Reducing Off-Axis Talker Distraction with Combined Spatial and Denoising Processing in Hearing Aids

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Abstract

Hearing aid users frequently report competing talkers as highly disturbing in everyday life. Deep neural network (DNN)–based denoising has been introduced to improve speech in noise, but its benefit depends on how it is integrated with directionality to support selective attention. This paper evaluates Beltone hearing aids with True Focus—a combination of 4-microphone beamforming and DNN-based denoising—against another premium RIE hearing aid with DNN denoising. Participants rated the most audible talker in diffuse noise with three spatially separated competing talkers. Consistent with an earlier study[1] evaluating objective speech recognition performance, Beltone hearing aids with True Focus provided a clear advantage for maintaining focus on the talker in front compared to the other brand, including when that talker was softer than competing talkers. True Focus delivers the best audibility advantage to other current DNN denoising solutions and supports selective-attention listening better than the denoising system of another premium brand.

Imagine meeting a friend to catch up at a busy local coffee shop. There would be a mix of many sounds that potentially could interfere with your conversation including the whirr of coffee grinders, espresso machines and blenders, the beeping of timers, the clink of spoons, cups and saucers, perhaps ambient music, and the door to the shop opening and closing. Added to that are the sounds of other people talking and making non-verbal sounds like laughing, coughing or a baby crying. Which of these sounds would be most disruptive to your ability to focus on your conversation? If you are a hearing aid user – and probably even if you aren't – the answer would likely be the verbal sounds of other people. Skagerstrand et al[2] asked hearing aid users to keep a log of sounds that they found annoying while wearing hearing aids in their daily environments for 2 weeks. Ninety-one percent of the participants reported experiencing annoying sounds and the researchers were able to sort these into 18 categories. The most frequently reported annoying sound category was indeed verbal human sounds.

The finding that human verbal sounds are the most annoying in hearing aid users' daily soundscapes fits well with subjective reports from hearing aid users that they have trouble when listening in environments with multiple people talking.[3,4] This subjective experience is in turn strongly supported by lab studies where speech is both the target and the interfering signal.[5,6] One reason listening to speech in the presence of other speech is such a common complaint is simply that it frequently occurs in people's daily lives. However, a deeper understanding of why it tops the list can be gained by considering how the listener's auditory system is affected depending on the nature of different interfering sounds.

Speech as a competing noise disturbs understanding of desired speech in various and complex ways. For the sake of simplification, we can sum these disturbances up as energetic and informational masking. These different types of maskers place different demands on processing by the listener as sound is transduced, transmitted and decoded in the auditory system. Put in the simplest terms, the acoustic overlap of target and masker sources creates energetic masking that originates in the peripheral part of the auditory system. It limits the amount of information that is available for processing at higher levels of the auditory system. Energetic masking is also what is created with the steady-state noises often used in speech-in-noise recognition tasks and is the primary determinant of the SRT (Speech Reception Threshold). As implied by the name, informational masking occurs despite both the target and the masker being available. In the case of informational masking, the listener has trouble in perceptually separating the desired speech from the masker speech which limits their ability to selectively pay attention to the desired speech. The amount of difficulty experienced depends on

many factors such as task demands, a priori knowledge about the speech sources, contextual cues and predictability of the speech, to name a few. The ability to selectively pay attention to a desired talker is vital for carrying on conversations in noisy environments, and especially in ones with other talkers that create informational masking, such as the coffee shop example introduced previously.

Hearing aids increase audibility of desired sounds, but also of undesired sounds. In challenging listening environments, the benefit of wearing hearing aids is decreased by the occurrence of both energetic and informational masking. Therefore, hearing aids employ varying noise management strategies to maintain benefit in these difficult conditions. The most documented effective solution is directional microphones. They can decrease both types of masking by limiting the audibility of sound depending on its location relative to the hearing aid wearer. Most often, directional microphone systems are designed to preferentially amplify sound in front of the hearing aid user. This corresponds well to expected listener behavior in very noisy listening conditions.

But what about the residual unwanted noise? Or the blend of desired and undesired speech and other sound coming from the same direction? Single channel noise reduction features are meant to address these issues. This type of noise management aims to improve the hearing aid user's experience of listening in noise when the desired speech and unwanted noise are mixed. Nearly all single channel noise reduction systems – also called digital noise reduction - in hearing aids today use a rule-based subtractive approach. They attempt to identify speech and then measure the spectrum of the signal when speech does not seem to be present. Then, rules that specify gain reduction per band according to estimated SNR (signal-to-noise ratio) and possibly also signal level are applied. While this approach to noise reduction has documented benefits in listening comfort,[7] the assumptions made in the operation of this type of system – such as the stability of background noise – may be violated in real listening conditions and could introduce distortions of the speech quality.

