Gain mismatch and horizontal localization performance

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Hearing aids are becoming increasingly sophisticated, with current advancements being made in the area of binaural signal processing. Binaural synchronization of volume control adjustments and program selection has already been available for some time[1]. This feature greatly reduces the chance of hearing aid users inadvertently implementing grossly imbalanced loudness settings across ears. A loudness mismatch across ears can interfere with the ability to accurately discriminate between left and right sound sources in the median plane due to distortion of interaural intensity difference (IID) cues[2]. However, distortion of the IID can also occur in a pair of wide dynamic range compression (WDRC) hearing aids that operate independently of each other, even if they are perfectly balanced for sounds arriving from the median plane. As the sound source moves away from the median plane, the intensity level of the sound arriving at the ear that is closer to the sound source increases, which results in the application of less gain to that ear. The net result is that the natural difference in intensity level between ears – the IID – is reduced[3]. The greater the compression ratio in the instruments, the greater the reduction of IID. To overcome this problem, some recent products have introduced binaural signal processing that ensures the typical IID caused by the head shadow effect is maintained[4]. While this is likely a positive step forward in terms of achieving a more natural perception of the soundscape, it should be remembered that the arrival time of a sound to each ear is also used for left/right discrimination. The interaural time difference (ITD)is not affected by compression and is the dominant cue for horizontal localization when frequency information below 1500 Hz is present[5].

Using stimuli with different spectral shape and bandwidth, this study investigated the effect of gain mismatch between ears on left/right discrimination. The test conditions included interaural gain mismatches of 0, 3, 6, and 9 dB.

Participants

Three female and six male participants, all of whom were familiar with horizontal localization testing, were recruited. Their ages ranged from 50 to 79 years, with a median age of 77. All participants had symmetrical sensorineural hearing loss and a minimum of six months' prior experience with bilateral amplification at the time of testing. The pure tone average (PTA) hearing loss of the group ranged from 33 to 62 dB HL, with a mean of 45 dB HL.

Test conditions

The participants were fitted bilaterally with two pairs of Siemens Triano S behind-the-ear (BTE) hearing aids, each with two active programs, for a total of four available listening programs. Hard acrylic skeleton earmolds with 1 mm vents were used. The gain and frequency response were initially adjusted via the Siemens Connexx fitting software to match each participant's NAL-NL1 real-ear insertion gain (REIG) target at 65 dB SPL[6]. Compression was set to syllabic and all adaptive features were disabled. Fittings were verified using probe-tube measurements.

To ensure that the participants' hearing aids were balanced for the 0 dB gain mismatch condition, continuous speech was presented at 65 dB SPL in the free field from a loudspeaker positioned at 0° azimuth relative to the participant. Participants were asked to indicate whether the speech sounded as if it were coming from the right, centre, or left of the loudspeaker. Depending on the participant's response, the overall gain of one hearing aid (the left for five participants, the right for four participants) was then increased or decreased by 3 dB until the participant's response changed. The procedure was repeated until three reversals in both directions (more left, more right) were obtained. The gain level at which the participant consistently reported a balance of loudness was selected as the 0 dB gain mismatch condition and saved into program 1 of the first set of hearing aids. The overall gain was then adjusted to create gain mismatches of 3, 6, and 9 dB in each of the three remaining programs. This was achieved by decreasing gain by 3 dB in one device for the 3 dB mismatch, then increasing gain by 3 dB in the opposite device for the 6 dB mismatch. Finally, gain was reduced by a further 3 dB in the first device to achieve the 9 dB mismatch. Figure 1 shows the REIG curves measured for each ear and gain mismatch condition for one participant. Gain increases were implemented in the left device for half the participants and the right device for the other half.

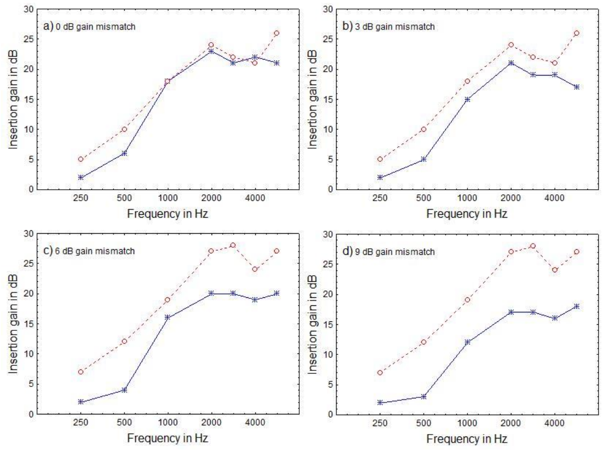

Figure 1: An example of how gain is changed in the left (blue asterisk) and right (red circle) devices to achieve gain mismatches of b) 3 dB, c) 6 dB, and d) 9 dB relative to a) the insertion gain that has been balanced for loudness across ears (0 dB gain mismatch condition).

