AutoART – A system for automatic determination of eCAP thresholds

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Introduction

In cochlear implant (CI) users, measurement of so-called electrically evoked compound action potentials (eCAP) can provide information about coupling between the peripheral auditory nerve fibers and the CI electrodes. Furthermore, this objective measure allows longitudinal monitoring of the healthiness of the auditory nerve fibers (Strahl et al., 2016) and it can also be used to determine initial stimulation-intensity values that are needed to program the speech processor. Generally eCAP measurements can be affected by noise and artifacts, therefore special methods such as averaging over repeated stimulation parameters are necessary (Hey et al., 2015).

Material and Method

In the clinical software MAESTRO 7 (MED-EL, Innsbruck, Austria) the following new procedures were implemented in the AutoART task to increase the accuracy of the eCAP threshold determination, improve the eCAP recognition rate as well as to allow for an automatic measurement process.

A) Amplitude Growth Function Measurement: fine-grain paradigm

One of the eCAP-based objective measurements in the clinical routine comprises sampling of the amplitude growth function (AGF). It represents changes of the eCAP response amplitude due to changes in the stimulus intensity. To improve the signal to noise ratio, recordings are usually averaged over 15 to 100 repetitions. To minimize the measurement time for the CI user, usually five to ten different stimulation intensities are measured, as illustrated in Figure 1A. In the AutoART task, a new paradigm (FineGrain AGF) was implemented, in which the stimulation intensity is increased in quasi-continuous steps (Figure 1B; Gärtner et al., 2014). Instead of averaging over repeated recordings with the same stimulation intensity, moving averages are computed over a small range of approximately identical stimulation levels. The total number of eCAP recordings remains the same, resulting in identical measurement durations for both paradigms.

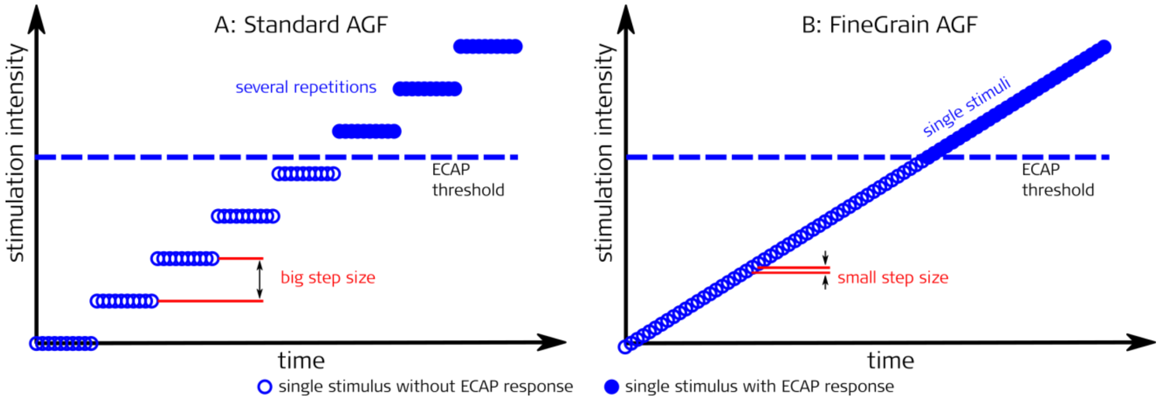

Figure 1: Standard (left pane) and fine-grain (right pane) method of sampling amplitude growth functions.

B) ECAP Amplitude: two-dimensional analysis

For each individual eCAP recording, the eCAP amplitude is determined by calculating the amplitude difference between the first negative and second positive peak (see Figure 3). Traditionally, determination of the peaks is performed separately for each eCAP measurement. This omits any mutual dependencies between eCAP responses within an AGF, i.e. continuous change of the amplitude and latencies of the measured peaks. To utilize such additional information, AutoART determines the peaks of a single eCAP measurement from a two-dimensional surface that is fitted to all eCAP responses of an AGF.

C) ECAP detection: physiological nerve model

Beside the desired nerve response, eCAP recordings can contain also other signals like artifacts, originating e.g. from the interaction between the stimulation pulse and the electrode-tissue interface. To exclude recordings that do not contain any potential nerve responses, AutoART uses an automatic classifier that estimates the firing probability from a given eCAP recording, and evaluates whether that probability lies within human physiological range.

