Recording the Electrically Evoked Compound Action Potential in a Clinical Setting

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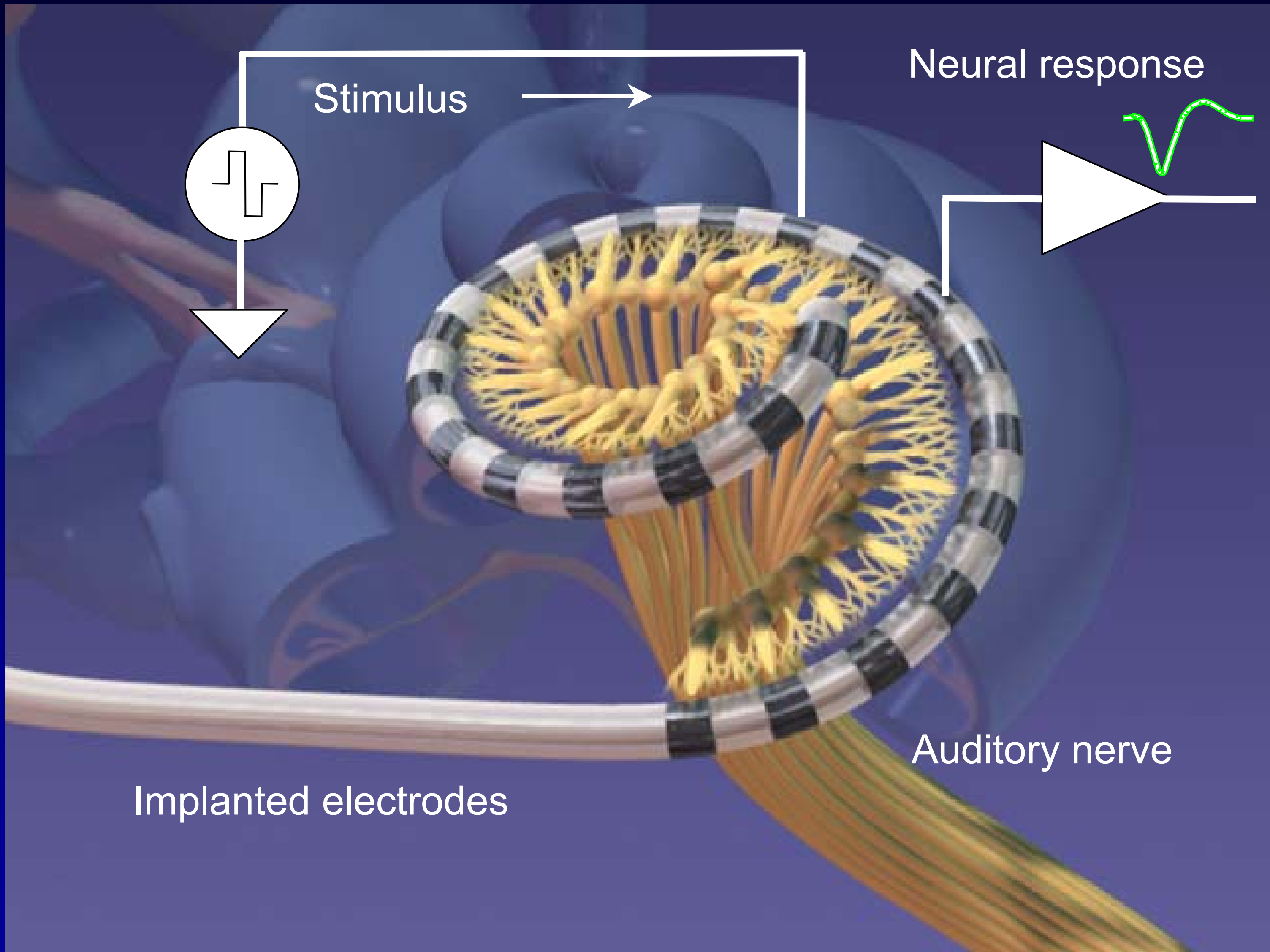
Challenges for improved performance with cochlear implants

- Selective stimulation of small groups of nerve fibers (with minimal channel interaction)
- Adequate and suitable signal processing strategies
- Appropriate mapping of signal parameters to patient-specific psycho-electrical stimulation conditions (loudness, pitch, timbre)

Possible reasons for objective measures

- Obtain precise information about the status of the peripheral auditory system
- Verify electrical excitability of neural elements
- Monitor changes and identify problem areas related to the cochlear implant
- Support and improve postoperative fitting procedures
- Provide guidelines for rehabilitation and training
- Documentation, quality assurance

Intracochlear recordings of electrically evoked compound action potentials (ECAP)



NRT recordings

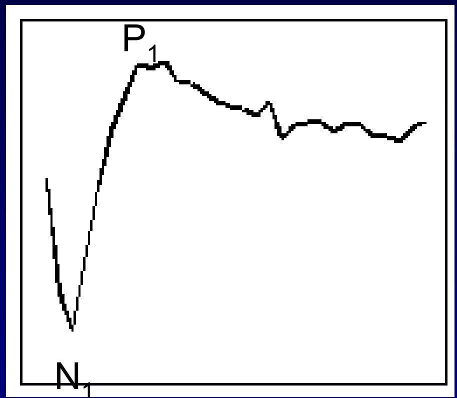
- Assess peripheral function of auditory pathway (not central mechanisms!)
- Can be obtained intraoperatively
- Can be repeated any time even with uncooperative, sleeping or (hyper)active subjects
- Can be performed as a simple, semi-automatic procedure for routine clinical use or using more sophisticated, research-oriented paradigms

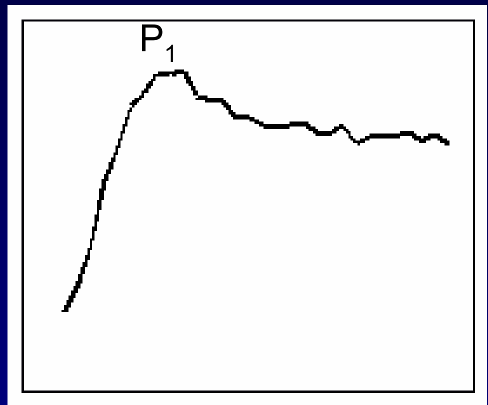
NRT studies

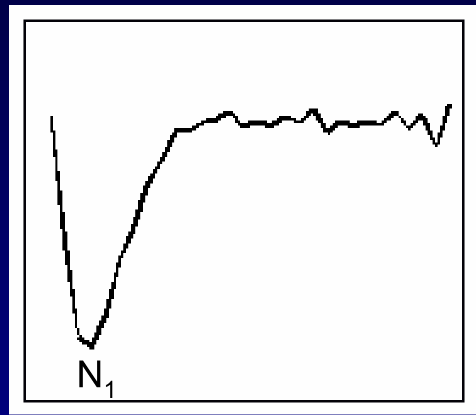
- Optimal recording parameters
- Relationship between NRT thresholds and behavioural T- and C-levels
- Speech processor fitting strategies based on
  - NRT threshold profiles
  - NRT recovery functions
  - NRT rate dependence
  - NRT masking patterns
- Basic research, models of electrical stimulation, technical improvements of software and hardware

NRT waveform classification

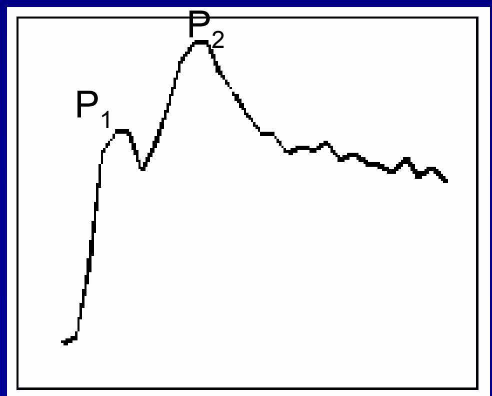
Type I (a) (b) (c)



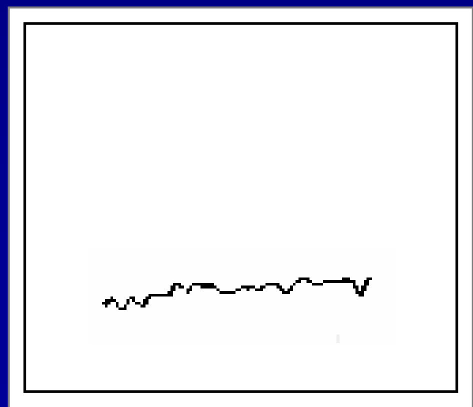




Type II



NR

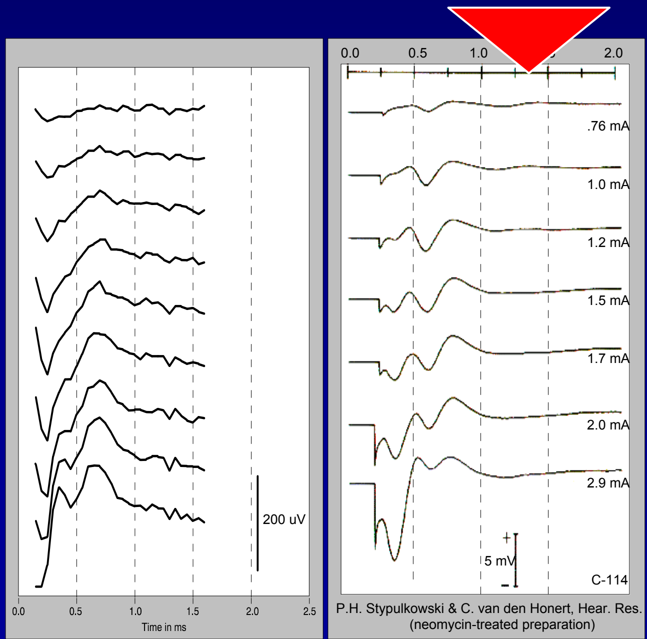


Double positive peak responses

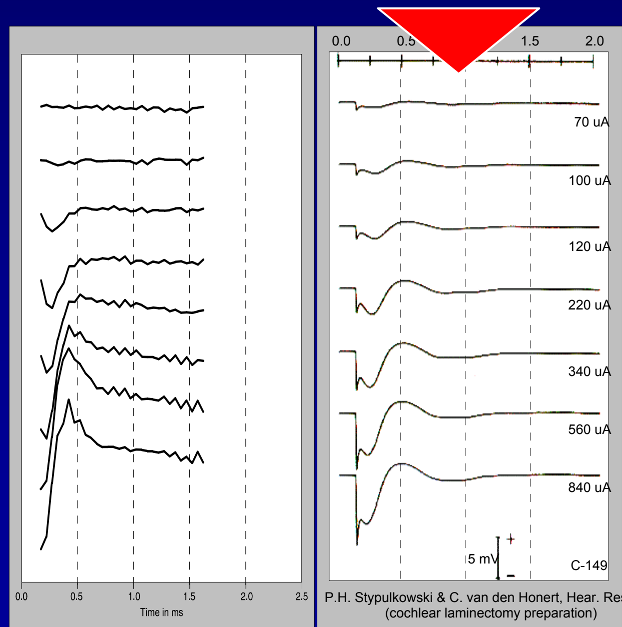
- Type I responses consist of about 90% of observed waveforms
- Type II responses (10%) are found mostly with apical stimulation electrodes

Stypulkowski & van den Honert [1984] reported double peak ECAPs from intact auditory nerves (from cats)

Following cochlear laminectomy (removal of basilar membrane), only the earlier of the two positive peaks remained.



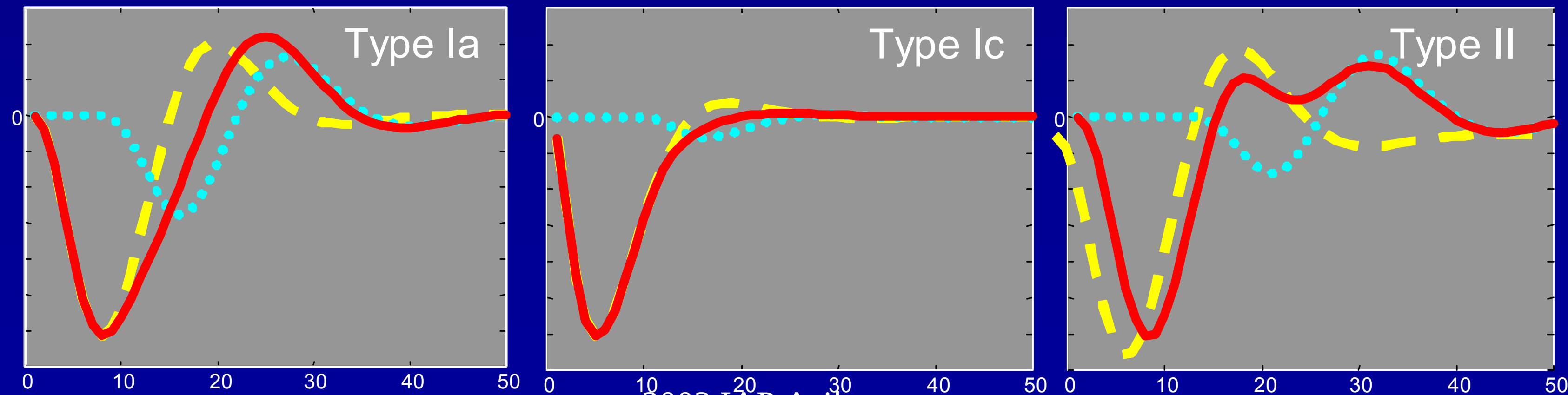
NRT Recordings



NRT Recordings

Model simulation results

- Simulation results show that a single mechanism involving two neural response components is able to account for the main types of NRT response waveforms
- The various response types could indicate the relative proportion of axonal and dendritic activity in response to electrical stimulation
  - Type Ia : Axonal component about twice the size of dendritic component
  - Type Ic : Very small dendritic compared to axonal component
  - Type II : Delay in dendritic component greater than in Type Ia



Advantages of neural response telemetry (NRT) measurements

- Function of the auditory nerve along the electrode array can be assessed
- NRT recordings can be more easily and faster obtained than electrically evoked brainstem responses (EABR)
- The resulting data can be useful during speech processor fitting (estimation of thresholds and comfortable loudness levels, selection of electrodes)
- This can eventually be helpful in fitting young children

Intraoperative neural response telemetry (NRT) measurements

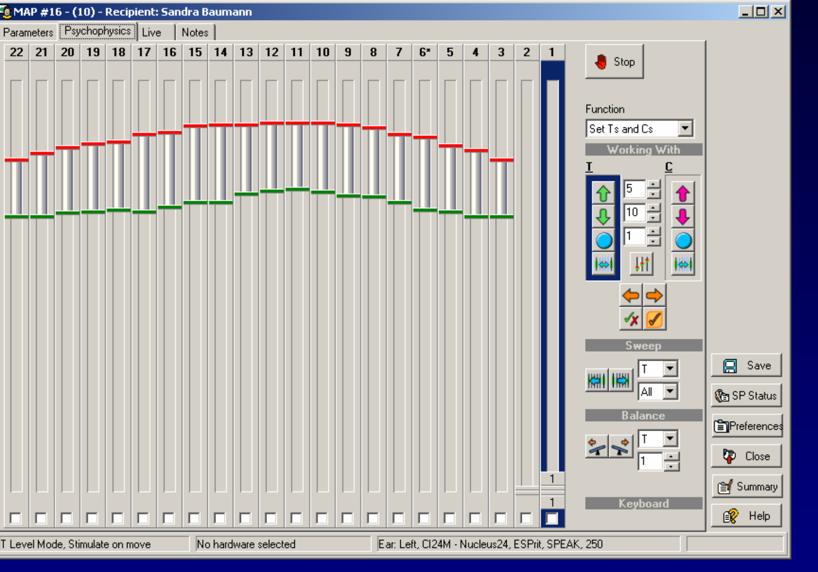
- Confirmation of device function
- Confirmation of neural responses
- Estimation of the threshold for NRT (i.e. the lowest level at which a neural response can be recorded) for all 22 intracochlear electrodes

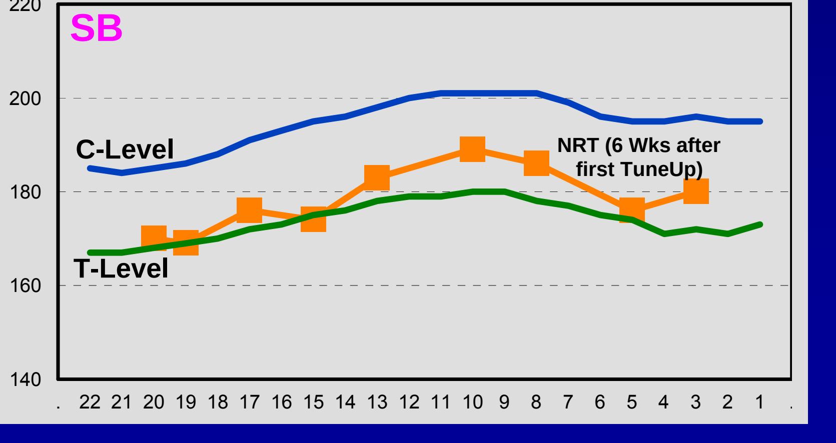
NRT Data and Speech Processor Maps

- Several studies have shown that the Neural Response threshold often lies within the T- and C-levels of the patient's Map

- The profile across the electrode array of the Neural Response thresholds are also often parallel to the profile across the array of the T- and C-levels of the Maps

