THE MANY EFFECTS OF HEARING AID DELAY IN OPEN FITTINGS

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The physics of hearing aid delay

- Hearing aid processing delay causes amplified sound to be delayed relative to direct sound by 0.5 to ~10 ms.
- Unproblematic for closed fittings, but spectral and temporal artefacts for open and vented fittings. Most apparent artefact is pitch sensation known as coloration pitch, seen as comb-filtering in Figure 1.

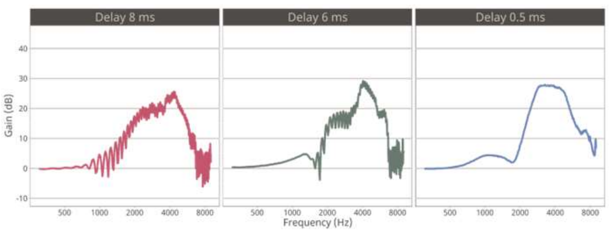

Figure 1: Gain over frequency measured in open 711 coupler for hearing aids with different average group delays. Clear comb-filtering is observed for the longer delays but not below 1 ms.

At which delays are changes audible? (Stiefenhofer, 2022)

- **Stimuli:** Noises processed in HA simulator with linear amplification and amplified sound delayed 0.1 to 2 ms.
- **Procedure:** Two-alternative forced choice between two pairs of noise bursts, one pair with identical delays and one pair with a delay difference.
- **Participants:** n = 9 with normal hearing (NH), n = 12 with hearing loss (HL).
- **Results:** Threshold for correct discrimination (defined as 75%) 0.25-0.35 ms for NH, ~0.6 ms for N2 HL and ~1 ms for N3 HL.
- **Conclusion:** At delays <1 ms coloration-pitch change is inaudible for HA wearers that are candidates for open fits, while coloration-pitch change is audible ≥1 ms. Delays must be very short to be inaudible.

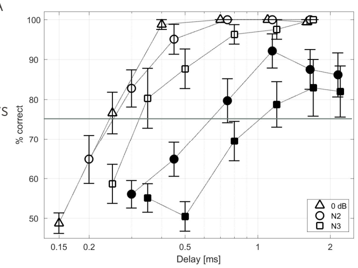

Figure 2: Mean percent correct scores for discrimination of coloration pitch. Filled shapes are HL group, open shapes are NH. Guessing probability is 50%.

Sound quality preferences I: Guided walk (Balling *et al.*, 2020)

- **Stimuli:** 20 real-life sounds in 14 scenarios, including speech, own voice, ambient noises, and specific impulse and broadband sounds.
- **Procedure:** Double-blind comparison of 0.5 ms vs. 2.5 ms delay in HAs fit to N2 hearing loss, 7-point rating of relative preference.
- **Participants:** n = 13 participants with mild-to-moderate HL, n = 8 NH.
- Results
  - Lower delay preferred in 73% (HL) and 83% (NH) of ratings.
  - Final preference for lower delay 85% (HL) and 100% (NH) (Figure 3, right).
  - Degree of preference variation between situations, but on average in favor of lower delay for all types of sounds (Figure 3, left)
- **Conclusion:** Preference for lower delay in wide range of realistic scenarios.

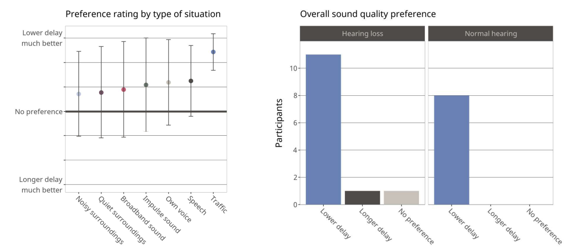

Figure 3: Mean preference rating per type of sound with whiskers representing +/- 1 SD (left) and final delay preference at the end of the study (right).

