Comparing Neural Response Telemetry Amplitude Growth Functions with Loudness Growth Functions: Preliminary Results

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Comparisons of the subjective loudness growth function and the objective evoked compound action potential (ECAP) amplitude growth function indicate that both functions are exponential in nature. This implies that a more accurate estimate of the ECAP threshold would be obtained using exponential regression of the amplitude growth function instead of the currently used linear regression. The perceptual threshold and the ECAP threshold seem to approach each other when the stimulation rate is lowered to reduce temporal summation effects. The effect of the stimulation rate on the perceptual threshold will have to be taken into account when trying to use the ECAP threshold for predicting the perceptual threshold.

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At present, the clinical use of neural response telemetry (NRT) recordings is limited to helping set the initial profile of the map Threshold and Comfortable (T & C) values across the array. Theoretically, it should be possible to use the evoked compound action potential (ECAP) threshold to predict the corresponding behavioral threshold. To better understand the relationship between the objectively measured ECAP threshold and its behavioral counterpart, a study was designed to compare the ECAP input–output function (the amplitude growth function [AGF]) against the corresponding behavioral loudness growth function (LGF). Preliminary results from this study are presented here.

The AGF depicts changes in the ECAP amplitude in response to a single pulse as a function of the stimulation level. The LGF, on the other hand, depicts the change in the subjective loudness to a train of pulses as a function of the stimulation level. The latter LGF is therefore subject to temporal integration effects that lower or raise the perceptual threshold with increasing or decreasing rates, respectively. Studies such as those by Shannon (1985), Zeng & Shannon (1994), and Zimmerling & Hochmair (2002) have indicated that there is little temporal integration effects below 80 Hz. To reduce temporal integration effects, the behavioral measures were made with a pulse train at low rates (80 Hz).

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Method

The LGF was determined using a custom-developed psychophysics test interface (PICNIC) that was programmed using Matlab and the Nucleus Matlab Toolbox from Cochlear Ltd. PICNIC allows the tester to configure an arbitrary train of pulses for direct presentation to a subject's implant in a psychophysical task. In this study, a categorical loudness-scaling task was used.

The loudness scale consisted of categories ranging from "very, very soft" (just audible), "very soft," "soft," "middle/comfortable," "loud," "very loud," to "too loud," similar to categorical scales reported in other studies (e.g., Blamey, Dooley, James, et al., 2000). This loudness scale was chosen because of its similarity to that used by the subjects in the clinical routine for setting map T & C levels. The above categories also were assigned respective linear numeric values as follows: {1, 5, 9, 13, 17, 21, 24}.

The stimuli used in this particular experiment consisted of a train of pulse pairs, similar to the masker-probe pairs used for NRT recordings. The two pulses of each pair were separated by 300 μs, and the preceding pulse was always larger than its counterpart pulse by 10 current level units. The pulse pairs were repeated at an arbitrarily selected low rate of 80 Hz.

First, the range of stimulation levels corresponding to behavioral threshold and comfortable levels for the above pulse train were interactively determined. In the ensuing loudness-scaling task, stimulation levels within this range were presented randomly to the subject, who then indicated the perceived loudness of the stimulus on the categorical loudness scale provided. This yielded the required LGF. Note that stimulation levels louder than comfortable were never used in the loudness-scaling task.

Results from four subjects (three CI24RE (Freedom) implants; one CI24M implant) are presented here. All four subjects were adults who had been using their implant for more than 1 yr and were familiar with the task of indicating the loudness of a stimulus on the clinical categorical loudness scale when setting their speech-processor map T & C levels.

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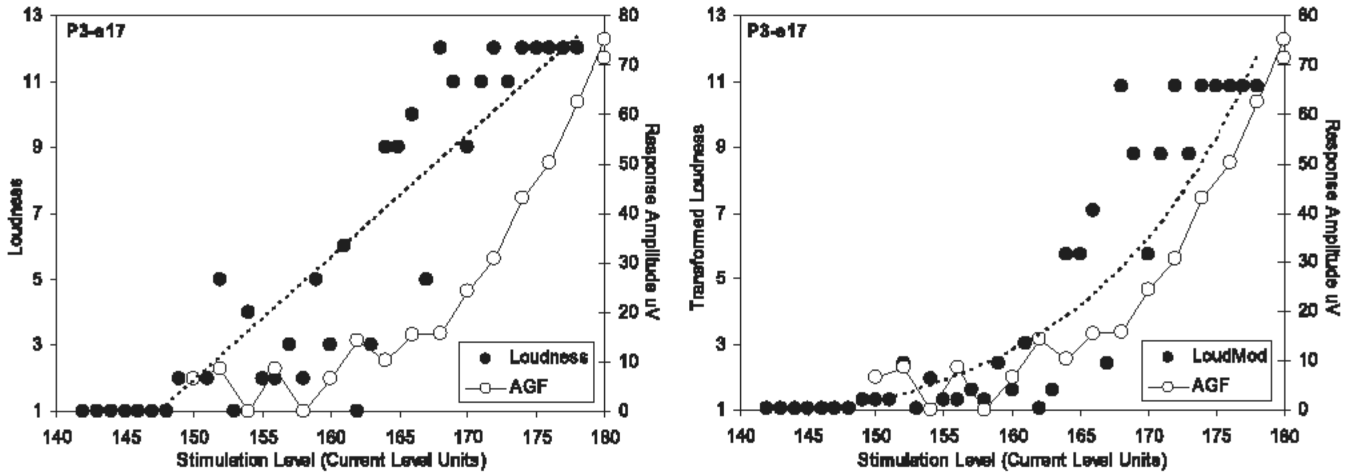

