Organic Hearing drives user preference for True Focus

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Abstract

With Beltone Envision™, we introduce a DNN-based noise reduction, True Noise Reduction. This combines with an upgraded 4-microphone binaural beamformer to form True Focus, our new default for the Hear in Noise program in premium hearing aids. This paper reports on three studies that quantified different aspects of True Noise Reduction and True Focus including listener preference compared to the legacy Ultra Focus 2 feature, directional benefit of the upgraded beamforming, and efficiency of the DNN compared to another premium brand with DNN-based noise reduction.

Hearing in noise is an issue for people with hearing loss even when wearing hearing aids. The Beltone approach to supporting the ability to listen effectively in noisy environments builds on our Organic Hearing™ philosophy. This means that we seek to mimic natural hearing processes that enable the hearing aid user to use innate strategies to hear what they want in any environment. An example of how we apply this is the automatic "CrossLink Directionality 4" program. Based on the acoustic environment, we apply technologies in a way that supports how people naturally tend to use their hearing in those scenes. Directionality is a particularly important technology in this scheme.

Beltone uses a unique directional feature that applies strong 4-microphone binaural beamforming in the speech-important mid-frequencies, a 2-microphone fixed directional response in the high frequencies and omnidirectionality in the low frequencies. This approach provides impressive signal-to-noise ratio (SNR) improvement[1, 2] while preserving binaural hearing cues and ensuring seamless sound quality regardless of the active listening mode in CrossLink Directionality 4. The algorithm that controls listening modes uses straightforward rules and operates slowly to ensure smooth transitions.

Another important technology for more effective listening in noise is single-microphone noise reduction. Sound Cleaner is an example of this and is an integral part of both the CrossLink Directionality 4 program, as well as the dedicated user-selectable program for hearing in challenging situations, called "Hear in Noise". Single-microphone noise reduction has the goal of separating speech and noise that are mixed; it is not dependent on the desired sound and the competing sound being spatially separated as is the case with directionality. The principle of single-microphone noise reduction is to reduce gain according to the spectrum of the noise while preserving speech audibility. Sound Cleaner can perform this quite well based on the assumption that noise backgrounds do not change as quickly as speech. It uses knowledge about speech acoustics – a model of speech - to identify the speech spectrum and assumes that the spectrum in pauses of speech is noise to be reduced. Unlike determining the best listening mode and when to apply directionality, calculating the gain reduction settings for Sound Cleaner is complex and must be done very quickly.

In real life environments, background noise is often dynamic and can quickly vary in level and frequency content. For example, dishes clattering, keys jangling, a dog barking, a few people bursting into laughter – all of these are everyday sounds found in hearing aid users' real surroundings and that may be bothersome to them. This means that the assumption of noise backgrounds being stable that is made in single-microphone noise reduction systems like Sound Cleaner are often not true. The risk is that the speech portion of a signal could be degraded in quality or made inaudible. We therefore considered whether deep learning, a type of artificial intelligence, might be able to provide a better method for calculating single-microphone noise reduction settings at a pace that could keep up with both speech and noise background dynamics. A deep neural network (DNN) was trained on many speech and noise samples to be able to recognise and separate the speech from the noise, and to calculate gain reduction settings that would affect only the noise. The goal of this data-driven single-microphone noise reduction system, called "True Noise Reduction" is to increase listening comfort with preserved sound quality. See Schumacher & Groth[3] for more details on True Noise Reduction.

Implementation in the Hear in Noise program

The manually selectable Hear in Noise program introduced in premium level technology combines True Noise Reduction with an upgraded 4-microphone binaural beamformer that extends the low frequency directional response to 250 Hz to maximise the potential for SNR benefit. A previous investigation of the effect of the Directional Mix setting (which defines the crossover frequency between directional and omnidirectional processing in the low frequencies) found that directional benefit for occluding fittings increased as the frequency area where directionality was applied was extended to lower frequencies.[4] Based on those results, the upgraded directional feature could be expected to provide 1 to 2 dB additional SNR improvement for people with occluding fittings. Minimal additional benefit might also be a result due to minor optimisation of the beamforming parameters relative to the legacy 4-microphone binaural beamformer used in the Ultra Focus 2 feature.

