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New objective measurement techniques and their relationship to HiRes™ program settings

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Abstract. To date, no "fail-safe" method exist for using objective measures to optimize programs for cochlear implant users in the absence of behavioral information. One reason for this difficulty may be due to differences in temporal/spatial integration between the slow-rate single-channel stimuli used to obtain the objective measure and the multi-channel higher-rate stimulation used in the "typical" cochlear implant program. These differences are exacerbated as the program stimulation rate is increased. Because typical CII/HiRes 90K™ programs use high stimulation rates, new techniques are being investigated to find more useful measures to assist in programming. These include: (1) charge normalization for pulse width differences between measures; (2) measuring neural responses elicited by high-rate amplitude modulated stimuli on single and multiple electrodes; (3) simultaneous neural response measurements on multiple electrodes; and (4) multi-channel elicited stapedial reflexes. These four techniques will be reviewed focusing on how they may provide information for program optimization in patients where behavioral information is limited. © 2004 Elsevier B.V. All rights reserved.

Keywords: Cochlear implants; Objective measures; Compound action potential; Stapedial reflex

1. Introduction

Historically, in the absence of behavioral data, it has proven difficult to reliably fit cochlear implant patients based on objective measures alone. Experiments in adults show that electrically evoked compound action potential (ECAP) based programs typically fall short of "flat" or behaviorally based programs in terms of user preference while delivering surprisingly comparable speech perception (assuming ECAP and flat contour correction

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by at least one behavioral measure) [1,2]. This preference mismatch may, in part, be due to differences in stimuli used between "live-speech" programs and objective measures in terms of their spatial and temporal integration properties. This mismatch appears to increase as a function of stimulation frequency of the behavioral signal [3]. Since successful recording of the ECAP requires slow-rate stimulation in order to produce sufficient neural synchronization to generate a recordable signal, using unmodulated high-rate "program" like stimuli to elicit the ECAP does not appear to provide a viable method to improve the correlation between behavioral and objective measures or to improve ECAP recording "hit" rates. In contrast, the electrically evoked stapedius reflex threshold (ESRT) does not suffer from the same recording constraints as the ECAP. For the ESRT, one can utilize program-like stimuli to elicit the response. The main drawback of the ESRT is that the reflex is absent in many patients and it is often difficult to obtain in small children. In spite of these limitations, the ECAP and ESRT have proven useful in the fitting of many young children as well as certain adults [4,5].

Here, we provide an update regarding new techniques that are being investigated for aiding in the optimization of HiRes programming parameters. These methods attempt to compensate for the differences between objective measure stimuli and program-like stimuli.

2. Method review

2.1. Single channel NRI and charge normalization

Since HiRes programs are generated using an adaptive pulse width algorithm to insure voltage compliance, they typically have pulse widths different than those used for Neural Response Imaging (NRI is the ECAP recording tool for the CII and 90K implants, the default pulse width is 32 μs). Normalizing to charge has been shown to allow meaningful comparisons across measures obtained with different pulse widths typical for HiRes (11–75 μs) thus eliminating the need to re-measure should the program change [6]. Similar to previous ECAP reports, correlations between HiRes programs and single channel NRI tend to be poor unless at least one behavioral correction is used. Using one behavioral correction along with charge normalization, one can obtain ECAP correlations to HiRes programs comparable to those reported for slow-rate programs, i.e. $r>0.70$ using similar techniques [7].

2.2. High rate NRI

It has been shown that by increasing the stimulation rate of an unmodulated pulse train that the ECAP magnitude diminishes as a function of stimulation frequency. Above ~3 kHz, the ECAP is not typically recordable due to desynchronized firing and/or neural adaptation [8]. Lee and Litvak [9] have reported that, by modulating the pulses within the train, it is possible to induce further neural synchronization sufficient to record the ECAP, even at high rates. For high rate stimulation, it may be that by maximizing the capacity for residual synchronization to modulations of the carrier one may be able to better optimize program stimulation rate. Given that, even in the best patients, masking-interaction functions indicate interactions across several millimeters of cochlear-length, it is reasonable to suspect that the actual neural stimulation rate for the cochlear implant program is much higher than what is indicated by the single channel rate. Using program like "maskers" presented across the array at relevant rates, one may be able to understand how the interactive rate impacts a given "channels" ability to transmit information to the auditory nerve. Such techniques are now possible with the CII and 90 K implants using the Research Software Interface (RSI) allowing for NRI stimuli >5 kHz per contact to be used. Present work is focused on understanding how to use this tool to optimize the relationship between rate and channel configuration.