Fig. 1. The original response values (left) are subjected to an exponential transform to match the LGF (solid circles, left axis) with the AGF (open circles, right axis) as closely as possible. The transform is made such that the maximum and minimum values of both y-axes are unchanged, and only the intermediate scaling is affected (right). The x-axis range corresponds to the T & C level.

From each subject, LGFs and corresponding AGFs from at least two electrodes were collected. The AGF recordings for the three CI24RE subjects were made at a stimulation rate of 80 Hz, whereas those for the CI24M subject were made at 250 Hz. A total of 11 matching LGF–AGF datasets were collected and analyzed.

RESULTS

For comparison, the LGF and the corresponding AGF were plotted such that the stimulation level (x-axis) shared the same range. The y-axes of the two functions were then normalized with respect to each other by scaling their respective y-axes (loudness and amplitude) such that the two functions spanned the full range. An exponential transform was then applied to the y-axis (loudness) scale of the LGF to match the curvature of the corresponding AGF (Fig. 1). This was justified on the basis that the exact intervals of the original categorical loudness scale can vary from subject to subject. Although slightly different transforms were applied for each subject, the same exponential transform was applied to the different LGFs (electrodes) for a given subject.

Using the exponential transforms, it was possible to match the LGF and the AGF very closely in 8 of the 11 datasets (Fig. 2). In two datasets, the AGF was only available at the upper end of the range of stimulation levels. In only one dataset did the transformed LGF not provide a good match with the AGF.

The results reinforce the assumption that an exponential regression function is more appropriate for estimating the ECAP threshold from the AGF than the linear regression algorithm currently implemented in the NRT software.

The suprathreshold response amplitudes at behaviorally comfortable levels for different electrode sites also were examined, but they showed little correlation between response amplitudes at the perceived comfortable level (Fig. 3). The response amplitude at C level was much higher for the CI24M subject (P4) than with the other three CI24RE subjects.

DISCUSSION

The exponential transform applied to the LGF merely served to highlight the exponential nature of the LGF and the AGF and should not be interpreted as a means to equate them. As mentioned in the introduction, the AGF is based on a single pulse, whereas the LGF is based on a train of pulses whose stimulation rate is expected to affect the exact shape of the exponential function.

The exponential nature of the AGF is more evident at the lower response amplitudes that can now be recorded using the improved measurement amplifier of the CI24RE implant. Its predecessor, the CI24M implant, had a higher noise floor that often revealed only the upper portion of the AGF, which appeared to be more linear in nature.

The present data are only preliminary and do not indicate the exact exponential function parameters required to fit the AGF for estimating the ECAP threshold. Further experiments will have to be conducted using simple pulse trains rather than a train of pulse pairs, as used here. It is expected that similar results will be obtained.

By using a pulse train at low rates (80 Hz) for the loudness-scaling task, it was possible to reduce potential temporal integration effects such that the