The combination of the new 4-microphone binaural beamformer and the DNN-based noise reduction comprises the new True Focus feature which initially will be available in the microRIE form factor. Other styles will also offer the upgraded 4-microphone binaural beamformer, but with classic Sound Cleaner single-microphone noise reduction. This feature is called Clear Focus. Table 1 provides an overview of the directional response and single-microphone noise reduction system in True Focus, Clear Focus, and the legacy Ultra Focus 2.

Table 1

	Noise reduction system	Directional response
True Focus	True Noise Reduction	Binaural beamforming 250-5000 Hz
Clear Focus	Sound Cleaner	Binaural beamforming 250-5000 Hz
Ultra Focus 2	Sound Cleaner	Binaural beamforming 550*-5000 Hz

*for microRIE; the precise frequency depends on the hearing aid style

To learn how hearing aid users might benefit from the DNN-based noise reduction as well as the upgraded 4-microphone binaural beamformer, three studies were carried out. They focused on sound quality preferences, speech recognition in noise with both speech and noise in front, and efficiency of DNN based on speech recognition in noise with speech from changing locations.

Study 1: Sound Quality Preference

Methods

Participants

Twenty participants with bilateral mild-to-moderate sensorineural hearing loss participated in the test (13 male and 7 female). The test participants' median age was 78 years with a 1st quartile of 73 years and a 3rd quartile of 80 years. The test participants were experienced hearing aid users and current users of premium Receiver-in-the-Ear (RIE) hearing aids. The median years of experience with amplification was 14 years (1st quartile: 7 years and 3rd quartile: 20 years).

Hearing aids and fitting

A pair of rechargeable Beltone Envision (ENV960S-DRWC) RIE hearing aids were used for the sound quality experiment. The hearing aids were fitted with gain prescribed to an N3 audiogram[5] for experienced hearing aid users, using the proprietary BAFA fitting rationale and power domes to optimise the hearing aid signal processing benefit. The hearing aids were fitted with four programs. One was the Hear in Noise program, while the other three were duplicates but with the following differences: Two of the four Hear in Noise programs were fitted with True Focus (see table 1). These two programs were fitted with two different levels of True Noise Reduction ("Considerable" and "Strong"). The two remaining Hear in Noise programs were fitted with the legacy feature Ultra Focus 2. These two programs were fitted with two different levels of Sound Cleaner ("Moderate" and "Strong").

Test conditions, material, and setup

Beltone and other hearing aid manufacturers have often carried out sound quality preference experiments by making recordings on an acoustic manikin and having test participants evaluate the conditions under headphones using the SenseLabOnline test system from FORCE Technology.[6, 7] The SenseLabOnline test system offers double blinding and eliminates multiple other sources of bias. The sound quality testing was conducted by having test participants do sound quality preference testing on the following pairs of conditions:

- True Focus ("considerable") versus Ultra Focus 2 ("moderate")
- True Focus ("strong") versus Ultra Focus 2 ("moderate")
- True Focus ("strong") versus Ultra Focus 2 ("strong")

The testing order of the conditions was counterbalanced across participants. The participants repeated the paired comparisons while listening to multiple sound scenarios. A description of the sound scenarios is shown in Table 2. Except for the kitchen noise scene, which was recorded in an actual kitchen for the purpose of this test, the sound scenarios were selected from the ETSI noise database which is a public database containing various recordings of realistic background noises.[8] The sound scenes were supplemented with a concatenation of Dantale II and HINT female and male speech.

