Effect of directional strategy on audibility of sounds in the environment

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ABSTRACT
Directional microphones in hearing aids have been well-documented to improve speech recognition in noise in laboratory conditions. The real-world perceived benefits of directionality have been less dramatic. The development of directional technology during the past decade has focused on improving laboratory benefit by means of adaptive behavior, and more recently, binaural beamforming made possible by ear-to-ear audio streaming. In contrast, ReSound has pursued a strategy for applying directional technology that takes advantage of auditory processing by the brain, with the goal of optimizing real-world benefit. In this study, ReSound Binaural Directionality III is compared to two commercially available binaural beamformers to explore the possible advantages and disadvantages of these very different approaches to applying hearing aid directionality.

INTRODUCTION
Directional microphones amplify sound coming from a particular direction relatively more than sounds coming from other directions. They are the only hearing aid technology proven to improve speech understanding in noisy situations. However, some conditions must be met in order to benefit from a directional microphone. For one thing, the signal of interest must be spatially separated from the noise sources. In addition, the signal of interest must be located within the directional beam and should be within two meters of the listener. Directional microphones in hearing aids are designed to have a forward-facing beam as worn on the head. This means that the hearing aid wearer must face what they want to listen to. By constructing a test environment that fulfills these conditions, the benefit of directional microphones in hearing aids is easily demonstrated. However, real-world environments bear little resemblance to contrived laboratory test environments. Real listening environments are unpredictable in terms of the acoustics, the type and location of the sounds of interest, and the type and location of interfering noises. To complicate matters further, any of these sounds may move, and the listener may want to shift attention from one sound to another. A sound that is the signal of interest one moment may be the interfering noise the next.

It has been observed that the benefit of directional microphones is not perceived to the degree that laboratory tests of directional benefit would imply. There are numerous acoustic and personal intrinsic factors that play a role in this discrepancy. An additional factor is simply that directional microphones can interfere with audibility of the sound of interest when it does not originate from the direction that the hearing aid wearer is facing. It is assumed that individuals wearing directional hearing aids will orient their heads toward what they want to hear. However, in daily life it is not at all unusual to listen to sounds that one is not facing. In fact, it has been shown that more than 30% of adults’ active listening time is spent attending to sounds that are not in front, where there are multiple target sounds, where the sounds are moving, or any combination of these.

ReSound has taken an unconventional approach to applying directionality that considers both the advantages and disadvantages of this type of technology. Binaural Directionality III leverages the brain’s ability to compare and contrast the separate inputs from each ear to form an auditory image of the listening environment. By providing access to an improved signal-to-noise ratio (SNR) for sounds in front while maintaining audibility for sounds not in front, Binaural Directionality III allows hearing aid wearers to focus on specific sounds, to stay connected to their auditory environment, and to shift their attention at will. The Binaural Directionality III strategy controls the microphone mode of each hearing aid depending on the presence of speech and noise in the environment, as well as the direction-of-arrival of the speech. The possible configurations that can result include bilateral Spatial Sense, bilateral directionality, asymmetric directionality with directionality on the right side, and asymmetric directionality with directionality on the left side. The rationale behind Binaural Directionality III contrasts sharply with the advanced directional technologies.
in other premium hearing aids. The focus of development of these technologies has been to maximize SNR improvement in laboratory environments. The most recent advancement in this area is to use two microphones on two bilaterally worn dual microphone hearing aids to attain a greater degree of directivity, commonly referred to as binaural beamforming. A binaural beamformer creates one monaural signal which is delivered to both ears. While there may be additional features that attempt to preserve some cues for localization, the overall effect of this approach is to eliminate the contrasts in the per ear acoustic signals that enable binaural hearing. Speech-in-noise testing under laboratory conditions has shown which is delivered to both ears. While there may be additional features of reduced auditory ability from speech coming from other directions? To begin to answer this question, it is of interest to explore how performance on speech recognition in noise under laboratory conditions is affected when speech arises from varying directions. The investigation described in this paper compared performance for participants fitted with ReSound hearing aids with Binaural Directionality III and two commercially available premium hearing aids with binaural beamforming.

The research questions were:

- Is there a difference in speech recognition in noise for hearing aids with Binaural Directionality III versus binaural beamformers and, if so, how great?
- Is there a difference in speech recognition in noise for hearing aids with Binaural Directionality III versus binaural beamformers and, if so, how great?

TEST SETUP

Subjects
Ten hearing-impaired individuals (6 male and 4 female) with moderate bilateral hearing loss participated in this test.

Hearing instruments and fitting
The hearing aids tested were ReSound BTEs with Binaural Directionality III and premium BTE hearing aids from two other manufacturers that use binaural beamforming (hereafter referred to as “Hearing Aid A” and “Hearing Aid B”). The test participants completed a speech-intelligibility listening test based on the Danish open-set speech corpus for competing-speech studies. This test will hereafter be referred to as the “DAT” test. It is an adaptive test that results in a SRT at the speech reception threshold (SRT). In this test, both the signal and the competing noise are individual talkers, which is different than many other adaptive speech-in-noise tests that use speech babble noise as the masker. A test with individual talkers as the competing signals is exceptionally challenging, as there is informational as well as energetic masking taking place. Because the competing speech is intelligible, the DAT test may be more representative of a real-world situation than typical speech-in-noise tests. The speech corpus contains three sets of 200 unique Danish sentences. The sentences are composed of a fixed carrier sentence with two interchangeable target words:

- “[Name] thought about [noun] and [noun] yesterday”
- “Name” represents the call sign, and each blank represents a unique noun. The nouns are in singular form and include the Danish indefinite articles (“en” and “et”) before each noun.

