Evidence for clearer, fuller and richer sound quality with Beltone Amaze™

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ABSTRACT

Sound quality is important to hearing aid users. As hearing aids become more advanced and sound processing capabilities continue to improve, focus on providing superior sound quality is an increasing concern of hearing aid manufacturers. Beltone Amaze is a premium hearing aid built on a new platform that provides advances in audio quality. This paper describes how structured methodology was used to document how the sound quality of Beltone Amaze for both everyday listening and streaming compares to other premium hearing aids. As a supplement to informal subjective reports from hearing aid users, this approach provides strong evidence for the fuller and clearer sound that gives users a richer listening experience with Beltone Amaze.

Both hearing aid users and hearing care professionals (HCPs) have high expectations about hearing aid sound quality. Therefore, it is important for hearing aid manufacturers to consider sound quality as one of the basic consumer requirements to hearing aids in the product development process. This is complicated, as there is no consensus among HCPs or hearing aid users as to what "sound quality" means or when it is achieved. It is easy to know if a requirement that a product is manufactured in 4 colors is met, or that a requirement of maximum gain is met. But how do you know if the requirement of superior sound quality is met?

The first step in evaluating sound quality is to define it. At Beltone, our definition of sound quality for hearing aids has objective and subjective components. We call the objective component "transparency". By this it is meant that the sound reproduced by the hearing aid is acoustically as similar as possible to the original sound. It is possible to quantify how transparent the hearing aid is objectively with measures of acoustic fidelity. We call the second component of sound quality "clarity". This is a perceptual construct, requiring listener judgment. When a hearing aid user experiences clarity, our premise is that this relates to low cognitive effort in processing the sound. By design, hearing aids change the sound in ways that disturb transparency as they aim to compensate for issues associated with hearing loss. The most basic of these is frequency shaping to provide audibility at frequencies most affected by the hearing loss. Most other signal processing in hearing aids and the way hearing aids are fit to the individual user can also detract from the acoustic transparency of the device. However, clarity may still be experienced subjectively by users even when the hearing aids are not completely transparent. Part of the challenge of developing – and fitting – hearing aids is finding the optimum balance of transparency and clarity that the user will perceive as excellent sound quality.

Evaluating sound quality

With a working definition of sound quality, it is possible to devise ways to evaluate it. As mentioned, the transparency aspect of sound quality can be captured with technical measurements. For Beltone Amaze, technical improvements and their effects on transparency are discussed in a companion paper[1]. In this paper, we focus on evaluation of the clarity dimension of our definition of sound quality. As part of product development at Beltone, users participate in extensive trials and various outcomes are measured. These users also provide subjective feedback on their experiences, including sound quality. While this is extremely helpful and informative, it is also important to have a structured methodology to benchmark against previous technology as well as other current hearing aids in order to know that sound quality goals have truly been met. As a supplement to the purely subjective evaluations of trial participants, results from a more formalized procedure provide strong evidence for excellent sound quality.

Beltone has worked closely with DELTA SenseLab to develop a structured, unbiased method for validating sound quality during hearing aid development[2]. Delta SenseLab is an independent test laboratory specialized in performing listening tests in a variety of domains. The methodology is inspired by the food and fragrance industry, which uses sensory panels consisting of trained assessors to evaluate products based on methodologies that are well-established within food science. The idea is that methodologies used to assess the sensory domains of taste and smell can be transferred to other sensory domains such as hearing. The methodology is double blinded in that neither the assessors nor the tester know which conditions are presented. This is important to eliminate biases. The methodology become the preferred means for hearing aid manufacturers to investigate hearing aid sound quality.

Documenting the sound quality of Beltone Amaze

For any hearing aid, the sound processing algorithms tend to be given the starring role in determining the overall sound quality. To be sure, they do play an essential role, but the hearing aid hardware and components, electroacoustic design, and the processing platform itself are just as important. For inputs other than the acoustic microphone, the delivery of the signal to the hearing aids is also a sound quality contributor. For example, if the signal is delivered via wireless streaming, then the streaming protocol has a significant impact on the audio quality. Wireless streaming protocols are not yet standardized for hearing aids, so no assumptions can be made as to how different hearing aids with streaming capabilities compare. For this reason, structured sound quality evaluations for Beltone Amaze were carried out with both acoustic and streaming inputs to capture a complete picture of its performance. Specifically, the research questions addressed how Beltone Amaze sound quality compares to other premium hearing aids for:

- Various daily sounds picked up acoustically via the mic-rophones
- Music picked up acoustically via the microphones
- Streaming of music and other sounds direct from the iPhone
- Streaming of music and other sounds via the proprietary TV streaming accessory

METHODS

Three experiments were carried out using the Delta Senselab methodology. The first one focused on general hearing aid sound quality in the default hearing aid program using the acoustic microphones. The second experiment tested hearing aid sound quality when listening to music using the hearing aid's proprietary music program acoustically. The third validated streamed sound quality. Table 1 provides an overview of the testing that was carried out.