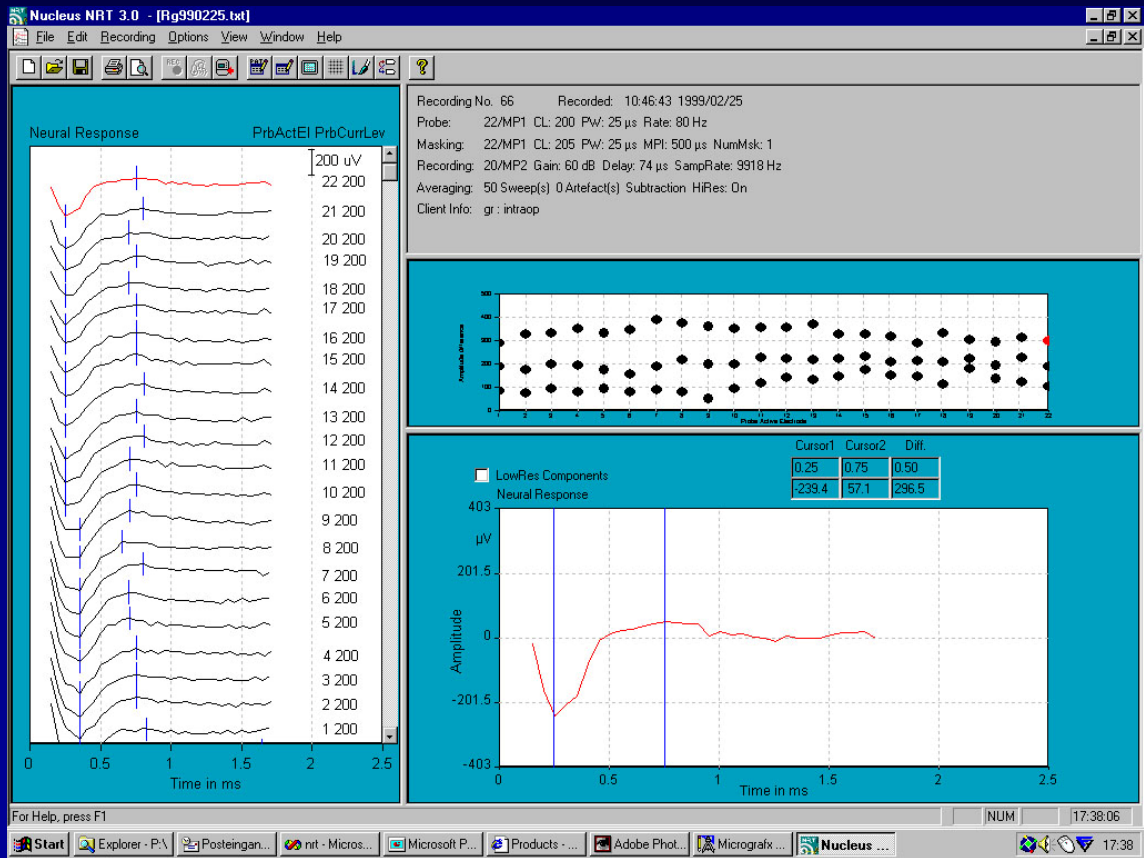
- This may help us to
  - Locate the operating range of the Map quickly and
  - Set the Map profile across the array with only a small amount of data



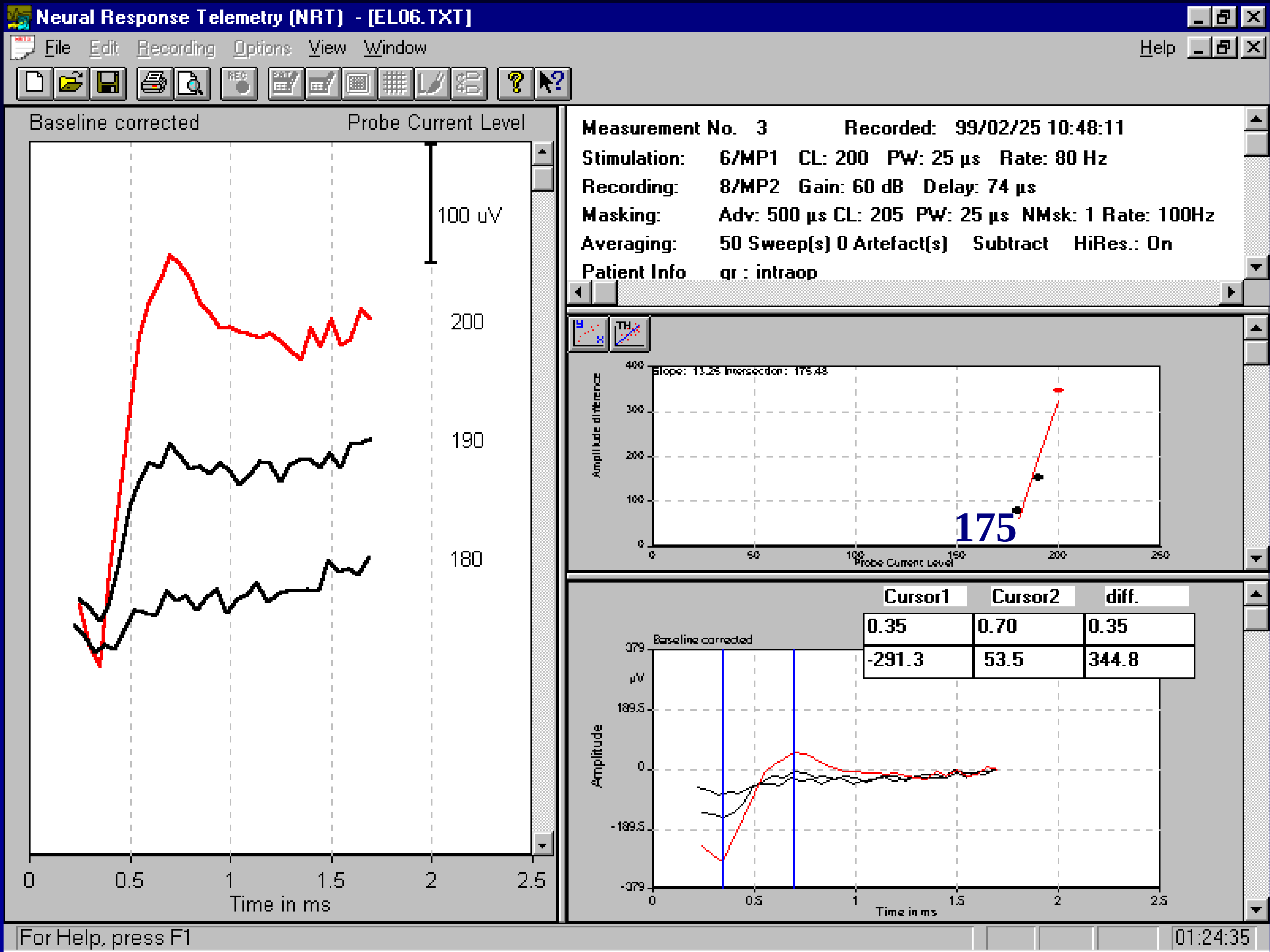


Benefits of performing intraoperative measurements

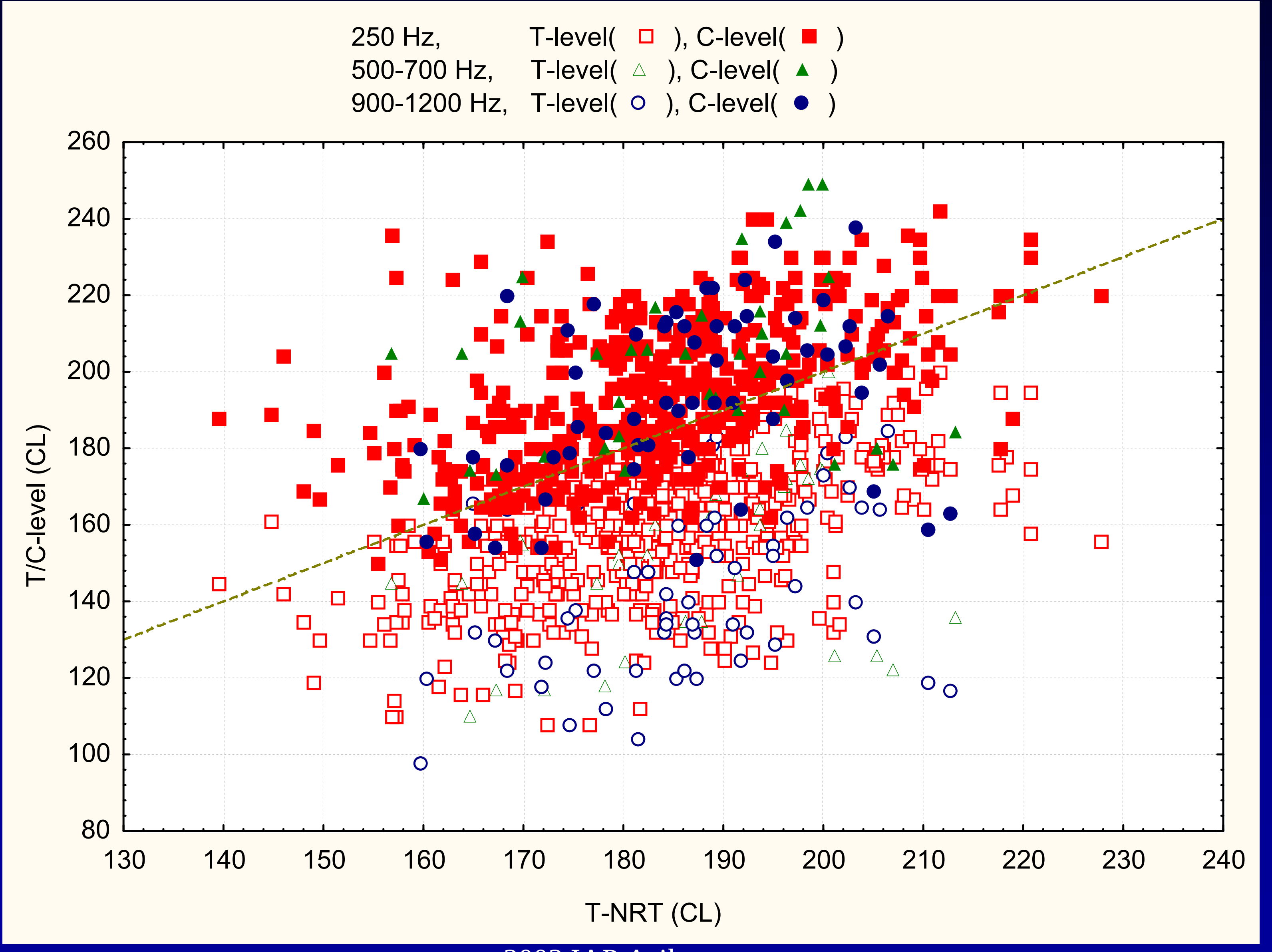
- NRT data is available prior to Speech Processor fitting
- NRT measurements can be made in the OR while the surgeon is finishing the operation
- Data for estimating the Neural Response threshold for all 22 intracochlear electrodes can be collected within less than 10 minutes in the Operating room using automated procedures



NRT threshold estimation

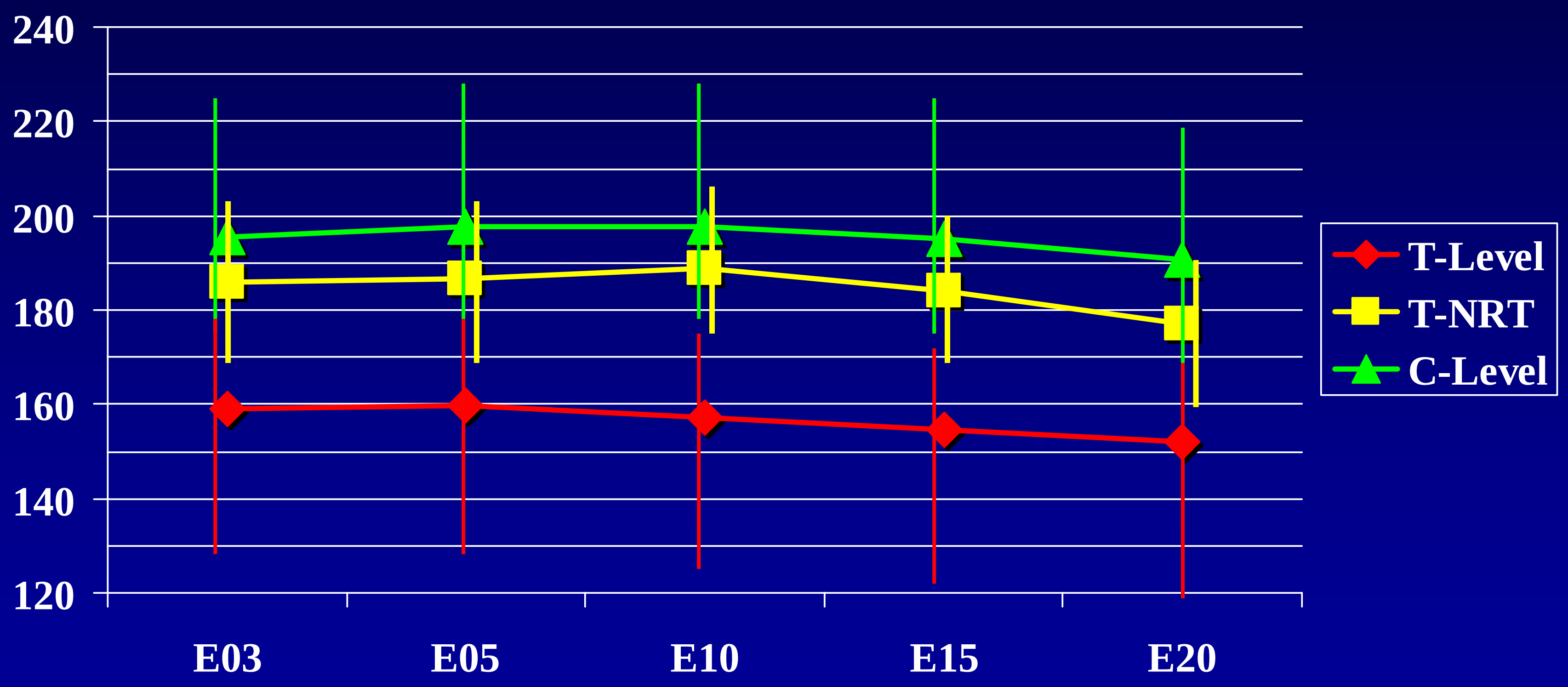


NRT and MAP T- and C- Levels



N=147

NRT vs. Map T/C-levels

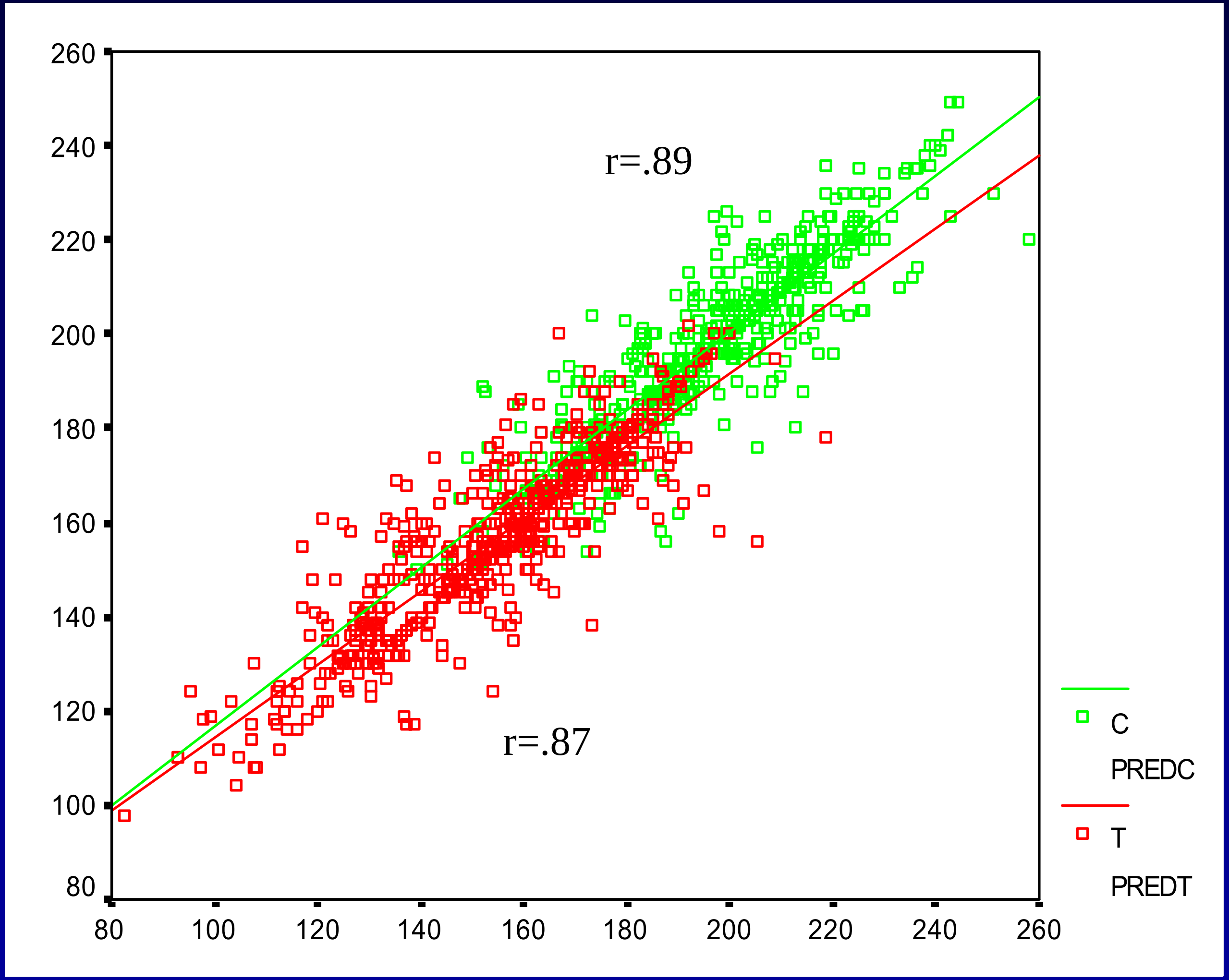


(n=147)

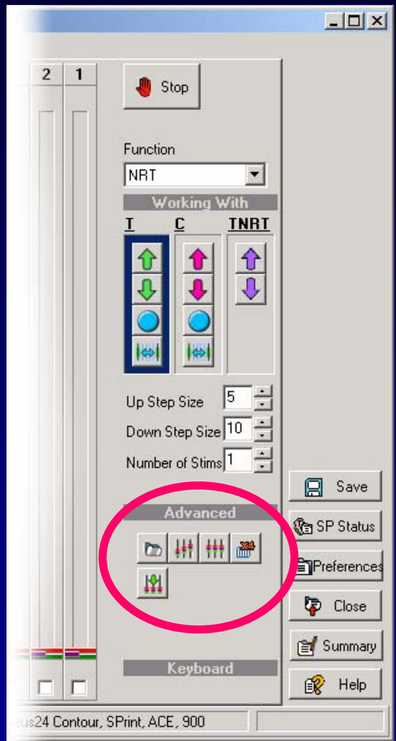
Adjustment of NRT threshold by behavioral measure

