Journal of Neuroscience Methods 239 (2015) 214–222

Contents lists available at ScienceDirect

Journal of Neuroscience Methods

journal homepage: www.elsevier.com/locate/jneumeth

Clinical Neuroscience

Accuracy of measurement in electrically evoked compound action potentials

Matthias Hey*, Joachim Müller-Deile

Department of Otorhinolaryngology, Christian-Albrechts-University of Kiel, Germany

HIGHLIGHTS

- Single point error was used to evaluate N1P1 error in ECAP measurements using raw data.
- Errors of N1P1 amplitudes depend on the number of averagings and gain of the CI amplifier.
- Errors of the N1P1 amplitudes do not depend on stimulation level.
- Retrospective approximation of measurement error from the averaged data is possible.
- Error approximation method D-trace can evaluate error level for each ECAP curve.

ARTICLE INFO

Article history:
Received 19 August 2014
Received in revised form 13 October 2014
Accepted 14 October 2014
Available online 25 October 2014

Keywords:
Cochlear implant
ECAP
NRT
Error

ABSTRACT

Background: Electrically evoked compound action potentials (ECAP) in cochlear implant (CI) patients are characterized by the amplitude of the N1P1 complex. The measurement of evoked potentials yields a combination of the measured signal with various noise components but for ECAP procedures performed in the clinical routine, only the averaged curve is accessible. To date no detailed analysis of error dimension has been published. The aim of this study was to determine the error of the N1P1 amplitude and to determine the factors that impact the outcome.
New methods: Measurements were performed on 32 CI patients with either CI24RE (CA) or CI512 implants using the Software Custom Sound EP (Cochlear). N1P1 error approximation of non-averaged raw data consisting of recorded single-sweeps was compared to methods of error approximation based on mean curves.
Results: The error approximation of the N1P1 amplitude using averaged data showed comparable results to single-point error estimation. The error of the N1P1 amplitude depends on the number of averaging steps and amplification; in contrast, the error of the N1P1 amplitude is not dependent on the stimulus intensity.
Comparison with existing method(s): Single-point error showed smaller N1P1 error and better coincidence with $1/\sqrt{(N)}$ function (N is the number of measured sweeps) compared to the known maximum–minimum criterion.
Conclusion: Evaluation of N1P1 amplitude should be accompanied by indication of its error. The retrospective approximation of this measurement error from the averaged data available in clinically used software is possible and best done utilizing the D-trace in forward masking artefact reduction mode (no stimulation applied and recording contains only the switch-on-artefact).

1. Introduction

The measurement of electrically evoked brainstem potentials of the auditory system (EABR) (Shallop et al., 1991; Kasper et al., 1992) and electrically evoked compound action potentials (ECAP) (Gantz et al., 1994; Dillier et al., 2002; Cafarelli Dees et al., 2005) have been introduced as valuable audiological tools in the treatment of cochlear implant (CI) patients.

* Corresponding author at: Klinik für Hals-, Nasen-, Ohrenheilkunde, Kopf- und Halschirurgie, Audiologisches Labor, Arnold-Heller-Straße 14, D-24105 Kiel, Germany. Tel.: +49 431 597 2325; fax: +49 431 597 5707.
E-mail addresses: hey@audio.uni-kiel.de (M. Hey), jmd@audio.uni-kiel.de (J. Müller-Deile).