The recordings were binaural recordings made at ecologically valid SNRs to simulate real-life conversations. In real-life, conversations mostly happen at positive SNRs, because speakers adapt their vocal effort and distance to the listener when noise is present.[9-12] Hearing aid users typically do not expose themselves to conversations at negative SNRs, which are uncommon in the real world - also for people with normal hearing.[11-14] When testing for sound quality preference, it is desirable to present highly intelligible samples to keep participants engaged in the task.[14] As we were testing noise reduction systems, noise had to be present, but the SNRs needed to be high enough

for the test participant to understand most speech comfortably. If the SNR is below 0 dB, the participant is likely to give up without expressing any preference.

Table 2. The sound scenarios and SNRs were according to the table below:

Background noise	SPL(A)	SPL	SNR(A)
Cafeteria	66 dB	70 dB	4 dB
Traffic	70 dB	74 dB	4 dB
Voice distractor	65 dB	68 dB	3 dB
Cafe	70 dB	75 dB	5 dB
Car	65 dB	70 dB	5 dB
Kitchen	68 dB	73 dB	5 dB

The six sound scenario recordings with the concatenated speech at the SNR(A)s listed in Table 2 were recorded with a Brüel & Kjær Type 4128 Head and Torso Simulator (HATS). The recordings were made for each sound scenario and test condition (each of the four hearing aid programs) while the test hearing aids (binaural recordings) were placed on the HATS' ear simulators.

When making the recordings, the audio source material was played for at least 60 seconds before the clips used for the test were recorded. This was done to give the hearing aids' adaptive algorithms time to adapt to each sound scenario.

The recordings were played back for the test participants over Beyerdynamic DT-990 Pro headphones. The stimuli were equalised to remove the influence of the HATS' ear canals and the headphone frequency response. The test participants were asked to adjust the playback level so that the Danish talker was at a comfortable level.

Results/Discussion

True Focus "Considerable" versus Ultra Focus 2 "Moderate"

The preference of True Focus with "considerable" True Noise Reduction noise reduction versus Ultra Focus 2 with "moderate" Sound Cleaner noise reduction in the Hear in Noise program is shown in Figure 1. The preference is shown for the five sound scenarios for which there was a statistically significant preference. A binomial statistical test was used to determine in which sound scenarios there were statistically significant differences. These were "Café" ($p<0.05$), "Car" ($p<0.001$), "Cafeteria" ($p<0.01$), "Voice distractor" ($p<0.001$) and "Traffic" ($p<0.05$). There was not a statistically significant difference for the "Kitchen" scenario ($p=0.12$).

The Hear in Noise program with True Focus was preferred over the Hear in Noise program with Ultra Focus 2 in 87 of 100 trials while the Hear in Noise program with Ultra Focus 2 only was preferred in 13 of 100 trials when summarising the preferences across background noises. True Focus with True Noise Reduction was thus preferred 87% of the time compared to legacy noise reduction.

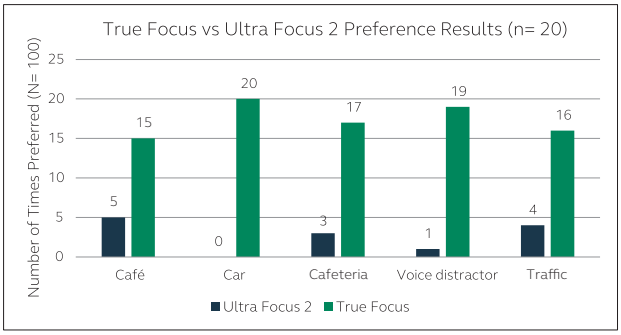


Figure 1. Preferences for True Focus compared to Ultra Focus 2 for the 20 participants with mild-to-moderate hearing loss, and for the 5 sound scenarios for which there was a statistically significant preference.