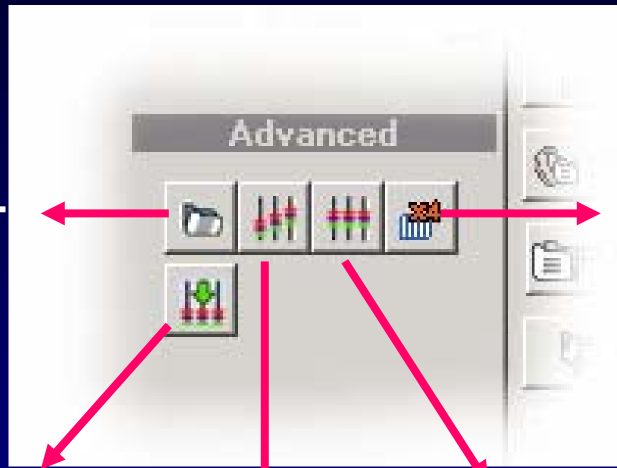
- When the method proposed originally by Brown et al. (2000), using one behavioral threshold value for electrode 10 to correct for the NRT profile offset, is applied to this data set, the correlation between T-NRT and predicted T- and C-levels increases to 0.89 and 0.87 respectively

Correlations of predicted and measured T/C levels



Fitting options based on NRT-threshold profiles





Import an NRT file

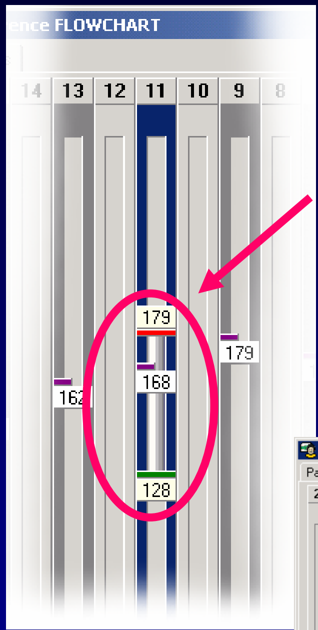
Progressive pre-set MAPs
(eg, Almqvist, Novy)

Reset TNRT levels to zero

Parametric Shift/Tilt profile
(eg, Smoorenburg, Franck)

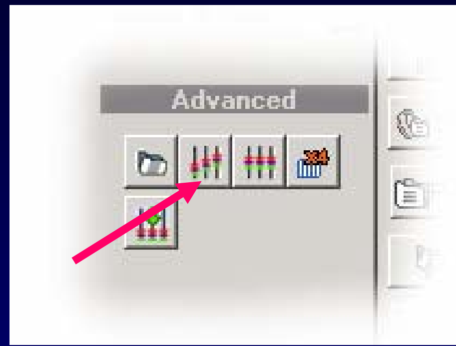
Determine T/C offset
(eg, Brown, Cooper & Craddock)

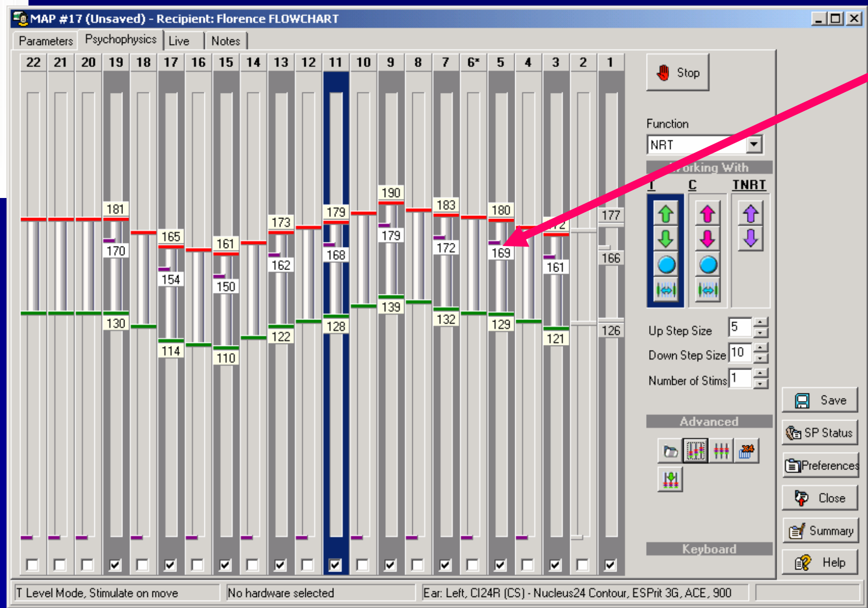
T/C Offset estimation
(first suggested by Brown et al.)



1. Measure behavioural T/C levels on 1 channel

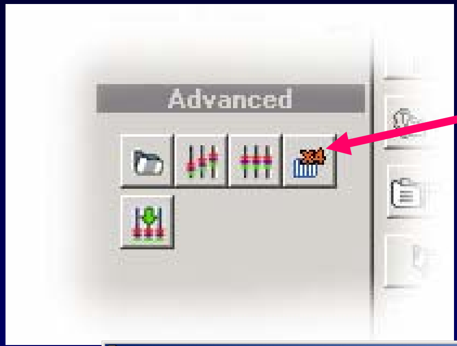
2. Apply T/C offset to whole profile





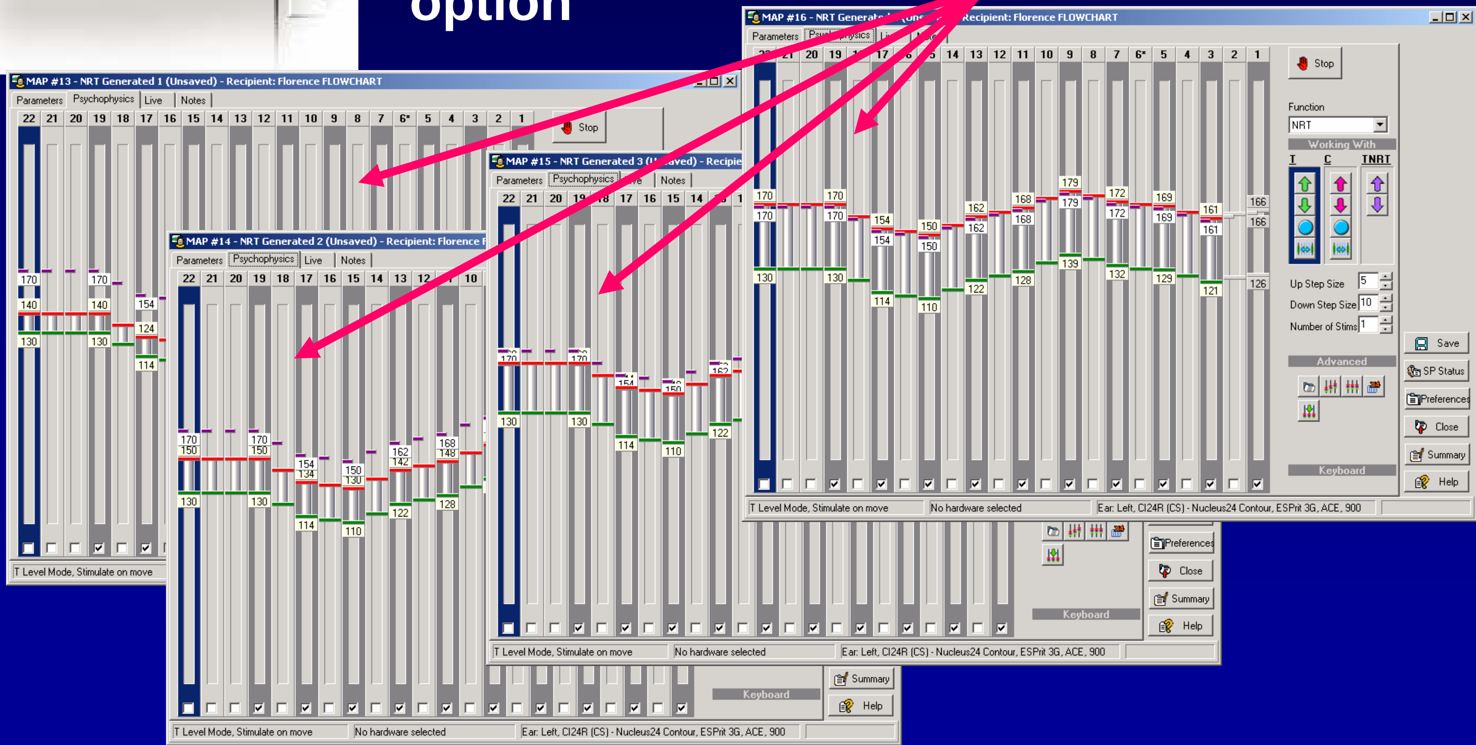
3. MAP is created

Progressive T/C Maps
(suggested by Almqvist / Novy…)

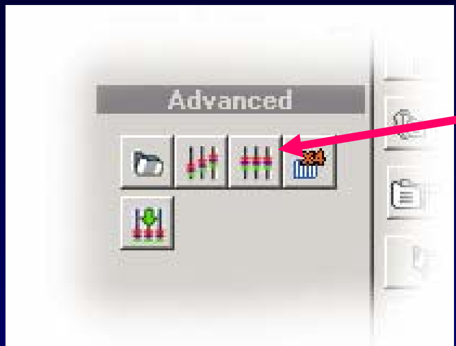


1. Select progressive preset MAP's option

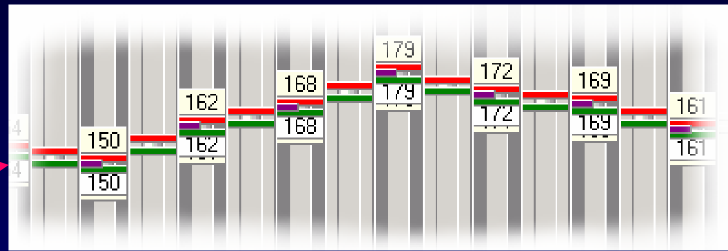
2. Sequence of 4 MAPs created (place in P1 – P4 of SPrint)

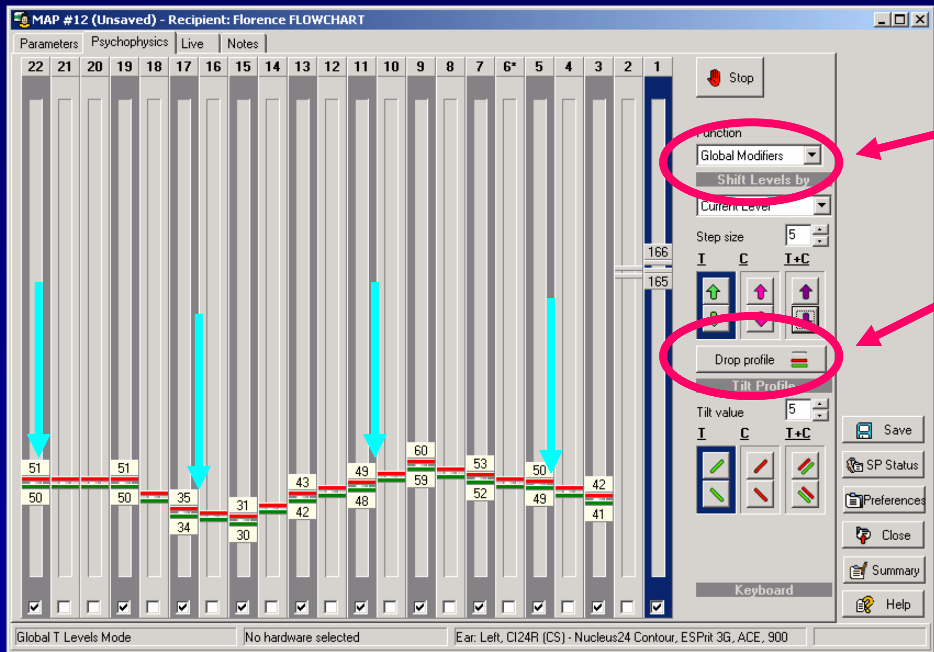


Parametric Shift/Tilt
(suggested by Smoorenburg et al.)



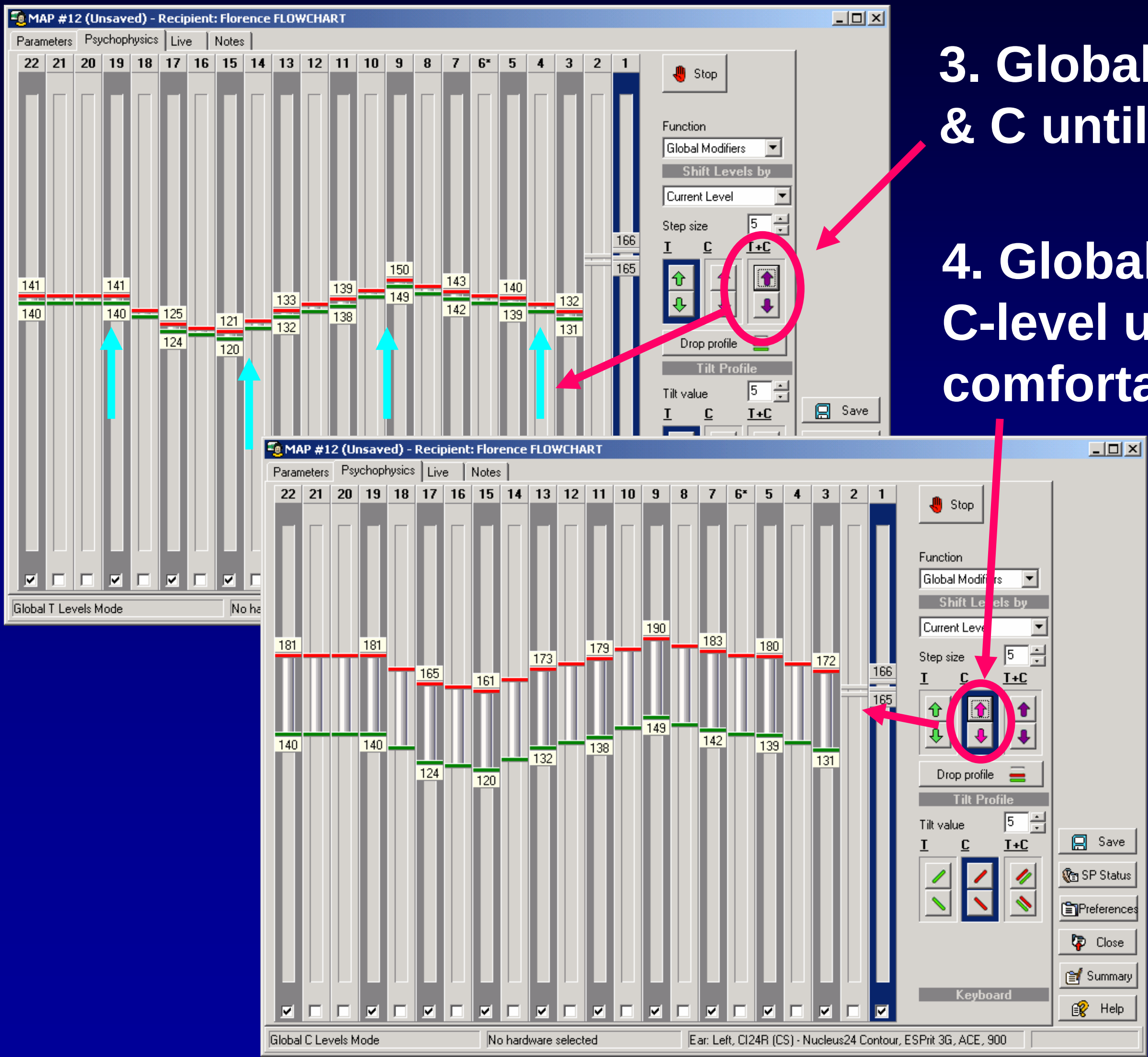
1. Set T levels equal to TNRT profile, C levels 1 CL higher





2. Select "Global Modifiers" and then "Drop Profile"

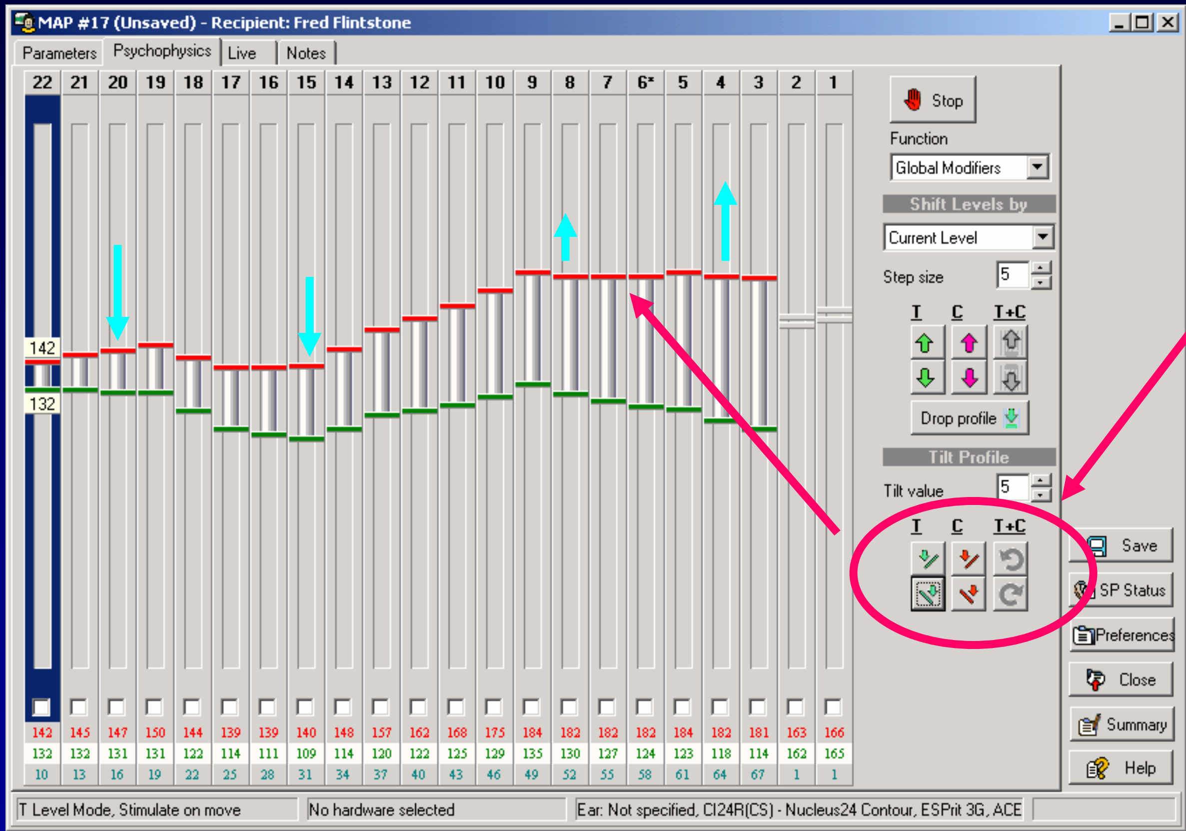
Parametric Shift/Tilt
(suggested by Smoorenburg et al.)



