A preliminary investigation into delay and phase preferences with music, open-canal hearing aids, and mild hearing loss.

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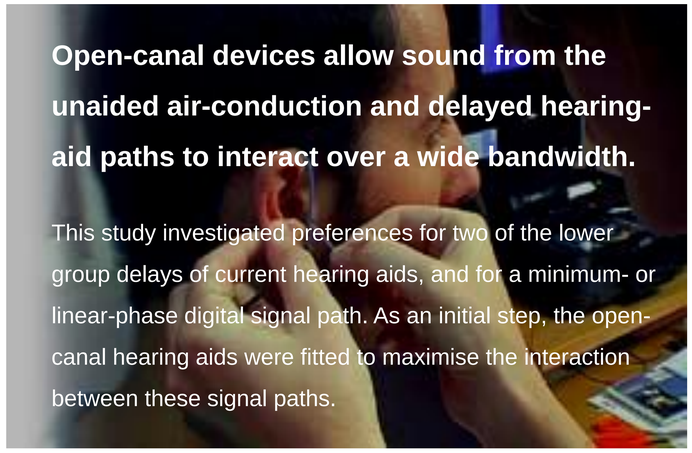


Open-canal devices allow sound from the unaided air-conduction and delayed hearing-aid paths to interact over a wide bandwidth.

This study investigated preferences for two of the lower group delays of current hearing aids, and for a minimum- or linear-phase digital signal path. As an initial step, the open-canal hearing aids were fitted to maximise the interaction between these signal paths.

Introduction

Several studies have investigated the effects of hearing-aid group delay with occluded fittings (Stone & Moore, 1999; 2002; 2003; 2005), although newer open-canal fittings have received less attention (Groth & Søndergaard, 2004; Stone et al, 2008). With an open ear canal, sound from the hearing-aid path can mix with external sounds from the air-conduction path over a wide bandwidth. While speech is undoubtedly an important stimulus, we are aware of only one open-canal study that used music as a stimulus (Groth & Søndergaard, 2004). For external speech and music, there was no significant difference in disturbance between delays of 2, 4 and 10 ms for mildly impaired participants fitted with a flat, linear, 10-dB insertion gain above 800 Hz (the input was adjusted to a comfortable level). The current study used a similar methodology to investigate delay and phase response (variation of delay with frequency) preferences with a lower-gain fitting that maximised the interaction between the hearing-aid and air-conduction paths (approximately 0-dB insertion gain above 750 Hz). In addition, preferences for a new feedback canceller and whether it created artefacts were investigated for different group delays.

Hearing aids

Two open-platform, BTE hearing aids with comfort tips (no domes) were loaded with DSP software that had the signal-processing architecture shown in Figure 1. Table 1 shows the signal-path delay and phase settings that could be selected via the fitting software.

Table 1. Signal-path processing settings that were selectable via the fitting software.

Processing	Phase response	Nominal Group Delay
Ultra-Low Delay (**ULD**)	Minimum	1.4 ms
Low Delay (**LD**)	Linear	3.4 ms
ULD+2ms delay line	Minimum	3.4 ms

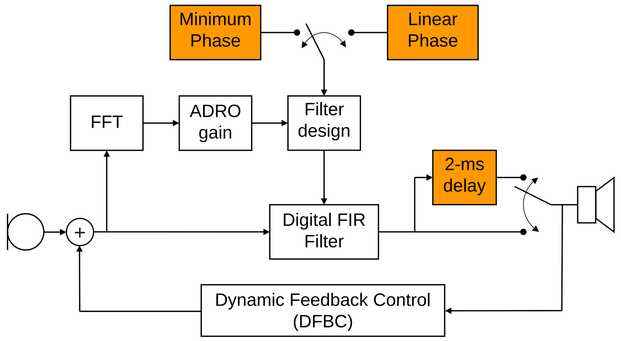


Figure 1. Signal-processing architecture of the DSP software used in this study.