Examples of sentences include (English/Danish):

- Dagmar thought about a rescue and a suitcase yesterday/Dagmar tænkte på en redding og en kuffert i går
- Dagmar thought about a predator and a toy yesterday/Dagmar tænkte på et rødvy og en kuffert i går

Each of the three sets of 200 sentences is spoken by a different female talker and starts with a specific name. The names are Dagmar, Astrid, and Tina. The name of this test, “DAT”, is a reference to the first initial of each of their names.

The task of the test participants in this study was to listen for and repeat the target nouns of the sentences that start with the name “Dagmar”. Target sentences were played consistently at 65 dB SPL. The “Asta” and “Tina” sentences comprised the maskers. Masker sentences were played simultaneously from other loudspeakers while the “Dagmar” sentence was played, but the test participants were not informed about any questions about the masker sentences. On each trial, two masker sentences were randomly selected from the two sets of 200 masker sentences. The masker sentences were also presented at 65 dB SPL initially. When the test participants were able to repeat both of the target nouns in a sentence successfully, the sound pressure level of the maskers was raised by 2 dB. If one or none of the target nouns was correctly identified, the sound pressure level of the maskers was lowered by 2 dB. The test participants did not receive any feedback concerning whether their responses were correct or incorrect.

Because the duration of all of the recorded sentences is naturally slightly different, time expansion or compression was applied to each of the masker sentences on each trial so that they precisely matched the length of the target sentence. The time expansion and compression was done using the speech analysis program PRAAT. Because the sentence lists are not all of equal difficulty, an attempt was made to balance the difficulty so that the influence of this across all test participants was reduced.

All of the hearing aids tested have adaptive features that rely on identification of speech and noise in the environment. Therefore, an attempt was made to ensure that adaptive features would engage in addition to the DAT corpus. Speech-shaped noise from the Dantale II test was played at a level of 45 dB SPL. The speech-shaped noise was played from loudspeakers directly to the left, directly behind, and directly to the right of the test subject. Furthermore, the ISTS signal was played at 65 dB SPL from the front loudspeaker throughout the duration of the test with only brief pauses while the target and masker sentences were played. For each test condition, the ISTS signal and the Dantale II test noise were started thirty seconds before the first trial in order to activate any adaptive settings in the hearing aids.

For each set of hearing instruments, three conditions were completed in which the target sentences came from three different loudspeakers. One condition was with the target sentences coming from the loudspeaker directly in front of the test participant. A second condition was with the target sentences coming from the left and slightly behind the test participant, and the third condition was with the target sentences coming from behind and slightly to the right of the test participant. The sequence of these conditions was counterbalanced among test participants. The maskers were played from the remaining two loudspeakers. The three test setups are illustrated in Figure 1.

RESULTS

For each of the three target-talker positions, statistical comparisons were performed between pairs of devices. The Tukey Honest Significant Difference statistical criterion was used for the comparisons.

There was no significant difference between the SRTs obtained with the two hearing aids with binaural beamforming when the target talker was positioned in front of the test participant (p > 0.23) as can be seen in Figure 2. Hearing Aid A performed significantly better than the ReSound hearing aid (p < 0.001) when the target talker was in front of the test participant. There was no significant difference found between the ReSound hearing aid and Hearing Aid B.

In the test setup with the target talker positioned to the left of the test participant there was no significant difference between the SRTs obtained with Hearing Aid A and Hearing Aid B (p = 0.41). The SRTs obtained with the ReSound hearing aid were found to be significantly better than with Hearing Aid A (p < 0.001) and Hearing Aid B (p = 0.03) as can be seen in Figure 3.

There was no significant difference between the SRIs obtained with Hearing Aid A and Hearing Aid B (p = 0.44) when the target talker was positioned behind the test participant. Speech reception thresholds measured with the ReSound hearing aid were found to be significantly better than the other two for this condition. When the target talker was behind the test participant, performance in the ReSound hearing aid condition was highly significantly better than for Hearing Aid B (p < 0.001) and Hearing Aid A (p < 0.01) as shown in Figure 4.
toward it. One might argue that this represents an unnatural
behavior. That is, once the target speech in a particular
direction is done for a modest potential advantage when all everyday
speech is often both the sound of interest as well as the competing noise. A
simple, everyday example is a family gathering. Family members
engaging in lively conversation will quickly change turns
talking and even talk over each other. There may be multiple
conversations going on at once, and the topics of conversation
shift rapidly. To be limited to hearing in one direction necessar-
ily limits the ability to participate in such an environment.