3. Globally increase T & C until just audible

4. Globally increase C-level until comfortable

Parametric Shift/Tilt
(suggested by Smoorenburg et al.)



5. Apply tilt factors to T/C levels

NOTE: In the Parametric Shift/Tilt technique, tilts are more typically applied when establishing a live MAP detection threshold using a MAP dynamic range of 1 CL.

Using intra-operative NRT thresholds for initial programming in adults: an evaluation of two methods

Craddock LC, Cooper HR, Wiegman J
and Fielden, CL, Birmingham UK (2003)

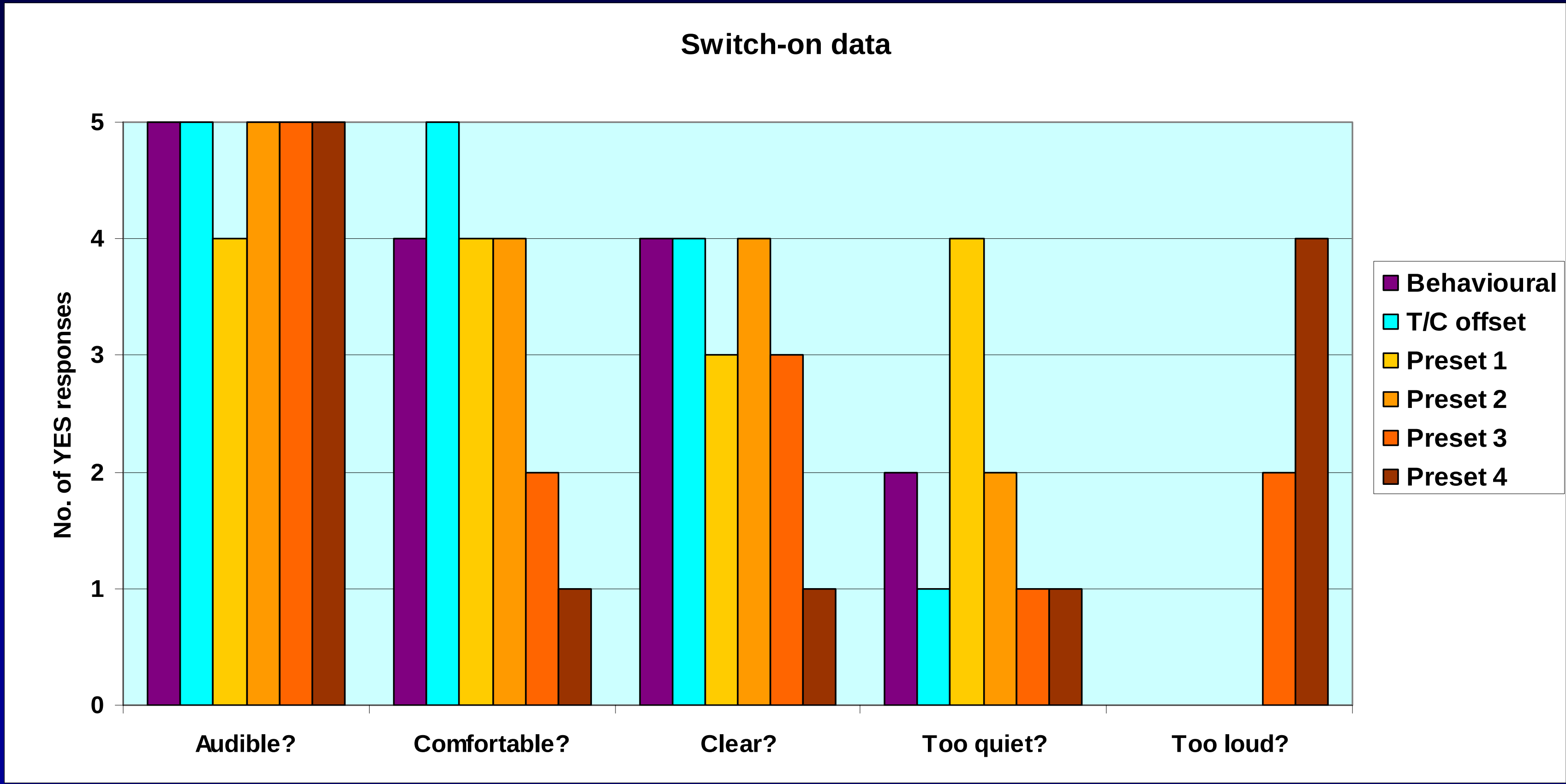
T/C Offset

- T-NRT's measured
- Behavioural T/C's entered on 3 channels
- T/C offset determined at these 3 points
- Remaining T/C offsets interpolated

Progressive Preset

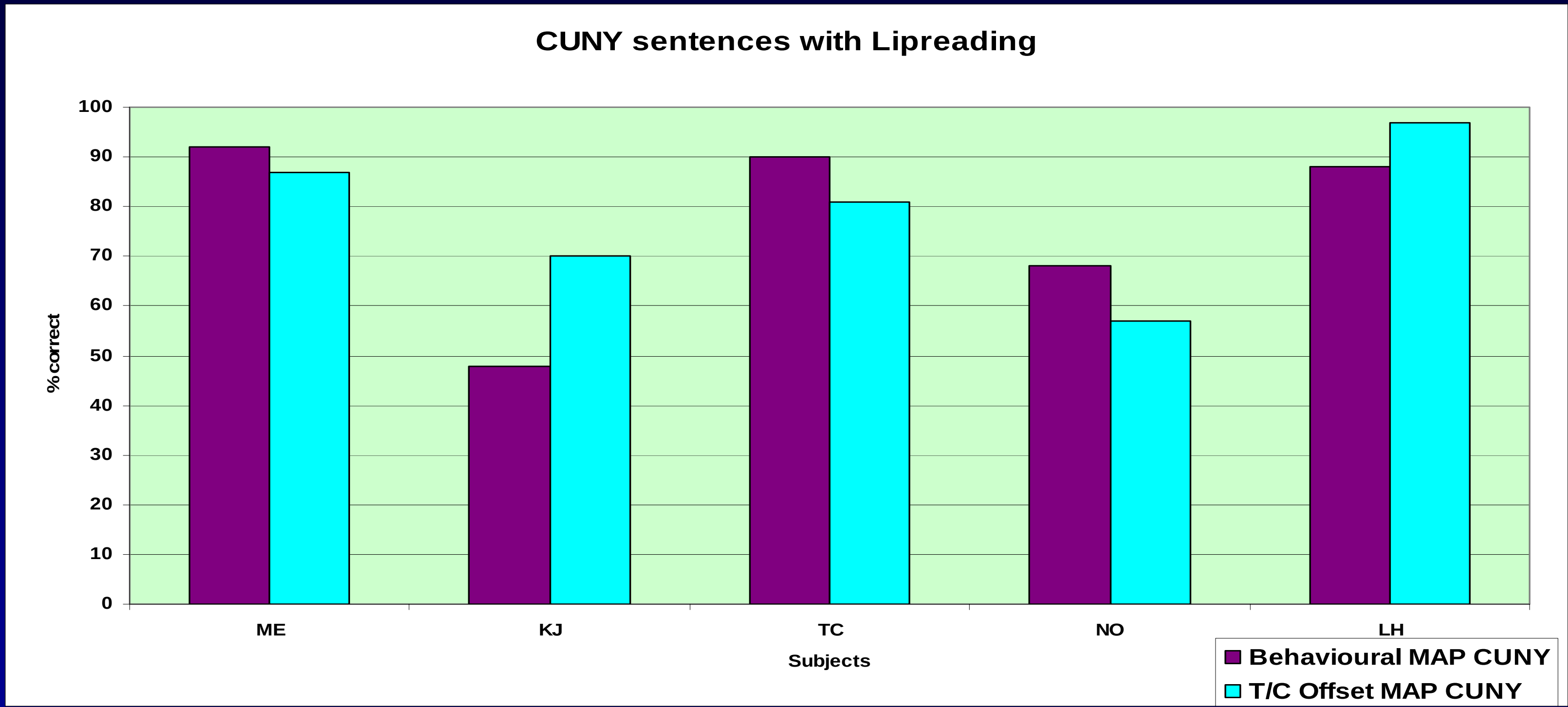
- 4 preset MAPs based on T-NRT only:
- a) T= T-NRT - 40
  C= T-NRT - 30
- b) C= T-NRT - 20
- c) C= T-NRT - 10
- d) C= T-NRT

Initial Quality of Sound Questionnaires



Craddock LC, Cooper HR, Wiegman J and Fielden, CL, Birmingham UK (2003)

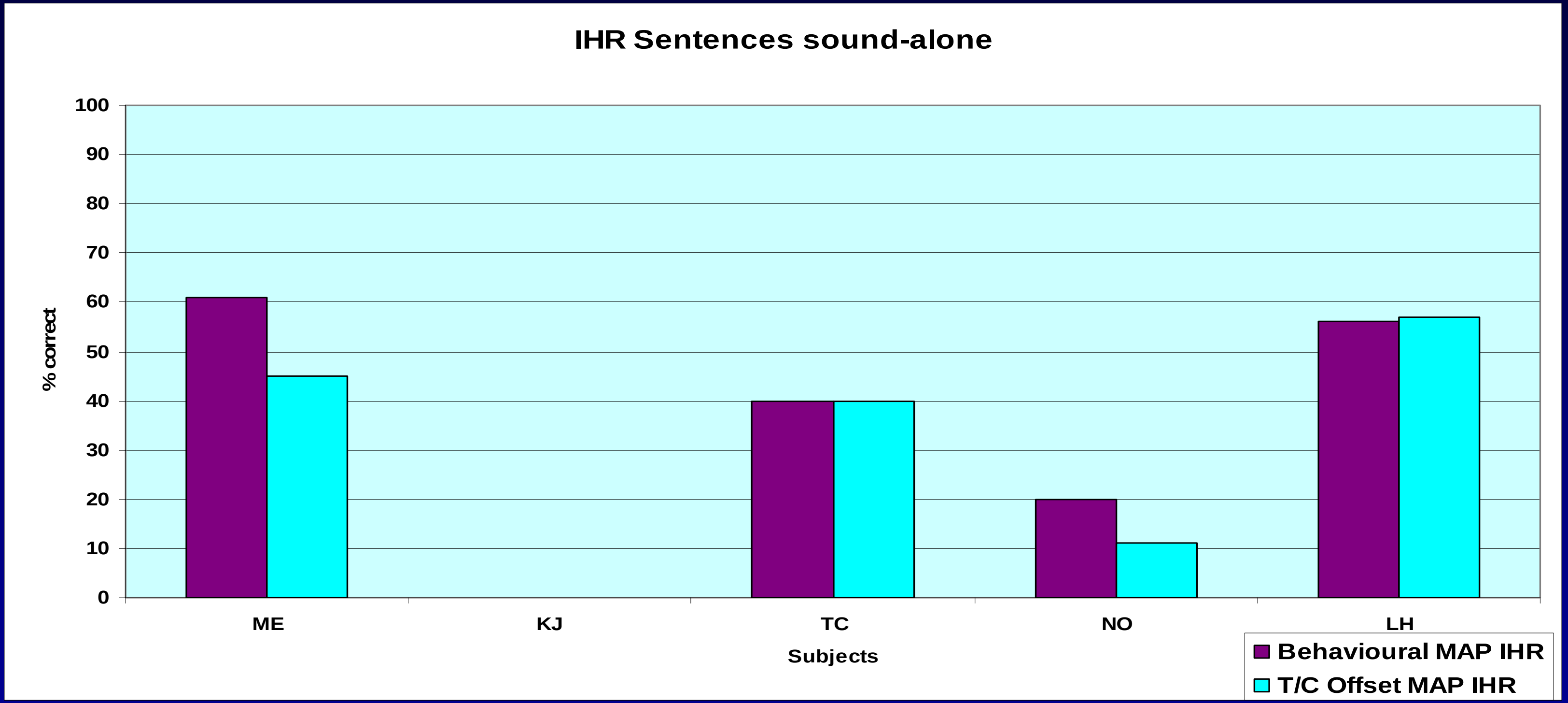
Week 1 speech performance



No statistically significant difference in performance between MAPs ($p=0.857$)

Craddock LC, Cooper HR, Wiegman J and Fielden, CL, Birmingham UK (2003)

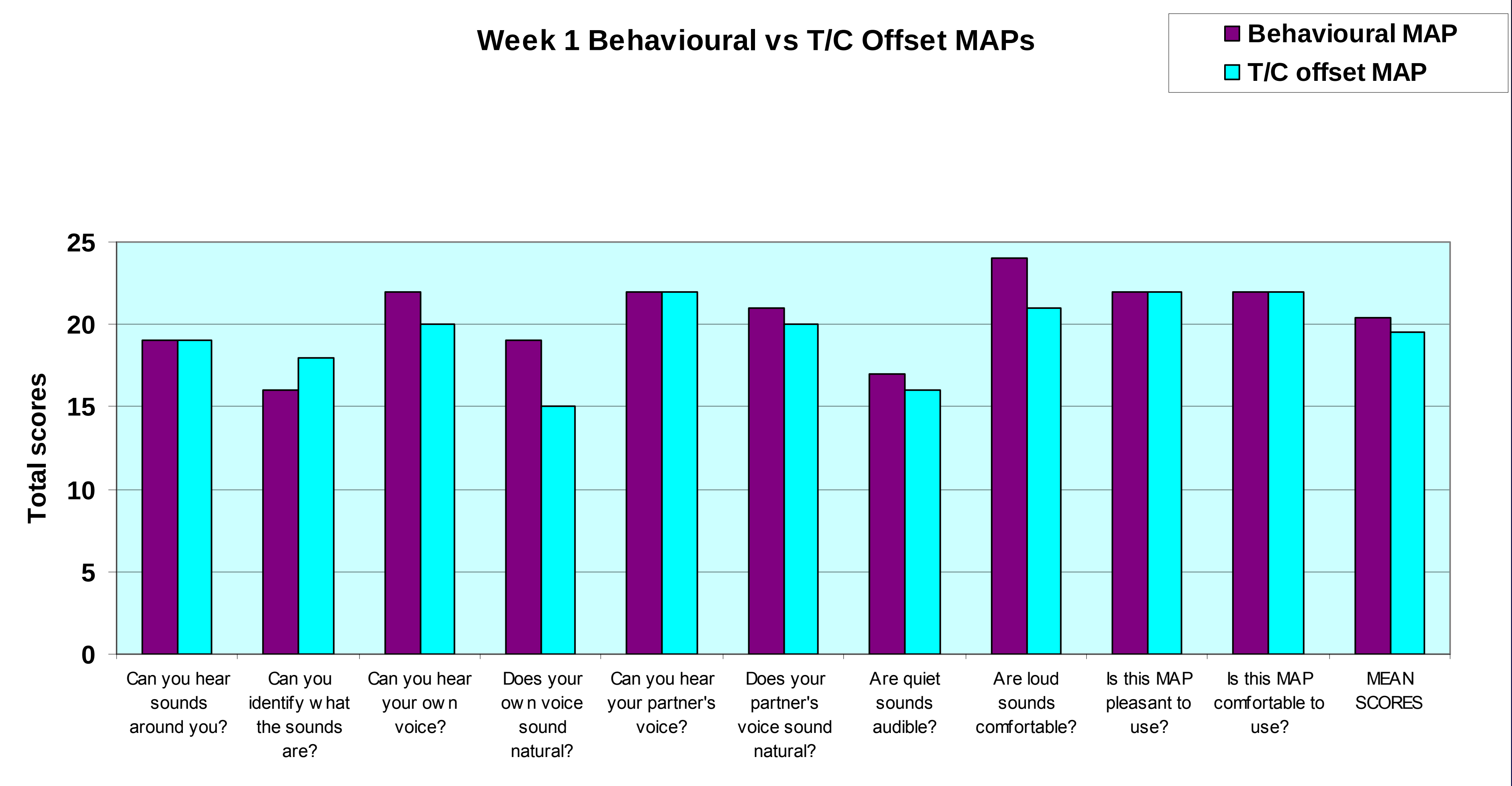
Week 1 speech performance



No statistically significant difference in performance between MAPs (p=0.224)

Craddock LC, Cooper HR, Wiegman J and Fielden, CL, Birmingham UK (2003)

Week 1 Questionnaire



Craddock LC, Cooper HR, Wiegman J and Fielden, CL, Birmingham UK (2003)

Conclusions

- Can intra-operative NRT responses be used to create acceptable switch-on MAPs in adults? **YES**
- Is behavioural information necessary?
- How do these MAPs compare with behavioural MAPs for new listeners?

Craddock LC, Cooper HR, Wiegman J and Fielden, CL, Birmingham UK (2003)

Conclusions

- Can intra-operative NRT responses be used to create useable switch-on MAPs in adults? YES
- Is behavioural information necessary? **YES !**
- How do these MAPs compare with behavioural MAPs for new listeners?

Craddock LC, Cooper HR, Wiegman J and Fielden, CL, Birmingham UK (2003)

Conclusions

How do T/C offset MAPs compare with behavioural MAPs for new listeners?

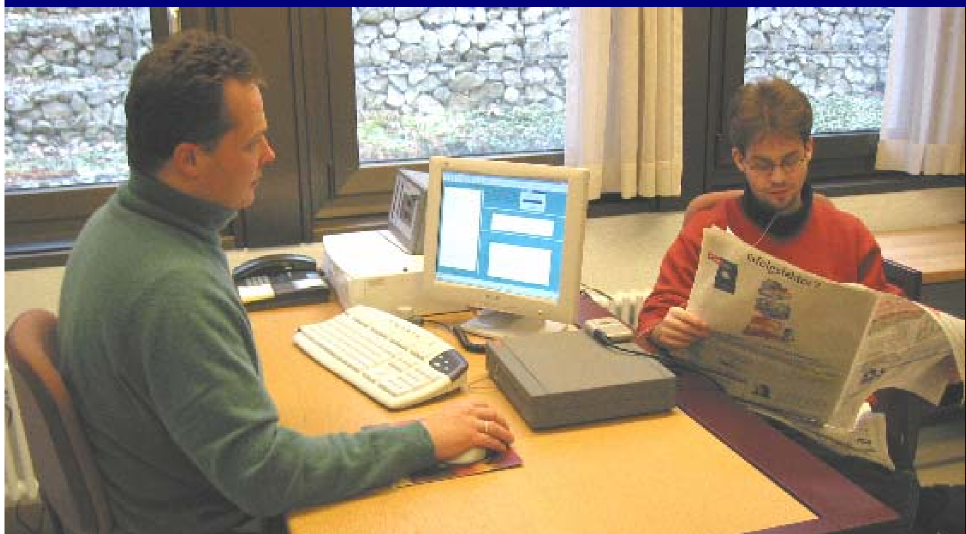
- Equivalent speech performance
- Improved soundfield responses
- Equivalent listening performance
- Often preferred.

