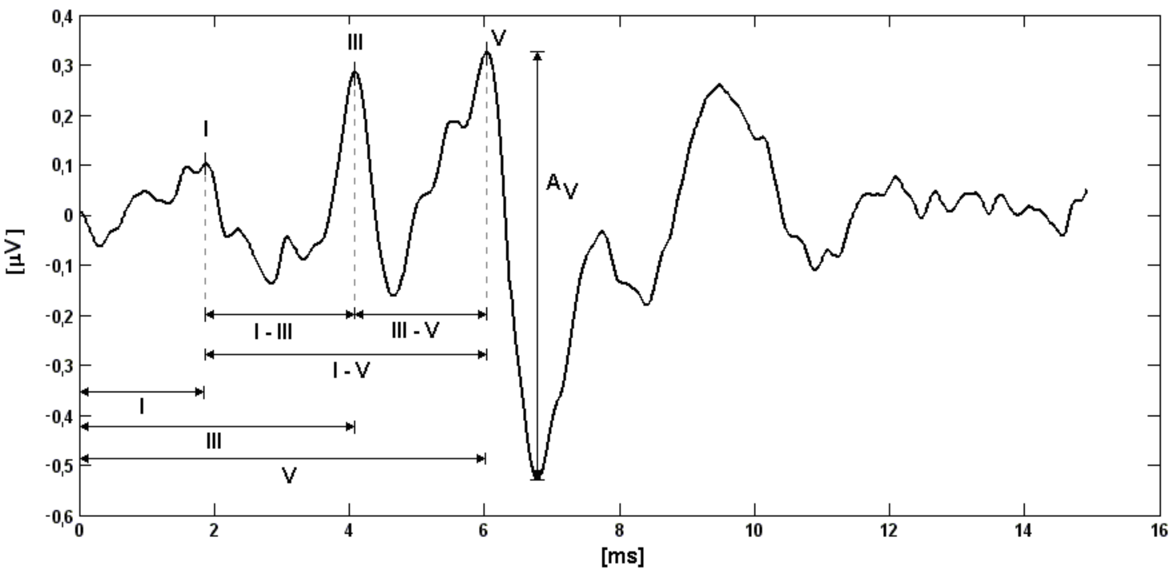

Fig. 2. ABR signal with marked main waves (I, III, and V) and wave latencies (I, III, V, I-III, III-V, I-V) and wave V amplitude (AV).

According to Hall [8] and Kochanek [10] latencies of waves and intervals between them depends on a patient's age, sex and body temperature.

The main use of the evoked auditory brainstem response analysis is a determination of sensibility of hearing organs, a diagnosis of hearing loss including retrocochlear hearing loss.

2. AUTOMATIC DETERMINATION OF ABR WAVES

So far, many different approaches have been proposed for finding waves I-V in the ABR signal. Primarily, signal processing methods are used (including FFT analysis) [1]. Moreover a determination of extrema of a signal with the first derivative as well as a wavelet decomposition and neural network analysis [12]. To determine wave V a method using correlation was also used [13].

This study focused on IPAN99 algorithm as an algorithm of finding waves I, III, and V in the ABR signal.

2.1. MEASUREMENT AND DATA PREPARATION

The measurement of auditory evoked potentials was conducted during 20 minutes for each subject by means of EP workstation with silver-silver chloride electrodes to achieve a low contact impedance - below $2k\Omega$. The electrodes were placed as presented in the Fig. 1. The monaural click stimuli (100μs duration) were presented by TDH-39 headphones at 31 clicks/s rate. ABR measurement was conducted using a stimulus intensity range from 80 dB nHL to 40 dB nHL.

The data obtained from the measurement device is a string of 16 bit numbers in two channels. The first channel contains ABR signal the second one contains click stimuli that elicited the response. Each survey consists of 4096 sweeps. Sweeps are averaged (the arithmetic mean of all points of the response) to get the result ABR signal without noise. The best results are obtained while the patient sleeps due to the absence of interference of EEG and EMG origin. Additionally, averaged signal was filtered with high-pass filter (100 Hz) and low-pass filter (1,5 kHz) before waves' determination. The method of waves I, III and V determination must meet two criteria. The first one is to find all extrema of the signal, the second one is qualification of the extremum as a proper wave.