Stimuli

Five test stimuli were used, three of which represented broadband everyday sounds: speech, traffic noise, and the sound of screeching cockatoos. These sound samples had very different spectral characteristics, as shown in Figure 2. Relative to the speech sample, traffic noise was low-frequency weighted, while cockatoo noise was high-frequency weighted. Each of the three broadband stimuli was 2 s in length with 10 ms onset-offset ramps applied. The remaining two stimuli were 400 and 3150 Hz octave-band filtered pink noise. Each pink noise stimulus was four pulses in length and had 150 ms pulse durations, 50 ms inter-pulse intervals, and 10 ms rise and fall times. All stimuli were filtered to compensate for the average response of the 20 loudspeakers used in the localization test.

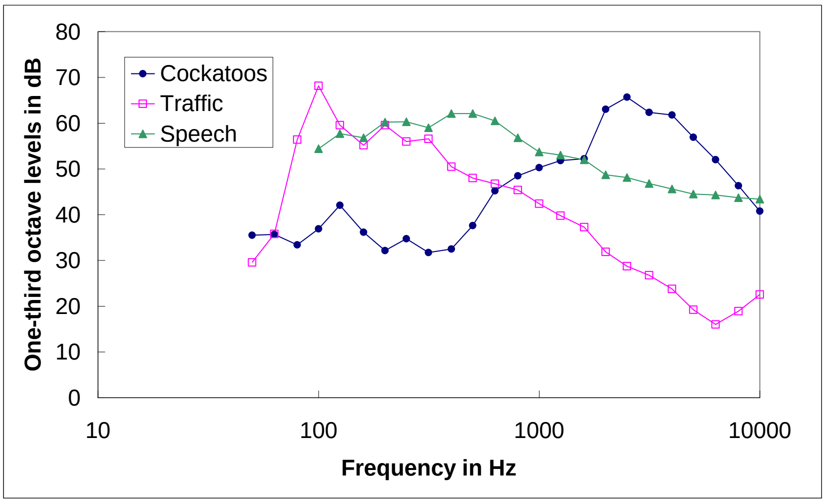

Figure 2: One-third octave spectra of the three broadband stimuli: speech (green open triangles), traffic noise (pink open squares), and cockatoo noise (blue filled circles).

Localization testing

The instrumentation for localization testing has been previously described in Keidser et al. (2006)[3]. In brief, the localization testing was conducted in an anechoic chamber using 20 loudspeakers, each positioned 18° apart, that were mounted on a 360° horizontal metal arc that measured 3.4 m in diameter. A screen of black, acoustically transparent fabric was hung on both sides of the loudspeaker array to ensure that the loudspeakers were not visible to the participant at any time during the experiment. Inside the loudspeaker array, the fabric screen was labelled at 10° intervals.

During the localization testing, participants were seated in the centre of the loudspeaker array facing 0^o azimuth. To ensure consistency of head position, participants wore a battery-operated headlamp and were instructed to keep the light beam focused on the 0^o marker prior to and during each stimulus presentation. Each of the five stimuli was presented twice in a random order from each of 20 loudspeaker positions for each of the four gain mismatch conditions. The order of the stimuli and conditions for each participant were determined by a balanced Latin square. The presentation level of the stimuli was 65 dB SPL in the free field with a ±3 dB roving effect applied. Participants were asked to verbally report the perceived direction of the stimuli.

Results

For the analysis, all presentations and responses to the rear hemisphere were folded to the mirrored positions in the front hemisphere. This folding ensured that front/back confusions were ignored and only left/right confusions were accounted for[7,8]. For each participant, stimulus, and gain mismatch, the root-mean-square (RMS) and mean localization errors were calculated. While the RMS error describes the general accuracy with which a person can localize a sound from different directions, the mean error, if significantly different from zero, indicates if there is a consistent bias to either side of the head. As half the participants had the overall gain increased in their right aid relative to the overall gain provided in the left aid, whereas the other half of the group experienced the gain increase in the other ear, the azimuths were reversed for half the participants after folding. Consequently, a positive mean value indicates a bias toward the right ear (softer presentation level), while a negative mean value indicates a bias toward the left ear (louder presentation level).