Intra-operative NRT combined with limited behavioural information is a valid method of programming adults at switch-on.

Craddock LC, Cooper HR, Wiegman J and Fielden, CL, Birmingham UK (2003)

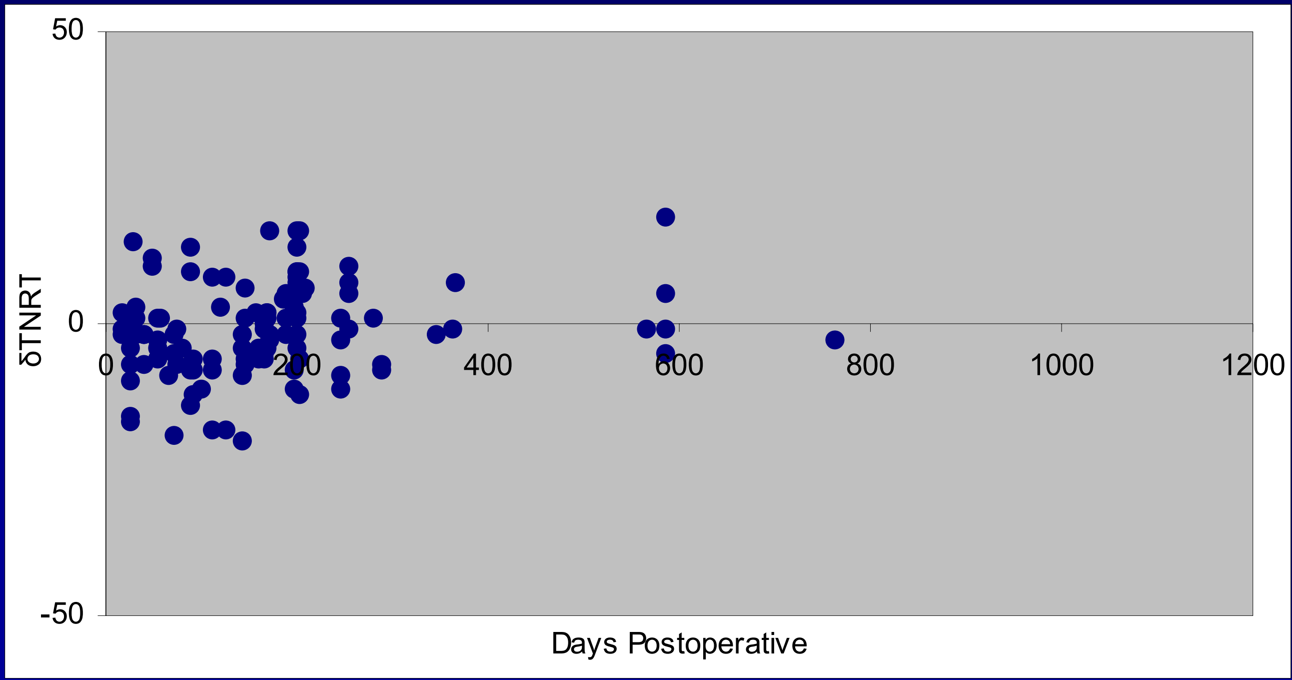
Postoperative NRT measurements

- Detect possible changes of neural responses
- The activity of the auditory nerve can be monitored routinely for possible changes
- The measurements can be performed in short time while the patient can relax or play



TNRT changes over time

- Long term observations (Lai *et al*, 2003) suggest that the neural response amplitudes are generally stable in the long term. Changes are more likely to occur within the first year after implantation
- Changes in TNRT, however, remained reasonably small (within system measurement error) and constant over time



Lai, WK, Aksit M, Akdas F, Dillier N (2003). Longitudinal behaviour of Neural Response Telemetry dataand clinical implications. Int J. Audiology (in Press)

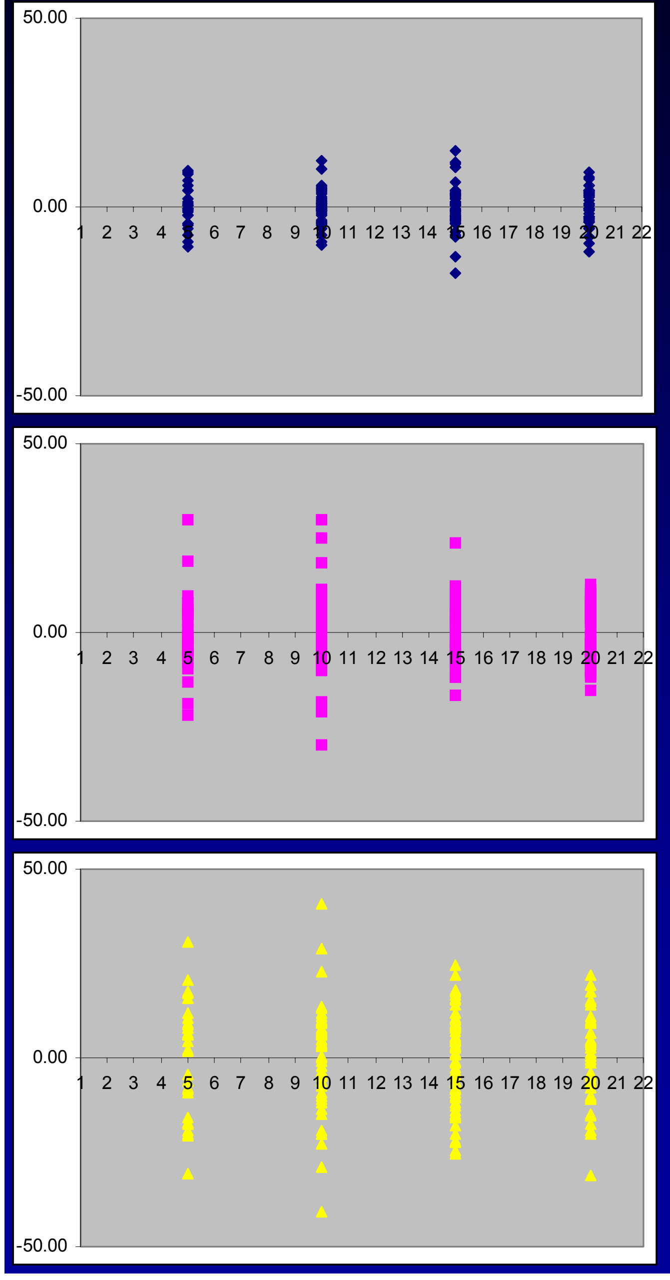
Questions

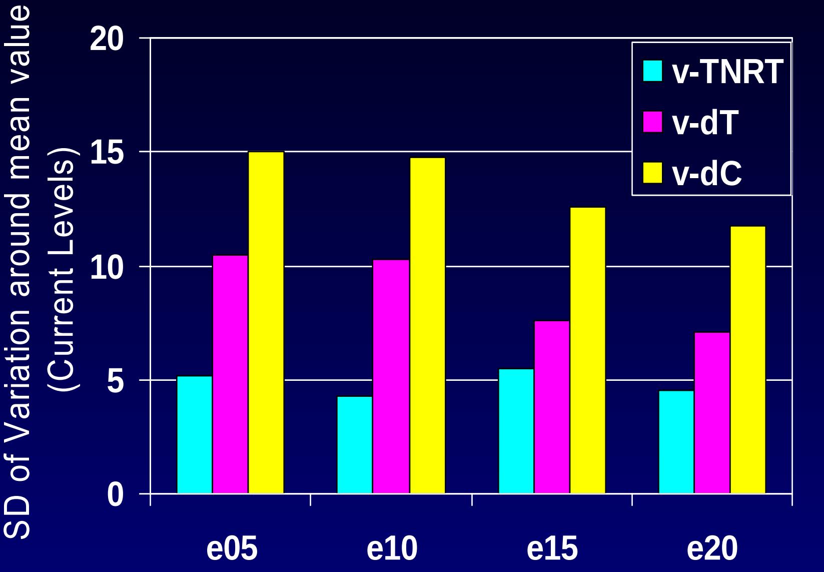
- How do TNRTs across the electrode array (ie. the profile) change over time?
- How does this affect the approximation to actual Map T & C levels across the electrode array?

Subjects and Data

- 26 subjects were monitored over 36 months from time of implantation
- TNRTs computed from AGFs collected from up to 4 electrodes (e05, e10, e15 & e20) evenly spread out across the array
- Intraoperative TNRT data as the baseline, and compared to subsequent (postoperative) data for changes
- TNRT also compared with Map T & C levels from the same day when the postoperative NRT data was collected
  - dT: difference between TNRT and T-level
  - dC: difference between TNRT and C-level

Variations around mean value

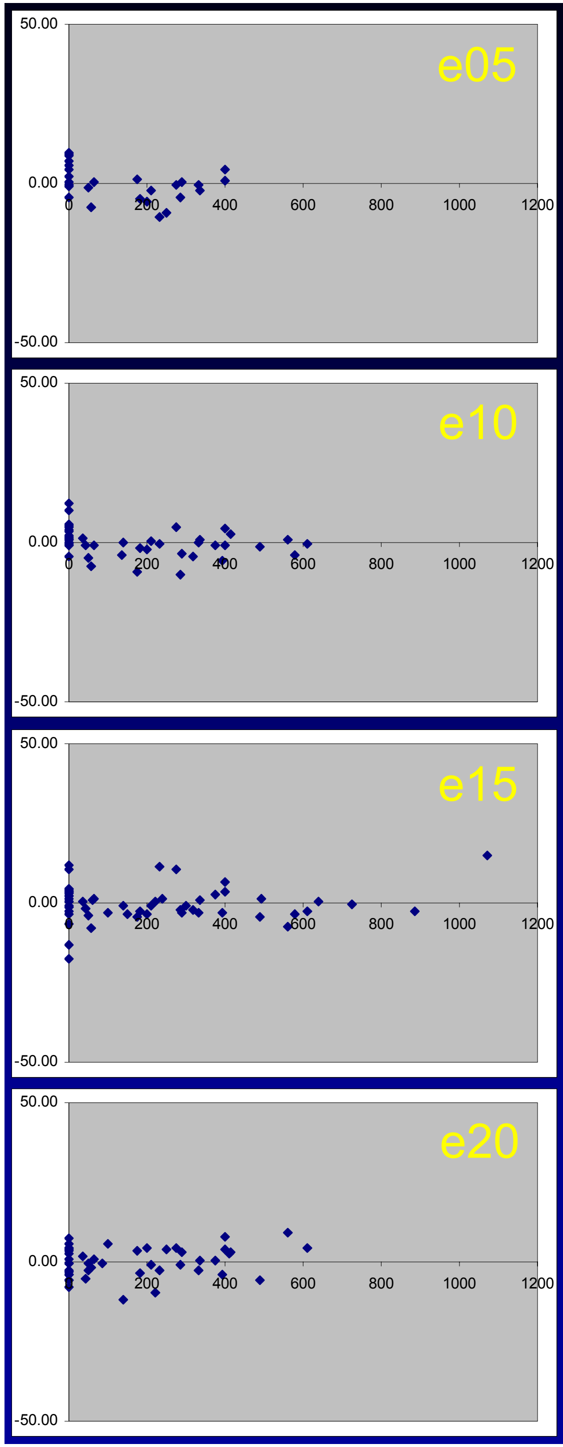




► Variation of TNRT around mean value is relatively small and similar across array.

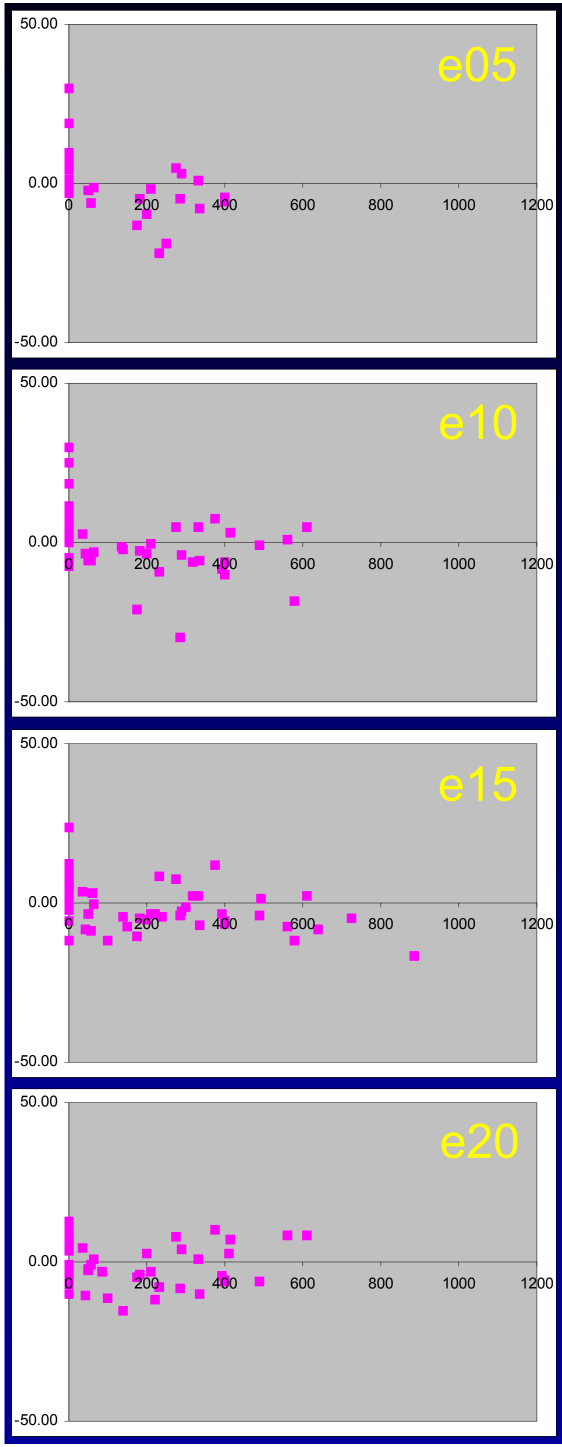
► Variation of dT around mean value is larger, and diminishes towards apical end of array.

► Variation of dC around mean value is largest, also diminishing towards apex.



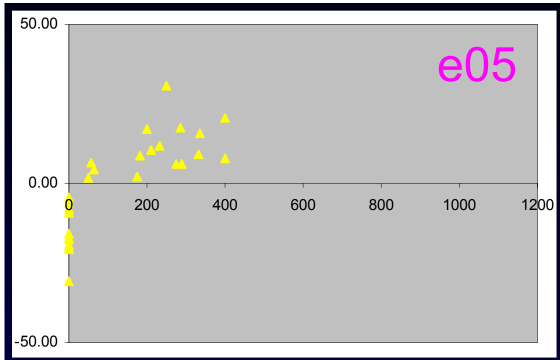
Variation over time: TNRT

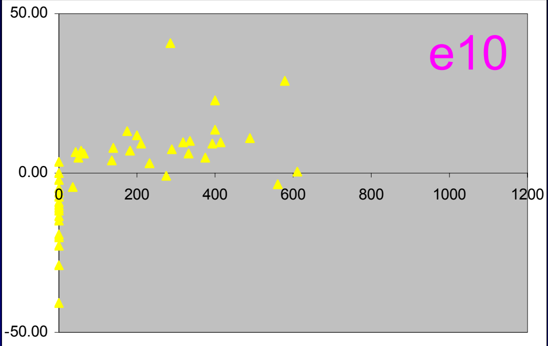
- Variation around the mean TNRT value remains small over time
- Variations do not grow nor diminish over time
- Variation across the array appears to be similar

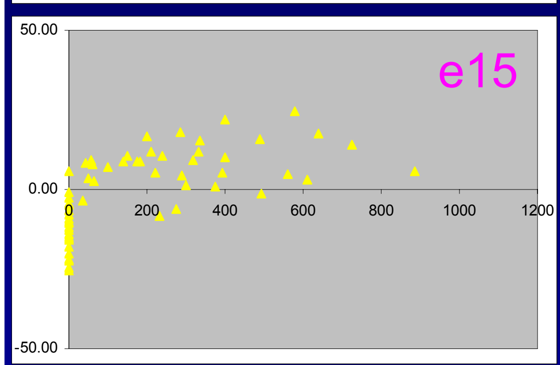


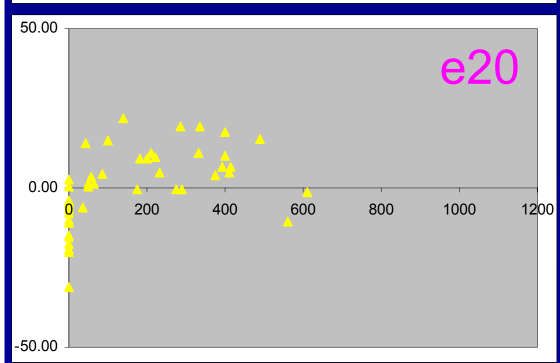
Variation over time: dT

- Variation around the mean dT is slightly larger at the beginning (initial fitting session)
- Variations diminish with time
- Variations are slightly less towards apical electrodes









Variation over time: dC

- Variation around the mean dC is largest at the beginning (initial fitting session)
- C levels typically underestimated at the beginning (dC values less than mean value)
- Variations diminish with time
- Variations are slightly less towards apical electrodes

Discussion

- TNRT profiles appear to be generally stable over time, and variations can be accounted for by measurement noise.
- Differences between TNRT and Map T & C levels show greater variations over time, mainly due to changes in the Map levels.
- Differences between TNRT and C-levels fluctuate more over time compared to differences with T-levels.
  - C-levels are more subjective in nature than T-levels, and tend to be more conservatively set in the initial fitting session.
- Slightly less variations towards apical electrodes probably due to lower pitch sounds being more pleasant and therefore less prone to changes in tolerance or mood of subjects (applies mainly to C-level).