2.1.1. IPAN99 ALGORITHM

In the study, a very fast and efficient algorithm IPAN99 has been applied (published in 1999) [3]. The algorithm IPAN99 defines the corner as a point of a given curve if it is possible to inscribe in that curve a triangle with a given size and angle of the vertical gap. The analysed curve has to be a set of discrete points $P = \{p_1, p_2, ..., p_n\}$.

In the first stage, the algorithm reviews the string of points and selects the candidates for corners. In the second stage, the redundant candidates are eliminated:

$$d^2_{min} \leq |p - p^+|^2 \leq d^2_{max} \quad (1)$$

$$d^2_{min} \leq |p - p^-|^2 \leq d^2_{max} \quad (2)$$

$$\alpha \leq \alpha_{max} \quad (3)$$

where:

- $|p - p^+| = |a| = a$ the distance between points p and p^+,
- $|p - p^-| = |b| = b$ the distance between points p and p^-,
- $\alpha \in [-\pi, \pi]$ the triangle angle of vertical crack defined as follows:
- $\alpha = arccos\frac{a^2+b^2-c^2}{2ab}$.

Values d_{min} and d_{max} are entered into the algorithm as its parameters.

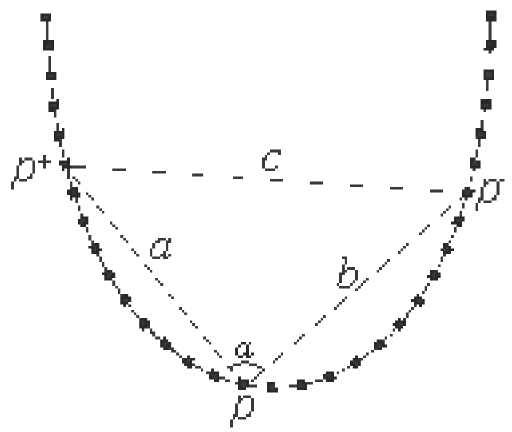

Fig. 3. Detection of points with the highest curvature by means of the IPAN99 [7].

Triangle, which meets the conditions (1), (2) and (3) is so-called an acceptable one. The searching for an acceptable triangle is started from the point p on the outside that is from the shortest length of the triangle sides, and stops if any part of the conditions (1) is fulfilled (therefore the restricted number of neighbouring points is taken into consideration). Among all acceptable triangles, the one with the smallest angle of vertical crack is selected $\alpha(p)$. The point p_i belongs to the neighbourhood of p point, if $|p - p_i|^2 \leq d_{min}^2$.

IPAN99 algorithm parameters:

- d_{min} - the parameter restricting the length of sides from the "bottom". Small values cause that algorithm reacts to small corners,
- d_{max} - the parameter restricting the length of sides from the "top". It is necessary to avoid false acute angles created by distant points of the curve,
- α_{max} - boundary angle specifying the minimal acuteness, which has to have a point in order to classify it as the candidate for the corner.

The candidate p point is rejected if it has a shaper neighbour that is p_i - point, which is also a candidate, and which was assigned a greater strength of the corner: $\alpha(p) > \alpha(p_{i)})$.

The IPAN99 algorithm had been chosen for finding waves due to its well documented efficiency of detection of high curvature of the shape. This feature allows fast finding the main waves in the signal but not all peaks as the first derivative method does.

2.2. ADJUSTING THE IPAN99 ALGORITHM PARAMETERS

The ABR data used for this study were sampled with 50 kHz frequency. The response was registered 15 ms after a click stimuli. Hence, each result ABR signal consisted of 750 points. Due to the constant sampling frequency, it was assumed that the difference between every two neighbouring points of the signal is 1 point.

The algorithm parameters were adjusted as follows: the parameter d_{min} values were changed from 5 to 100 points with step 5 points, the next parameter d_{max} values were iterated from 10 to 100 points with step 5 points and finally the α_{max} values varied from very acute angle of 10 degrees to almost straight angle of 170 degrees with step 5 degrees. $d_{min} = \{5, 10, ..., 100\}, d_{max} = \{10, 15, ..., 100\}$, $\alpha_{max} = \{10, 15, ..., 170\}$.

The biggest distance between two peaks of a signal does not exceed 100 points in all analysed ABR signals therefore the maximum values of the d_{min} and d_{max} parameters were established to 100 points. The maximum value of the α_{max} angle was established experimentally as well. It must be emphasized that values of the d_{min} and d_{max} parameters highly depend on device frequency used for measurement. The frequency directly affects the number of points of a sweep.