True Focus "Strong" versus Ultra Focus 2 "Moderate"

The preference of True Focus with "strong" True Noise Reduction noise reduction compared to Ultra Focus 2 with "moderate" Sound Cleaner noise reduction in the Hear in Noise program is shown in Figure 2. A binomial statistical test was used to determine whether the differences in preference were statistically significant differences. There was a statistically significant preference for True Focus for all six sound scenarios, including "Café" ($p<0.001$), "Car" ($p<0.001$), "Kitchen" ($p<0.01$), "Cafeteria" ($p<0.05$), "Voice distractor" ($p<.001$), and "Traffic" ($p<0.01$). When the preferences are combined across background noises, True Focus with True Noise Reduction was preferred 89% of the time compared to legacy noise reduction.

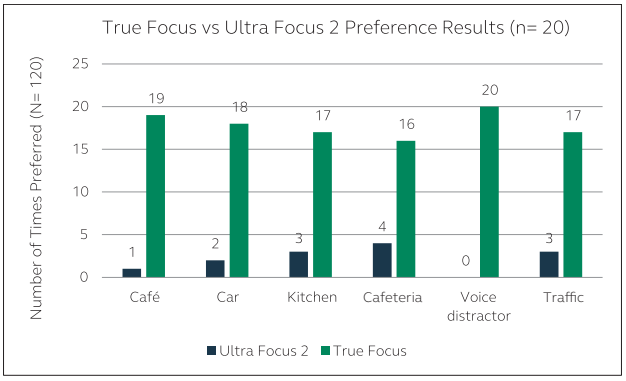


Figure 2. Preference for True Focus compared to Ultra Focus 2 for the 20 participants with mild-to-moderate hearing loss and for all 6 sound scenarios as there was a statistically significant preference in all sounds.

True Focus "Strong" versus Ultra Focus 2 "Strong"

The preference of True Focus with "strong" noise reduction compared to Ultra Focus 2 with "strong" noise reduction in the Hear in Noise program is shown in Figure 3. The preference is shown for the four sound scenarios for which there was a statistically significant preference. A binomial statistical test was used to determine in which sound scenarios there were statistically significant differences. These were "Café" ($p<0.001$), "Car" ($p<0.05$), "Cafeteria" ($p<0.001$) and "Voice distractor" ($p<0.001$). There was not a statistically significant difference for the "Kitchen" ($p=0.26$) and "Traffic" ($p=1.00$) scenarios.

The Hear in Noise program with True Focus was preferred over the Hear in Noise program with Ultra Focus 2 71 of the times while the Hear in Noise program with Ultra Focus 2 only was preferred 9 times when summarising the preferences across background noises. True Focus with True Noise Reduction is preferred 89% of the time compared to legacy noise reduction.

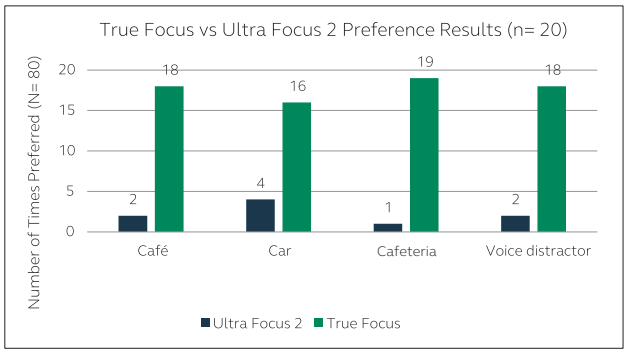


Figure 3. Preferences for True Focus compared to Ultra Focus 2 both with a strong level of noise reduction for the 20 participants with mild-to-moderate hearing loss and for four of the sounds for which there was a statistically significant preference.

Study 2: Speech Intelligibility in Noise

Methods

Participants

Eighteen of the twenty participants that participated in the sound quality preference test also participated in a speech intelligibility in noise test in an optimised 4-microphone beamformer test setup.