	Purpose	Conditions	Method	Benchmark
Experiment 1	General sound quality	Participants listened to varying sound scenarios	Ranking	Other premium hearing aids
Experiment 2, part 1	Validation of specialized settings for music	Participants listened to music with default All-Around program, Music program, and with streaming inputs	Paired comparison	Beltone Amaze All-Around program
Experiment 2, part 2	Sound quality for music	Participants listened to music in a dedicated music program	Paired comparison	Other premium hearing aids with dedicated music programs
Experiment 3, part 1	Sound quality for streaming	Participants listened to varying sounds streamed from an iPhone	Paired comparison	Other premium MFi hearing aids
Experiment 3, part 2	Sound quality for streaming	Participants listened to varying sounds streamed via a proprietary TV streamer accessory	Paired comparison	Other premium hearing aids with a wireless TV streamer accessory

Table 1. Overview of sound evaluations that were carried out to validate Beltone Amaze sound quality.

Ten experienced hearing aid users (8 male and 2 female; mean age 73 years) participated as assessors in Experiment 1 and Experiment 2. Fifteen experienced hearing aid users (9 male and 6 female; mean age 72 years) participated in Experiment 3. All participants had a moderate hearing loss within 10 dB of the mild-to-moderately sloping N3 hearing loss[3]. They had all qualified for participation in the sound quality evaluation via performance on various discrimination tests[4].

Beltone Amaze receiver-in-the-ear (RIE) hearing aids with medium power receivers and five other premium hearing aids mounted with similar power receivers were included. All hearing aids were programmed to the manufacturer's default settings for the N3 hearing loss[3] in all three experiments. To minimize bias, overcome auditory memory limitations, and allow participants to easily listen multiple times to the stimuli, the evaluation was done using recordings made with the hearing aids. Table 2 provides an overview of the recording conditions for each experiment.

	Listening program	Sounds	Hearing aids
Experiment 1	Default program	Eight everyday sound scenarios	Beltone Amaze, A, B, C, D
Experiment 2, part 1	Beltone Amaze default program, Music program, streaming program	Pop music	Beltone Amaze
Experiment 2, part 2	Music program	Pop music	Beltone Amaze, A, B
Experiment 3, part 1	Streaming program with input from iPhone	Speech, music, traffic scene	Beltone Amaze, B, C, D,E
Experiment 3, part 2	Streaming program with input from TV streamer	Speech, music, traffic scene	Beltone Amaze, A, B, C, D

Table 2. Overview of the recordings that were made to serve as stimuli in each of the experiments.

Recordings and presentation

The sound scenarios for all the variations shown in Table 2 were recorded through each of the hearing aids placed on a Brüel & Kjær Head and Torso Simulator (HATS) placed in the center of a calibrated multichannel loudspeaker setup in a sound booth. The loudspeakers were calibrated individually to have a flat frequency response and equal overall levels measured at the listener's (HATS) position. To ensure that the hearing aids were fully adapted to the sound scenario, each scenario was played twice in the recording phase. It was assumed that the hearing aid would adapt during the first presentation and that the recording from the second presentation would be a fair representation of the sound for the product evaluations. The recordings were compensated for the HATS ear canal (ERP-DRP) and headphone frequency response.

During the tests, participants listened to the test stimuli reproduced at calibrated level over Sennheiser HD650 headphones and with the participants seated in a quiet fitting room. The background noise levels were below those defined in ISO 8253-1 (2010) for air conduction audiometry[5].

Procedures

For the first experiment, participants evaluated the hearing aids using a visual analog scale where they indicated to what degree they liked or disliked the sound. As shown in Figure 1, the anchors of the scale were "Extremely like" and "Extremely dislike". Each participant was instructed prior to the evaluation both in writing and verbally in order to ensure a correct understanding of the task. While listening, the participant could switch among the recordings being compared, without interrupting playback. The sequence of the hearing aids being tested was anonymous and randomized to avoid order effects.

In the second and third experiments, a paired comparison method was used. Similar to the first study, participants were able to switch back-and-forth between the two recordings that were to be compared and to listen to each as many times as they wanted. The same procedures were followed in terms of participant instruction and randomization of presentation.

