Monaural and Binaural Categorical Loudness Scaling in Electric Hearing

Florian Wippel[1,2], Piotr Majdak[1], and Bernhard Laback[1]

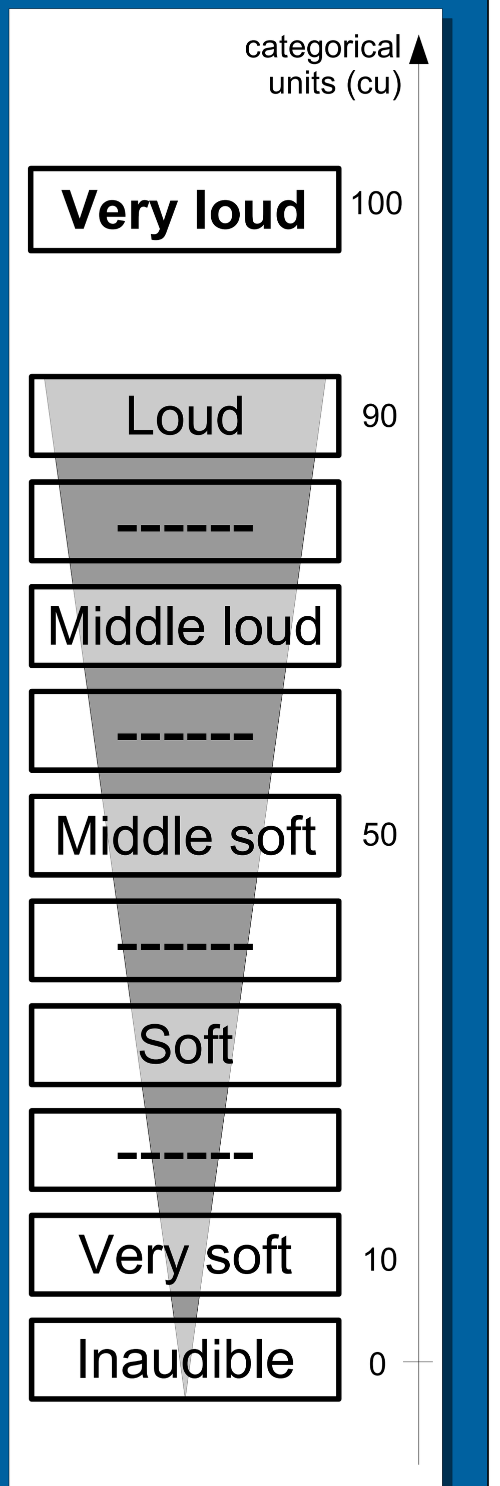
1) Acoustics Research Institute, Austrian Academy of Sciences, Austria

2) Institute of General Physics, Vienna University of Technology, Austria

CIAP 2007

Conference on Implantable Auditory Prostheses

Granlibakken Conference Center
Lake Tahoe, CA
U. S. A.



1. General

- In this study efficient monaural and binaural adaptive procedures for categorical loudness scaling in electric hearing were developed. The procedure is based on the Oldenburg adaptive and constant stimuli procedures for acoustic hearing (Brand and Hohmann, 2002), which were adapted to the requirements for cochlear implant listeners. For the monaural procedure, the aim is to quickly measure the loudness growth as a function of the current level of the electric stimulus using a categorical scale (shown on the left border). The binaural procedure relies on the results from the monaural tests performed at both ears and takes the binaural loudness summation into account. It was validated by binaural loudness balancing experiments.
- Seven bilaterally implanted subjects were tested:
  - Two prelingually deafened subjects (age: 12 and 15 years)
  - Five postlingually deafened subjects (ages from 28 to 59 years)
  - All subject used MED-EL C40 or C40+ providing monopolar stimulation
- Unmodulated pulse trains were presented via direct stimulation at:
  - one electrode (monaural)
  - one binaurally fused (Eddington et al., 2003) electrode pair (binaural)

