Promoting off-axis listening and preserving spatial cues with Binaural Directionality II

TOBIAS PIECHOWIAK[1,*], JESPER UDESEN[1], KIMI MOELLER[1], FREDRIK GRAN[1], AND ANDREW DITTBERNER[2]

[1] *GN ReSound A/S, Ballerup, Denmark*

[2] *GN ReSound North America, Glenview, IL, USA*

Hearing in complex acoustic scenes is a challenge for hearing-impaired persons that often persists after amplification is applied even when fitted bilaterally. From a hearing aid (HA) processing point of view there can be several reasons for this. First, directional filters in a symmetric fitting can help increase signal-to-noise ratio for on-axis signals-of-interest. However, they also can render off-axis signals inaudible. Second, HA microphone location can degrade spatial cues that are important for localization and thus listening in complex acoustic scenes. Third, amplification itself, when applied independently at both ears, can affect spatial cues, mainly interaural-level-differences. Finally, changing acoustic scenes might require changing processing. In order to overcome some of these challenges we propose a bilateral fitting scheme that can be symmetric or asymmetric depending on the acoustic scene. The respective HA processing modes can be (a) omnidirectional, (b) directional, or (c) directional with preservation of spatial cues. In this study it was shown that asymmetric fitting helps improve off-axis audibility when prioritized while it provides natural sound and decreases listening effort for symmetric fitting in situations when audibility is not the main focus.

INTRODUCTION

Hearing aids' primary objective is to restore audibility of desired target signals. This is usually done by applying frequency dependent gains on the input signal. However, it does not solve the problem hearing aid users have in background noise (Kochkin, 2000). Directional filters can help alleviate some of the problems by supressing distracting sounds from a certain direction. However, there are some drawbacks to this approach. Generally, benefits of directional filters are most salient in laboratory investigations and studies have failed to establish comparable benefits in "real-world environments" (e.g., Walden *et al.*, 2000; Nielsen, 1973). There might be several reasons for this. First, directional benefit is largest in anechoic environments but dimishes relatively quickly when reverberation is added **?**. This is also the case when multiple sound sources are presented creating a more diffuse sound field that decreases the performance of a directional filter. Second, directional filters create worse "off-axis" listening. Sounds from the sides and rear are reduced in amplification, users may report feelings of

*Corresponding author: tpiechowiak@gnresound.com

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"tunnel hearing" being cut off from their surroundings and not being able to re-orientate their focus to other, new target signals. This is especially true when target/interferer sources are moving as is usually the case in real acoustic environments. Third, and very related to the previous point, is that directional filters and microphone placement alone on the device itself can deteriorate spatial cues and can lead to a decrease in loclalization performance (Van den Bogaert *et al.*, 2006; Keidser *et al.*, 2006). It has also been shown that the usage of spatial cues are the main key to spatial unmasking which constitutes an important part of speech understanding in complex environments (Edmonds and Culling, 2005, 2006). Another reason, more of psychological nature, is the fact that only a small fraction (30%) of hearing aid users with switchable hearing aids use this feature (Cord *et al.*, 2004) although it could be beneficial. The reasons for this neglect is that in most situations the user does not know when to switch or does not know in which situations the respective programs could be of benefit. In order to alleviate some of the listed challenges above we introduced a asymmetric fitting scheme that adaptively switches between different microphone processing modes which in the following will be called Binaural Directionality II (BDII). Its ultimate rationale is to increase audibility in challenging situations when the target signal is well defined while maximizing spatial awareness in quieter situations and when the target signal is not clearly defined.

CONCEPT

There are four mircophone processing modes for BDII:

Omnidirectional (Omni) : The front microphone is used as input.

Fixed Directionality (Dir) is a fixed 2-mic beamformer that maximizes DI.

Pinna Restoration (PR) mimics the open-ear response of a KEMAR ear at the coupler by a fixed 2-mic beamformer. Its rationale is to deteriorate spatial cues less than with classical microphone modes like omnidirectional mode and to provide better natural sound.

Bilateral Compression (BC) aims to preserve natural interaural-level-differences and thus mimics the head shadow effect. This is done with the help of ear-to-ear synchronization and the exchange of envelope power estimates across ears.

The functionality of the different microphone modes is illustrated in the intensity plots in Fig. 1. The open ear response shows the characteristic "pinna valley" around 120° and between $5-7$ kHz. In this frequency range scattering from the pinna mainly takes place. Pinna Restoration is a 2-mic beamformer that optimizes towards a KEMAR's coupler response. This is shown in the plot where the "pinna valley" is clearly indicated. In contrast the omnidirectional mode is listening "sideways" having its direction of maximum sensitivity around 100° across all frequencies. Fixed directionality has a hypercardioid shape with maximum sensitivity at 40° and its "null" at around 120°.

