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Electrically evoked compound action potentials artefact rejection by independent component analysis: Procedure automation

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HIGHLIGHTS

- Electrically-evoked compound action potentials can be extracted from artefact using independent component analysis: this paper shows how to automate it.
- Raw-ECAP recordings are projected in 4 sources that can be classified as: sharp artefact, slow artefact, recording noise and ECAP.
- Each source is detected sequentially and cancelled and this results in the ECAP signal.

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ABSTRACT

Background: Independent-components-analysis (ICA) successfully separated electrically-evoked compound action potentials (ECAPs) from the stimulation artefact and noise (ECAP-ICA, Akhoun et al., 2013).
New method: This paper shows how to automate the ECAP-ICA artefact cancellation process. Raw-ECAPs without artefact rejection were consecutively recorded for each stimulation condition from at least 8 intra-cochlear electrodes. Firstly, amplifier-saturated recordings were discarded, and the data from different stimulus conditions (different current-levels) were concatenated temporally. The key aspect of the automation procedure was the sequential deductive source categorisation after ICA was applied with a restriction to 4 sources. The stereotypical aspect of the 4 sources enables their automatic classification as two artefact components, a noise and the sought ECAP based on theoretical and empirical considerations.
Results: The automatic procedure was tested using 8 cochlear implant (CI) users and one to four stimulus electrodes. The artefact and noise sources were successively identified and discarded, leaving the ECAP as the remaining source. The automated ECAP-ICA procedure successfully extracted the correct ECAPs compared to standard clinical forward masking paradigm in 22 out of 26 cases.
Comparison with existing method(s): ECAP-ICA does not require extracting the ECAP from a combination of distinct buffers as it is the case with regular methods. It is an alternative that does not have the possible bias of traditional artefact rejections such as alternate-polarity or forward-masking paradigms.
Conclusions: The ECAP-ICA procedure bears clinical relevance, for example as the artefact rejection submodule of automated ECAP-threshold detection techniques, which are common features of CI clinical fitting software.

Abbreviations: AN, auditory nerve; CI, cochlear implant; ECAP, electrically-evoked compound action potential; ECAP-FM, ECAP obtained with the forward-masking technique; ECAP-ICA, ECAP obtained with the ICA artefact rejection technique; IC, independent component (or source); ICA, independent component analysis; JADE-R, Joint approximate diagonalisation of the cross-cumulants eigenmatrices (Computational implementation of ICA); Raw-ECAP, measurement of ECAP to one pulse that contains the ECAP and the artefact with some additional recording noise; RMS, root mean square; SNR, signal to noise ratio.

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1. Introduction

1.1. Clinical implication of ECAPs

Electrically-evoked compound action potentials (ECAPs) reflect the compound activity of a portion of auditory nerve (AN) fibres to cochlear implant (CI) electrical stimulation. Cochlear implant electrodes can record ECAPs in situ. This process is commonly referred to as Neural Response Telemetry (NRT™) for Cochlear, Neural Response Imaging (NRI™) for Advanced Bionics and Auditory Nerve Response Telemetry (ART™) for Medel. Intracochlear ECAP do not require scalp electrode application and are immune to the patient's state of awareness or interference from muscular artefact or other noise. Device manufacturers have developed user-friendly telemetry systems that allow ECAP recording in clinical settings by otolaryngologists and audiologists. Reliability and automation are key factors for the success of ECAP clinical implementation (Botros et al., 2007). ECAPs are routinely used in clinics to objectively measure the functionality of auditory nerve activation. ECAP measurement has been widely accepted as an objective tool to predict variation of hearing thresholds across the intracochlear electrode array (Miller et al., 2008 for a review). ECAP measurements need to be accurate and give uncorrupted precise measurements. The artefact rejection step clearly plays a role in ECAP accuracy. It is worth noting that no gold-standard exists as a quantifying reference of AN activity, at least in humans.

1.2. ECAP-ICA artefact rejection

As presented in the ECAP-ICA technique validation study (Akhoun et al., 2013), ICA processing of several raw-ECAPs (combination of ECAPs with artefacts and noise) could isolate ECAP from artefact and noise. Artefact and ECAP could be successfully separated as they behaved independently across a set of intra-cochlear recording sites. This paper presents an automation of the ECAP-ICA procedure.