  Parameters:
  - Biphasic pulses with a phase duration of 26.7 µs (C40+) and 40 µs (C40)
  - Pulse rate: 200 pps
  - Duration: 600 ms
- The loudness scaling procedure (monaural and binaural) consists of:
  - Dynamic range estimation
  - Adaptive loudness scaling
  - Fitting the data to a model

2a. Procedure: dynamic range estimation

Estimate the level required to stimulate "loud" (Fig. 1):

- Begin at 80% of the dynamic range given by the clinical fitting
- Increase the level by 4% until response is equal or higher than "loud"
- In cases where the first response is already "loud" or even "very loud" decrease the level by 15% and then continue with the increment.

Estimate the level near the threshold:

- Begin at 50% of the dynamic range
- Decrease the level by 14% until the stimulus is not heard
- Increase the level by 4% until the stimulus can be heard

Fig. 1: Dynamic range estimation

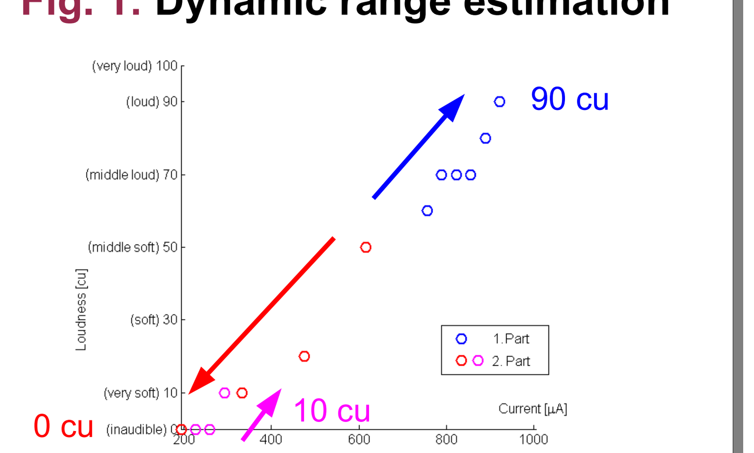
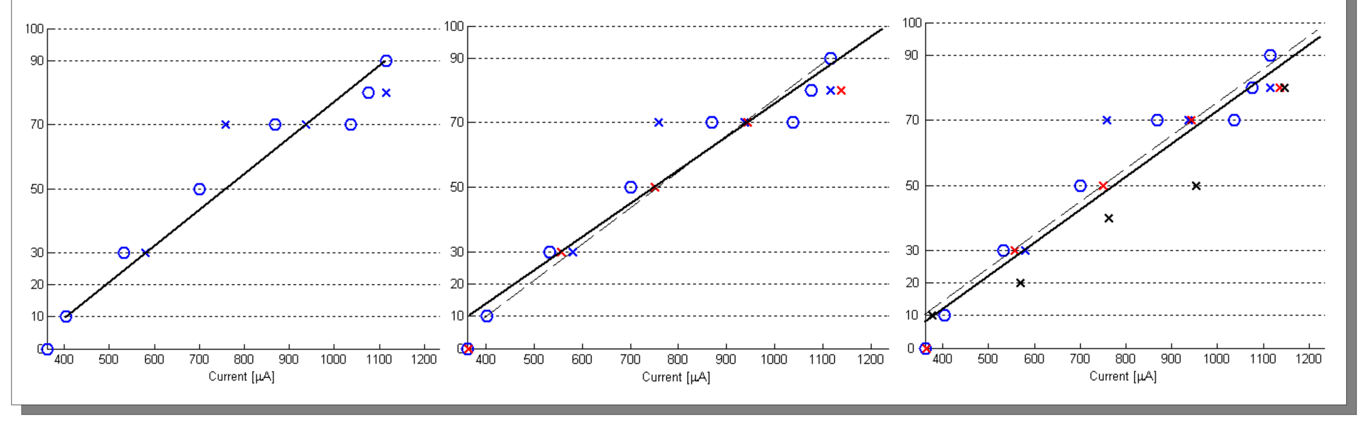