Hearing aids, fitting and test conditions

Beltone Envision RIE hearing aids were fitted binaurally with power domes to optimise the 4-microphone binaural beamformer and noise reduction benefit. The hearing aids were fitted to the test participants' individual hearing loss and experience with amplification based on the proprietary fitting rationale BAFA. The hearing aids were fitted with the following hearing aid programs:

- Program 1: Hear in Noise program with legacy Ultra Focus 2
- Program 2: Hear in Noise program with Clear Focus
- Program 3: Hear in Noise program with omnidirectional processing instead of 4-microphone beamforming

In addition, premium RIE hearing aids from another leading brand were tested. They were also fitted with power domes to optimise the 4-microphone beamformer and noise reduction benefit. The hearing aids were fitted to the participants' individual hearing loss and experience with amplification based on the manufacturer's default fitting rationale. The hearing aids were fitted with a dedicated program for hearing in noise with 4-microphone beamforming as well as a copy of this program with omnidirectional processing instead of 4-microphone beamforming.

Test material

The participants completed a speech intelligibility in noise test that is a slightly modified version of the Dantale II test.[15] The test is comprised of 5-word sentences and was presented in a background of static speech-shaped noise at 65 dB SPL. Thirty sentences were administered for each test. The level of the speech was manipulated to determine a speech reception threshold (SRT) of 50% correct performance, resulting in a dB SNR score, with better performance revealed through lower dB SNR scores. The hearing aids tested have adaptive features that rely on identification of speech and noise in the environment. To ensure that all adaptive features were activated during testing, the Dantale II test noise was started 60 seconds before testing was initiated. The test was conducted in an idealised situation to maximise possible benefit from the directional features.

Test setup

Testing was completed with the participants seated in a sound booth with speech presented at 0 degrees azimuth, and static noise presented at 75 degrees azimuth to the right. The positioning of the competing noise in the front plane was intended to highlight the stronger directional response - which can also be thought of in terms of a narrower directional beam. The setup is illustrated in Figure 4. The testing order of conditions and the sentence lists were counterbalanced across participants.

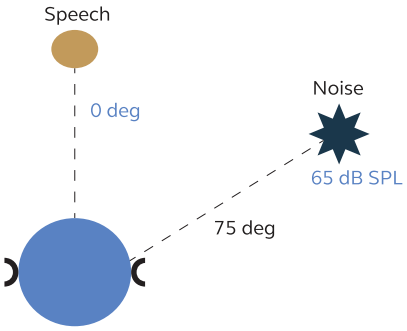


Figure 4. Test setup used for measuring SRTs with adaptive SNRs for a front talker in omnidirectional-, Ultra Focus 2- and Clear Focus mode.

The Dantale II speech and noise material was band-pass filtered from 550-4000 Hz to increase task difficulty and avoid ceiling effects in this test setup. The bandpass filtering was performed in Adobe Audition using the FFT filter plugin, with as steep as possible ramp-up and ramp-down of the filter.

Results/Discussion

No significant differences were observed between Clear Focus and Ultra Focus 2 on a group level. This result was unsurprising as the test setup with the band-filtered speech and noise was expected to underestimate the added benefit of Clear Focus; the primary difference between Clear Focus and the legacy Ultra Focus 2 is the low frequency directionality response. Even so, 61% (11 of the 18) test participants performed better on the speech intelligibility test in noise with Clear Focus in the Hear in Noise

program than they did with legacy Ultra Focus 2 in the Hear in Noise program. This may reflect the small optimisations made in the beamforming that could have affected benefit for individuals if not on average.

When comparing directional benefit with Clear Focus to 4-microphone beamforming in another premium brand on this test, both provided significant mean benefit compared to omnidirectional (Table 3). Compared to the other brand, the directional benefit provided by Clear Focus was significantly better (p<.01) as shown in Figure 5. A 2024 study showed similar directional benefit with a previous product from the same brand (Table 3). Both Clear Focus and Ultra Focus 2 provided a directional benefit greater than that provided by the 4-microphone binaural beamforming in the other brand. In addition, 83% (15 of 18 test participants) showed better speech recognition in noise performance with Clear Focus than with the 4-microphone beamforming from the other premium brand.