A new approach to single channel noise reduction in hearing aids is to train a deep neural network (DNN) to segregate speech from background noise and selectively suppress the background noise. DNNs are a common form of Artificial Intelligence that are inspired by human learning. The advantage that a DNN-based method provides over subtractive methods is that once the algorithm has gathered enough information, it can make its own decisions, without the need for explicit instructions or manual input from a human writing or operating the algorithm. It can better handle fast-changing, novel or ambiguous input because it has previous experience with similar data and can now make informed decisions that are flexible and adaptable. When used for acoustic noise reduction, this type of system is often called denoising.

A challenge in employing denoising in hearing aids is that it requires more processing power than existing hearing aid platforms have been designed to handle. At time of writing, there are only two commercial solutions capable of DNN-based denoising. Each solution implements an additional accelerator chip that is dedicated to its DNN. In addition, both solutions combine denoising with directionality to increase SNR and help the denoising to spotlight the most likely talker of interest in front of the hearing aid user when conditions are especially noisy. Without directionality, the denoising risks enhancing the loudest talker regardless of where the talker is located relative to the hearing aid user. The Beltone denoising feature combines with strong 4-microphone beamforming to form True Focus. The denoising feature in the other premium brand hearing aid is paired with 2-microphone directionality with a wide beamwidth. In a previous study, we found that listeners performed better on a selective attention task with True Focus than with the other solution.[1]

The ability to selectively attend means that the listener is in control. This has serious implications for their listening experience in challenging situations. Since the two solutions tested in our previous study showed differences in how well they supported selective attention tasks measured objectively, we were curious to know more about how listeners experienced these two denoising features. We therefore carried out a study aimed at evaluating the subjectively perceived balance of talker audibility with Beltone True Focus and the other premium brand of Receiver-in-the-ear (RIE) hearing aid with DNN denoising. The subjective audibility was rated by selecting the best audible talker in a mixture of three talkers in a diffuse background noise scenario. In designing the test conditions, we considered different azimuths, talker gender, and presentation levels.

Methods

The study was designed as a single-blind study where the investigators knew which hearing aids the participants were testing. Participants were at no point informed about which hearing aids were included in the study.

Participants

A total of 24 participants (12 males, 12 females) with symmetric moderate sensorineural hearing loss (+/- 20 dB HL between ears per frequency) participated in the study. They were selected to have hearing loss consistent with the standard N3 and N4 audiograms[8] and at least 6 months of experience with amplification. All were current users of premium RIE hearing aids from various hearing aid brands. The participants' median age was 75 years (interquartile range 65 - 79 years).

Hearing aids and fitting

Each participant was fitted with a pair of Beltone RIE hearing aids with True Focus as well as a pair of RIE hearing aids from one other premium brand offering DNN denoising (Brand A). The hearing aids were fitted with each hearing aid brand's default gain prescription for experienced hearing aid users (100% gain). Both pairs of hearing aids were fitted with receivers based on the test participants' hearing loss and closed ear tips (power domes or sleeve domes). Closed ear tips were chosen to ensure maximum benefit from the hearing aid signal processing. The goal of the study was to compare the effects of applying the denoising and related technologies on audibility of talkers and not to evaluate whether the controlled algorithm provided accurate switching to those settings, and for this reason we programmed the hearing aids with each brand's expected settings for the given listening environment instead of using the automatic program. In both cases, this included directionality combined with the denoising feature.

Test setup and conditions

The study was set up as a counterbalanced crossover design, where each participant was fitted and tested with both pairs of hearing aids. The hearing aids were tested in two different sound scenes with 3 talkers at different azimuths in front, behind and lateral to the test participant. The lateral talker location was at -90 degrees azimuth for Scene A and -45 degrees azimuth for Scene B. Testing of the two pairs of hearing aids as well as the two sound scenes was randomized to avoid order effects.