Fig. 2 Adaptive loudness scaling procedure



2b. Procedure: adaptive loudness scaling

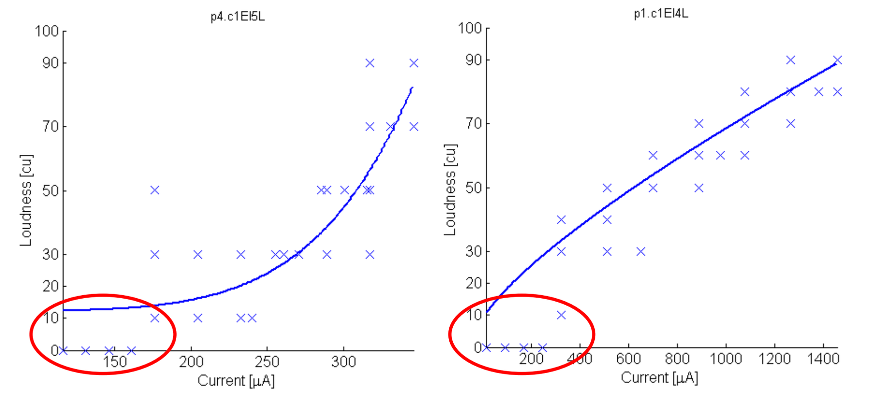
- Perform a linear interpolation between "very soft" and "loud" (Fig. 2)
- Collect loudness responses for levels "soft", "middle soft", "middle loud", and "loud" obtained from the interpolation
- Perform a linear robust least-square fit to all available data
- Repeat to collect enough data for modelling (here: 8 times)

2c. Procedure: data modeling

Power function (Stevens, 1975):

- Large errors near the threshold (Fig. 3)

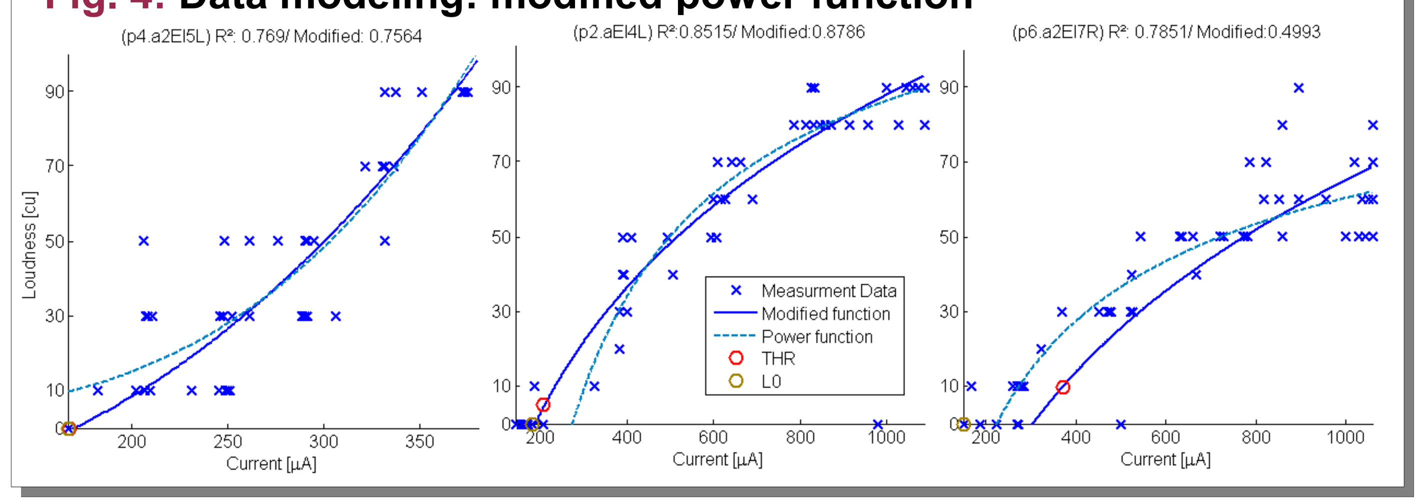
Fig. 3: Data modeling: power function



Modified power function (Fig. 4):