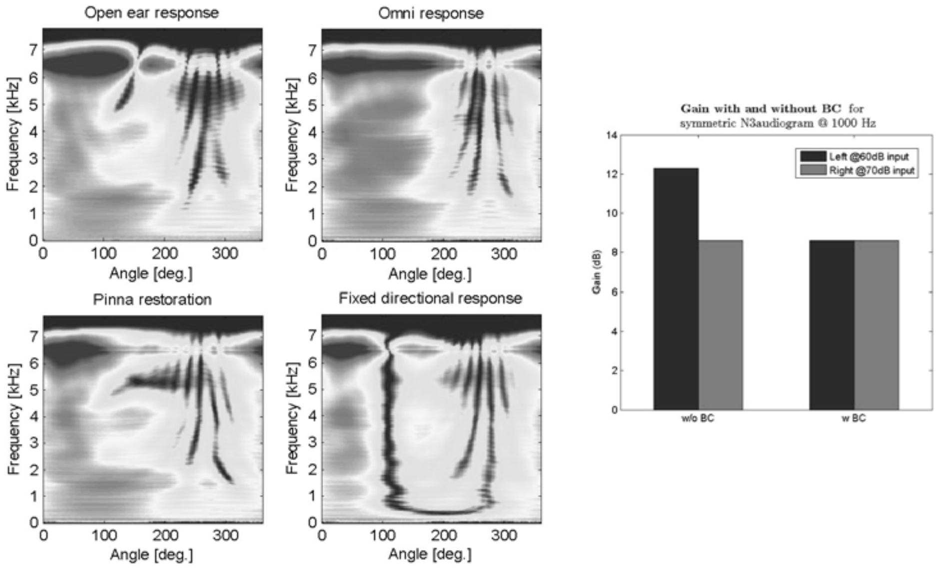

Fig. 1: Left panel: Intensity plots showing the open ear, omnidirectional, Pinna Restoration (PR) and Fixed Directionality (Dir) responses. The hearing aid was placed on KEMAR's left ear. Right panel: Gain, given with and without Bilateral Compression for a typical audiogram

The right panel shows a working example of BC. Insertion gain is shown when BC is switched on and when it is switched off. Hearing loss at 1000 Hz was symmetric and difference in input power (ILD) was 10 dB. Without BC the ILD will *decrease* from 10 dB to 6 dB while the original ILD is preserved when BC is switched on. For Binaural Directionality II, PR and BC are only applied jointly. PR serves as a front-end for BC in order to achieve a reliable ILD estimate (close to the ear-drum). As stated before in the Binaural Directionality concept, microphone modes are changed according to the acoustic environment. Figure 2 shows the switching strategy of BDI and BDII.

Concept	Acoustic scene	Left device		Right device	
		BD I	BD II	BD I	BD II
Spatial Cue Preservation	Quiet w/o speech	Omni	PR + BC	Omni	PR + BC
	Quiet w/ speech	Omni	PR + BC	Omni	PR + BC
Better-ear effect	Noise w/o speech	Omni		Dir	
	Noise w/ speech	Omni		Dir	
Speech enhancement	Noise w/ speech dominance in front of listener	Dir		Dir	
	Noise w/ speech dominance at Right device	Dir		Omni	

Fig. 2: Switching strategy for Binaural Directionality I/II depending on the respective acoustic scene.

There are three different concepts that are applied here. Spatial cue preservation is the new concept in Binaural Directionality II. It is applied when speech is present in a relative quiet environment. In BDI omnidirectional mode is used instead.

EXPERIMENTS

Subjects and fitting

The same 11 hearing-impaired subjects participated in all the experiments. They were fitted with open domes of various sizes. The mean audiograms of the subjects are shown in Fig. 3.

Corresponding gains were obtained by using GN Resound's *Audiogram+* fitting rule. After applying prescribed gains, fine tuning was performed on each subject. No real-ear measurement (REM) was performed.

Localization

Subjects were placed onto a chair inside the array of 12 speakers facing the speaker at 0° as shown in Fig. 5. The stimulus was a 1-sec broadband telephone signal in quiet. It was presented at 70 dB SPL at the position of the head. The task was to identify the loudspeaker from which sound emanated by naming the number of the respective speaker. With each subject two sessions were held two weeks apart. This was done for testing test-retest reliability and also to assess if learning took place for localization during the time interval between visits (see section 3.4). Front-back confusions and the root-mean-square (RMS) error were used for data analysis.