Sound quality preferences II: Lab study (Lelic *et al.*, 2022)

- **Stimuli:** Recordings of raindrops on umbrella, male speech in quiet, and keystrokes on computer keyboard, processed in HA simulator with linear amplification and delays of 0.5 to 10 ms.
- **Procedure:** A-B comparisons with forced-choice sound preference.
- **Participants:** n = 13 NH, n = 20 with mild-to-moderate HL.
- Results
  - Overall preference for lower delays.
  - Significant preference for 0.5 ms delay for NH.
  - For HL, correlation between preference for 0.5 ms delay and low-frequency hearing thresholds (figure 5).
- **Conclusion:** Preference for lower delay also in lab setting.

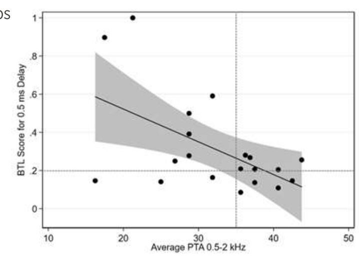

Figure 5: Correlation between preference for 0.5 ms delay (Bradley-Terry-Luce (BTL) score, Bradley, 1984) and low-frequency thresholds.

Envelope-following response (Slugocki *et al.*, 2020)

- **Stimuli:** 8000 repetitions of synthesised /da/ syllable presented in free field, with participants seated 1 meter from loudspeaker.
- **Procedure:** EEG recorded for each of three hearing aids with delays of 8, 6 and 0.5 ms. Fit to NAL-NL2 with open ear-tips.
- **Participants:** n = 16 participants with mild-to-moderate HL.
- Results
  - Peak f_0 energy significantly affected by hearing aid condition ($F = 6.48$, $p = 0.016$).
  - EFR for lowest delay (Figure 6, bottom panel) most similar to stimulus envelope (Figure 6, upper panel).
  - Distorted EFRs for longer delays (Figure 6, middle panels).
- **Conclusion:** Stronger EFR associated with less effort and more robust speech comprehension → delay is relevant parameter in HA design.

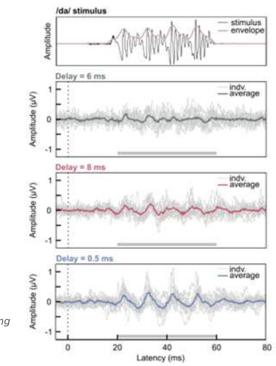

Figure 6: Envelope for /da/-stimulus (top panel) and envelope-following responses (EFRs) for HAs with delays of 8, 6 and 0.5 ms.

Spatial perception (Korhonen *et al.*, 2022)

- **Stimuli:** Recordings of three different hearing aids with delays of 8, 6 and 0.5 ms on KEMAR in three different room positions, with NAL-NL2 fitting for N1, N2, N3 or S1 audiogram.
- **Procedure:** Three-alternative forced choice between recordings with same HA in different room positions.
- **Participants:** n = 15 participants with mild-to-moderate HL.
- **Results:** Significantly higher accuracy for 0.5 ms delay, with no difference between 6 and 8 ms.
- **Conclusion:** Hearing aid delay may interfere with timing of room reflections, affecting perception of space, distance, and naturalness.

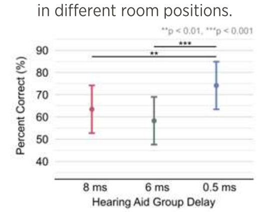

Figure 6: Mean accuracy on 3AFC spatial discrimination task. Vertical bars show 95% confidence intervals.

Conclusions

- Hearing aid delay affects users with open and vented fittings.
- Delays above 1 ms are audible for candidates for open-fit HAs → lowering delay to below this threshold may benefit wearers with mild-to-moderate hearing loss in terms of
  - Sound quality
  - Neural representation
  - Spatial perception
- HA delay of 0.5 ms is preferred by listeners with mild-to-moderate HL in laboratory and real-life sound experiences (see also Balling *et al.,* 2021).
- Possible implications for hearing aid acceptance (especially first-time users), speech comprehension, identification of voices, and effort.
- Further research should isolate delay from other hearing aid parameters.

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