2.3. Banded NRI

Given the difficulties of recording cochlear responses to high rate stimuli, another approach being investigated attempts to generate an NRI stimulus that produces sufficient neural synchronization yet elicits loudness growth more similar to program-like stimuli [10]. This is accomplished by simultaneously banding the NRI stimulus across several electrodes (typically 4). One hypothesis is that, if the NRI stimulus can be configured to grow more similar to a program-like stimulus in terms of loudness, then the measure may be more predictive of program levels. Initial findings appear promising (Fig. 1) demonstrating that the banded NRI measure exhibited growth similar to the high-rate program-like stimuli called a speech-burst. The speech-burst is a multi-channel noise stimulus, typically four contacts per band, of interleaved pulses running at live-speech rates. This is the default stimulus for setting HiRes program levels. Runge-Samuelson [10] also reported that, even in instances where the patient had both unreliable behavioral and neural responses to single channel measures, the banded measures appeared to be more robust and consistent with the program measure.

2.4. Banded ESRT

The ESRT can be elicited using the speech-burst programming stimulus [7]. The speech-burst elicited reflex thresholds typically fall just below the "loud-but-comfortable"

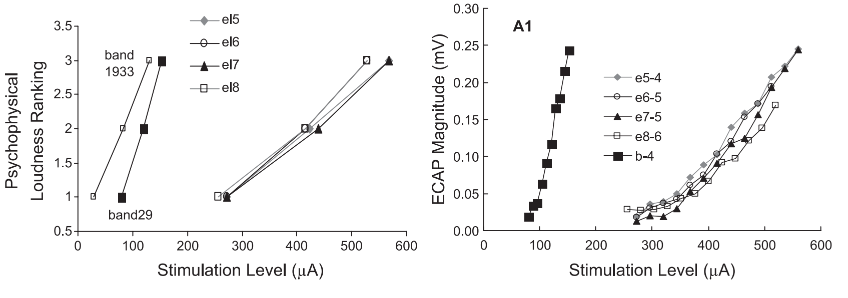

Fig. 1. (Left) shows the loudness ranking of the speech-burst (band 1933) running at 1933 Hz per contact for a duration of 250 ms, the simultaneous NRI stimulus at 29 Hz as well as the loudness ranking for electrodes 5–8 collected individually for patient A1. Note that both the sequential "band 1933" and the simultaneous "band 29" show similar loudness growth in contrast to the single channel measures. (Right) shows the ECAP growth functions measured for the band 29 (indicated as b-4) as well as for the same electrodes measured individually (e5–e8). They noted that the banded measures tended to exhibit ~4 times the growth and have ~1/4 the threshold when compared to single channel measures comprising the band. Figures are courtesy of Runge-Samuelson [10].

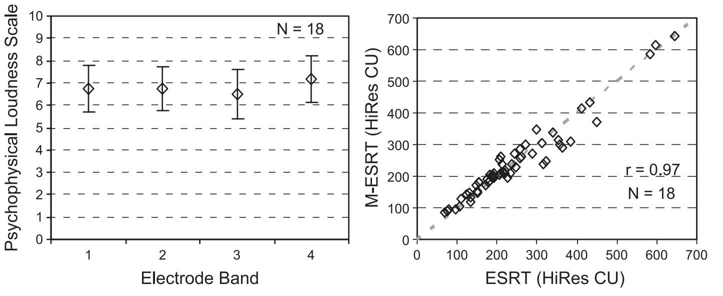

Fig. 2. (Left plot) shows the loudness rankings (standard deviations indicated by error bars) of the speech-burst stimulus at the ESRT for each band of 4 electrodes in the 16 contact array (band 1=most apical, band 4=most basal) (1=barely audible, 6=most comfortable, 8=loud but comfortable). (Right plot) shows ESRT contour M as a function of the ESRT for the data in (left plot). Note that, unlike ECAP measures, the speech-burst appears to grow 1:1 with the loudness shifted contour. This suggests that the reflex may better account for temporal and spatial integration as well as adaptation issues when compared to the ECAP. Figures are courtesy of Buckler et al. [7].

range for most patients (Fig 2). Additionally, ESRTs for speech-bursts, tend to be close to live-speech adjusted program M levels.

3. Summary

1. The SoundWave Professional Suite provides a platform for time efficient HiRes program generation, NRI and ESRT recording tools.
2. Single channel NRI measures are able to provide a ball-park estimation of M. Correlations can be significantly improved if the NRI contour is shifted by one behavioral or speech burst ESRT measurement.
3. High rate NRI, now available via the RSI, may provide further insight into stochastic resonance, neural adaptation and rate optimization.
4. Banded NRI provides the first ECAP method that demonstrates psychophysical loudness growth similar to that of the speech burst and program-like high rate stimuli. This tool appears useful even when single channel measures are not consistent.
5. Banded ESRT provides the most accurate objective measure to date for estimating the upper limit of the dynamic range for high rate programs such as HiRes.

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