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Auditory evoked potentials, speech perception, and temporal and spectral auditory processing in adults with cochlear implants: Effects of implant experience and auditory training - in partnership with Seminars in Hearing

Presenter: Suzanne C Purdy, Ph.D. – The University of Auckland
Mridula Sharma PhD – Macquire University

Moderator: Carolyn Smaka, AuD, Editor in Chief, AudiologyOnline

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Auditory evoked potentials, speech perception, and temporal and spectral auditory processing in adults with cochlear implants: Effects of implant experience and auditory training - in partnership with Seminars in Hearing

Suzanne C Purdy, Ph.D. & Mridula Sharma PhD

2017 AudiologyOnline Webinar
Learner outcomes

1. Describe effects of auditory experience and training on cortical auditory evoked potentials in adults with cochlear implants

2. Discuss effectiveness of auditory training paradigms for adults with cochlear implants

3. Describe links between speech perception performance and auditory evoked potentials in adults with cochlear implants

Change in Speech Perception and Auditory Evoked Potentials over Time after Unilateral Cochlear Implantation in Postlingually Deaf Adults

Suzanne C Purdy, Ph.D.
Speech Science, School of Psychology, Faculty of Science, Tāmaki Campus

2017 AudiologyOnline Webinar
Background

- Improvements in speech perception over time are well documented for cochlear implant users
- Most improvement occurs within a short time after cochlear implantation in adults, with some studies showing a plateau in performance after several years
- Auditory evoked potentials are of interest as they provide an objective measure of auditory brain change, with some measures, especially cortical evoked potentials, correlating with performance
- The links between behavioral measures and specific auditory evoked potential measures is still not well established and hence there is no agreed protocol

Cortical auditory evoked potentials (CAEPs)

Research in other populations (e.g. normal hearing, auditory processing disorder, dyslexia) shows an association between P1-N1-P2 latencies or amplitudes and auditory performance

In children the focus is on P1, the prominent peak in the immature CAEP waveform

In adults the focus is on N1 and P2

Recording considerations

Cochlear implant artefact

Electrode montage

Acoustic (loudspeaker) vs. direct electrical stimulation

Example of stimulus artifact at different electrode locations recorded from 44 yr old male, left ear Cochlear ESPrit 3G (contralateral earlobe reference)

Artefact finishes at about 151 ms, related to stimulus level, stimulus 60 ms duration
Key points from the following 3 publications

1. Cortical auditory evoked potential amplitudes correlate with speech perception performance in adults with CIs
2. Pattern of change over time varies across individuals
3. Changes in speech scores do not always follow changes in cortical evoked potentials

CAEPs versus Speech Scores

- Age range 27–74 years
- Implant use 1.3-5.2 years
- Nucleus® CI-22M
- CAEPs recorded to tones delivered via loudspeaker
- Cz-contra earlobe electrode montage

Black = NH control group
Red = “better” CI (N=8) sentence scores >85%
Blue = “poorer” CI (n=4) sentence scores <40%
Effects of CI experience on CAEPs
Dynamics of auditory plasticity after cochlear Implantation:
A longitudinal study. Cerebral Cortex 16:31-36.

McNeill, Sharma, Purdy & Agung
Cochlear Implants Int. 8(4), 189–199, 2007
ESPrit 3G ACE, 64-yr old male, R prof deafness since childhood
L fluctuating/deteriorating SNHL, R implanted

R-CI alone, 4kHz, soundfield, Cz-mastoid: 3 months 6 months 9 months

CUNY sentence scores at 65 dB SPL

<table>
<thead>
<tr>
<th></th>
<th>Post-CI</th>
<th>L-aided</th>
<th>R-CI</th>
<th>Bimodal</th>
</tr>
</thead>
<tbody>
<tr>
<td>6 months</td>
<td>7%</td>
<td>66%</td>
<td>47%</td>
<td></td>
</tr>
<tr>
<td>9 months</td>
<td>9%</td>
<td>58%</td>
<td>87%</td>
<td></td>
</tr>
</tbody>
</table>
Longitudinal study of adult Nucleus CI24 implant users ($N=10$)

