Effects of Hearing Loss on Self-Hearing During Speech Production

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Speech Reception

- comprehension (new information)
- listen only
- auditory input (air-born)

Speech Production

- expression (known message)
- listen + speak
- auditory + haptic (air-born + bone-conducted)

Self-generated speech feedback

- development and maintenance of “speaking skill”
- speech regulation
What is the Role of Self-Hearing in Speech Regulation?

Significance of the question

Practical
- speech training
- acceptance of hearing technology

Theoretical
- perception–production link
- phonetics–phonology relationship
Research Program

Q1: How is speech feedback perceived?

Q2: How does self-hearing affect speech production?

Effects of reduced access to auditory feedback
How do we go about investigating self-hearing and its role in speech regulation?

Introduce speech feedback alterations
- Temporal (asynchrony re articulation)
- Spectral (loss of intelligibility)
- Level (loudness change, breaks in the signal)

- Test awareness of the changes (perception studies)
- Measure speech performance (production studies)
Perception Studies

Approach

Psycho-physics of self-hearing
- S–R relationship
- *Minimal* perceptible feedback delay

➢ Develop and automate procedures for:
  (1) Real-time alterations of speech feedback
  (2) Subject testing
Perception Studies

Experimental Setup

Subject’s side  Experimenter’s side

Earphones -> PC Monitor

PC -> Signal Processing Device

Signal Processing Device -> Recorder

Recorder -> Audimeter
Perception Studies

Testing Procedure

- **Two Interval Forced Choice Procedure**

- **Stimuli**
  - self-paced utterances of a pre-selected syllable
  - muted onset & limited duration (1800 ms) of the speech feedback

- **Response:** Choose interval with *delayed* feedback
Perception Studies

Delay Detection

Procedures

3 groups:
- Cochlear Implant (CI) users (4 participants)
- Hearing Aid (HA) users (6 participants)
- Hearing (9 participants)

Repeated testing
- 9 tests per participant

Minimal detectable delay
- 71% correct identification
Perception Studies

Delay Detection

![Chart showing minimal detectable delay (ms) for CI Users, HA Users, and Hearing Subjects.]

CI Users | HA Users | Hearing Subjects
---|---|---
C1 | H1 | N1
C2 | H2 | N2
C3 | H3 | N3
C4 | H4 | N4
| | H5 | N5
| | H6 | N6
| | | N7
| | | N8
| | | N9
Production Studies

Speaking with altered auditory feedback

Feedback alterations
- Delay
  25, 50, 100, 200 ms
  + no delay (0 ms)
- Spectral Smearing
  4 band (N4) & 1 band (N1)
  noise + speech (SP)

5 HA and 5 CI users: Reading task

Speech production analyses
- Acoustic measurements: *speech rate*, *voice pitch*
- Evaluation of *speech quality*
Production Studies

Speech Rate

<table>
<thead>
<tr>
<th>Delay (ms)</th>
<th>CI group</th>
<th>HA group</th>
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<tbody>
<tr>
<td>210</td>
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<td>220</td>
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Average Syllable Duration (ms)

Delay (ms)
Production Studies

Voice Pitch

**CI group**

**HA group**

<table>
<thead>
<tr>
<th>Delay (ms)</th>
<th>Fundamental Frequency (Hz)</th>
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<tr>
<td>0</td>
<td>SP N4 N1</td>
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<tr>
<td>25</td>
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<td>50</td>
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<td>100</td>
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<td>200</td>
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Delay (ms)
Can a listener perceive the changes in speech that are due to poor speech feedback?

Speech samples from 4 feedback conditions
- Unaltered feedback (SP)
- Spectrally degraded signal (N4 and N1)
- Babble noise (BN)

Speakers: 5 HA and 5 CI Users

Evaluation of speech quality: Paired comparisons
- 6 possible combinations (SP–N4, SP–N1, SP–BN, N4–N1, N4–BN, N1–BN)
- Individual sentences (5 per condition; equal content in the pair)
  - “Choose utterance that sounds better”

10 judges (all hearing)

Preference frequency (PF) for the better (SP > N4 > N1 > BN) feedback condition
- \( PF_{\text{max}} = 100 \) per comparison (10 judges * 5 sentences * 2 repetitions)
Production Studies
Speech Quality Evaluation

Mean Preference Frequency

Feedback Condition

- HA
- CI

\( p > 0.01 \)

- ▲ SP
- ○ N4
- + N1
Sign Production: Role of Self-Generated Visual and Haptic Feedback

Effect of visual feedback alterations
- altered view-point: top, front and mirror views
- control conditions: natural and no view

Effect of haptic feedback alterations
- altered mass/moment of inertia of the fingers and hand

Connected utterances
- based on the picture or signed description of a scene

Native signers versus novices

Sign production analyses
- error analyses
  kinematic measurements
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