The best results were obtained for following values of IPAN99 algorithm parameters: $d_{min} = 5$, $d_{max} = 100$, $\alpha_{max} = 100$. Finally, we obtained a set of k extremum points $M = (t_i, m_i)$ where $i = 1, 2, ..., k$.

2.3. DETERMINATION OF WAVES

The second stage of the research is the qualification the extremum (local maximum) as a proper wave. It must be emphasized that the latency of each wave and even the presence of the wave depends on many factors i.e. a stimulus sound intensity or age as authors present in [8],[4],[9]. According to Hall [8], Don and Eggermont [6] each of the waves occurs in a specified time of the brainstem response depending on the intensity of stimuli. The table below shows the latencies for wave V.

A standard deviation of wave V appearance is from 4% to 7% (relatively to the stimuli intensity). Waves III and I were searched in the same way but in proper range of their latencies [4],[6].

Determination of subsequent waves I, III, V is finding the maximum peak within a specified time

Table 1. Values of ABR parameters according to Don and Eggermont [6].

dB nHL	Latency (average value)
90	6.00
80	6.00
70	6.15
60	6.45
50	6.85
40	7.20
30	7.70
20	8.25
10	8.70

interval (presented with formula 4). Hence the determination of peak latency is crucial for diagnosis.

$$\exists_{t_i} : t_i \in T_n \cap max(m_i) \quad (4)$$

where: $n = I, III, V$, $T_I = [t_{I_{min}}; t_{I_{max}}]$, $T_{III} = [t_{III_{min}}; t_{III_{max}}]$, $T_V = [t_{V_{min}}; t_{V_{max}}]$.

Additionally, after wave determination the amplitude of the wave V was calculated according to the formula below:

$$A_V = m_i - m_{i+1} : m_i = max(M)|_{t_i \in T_V} \quad (5)$$

The IPAN99 algorithm was used to find all minima and maxima between 1 and 10 milliseconds of the response as presented in the Fig. 4.

The measurement parameters were: 80 dB nHL, rating 31 clicks/s, left ear, the patient was 14 years old.

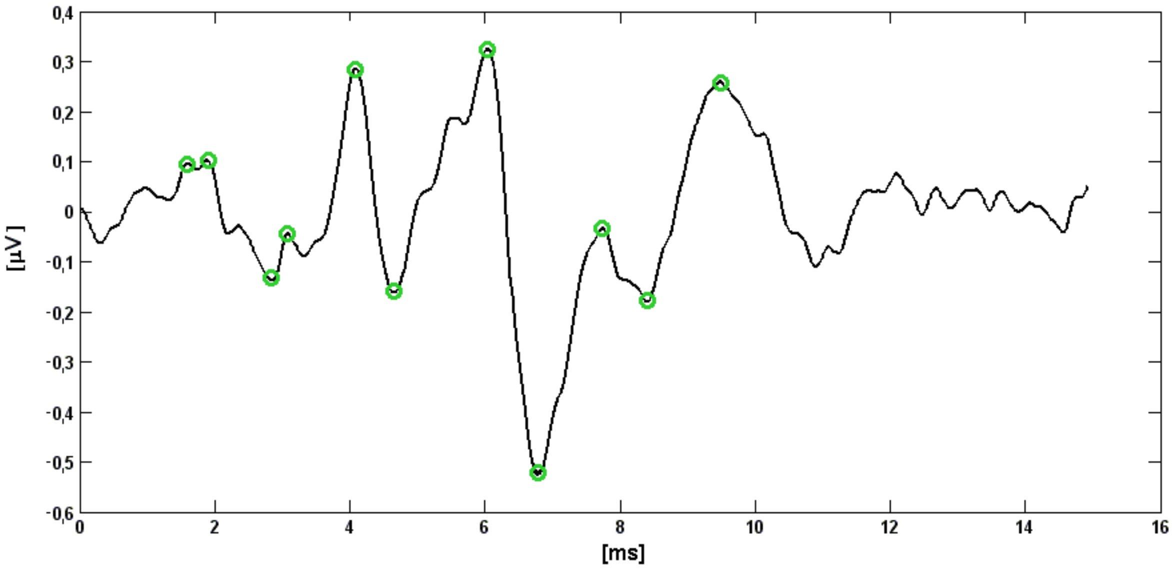

Fig. 4. All maxima and minima found by IPAN99 algorithm.