- Tested at switch-on week and 1, 3, 6, 9 months
- Measured HINT sentence and CNC word and phoneme scores
- Recorded MLR, P1-N1-P2, MMN

Participant characteristics

- 4 men, 6 women
- Average age implantation 43.1 years (range 27-57, std dev 12.0)
- Average duration profound deafness 6.7 years (range 1-30, std dev 8.7)
HINT sentence and CNC word and phoneme scores

Middle latency response (MLR) generally poorly defined and showed minimal change over time
MLR morphology varied across individuals, no association with speech scores

<table>
<thead>
<tr>
<th>MLR morphology</th>
<th>( \mu )</th>
<th>Final HINT sentence score (%)</th>
<th>Age (years)</th>
<th>Duration profound hearing loss (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Typical</td>
<td>5</td>
<td>97, 90, 75, 74, 49</td>
<td>34, 37, 26, 29, 45</td>
<td>2-10</td>
</tr>
<tr>
<td>Late broad</td>
<td>2</td>
<td>11, 84</td>
<td>36, 55</td>
<td>30, 1</td>
</tr>
<tr>
<td>Absent</td>
<td>3</td>
<td>19, 62, 79</td>
<td>51, 59, 57</td>
<td>1, 5, 10</td>
</tr>
</tbody>
</table>

**CAEPs:** 57 year old woman with congenital hearing loss, profoundly deaf for 10 years. P1 changed very little, N1 reached stable amplitudes at 1 month, P2 increased in amplitude over the 9 months.
Change in N1 amplitude over time was not consistent and varied across individual participants, not correlated with speech scores.

Hemispheric differences in CAEPs (greatest change over time at C4)
Changes in P2 area over the five visits:

- no change for most electrode locations over first 6 months
- C4 (ipsi to CI for 8/10 participants) shows steady P2 increase over time

Changes in CAEPs: P2

- P2 latencies did not change significantly over time
- P2 became wider as well as larger over time, peak areas, hence rather than peak amplitudes were measured
- P2 area growth was relatively slow, most evident at visits 4 and 5 (6 and 9 months)
- P2 area growth was most consistent over the right hemisphere (C4), which was ipsilateral to the CI for the eight participants with right-sided CIs
- P2 changes are seen in auditory training studies (Tremblay et al. 2005) and could reflect changes in pitch salience (Mathew et al. 2016) or auditory attention (Harris et al. 2005)
References


Enhanced P2 for N6 tonal complex, resolved harmonics, greater pitch salience
**P2 versus performance**

- Kelly et al. and Makhdoum et al. found shorter P2 latencies in participants with better speech scores.
- Most studies report N1-P2 amplitudes (e.g. Firszt et al. 2002) and not P2 area; more research with larger sample sizes need to determine links with performance.

**References**


**Mismatch negativity (MMN)**

- Oddball paradigm with 1000 Hz standard tone and infrequent 1500 Hz deviant tone.
- Passive listening (watching subtitled video), as was the case for the other evoked potentials.
- 60% of participants had a recordable MMN visit 1 and 100% had MMN at the final visit.
- No correlation with speech scores.
- Case example shows participant with no MMN initially.
MMN: 37yr man, congenital, profound 2yr pre-CI

Thin line = standard tone
Thick line = 1500 Hz deviant
Bottom line = MMN = difference waveform

MMN across visits showed trend for improvement but considerable inter-subject variability
Summary

- MLR and MMN evoked potentials not correlated with performance and did not change significantly over time, although detectability of MMN improved
- P2 showed systematic growth at C4 electrode site from activation to 9 months post-CI
- Hemispheric effect could reflect changes in cortical organisation as a result of introducing sound to one ear only in the participants who had only one CI, mostly in their right ear
- Changes in P2 may reflect alterations in pitch perception or auditory attention over time

Further Reading


Thank you for listening.