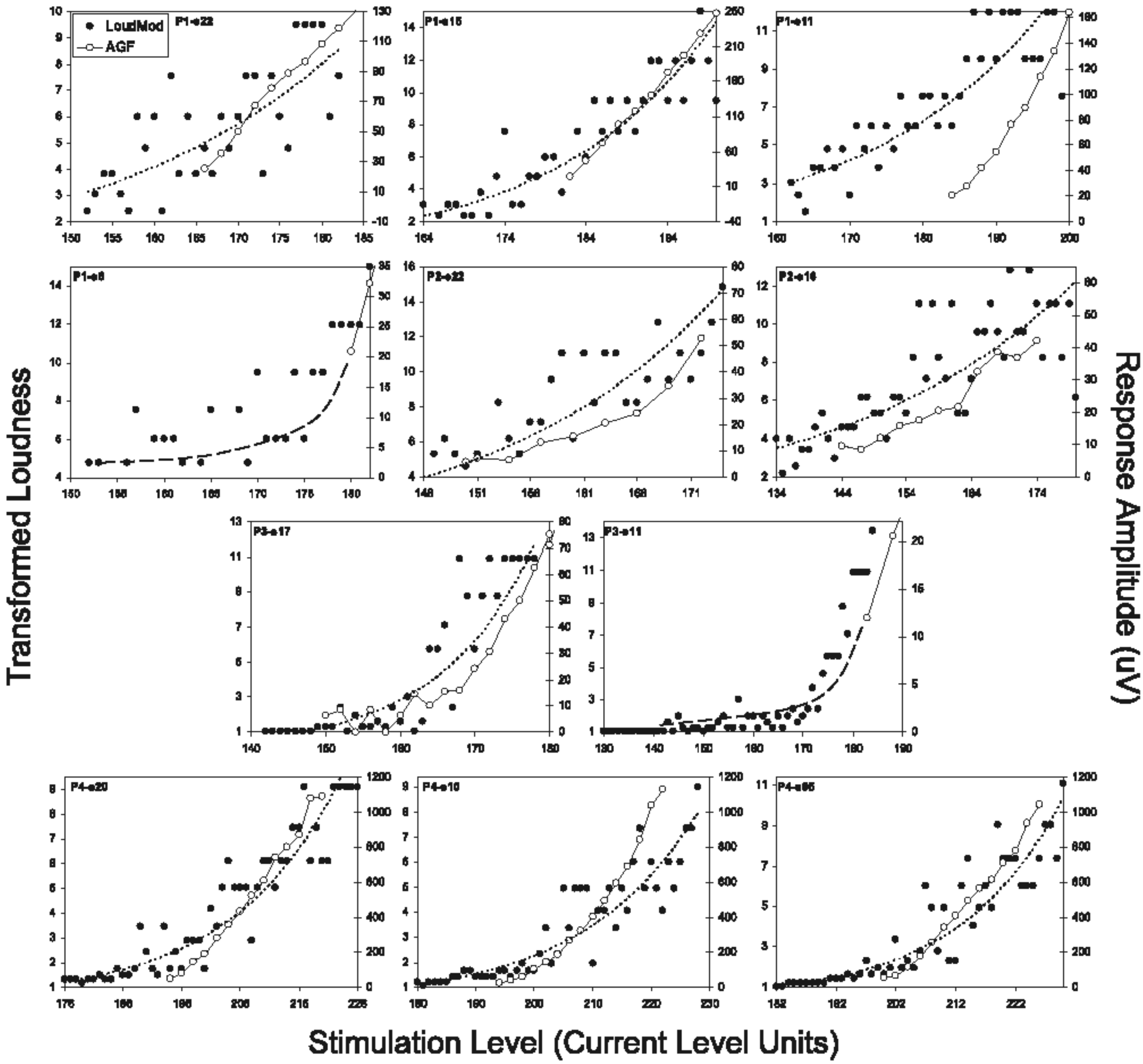

Fig. 2. Results from all 11 datasets. The exponential regression function for the transformed LGF is shown with dashed lines. In two datasets, the response amplitudes were too small to be measured much below C level. The transformed LGF is not shown in these two cases (P1-e6 and P3-e11). Instead, a possible projection of the AGF is indicated.

perceptual and behavioral thresholds began to agree with one another.

Note that the stimulation rate used for measuring AGF primarily affects the duration of the recordings. Refractory effects at higher stimulation rates may yield reduced response amplitudes, but the shape of the AGF is unaffected by this.

At suprathreshold stimulation levels, the relationship between the subjective loudness and the objective response amplitudes become less clear. This lack of correlation is not surprising, considering that we are comparing peripheral versus central phenomena. The higher response amplitudes at C level for the CI24M subject P4 could merely indicate that this subject is less sensitive to peripheral activity. There are insufficient data here to draw any definitive conclusions regarding this observation. Further studies examining suprathreshold percepts should take into account loudness recruitment effects (Harrison & Aran, 1982) or temporal integration effects (McKay, Fewster, & Dawson, 2005).

The next step would be to investigate changes in the behavioral threshold as a function of rate. Many studies have examined this relationship (e.g., Shannon, 1985; Zeng & Shannon, 1994; Fu, 2004), which will be useful in the search for the desired relationship be-

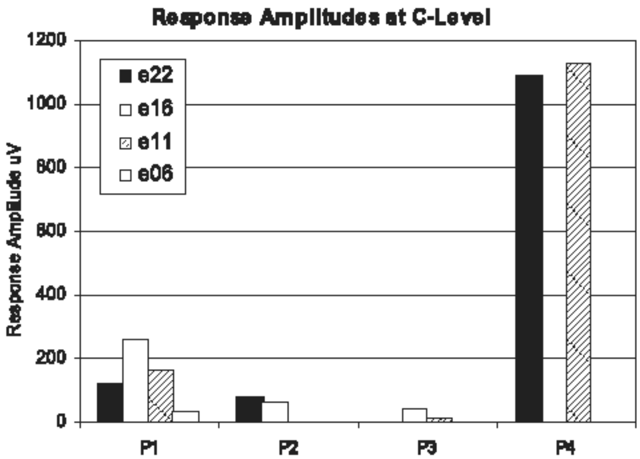

Fig. 3. The response amplitudes at C level for different electrode sites show little correlation from one subject to the other.

tween ECAP threshold and the behavioral threshold at different stimulation rates.

Conclusion

The ECAP threshold could be matched quite well with the behavioral threshold at low stimulation rates (80 Hz), provided that an exponential regression was applied to the AGF. Further studies will be required to determine the exact parameters needed for such an exponential regression function.

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