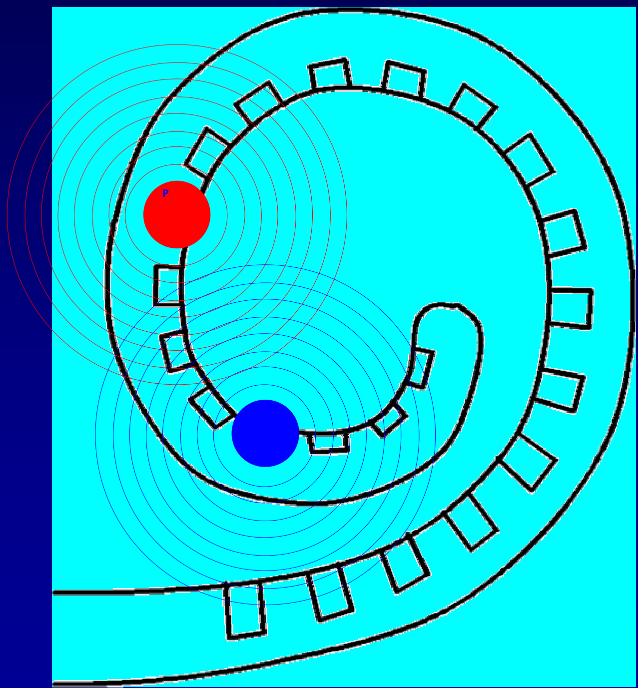
Conclusions (postop. NRT)

- TNRT profiles can generally be regarded as stable over time.
- Changes in the relationship between TNRT and Map levels over time are mainly due to changes in the Map T & C levels.
- Changes in the behavioural Map T & C levels are difficult to predict, resulting in reduced accuracy when using the TNRT profile to predict the map profiles.
- Further analysis is required to determine how variations over time of dT and dC may be accounted for on an individual basis
- NRT measurements can provide valuable information for speech processor map generation but do not completely replace behavioural methods

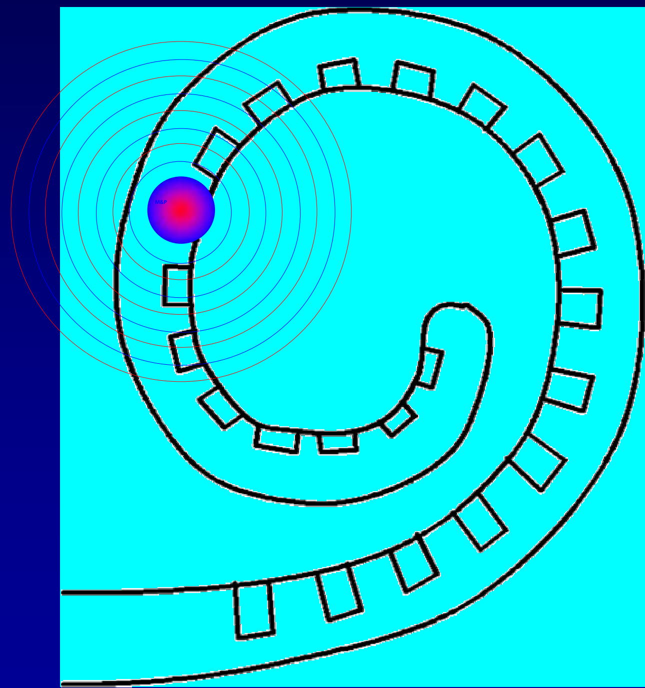
New and future NRT options

- Selectivity measures through variation of masker electrode
- Statistical signal analysis for adaptive procedures and improved recording quality, neural networks and classifications algorithms
- Improved amplifier and electronic circuit characteristics (RP8)
- Fully automatic NRT based fitting system (future?)

Selectivity and spread of excitation measurements: variations of masker and recording electrode position

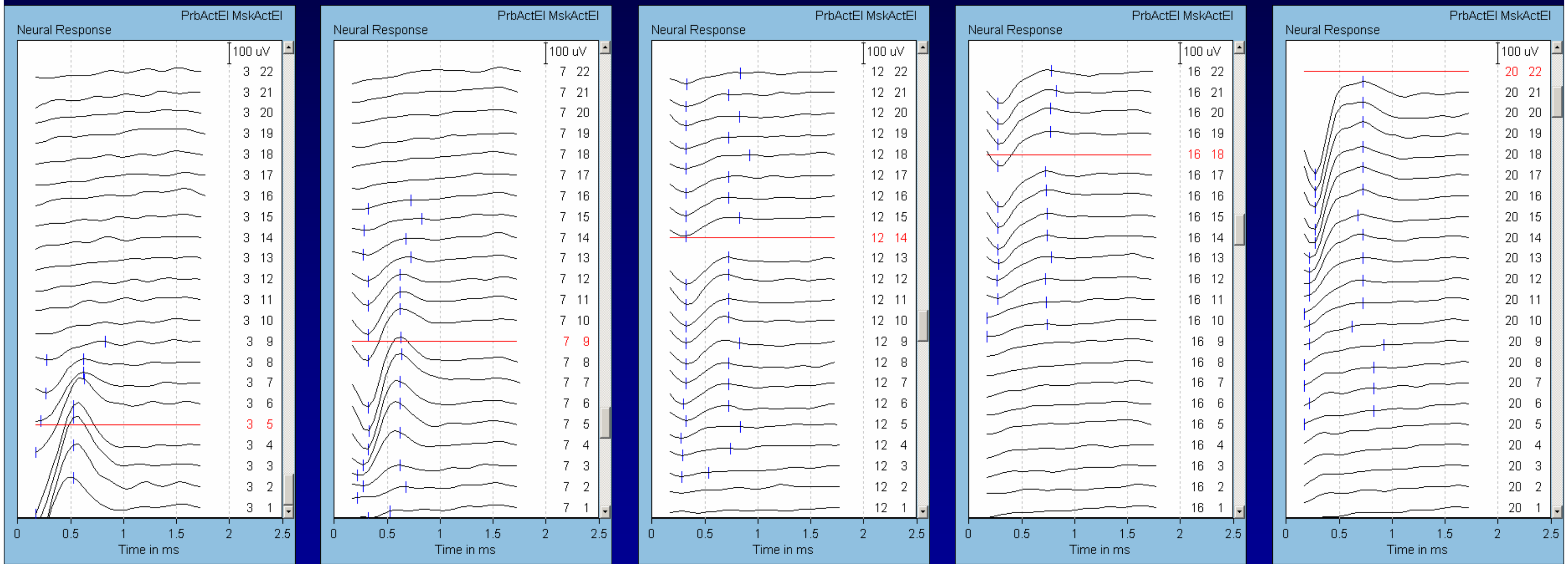


Masker and Probe on different electrodes



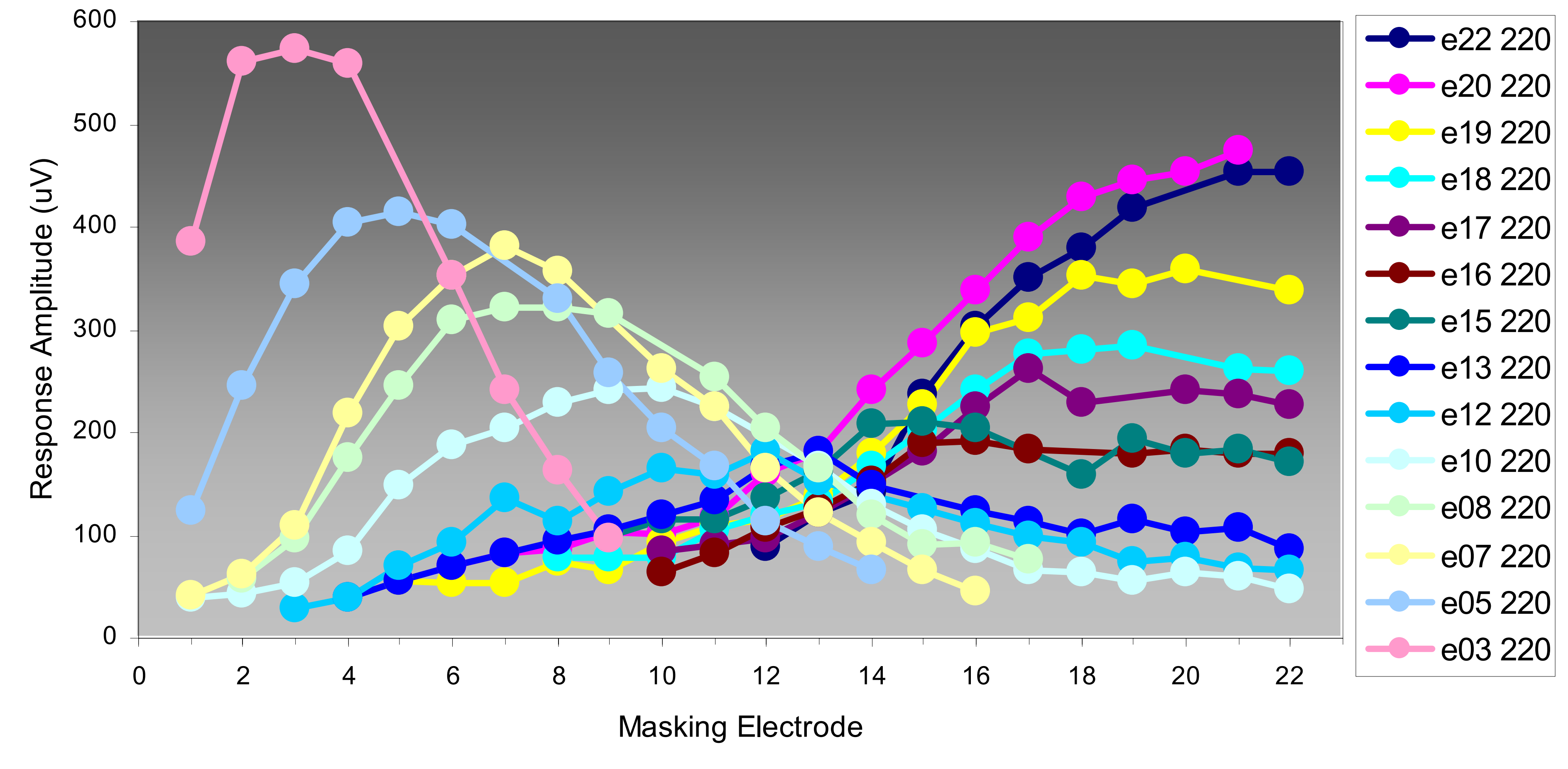
Masker and Probe on same electrode

Masker electrode variation

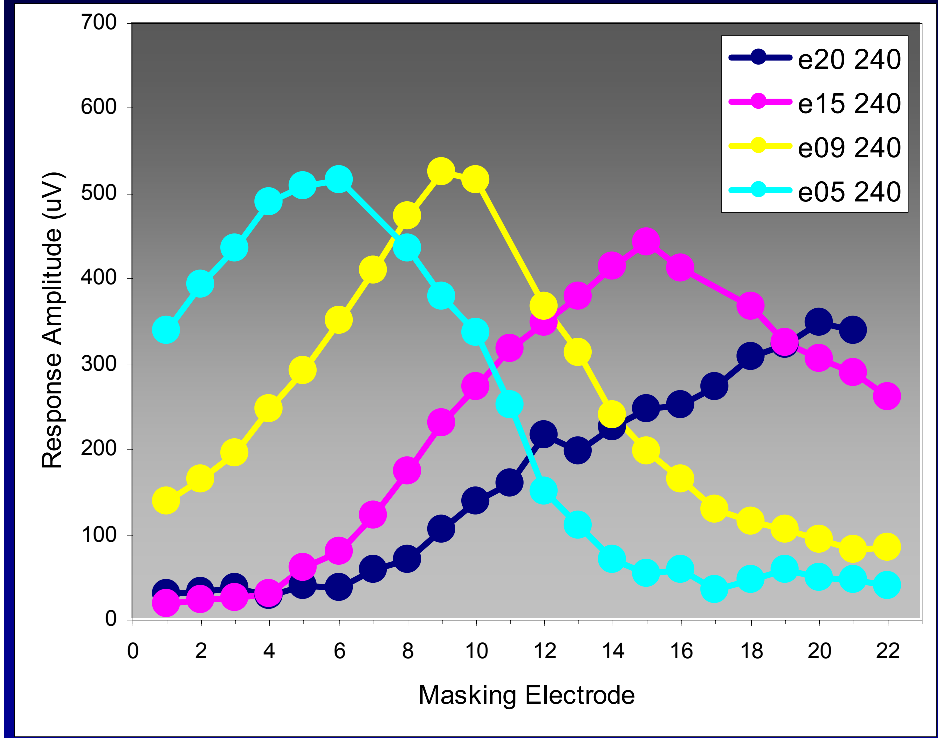


3 7 12 16 20

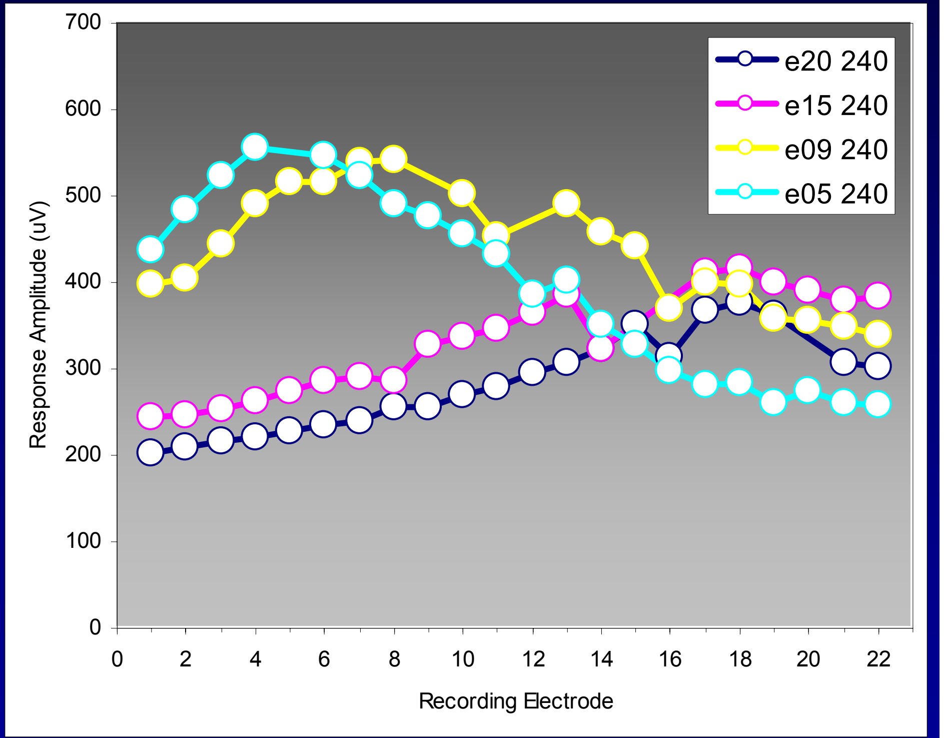
Masking series curves for different probe electrodes