If you have questions please contact me at:

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Suzanne C Purdy, Ph.D. & Mridula Sharma PhD

2017 AudiologyOnline Webinar
Part II: The effect of short-term auditory training in adults with cochlear implants

A/Professor Mridula Sharma, PhD
Audiology program, Linguistics Department
Aims

I. Background
II. Auditory training
III. Auditory plasticity
IV. Choice of outcome measure
V. Study (SiH paper: Nathan et al 2016)
VI. Conclusions
VII. Future directions

I. Background…

Cochlear implant (CI) listeners achieve a high level of speech perception, BUT outcomes vary widely among CI users

(Krueger et al, 2008; Wilson & Dorman, 2008; Blamey et al, 2013)

especially in noisy situations (Hazrati & Loizou, 2012)
Previous research

There is considerable variability in terms of outcomes amongst populations with CI (Gantz et al, 1993; Dowell et al, 2003; UK Cochlear Implant Study Group, 2004; Fu et al, 2007)

There are variety of factors “believed” to contribute to the differences based on strong correlations with speech perception performance

Duration of deafness (Eggermont et al, 2003; UK Cochlear Implant Study Group, 2004)
Differences in the auditory system (Kelly et al, 2005)
Electrode discrimination, (Donaldson, 1999;)
Temporal modulation detection, (Fu et al, 2002; Cazals et al, 1994)
Gap detection (Muchnik et al, 1994; Busby et al, 1999)

Other factors...

Internal strategies of cochlear implants
Speech processor parameters have been modified, trialed to provide the best possible signal
  Continuous Interleaving Strategy (Dorman et al, 1997)
  Adaptive Dynamic Range Optimization (Dawson et al, 2004)

The strategies, of course have to work within the constraints of the psychophysical capabilities and/or auditory processing abilities of the population

More importantly, improvements due to optimizing CI strategies is dependent on the “passive” learning of the implantees  McNeill et al (2007)
So what can we do?

“The auditory system is able to use the highly impoverished input provided by implants to interpret speech, but this only works well in those who have developed language before their deafness or in those who receive their implant at a very young age.”

“Recent evidence suggests that developing the ability of the brain to learn how to use an implant may be as important as further improvements of the implant technology.”

II. Auditory training as a way to reduce variability in outcomes (Sweetow et al, 2002)

There are some auditory training computer-based programs that are currently available for CIs

Sound and Beyond (Cochlear)
Hearing for Life (Advanced Bionics)

But only a few studies available that have trialed these interventions independently from the program developers
Fu et al, 2007 & Stacey et al, 2010

Narrative review of evidence published (Zhang et al.), aim was to inform readers about currently available home-based training programs
What is Auditory training (AT)?
Blamey et al (1994)

A development and/or improvement of the ability to
discriminate speech and non-speech signals, such as
loudness, pitch, and rhythm (Goldstein, 1939)

Teaching the child or adult with hearing loss to take full
advantage of sound cues
(Carhart, 1960, p. 373)

Creating auditory communication conditions where teachers
and audiologists help the children with hearing loss to acquire
many of the auditory speech perception abilities (Erber, 1982)

AT: Cognitive Neuroscience

Directed
Intense
Stimulation

Plasticity

Learning
and
Memory

“It appears that the brain reorganizes itself to
best meet the auditory processing demands”
(Chermak and Musiek, 1997, page 176)
III. Auditory plasticity

“Plasticity is the alteration of nerve cells to better conform to immediate environmental influences; this alteration is often associated with behavioural change”

(FE Musiek April 2002 Hear J p.70)

“Neural plasticity can be broadly defined as dynamic changes in the structural and functional characteristics of neurons that occur in response to changes in the nature or significance of their input and this is different from
- Passive consequence of change
- Age”

Irwin 2007

Auditory training programs reviewed

- A systematic review of evidence published before 2005 (Sweetow & Palmer, 2005) concluded that studies of individual auditory training noted lack of control groups, small numbers of subjects, and a lack of validity of outcome measures, leaving little evidence of its effectiveness but some evidence of its efficacy.
IV. Why is speech understanding in noise necessary?

• The process of understanding speech in noise differs substantially from understanding in quiet

  ➢ One of the biggest concerns that adults have is listening in noise
  ➢ Expected functional outcome

  ➢ Therefore the aim of the current study was to determine if auditory training can improve speech perception in noise in adults with unilateral CI

V. Short term auditory training in adult unilateral CI
Barlow, Purdy, Sharma, Giles, Narne (2016)

Speech perception in noise requires perception of subtle amplitude changes and spectro-temporal details of the speech signal (Meister et al, 2011)

Spectral resolution is restricted in CIs due to the limited number of electrodes stimulating the surviving auditory nerve fibers and the associated spread of excitation of the electrical field (e.g., Rubinstein, 2004; Fu and Nogaki, 2005)
What material did we use for training?