Test participants were instructed to indicate which talker was most audible for 24 different sound scenes per hearing aid condition (by verbally responding or by pointing). The test setup consisted of a 16-channel loudspeaker setup in a sound booth. The two test conditions each included talkers in front, lateral and behind while all 16 loudspeakers played diffuse cafeteria noise. The participant was seated in the center of the loudspeaker array. The test setup is illustrated in Figure 1. The speech material used was matrix sentences from the OLSA (Oldenburg sentence test)[9-12] and the ISTS (International Speech Test Signal).[13] OLSA sentences were always used for the front talker (Talker 2) and lateral talker (Talker 1) while ISTS was always used for the talker in back (Talker 3). The talker genders were systematically varied such that an equal number of trials were carried out with each configuration. These configurations were:

- Female front, male lateral, female back
- Male front, female lateral, female back
- Male front, female lateral, male back

Three presentation levels of Talker 2 were used including 70, 73 and 76 dBA. Six presentations were with a 0 dB SNR between Talker 2 and the other talkers (front talker and other talkers presented at same level), and six presentations were with a -3 dB SNR between Talker 2 and the other talkers. (front talker softer than other talkers).

Participants were strictly instructed to look straight ahead at 0-degree azimuth which was the location of talker 2. For each presentation, participants were instructed to listen to the scene for at least 20 seconds and then switch their focus between talkers to determine the most audible talker. Talkers were presented against a diffuse cafeteria noise, which was presented from all loudspeakers at 70 dBA. The noise presentation was not stopped when switching between the scenes.

Test retesting was also part of the test. For the analysis of voice effects, only the SNR conditions with equal talker levels were taken into account.

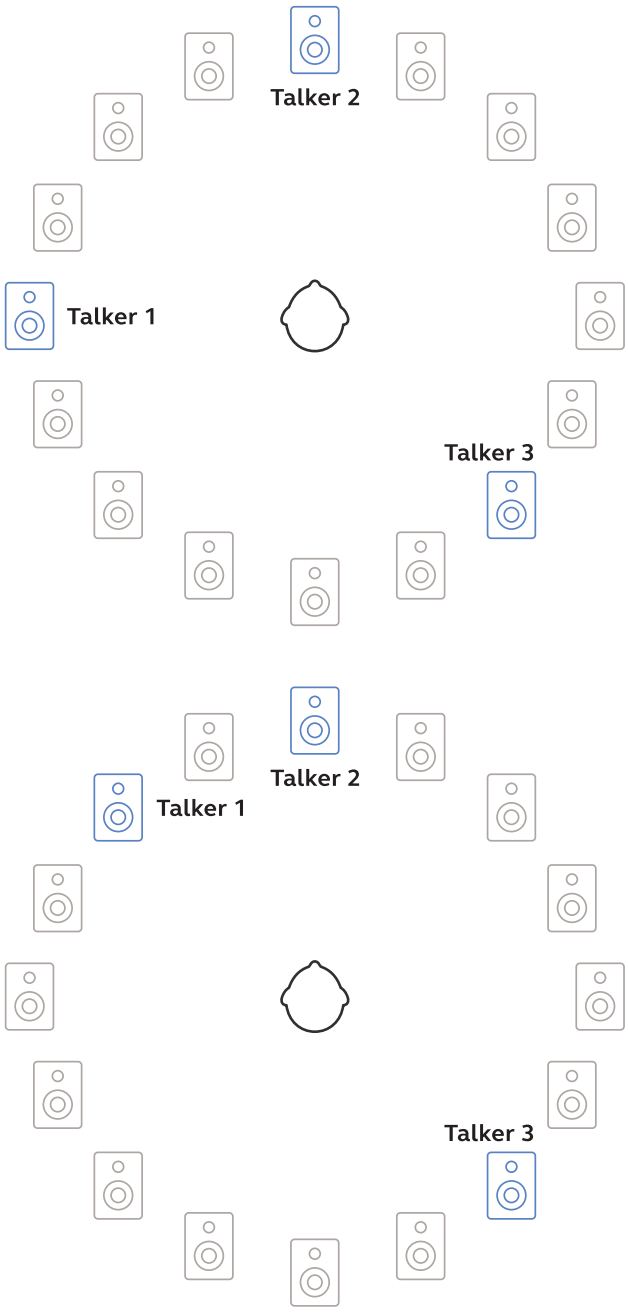


Figure 1. Illustration of placements of talkers (blue) in a horizontal 16 channel loudspeaker setup: In Sound scene A (top panel) the distractor talker was at -90 degrees. In Sound scene B (bottom panel) the distractor talker was at -45 degrees. The listener was seated in the center of the array. A diffuse cafeteria noise was played back via all 16 loudspeakers.