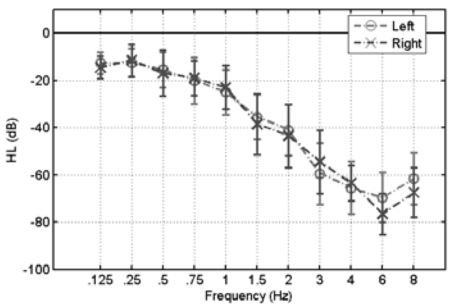

Fig. 3: Audiogram of the participating subjects.

Speech intelligibility

The setup for speech intelligibility measurements is shown in Fig. 4. It was inspired by the work of Hornsby and Ricketts (2007). The rationale was that, depending on the listening situations, switching between different microphone modes would yield the best performance compared to a single symmetric mode. In this study symmetric Omni mode (Omni/Omni) served as reference. HINT sentence material was used to determine speech reception thresholds (SRTs) with an adaptive 2-up 1-down procedure.

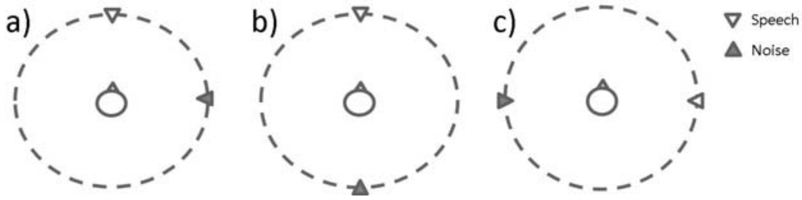

Fig. 4: The three different acoustic environments which are used in the intelligibility test: a) speech from front, noise from side; b)speech from front, noise from behind; c) speech from side, noise from side.

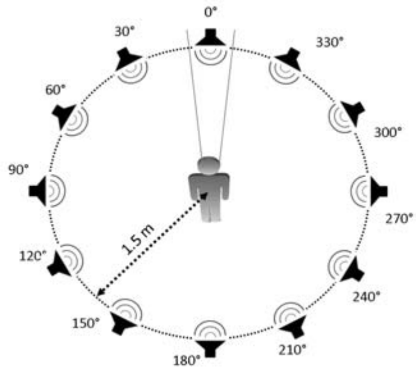

Fig. 5: Setup of the localization experiment.

Field trial

In order to evaluate efficiency of BDII ("real-world benefit") a simple crossover design was used. Five of the 11 subjects were initially fitted with BDI activated. The remaining subjects were fitted with BDII activated. The SSQ questionnaire (Gatehouse and Noble, 2004) was used to evaluate naturalness of sound, listening effort and orientation ability:

- Q1: You are talking with one other person and there is a TV in the same room. Can you follow what the person you are talking to says? (Anchors: Not at all - Perfectly)
- Q2: You are in a group of about five people, sitting around a table. It is an otherwise quiet place. You can see everyone else in the group. Can you follow the conversation?
- Q3: You are in a group of about five people in a busy restaurant. You can see everyone else in the group. Can you follow the conversation? (Anchors: Not at all - Perfectly)
- Q4: You are outside. A dog barks loudly. Can you tell immediately where it is, without having to look? (Anchors: Not at all - Perfectly)
- Q5: Can you tell how far away a bus or truck is, from the sound? (Anchors: Not at all - Perfectly)
- Q6: Can you tell from the sound whether a bus or truck is coming towards you or going away? (Anchors: Not at all - Perfectly)
- Q7: Do everyday sounds that you can hear easily seem clear to you (not blurred)? (Anchors: Not at all - Perfectly)
- Q8: Do you have to concentrate very much when listening to someone or something? (Anchors: Concentrate Hard - Not need to concentrate)

Q9: When you are the driver in a car can you easily hear what someone is saying who is sitting alongside you? (Anchors: Not at all - Perfectly)

Q10: When you are a passenger can you easily hear what the driver is saying sitting alongside you? (Anchors: Not at all - Perfectly)

After a two-week use, devices were re-programmed to the alternative setting and again were worn for a period of another two-weeks. At each visit subjects were instructed to complete the SSQ questionnaire. Individual subject audiograms were used to define *Audiogram+* target gains. Only one program was made available at a time (either BDI or BDII) so that subjects could not unintendedly change the settings.

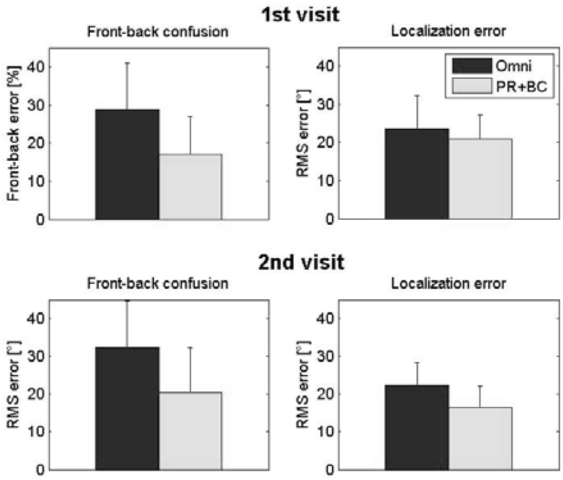

Fig. 6: Upper panel: Front-back confusion and RMS error at first visit. Lower panels: Front-back confusion and RMS error at second visit.