Auditory training included tasks such as

SPECTRAL RESOLUTION
ENVELOPE CUES
TEMPORAL FINE STRUCTURE
TEMPORAL RESOLUTION

All of these tasks have been found to correlate strongly with speech perception (Busby & Clark, 1999; Cazals et al, 1991; Muchnik et al, 1994; Cazals et al, 1994; Fu, 2002)

Auditory processing skills and tasks

Temporal envelope cues: Temporal Modulation Transfer Function (TMTF)
Temporal fine structure: Iterated Ripple Noise (IRN)
Spectral resolution: Spectral Ripple Noise (SRN); Frequency Discrimination (FD) Temporal Resolution: Gaps In Noise (GiN)

Why do we need these?
Behaviour studies have shown that envelope cues are useful in quiet but in noise temporal fine structure is important as well

Training tasks required Same/Different decision or pick the different sound from a choice of three. All tasks had a time bar & visual feedback on performance.

Peter et al 2013
Hopkins & Moore 2009
Methodology

- 10 unilateral CI, congenital hearing loss, implanted in one ear at least 2 yrs ago
- Auditory training for 1 hr at home everyday for 7 days

Pre- and Post-testing:
- 3 baselines and one post training measurement
- 2 baselines on 2 consecutive days and a 3rd one week later
- then training began for 7 days before post-testing

CAEPS (CVCV IN NOISE) (5-12 dB SNR)
SPEECH SCORES – LNT & MLNT WORDS IN NOISE (10 dB SNR):
COMPOSITE SCORE – AVERAGING ACROSS 2 LNT AND 2 MNT LISTS

LNT: Lexical Neighbourhood Test

- Neighborhood Activation model (NAM) provides a theoretical framework for understanding how spoken words are recognized and identified from sensory inputs (Luce & Pisoni, 1998).
- NAM assumes that a stimulus input activates a set of similar acoustic–phonetic patterns in memory, a lexical neighborhood.
- A word can therefore be ‘hard’ to perceive either because it has lots of neighbours and/or because its frequency of occurrence is much lower than that of its neighbours.
- Although this test was created for children, it has been used with adults with CI (postlingual) (Kaiser et al, 2003)
Participants:
All using Freedom processor with ACE strategy

<table>
<thead>
<tr>
<th>CI</th>
<th>Duration of implant use (years)</th>
<th>Age at aiding (years)</th>
<th>Age at implant (years)</th>
<th>Implant ear</th>
<th>Probable cause of hearing loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3</td>
<td>Early, regular since 18</td>
<td>57</td>
<td>Left</td>
<td>Possibly genetic</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>1</td>
<td>44.9</td>
<td>Left</td>
<td>Rubella</td>
</tr>
<tr>
<td>3</td>
<td>2.5</td>
<td>1</td>
<td>48</td>
<td>Right</td>
<td>Rubella</td>
</tr>
<tr>
<td>4</td>
<td>1.5</td>
<td>12</td>
<td>37</td>
<td>Left</td>
<td>Progressive in last 13-14 yrs</td>
</tr>
<tr>
<td>5</td>
<td>3</td>
<td>3</td>
<td>41.8</td>
<td>Right</td>
<td>Fever</td>
</tr>
<tr>
<td>6</td>
<td>3</td>
<td>5</td>
<td>57.6</td>
<td>Left</td>
<td>Hereditary</td>
</tr>
<tr>
<td>7</td>
<td>3.3</td>
<td>39</td>
<td>66.9</td>
<td>Left</td>
<td>Otosclerosis /Progressive</td>
</tr>
<tr>
<td>8</td>
<td>5.1</td>
<td>35</td>
<td>74.9</td>
<td>Left</td>
<td>Congenital progressive</td>
</tr>
<tr>
<td>9</td>
<td>3.2</td>
<td>8</td>
<td>69.1</td>
<td>Left</td>
<td>Progressive sensorineural</td>
</tr>
<tr>
<td>10</td>
<td>2.5</td>
<td>5</td>
<td>38</td>
<td>Right</td>
<td>Progressive, 5 yrs profound</td>
</tr>
</tbody>
</table>