Subjective audibility rating

The task of judging which talker was most audible in a scene addressed subjective masking-level differences between talkers. The term “most audible” was chosen for the task based on the following considerations. As presentation levels were higher than masking and intelligibility thresholds, “audible” would not be misunderstood as “detectable”. Furthermore, it was decided not to address loudness or salience, as these terms would explicitly exclude intelligibility. Finally, asking participants to choose the “most intelligible” talker would be expected to elicit judgements of things like semantic content or pronunciation. “Most audible” is considered to communicate an energetic focus without excluding intelligibility completely. In the instruction, it was mentioned that the nonsense speech (ISTS) in the back hemifield could also be judged as “most audible”. This aimed at demonstrating to the participants that the intelligibility of the content was irrelevant to their task. For the main outcome measure, the percentages of most-audible-talker judgements were computed based on 24 judgements; there were 12 conditions where distractor level and talker gender was varied, and the 12 conditions were completed for both Scene A and Scene B.

Results

Most audible Talker

Figure 2 shows the percentage of trials where participants selected each of the three talkers as most audible. Per participant, the score for the side-, the front-, and back talkers are in total 100% (for each hearing aid condition). For True Focus, the front talkers were selected most often. The front talker was judged most audible in 54% of the scenes, the side talkers were selected in 27% of the scenes, and the talkers in back 15% (medians). Results for Brand A showed that the side talkers were judged as most audible in the majority of cases. The talkers from the side were judged most audible 50% of the time, front talkers 38%, and talkers from the back 8% (medians). As the data are normally distributed (Shapiro-Wilk Test, $p>0.05$), hypotheses were tested using parametric statistics.

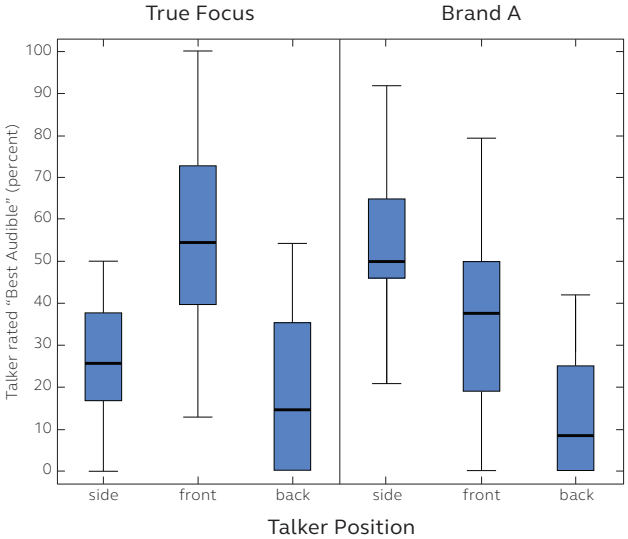


Figure 2 : Best-audibility ratings for the three talkers at equal levels (medians and interquartile ranges); pooled data for all SNR, side talker azimuths, and talker gender conditions; the left panel shows results for Beltone True Focus; the right panel shows the Brand A results.

Figure 3 shows audibility ratings for the conditions with louder distractors. For Beltone True Focus, the front talkers were best audible in 31% of the scenes, the side talkers were chosen at 52%, and the back at 25% (medians). The Brand A hearing aid showed best audibility for the front talkers at 4%, side talkers at 77% and back talkers at 17% (medians). These data are not normally distributed (Shapiro-Wilk Test, $p<0.05$). Consequently, related hypotheses were tested using non-parametric tests.

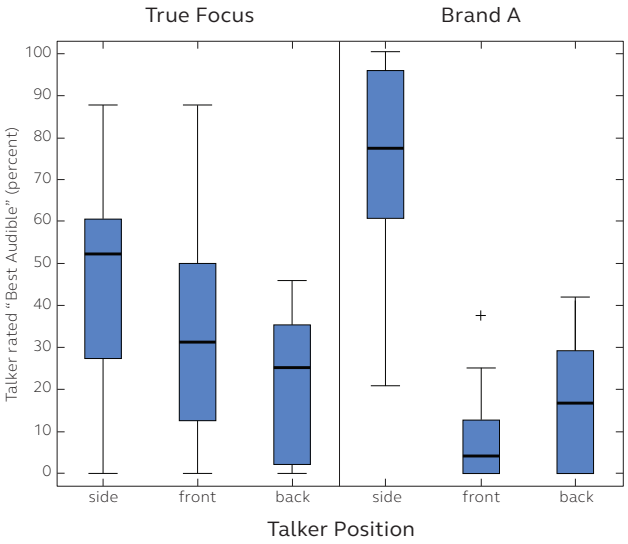


Figure 3: Best-audibility ratings for the three talkers with louder side and back talkers (medians and interquartile ranges); pooled data for all SNR, side talker azimuths, and talker gender conditions; the left panel shows results for Beltone True Focus; the right panel shows the Brand A hearing aid results.