Masking and Recording Site Series

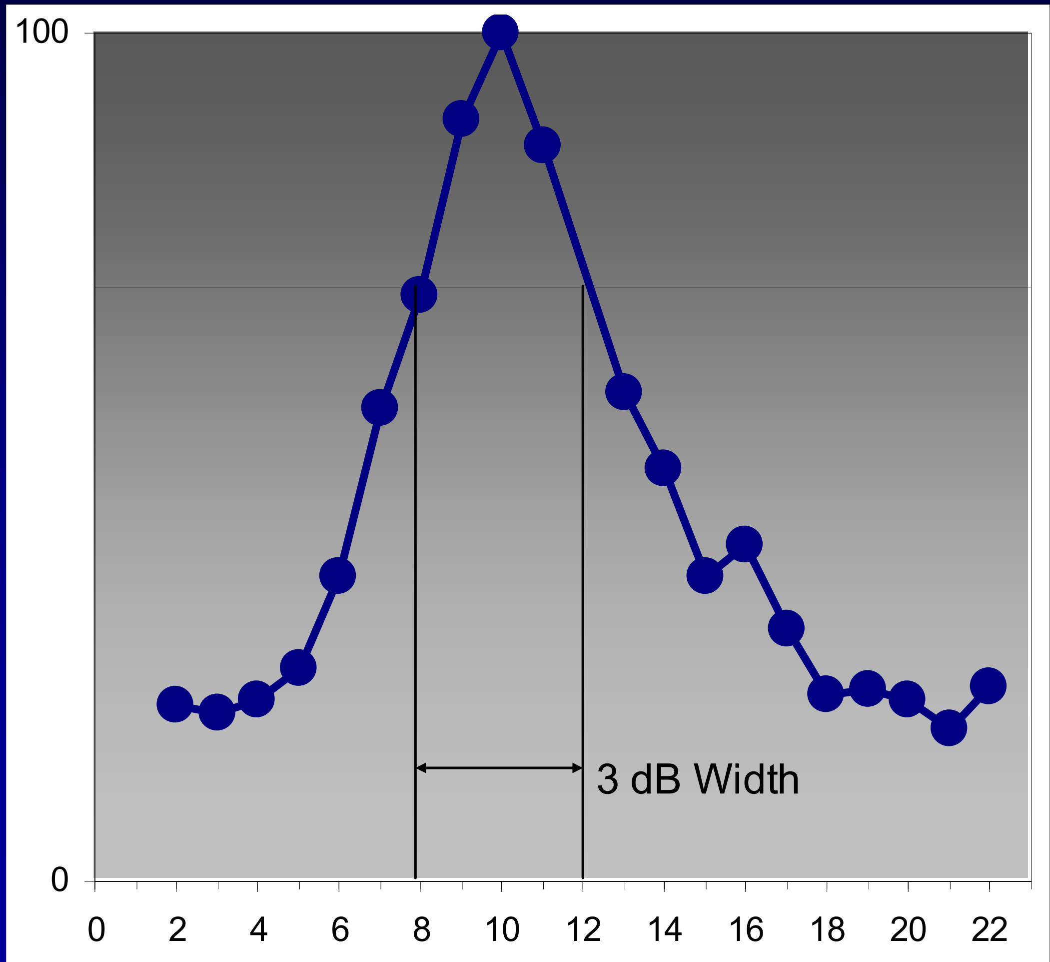


Masking series

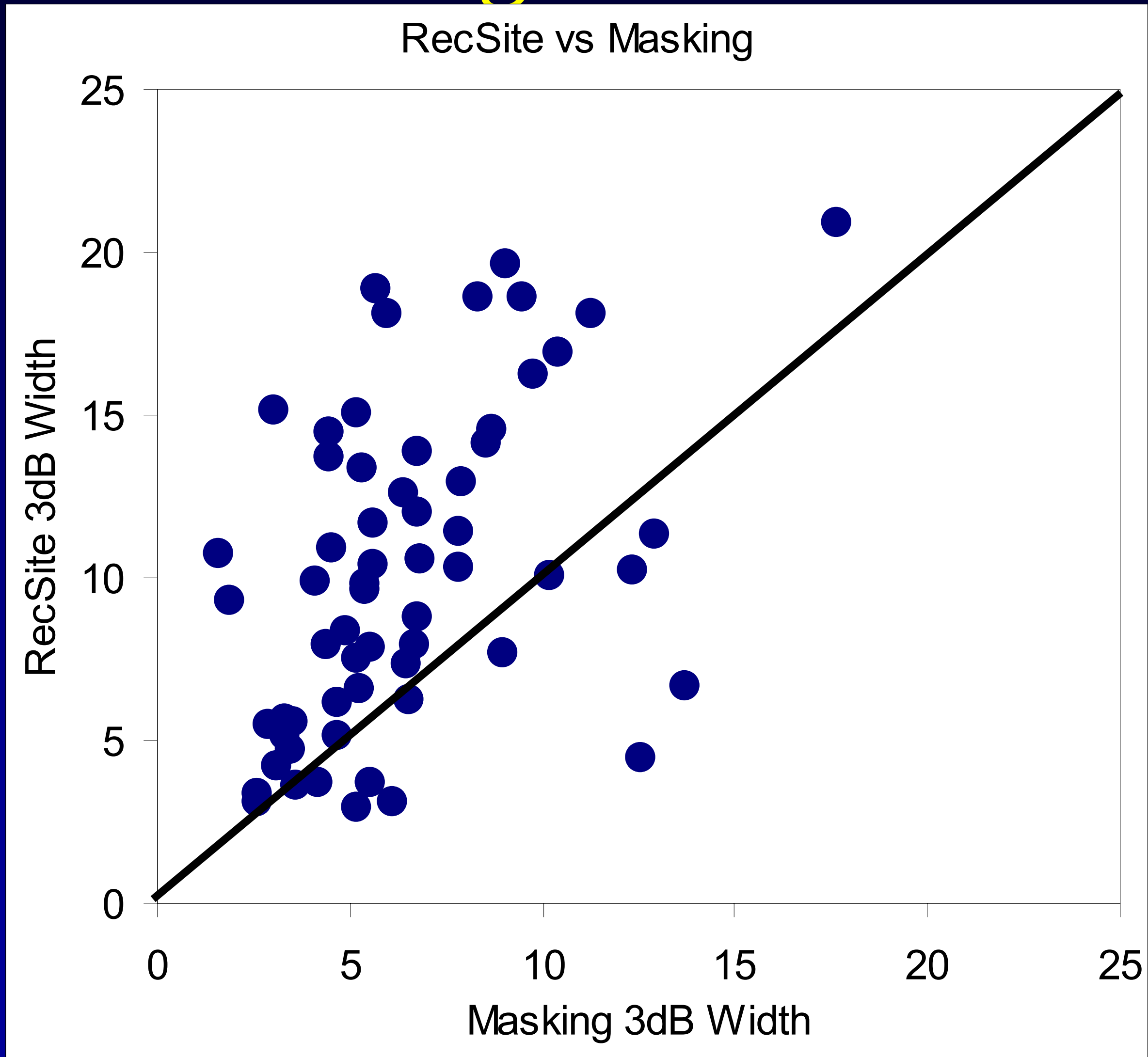


Recording site series

3 dB width calculation for masking series curves

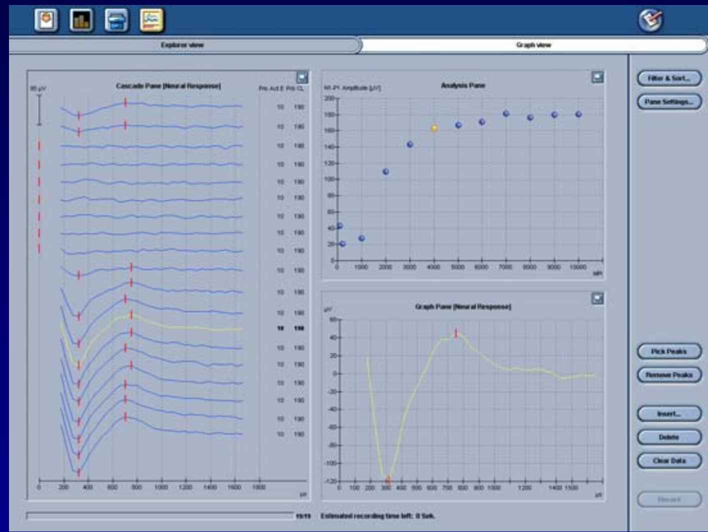


3 dB widths of masking vs. recording site curves



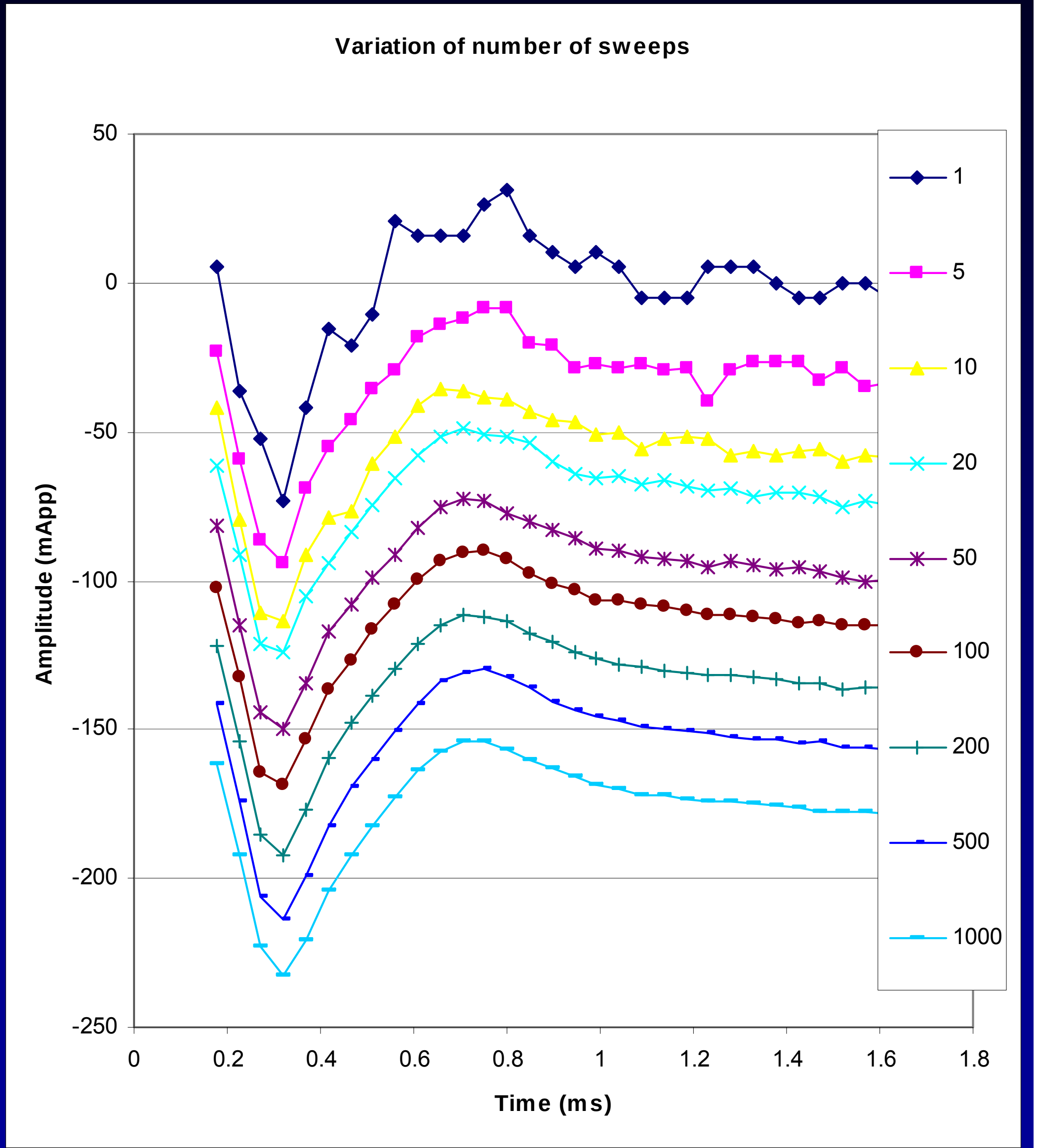
Research Platform (RP8)

CI24RE **L34SP** **NPE**

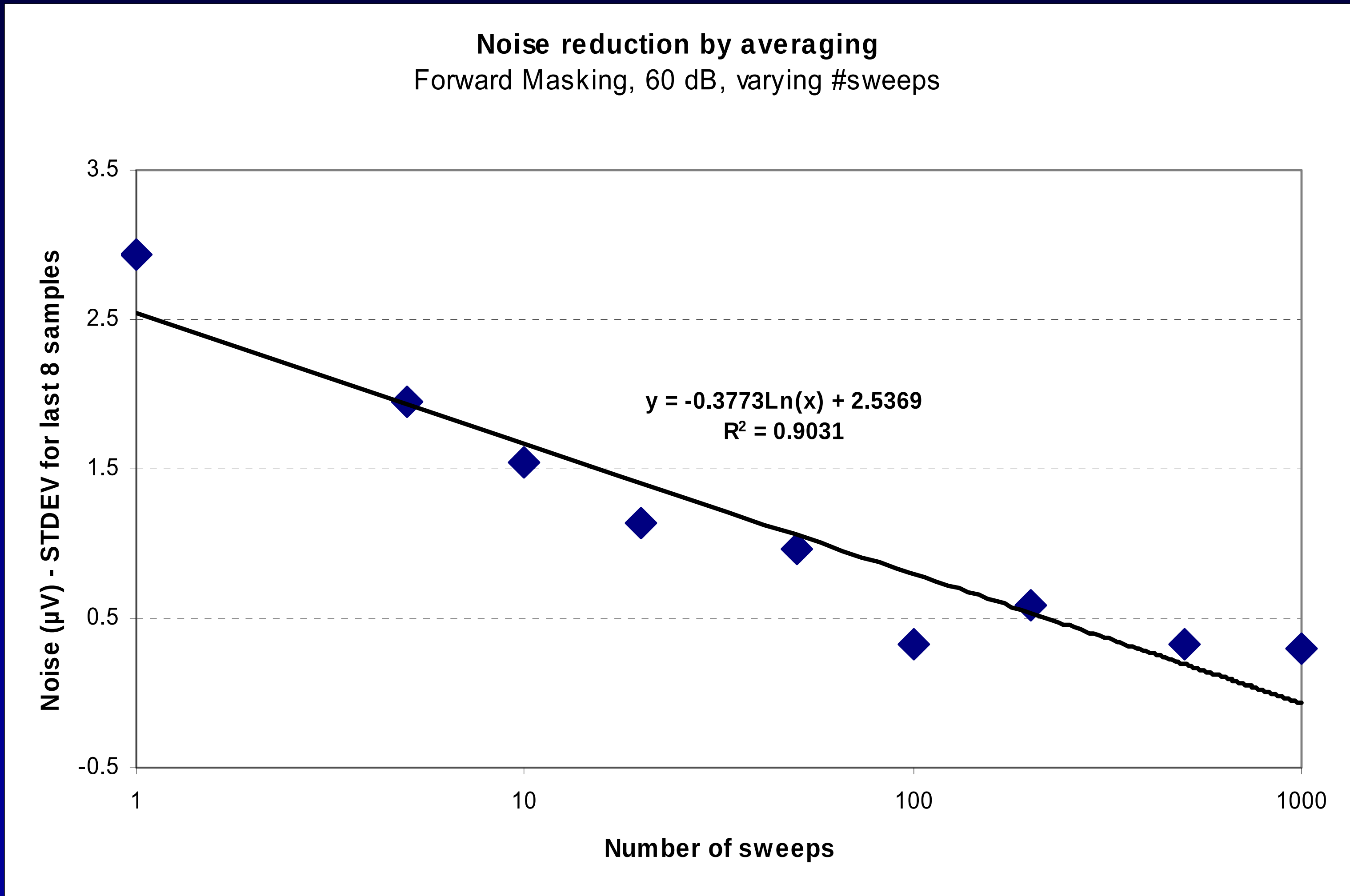


- Improved NRT amplifier linearity, symmetry and saturation recovery
- Inbuilt artifact suppression features.
- Fine gain adjustments: 40, 50, 60, 70 dB
- NRT sample rate: 20,000 samples per second, oversampling up to 200.000 samples per second.
- Sample windows: 16, 32 or 64 samples per sweep.