D) Amplitude Growth Function Analysis: sigmoid fit

In the clinical evaluation of an eCAP AGF, its threshold and slope are of primary interest. AutoART automatically determines the eCAP threshold and slope by fitting a sigmoidal function (see Figure 2) to the AGF. The sigmoid function can be understood as a physiological model for the non-linear relation between the stimulation intensity and the number of recruited nerve fibers. The large amount of available fine-grain data points allows for a robust fitting of the parameters of the sigmoid function. The eCAP threshold and slope are derived analytically from the sigmoid formula. It should be noted that AutoART defines the eCAP threshold (ECAP-THR) as the intersection of the linear extrapolation in the inflection point of the sigmoid and the baseline.

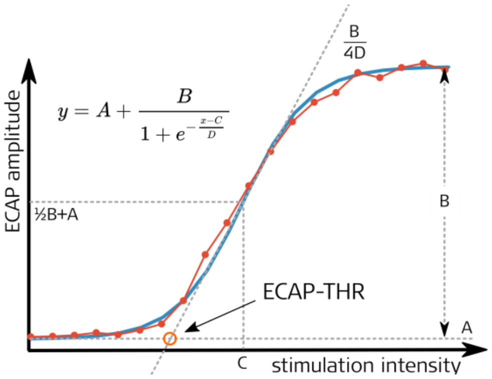

Figure 2: Sigmoid fit of an eCAP amplitude growth function.

E) Multiple Recording Electrodes: redundancy

Artifacts, resulting for example from the interaction between the stimulating pulse and the electrode-tissue interface, can mask the nerve response on a specific stimulation-recording electrode pair. To minimize problems resulting from such artifacts, AutoART uses by default up to two neighboring apical and up to two neighboring basal recording electrodes for each stimulation electrode, and selects automatically the best electrode pair.

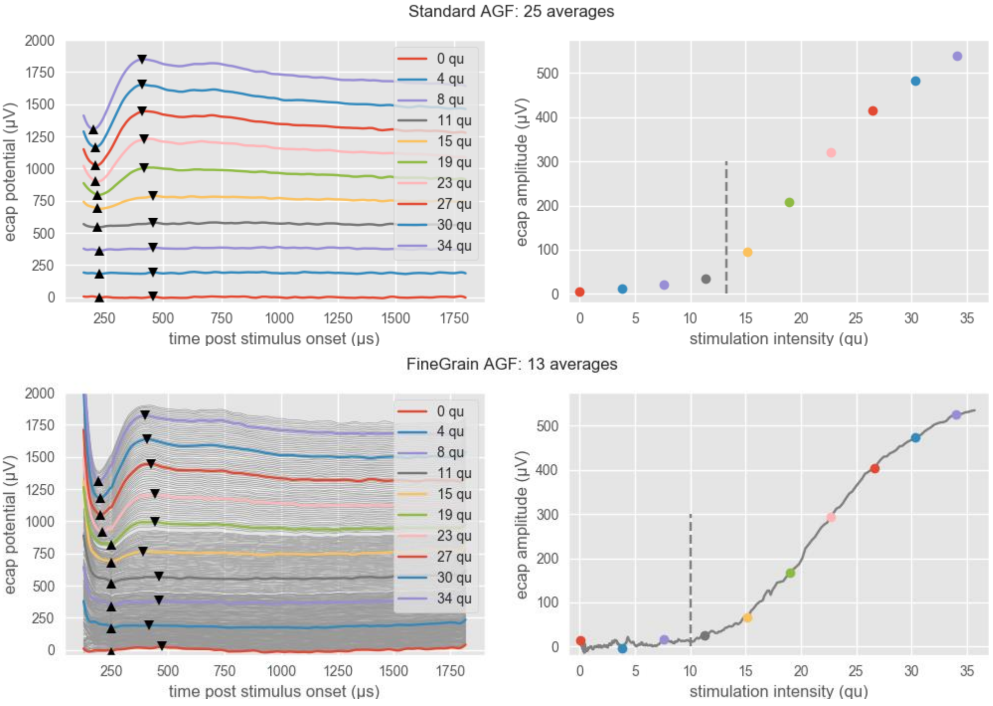

Figure 3: Standard AGF (upper row) and FineGrain AGF (lower row) recorded in the same CI subject within 30 minutes. It should be noted that a large number of recordings are available additionally in fine-grain recording paradigm (grey potentials) in addition to those that are recorded in both paradigms (colored identical). The left side shows waterfall plots of individual eCAP recordings at different stimulations intensities. The first negative peak is marked with an upward black triangle, the second positive peak with a downward black triangle. The right side shows the corresponding eCAP amplitudes (colored dots) in an amplitude growth function.

Results

The benefits provided by the aforementioned new procedures were examined both separately as well as in terms of overall performance of the whole system in comparison with human experts.