Discussion

As expected, the audibility of the front-talker (54% median) is better than the audibility of the other talkers for the Beltone True Focus feature. Yet, the other talkers were chosen to some degree. This might have been caused by individual biases (e.g., directions or voices) that correspond to the individual hearing losses. Brand A shows an inferior audibility of the front talker (38% median) compared to the side talkers. In other words, it shows the tendency to enhance talkers from the side, which might be detrimental if a listener is seeking eye-contact with her/his conversation partner. In particular, if a talker in front is softer than competing talkers, Brand A almost never provides best audibility for this talker. The front talker was selected as most audible only 4% of the time when the side and back talkers were louder. Even the talkers in back were judged most audible more often than talkers in front when the side and back talkers were louder. This demonstrates a failure in enhancing the talker that the hearing aid user would be most likely to want to hear. In contrast, True Focus is judged as making the front talker most audible 31% of the time when the side and back talkers are louder. Compared to 4% with Brand A, a hearing aid user can expect better support for their listening goals with True Focus. To provide control of enhancing the audibility of a desired talker to the user, the strategy of the True Focus feature achieves its goals to a high degree.

In our previous study,[1] we showed that listeners performed better on a selective attention task with True Focus than with the DNN-based denoising system of the same other premium brand. In that work, the key outcome was objective: when listeners were instructed to selectively attend to a front talker while ignoring competing talkers from other directions, the Beltone hearing aids with True Focus supported this selective-attention strategy more effectively than Brand A. The present study complements those objective findings with a more ecologically oriented measure of subjective audibility, asking listeners which talker in a multi-talker mixture was "most audible" under different spatial and level configurations. Together, these two studies provide converging objective and subjective evidence that True Focus better supports the listener's ability to focus on the intended talker in complex acoustic scenes.

Viewed in the context of current DNN-based denoising solutions, the combined results emphasize that how denoising is integrated with directionality is crucial. In both studies, the Beltone hearing aids employed True Focus, which combines strong 4-microphone beamforming with DNN denoising to emphasize talkers in front while controlling off-axis talkers and diffuse noise. The other premium brand used a DNN denoiser paired with 2-microphone directionality with a wider beam, making its denoising more likely to follow the loudest talker rather than the most probable intended talker. Against this backdrop, True Focus delivers the best audibility advantage to other DNN denoising solutions. This advantage is not only seen in front-talker hit rates, but also in how robustly the system maintains the audibility of a softer front talker when competing talkers from other directions are louder.

The current results also clarify how these signal-processing differences are experienced by listeners. In the previous study, the benefit of True Focus was expressed as improved performance on a selective-attention listening task. In the present data, the same benefit appears as a higher likelihood that the front talker is judged "most audible," particularly in challenging level configurations.

In other words, listeners with True Focus are less distracted by competing talkers in complex listening environments. Instead of the system occasionally "jumping" to a lateral talker when that talker becomes more intense, the acoustic scene remains more stable, with the talker in front maintaining a consistent advantage.

Importantly, the pattern of front-hemifield emphasis with True Focus matches how people naturally use gaze and attention in conversation. Listeners report that True Focus enhances talkers in the front hemifield while suppressing talkers from other locations. This directional weighting helps align the hearing aid's behavior with the user's intuitive strategy of looking at the person they want to hear. In contrast, when the denoising system prioritizes the loudest or nearest talker regardless of direction, listeners can experience a disconnection between where they are looking and whom they are hearing best, which can be frustrating and fatiguing over time.

Taken together, the first study[1] and the present study highlight that the benefit of True Focus goes beyond simple noise reduction or global improvements in SNR. The consistent pattern across objective task performance and subjective "most audible" ratings suggests that True Focus supports the cognitive process of selecting and maintaining attention to a target talker. In practical terms, True Focus supports selective-attention listening better than the denoising system of another premium brand. For hearing-aid users who frequently communicate in multi-talker environments, this alignment between signal processing and selective attention is likely to be just as important as traditional audiological outcome measures, because it directly affects how well they can stay with the conversation they care about.

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