- $F(I)=a\cdot\left(I^p-I^p_{THR}\right)+L_{THR} \;\wedge\; L_0\leq F(0)$
  - I_{THR}: $S(I_{THR})=75\%$ for a sigmoidal fit to data: $S(I)=\begin{cases}1 \;\ldots\; L(I)>\text{"Inaudible"}\\ 0 \;\ldots\; L(I)=\text{"Inaudible"}\end{cases}$
  - L_{THR}: fit parameter, "Inaudible" $< L_{THR} \leq$ "Very soft"
  - a, p: fit parameters with no restrictions
- Good estimation of the loudness even at the threshold

Fig. 4: Data modeling: modified power function



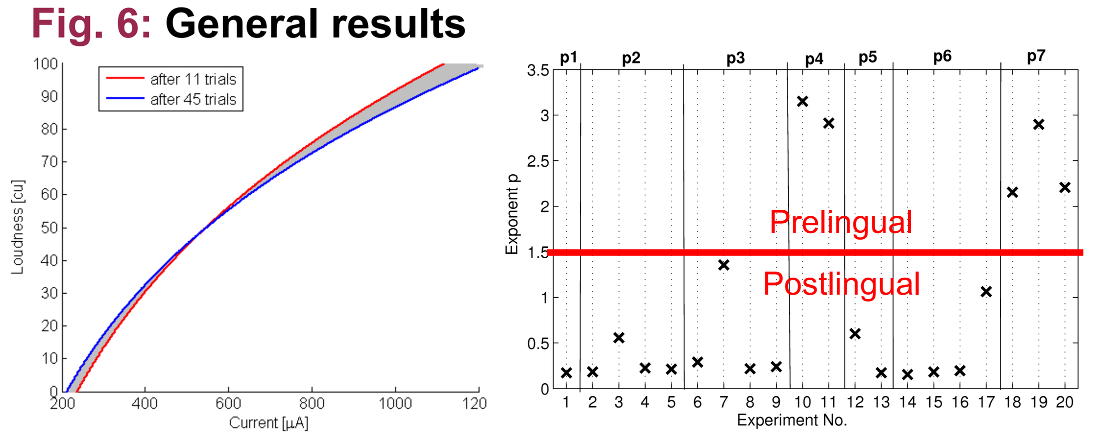
3. Binaural condition

- Perform the dynamic range estimation beginning at "Middle loud" (derived from the monaural loudness function at each ear)
- Perform the adaptive loudness scaling procedure calculating the levels for both ears separately
- Model the data for both ears using the modified power functions (see Fig. 5)

4. General results

- 90% of all adaptive runs converged within 45 stimuli (Fig. 6, left panel)
- The data of all postlingually deafened subjects fit best to models with an exponent lower than 1.5 (Fig. 6, right panel)
- The data of the two prelingually deafened subjects fit best to models with an exponent higher than 1.5
- Loudness summation could be confirmed in the binaural data