In this study, we observed that, as expected, all three hearing aids provided directional benefit for speech presented from in
front. Compared to the hearing aids using binaural beamform-
ing, performance with the ReSound hearing aid with Binaural
Directionality III was 4-6 dB worse than Hearing Aid A, while there was
no significant difference compared to Hearing Aid B. For
this limited listening condition, these results indicate an advan-
tage of binaural beamforming that may be dependent on the
specific technology. However, when the target speech was pre-
sented from the side or back, performance with the ReSound
hearing aids was 10 to 19 dB better than either of the hearing
aids with binaural beamforming. Thus the disadvantage of lack
of audibility for target sound that was not in front with the bina-
ural beamformers was many orders of magnitude larger than
the SNR advantage of binaural beamforming compared to Bin-
aural Directionality III. In other words, a lot of potential damage is
done for a modest potential advantage when all everyday
listening situations are considered.

Participants in this study were instructed to look forward dur-
ing the test. That is, once the target speech in a particular trial was identified, they were not allowed to turn their heads
toward it. One might argue that this represents an unnatural
listening situation, and that in the real world people would, via
head movements, orient to their listening environments and
turn their heads toward what they want to hear. This is certainly true.
Better performance for the target speech from the side and
back would be expected if the participants had turned to-
ward it. However, it is difficult to turn toward something that
one cannot detect. The enormous SNR advantage of Binaural
Directionality III over the binaural beamformers implies much
greater awareness of off-axis sounds as well as better speech
recognition. In other words, better performance with Binau-
ral Directionality III would also be expected even if the par-
ticipants had been allowed to turn their heads simply because
they would have been able to detect and orient themselves to
the target speech more easily and quickly.

The notion that directionality can interfere with natural orient-
ating behavior when listening is supported by Brimjow et al. They
asked participants to locate a particular talker in a back-
ground of speech babble and tracked their head movements.
Participants were fit with directional microphones that provid-
ed either high or low in situ directionality. Their results showed
that, not only did it take longer for listeners wearing highly
directional microphones to locate the speaker of interest, but
that they also exhibited larger head movements and even
moved their heads away from the speaker of interest before
locating the target. This longer, more complex search behavior
could result in more of a new target signal being lost in situ-
ations such as a multitalker conversation in noisy restaurant.

Best et al. added further support that a high degree of direc-
tionality can decrease a listener’s ability to find and attend
to speech in the environment. They presented target speech at
azimuths ±67.5°, ±22°, and ±35°, and instructed listeners
to locate and turn their heads toward the target speech. They
compared performance with the participants using conven-
tional directional processing and 2 different binaural beam- 
formers. They found a small increase in performance of less
than 5% speech understanding with the binaural beamform-
ers versus conventional directionality as long as the speech
was in front or at the 22° azimuths. When the target speech
was presented at a wider angle, performance dropped for both
conventional directionality and the binaural beamformers, but
more dramatically for the latter. A decrement of approximately
15% was observed for the binaural beamformers relative to
conventional directionality. This decrement probably reflects
both the more effortful search behavior necessary to locate
the speech as well as inability to properly orient the narrow di-
rectional beam when not looking to the front. The helpfulness
of binaural beamformers in improving speech understanding
in noisy situations is complicated by the unpredictability and
complexity of real-life listening demands, and may in fact be
detrimental depending on the user and the specific situation.

Even though testing was done under laboratory conditions,
the results of the current study illustrate some of the trade-offs as-
sociated with the traditional school of thought regarding direc-
tionality and the way it is applied. A system that seeks only to
maximize SNR improvement for sounds coming in from in front
may offer a slight advantage in the specific case for which it
is designed, but provide very poor performance in other cases.
For optimum benefit in the real world, the advantage for one
particular use case should not cause even greater disadvantag-
es for others. The ReSound approach to directionality seeks to
strike the best balance between directional benefit and audibil-
ity of environmental sounds. In this way, hearing aid wearers
can listen with the ear that has the best representation of what
they would like to hear, yet the information is available for them
to shift their attention if they would like. Binaural Directionality 
III provides access to an improved SNR, but without limiting the
wearers’ ability to keep in touch with what is going on around
them in the acoustic environment. Binaural hearing advantag-
es arise from the brain’s ability to compare and contrast the dif-
ferent sounds being delivered from the right and left ears, and
Binaural Directionality III supplies the brain with differentiated
sound streams that allow for binaural hearing.

CONCLUSIONS
• The directionality in all three hearing aids tested provided
directional benefit compared to omnidirectional for speech
originating from in front of the listener in this laboratory
test.
• The binaural beamformer in Hearing Aid B did not provide
significantly more benefit than Binaural Directionality III
when the target speech was in front of the listener, while the
binaural beamformer in Hearing Aid A did.
• When the target speech was not in front of the listener, pos-
tive SNRs were necessary for 50% speech recognition in
noise for all three hearing aids tested.
• When the target speech was not in front of the listener, Bin-
aural Directionality III provided an enormous advantage ex-
sceeding 10 dB compared to the hearing aids with binaural
beamforming.
REFERENCES


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