The Use of Objective Measures with Cochlear Implants

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Disclosures

• Investigator for MED-EL IDE G040002 (EAS study) at BTN RH

• Research supported by NIH, NIDCD
  – Cochlear, Advanced Bionics, and MED-EL provide equipment on loan

• Member, American Academy of Audiology Clinical Practice Guidelines Task Force for Cochlear Implants
Introduction

- Programming (“mapping”) a CI involves subjective feedback:
  - Detection of electrical pulse trains (T-levels)
  - Most comfortable or upper comfort levels (C/M-levels)
  - Loudness balancing
  - Pitch ranking
  - Subjective preferences or speech perception to compare maps with different parameters (e.g., strategy type, stimulation rate)
Introduction

• What if you can’t get that behavioral feedback or what you get is unreliable?
  – Monopolar stimulation:
    • Levels more uniform
    • Better for interpolation
    • Requires fewer behavioral responses
  – Objective measures
Introduction

• Objective measures are used to:
  – Verify device function
  – Verify auditory pathway function
  – Programming guidance when behavioral feedback is limited or absent
Introduction

Most common objective measures:

- Electrode impedance
- Electrically evoked compound action potential (ECAP)
- Electrically evoked stapedial reflex threshold (ESRT)
Electrode Impedance

• Measured via device’s telemetry capabilities

• Informs of:
  – Short circuits
  – Open circuits
  – Voltage compliance
  – Atypical impedance
Electrode Impedance

• Possible consequences of including abnormally functioning electrodes in maps:
  
  – Non-auditory percepts
  – Poor sound quality
  – Pitch confusions/reversals
  – Reduced performance
Electrode Impedance

• Short/open circuits can be easily identified and flagged in the commercial software

Open circuit in Cochlear’s Custom Sound
Electrode Impedance

- Short/open circuits can be easily identified and flagged in the commercial software

Short circuit in Advanced Bionics’ SoundWave
Electrode Impedance

• Short/open circuits can be easily identified and flagged in the commercial software

Open circuit in MED-EL’s Maestro
Electrode Impedance

“Out of voltage compliance”

- Ohm’s Law: $V=IR$
- Insufficient voltage to achieve the current (amplitude) requested
- Lengthen pulse duration so amplitude can be reduced for same overall charge
Electrode Impedance

- Voltage compliance not always flagged and not automatically limited
Electrode Impedance

Neuburger et al. (2009):

• Stimulating when OVC can result in:
  – Potential for asymmetric current pulses
  – Insufficient loudness growth
  – Further increases in impedance

• Recommend widening pulse duration to avoid OVC
Electrode Impedance

- Atypical impedance requires longitudinal monitoring (Cochlear Ltd. 2011; Cullington 2013)
ECAP

• Measured via device’s telemetry capabilities
• Aggregate response of auditory neurons
ECAP

- Measured via device’s telemetry capabilities
- Aggregate response of auditory neurons
ECAP

- Device function
- Auditory nerve function
- Spatial excitation patterns (potential indications of electrode foldover) 
  (Grolman et al. 2008)

Fig. 2, Grolman et al. (2008)
ECAP

- Used to guide mapping

**Step 1: ECAP thresholds**

**Step 2: Behavioral**

**Step 3: Shift**

ECAP

- Used to guide mapping

Fig. 3b, Hughes et al (2000)
ECAP

• But in some cases, ECAPs don’t predict map profile:

Fig 4, Holstad et al (2009)
ECAP

- Used to guide mapping

ECAP: Important Considerations

• ECAPs almost always fall above behavioral threshold
  – AUDIBLE
  – Starting point for conditioning for behavioral testing

• May fall within map dynamic range or above C/M. Contributing factors:
  – Map rate
  – How upper comfort levels are defined
ECAP: Important Considerations

- Effect of map rate:

**Slow Map Rate**

- Current Level
- Electrode
- ECAP Thr
- MAP C
- MAP T

**Fast Map Rate**

- Current Level
- Electrode
- ECAP Thr
- MAP C
- MAP T
ECAP: Important Considerations

– Effect of how upper end of DR is defined:

Upper Boundary=UCL

Upper Boundary=MCL

Electrode
ESRT

• Similar to acoustic counterpart; CI provides stimulus

Figure 6-1, Hughes (2012)
ESRT

• Good correlation with upper comfort levels, but can also overestimate UCL.

• Again, upper limit of DR is defined differently.

Fig. 2, Hodges et al. (1999)  
Fig. 1, Buckler et al. (2003)  
Fig. 6-4, Hughes (2012)
ESRT

• Good to use for young prelingually deafened children who lack the concept of “loud”

• More challenging to measure than ECAP
  – ESRT requires healthy middle ear
  – Recipient must sit still and maintain pressurized seal
  – ESRT measurable in ~65-80% of CI users (e.g., Hodges et al. 1999; Caner et al. 2007; Wolfe & Kasulis 2008)
  – ECAP measurable in ~95% of CI users (e.g., Cafarelli Dees et al. 2005; van Dijk et al. 2007)
Performance

• Speech perception in adults with ECAP-based maps or with ESRT-based maps show similar or slightly poorer performance compared with behaviorally measured maps.

(e.g., Seyle & Brown 2002; Smoorenburg et al. 2002; Hodges et al. 1997; Wolfe & Kasulis, 2008)
Conclusions

• Objective measures offer valuable information when subjective/behavioral feedback is not available.

• Predictive ability is not precise, but can be sufficient enough to provide adequate audibility for speech/language development while children mature.
References