Fig. 6: General results



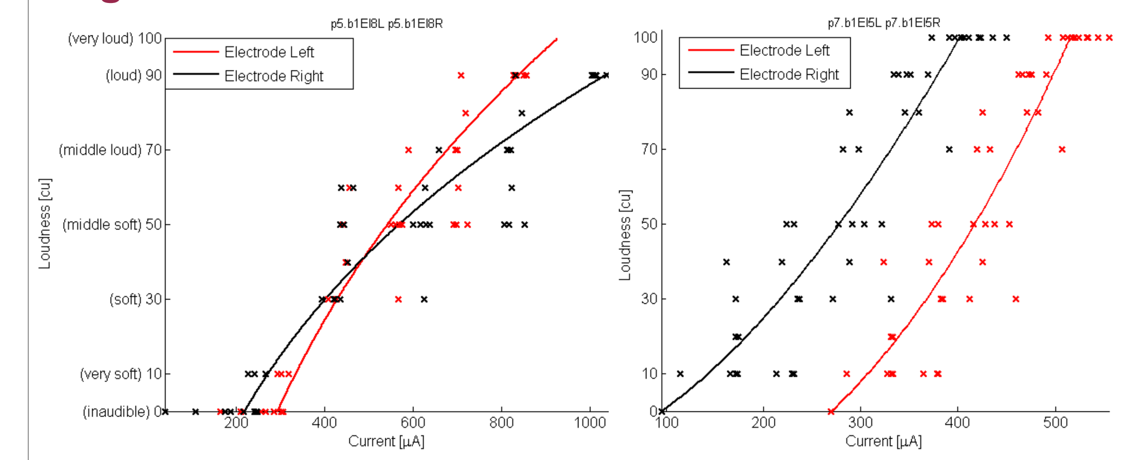
5. Quality check

- **Binaural loudness balancing** tests were performed. Six subjects with 18 electrode pairs in total were tested.
- Comparison of the binaurally balanced levels and the corresponding levels obtained with the **adaptive procedure** showed (see Fig. 7, left panel):
  - equal loudness in 77% of all cases
  - RMS loudness error: 4.0 cu; maximal error: 8 cu
- Comparison of the binaural balanced levels and the corresponding levels resulting from the **constant stimuli procedure** showed (Fig. 7, right panel):
  - equal loudness in 61% of all cases
  - RMS loudness error: 7.6 cu; maximal error: 20 cu
- Comparison between the data obtained with the adaptive and constant stimuli procedure showed (Fig. 8):
  - a significant difference (p=0.003) for "Middle loud" or louder stimuli
  - no significant difference (p=0.25) for stimuli softer than "Middle loud"

References:

- *Stevens, S.S. (1975). Psychophysics, Introduction to its perceptual neural and social prospects (John Wiley, New York)*
- *Brand, T. and Hohmann (2002). "An adaptive procedure for categorical loudness scaling," J. Acoust. Soc. Am. 112, 1597-1604*
- *Eddington, D. K. et al. (2003). "Speech processors for auditory prostheses: Fifth Quarterly Progress Report," Neural Prosthesis Program, National Institutes of Health*

Fig. 5: Binaural loudness functions



6. Conclusions

- The adaptive binaural loudness scaling procedure resulted in more accurate loudness functions than the constant stimuli procedure by:
  - Presenting and collecting data over a larger range of levels
  - Providing more often binaurally loudness-balanced levels
  - Showing a smaller difference in loudness in cases where the levels resulted in unbalanced loudness.

  This is in agreement with the results of Brand and Hohmann (2002).
- The presented procedure shows a high efficiency by converging very fast and thus allows to estimate a loudness function within minutes of testing. However, as a disadvantage the adaptive procedure is more susceptible to instability.
- The results for the prelingually and postlingually deafened subjects showed a difference in a model parameter – the exponent was higher and lower than 1.5 for the prelingually and postlingually deafened subjects, respectively.
- Even though this study was not designed for a direct comparison of the binaural and monaural conditions, the data reveal a binaural loudness summation effect.