Table 3.

	Beltone Envision Clear Focus	Beltone Serene™ Ultra Focus 2	Brand A 4-mic beamforming (2025 hearing aid)	Brand A 4-mic beamforming (2024 hearing aid)*
Directional benefit	7.6 dB (p<.001)	7.0 dB (p<.001)	4.9 dB (p<.001)	4.0 dB (p<.001)

*Jespersen et al (2024)[2]

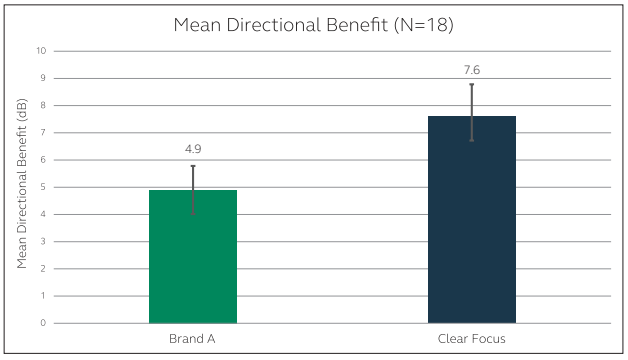


Figure 5. Test participants' mean directional benefit with Beltone's Clear Focus and another premium brand's 4-microphone binaural beamforming. Error bars show 95% confidence intervals.

Study 3: Efficiency of DNN-based noise reduction

Methods

Participants

Fourteen of the twenty participants that participated in the sound quality preference test also participated in a speech intelligibility in noise test that is more representative of a real-world situation than typical speech-in-noise tests. This test has competing single talkers, and the target talker randomly is presented from in front of and behind the listener which makes the task quite difficult. This test also allows assessment of accessibility of off-axis sound that might be of interest to the listener.

Hearing aids, fitting and test conditions

Beltone Envision RIE hearing aids were fitted binaurally with power domes to optimize the 4-microphone binaural beamformer and noise reduction benefit. The hearing aids were fitted to the test participants' individual hearing losses and experience with amplification based on the proprietary fitting rationale BAFA. The hearing aids were fitted with the following hearing aid programs:

- Program 1: Hear in Noise program with True Focus.
- Program 2: Hear in Noise program with Clear Focus.

Premium RIE hearing aids from another leading brand were fitted binaurally with power domes to optimize the directional and noise reduction benefit. The hearing aids were fitted to the test participants' individual hearing loss and experience with amplification based on the brand's default fitting rationale. The hearing aids were fitted with the following hearing aid programs:

- Program 1: Dedicated program for hearing in noise with directionality and DNN-based noise reduction.
- Program 2: Dedicated program for hearing in noise with directionality and no noise reduction.

Test material

The test participants completed an adaptive speech intelligibility listening test, hereafter referred to as the "DAT" test.[16] This test yields the SNR at the speech reception threshold (SRT). In this test, both the signal and the competing noise are individual talkers, which is exceptionally challenging compared to speech-shaped noise or babble, as there is informational as well as energetic masking taking place. The target talker sentences were played at 65 dB SPL, and the presentation level of the competing talkers was varied adaptively in 2 dB steps beginning at 55 dB SPL. Four conditions were completed in which the target sentences came from either the front or back loudspeaker as illustrated in Figure 6. The sequence of the conditions was counterbalanced among test participants. The masker talkers were played from the remaining two loudspeakers.

The programs tested in each brand's hearing aids have adaptive features that rely on identification of speech and noise in the environment. Therefore, an attempt was made to ensure that adaptive features will engage. In addition to the DAT corpus, speech-shaped noise from the Dantale II test[16] 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 participant. Furthermore, the ISTS signal was played at 65 dB SPL from the front loudspeaker throughout the duration of the test except 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 test to activate any adaptive settings in the hearing aids.