Verification

For this study, 32-channel ADRO® was set to linear-gain mode with a maximum output limiter in each channel (250-Hz spacing). Figures 2 and 3 show group delay measurements with the aids set to the mean 2-cc coupler gain to achieve the insertion gain used in this study.

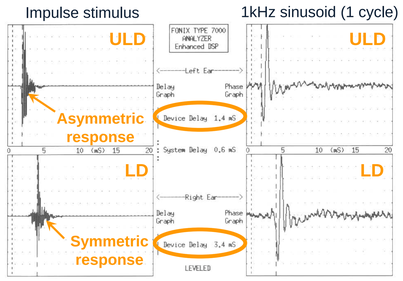


Figure 2. Group delay and temporal response as measured with a Frye FONIX 7000 test box.

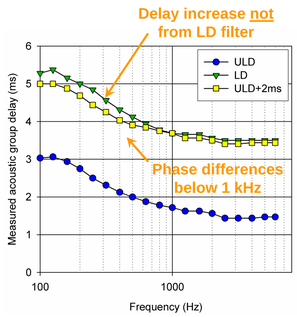


Figure 3. Group delay manually measured with sinusoids at 1/3rd octave frequencies.

Methods

Twelve hearing-impaired musicians were recruited, since a goal of this study was to investigate hearing-aid processing that best meets their requirements. Two participants listened monaurally (ear with HTLs > 80 dB HL occluded during testing). Figure 4 shows the mean audiogram for the 22 test ears.

The participants were initially fitted with a flat 10-dB REIG from 750-6000 Hz and ULD to avoid large comb-filtering effects (gain rolled off < 750 Hz). The 2-cc coupler gains were then reduced by 10 dB so that sound from the hearing-aid and air-conduction paths had similar amplitude from 750-6000 Hz (approx. 0 dB REIG).

Informal listening revealed that the audibility of processing differences varied with music stimulus. A pilot study with two normal-hearing musicians was used to avoid using music stimuli where even normal-hearing participants could **not** detect processing differences. Thus, the main delay study aimed to evaluate whether delay preferences exist in worst-case conditions for signal interactions. The selected music samples for the delay comparisons were 7-8 second excerpts from:

1) Borodin's String Quartet No. 2: Nocturne
2) Pergolesi's Stabat Mater

In addition, a Jazz sample (Miles Davis, Freddie Freeloader) was used for the DFBC comparisons.

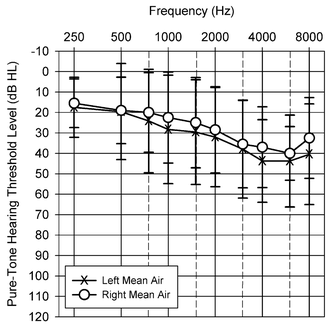


Figure 4. Mean audiogram (+/-1 std. dev.)

The participants were seated in a sound booth with a studio-quality loudspeaker. With the aids muted, the presentation level of each sample was adjusted to each participant's preference (these levels were then used throughout the study). The participants then blindly compared pairs of processing conditions and rated their preferred condition a 3-point scale (Slightly Prefer, Prefer, Strongly Prefer):

Experiment 1 (for Borodin and Pergolesi)**:**

- **ULD** vs. **LD** (1.4 ms minimum phase vs. 3.4 ms linear phase)
- **ULD** vs. **ULD+2ms** (1.4 ms minimum phase vs. 3.4 ms minimum phase)
- **LD** vs. **ULD+2ms** (3.4 ms linear phase vs. 3.4 ms minimum phase)

Experiment 2 (for Borodin and Pergolesi)**:**

- **ULD** vs. **Mute** (1.4 ms minimum phase vs. no hearing-aid output)
- **ULD+2ms** vs. **Mute** (3.4 ms minimum phase vs. no hearing-aid output)
- **LD** vs. **Mute** (3.4 ms linear phase vs. no hearing-aid output)

In addition to preferences, the presence of artefacts (None, Some, Many) were rated with the DFBC:

Experiment 3 (for Miles Davis)**:**

- **DFBC On** vs. **DFBC Off** for each of the three processing conditions

Results

Figures 5, 6 and 7 show the results from Experiments 1, 2 and 3 respectively. Non-parametric two-tailed sign tests and Wilcoxon signed rank tests were performed. The only significant result was that ULD+2ms was preferred to LD for the Borodin sample and vice-versa for the Pergolesi sample (sign test, $p<0.04$).