Fig. 7: Binaural loudness balancing check

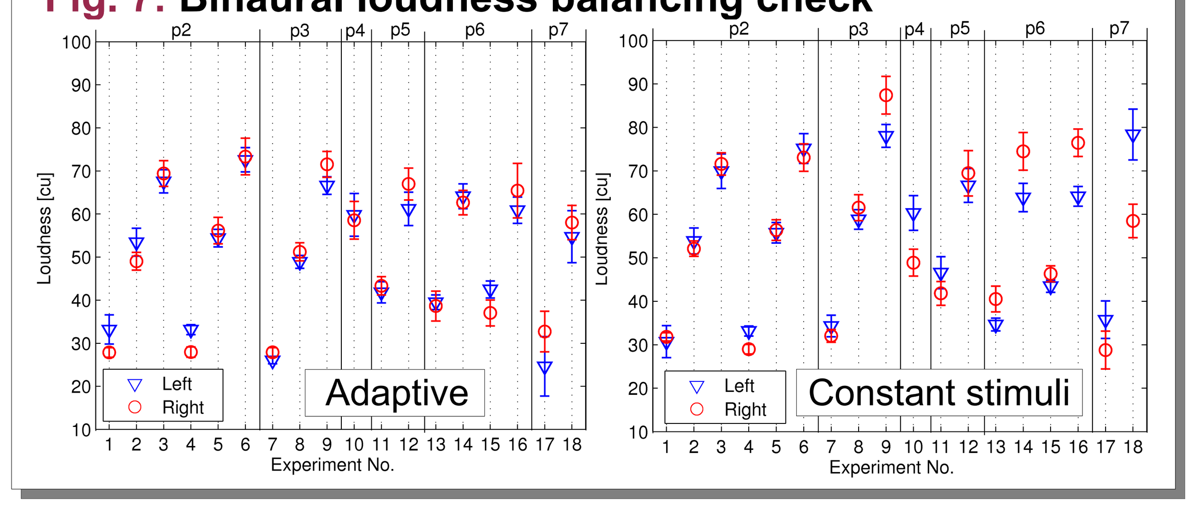
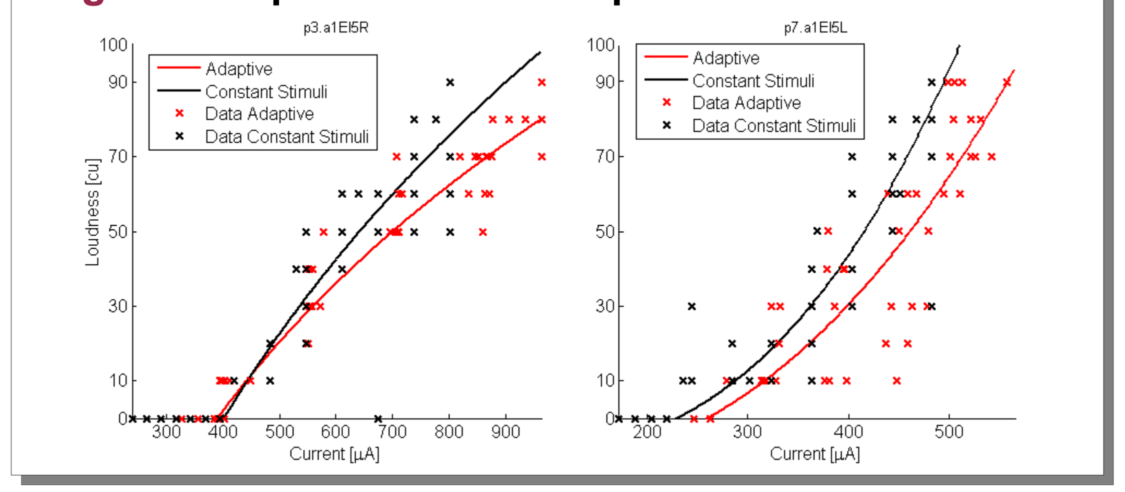


Fig. 8: Comparison between procedures



Corresp. Author: Piotr Majdak, Acoustics Research Institute, Austrian Academy of Sciences, Wohllebengasse 12-14, A-1040 Wien, Austria

E-Mail: piotr@majdak.com

http://www.kfs.oeaw.ac.at

We thank the CI listeners for their enthusiastic participation in this study.
The equipment for direct electrical stimulation was provided by MED-EL Corp.
This research was supported by the Austrian Academy of Sciences