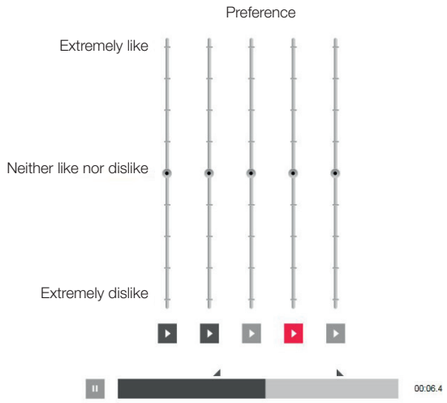


Figure 1. The interface for the Experiment 1 preference test in the first experiment as provided by the web-based listening test tool SenselabOnline[6].

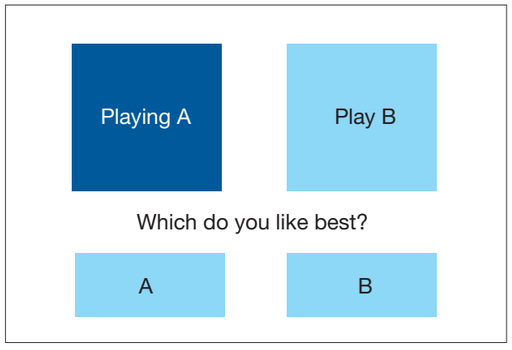


Figure 2. The interface for the preference test in the second and third experiments based on paired comparisons a provided by the web-based listening test tool SenselabOnline[6].

Statistical analysis

For experiment 1, a Tukey honest significance test was used to detect significant differences among mean ratings at a significance level of $p<0.05$. For experiments 2 and 3, a binomial test at a significance level of $p<0.05$ was used to detect significant differences in percentages of preferences.

Results and discussion

Experiment 1

The first study focused on overall sound quality preference in the default hearing instrument program with the acoustic microphones. Figure 3 shows the results for all preference judgments compiled. When examined in this way, two things are apparent. First of all, since participants were not required to use the entire scale, averaged ratings tended to group in the middle of the scale, and the distributions of the ratings were small. This reflects that overall, participants did not "extremely like" or "extremely dislike" any of the hearing aids evaluated. Secondly, there were no significant differences among hearing aids in the summed ratings, except that A was rated significantly higher than C. In general, C trended lower than any of the other devices. Along with B, it was the only device whose overall ratings put it in the "dislike" half of the rating scale. Compared to other sound quality evaluations using this methodology[2], participants were not required to "anchor" their evaluations by selecting one condition as "like most" and one as "like least". While this has the advantage of allowing listeners to make nuanced judgments of each condition individually, it does not force them to make preference choices among the hearing aids tested. Thus, actual preferences can be obscured to some extent. In other words, although the summed data suggest that the participants liked the overall sound quality of the hearing aids tested approximately equally (except for C), it is not known whether - if asked to choose - a favorite would have emerged.

The results as presented in Figure 3 give an overall impression that most premium hearing aids today provide good sound quality viewed over a range of different types of sounds. A disadvantage of examining the results this way is that it can conceal possible preference trends for specific types of sounds. When examining results for each individual sound type, Beltone Amaze was consistently rated in the neutral or "like" part of the scale, with three particular sounds rated very highly on the scale. These were three very different types of sounds: speech, percussive music and a traffic scene. When results for these sound scenarios are considered by themselves, Beltone Amaze was rated significantly higher than B and C (Figure 4).

Another consideration is the range in the averaged ratings for the different sound scenarios. A low range means that the sound quality was rated consistently. A higher range means that sound quality rating differed to a greater extent depending on the sound scenario. As shown in Figure 5, the range of ratings was only

about 1 scaling unit for Beltone Amaze. The ranges in ratings for the other devices tested were greater in all cases. This suggests that sound quality perception may vary more depending on the particular sound for other hearing aids than for Beltone Amaze.

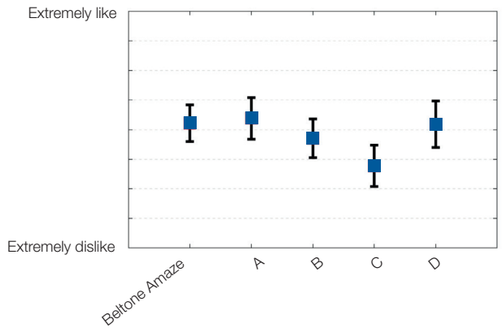


Figure 3. Sound quality preferences for all sound scenarios combined and for all devices tested.