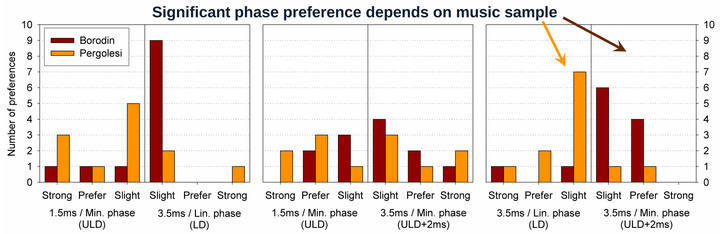


Figure 5. Preferences for the three comparisons of aided conditions.

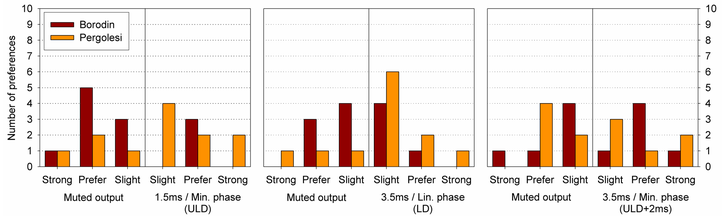


Figure 6. Preferences for the three aided vs. unaided comparisons.

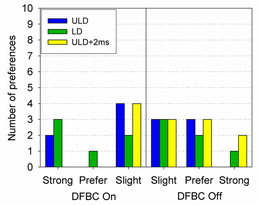
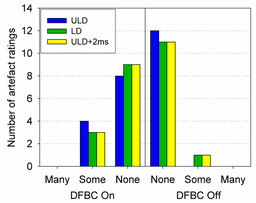


Figure 7. Preferences (left) and artefact ratings (right) for the DFBC On vs. Off for each aided signal-path processing condition.



Conclusions

When trained musicians are binaurally fitted with open-canal hearing aids at 0 dB insertion gain, and listen to music samples where normal-hearing musicians can hear the effects of group delay differences:

- There was no preference between a muted hearing-aid output and a delayed audio signal.
- At a nominal group delay of 3.4 ms, the preference for minimum- or linear-phase processing can depend on the music sample.
- There was no preference between ULD and LD processing, or between ULD and ULD+2ms.
- The was no preference for the DFBC on or off, and no difference in artefacts.

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References

Groth, J. & Sondergaard, M.B. (2004). Disturbance caused by varying propagation delay in non-occluding hearing aid fittings. *International Journal of Audiology*, 43, 594-599.

Stone, M.A., & Moore, B.C.J. (1999). Tolerable hearing aid delays. I. Estimation of limits imposed by the auditory path alone using simulated hearing losses. *Ear Hear.*, 20(3), 182-192.

Stone, M.A., & Moore, B.C.J. (2002). Tolerable hearing aid delays. II. Estimation of limits imposed during speech production. *Ear Hear.*, 23(4), 325-338.

Stone, M.A., & Moore, B.C.J. (2003). Tolerable hearing aid delays. III. Effects on speech production and perception of across-frequency variation in delay. *Ear Hear.*, 24(2), 175-183.

Stone, M.A., & Moore, B.C.J. (2005). Tolerable hearing-aid delays: IV. Effects on subjective disturbance during speech production by hearing-impaired subjects. *Ear Hear.*, 26(2), 225-235.

Stone, M.A., Moore, B.C.J., Meisenbacher, K., & Derleth, R.P. (2008). Tolerable hearing aid delays. V. Estimation of limits for open canal fittings. *Ear Hear.*, 29(4), 601-617.

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