http://dx.doi.org/10.1016/j.jneumeth.2014.10.012
0165-0270/

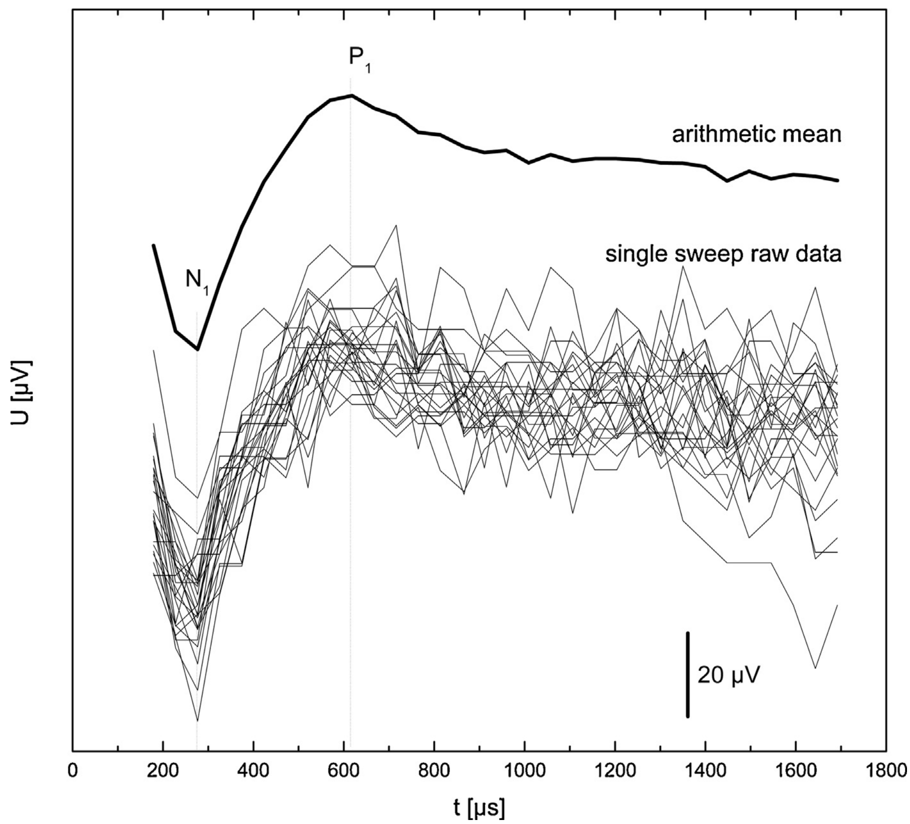

Fig. 1. Single-sweep recordings of an ECAP measurement (N = 50 sweeps) and their arithmetic mean (thick line plotted with a positive offset for better readability). N1 and P1 are the local minimum and maximum for further evaluation of the difference amplitude N1P1.

The measurement methods can successfully be used during surgery to evaluate the integrity of the cochlear implant system, as well as to record parameters of the electrode–nerve interface and provide information on the position of the electrode array. During the post-surgical care, they are extremely helpful in monitoring changes in the auditory system, and the results of these recordings can be used to assist the individual programming of the speech processors not only in young and very young children but also in adults (Brown et al., 1994; Kileny, 1991; Shallop, 1997; Smoorenburg et al., 2002; Müller-Deile and Hey, 2013).

The telemetric recording of the ECAP is supported by most of the existing cochlear implant systems allowing for the stimulation of the auditory nerve and the measurement of its reaction with the same equipment that is clinically used to program the speech processors.

Evoked potentials are extracellular recorded electrical signals of neural activity that occur after adequate or inadequate stimulation of excitable structures. The recording can be obtained in the immediate vicinity of the electrical potential generators as in ECAP or at a greater distance from the scalp as in EABR. It is assumed that the measured bioactivity consists of a stimulus-synchronous signal, the evoked potential, and a stochastic noise component. Under this premise, the averaging of N sweeps causes a reduction of the noise component by a factor $1/\sqrt{N}$. This statement for the averaging process can be made on the basis of some simplistic conceptual assumptions (Rompelmann and Ross, 1986):

- the evoked potential has decayed before the next stimulus occurs;
- the evoked potential is time-invariant; each stimulus triggers identical evoked potentials;
- the noise component is stationary; it does not correlate with the stimulus and the evoked potential; and
- the noise component is normally distributed with an expected mean value of zero; the autocorrelation function is zero following the period of the evoked potential.

However these assumptions are only approximately fulfilled in general practice.

Evoked potentials are described quantitatively by the parameters of latency and amplitude. Measurements of physical quantities, however, are always subject to error, either through imperfections in the measuring apparatus or by external processes influencing the measurement. In the recording of ECAP, the measured signal is combined with noise components (Fig. 1). Systematic errors are caused by stimulus correlated signals (e.g., the stimulation artefact or myogenic-triggered artefacts) and by stochastic signals. The latter may be triggered by various processes occurring randomly (e.g., by spontaneous EEG or motion artefacts). Thus, each result of an evoked potential is to be regarded as an approximation only in the context of the problems encountered in the measurement process. For quality estimation of the amplitudes recorded, an error range must be specified.

The acoustically and electrically evoked potentials are quantified with respect to the parameters of latency and amplitude for the individual waves. The measurement of the evoked potentials and the determination of the latencies of individual waves comprise three steps (Graffunder, 1996):

- *Local extrema must be detected*: the recognition of the potential can be complicated by the presence of residual noise – existing