RESULTS

Localization

Results for the localization experiment are shown in Fig. 6. A two-tailed *t*-test revealed that front-back confusions were significantly lower for BDII than for BDI at both visits (first visit: $t(10) = 2.5, p < 0.05$, second visit: $t(10) = 2.9, p < 0.05$). However, there was no significant difference between front-back confusions between first and second visit for either program. No difference in RMS errors was found, neither between programs nor across visits.

Speech intelligibility

Speech intelligibility results are shown in Fig. 7. Directional benefit was defined as the difference between SRTs in the respective microphone modes and the omnidirectional mode which served as reference. Generally, for speech coming from the front, all directional microphone modes provided higher SRT than symmetric omnidirectional mode. The situation was different when speech was presented from the side. Here, Dir/Dir was significantly worse than the reference while Dir/Omni performed significantly better. The microphone modes that provided benefit in all three conditions were those that are automatically chosen by Binaural Directionality in the respective environment.

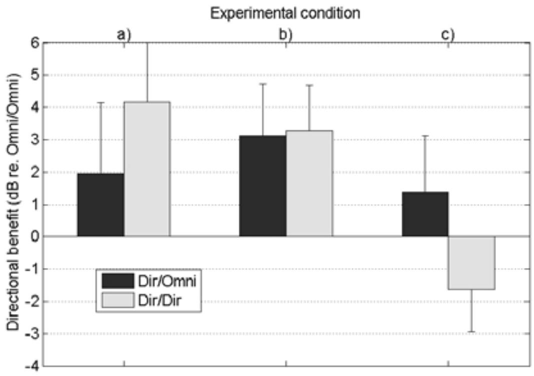

Fig. 7: Speech reception thresholds for the three experimental conditions shown in section 3.3

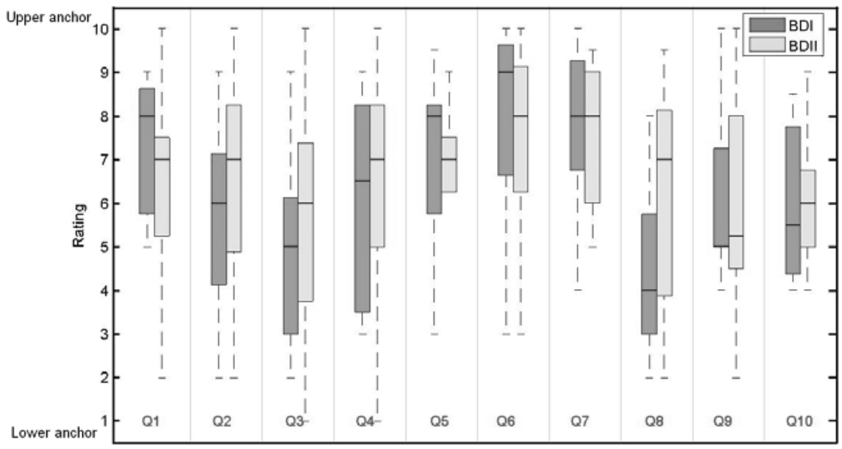

Fig. 8: Results from the field trial are shown for the two program modes BDI and BDII. The box plots show the median and the 25% and 75% whiskers. Questions(Q1 - Q10) are indicated on the *x*-axis below each pair of data.

Field trial

Results from the field trial are shown in Fig. 8. Questions are indicated on the *x*-axis. The *y*-axis shows the 10-point rating scale having the low anchor at the bottom (e.g., *Not at all*) and the high anchor at the top (e.g., *Perfectly*). The rating in question 8 (Q8) was shown to be significantly different for BDI and BDII (two-tailed *t*-test:

$t(10) = 2.5, p < 0.05$). Thus, listening is perceived as more effortless in BDII than in BDI.

CONCLUSIONS

Binaural Directionality II is a concept that switches hearing aid microphone input modes depending on the acoustic scene. It also tries to preserves spatial cues in less challenging (meaning good SNR) situations. It was found that BDII (a) provided higher off-axis intelligibility, (b) gave better localization, (c) required less effort listening in real-world acoustic situations, and (d) tended to be preferred in multi-talker situations.

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