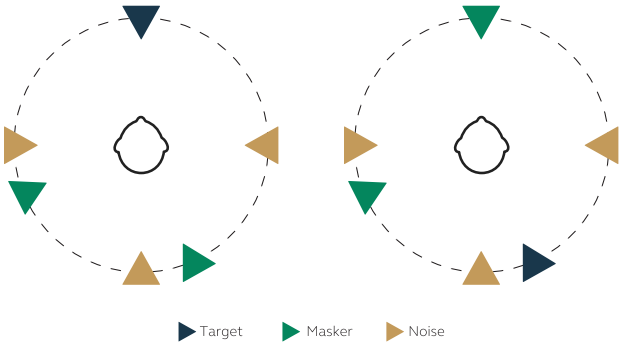


Figure 6. In the DAT test setup, target speech was presented either from the front or the back, with single talker maskers presented simultaneously from the side and either the front or back. Low level speech-shaped noise was also presented in the rear hemifield.

The test participants completed the two test setup conditions for each of the four test conditions. The sequence of the conditions was randomised for the test participants. Each test participant completed three training lists prior to beginning data collection.

Results/Discussion

The mean benefit of True Focus was -5.4 dB while the mean benefit of the other brand's program for hearing in noise with directionality and DNN-based noise reduction was -2.7 dB. While this advantage for True Focus was not significant at a group level, 9 of the 14 (64%) test participants obtained better results with True Focus.

One purpose of carrying out this test was to estimate the effect of the DNN-based noise reduction. The DAT test was chosen due to its difficulty and the fact that both target speech and maskers occur both from the front and from the back, and that speech can be both a target and a masker. It has been established that full bandwidth 4-microphone binaural beamforming can work against audibility when target speech is in back.[17] It is also of interest to know whether the DNN-based noise reduction might make matters better or worse. By subtracting the test condition without DNN-based noise reduction from the condition with DNN-based noise reduction, it is possible to isolate the effect of this feature. Due to limitations in programming the Beltone hearing aids, the benefit of the True Noise Reduction (the DNN-based noise reduction) is compared to legacy Sound Cleaner while the comparison for the other brand is for the feature on versus off. This means that the benefit for Beltone compared to the other brand may be underestimated. The benefit for target speech in front and in back were averaged. The average benefit of True Noise Reduction compared to Sound Cleaner was .6 dB while the benefit of the DNN-based noise reduction for the other brand was 1.1 dB. This difference is insignificant and so small that the benefit can be considered equivalent.

As discussed in Schumacher & Groth[3] the DNN chip in the Beltone Envision hearing aids was scaled to optimise the relationship between hearing aid capabilities, size of the chip, and power consumption. By comparing the benefit of the DNN-based noise reduction systems in the two brands of hearing aids in relation to the reported size of their DNNs, it is possible to quantify the efficiency of one versus the other. This can be accomplished by computing the ratio of the benefit per node of each DNN. Since no significant difference in benefit per brand was shown, the efficiency is simply the ratio of the difference in size in the two DNNs. The Beltone DNN has 17 times fewer nodes than the DNN of the other brand. This means that the DNN is 17 times more efficient, or that each node works 17 times harder in the Beltone system. The advantage of this efficiency is that users receive equivalent benefit, but in a device that can be physically smaller and use less battery.

Conclusion

We carried out three studies to illustrate different aspects of the True Focus feature and conclude:

- Listeners show a strong preference for True Focus compared to legacy Ultra Focus 2 in a variety of noise backgrounds.
- Directional performance of the upgraded 4-microphone binaural beamformer is equivalent to the legacy system when tested with band-filtered speech and noise, both presented in the front hemifield. Most individuals showed better performance with the new technology.
- Directional benefit of the upgraded 4-microphone binaural beamformer is significantly better than the benefit provided by another premium brand's 4-microphone binaural beamformer.
- The Beltone DNN is 17 times more efficient than the DNN of another premium brand.

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