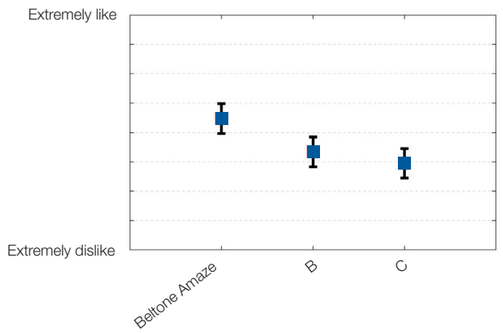


Figure 4. Beltone Amaze was rated significantly higher than B and C for three specific sound scenarios.

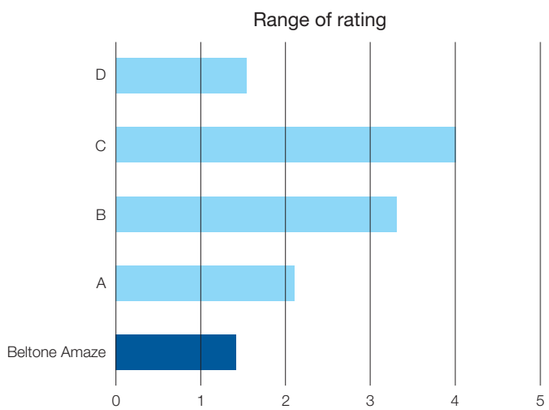


Figure 5. Beltone Amaze was rated the most consistently for sound quality across different scenarios. This suggests that the sound quality experience may be less dependent on the listening environment for Beltone Amaze than for the other hearing aids tested.

Experiment 2

This study focused on hearing instrument preference when listening to pop music. As discussed in the companion paper[1], music is a challenging signal for hearing aids to amplify without introducing distortion and artifacts. In addition, many people listen to music at higher levels than are typical of most daily listening environments, which makes matters even worse. Therefore, if hearing aids are experienced positively in terms of music listening, this represents an ultimate proof point for sound quality.

The first part of experiment 2 validated that the dedicated Music program, as well as the streaming options, are preferred for intentional music listening. This is an interesting question because music listening differs from general hearing aid use in that the focus is on the transparency of the hearing aid to reproduce the music with as much fidelity as possible. The Music program and to some extent the streaming solutions disable special features that are intended to improve speech understanding and increase listening comfort. The intent is to increase transparency. The results showed a significant preference for listening to music using the Beltone Amaze Music program and using streaming through the iPhone and TV streamer over the default All-Around program. There were no differences in preferences for listening to music with the Music program versus streamed via the iPhone or TV Streamer. These results indicate that when users want to enjoy live or recorded music, the specialized settings of the Music program and the streaming options all can enhance the experience.

The acoustic differences between speech and speech-in-noise signals and music are well-known, as are the ways in which hearing aids potentially can disturb the way music sounds. Therefore, it is likely that most hearing aid manufacturers follow similar principles in setting their dedicated music programs. The second part of experiment 2 investigated preferences when listening to pop music using the Music program in the Beltone Amaze compared to two other premium hearing aids with dedicated music programs. Because music program settings for each device would be based on a rationale of preserving transparency, this comparison would be the most fair when music is the stimulus. In this experiment, a clear preference was demonstrated for Beltone Amaze. Ninety percent of the participants preferred Beltone Amaze over hearing aid B, while 100% preferred Beltone Amaze over hearing aid A. This reflects extremely well on music listening with Beltone Amaze, but is also of interest for another reason. The other two hearing aids tested automatically change to their music programs when music is identified by the environmental classification system. It has been shown that the presence and detection of music in an environment by an environmental classifier may be somewhat at odds with how listeners might classify the same environments[7]In a complex environment where music is only one element, it may conflict with a user's listening goals to prioritize music listening settings. Because it is not possible for the hearing aids to know with any degree of certainty whether detected music is of interest to the hearing aid user at any given moment, Beltone has chosen to provide opportunities for the hearing aid wearer to purposefully choose music listening when desired.

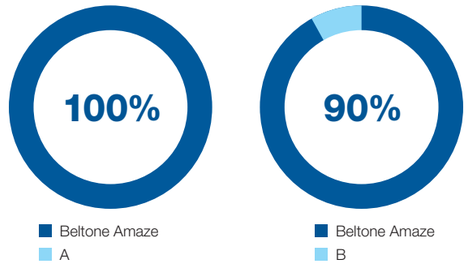


Figure 6. All of the test participants preferred Beltone Amaze over hearing aid A for music listening. Nine out of 10 preferred Beltone Amaze over hearing aid B.