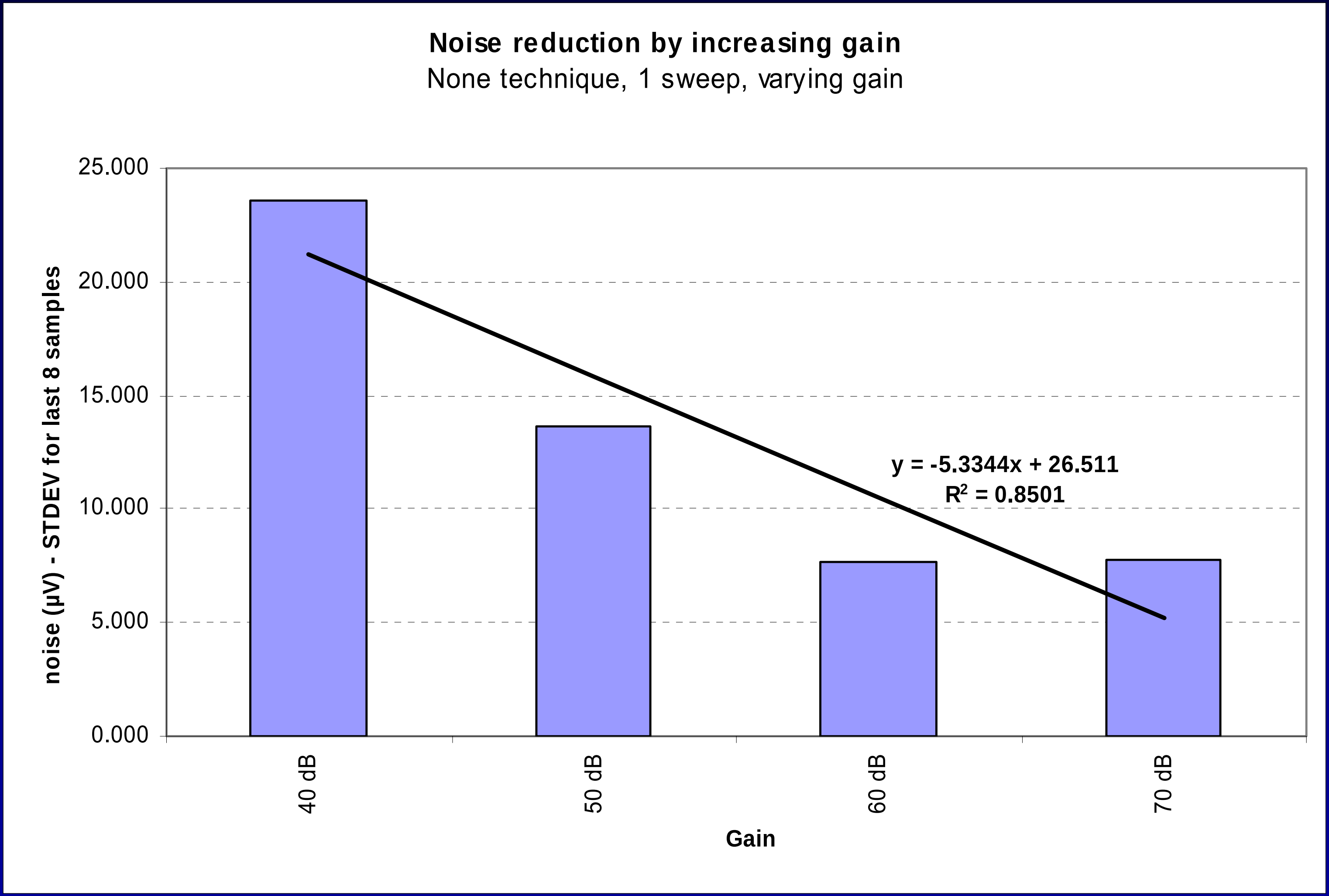
Variation of number of averaged sweeps



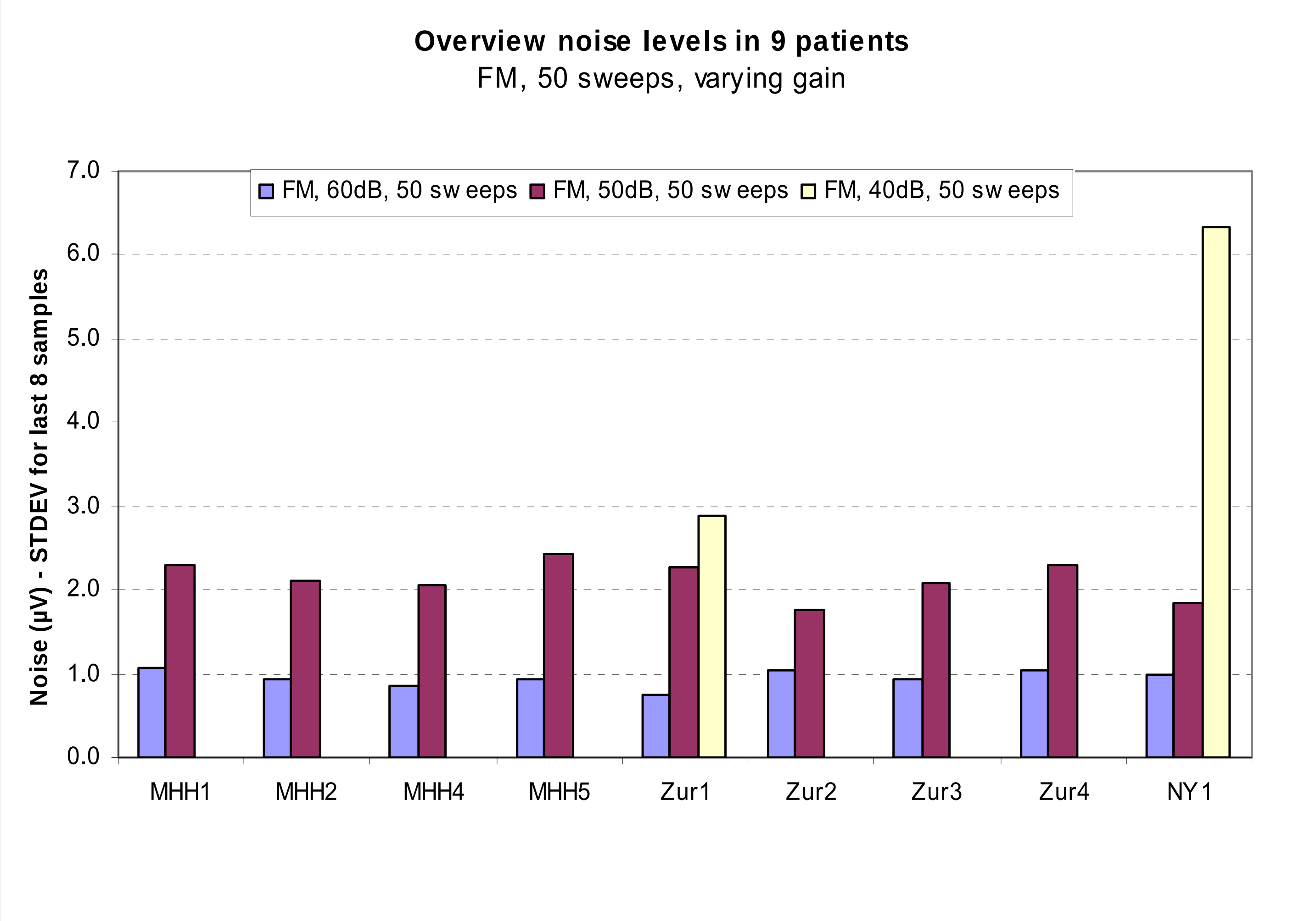
Noise level vs. number of sweeps



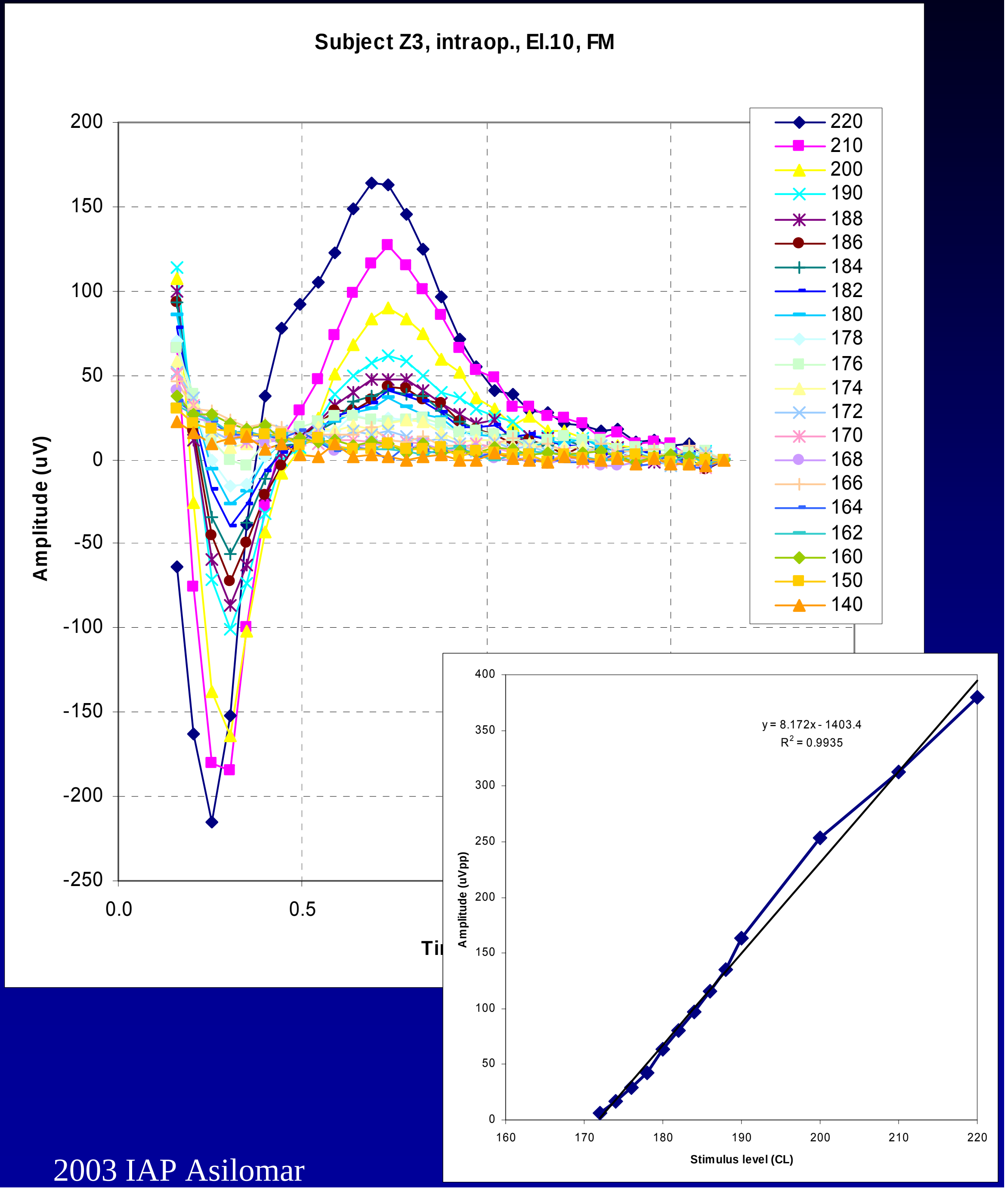
Noise level vs. amplifier gain



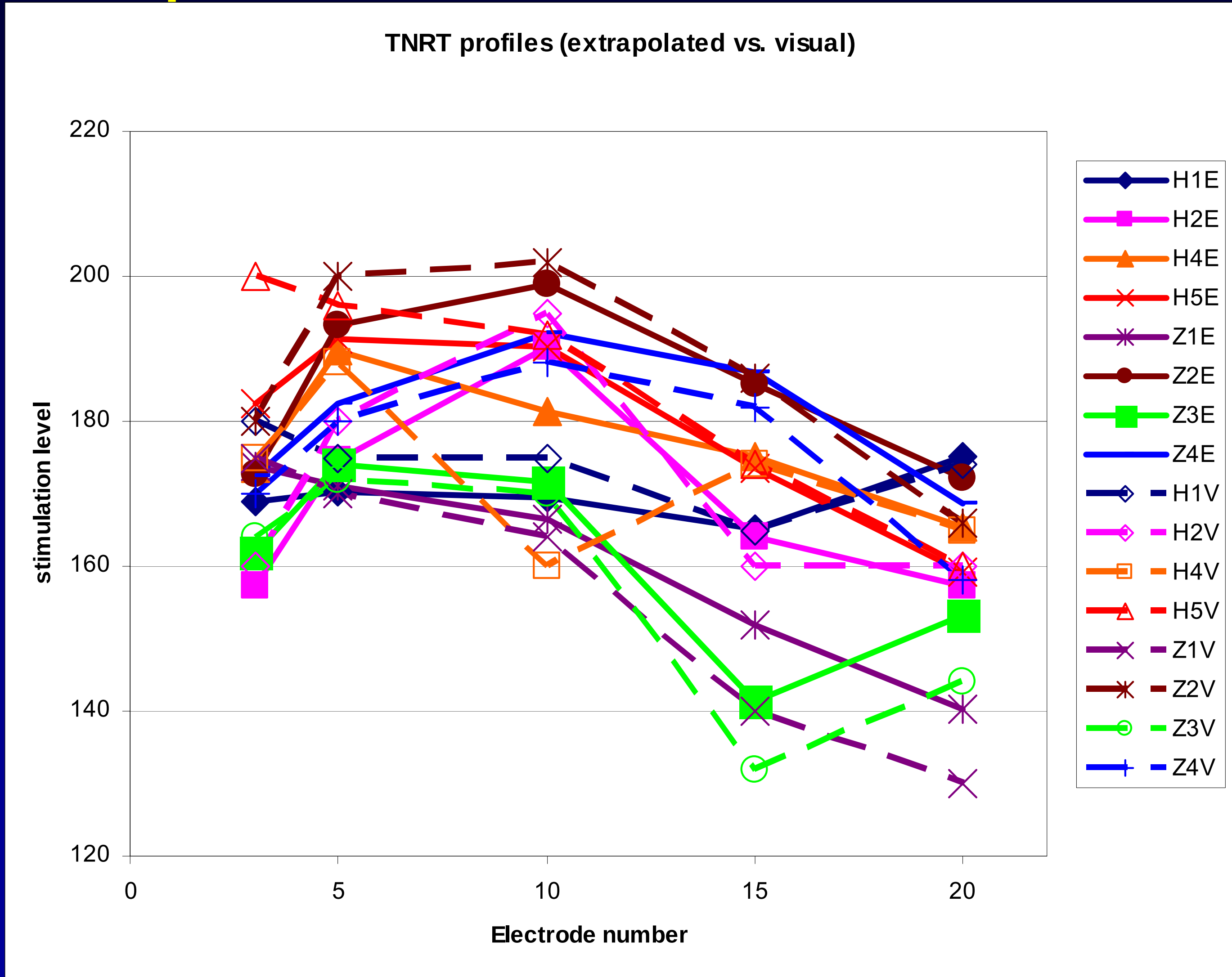
Calculated noise levels (9 subjects)



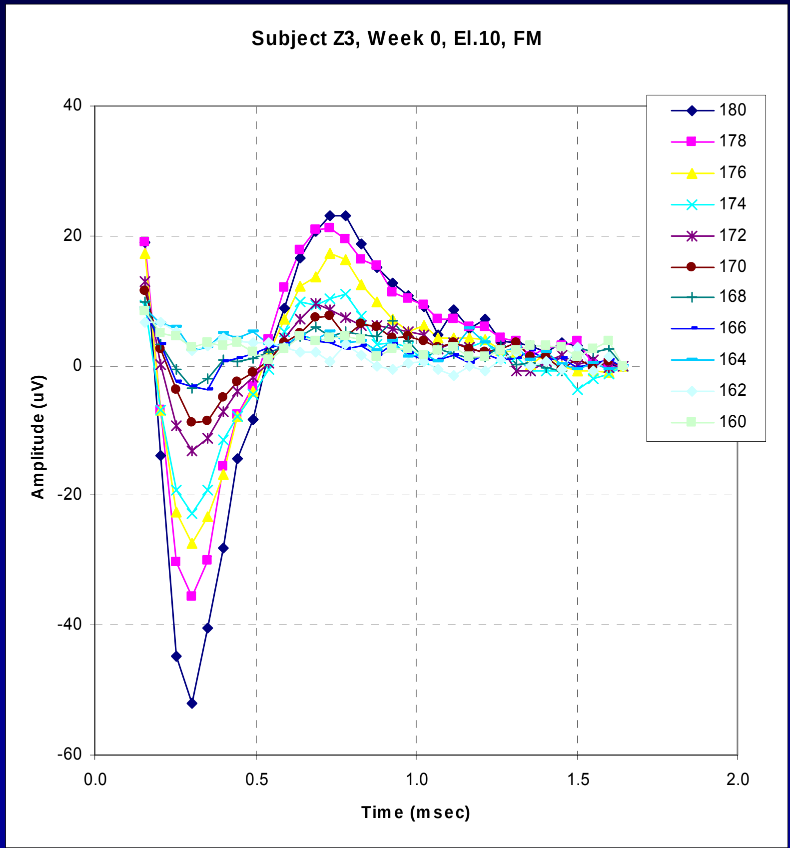
Intraoperative estimation of NRT thresholds (T-NRT)

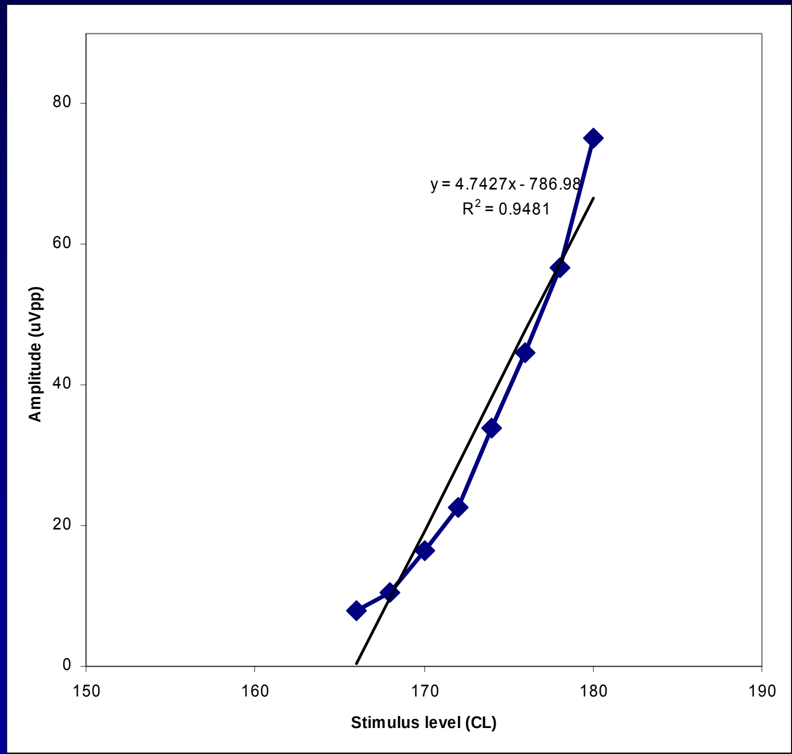


TNRT profiles (8 subjects, extrapolation and visual detection)

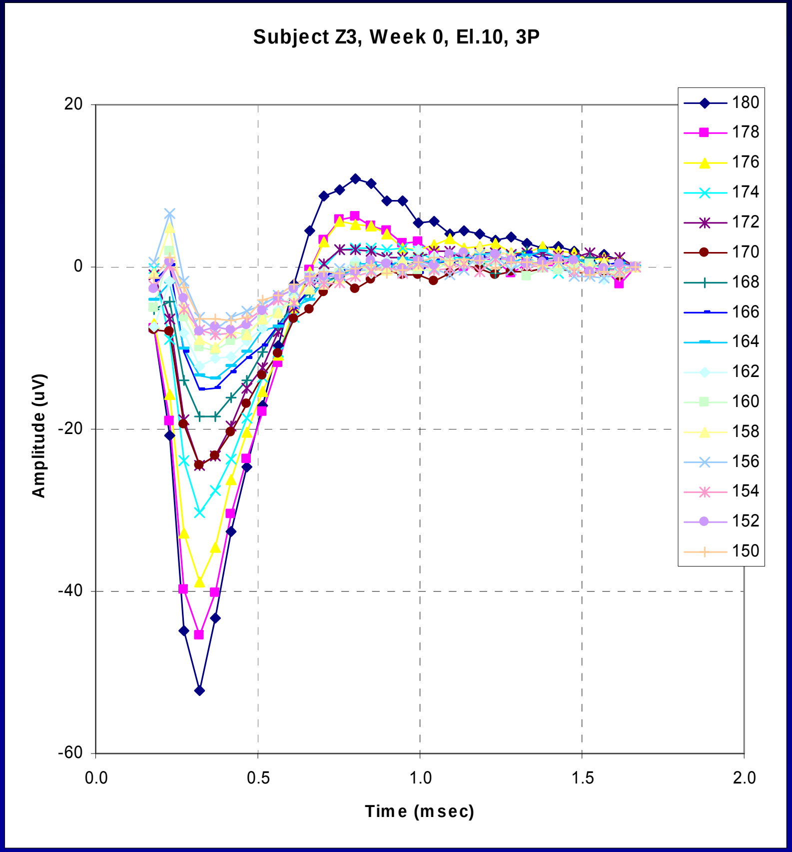


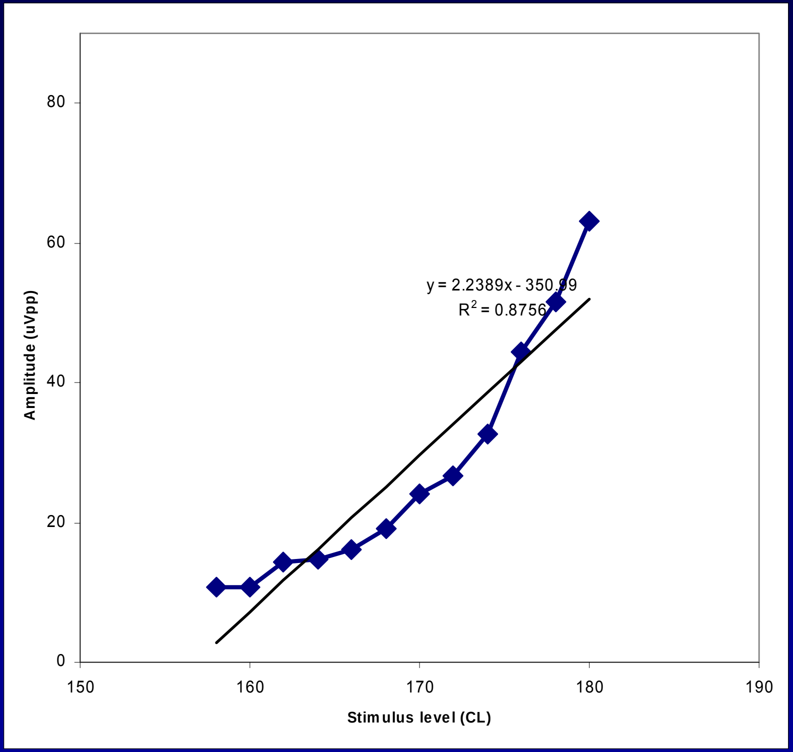
Artifact cancellation with Forward Masking (subtraction paradigm)





Artifact reduction with 3rd phase





Conclusions (RP8)

- The enhanced signal-to-noise ratio combined with the new artifact cancellation option allow good quality recordings with only a limited number of averages.
- These results suggest more reliable, faster and easier NRT recordings in the next generation of Nucleus cochlear implant systems.

Summary

- Intraoperative measures provide useful information
- Speech processor map generation based on NRT profiles is feasible and helpful in clinical practice
- Postoperative long term variations of NRT parameters are relatively small
- Automated measurements of selectivity and spread of excitation may provide addditional options for processor map optimization
- Improved amplifier characteristics and additional artifact cancellation options may further improve the cllinical usefulness of these objective measures


Thank You
GORDON R
THESES
e, chairperson
vice chairperson
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