TOLERABLE DELAY FOR SPEECH PROCESSING: EFFECTS OF HEARING ABILITY AND ACCLIMATISATION

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Introduction

Own voice

External voice

Cochlea picture: http://storage3d.com/storage/2006.10/5770ca614015fd13ae99fc999dff667e.jpg

Bone conduction

Air conduction

Processed signal

DSP

Level-ratio

Delay

Direct signal

Processed signal

DSP

Level-ratio

Cochlea
Perceptual effects of delay on speech communication:

- Audio-visual synchronicity (> 80 ms) [1]
- Auditory-proprioceptive feedback (> 80 ms) [2,3]
- Distinct echo perception (> 50 ms) [4]
- Changes to speech production rate (from 43 ms) [3]
- Timbre alterations due to comb-filter effect (< 50 ms)

Literature suggests upper limit of delay for hearing devices: 10 ms

- Do hearing-impaired people tolerate longer output delays than normal-hearing people when tested on the same setup?
- Do experienced users of hearing aids tolerate longer delays?
- Does long-term acclimatisation to delay increase tolerance?
Overview

- Study 1: Effects of hearing ability and experience with HA
- Study 2: Effects of long-term acclimatisation
Methods: Study 1

- **Participants:**
  - 20 NH: Age 18-45 y, 8 fem.
  - 20 HL: Age 45-81 y, 8 fem.
  - 10 new, 10 experienced with HA

- **Setup:**
  - Real-time processing (DSP: Linear mixer and delay, at fs=48 kHz)
  - Headphones (closed, circumaural, at 65 dB(A))

- **Fitting gain:**
  - Half-gain rule based on hearing thresholds (HL group)

- **Conditions:**
  - 5 delay: [10…50] ms and 3 voice: own and external (2)

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**Own voice**

(OwnV)

**External voice**

(Ext0dB, Ext20dB)
Results: comparison NH vs. HL

Subjective rating of annoyance (7-point scale)
1 min. listening/reading per stimulus condition @ 65 dB(A)

Effect of hearing ability:

Significant effect of hearing ability (NH/HL). [F(1,38)=4.619, p=0.038]
Results: HI group (PTA)

Split 20 HL in three subgroups based on PTA (500, 1000, 2000 Hz):

LOW < 35 dB HL < MID < 50 dB HL < HIGH, n=5/8/7

No significant effect of subgroup (LOW/MID/HIGH).

Significant correlation between average slopes of ratings and PTA within HL group (r=-0.51, p=0.022).
Results: HI group (experience)

Split HI group in two subgroups based on experience with hearing aids:

**NEW** and **EXP**, n=10/10,

No significant effect of experience (NEW/EXP).

Similar ages (67.1 vs. 66.9 years),
but different PTA for NEW and EXP (37.4 vs. 50.2 dB HL).
Overview

- Study 1: Effects of hearing ability and experience with HA
- Study 2: Effects of long-term acclimatisation
Methods: Study 2

- **Participants:** 8 NH  
  Age: 20.9 y, 4 fem., NH thresholds

- **Setup:**  
  Real-time processing  
  iPhone (4S, 5) with earplugs  
  (DSP: delay, limiter, at fs=48 kHz)  
  (in-ear, int. microphone, at 65 dB(A))

- **Conditions:**  
  4 delay: [10,20,30,40] ms and 3 level-ratio: [0,10,20] dB

- **iPhone Ear App:**
  2 delay settings:  
  Group 1: 20 ms  
  Group 2: 40 ms  

  5 days of use (1 week)

**PRE**  2  3  4  **POST**

App made by Dr. Nick Clark  
(Mimi Hearing Technologies)
Results: Comparison of PRE / POST

Contourplots for ALL / PRE / POST test and both groups:
Yellow – higher annoyance, Green – lower annoyance

Group 1 = 20 ms
Group 2 = 40 ms
Compare **Group1** and **Group 2**, n=4/4, averages across level-ratios:

Significant difference between groups for post test \( [F(1,6)=7.665, p=0.032] \).

Some acclimatisation for **Group1**, but also bit lower tolerance for **Group2** …
Conclusion

- Hearing loss increased tolerance of delay over NH (average ratings)

- Lower sensitivity to changes in delay with stronger HL (average slopes)

- Experience with hearing aids showed some trends but no significant effect of tolerance and potential confound with HL

- Long-term acclimatisation increased tolerance of delay for NH (Ear App)

- Results extend findings of previous study (Stone and Moore, 2005) to external voice conditions and linear processing (no WDRC)

- Limitations of study: linear signal processing, only speech stimuli (e.g. no music) and presentation via closed headphones / earplugs
  - most likely different to perception with commercial hearing aids!!
Future work and ideas

- Long-term study with HI listeners and actual HA devices?
- Effect of experience with matched PTA/Age between groups?

- Algorithms with potential benefits from increased delay:
  - Noise reduction based on machine learning (GMM, DNN)
  - Decorrelation for feedback cancellation
  - Wireless streaming of audio (binaural, HA+CI, smartphones…)

- More energy-efficient processing with larger time window?
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appendix
Results: Comparison of PRE/POST

Results for **PRE** / **POST** test and both groups:

**Group 1**
(20 ms)

**Group 2**
(40 ms)