The sample result of finding waves I, III, V in the ABR signal is presented in the Fig. 5. Consequently, the intervals between waves I-III, III-V and I-V were computed as shown in the Fig. 2. The results are shown in the table below.

The relative error of waves' detection in the analysed set of data is shown in the Table 3. 96 responses were analysed.

In comparison to the expert's waves identification almost in all cases of automatic detection of waves was the same (excluding those which lie out of range of searching).

In comparison to other studies and involved methods [1],[12],[13] the relative error of primary waves detection (I, III, V) is comparable - it varies from 1% to 5 %.

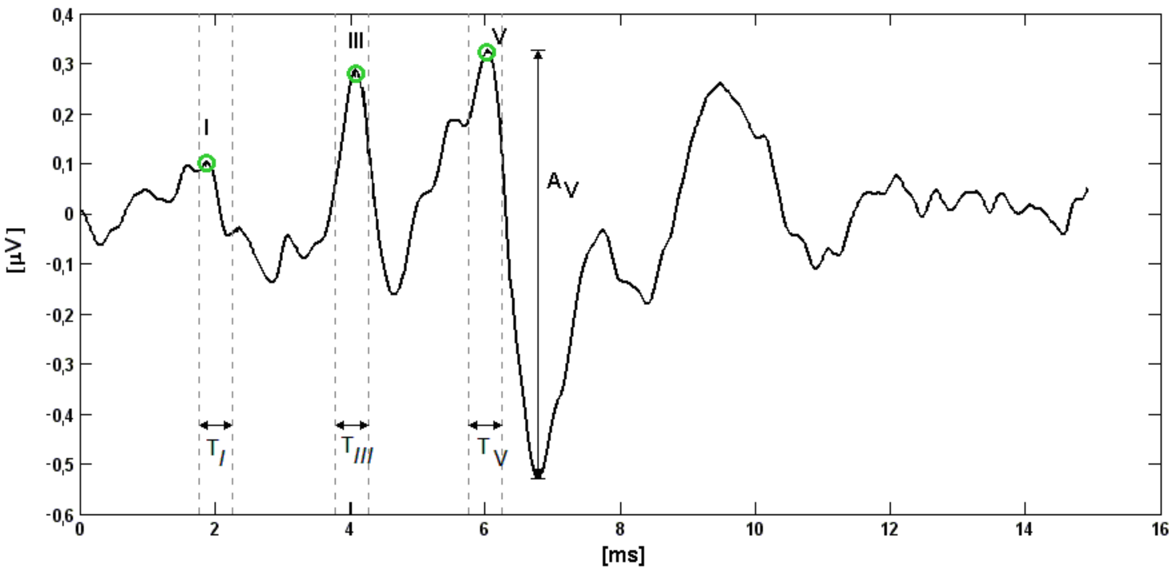

Fig. 5. Determination of I, III and V waves.

Table 2. Results of ABR parameters determination.

ABR parameter	**Result**
Wave I latency	1,90 ms
Wave III latency	4,08 ms
Wave V latency	6,04 ms
I-III interwave latency	2,18 ms
III-V interwave latency	1,96 ms
I-V interwave latency	4,14 ms
Wave V amplitude	0,82 μ V

Table 3. Relative errors.

dB nHL	**wave I**	**wave III**	**wave V**
	[%]	[%]	[%]
80	1,04	1,04	1,04
70	1,04	1,04	1,04
60	1,04	1,04	1,04
50	1,04	1,04	1,04
40	4,17	2,08	1,04

3. SUMMARY

All data was collected from healthy people aged from 14 to 50 years. 96 auditory brainstem responses were analysed.

The results of the research show that IPAN99 algorithm with established parameters and taking into account clinical determined time domain constraints on waves' searching is useful for finding waves I, III and V in the auditory brainstem response signal. Consequently, another important ABR parameters are automatic calculated.

In this study we assumed that each wave (I, III, V) had been searched in a specific range of time as described in point 2.3. Extending this range into two times of standard deviation caused that all waves had been found.

Computation time of peaks determination was about 40 ms in MATLAB software. Hence the algorithm is very fast and could be potentially implemented into a measurement software for automatic detection of specified waves.

Concluding, we put emphasis on fact that latencies of waves depend on many factors from the age to stimulus and measurement parameters (stimulus duration, frequency of sampling) therefore before implementing the method it should be calibrated for a specific device and measurement parameters.

The next step of the research is to extend the method to determination of all waves of ABR data from healthy subjects in a wider range of a stimulus intensity.

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