Fig. 1 schematically represents the steps of the ECAP-ICA procedure. Raw-ECAPs recordings were obtained by stimulating a given electrode and recording on eight adjacent more basal electrodes. For instance when stimulating on electrode 14 (resp. electrode 17 or 22), raw-ECAPs were measured on electrodes 5–12 (resp. 8–15 and 13–20). This was repeated for several current-levels (Table 1). If a signal corrupted by amplifier saturation was detected, all signals recorded on this electrode were not retained for further analysis. Raw-ECAPs obtained for all stimulus current-levels were concatenated for each recording electrode. For instance for S1 on stimulus electrode 14, 5 current-levels were tested (150, 160, 170, 180 and 190 CLs). In that case, the concatenation resulted in a set of eight 8000 μs-long concatenated raw-ECAPS (5 × 1600 μs). Concatenation was found particularly useful if sub-threshold stimulus currents were included because it reinforced the independence between artefact, which decreased linearly with lower stimulus currents and the ECAP, which disappeared below threshold. ICA was applied on the concatenated raw-ECAPs. ICA output was restricted to 4 sources. The 4 sources could be visually classified into four categories: ARTEFACT-SPIKE, ARTEFACT-LOWPASS, NOISE and ECAP. The artefact free ECAP-ICA was reconstructed and unconcatenated based on the ECAP source only. This paper describes an automation method to classify the four sources, replacing the visual classification used in the previous paper, and enabling the whole ECAP-ICA procedure to be automated.

1.3. ECAP-ICA requirements for clinical implementation

To facilitate possible clinical implementations, ICA parameters and analysis procedures were developed so that the process of identifying ECAPs was fully automated, and thus did not include steps that required clinician decision or input. In particular, the steps needing to be automated were the identification of amplifier saturation and the identification of the ICA sources. The ECAP-ICA procedure automation is a first step to separate ECAPs from artefacts, after which the recovered ECAPs can be used with existing automated ECAP-threshold measurement functionalities that are commonly used in clinical CI fitting software.

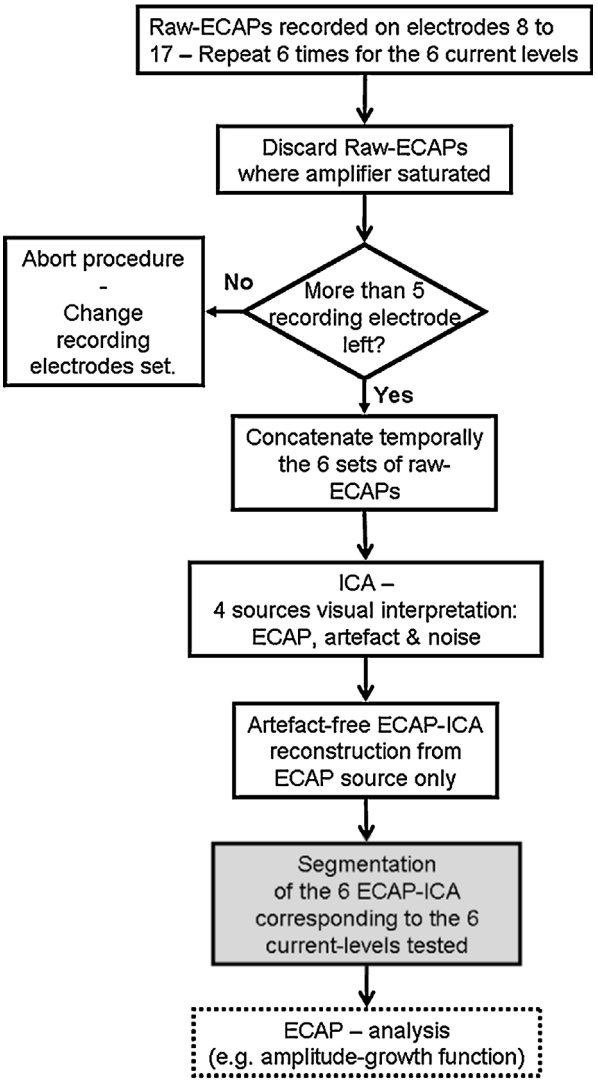

Fig. 1. ECAP-ICA procedure summary flowchart. In this example, six ECAPs were recorded at six different current-levels for a stimulus delivered by electrode 17 and raw-ECAPs were recorded on electrodes 8–15.

2. Materials and methods

2.1. Subjects and experimental setup

The same dataset from the eight adult CI24-RE Nucleus Freedom™ (Cochlear Ltd.®) cochlear implant recipients described in our previous study were considered (Akhoun et al., 2013). Table 1 summarizes the subject details and testing conditions used. The study was approved by the NHS North-West Ethics Committee.