The FineGrain AGF enabled to determine the eCAP threshold even at low signal-to-noise ratios (Gärtner et al., 2015). The two-dimensional surface fit resulted in a more robust latency determination than a traditional approach that takes only a single curve into account in the latency determination (Schwarz et al., 2015). The eCAP detection based on human physiological firing latencies achieved a detection rate of 93.3% for eCAP traces (Strahl et al., 2017). Determination of the eCAP threshold based on a sigmoidal fitting of the AGF allowed a robust and precise determination being indistinguishable from evaluations by human experts (Schwarz et al., 2011). The selection of the best recording electrode could increase the success rate to detect an eCAP up to 10% (Gärtner et al., 2017a).

Considering the overall system, the automatically detected eCAP threshold values were compared with judgments done by five experts (see Figure 4). The median Pearson correlation between the expert judgements was r = 0.88 and between AutoART predictions and the experts judgements r = 0.83 (Gärtner et al., 2017b).

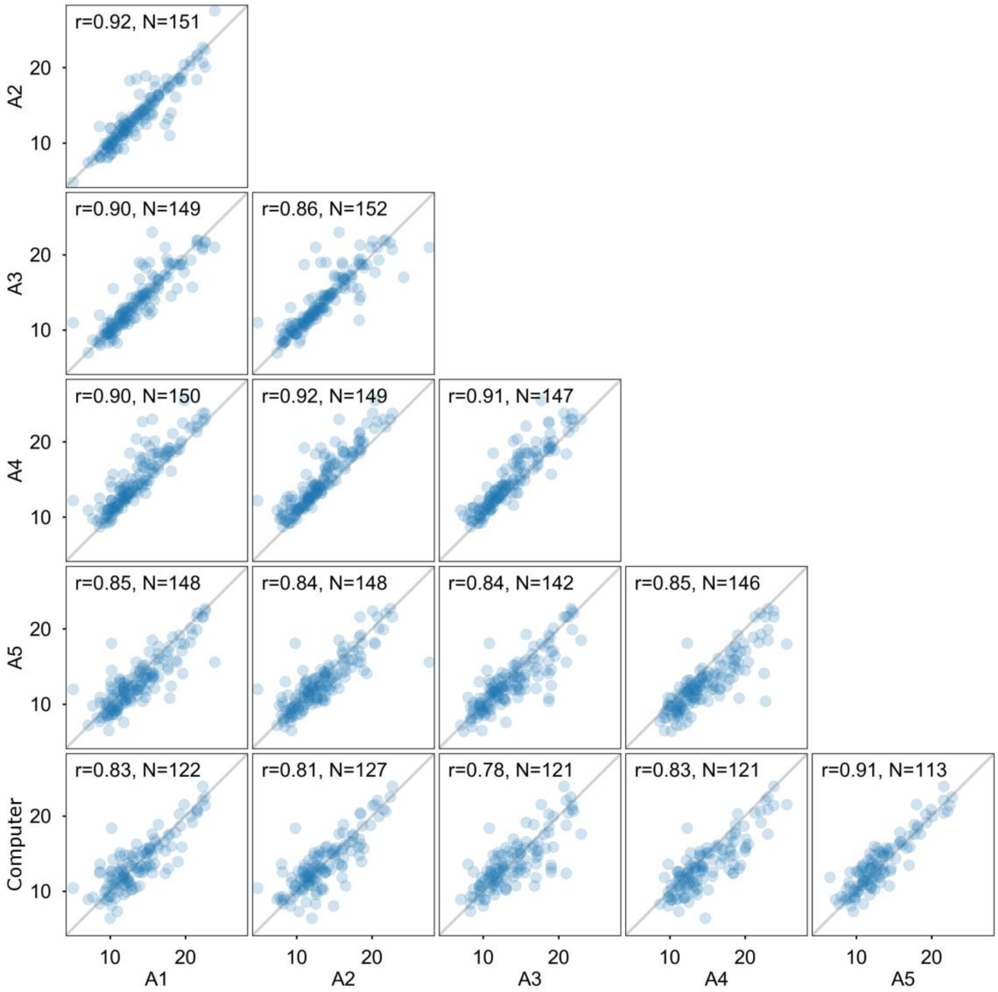

Figure 4: Scatter plots and distributions showing the agreement in eCAP-threshold judgements between the five human experts (A1-A5) and between their judgements and the estimates obtained with the AutoART algorithm (computer). Each point represents an eCAP threshold (charge unit qu). 1 qu equals approximately 1 nC. Only results categorized as "eCAP yes" are included.

Conclusion

Several new processes were designed to facilitate autonomous eCAP-threshold detection. The results demonstrate that the individual processes provide considerable improvements both in accuracy and robustness of the eCAP detection. This makes the predictions from the overall system indistinguishable from judgements of experts.

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