Figure 3 shows the average RMS errors. An analysis of variance (ANOVA) of repeated measures was conducted on these data using stimulus and gain mismatch as repeated measures. This analysis showed a significant effect of stimulus (p = 0.0002), but neither gain mismatch nor the interaction between the two main factors showed significance (p = 0.29 and p = 0.43, respectively). A Newman-Keuls post hoc test performed on stimulus showed no significance between any pairs of means, but revealed that the three broadband stimuli produced lower RMS errors than did the pulsed narrowband noise stimuli. There was also a tendency for the two low-frequency weighted stimuli (traffic-noise and 400 Hz pulsed pink noise) to produce lower average modified RMS errors than did their high-frequency weighted counterparts (cockatoo noise and 3150 Hz pulsed pink noise, respectively). These findings are all consistent with the expectation that the ITD will be the dominant cue for left/right discrimination when low-frequency information is present in the signal.

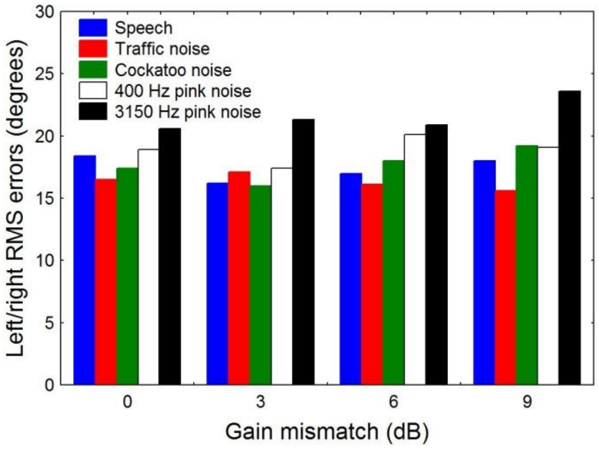

Figure 3: The average RMS localization errors for each stimulus and level of gain mismatch.

Figure 4 shows the average mean localization errors. An ANOVA of repeated measures was performed on these data using stimulus and gain mismatch as repeated measures. In this case, stimulus and the interaction between stimulus and gain mismatch showed significance (p = 0.007 and p = 0.004, respectively). A Newman-Keuls post hoc analysis of means of the interaction effect revealed that for the one octave 3150 Hz pink noise, the mean localization error became significantly more negative as the gain mismatch increased. That is, increasingly more responses occurred to the left of the presentation azimuth, which is the side at which gain was increased. Further, the mean localization error produced for the 3150 Hz pulsed pink noise was significantly more negative than the mean errors produced for the low-frequency weighted stimuli (traffic noise and 400 Hz pulsed pink noise) for each gain mismatch condition larger than 0 dB. In fact, for the two low-frequency weighted stimuli, the mean error remains close to zero for all the gain mismatch conditions. Again, this finding is consistent with the IID only becoming the dominant cue when low-frequency information is removed from the stimulus[5].

These findings are also in agreement with Keidser et al. (2006)[3], who showed that while non-synchronized compression reduced IID, this distortion had no significant effect on the hearing aid wearers' ability to localize a broadband sound in the horizontal plane.

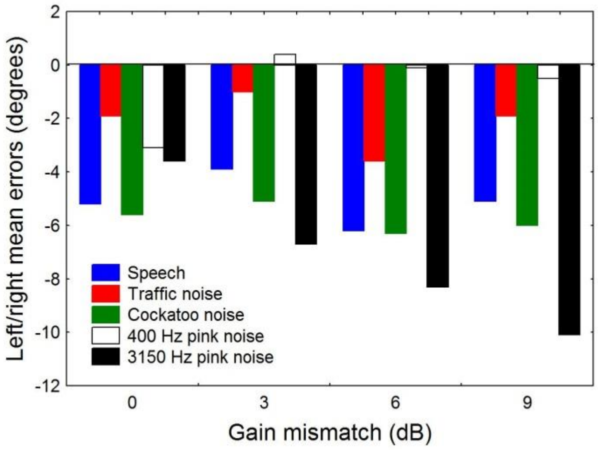

Figure 4: The average mean localization errors for each stimulus and gain mismatch condition.

Summary

Data from this study suggest that as long as a sound contains the low-frequency information that allows ITD cues to be accessed, left/right discrimination is not severely affected by an interaural gain mismatch of up to 9 dB. Consequently, for the purpose of improving localization performance, it is more important to preserve the ITD than the IID cues in bilaterally fitted hearing aids. That is, a mismatch of devices that produce different time delays, vent sizes, or microphone modes across ears are more likely to interfere with the ability to localize sounds in the horizontal plane than are gain mismatches caused by non-synchronized compression.

References

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