Testing methodology

CAEP speech tokens
/baba/: 446ms; 110 + 55+ 281
/BABA/: 356; 136 + 44 + 176
/baBA/: 438; 131+ 88 + 219

LNT easy words in quiet
LNT easy & hard words in noise
MLNT easy & hard words in noise

Speech perception tests
Comparison between the normal hearing controls (blocked left ear) and unilateral CIs on CAEPs to the 3 /baba/ tokens in quiet

Results

<table>
<thead>
<tr>
<th>Task Type</th>
<th>Task Name (units)</th>
<th>Day 1 Mean (SD)</th>
<th>Day 7 Mean (SD)</th>
<th>Normal hearing adults</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temporal</td>
<td>Gap-in-Noise (ms)</td>
<td>8.7 (6.3)</td>
<td>6.3 (4.4)</td>
<td>4.7 (1.0)*</td>
</tr>
<tr>
<td></td>
<td>Iterated Ripple Noise (IRN to noise ratio)</td>
<td>0.15 (0.11)</td>
<td>0.14 (0.11)</td>
<td>0.05 (0.01)†</td>
</tr>
<tr>
<td>Spectral</td>
<td>Frequency Discrimination (Hz) at 1000 Hz</td>
<td>110.2 (49.3)</td>
<td>97.1 (59.8)</td>
<td>20.2 (15.1)*</td>
</tr>
<tr>
<td></td>
<td>Frequency Discrimination (Hz) at 4000 Hz</td>
<td>138.8 (48.0)</td>
<td>113.8 (29.1)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Spectral Ripple Noise (ripples/octave)</td>
<td>2.65 (2.6)</td>
<td>5.19 (2.7)</td>
<td>5.52 (2.48)†</td>
</tr>
</tbody>
</table>

*(Meha-Bettison, 2013)
†(Peter et al, 2014)
Training effect on TMTF

Pre vs Post training..

N1P2 amplitude is significant (p=0.005) only for /baba/ in quiet

Pre visit 3

Post visit 4
CAEPs (n=10) to CVCV speech tokens in noise

Pre visit 3  Post visit 4

Combined easy & hard word list LNT scores across visits. There is a significant difference for these two lists between visit 3 (pre-training) and visit 4 (post-training).

Effect size for the change pre- versus post-training in:

1. N1-P2 amplitude /baba/ (Cohen $d = 0.65$; $r = 0.30$)
2. Easy LNT words ($d = 0.57$; $r = 0.27$)
3. Hard monosyllabic LNT words ($d = 0.30$; $r = 0.14$)
4. SRD psychophysical scores ($d = 0.81$; $r = 0.38$)
Results: Training effects

There are some training effects on Speech scores and CAEPs

SRN (Spectral Resolution) changed by 78%

LNT Scores In Noise increased by 11% between pre-training visits and Visit 4

N1P2 amplitude increased post-training only for one speech token (baba)

There were no correlations between CAEP and behavioral changes

VI: what do we need to know…

- Dosage.. How often and how much training should we do?
- What material should we use for training?
- We used auditory training that was mostly concentrated on auditory processing

- BUT MAYBE WE SHOULD BE DOING TOP-DOWN TRAINING:
  
  Working memory; language and/or attention
VII: Future directions: Attention, memory, auditory processing and listening in noise

Listening in the presence of background noise is a consequence of working memory, auditory processing and/or attention that interact to assist with allocation of resources (Pichora-Fuller, 2003a, 2003b).

A deficit in any of the factors may mean that the task of listening to a single talker would engage most of the capacity to cope with the deficit and the remaining capacity would then be inadequate to simultaneously monitor other inputs (Rudner et al., 2012).

Future directions: Approaches to management

Environmental modification
Auditory training: music based
Language based training
Auditory memory training
Metacognitive strategies

Chermak & Musiek
(CAPO New Perspectives, 1997)
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Thank you

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