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Automatic quality assessment and peak identification of auditory brainstem responses with fitted parametric peaks

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ABSTRACT

The recording of the auditory brainstem response (ABR) is used worldwide for hearing screening purposes. In this process, a precise estimation of the most relevant components is essential for an accurate interpretation of these signals. This evaluation is usually carried out subjectively by an audiologist. However, the use of automatic methods for this purpose is being encouraged nowadays in order to reduce human evaluation biases and ensure uniformity among test conditions, patients, and screening personnel. This article describes a new method that performs automatic quality assessment and identification of the peaks, the fitted parametric peaks (*FPP*). This method is based on the use of synthesized peaks that are adjusted to the ABR response. The *FPP* is validated, on one hand, by an analysis of amplitudes and latencies measured manually by an audiologist and automatically by the *FPP* method in ABR signals recorded at different stimulation rates; and on the other hand, contrasting the performance of the *FPP* method with the automatic evaluation techniques based on the correlation coefficient, F_{SP}, and cross correlation with a predefined template waveform by comparing the automatic evaluations of the quality of these methods with subjective evaluations provided by five experienced evaluators on a set of ABR signals of different quality. The results of this study suggest (a) that the *FPP* method can be used to provide an accurate parameterization of the peaks in terms of amplitude, latency, and width, and (b) that the *FPP* remains as the method that best approaches the averaged subjective quality evaluation, as well as provides the best results in terms of sensitivity and specificity in ABR signals validation. The significance of these findings and the clinical value of the *FPP* method are highlighted on this paper.

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1. Introduction

The auditory brainstem response (ABR) is the electrical activity of the auditory nerve generated in the brainstem associated with a stimulus [1]. The recording of the ABR has been extensively used in human and animal studies for both clinical and research purposes due to its noninvasive nature. The recording of this signal is commonly used in hospitals and clinics worldwide as a hearing screening tool, to detect the hearing threshold and to detect peripheral and central lesions. Furthermore, the analysis of the ABR may help understand the underlying mechanisms of the process of hearing [2–8]. The ABR comprises a number of waves that occur during the first 10 ms from stimulus onset [9]. These waves are indicated by sequential Roman numerals as originally proposed by Jewett and Williston [10]. Although up to seven peaks can be identified in the ABR, the most robust are III and V.

The quality of the responses is related to the probability that a response is present, which is usually associated with the amount of noise of the recording [11,12]. The use of automatic methods for quality assessment and response detection of ABR signals may help improve the process of automatically stopping averaging, avoiding the recording of unnecessary sweeps when there already exists an ABR of sufficient quality and consequently, making a more efficient use of the recording time [13–15]. Furthermore, the automated identification of the peaks, i.e., amplitudes and latencies, is also a useful tool to provide an automatic interpretation of the ABR [16]. Additionally, automated methods eliminate the need for subjective interpretations of ABR, reduce human biases, and improve uniformity among test conditions, patients, and screening assistants [17–22]. These advantages promote the use of automated response detection in audiology screening in order to help the operator interpretation and decision making [23].

A number of methods have been proposed in automatic evaluation of ABR [11]. Some of them include the Raleigh test, Watson's *U*2 test, Kuiper's test, Hodges–Ajne's test, Cochran's Q-test, and Friedman test [24,25]; automatic computer-assisted recognition of the pattern for ABR latency/intensity functions [26]; MASTER, a Windows-based data acquisition system designed to assess human hearing by recording auditory steady-state responses [27]; zero crossing method [28]; adaptive signal enhancement [29]; multifilters and attributed automaton [30]; single-trial covariance analysis [31]; and automatic analysis methods for peak identification based on a database of ABR signals from a large (>80) number of normal hearing subjects [32,33]. Despite the large number of automatic evaluation techniques, few of them have been implemented in commercial devices [34]. The most common reported strategies of automated ABR analysis are the correlation coefficient and the *F* distribution based estimation of the signal to noise ratio (SNR) using a single point of the response (F_{SP}). The correlation coefficient procedure relies on the reproducibility of two consecutive ABR signals obtained in similar conditions to determine the presence or absence of the ABR [35]. F_{SP} provides an estimation of the response SNR evaluated from the distribution of amplitudes of a single point of the response for different sweeps. The power of noise is evaluated by matching the single point distribution of amplitudes with an *F* distribution, while the power of the signal is estimated from the averaged response [36].

This article describes a new method that performs an automatic evaluation of the quality of ABR signals and identification of the peaks based on the use of templates. We have called this method fitted parametric peaks (*FPP*). The *FPP* method can be useful (a) to automatically parameterize the most relevant waves of ABR signals in terms of amplitude, latency, and width, and (b) to provide an automatic estimation of the quality of ABR signals based on the individual assessment of the quality of each wave. Preliminary results of this work were presented in [37].

The rest of the paper is organized as follows. Section 2 describes in detail the fitted parametric peaks (*FPP*) method. In Section 3, the performance of the described method is assessed by two experiments. Experiment 1 compares the automatic parameterization of the peaks provided by the *FPP* method with a manual procedure performed by an audiologist in a number of ABR signals obtained at different stimulation rates. Experiment 2 compares the automatic quality assessment of the *FPP* method with the automatic quality evaluation techniques based on the correlation coefficient, F_{SP}, and cross correlation with a predefined template in terms of the grade of similarity to a subjective evaluation provided by a number of experts on ABR signals of different quality. Additionally, this experiment includes a comparative study of response validation in terms of sensitivity and specificity. Section 4 presents a summary and a discussion of the results. Finally, Section 5 highlights the significance and the main contributions of this article.

2. Description of the method

The most usual approach for assessing the quality of ABR signals is based in subjective evaluations provided by audiologists. However, it is well known that subjective evaluations may differ from one evaluator to another [33,38,39]. This bias represents a problem that could be solved using automatic quality evaluation techniques [17–23]. This section describes the fitted parametric peaks (*FPP*) method, a new technique that provides an automatic evaluation of the quality of ABR signals and parameterization of the peaks in terms of amplitude (*A*), latency (*L*), and width (*W*).

2.1. Fitted parametric peaks

The approach of this method is based on the use of templates that fit the peaks of the ABR. The use of templates for this purpose was first proposed in [40], in which the ABR used for test is cross correlated with a template used as reference. The major disadvantage of this technique is that it requires the compilation of a database of templates corresponding to each stimulation settings (e.g., level, rate, polarity, etc.). In contrast, the *FPP* does not require the use of a database since it uses as template a parametric function. The motivation of the *FPP* quality assessment procedure relies on the subjective criterion usually applied by audiologists for the evaluation of ABR. The most persistent peaks are usually waves III and V,