Experiment 3 – MFi streaming

In the first part of experiment 3 comparisons were made for audio streamed directly from an iPhone with the iOS music app to the hearing aids. Beltone Amaze was compared to each of the other hearing aids one at a time, and test participants chose which they preferred in paired comparisons. As noted in Table 2, three audio clips were streamed to the hearing aids including rhythmic music, speech and a traffic scenario. Overall, Beltone Amaze was preferred in 67% of the total trials compared to the four other hearing aids that were capable of streaming from an iPhone (hearing aids B, C, D and E). Participants preferred audio streamed from an iPhone with Beltone Amaze over hearing aid B 67% of the time, which is a significant preference. Participants preferred Beltone Amaze over hearing aid C 58% of the time, and hearing aid D 56% of the time. Neither of these findings reached statistical significance. Beltone Amaze was also significantly preferred over hearing aid E 76% of the time. In all, participants preferred the sound quality of streaming via MFi 64% of the time compared to other MFi hearing aids.

It is not surprising that Beltone Amaze was preferred for MFi streaming. Because Beltone collaborated with Apple in creating the proprietary streaming protocol that Apple now offers to all hearing aid manufacturers, Beltone is given unique access to a wider frequency streaming bandwidth (see Groth[1] for bandwidth measurements). The additional high frequency amplification may contribute to more full and clear sound quality perceived by the participants.

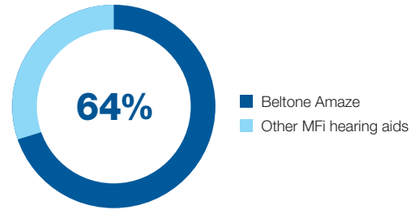


Figure 7. Overall, participants preferred the sound quality of streaming from the iPhone with Beltone Amaze over other MFi capable hearing aids.

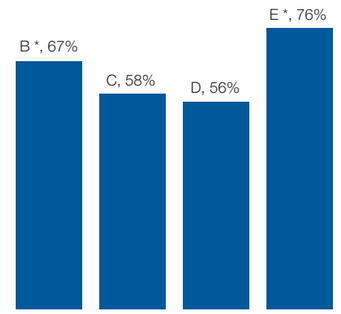


Figure 8. Sound quality preference results for Beltone Amaze compared to the individual MFi capable hearing aids. Beltone Amaze was preferred in a greater percentage of trials compared to each.
* indicates significant differences.

Experiment 3 – TV streamers

As mentioned, variability in sound quality can be expected as a function of the communication protocol used for streaming via the proprietary TV Streamers offered by different manufacturers. Beltone was the first manufacturer to enable streaming direct from a TV Streamer to hearing aids in high quality stereo and continues to use this technology. Because the signal bandwidth extends to 10 kHz, Beltone Amaze is the first Beltone hearing aid that can fully reproduce the signal. In the current test, the participants showed a

significant preference for Beltone Amaze over hearing aid A and its proprietary streamer 84% of the time. Beltone Amaze was also preferred by a significant margin over hearing aids B and C. Although Beltone Amaze was preferred 60% of the time over hearing aid D and its TV streamer, this difference was not statistically significant. Overall, participants preferred the sound quality of streaming via the Beltone wireless TV streamer 71% of the time compared to other premium hearing aids and their proprietary TV streamers.

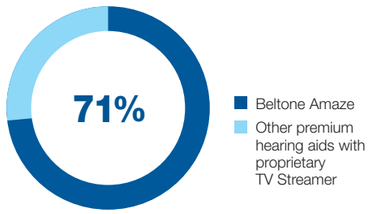


Figure 9. Participants preferred sound quality streamed sound with Beltone Amaze and the TV Streamer 2 over other premium hearing aids and their proprietary TV streamers.

Summary

Sound quality is an important attribute for hearing aid users and is considered in hearing aid selection by HCPs. It is therefore a priority for hearing aid manufacturers to consider how to ensure and validate that good sound quality is achieved in product development. In addition to unstructured subjective feedback from users, Beltone relies on formalized methods of benchmarking sound quality with as little bias as possible. Results from such evaluations with experienced hearing aid users have shown sound quality with Beltone Amaze is in some cases equivalent to, and in many cases preferred over the sound quality of other premium hearing aids. In particular, when listening acoustically with the hearing aid microphones Beltone Amaze is consistently judged positively and is especially advantageous for music listening. When listening via streaming from either the iPhone or via the proprietary TV streamer, Beltone Amaze sound quality is preferred compared to other hearing aids. Taken together, these results support the clearer, fuller and richer sound experience provided by Beltone Amaze.

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